A composite beam (10) comprising a base (13), a pair of opposed side walls (11) and a beam top (12) wherein said base (13) and said pair of opposed side walls (11) comprise a plurality of longitudinal fibre reinforced plastics members and said beam top (12) comprises a longitudinal compressive member.
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A COMPOSITE BEAM AND
A METHOD OF MANUFACTURE THEREOF

FIELD OF THE INVENTION
The invention relates to a composite beam and a method of manufacture thereof.

BACKGROUND OF THE INVENTION
The superior physical properties of fibre-reinforced plastic are well recognised. However, to date, there have been difficulties with producing viable large-scale projects, such as bridges, using fibre-reinforced plastic, due to cost.

One approach to building bridges is to build large pultrusion machines that utilise large dies to pultrude continuous sections of a bridge. This enables large sections of the bridge to be completed in a single pultrusion operation.

However, the cost of such a large machine and large die is extremely expensive. Further, the die can only be used for one specific structural element. If the depth of the bridge needs to be changed, then a new die needs to be produced, which is uneconomical.

Also, the longitudinal profile of the bridge element that is produced is straight due to the nature of pultrusion. However, due to the self-weight of the bridge and the road surface the initial straight pultrusions deflect without any presence of traffic on the bridge. This deflection causes the general public to doubt the structural integrity of the bridge.

One other problem with current fibre-reinforced plastic bridges is that if the bridge fails structurally, then the failure is generally brittle. That is, the bridge fails suddenly without much warning having the potential to cause massive damage and loss of life.

OBJECT OF THE INVENTION
It is an object of the invention to overcome or alleviate at least one of the abovementioned disadvantages or provide the consumer with a useful or commercial choice.

SUMMARY OF THE INVENTION
In one broad form the invention relates to a composite beam
comprising a base, a pair of opposed side walls and a beam top wherein said base and said pair of opposed side walls comprise a plurality of longitudinal fibre reinforced plastic members and said beam top comprises a longitudinal compressive member.

In another form the invention resides in a composite beam comprising:

a plurality of fibre-reinforced plastic members;

a compressive member; and

means to adhere the members;

wherein at least one fibre-reinforced plastic member is adhered to an adjacent fibre-reinforced plastic member and to the prefabricated compressive member.

In another form, the invention resides in a method of manufacturing a composite beam including the steps of:

adhering a plurality of fibre-reinforced plastic members together to form a base;

adhering a plurality of fibre-reinforced plastic members together to form a pair of opposed sidewalls;

adhering the base to the pair of opposed sidewalls to form a composite sub-structure;

adhering a compressive member to the composite sub-structure.

The fibre-reinforced plastics members may be produced using any suitable polymeric material. It is preferred that the polymeric material is a thermosetting polymer such as a polyester, a vinylester or an epoxy resin. The polymeric material may be reinforced using any suitable reinforcing fibre. It is preferred that the reinforcing fibre is glass fibre, carbon fibre or Kevlar™ fibre.

The fibre-reinforced plastic members may be produced using any suitable manufacturing process. It is preferred that the fibre reinforced plastics members are produced using pultrusion.

Preferably, the fibre-reinforced plastic members have at least two sides of their outer periphery that are substantially flat or have a profile
that readily engages with an adjacent fibre-reinforced plastic member. This enables the fibre-reinforced plastic members to be readily adhered to each other. In this regard it is preferred that the fibre-reinforced plastic members may be of uniform cross-section throughout their length.

In one preferred embodiment the fibre-reinforced plastic members may all be of substantially the same shape and dimension. In another embodiment the fibre-reinforced plastic members used to form the base of the composite beam may be of the same shape and dimension and each of the fibre reinforced plastic members used to form the opposed sidewalls of the composite beam may be of a different shape and dimension to those used for the base.

The fibre-reinforced plastic members may have an outer periphery that is substantially rectangular in transverse cross-section. Preferably, the fibre reinforced plastic members are substantially square in transverse cross-section.

The fibre reinforced plastic members may preferably be tubular. An inner periphery of the fibre reinforced plastic members will generally conform to the outside shape of the fibre reinforced plastics member. The hollow of the tubular member may be left hollow or in certain applications be filled with a stiffening material such as particulate filled resin. Whilst a variety of fillers may be used to fill the tubular fibre reinforced plastics member the use of particulate filled resin is preferred.

The fibre-reinforced members may be adhered to each other to form the base and the opposed sidewalls. In this manner there may be formed a substantially U-shaped sub-structure. In certain applications it may be advantageous to fully or partially close the top of the U-shaped sub-structure using additional fibre reinforced members to form a top assembly. The compressive member may be supported on the opposed sidewalls or on the top assembly, or both.

Reinforcing members may be disposed between adjacent fibre-reinforcing members. The reinforcing members may be made of any convenient material, for example the reinforcing members may be made of fibre-reinforced plastics. Preferably, reinforcing members are adhered
between two adjacent members.

