A method of repairing, reinforcing or reinstating a bridge, comprising fixing a reinforcing plate in a spaced relationship with an existing plate or girder, especially on the underside of the bridge structure, to form a closed cavity, and injecting plastics or polymer material into said cavity in liquid form, whereby said plastics or polymer material sets or cures so as to bond to said reinforcing and existing plates with sufficient strength to transfer shear forces therebetween.
METHOD OF REINFORCING A BRIDGE

[0001] The present invention relates to the repair or reinforcement of bridges, in particular, all-steel orthotropic bridges, all-steel railroad bridges and composite concrete-deck, steel-girder bridges.

[0002] Structural sandwich plate members which comprise two outer metal plates and a core of plastics or polymer material, e.g., unfoamed polyurethane, bonded to the outer plates with sufficient strength to substantially contribute to the structural strength of the member are described in U.S. Pat. No. 5,778,815 and U.S. Pat. No. 6,050,208, which documents are hereby incorporated by reference. These sandwich plate systems (SPS) may be used in many forms of construction to replace stiffened steel plates, formed steel plates, reinforced concrete or composite steel-concrete structures and greatly simplify the resultant structures, improving strength and structural performance (e.g. stiffness, damping characteristics) while saving weight. Further developments of these structural sandwich plate members are described in WO 01/32414, also incorporated hereby by reference. As described therein, foam forms or inserts may be incorporated in the core layer to reduce weight and transverse metal shear plates may be added to improve stiffness.

[0003] According to the teachings of WO 01/32414 the foam forms can be either hollow or solid. Hollow forms generate a greater weight reduction and are therefore advantageous. The other forms described in that document are not confined to being made of light weight foam material and can also be made of other materials such as wood or steel boxes, plastic extruded shapes and hollow plastic shapes.

[0004] As well as new build applications, the principles of SPS construction have been applied to the repair of maritime structures, in particular vehicle decks of RoRo ferries. This procedure, known as overlay, is described in WO 02/20341, which document is hereby incorporated in its entirety by reference. Briefly, the existing metal panel is cleaned and prepared, e.g. by grit blasting, then a reinforcement plate is welded above the existing metal panel so that a cavity is formed. The cavity is then filled with a liquid thermoset polymer, such as polyurethane, which sets and bonds the reinforcement plate to the existing panel with sufficient strength to transfer shear forces between the existing panel and reinforcement plate. This repair method can be performed in much less time than a traditional cut-and-replace repair, reducing the period for which the vessel is out of action, and can provide a deck with improved structural and wear characteristics.

[0005] It has also been proposed to use SPS panels to form the deck of D-bridges, Bailey bridges and girder bridges, as described in WO 02/29160.

[0006] Many road and rail bridges are made of steel or composite (steel & concrete) construction. A transverse cross-section through a typical composite road bridge is shown in FIG. 1 of the accompanying drawings. As can be seen, a concrete deck 10 is supported by longitudinal steel girders 11. The size, spacing and number of girders depend on the size of the bridge, loads to be carried and the designer’s choices. Traditional repair methods associated with concrete deck deterioration vary from resurfacing to complete deck replacement. Deck replacement requires the old concrete deck to be removed and is generally replaced with precast prestressed concrete planks that span across several girders. The planks contain block outs for continuity reinforcing steel, shear connectors, guard rails, traffic barriers and abutting joints. Subsequently to being placed these planks are post tensioned and grouted to make them continuous and composite with the existing girders. The durability of the in-field grouted joints is questionable.

[0007] An all-steel orthotropic bridge is shown in FIG. 2 of the accompanying drawings. In this bridge, the steel deck 20, which may for example carry an asphalt road, is stiffened by a number of longitudinal troughs, also of steel. A steel box girder 22 spans between piers to support transverse beams and the orthotropic deck. Bridges of this type are susceptible to fatigue, with cracks forming in the deck plate at or near welds joining the trough stiffeners to the deck plate or in the webs or transverse beams/diaphragms where the trough stiffeners pass through the web. Traditional repair methods require identification of the fatigue cracks, back gouging and (re)welding of the cracks. Additional local reinforcement may be applied, or modifications to the geometry or weld groups made, to lessen the stress range locally and the probability of the reformation of these cracks.

