PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : **E01D 19/12**

A1

(11) International Publication Number: **WO 97/18356**

(43) International Publication Date: 22 May 1997 (22.05.97)

(21) International Application Number: PCT/US96/18367

(22) International Filing Date: 13 November 1996 (13.11.96)

(30) Priority Data:
08/556,359 13 November 1995 (13.11.95) US
60/013,431 14 March 1996 (14.03.96) US

(60) Parent Applications or Grants
(63) Related by Continuation
US 08/556,359 (CIP)
Filed on 13 November 1995 (13.11.95)
US 60/013,431 (CIP)
Filed on 13 March 1996 (13.03.96)

(71) Applicant *(for all designated States except US)*: REYNOLDS METALS COMPANY [US/US]; Reynolds Metals Building, 6601 West Broad Street, Richmond, VA 23230 (US).

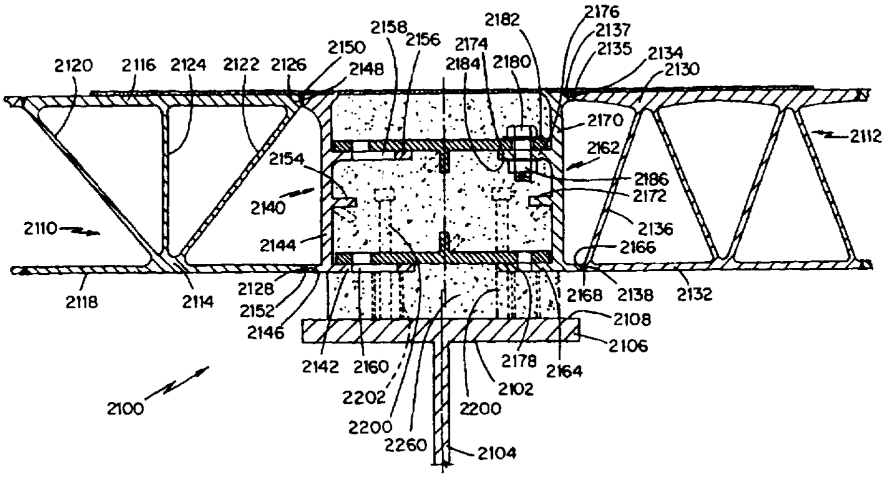
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: MATTEO, Adam, D. [US/US]; 4630 Kensington Avenue, Richmond, VA 23226 (US). MALLOY, Brian, J. [US/US]; 7476 Rockfalls Drive, Richmond, VA 23225 (US). WALKER, Kenneth, A. [US/US]; 906 Huntsman Road, Towson, MD 21286 (US). WOLCHUK, Roman [US/US]; 2801 Kennedy Boulevard, Jersey City, NJ 07306 (US). AHLSKOG, John, J. [US/US]; 1019 Calle de Celina, Corrales, NM 87048 (US). KISSELL, John, Randolph [US/US]; 10 Shepard Springs Court, Durham, NC 27713 (US). TAYLOR, Glen, A. [US/US]; 1042 Robmont Drive, Richmond, VA 23236 (US). THOMPSON, Kurt, P. [US/US]; 8761 Battlefield Park Road, Richmond, VA 23231 (US). TYLER, George, B. [US/US]; 2309 Wistar Place, Richmond, VA 23294 (US). GARBER, Douglas, W. [US/US]; 11860 Haversham Drive, Midlothian, VA 23113 (US). WEIR, John, R. [US/US]; 11710 Blakeston Court, Richmond, VA 23236 (US). ROBBINS, Bruce [US/US]; 1506 Treboy Avenue, Richmond, VA 23226 (US).

(74) Agents: PRICE, Robert, L. et al.; Lowe, Price, LeBlanc & Becker, Suite 300, 99 Canal Center Plaza, Alexandria, VA 22314 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: MODULAR BRIDGE DECK SYSTEM INCLUDING HOLLOW EXTRUDED ALUMINUM ELEMENTS SECURELY MOUNTED TO SUPPORT GIRDERS