In a preferred embodiment of the present invention reinforcing members in the form of carbon strips are disposed between adjacent fibre reinforced members. The carbon strips are adhered to the respective fibre reinforced members. It is particularly preferred that the carbon strips are use in the base of the composite beam, but of course in certain applications carbon strips may be used between fibre reinforced members from which the opposed sidewalls and the top assembly.

It is preferred that the base be laminated on its top surface. The base may be laminated with a fibre reinforced plastic material. The configuration and orientation of fibres in the lamination may be selected dependent upon the length of the composite beam, the span of the composite beam, the depth of the composite beam and the load rating of the composite beam. In a preferred embodiment fibres are aligned along the length of the base and a thermosetting resin is used to form the fibre reinforced laminate. It is also preferred to use fibres aligned laterally in addition to those fibres aligned longitudinally. Unidirectional fibres may be used. Alternatively bi-directional or double bias fibres may be used either alone or in combination with unidirectional fibres.

It is preferred that the opposed sidewalls be laminated on their internal walls. The opposed sidewalls may be laminated with fibre reinforced plastic materials. In a preferred embodiment fibres are aligned along the length of the opposed sidewalls and a thermosetting resin is used to form the fibre reinforced laminate. It is also preferred to use fibres aligned laterally in addition to those fibres aligned longitudinally. Unidirectional fibres may be used. Alternatively bi-directional or double bias fibres may be used either alone or in combination with unidirectional fibres.

Where carbon spacers are used as reinforcing spacers between adjacent fibre reinforced members in the base of the composite beam and a top assembly encloses the beam, a spacer may be used to pack out the top assembly such that it is of the same width as the base. Glass spacers may be conveniently used in this application.

L-shaped flanges may be used to strengthen the joints between
the base and the opposed sidewalls and the joints between the opposed sidewalls and the top assembly.

The compressive member may be prefabricated from a cementitious material. Preferably, the compressive member is prefabricated from concrete. In an alternate configuration the compressive member may be formed in situ. The compressive member may be cast into a trough formed on the top assembly.

The fibre-reinforced members may be adhered to each other and to the prefabricated compressive member using glue. Preferably, the glue is an epoxy resin.

A wrap may be placed around the outer periphery of the prefabricated compressive member and fibre-reinforced plastics members. The wrap may extend the length of the beam. The wrap may be made from a fibre-reinforced plastic. The wrap may be adhered to the prefabricated compressive member and fibre-reinforced plastics members. The wrap may encase the composite beam or the wrap may simply encase the base and the opposed sidewalls, leaving the compressive member exposed.

Bulkheads may be disposed within the composite beam to improve strength. Bulkheads may be spaced at predetermined locations within the beam. The bulkheads may be disposed laterally or longitudinally. The bulkheads may be of any convenient form and preferably constructed from fibre-reinforced plastic members.

L-shaped flanges may be used to strengthen the joints between the bulkheads and the opposed sidewalls, the joints between the bulkheads and the opposed sidewalls and the joints between the bulkheads and the top assembly.

In the method of the present invention further steps may be included such as:

- adhering a reinforcing member between two adjacent fibre-reinforcing members; and
- encasing the composite beam with a wrap.

The composite beam of the present invention may be used in many structural and load-bearing applications. In a preferred application the
composite beam of the present invention may be employed in the construction of a bridge. Other applications for which the composite beam of the present invention will find use include buildings, wharfs and the like.

In a further embodiment of the present invention there is provided a bridge formed of a plurality of composite beams herein described.

The bridge may be a plank bridge wherein beams of the present invention form longitudinal "planks" supported at points adjacent the respective ends of the planks and, dependant upon the length of the bridge at intermediate points forming spans. Alternatively each span may be formed from separate lengths of beams. A plurality of beams is disposed side by side to form the bridge deck. A surface material may be formed over the bridge deck. For example, in road carriageway applications traffic bitumen or other road surface material may be laid over the bridge deck.

In an alternate configuration, a bridge may be formed with the composite beams of the present invention laid laterally.

In order that the invention may be more fully understood and put into practice, preferred embodiments thereof will now be described with reference to the accompanying drawings and worked examples.

**BRIEF DESCRIPTION OF THE DRAWINGS**

An embodiment of invention, by way of example only, will be described with reference to the accompanying drawings in which:

- Figure 1 is a perspective view of a composite beam according to a first embodiment of the invention.

- Figure 2 is a transverse cross-sectional view of the composite beam according to Figure 1.

- Figure 3 is a graph showing the load characteristics of the composite beam of Figure 1.

- Figure 4 is a side view of a bridge using composite beams of Figure 1 and Figure 2.

- Figure 5 is a transverse cross-sectional view of a composite beam according to a second embodiment of the invention.

- Figure 6 is a transverse cross-sectional view of the base of the composite beam according to Figure 5 before the fibre reinforced plastics
members are adhered together.