[0008] In the elevated steel railway bridge shown in FIG. 3 of the accompanying drawings, the steel panels 30 are used to hold ballast 31 which in turn supports sleepers (railway ties) and rails 32. The steel deck plate is pre-formed in double curvature and riveted to transverse beams 33. Repeated dynamic loads cause fatigue cracks to form through the plate within the cantilever section that protrudes beyond the flange tip of the transverse beams. With old structures, the steel grade may not be weldable, in which case the only known method of repair is to replace the pre-formed steel deck and transverse beams with new steel construction.

[0009] The methods of repair to rehabilitate the bridge types described disrupt traffic flow and adversely affect the local economy. As a result repair times are minimised and are often conducted with limited night-time or off-peak closures. However, complete closures may be required in some cases. Re-routing traffic also adds costs.

[0010] It is an aim of the present invention to provide a method by which a bridge may be repaired, reinstated or improved, e.g. to increase load carrying capacity or to enhance structural performance, in particular shear resistance and reduce structural borne noise.

[0011] According to a first aspect of the present invention existing concrete deck composite steel girder bridges can be rehabilitated by either replacing the existing concrete deck with prefabricated SPS deck panels, which are subsequently made composite with the steel girders by bolting and welding between panels, or by completely replacing the superstructure with SPS panels with integrated girders. In either case the use of prefabricated SPS deck panels offers simplicity in deck replacement which translates into shorter construction schedules that can be accommodated by limited closures. Prefabricated SPS deck panels offer further advantages of factory quality control and a limited amount of field fabrication which is well understood and widely used, thus providing a deck structure with a service life similar to the steel superstructure.

[0012] In addition the first aspect of the present invention can provide a deck of equivalent or greater strength and stiffness whilst weighing up to 75% less than the original corresponding reinforced concrete deck. Deck weight savings of this order of magnitude allow for either increase load
carrying capacity or an increased number of traffic lanes without need to reinforce the substructure or to add additional girders.

According to a second aspect of the present invention there is provided a method of repairing, reinforcing, or enhancing the structural performance of an existing bridge comprising fixing a reinforcing plate in a spaced relationship with an existing plate or girder of the bridge structure to form a closed cavity, and injecting plastics or polymer material into said cavity in liquid form, whereby said plastics or polymer material sets or cures so as to bond to said reinforcing and existing plates with sufficient strength to transfer shear forces therebetween.

By fixing the reinforcing plate to the underside of the bridge structure, minimum disruption to the load-carrying deck is caused and in many cases traffic may continue to flow throughout the repair process. The completed repair provides structural sandwich plates which have increased stiffness and provided better vibration damping characteristics. Increased transverse stiffness aids in lateral load sharing of concentrated wheel loads between adjacent truss stiffeners, and advantageously lessens the stress ranges at critical weld groups joining the truss stiffeners to the deck plate and where the troughs pass through either diaphragms or transverse beams, resulting in substantially increased fatigue resistance and service life.

The materials, dimensions and general properties of the reinforcing plates or the invention may be chosen as desired for the particular bridge to which the invention is to be applied and in general may be as described in U.S. Pat. No. 5,778,813 and U.S. Pat. No. 6,050,208. Steel or stainless steel is commonly used in thicknesses of 0.5 to 20 mm and aluminum may be used where weight is desirable. Similarly, the plastics or polymer core may be any suitable material, for example a compact elastomer such as polyurethane, as described in U.S. Pat. No. 5,778,813 and U.S. Pat. No. 6,050,208.

In the second aspect of the invention where the repair is applied to the underside of a bridge having a plurality of trough-shaped stiffeners, the reinforcing plate spans between the bottoms of the trough-shaped stiffeners and a lightweight form is provided in the space between the troughs, prior to injection of the core material. The lightweight forms or inserts should have a lower density than the concrete material and should resist sufficiently temperatures and pressures experienced in the injection and setting of the core material but otherwise their mechanical properties are not particularly important as they do not significantly contribute to the strength of the repaired structure. The lightweight forms should not completely fill the space between the troughs but should allow a layer of the core material all around them.

Conveniently, the lightweight forms may be hollow elongate bodies. In one particular embodiment, the lightweight forms are made of telescoping hollow prisms closed by end caps. The prisms may have trapezoidal cross-sections arranged to fit the space between the stiffening troughs.