(57) Abstract

A bridge structure includes an essentially isotropic bridge deck formed of modular deck panels (2110, 2112) spliced to each other on site. The deck panels (2110, 2112) are preferably shop fabricated by longitudinal welding of adjacently placed multi-void elongate aluminum structural elements (102). Longitudinally adjacent elongate elements are spliced by providing internally disposed shear elements (518, 520) prior to longitudinal welding of adjacent spliced elongate elements, with the end joints between spliced elongate elements being arrayed in a staggered manner.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	**GB**	United Kingdom	**MW**	Malawi
AT	Austria	**GE**	Georgia	**MX**	Mexico
AU	Australia	**GN**	Guinea	**NE**	Niger
BB	Barbados	**GR**	Greece	**NL**	Netherlands
BE	Belgium	**HU**	Hungary	**NO**	Norway
BF	Burkina Faso	**IE**	Ireland	**NZ**	New Zealand
BG	Bulgaria	**IT**	Italy	**PL**	Poland
BJ	Benin	**JP**	Japan	**PT**	Portugal
BR	Brazil	**KE**	Kenya	**RO**	Romania
BY	Belarus	**KG**	Kyrgystan	**RU**	Russian Federation
CA	Canada	**KP**	Democratic People's Republic of Korea	**SD**	Sudan
CF	Central African Republic			**SE**	Sweden
CG	Congo	**KR**	Republic of Korea	**SG**	Singapore
CH	Switzerland	**KZ**	Kazakhstan	**SI**	Slovenia
CI	Côte d'Ivoire	**LI**	Liechtenstein	**SK**	Slovakia
CM	Cameroon	**LK**	Sri Lanka	**SN**	Senegal
CN	China	**LR**	Liberia	**SZ**	Swaziland
CS	Czechoslovakia	**LT**	Lithuania	**TD**	Chad
CZ	Czech Republic	**LU**	Luxembourg	**TG**	Togo
DE	Germany	**LV**	Latvia	**TJ**	Tajikistan
DK	Denmark	**MC**	Monaco	**TT**	Trinidad and Tobago
EE	Estonia	**MD**	Republic of Moldova	**UA**	Ukraine
ES	Spain	**MG**	Madagascar	**UG**	Uganda
FI	Finland	**ML**	Mali	**US**	United States of America
FR	France	**MN**	Mongolia	**UZ**	Uzbekistan
GA	Gabon	**MR**	Mauritania	**VN**	Viet Nam

MODULAR BRIDGE DECK SYSTEM INCLUDING HOLLOW EXTRUDED ALUMINUM ELEMENTS SECURELY MOUNTED TO SUPPORT GIRDERS

Field of the Invention

This invention relates to a modular bridge deck system in which a bridge deck is made from modular deck panels formed to selected shape and size by shop-welding elongate hollow extruded aluminum elements, the panels being field-spliced to provide a readily assembled bridge deck securely mounted to primary bridge girders which are integrated by grouting with the deck panels and with optional curbs and safety rails.

Background of the Related Art

As existing bridges and their roadway decks age they deteriorate and need to be maintained with care. In many cases they must be replaced to ensure safety. There is increasing pressure everywhere to modify and strengthen existing bridge structures and to develop more durable, less expensive, lower maintenance, lighter weight, and more easily assembled bridge structures for the future.

It is desirable to reduce the weight of the bridge deck without sacrificing strength, rigidity, durability, and the ability to cope with unusually heavy loads, accidents and severe weather conditions. Traditional steel and concrete bridge decks are heavy and require expensive anti-corrosion treatment and/or painting. They are also quite flexible in the direction transverse to the direction of traffic flow. This leads to wearing surface failures, and makes steel decks more expensive to maintain than aluminum decks.

Serious consideration is therefore being given to developing light-weight, corrosion resistant, easily-handled, modular, aluminum deck structures. Initial construction is preferably done in a "shop" or factory to make modular elements which are then quickly and inexpensively assembled in the field. Prefabricating of such "deck panels" also gives the bridge designer freedom in selecting the dimensions and form of the resulting bridge deck.

There is a continuing need for improvements which allow the bridge to be built at reduced cost (including the cost of assembling the structure from prefabricated modular elements), permit occasional overloads by overweight vehicles and vehicle accidents, and satisfy government standards and professional codes. A strong durable connection between the bridge deck and an all-new or pre-existing support girder system is extremely important to ensure that the bridge deck and the girders act as a composite system that safely handles all anticipated shear and compression loads.