Figure 7 is a transverse cross-sectional view of the base of the composite beam according to Figure 5 with the fibre reinforced plastics members adhered together.

Figure 8 is a transverse cross-sectional view of the base of the composite beam according to Figure 5 with the fibre reinforced plastics members adhered together and laminated.

Figure 9 is a transverse cross-sectional view of a sidewall of the composite beam according to Figure 5 before the fibre reinforced plastics members are adhered together.

Figure 10 is a transverse cross-sectional view of a sidewall of the composite beam according to Figure 5 with the fibre reinforced plastics members adhered together.

Figure 11 is a transverse cross-sectional view of a sidewall of the composite beam according to Figure 5 with the fibre reinforced plastics members adhered together and laminated.

Figure 12 is a transverse cross-sectional view of the top assembly of the composite beam according to Figure 5 before the fibre reinforced plastics members are adhered together.

Figure 13 is a transverse cross-sectional view of the top assembly of the composite beam according to Figure 5 with the fibre reinforced plastics members adhered together.

Figure 14 is a transverse cross-sectional view of the top assembly of the composite beam according to Figure 5 with the fibre reinforced plastics members adhered together and laminated.

Figure 15 is a transverse cross-sectional view of the base of the composite beam according to another embodiment of the present invention before the fibre reinforced plastics members are adhered together.

Figure 16 is a transverse cross-sectional view of the base of the composite beam according to Figure 15 with the fibre reinforced plastics members adhered together.

Figure 17 is a transverse cross-sectional view of the base of the composite beam according to Figure 15 with the fibre reinforced plastics
members adhered together and laminated.

Figure 18 is a transverse cross-sectional view of the top assembly of the composite beam for incorporation into a composite beam having a base as shown in Figure 17 before the fibre reinforced plastics members are adhered together.

Figure 19 is a transverse cross-sectional view of the top assembly of the composite beam for incorporation into a composite beam having a base as shown in Figure 17 with the fibre reinforced plastics members adhered together.

Figure 20 is a transverse cross-sectional view of the top assembly of the composite beam for incorporation into a composite beam having a base as shown in Figure 17 with the fibre reinforced plastics members adhered together and laminated.

Figure 21 is a transverse cross-sectional view of a bulkhead of the composite beam of the type shown in Figure 5.

Figure 22 is a perspective view of a composite beam of the type shown in Figure 5 with the first stage of the bulkheads adhered to the beam top assembly.

Figure 23 is a perspective view of the composite beam of the type shown in Figure 22 with a sidewall adhered to the first stage bulkheads and the beam top assembly.

Figure 24 is a perspective view of the composite beam of the type shown in Figure 22 with the second stage of the bulkheads adhered to the beam top assembly and the sidewalls omitted for clarity.

Figure 25 is a perspective view of the composite beam of the type shown in Figure 22 with the full-length L-shaped flanges adhered to the beam top assembly and the sidewalls omitted for clarity.

Figure 26 is a perspective view of the sub-structure of the composite beam of the type shown in Figure 22.

Figure 27 is a perspective view with a part cutaway of a composite beam according to a third embodiment of the invention.

Figure 28 is a transverse cross-sectional view of the bulkhead of the composite beam according to Figure 27.
Figure 28 is an end view of the composite beam according to Figure 27.

Figure 29 is a transverse cross-sectional view of the composite beam according to a fourth embodiment of the invention.

Figure 30 is a transverse cross-sectional view of the compressive member of the composite beam according to Figure 29.

Figure 31 is a transverse cross-sectional view of the compressive member adhered to the opposed sidewalls of the composite beam according to Figure 29.

Figure 32 is a transverse cross-sectional view of the base of the composite beam according to Figure 29.

Figure 33 is a plan view of a plank bridge according to the present invention.

Figure 34 is a side view of the plank bridge according Figure 33.

Figure 35 is a perspective view of a plank bridge of the present invention with a large off-road mine haul truck transiting the bridge.

Figure 36 is a perspective view of a plank bridge of the present invention with a truck transiting the bridge.

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

Figures 1 and 2 show a composite beam 10 comprising sixteen pultruded fibre-reinforced plastic members 11 and a prefabricated concrete member 12.

The fibre-reinforced members 11 are constructed from glass fibre and vinylester. They are substantially square in shape in transverse cross-section and consistent in shape throughout their length. The lower corner of the fibre-reinforced plastic members 11A have a curved edge that forms the corner of the composite beam 10.

The prefabricated concrete member 12 is constructed using standard concrete forming principles. The top surface 12A of the concrete beam is curved in the transverse direction.

Carbon fibre-reinforcing members 13 are located between fibre-reinforced plastic members that form a base of the beam.