In the second aspect of the present invention, the repair may instead be applied to the deck surface. In this case it may be advantageous to use heat resistant adhesives to fix the perimeter bars of an SPS overlay cavity to the existing structure. Subsequent welding of the new deck faceplates to the perimeter bars and to each other will not damage the paint or corrosion protective coatings on the underside surface.

The present invention will be described below with reference to exemplary embodiments and the accompanying schematic drawings, in which:

FIG. 1 is a cross-sectional view of a typical concrete deck composite steel girder bridge;

FIG. 2 is an isotropic view of a typical steel orthotropic bridge with box girders;

FIG. 3 is an isotropic view of a railway bridge with preformed steel panels;

FIG. 4 is a cross-sectional view of the deck of a composite steel girder bridge according to a first embodiment of the invention;

FIG. 5 is an isotropic view of the deck of a composite steel girder bridge according to a second embodiment of the invention;

FIG. 6 is an isotropic view of the bridge depicted in FIG. 2 to which a method according to a third embodiment of the present invention has been applied to rehabilitate and reinforce the deck structure from the underside;

FIG. 7 is an expanded view of the repaired bridge of FIG. 6;

FIG. 8 is an isotropic view of the bridge depicted in FIG. 2 to which a method according to a fourth embodiment of the present invention has been applied, from above;

FIG. 9 is an isotropic view of the railway bridge depicted in FIG. 3 to which a method according to a fifth embodiment of the present invention has been applied;

FIG. 10 is a longitudinal section of the repaired bridge of FIG. 9;

FIG. 11 is a cross-section view illustrating a drain detail of the repaired-bridge of FIG. 9;

FIG. 12 is an expanded view of the panel of the repaired bridge of FIG. 9;

FIG. 13 is an isotropic view of a typical box girder bridge (without deck for clarity) with structurally enhanced webs according to a sixth embodiment of the present invention; and

FIG. 14 is an isotropic view of stiffened plate girder with structurally enhanced webs according to a sixth embodiment of the present invention.

In the various drawings, like parts are indicated by like reference numerals.

According to a first embodiment of the present invention existing concrete deck composite steel girder bridges is rehabilitated by replacing the existing concrete deck with prefabricated SPS deck panels 101, as illustrated in FIG. 4. The SPS deck panels are subsequently made composite with the existing steel girders 102 by bolting and welding between panels 101. The replacement SPS panels 101 are made continuous by welding them together at abutting edges. The existing, or a new, steel guard rail 103 may be bolted to the SPS deck panels.

The SPS panels 101 each comprise outer metal faceplates 104, 106 bonded together by an intermediate, or core, layer 105 of plastics or polymer material. The faceplates may be steel plates with a thickness in the range of from 2 to 20 mm, as required for the particular application. For the plastics or polymer material, preferably a compact (i.e. not a foam) thermosetting material such as polyurethane elastomer, is used. Core layer 105 may have a thickness in the range of from 15 to 200 mm and is bonded to the faceplates 104, 106 with sufficient strength and has sufficient mechanical properties to transfer shear forces expected in use between the reinforcement and existing structure. The bond strength
should be greater than 3 MPa, preferably 6 MPa, and the modulus of elasticity of the core material should be greater than 200 MPa, preferably greater than 250 MPa, especially if expected to be exposed to high temperatures in use. By virtue of the core layer, the reinforced structure has a strength and load bearing capacity of a stiffened steel plate having a substantially greater plate thickness and significant additional stiffening. The replacement panels 101, of course, need not be flat but may take whatever form is required to fit to the existing structure.  

[0037] The use of prefabricated SPS deck panels offers simplicity in deck replacement which translates into shorter construction schedules that can be accommodated by limited closures. Prefabricated SPS deck panels offer further advantage of factory quality control and a limited amount of field fabrication which is well understood and widely used, thus providing a deck structure with a service life similar to the steel superstructure.  

[0038] In a second embodiment of the invention the superstructure is completely replaced with SPS panels 201 with integrated girders 202, as illustrated in FIG. 5. The SPS panels 201 are essentially the same as the panels 101 of the first embodiment but the longitudinal and/or transverse girders 202 are integrated into the panels during off-site fabrication. The webs of the girders may form parts of the side walls to the cavities into which the core material is injected whilst one or both faceplates may act as the flanges of the beams. As in the first embodiment, the use of prefabricated SPS deck panels offers simplicity in deck replacement, factory quality control and a limited amount field fabrication with attendant advantages.  