The present invention is intended to meet such demands by providing, inter alia, a system for forming and securely connecting an aluminum bridge deck to one or more cooperating girders, the deck having essentially isotropic, rather than orthotropic, load-bearing properties. The loads are resisted by bending both longitudinally and transversely of the elongate elements in an essentially isotropic deck. Selected cross-sections of the basic elements provide corresponding functional advantages.

In all cases, the selected deck is very strongly mounted either to a newly installed system of supporting girders or to an existing set of girders from which an old bridge deck has been removed, with little field work, to create a strong composite bridge.

If a new bridge is being built, its location, inclination, size, strength, and other physical factors pertaining to the support girders can all be selected before the bridge deck structure is mounted over underlying pillars or other supports. It may therefore be somewhat easier to build an all-new bridge than would be the case where an existing deck structure is being replaced, but for economy or to meet urgent traffic needs the underlying old support girder system is sometimes reused to support a new deck. In the latter situation there may also be interest in providing a wider new deck. Consideration must be given to minimizing the total load, including that of the girder support system, which must be sustained with a suitable factor of safety by the underlying structure at both ends of the bridge and possibly between the ends if the bridge is long. Weight reduction of the overall bridge structure is of particular interest to the bridge designer, architect, and the contractor who may have to employ heavy equipment over the supporting girders while the bridge is being built anew or reconstructed. The present invention in its various embodiments is particularly advantageous from all of these perspectives.

Summary of the Invention

Accordingly, a principal object of this invention is to provide a bridge structure comprising a light-weight, easy-to-assemble bridge deck system utilizing prefabricated aluminum deck panels which are field-spliced easily and inexpensively and securely mounted to support girders.

Another object of this invention is to provide a modular, easily-assembled, bridge structure incorporating prefabricated deck panels made from hollow extruded aluminum elements that are spliced together in the field and in which the deck panels are secured to support girders with very little field work. The bridge deck is formed from hollow extruded aluminum elements field-spliced to each other with known fastening elements, and has a substantially continuous upper surface to which a wearing layer is applied for long-term use.

According to a preferred embodiment of this invention, there is provided a bridge structure in which an aluminum bridge deck is securely supported on a plurality of cooperating girders, in which the girders act compositely with the aluminum deck formed of a plurality of prefabricated deck panels longitudinally field-spliced together. Each deck panel is formed by longitudinally shop-welding a plurality of elongate, multi-void, extruded aluminum elements which are transversely end-spliced in a staggered arrangement. A plurality of field-bolted nesting extrusions provide the longitudinal field-splicing of adjacent panels to each other. The longitudinal shop-welding comprises full-penetration, longitudinal top and bottom welds between respective top and bottom flanges of adjoining ones of the elongate extruded aluminum elements, whereby the welded top flanges of the field-spliced panels provide a substantially continuous upper surface. The top flange of the decking is thus made substantially continuous and the bottom flange optionally may be made substantially continuous. Continuity of the bottom flange will provide the advantage of creating a bi-directional system having structural performance approaching that of an isotropic plate.

The deck structure preferably is securely mounted to the girders by flowing an initially uncured pourable medium into selected extruded elements, in the field or in the shop, to cure-in-place around studs that are welded to the girders so as to extend into corresponding holes drilled into the selected extruded elements.

Brief Description of the Drawings

Fig. 1 is a partial plan view of a bridge deck structure according to a first preferred embodiment thereof.

Fig. 2 is a vertical cross-sectional view of the bridge deck according to Fig. 1, at Section II-II therein, as incorporated into a bridge structure according to one aspect of this invention.

Fig. 3A is a vertical transverse cross-sectional view of the bridge deck structure of Fig. 1 where adjoining modular deck panels are field-spliced to one another and coated with a shared wearing layer. Fig. 3B is a similar transverse cross-sectional view to explain an alternative structure and method for field-splicing similar decks.

Fig. 4 is a plan view of a multi-element deck panel according to the preferred embodiment.

Fig. 5 is a transverse cross-section at Section V-V in Fig. 4, to illustrate the use of longitudinal triangular cross-section shear elements for staggered connection of elongate extruded elements of the deck panel according to Fig. 3A.

Fig. 6 is a vertical cross-sectional view of a portion of the bridge deck where it is connected to a bridge girder by means of a cured-in-place, initially flowable medium capable of transferring a shear force upon being cured.

Fig. 7 is a partial plan view of a side portion of a bridge deck along which is provided a concrete curb and means for supporting a safety rail system.