A fibreglass wrap 14 extends around the periphery of the beam.
Pultruding lengths of fibre-reinforced plastic form the composite beam. These fibre-reinforced plastic members 11 are glued to each other using epoxy resin with carbon fibre-reinforcing members 13 glued between lower fibre-reinforced plastic members. The carbon fibre-reinforcing members 13 increase the tensile strength of the composite beam. Further, the reinforcing members cannot be easily delaminated from the composite beam 10 as they are positioned within the composite beam 10.

Bulkheads 15 are placed at predetermined positions along the length of the beam. The bulkheads 15 provide additional strength to the composite beam 10 and further support the prefabricated concrete member 12. The bulkheads 15 are produced from the same fibre-reinforced plastic as the fibre-reinforced plastic members.

A prefabricated concrete member 12 is cast. When dry, the prefabricated concrete member 12 is glued to the fibre-reinforced plastic members 11 using epoxy resin. The prefabricated concrete member 12 does not require steel reinforcing, as the concrete member is used for compressive loads only.

The fibreglass wrap 14 is then wrapped around the outer periphery of the fibre-reinforced plastic members 11 and the prefabricated concrete member 12. The curvature of the top surface of prefabricated concrete beam 12A and edges of the lower corner fibre-reinforced plastic members 11A enable the wrap 14 to be applied tightly.

The composite beam 10 has improved load characteristics, as shown in Figure 3, due to application of the wrap 14. Upon failure of the prefabricated concrete member 12, shown at point “A” in Figure 3, the wrap holds the failed prefabricated concrete member 12 together to maintain the integrity of composite beam 10. This allows the composite beam 10 to be loaded above the failure load of the prefabricated concrete member 12 until critical failure of the composite beam 10 occurs, shown at point “B” of Figure 3.

This “two step” failure is advantageous. If the prefabricated concrete member 12 fails, then this is indicative that the composite beam 10 needs to be repaired or replaced. As the composite beam can be loaded
above the failure load of the prefabricated concrete member, then there is a safety factor that is inherent in the composite beam 10. That is, the composite beam 10 will not fail critically until the prefabricated concrete member 14 fails first.

The composite beam 10 described can be used for a variety of applications including bridges, buildings and wharfs. One specific example of using composite beams 10 is in a plank bridge 20 as shown in Figure 4. In this embodiment, the composite beams can be used to replace existing concrete beams. Transfer stressing is applied to pull the beams together in order to achieve load sharing between the beams. Asphalt 21 can then be laid over the composite beams in a normal manner.

An advantage of the composite beam 10 is that a ten metre composite beam weighs approximately 1 tonne whereas an equivalent concrete beam weighs approximately 6 tonne. Hence, the composite beams 10 can be transported and fitted more quickly and cheaply to plank bridges than the conventional concrete beams.

Figure 5 shows composite beam 25. Composite beam 25 has a compressive member in the form of a cast concrete top 26. The cast concrete top 26 is adhered to a beam top assembly 27 that in turn is adhered to a pair of opposed sidewalls 28, 29. L-shaped flanges 30, 31 are adhered to the inside corners between the opposed sidewalls 28, 29 and the beam top assembly 27. The opposed sidewalls 28, 29 are adhered to the base 34. L-shaped flanges 32, 33 are adhered to the inside corners between the opposed sidewalls 28, 29 and the base 34.

The base 34, the opposed sidewalls 28,29 and the beam top assembly 27 form the composite beam sub-structure 35. A wrap 36 covers the outer side of the composite beam sub-structure 35. The wrap 36 is formed from an epoxy resin having layers of reinforcing fibre mat embedded therein.

Figures 6, 7 and 8 show the base 34 during various stages of construction. The base 34 is formed from seven pultruded fibre reinforced longitudinal members 37, 38, 39, 40, 41, 42, 43. The pultruded fibre reinforced longitudinal members 37, 38, 39, 40, 41, 42, 43 are 50.5mm x
50.5mm in external diameter and have a wall thickness of 5mm. The end pultruded fibre reinforced longitudinal members 37, 43 are filled with particulate filled resin (PFR) 45, 46. In the process of filling the end pultruded fibre reinforced longitudinal members 37, 43 the members 37, 43 are split and the split lines are oriented vertically.

Between each adjacent pultruded fibre reinforced longitudinal members 37, 38, 39, 40, 41, 42, 43 is disposed a carbon strip 47. The carbon strips 47 are 1mm in thickness. The pultruded fibre reinforced longitudinal members 37, 38, 39, 40, 41, 42, 43 and carbon strips 47 are adhered as shown in Figure 7. Figure 8 shows a laminate 48 applied to the top of the base 34. The laminate 48 is formed from an epoxy resin having four layers of fibre mat embedded therein. The layer adjacent the pultruded fibre reinforced longitudinal members 37, 38, 39, 40, 41, 42, 43 is uni E-glass oriented longitudinally and the three subsequent layers are double bias E-glass.