[0039] In addition, the first and second embodiments of the present invention provide a deck of equivalent or greater strength and stiffness than the original corresponding reinforced concrete deck whilst weighing up to 75% less. Deck weight savings of this order of magnitude allow for either increase load carrying capacity or an increase number of traffic lanes without need to reinforce the substructure or to add additional girders.  

[0040] In a third embodiment of the invention, shown in FIG. 6, the existing structure of a bridge comprising load carrying deck 20 and stiffening troughs 21 has been repaired or reinforced by the addition of a reinforcing plate 331 which spans between the bottoms of stiffening troughs 21. The reinforcing plate 331 may be a steel plate with a thickness in the range of from 2 to 20 mm, as required for the particular application. To bond the reinforcing plate 331 to the existing structure, a core layer 332 of plastics or polymer material, preferably a compact thermosetting material such as polyurethane elastomer, is used. This core may have a thickness in the range of from 15 to 200 mm. The core 332 is bonded to the reinforcing plates 331 and the existing structure 20, 21 with sufficient strength and has sufficient mechanical properties to transfer shear forces expected in use between the reinforcement and existing structure. The bond strength should be greater than 3 MPa, preferably 6 MPa, and the modulus of elasticity of the core material should be greater than 200 MPa, preferably greater than 250 MPa, especially if expected to be exposed to high temperatures in use. By virtue of the core layer, the reinforced structure has a strength and load bearing capacity of a stiffened steel plate having a substantially greater plate thickness and significant additional stiffening. The reinforcing plate, of course, need not be flat but may take whatever form is required to fit to the existing structure.  

[0041] To reduce the volume of core material required to bond the reinforcement to the existing structure, lightweight forms or inserts 333 are provided in the space between stiffening troughs 21. The forms 333 preferably have a cross-sectional shape matching that of the space between troughs but sized so as to leave a layer of core material of thickness in the range of from 15 to 200 mm all around. The forms are preferably elongate hollow bodies of the appropriate cross-section but may also be made of lightweight materials such as foam. Each insert may also be made up from a plurality of elongate parts of standard cross-section, to avoid the need to manufacture special forms for each bridge.  

[0042] As more clearly shown in FIG. 7, which is an expanded view of the repaired bridge, each form 333 is preferably made of two parts 334 which fit into a sleeve 335 so that the length of the form may be adjusted by sliding the parts 334 into or out of the sleeve 335. End caps 336 close the two ends of the form. This arrangement suits bridges where the profile and spacing of the stiffening troughs is constant but the spacing between transverse girders may vary.  

[0043] Especially when hollow, the forms may be fitted around any utilities, e.g. water or gas pipes, power or communications cables, that may be attached to the underside of the bridge. Hollow forms can also serve as trunking for the later addition of utilities if suitable access points and through-holes in transverse girders are provided.  

[0044] To effect the repair, firstly the undersurfaces of all troughs 21 and exposed plates of the deck 20 are grit blasted to provide a clean surface to which the core material can adhere. Then the forms 333 are fixed in place, e.g. by tack welding, and the use of suitable spacers as required. Once this has been completed, laying bars are welded in place at the positions of the edges of the reinforcing plates so that the reinforcing plates can be welded in place. The cavities defined by the reinforcing plates and existing structure are sealed, leaving injection ports and vent holes as required. Core material is then injected and allowed to cure to form a strong bond between the reinforcing plates and existing structure. To finish off, the injection ports and vent holes can be sealed and ground flush before any desired surface treatment, e.g. paint, is applied to prevent corrosion or for aesthetic reasons.  

[0045] The same bridge may be repaired by the addition of an overlay to the top surface, as shown in FIG. 8, which illustrates a fourth embodiment of the invention. In this embodiment, a reinforcing plate 401 is fixed above the existing plate 20 so as to form a cavity. The cavity is then filled by injection of plastic or polymer material 402 which, when set, bonds the reinforcing plate 401 to the existing plate 20 with sufficient strength to transfer shear forces expected in use. In this respect, the fourth embodiment is the same as the other embodiments of the invention and the reinforcing plate and core material may be as described above. An asphalt road surface 403 is laid on top of the reinforcing plate once the core layer is fully cured.  

[0046] To fix the reinforcing plate 401 in place prior to the injection of the core, welded or adhered perimeter bars may be used to define the cavity to be filled. Spacers and lightweight forms or inserts may also be employed, as in the other embodiments of the invention.  