Fig. 8 is a vertical schematic cross-sectional view of the bridge deck at Section VIII-VIII in Fig. 7.

Fig. 9 is a cross-sectional view taken at Section IX-IX in Fig. 7, to illustrate a preferred manner of supporting a curb and safety rail structure cooperating with the bridge deck.

Fig. 10 is a partial transverse vertical cross-sectional view to illustrate details of the first of two preferred elongate elements which are welded together form an essentially isotropic plate. Two such elongate elements are shown together to illustrate the one-side, full-penetration, longitudinal welding between the respective top and bottom flange portions of adjacent multi-void extruded aluminum elements forming a deck panel according to the preferred embodiment.

Fig. 11 is a partial vertical cross-sectional view to illustrate the manner of use of a pneumatically or hydraulically positioned removable backing bar for welding elongate hollow shapes.

Fig. 12 is a partial cross-sectional view of the second of two alternative forms of elongate elements which, when welded together, form an essentially isotropic plate.

Fig. 13 is a cross-sectional view of yet another alternative form of elongate element having four inclined webs between two parallel but unequally wide parallel flanges. This particular embodiment allows for two-side welding and will provide an orthotropic deck.

Fig. 14 is a transverse cross-sectional view across the full width of a bridge structure according to another aspect of this invention, to indicate an exemplary crowned bridge deck profile. Fig. 15 is an enlarged cross-sectional view, in a vertical plane across a location in the bridge structure per Fig. 14, which shows a pair of studs welded atop a girder and surrounded by poured curable medium to securely connect the bridge deck and to the girder when the medium is cured.

Fig. 16 is a bottom view of the bridge deck in the vicinity of the connection thereof to the girder, at section XVI-XVI in Fig. 15, to show a preferred pattern of openings formed into the bottom of an elongate multivoid element of the deck.

Fig. 17 is an elevation view of an exemplary end plate temporarily positioned at an end of the portion of the multivoid deck structure to define an enclosed space to be filled with an eventually cured-in-place medium.

Fig. 18 is a transverse cross-sectional view, in a bridge structure incorporating a bridge deck formed of multivoid elongate elements as illustrated in Fig. 12, to illustrate another preferred embodiment employing a plurality of studs extended upwardly of an upper surface of a support girder and surrounded by poured curable medium to securely connect the bridge deck to the girder when the medium is cured.

Fig. 19 is a transverse cross-sectional view, in a vertical plane across a location in a bridge structure in which a basic bridge deck generally similar to the bridge deck per Fig. 18 is connected to an underlying girder by a quantity of an initially flowable medium cured-in-place while extending through a plurality of elongate perforated plates, of which some are fixed to a bottom surface of the bridge deck and others are attached to extend upwardly and elongately of an upper surface of a girder.

Fig. 20 is a side elevation view of a portion of a perforated plate of the type employed in the system according to Fig. 19.

Fig. 21 is a transverse cross-sectional view, in a vertical plane, of another embodiment of a bridge structure in which adjacent preformed deck elements are connected to each other and securely supported on an underlying support girder.

Fig. 22 is an enlarged view of a central portion of Fig. 21.

Detailed Description of the Preferred Embodiments

As seen in Fig. 1, an exemplary deck panel 100 according to the preferred embodiment includes a plurality of longitudinally adjacent elongate, multi-void elements 102. Immediately adjacent elongate elements 102 do not end at the same point except at the ends of the deck, i.e., they are provided in a longitudinally staggered arrangement within the body of the deck panel. This minimizes local variations of strength or stiffness.

A preferred material for forming the multi-void elongate elements 102 comprises aluminum which provides reduced weight, corrosion resistance without protective coatings, precise manufacture, reduced welding, bi-directional stiffness, resistance to wearing layer delamination, increased wearing layer adhesion, possible use of recycled material, and overall economy. By conventional extrusion techniques, such elements are formed with voids of selected shape and dimension, defined by vertical and/or inclined webs between parallel upper and lower flanges, to quite substantial lengths. Bridge deck panels of suitable size can be readily manufactured from such elements in a manner which permits ease of shipment, local handling, placement, and structural assembly and installation at the point of use.