Figures 9, 10 and 11 show sidewall 29 during various stages of construction. Sidewall 28 is the mirror of sidewall 29. The sidewall 29 is formed from five pultruded fibre reinforced longitudinal members 49, 50, 51, 52, 53. The pultruded fibre reinforced longitudinal members 49, 50, 51, 52, 53 are 50.5mm x 50.5mm in external diameter and have a wall thickness of 5mm. The top pultruded fibre reinforced longitudinal member 49 is filled with particulate filled resin (PFR) 55. In the process of filling the top pultruded fibre reinforced longitudinal member 49 the member 49 is split and the split lines are oriented vertically.

The pultruded fibre reinforced longitudinal members 49, 50, 51, 52, 53 are adhered as shown in Figure 10. Figure 11 shows a laminate 56 applied to the internal surface of the sidewall 29. The laminate 56 is formed from an epoxy resin having five layers of fibre mat embedded therein. The layer adjacent the pultruded fibre reinforced longitudinal members 49, 50, 51, 52, 53 is uni E-glass, the three subsequent layers are double bias E-glass and the final layer is uni E-glass oriented laterally.

Figures 12, 13 and 14 show the beam top assembly 27 during various stages of construction. The beam top assembly 27 is formed from
seven pultruded fibre reinforced longitudinal members 57, 58, 59, 60, 61, 62, 63. The pultruded fibre reinforced longitudinal members 57, 58, 59, 60, 61, 62, 63 are 50.5mm x 50.5mm in external diameter and have a wall thickness of 5mm. The end pultruded fibre reinforced longitudinal members 57, 63 are filled with particulate filled resin (PFR) 65, 66. In the process of filling the end pultruded fibre reinforced longitudinal members 57, 63 the members 57, 63 are split and the split lines are oriented vertically.

Between adjacent pultruded fibre reinforced longitudinal members 59, 60 is disposed a glass spacer 67. The pultruded fibre reinforced longitudinal members 57, 58, 59, 60, 61, 62, 63 and glass spacer 67 are adhered as shown in Figure 13. Figure 14 shows laminates 68, 69 applied to the top and bottom of the beam top assembly 27. The laminates 68, 69 are formed from an epoxy resin having eight layers of fibre mat embedded therein. The layer adjacent the pultruded fibre reinforced longitudinal members 57, 58, 59, 60, 61, 62, 63 is uni E-glass oriented longitudinally and the two subsequent layers are uni E-glass oriented laterally, followed by uni E-glass oriented longitudinally, two layers of uni E-glass oriented laterally and an outer layer of uni E-glass oriented longitudinally.

Figures 15 to 20 show modification of the composite beam shown in Figures 5 to 14. The sidewalls employed in this modified composite beam are identical to those shown in Figures 9, 10, and 11. Figures 15, 16 and 17 show the base 74 during various stages of construction. The base 74 is formed from seven pultruded fibre reinforced longitudinal members 77, 78, 79, 80, 81, 82, 83. The pultruded fibre reinforced longitudinal members 77, 78, 79, 80, 81, 82, 83 are 50.5mm x 50.5mm in external diameter and have a wall thickness of 5mm. The outer pultruded fibre reinforced longitudinal members 77, 78, 81, 82, 83 are filled with particulate filled resin (PFR) 85. In the process of filling the outer pultruded fibre reinforced longitudinal members 77, 78, 81, 82, 83 the members 77, 78, 81, 82, 83 are split and the split lines are oriented vertically.

Between each adjacent pultruded fibre reinforced longitudinal members 77, 78, 79, 80, 81, 82, 83 is disposed a carbon strip 87. The carbon strips 87 are 1mm in thickness. The pultruded fibre reinforced
longitudinal members 77, 78, 79, 80, 81, 82, 83 and carbon strips 87 are adhered as shown in Figure 16. Figure 17 shows a laminate 88 applied to the top of the base 74. The laminate 88 is formed from an epoxy resin having four layers of fibre mat embedded therein. The layer adjacent the pultruded fibre reinforced longitudinal members 77, 78, 79, 80, 81, 82, 83 are uni E-glass oriented longitudinally and the three subsequent layers are double bias E-glass.

Figures 18, 19 and 20 show the beam top assembly 67 during various stages of construction. The beam top assembly 67 is formed from seven pultruded fibre reinforced longitudinal members 97, 98, 99, 100, 101, 102, 103. The pultruded fibre reinforced longitudinal members 97, 98, 99, 100, 101, 102, 103 are 50.5mm x 50.5mm in external diameter and have a wall thickness of 5mm. The outer pultruded fibre reinforced longitudinal members 97, 98, 101, 102, 103 are filled with particulate filled resin (PFR) 106. In the process of filling the end pultruded fibre reinforced longitudinal members 97, 98, 101, 102, 103 the members 97, 98, 101, 102, 103 are split and the split lines are oriented vertically.