[0047] In a fifth embodiment of the present invention a repair is applied to the underside of pre-formed steel plate of an elevated railway bridge to enhance the fatigue resistance and to extend the service life of the structure. The repair,
illustrated in FIG. 9, is consistent in shape and construction with the existing structure and does not detract from its historic nature.

[0048] Applied from below without disrupting rail services, two preformed plates 501, 502 of matching shapes to the existing structure are bolted to the webs of transverse beams of the existing structure and riveted with one-sided rivets to each other, forming a lap joint 503 at mid panel length that extends across the bridge as shown in FIG. 10. The lap joint provides a simple connection detail that will allow for dimensional variations that will occur in each panel along the length of the bridge. Subsequently drains 504 are re-established as shown in FIG. 11.

[0049] A combination of flexible, closed-cell foam-like material and caulking is used to seal the ends of the cavity. The cavity is subsequently injected from below, first through the central region and then at either end, to ensure complete filling with core material 505. This method of repair not only lessens the stress range in the existing pre-formed steel panel (at or near the leading edge where the cantilever plate section passes over the flange tip of the transverse beams) thereby increasing the fatigue resistance, it also provides a viscoelastic layer to absorb structural-borne noise, an added benefit for urban centres where elevated railway systems like this exist.

[0050] A sixth embodiment of the present invention is a modification to the existing structures by the application of SPS overlay 601 to webs 602 of box and plate girders 603, 604, as shown in FIGS. 13 and 14, with the prime objective to reduce structural-borne noise associated with vibrations induced by the traffic (road or rail) which the bridge carries. A by-product is a structural enhancement, increased shear resistance and fatigue resistance for weld groups joining the stiffeners to the web.

[0051] In the fifth and sixth embodiments the materials and dimensions of the reinforcing plates and the core layer may be the same as in the previously described embodiments.

[0052] It will be appreciated that the above description is not intended to be limiting and that other modifications and variations fall within the scope of the present invention, which is defined by the appended claims.

1. A method of repairing, reinforcing or reinstating a bridge, comprising fixing a reinforcement plate in a spaced relationship with an existing plate or girder of the bridge structure to form a closed cavity, and injecting plastics or polymer material into said cavity in liquid form, whereby said plastics or polymer material sets or cures so as to bond to said reinforcing and existing plates with sufficient strength to transfer shear forces therebetween.
2. A method according to claim 1 wherein the existing plate or girder is on the underside of the bridge.
3. A method according to claim 2 wherein the bridge has a plurality of trough-shaped stiffeners, the reinforcing plate spans between the bottoms of the trough-shaped stiffeners and a lightweight form is provided in the space between the troughs prior to injection of the core material.
4. A method according to claim 3 wherein the lightweight form has a lower density than the core material.
5. A method according to claim 3 wherein the lightweight forms are hollow elongate bodies.
6. A method according to claim 5 wherein the lightweight forms are made of telescoping hollow prisms closed by end caps.
7. A method according to claim 6 wherein the prisms have trapezoidal cross-sections arranged to fit the space between the stiffening troughs.
8. A method according to claim 2 wherein the bridge has a plurality of plates spanning between girders and said step of fixing a reinforcing plate comprises fixing a first reinforcing plate to a first girder and a second reinforcing plate to a second girder adjacent the first girder, the first and second reinforcing plates cooperating to span the distance between said girders.
9. A method according to claim 8 wherein said first and second reinforcing plates overlap in a lap joint.
10. A method according to claim 8 wherein the first and second reinforcing plates are curved to match the curvature of the existing plates.
11. A method according to claim 1 wherein the existing plate is a web of a box or plate girder.
12. A method according to claim 1 wherein the reinforcing plate is metal, e.g. steel, stainless steel or aluminum.
13. A method according to claim 1 wherein the reinforcing plate has a thicknesses in the range of from 0.5 to 20 mm.
14. A method according to claim 1 wherein the plastics or polymer core is an elastomer such as polyurethane.
15. A method according to claim 14 wherein the elastomer is compact.
16. A bridge comprising an existing structure adjacent which is provided a reinforcing plate, the reinforcing plate being bonded to the existing structure by an intermediate layer of plastics or polymer material that is bonded to the reinforcing plate and the existing structure with sufficient strength to transfer shear forces therebetween.

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