Where an existing bridge deck structure has deteriorated, is live-load restricted, and needs to be widened or modified, the old decking may be removed and with minor modifications a new deck per this invention is readily installed as discussed below. The key is to ensure that the bridge deck is mounted securely to the cooperating support girders (newly installed or left when an old bridge deck is removed), with adjoining modular panels securely spliced to each other so that the resulting structure is fully capable of handling anticipated traffic loads with the recommended factors of safety in accordance with existing industry standards and/or governmental codes.

Elongate elements 102 preferably are made of aluminum alloy 6063-T6 or other similar alloys having good structural properties and excellent resistance to chlorides and other similar corrosion-causing chemicals without the need for painting as with steel structures. The overall depth and geometry of the bridge deck 100 must be selected in light of anticipated loads, and must provide an ample second moment of area and section modulus to permit typical girder bridge configurations with minimal superstructure modification, particularly where existing structures are being replaced by a structure according to this invention.

Figs. 10, 12 and 13 show how the preferred cross-sectional shape of the exemplary extruded elongate elements 102 comprises webs which are perpendicular or inclined to upper and lower flanges to define elongate voids of essentially triangular cross-section. Element 102, seen in Fig. 12 in transverse cross-section, teaches "perfect triangulation". Similarly, element 102 as seen in transverse cross-section in Fig. 10 teaches perfect triangulation except for vertical element 110 which has been added to stabilize and stiffen flange 107. For decks utilizing a large element 102 in transverse cross-section, the section shown in Fig. 10 represents very efficient design requiring less aluminum material to develop the necessary strength and rigidity of the top flange.

When the bridge deck structure is complete, these extrusion voids are closed off at their outer ends to prevent animal infiltration and settlement of debris therein.

The low density of aluminum alloy allows forming of light-weight deck panels 100 weighing approximately 20 lbs. per sq. ft (in plan), thus allowing easy handling even of very large deck panels. The inherent strength and stiffness of such a structure also increases live-load capacity for new bridges since it may be replacing older concrete decking weighing from 100 to 150 pounds per square foot.

A deck panel 100 according to this invention is easily manufactured indoors, by welding together adjacently placed longitudinally spliced elongate extruded elements 102. The use of the prefix "shop-" to characterize welding, assembly, or the like is intended to identify an important aspect of the present invention, i.e., creation of modular elements such as the deck panel under controlled conditions. This allows safe use of expensive welding equipment for consistently high-quality welding, thorough inspection, and safe storage in indoor inventory until the deck panels are needed. This should be as distinguished from steps taken to complete the desired structure in the "field", i.e., at a structural site, in possibly inclement weather and in the face of other local hardships. Field-welding generally is heavily discouraged by many government agencies associated with bridge construction.

Shop-welding of the elongate extruded elements 102 allows a variety of geometries and slope transitions in the finished deck. Elongate extruded elements 100 need not necessarily and always be perfectly straight but, by the use of conventional equipment, may be formed to have desired curvatures or angulation.

As best understood with reference to Fig. 10, two laterally adjoining elongate extruded elements 102, 102 with their respective upper and lower flanges parallel allow the formation of elongate one-side full-penetration welds 104 and 106 to permanently bond together their respective upper and lower flanges. Elongate elements 102, 102 are preferably formed with beveled upper and lower outer edges 103, 103 in the upper flanges and 105, 105 in the lower flanges to accommodate the deposited weld metal of welds 104, 106, respectively. When two elongate extruded elements 102, 102 are thus welded to each other there is formed between them, by the welding, a relatively large, essentially triangular cross-sectioned void 352.

Each elongate element 102 preferably has a cross-section, e.g., per Figs. 10 and 12, in which two parallel flanges each have beveled outer edges and are interconnected by a series of webs, which may be inclined or substantially perpendicular to the parallel flanges, but which always define voids of essentially triangular cross-section within an elongate element 102 and also between welded elongate elements 102, 102 when they are connected. It is the inclined webs that define the most efficient structural system for the decking, i.e., the repeating triangles.

The repeating triangles make the deck composed of elements like those shown in Figs. 10 and 12 an essentially isotropic, rather than an orthotropic load-bearing structure. The centerlines of the webs and flanges intersect one another in forming these triangles, creating a truss in the direction perpendicular to the elongate elements 102 at any cross-section across the deck element. These inclined webs efficiently allow the top and the bottom flanges to become engaged in resisting bending perpendicular to the elongate elements 102 without creating localized bending in the webs or flanges.