Between adjacent pultruded fibre reinforced longitudinal members 99, 100 is disposed a glass spacer 107. The pultruded fibre reinforced longitudinal members 97, 98, 99, 100, 101, 102, 103 and glass spacer 107 are adhered as shown in Figure 19. Figure 20 shows laminates 108, 109 applied to the top and bottom of the beam top assembly 67. The laminates 108, 109 are formed from an epoxy resin having eight layers of fibre mat embedded therein. The layer adjacent the pultruded fibre reinforced longitudinal members 97, 98, 99, 100, 101, 102, 103 is uni E-glass oriented longitudinally and the two subsequent layers are uni E-glass oriented laterally, followed by uni E-glass oriented longitudinally, two layers of uni E-glass oriented laterally and an outer layer of uni E-glass oriented longitudinally.

Figure 21 shows a bulkhead 110 formed from five pultruded fibre reinforced longitudinal members 111, 112, 113, 114, 115. Each of the pultruded fibre reinforced longitudinal members 111, 112, 113, 114, 115 is filled with particulate filled resin (PFR) 116. The pultruded fibre reinforced longitudinal members 111, 112, 113, 114, 115 are adhered together. A
spacer 117 is disposed on the base of the bulkhead 110. L-shaped members 118, 119 are disposed on either side of the bulkhead 110 for adhesion to the sidewalls (not shown).

Figures 22, 23 24, 25 and 26 show the stages of assembly of the sub-structure of the composite beam. The beam top assembly of Figure 14 has the first stage of a bulkhead 110 adhered to it in Figure 22. Figure 23 shows the sidewalls being adhered to the beam top assembly and the bulkheads. Figure 24 shows the completion of the bulkheads 110 by adhesion of the remaining pulltrusions thereto. Figure 24 also shows the adhesion of L-shaped flanges to the corners between the beam top assembly, the sidewalls and the bulkheads. Figure 25 shows the adhesion of full length L-shaped flanges on the bottom edges of the bulkheads and spacers to the bottom of the bulkheads. Figure 26 shows the base adhered to the sidewalls, bulkheads and respective L-shaped flanges to form the sub-structure of the composite beam.

Testing of this beam found that he serviceability traffic moment is 65kNm, while the design moment capacity of the beam initial failure of the concrete is in excess 550kNm (at a theoretical deflection of 160mm). The residual composite box section left after compression failure of the concrete has ultimate design moment capacity of almost 700kNm, at a deflection of approximately 550mm.

A periodic overload was applied to the beam every 100,000 cycles. Each periodic overload consisted of two static tests a specific level of overload, the first at a loading rate of approximately 50mm per minute, immediately followed by a second overload at rate of approximately 400mm per minute. During the initial 1 million cycles applied to the beam, a periodic overload of 100kN (about three times serviceability) was applied to the beam every 100,000 cycles. There were no indications of damage. The load spike was then increased to 150kN, 5 times serviceability, every 100,000 cycles for the next 500,000 cycles. As there were still no indications of damage, the periodic overload was increased to 220kN, approximately seven times serviceability. This overload was applied every 100,000 cycles for another 500,000 cycles. This level of overload is 2.5 times the ultimate design load.
and generated a deflection of 100mm in the beam (Figure 5). Once again there were no indications of deterioration or damage either visually, or in the deflection and strain readings.

The load-displacement behaviour of the beam continued to be linear and consistent even at high levels of overload. At seven times overload, the concrete had a maximum compressive strain of 0.14% (1400) and the laminate had a maximum strain of 0.3%. In total the 10m beam underwent 2 million cycles (4 times the requirement of the Draft Australian Bridge Design Code) at the serviceability traffic load, as well as being loaded 16 times to 100kN, 10 times to 150kN, and 12 times to 220kN.

Figure 27 shows a composite beam 150 having a compressive member 151 adhered to sidewalls 153. Sidewalls 153 are adhered to base 152. The sidewalls 153 and base 152 are formed from pultrusions 154. The composite beam 150 is encased in wrap 157. The composite beam 150 has bulkheads 155 disposed at intermediate positions along its length. Members of the bulkhead 150 extend into the sidewalls 153. The bulkheads are positioned in the sidewalls 153 using particulate filled resin 156.

Figure 28 shows the bulkhead 155 in transverse cross-section. The bulkhead 155 is formed from a number of pultrusions. The bulkhead is positioned in the composite beam using particulate filled resin 156. The bulkhead 155 extends into the sidewalls 153 and interlink therewith.

Figure 29 shows the end of a composite beam 150 having an endcap 160 held within the end of the composite beam 150 using particulate filled resin 159.

Figure 30 shows a transverse cross-section of composite beam 161. The composite beam 161 is formed from a sub-structure 164 and a compressive member 163 encased in a wrap 162.

Figure 31 shows the compressive member 163 that is adhered to laminate 165. Figure 33 shows a base 167 formed from six pultrusions 166. The pultrusions 166 are adhered to each other with carbon spacers 169 therebetween. A laminate 168 is applied to the top of the base 167. Figure 32 shows the compressive member 161 adhered to the sidewalls 170.

Figures 33 and 34 show a plank bridge formed from 10
composite beams of the type shown in Figures 27, 28 and 29. The composite beams are fixed at each end to a hardwood packer mounted on a support beam. The support beam is a steel I-beam mounted on a concrete footing. Opposed concrete abutments provide the bearing surface for the bridge.

Using 10m beams of the type shown in Figures 5 to 26 a plank bridge was produced. Figures 36 and 37 show the plank bridge under load.

The bridge design is based on the traditional plank bridge concept, in which a number of individual beams are placed side by side to create a bridge. This bridge design was chosen because of the simplicity of construction in that there are no joints between deck and girders (the girders are the deck); excellent resistance against flood loading and side impact; significant redundancy in the structure due to large number of beams; the concept is well understood by bridge engineers; and because a significant understanding of the bridge behaviour can be obtained through testing of individual beams.

Two sets of 7 beams formed 2 sections with a width of approximately 2.5m are created as shown in figure 35. Each 2.5m section was provided with a strong composite laminate in transverse direction along the bottom of the beams in order to give the section adequate transverse stiffness.

Advantageously the 2.5m wide sections can be easily transported to site on a standard truck and assembled into a bridge using simple field joints. A full-scale bridge (10m span, 5m wide) based on the discussed design concept was constructed and installed in. The total bridge weighed approximately 20,000kg and was installed in less than 30 minutes.

The bridge consisted of 14 individual composite beams, fabricated into two halves. A mechanical joint was used to join each of the two halves. The mechanical connection was arranged such that shear bolts joined the bridge halves at the top and bottom. These shear bolts were located at 400 mm centres longitudinally. This particular joint allowed for investigation into the joint behaviour. By progressively tensioning the bolts in the top and bottom of the joint, the effect of increased transverse joint stiffness on bridge behaviour could be investigated. Early phase 1 testing investigated the
performance of this joint during assembly. A truck with two axles with a
separation of 5m was used to do “crawl” tests. Initially, no bolts were inserted
in the joint and the first tests were conducted by driving the truck along the
bridge centreline, and subsequently along the centreline of each half of the
bridge. The top shear bolts were then connected and the truck tests repeated.
Three shear bolts at the bottom of the bridge centre span were then placed
and the truck tests repeated. This provided a limited amount of transverse
flexural stiffness. Subsequently, all bottom shear bolts were placed, and the
tests repeated again. This provided a much more significant transverse
flexural stiffness. The gap movement between the two adjacent halves was
monitored as the joint was progressively completed. Experimental results
show that a shear connection at the top of the joint produced the greatest
reduction in movement. Even a relatively minor connection at the bottom of
the connection produces a significant reduction in movement at the bottom of
the joint. Full bolting at the bottom of the connection produces a relatively
minor additional reduction in joint movement. These results suggest that the
bridge of the present invention may be readily commissioned without needing
to install a joint with full transverse moment capacity. A connection with good
shear stiffness, and moderate flexural stiffness is more likely to be practical
and economical.

The response of the bridge to vehicles of different configuration
and mass was investigated. This included the response of the bridge to semi
trailers with tri-axle groups with masses up to 30 tonnes. The bridge handled
these loads extremely well. The behaviour of the bridge under a serious
overload was tested by increasing the total mass on the bridge to
approximately 60 tonnes at midspan by placing two 30 tonne tri-axle groups
on the bridge simultaneously. The minimal clearances available meant that
this could only be done statically. The resulting deflection (approximately 15
mm) was very close to the allowable serviceability deflection. It was
considered desirable to increase the load to produce deflections greater than
serviceability. The largest vehicle readily available was an off-road mine truck.
This could be loaded to a total mass of approximately 75 tonnes (representing
a rear axle load in excess of 45 tonnes) as shown ion Figure 36.
A series of tests were completed with this vehicle producing typical deflections of approximately 18 mm, and flexural strains on the bridge soffit of approximately 500.

It should be appreciated that various other changes and modifications may be made to the embodiment described without departing from the spirit or scope of the invention.
THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A composite beam comprising a base, a pair of opposed side walls and a beam top wherein said base and said pair of opposed side walls comprise a plurality of longitudinal fibre reinforced plastics members and said beam top comprises a longitudinal compressive member.

2. A composite beam according to claim 1 wherein the fibre-reinforced plastics members include a polymeric material selected from the group consisting of polyester, vinylester and epoxy resin.

3. A composite beam according to either claim 1 or claim 2 wherein the reinforcing fibre is selected from the group consisting of glass fibre, carbon fibre or Kevlar TM fibre.

4. A composite beam according to any one of claims 1 to 3 wherein the fibre reinforced plastics members are produced using pultrusion.

5. A composite beam according to any one of claims 1 to 4 wherein the fibre-reinforced plastic members have sides of their outer periphery that readily engages with adjacent fibre-reinforced plastic members.