While the embodiment according to Fig. 13 provides substantial bending strength in the direction of the extrusion, it is an essentially orthotropic system because the repeating, truss-like triangles are discontinued at top flange splices between adjacent elongate elements 102. The bottom flange continuity that is exhibited in the system according to Figs. 10 and 12 therefore is not present in a system consisting of extrusions according to Fig, 13.

The vertical web in the embodiment according to Fig. 10 helps to stiffen the top flange of the elongate element and eventually the deck by reducing the span between the inclined webs. This also enhances the durability of the wearing layer 108 finally applied above the upper flange by reducing local deflections. The inclined webs 316 preferably are each inclined relative to the parallel top and bottom flanges at an angle in the range about 30° - 70°.

The one-side, full penetration welds 104, 106, properly formed under shop conditions, allow for smooth stress transfer between the upper and lower flanges of the welded-together elongate elements 102, 102. Also, because of the formation of the essentially triangular void of cross-section 352 (best seen in Fig. 3(A), it becomes easy to inspect the resulting welds 104, 106 from both sides of the deck. This is a very significant advantage provided by this invention over the typical configurations which involve overlapping longitudinal lips or integral backer bars along elongate elements which, once they are welded to each other, cannot be carefully inspected on both sides of each weld.

The top flange of each elongate element 102 has an upper surface 107 which, with the top surface of elongate weld 104, allows the combination of a plurality of such elongate elements to provide a continuous upper surface of the bridge deck panel 100. By suitable selection of the thickness of the various flanges and webs, a competent designer can optimize weight reduction and cost while ensuring the desired strength in the resulting structure. Since this would depend on the properties of the alloy or material actually employed, and because this would be within the competence of persons of ordinary skill in the art, detailed calculations relating to such thicknesses are not included herein.

The combination of the upper and lower flanges and the perpendicular and inclined webs therebetween also serves to provide significant stiffness to the deck so that it will resist bending in directions both parallel and perpendicular to the traffic. The upper substantially continuous surface 107 also provides a suitable base to which is applied a wearing layer 108 formed of any suitable wear-resistant material. Epoxy compounds of known type, blended with aggregate preferably of a size in the range 0.05 - 0.25 in., are considered particularly suitable for this purpose and the final thickness of such a wear layer 108 can be selected in light of the anticipated traffic loads and the wearing layer material manufacturer's recommendations.

The connections between adjacent bottom flanges of the elongate elements 102 of each deck panel 100 also provide a continuous substantially flat bottom surface at which the deck panel may be strongly connected to suitable support members 110, as best seen in Fig. 2.

The resulting bridge deck need not be absolutely rectangular in plan view, because curved bridges occasionally are provided in curved roads. This may also require banking and/or crowning of the resulting deck wearing surface and the road surface to ensure proper drainage of rain therefrom.

The thickness of the bottom flange portion of the elongate elements 102 must be selected in light of the strength of the material and the anticipated need for adequate bearing strength both for fastening the deck to the support structure 110 and to ensure adequate resistance to forces and distortional effects caused by foreseeable loads, with adequate factors of safety.

The deck-to-girder connection at support 110 should allow each deck panel 100 to fully engage the underlying girder 112 to develop a substantially integrated bridge assembly in which the deck and girders act compositely to support all foreseeable loading with approved factors of safety. Such a connection will provide what is referred to in the industry as "composite action", which results in enhanced overall rigidity and strength. A preferred manner of forming the desired connection between such a deck panel 100 and an underlying girder is discussed below with reference to Fig. 6.

With bridge roadway widths generally exceeding the width of deck panels which can be conveniently transported, there is a need to field-splice together adjoining deck panels 100, 100 to each other along the outermost elongate structural element 102 of each. This is discussed below with particular reference to Figs. 3A and 3B.

If there is a direct physical connection between the curb and/or safety rail system and the deck panels there could be permanent deformation and/or intolerable stressing of the deck panel locally. Such damage could become expensive and might require interruption of traffic over the bridge to allow repairs. Accordingly, as best seen in Fig. 2, it is preferred to provide a plurality of suitably spaced cantilever brackets 120 supported by the girders 112 to provide a suitable base for mounting thereon of curb and bridge rail system 118 comprising an elongate curb supporting a bridge rail mounted thereon or a reinforced concrete barrier. This is discussed further with particular reference to Figs. 7-9 below. Shear studs 716 may be provided between a concrete pedestal 708 and the underlying cantilever brackets 120 in accordance with conventional bridge construction practice.