6. A composite beam according to any one of claims 1 to 5 wherein the fibre-reinforced plastic members are uniform cross-section throughout their length.

7. A composite beam according to any one of claims 1 to 6 wherein the fibre-reinforced plastic members may have an outer periphery that is substantially rectangular in transverse cross-section.

8. A composite beam according to any one of claims 1 to 6 wherein the fibre reinforced plastic members are substantially square in transverse cross-section.

9. A composite beam according to any one of claims 1 to 8 wherein the fibre reinforced plastic members are tubular.

10. A composite beam according to any one of claims 1 to 3 wherein the fibre reinforced plastic members are filled with a stiffening material.

11. A composite beam according to claim 10 wherein the stiffening material is particulate filled resin.

12. A composite beam according to any one of claims 1 to 11 wherein the fibre-reinforced members are adhered to each other to form the base
and the opposed sidewalls and wherein the base and the opposed sidewalls to form a substantially U-shaped sub-structure.

13. A composite beam according to claim 12 wherein the top of the U-shaped sub-structure is partially or completely closed using additional fibre reinforced members to form a top assembly.

14. A composite beam according to any one of claims 1 to 13 wherein the compressive member is supported on the opposed sidewalls or on the top assembly, or both.

15. A composite beam according to any one of claims 1 to 14 wherein reinforcing members are disposed between adjacent fibre-reinforcing members.

16. A composite beam according to claim 15 wherein the reinforcing members are made of carbon strips.

17. A composite beam according to any one of claims 1 to 16 wherein the base is laminated on its top surface.

18. A composite beam according to claim 17 wherein the base is laminated with a fibre reinforced plastic material.

19. A composite beam according to any one of claims 1 to 18 wherein the opposed sidewalls be laminated on their internal walls.

20. A composite beam according to claim 19 wherein the opposed sidewalls are laminated with fibre reinforced plastic materials.

21. A composite beam according to any one of claims 1 to 20 wherein the compressive member is prefabricated from a cementitious material.

22. A composite beam according to any one of claims 1 to 21 wherein the compressive member is prefabricated concrete.

23. A composite beam according to any one of claims 1 to 22 wherein the fibre-reinforced members are adhered to each other with an epoxy resin.

24. A composite beam according to any one of claims 1 to 23 wherein a wrap is formed around the outer periphery of the prefabricated compressive member and fibre-reinforced plastics members.

25. A composite beam according to claim 24 wherein the wrap is formed from fibre-reinforced plastic.

26. A composite beam according to any one of claims 1 to 23 wherein a
wrap may be adhered to the base and the opposed sidewalls, leaving the compressive member exposed.

27. A composite beam according to any one of claims 1 to 26 wherein bulkheads are disposed within the composite beam.

28. A composite beam according to claim 27 wherein the bulkheads are constructed from fibre-reinforced plastic members.

29. A composite beam comprising a plurality of fibre-reinforced plastic members; a compressive member; and means to adhere the members; wherein at least one fibre-reinforced plastic member is adhered to an adjacent fibre-reinforced plastic member and to the prefabricated compressive member.

30. A method of manufacturing a composite beam including the steps of: adhering a plurality of fibre-reinforced plastic members together to form a base; adhering a plurality of fibre-reinforced plastic members together to form a pair of opposed sidewalls; adhering the base to the pair of opposed sidewalls to form a composite sub-structure; and adhering a compressive member to the composite sub-structure.

31. A method of manufacturing a composite beam according to claim 30 wherein the method further comprises the step of adhering a reinforcing member between two adjacent fibre-reinforcing members.

32. A method of manufacturing a composite beam according to either claim 30 or claim 31 wherein the method further comprises the step of encasing the composite beam with a wrap.

33. A bridge comprising at least one composite beam according to any one of claims 1 to 29.

34. A building structure comprising at least one composite beam according to any one of claims 1 to 29.

35. A wharf comprising at least one composite beam according to any one of claims 1 to 29.
# INTERNATIONAL SEARCH REPORT

## A. CLASSIFICATION OF SUBJECT MATTER

| Int. Cl.: | E04C 3/29 |

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**DWPI + keywords** (beam, joist, girder, truss, composite, fibre, glass, resin, plastic, cement, concrete, tubular, etc.)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tr>
<td>X</td>
<td>WO 95/10665 A1 (RYAN) 20 April 1995 See figures 4 and 20 in particular.</td>
<td>1-3,5,7,10-12,17-23,29-31,33-35</td>
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<tr>
<td>X</td>
<td>US 5688426 A (KIRKWOOD et al.) 18 November 1997</td>
<td>29</td>
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<tr>
<td>X</td>
<td>US 5599599 A (MIRMIRAN et al.) 4 February 1997</td>
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**"&"** document member of the same patent family

Further documents are listed in the continuation of Box C

X See patent family annex

Date of the actual completion of the international search: 15 November 2002

Date of mailing of the international search report: 25 NOV 2002

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This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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END OF ANNEX