As best seen in Fig. 2, a transverse diaphragm 122 may be provided periodically to further strengthen and stiffen the overall bridge structure. The same applies to sudden impact forces experienced by the pedestal and bridge rail structure 118, i.e., these would be transferred via the cantilever bracket 120 to the immediately supporting girder 112 and, by way of the diaphragm 122, simultaneously to other cooperating girders.

Concrete curb 700 (best seen in Fig. 7) may be cast onto the edge of the deck 600 to intercept misdirected traffic by causing vehicular tires to bump against the curb, thus protecting the bridge rail and immediate supporting structure from contact with the impacting vehicle body. This protects the bridge rails such as 702 from permanent deformation and damage in the majority of potential collisions. Bridge parapet 702 is made of aluminum, steel, or reinforced concrete and is connected to the bridge superstructure through a support system comprising upright bridge rail posts 704 when steel or aluminum rails are used and continuously in the case of reinforced concrete rails. Rail 702 prevents pedestrians and/or vehicles from falling off the bridge. In other words, a concrete curb 700 and the totality of the bridge rail structure 118 may cooperate to minimize the harmful consequences of any collisions on the bridge deck.

Concrete curb 700 may be formed to avoid direct contact with the bridge rail posts 704 when these are made of steel or aluminum. This is done by providing a resilient, durable, compression seal 706, e.g., one made of neoprene, pressed in place between cast-in-place concrete pedestals 708 and aluminum extrusion end closure plates 710 which close off the ends of the voids in the elongate elements to keep out animals, birds, and ambient debris.

In an impact between a vehicle and the above-described protective structure, the tires and wheels of the vehicle will first impact curb 700. The resultant lateral force is resisted by aluminum shear angles or studs 712, best seen in transverse cross-section in Fig. 8. There may also be frictional forces between the bottom of curb 700 and the underlying wearing layer 108, tending to resist the lateral force of the impact of the vehicle on the curb.

The preferred aluminum and support post system 118 is to protect against severe collisions, and is provided through the bridge rail 702 and a plurality of supporting bridge rail posts 704 when bridge rail 702 is made. Bridge rail posts 704 are preferably connected to the bridge deck superstructure through a prefabricated support system. Thus, when a vehicle impacts the bridge rail, the consequential impact forces are transferred to and partially resisted by the bridge rail, steel shear studs 716 and the concrete pedestal 708. The impact forces are then transferred through steel bracket 120, gusset plate 718 and stiffener plate 720 into the exterior steel girder 112. Note that there is also provided a diaphragm 122 by which these and other such forces may be transmitted to and shared with adjacent interior girders (not shown) cooperating with girder 112.

All of the components of the above-described bridge rail system are preferably fabricated, i.e., formed, fitted and assembled, in a shop, with the exception of the cast-in place concrete. Even such concrete components can be prefabricated and then taken to the site, fitted, and installed in known manner. The only items which may require extensive field labor are the concrete pedestals 708 and the concrete curbs 700 when aluminum and steel parapets are utilized. High early strength concrete may be employed in forming concrete components in the field to expedite installation and the overall construction process.

The advantages of the above-described bridge rail system may be summarized as follows. The concrete curb 700 is formed, shaped and located to deflect small and glancing vehicular impacts, typically with the tires and wheels of misdirected vehicles. This protects the bridge rail system 118, and most particularly the bridge rail 702, bridge deck 600 and incidental superstructure, from direct impact damage and the need for subsequent repair. The bridge rail 702 is structurally connected to the bridge superstructure at discrete locations via bridge rail support posts 704, concrete pedestals 708, and brackets 120, and it is thus completely isolated from the bridge deck 600 and the upwardly protruding concrete curb 700. This allows impacts with even large heavy vehicles to be safely absorbed by the superstructure without damage to the aluminum deck.

Since the bridge rail system is thus comprised primarily of modular components, it can be quickly and easily installed and, after accidental damage, replaced. This reduces field labor, expense, and traffic delays which are inevitably caused by any construction along a busy roadway. The described bridge rail system preferably utilizes extruded aluminum bridge rails 702 and forged aluminum bridge rail support posts 704. These materials have a proven history as being effective, corrosion-resistant, and visually attractive for such structures. They are also light in weight and can be manufactured in the shop in modular form, and are thus easy to install. The aluminum bridge rail 702 also allows passing motorists the opportunity to view scenery to the sides of the bridge, i.e., the view of a passerby is not impeded thereby.

The preferred embodiment thus provides a composite highly integrated bridge structure including a bridge deck formed from a plurality of interconnected and cooperating deck panels each comprising a staggered arrangement of longitudinally shop-welded extruded elongate multi-void elements comprising aluminum. Adjoining deck panels are connected to each other as described below. The deck structure is firmly mounted to supporting girders or the like. A curb and safety rail system may be provided along each side of the bridge deck but not directly connected thereto. The uppermost surface of the bridge deck is provided a wear layer upon which traffic travels. In the bridge building industry, the term "wearing layer" is sometimes called the "wearing surface".

As best seen in Figs. 3A and 3B, two longitudinally adjoining exemplary deck panels 302 and 304 may be securely connected to each other in the field without compromising structural integrity. In a first embodiment, per Fig. 3A, this is done by means of a splicing system involving first and second splice elements 306, 308 shop-welded to the two deck panels 302, 304, respectively. Such longitudinal splicing may be necessary because the prefabricated aluminum deck panels 302, 304 may be limited in width by shipping constraints. Fig. 3B shows an alternative splicing system.

As best seen in Fig. 3A, a longitudinal field splice according to one preferred embodiment is performed by shop-welding to prefabricated deck panel 302 an elongate first splice element 306 which has an upper flange 320 and a lower flange 321, the flanges having beveled or tapered side edges as in elongate elements 102, 102. There is also provided a second elongate splice element 308, of generally L-shaped cross-section, which is shop-welded to an adjacent side of deck panel 304. Splice elements 306, 308 are preferably extrusions of the same material as elongate elements 102, 102. The connection between the respective splice elements and the corresponding outermost elongate elements of adjoining deck panels 302, 304 is effected by one-side full-penetration welds 104, 106 just as were employed in connecting adjacent elongate elements 102 to form the deck panels 302, 304, respectively. Once the splice elements are thus welded to the corresponding sides of the adjoining deck panels under shop conditions, the adjoining deck panels are field-spliced as shown in Fig. 3A.

Furthermore, in the embodiment of Fig. 3A, a flat elongate splicing plate 310 is positioned beneath the bottom flange of the elements 306, 304. With these elements correctly assembled, with the uppermost outer edge portion of first splice element 306 fitted to an elongate shear key 322 of the second splice element, a plurality of holes is drilled both at the top and the bottom portions of the deck panels. The purpose is to form the holes under shop conditions in element 308 so that when the bridge deck is to be assembled under field conditions the workers simply match drill the holes in element 306 using the predrilled hole in 308 to ensure proper bolting tolerances. The field-connection is preferably made by known one-side connection elements such as "HUCK" bolts 312, 312 passed through the upper flanges and bolts 314, 314 through the spliced plate into the bottom flanges. Thus, "HUCK" bolts 312, 312 each provide strong field-installed connections between the upper flanges of the first and second splice elements and, by their respective welding to adjoining deck panels, between the latter. Similarly, bolts 314, 314 respectively connect the first splice element 306 to splicing plate 310 and the splicing plate 310 to the lower flange of the outermost elongate element of deck panel 304. A strong field-installed splice between adjoining deck panels in the longitudinal direction is thus provided at relatively low expense of material and skilled labor.

The inclined webs 316, 316 of the triangulated first splice element 306 act as members of a truss, continuing the triangulated trusses of adjoining deck panels 302, 304. This allows for efficient transfer of forces between the deck panels in bending in a direction perpendicular to the length of the splice element 306. The vertical web 318 of the first splice element 306 provides local support for the top flange 320 thereof, and this controls the localized flexure and stress in the top flange. When L-shaped second splice element 308 is shop-welded to the prefabricated deck panel 304, it provides shear strength throughout the spliced joint by use of shear key 322 which engages the outermost upper edge of the triangulated first splice element 306 and thus of prefabricated deck panel 302.

Bending strength through this spliced joint is provided by the top flange of the L-shaped second splice element 308 which is bolted to the top flange 320 of the triangulated first splice element 306 and by the bottom flange connected to the splice plate 310. The top flange 324 of the L-shaped second splice element 308 fits into a recessed top flange 320 of the first splice element 306, thus creating an uppermost surface which is deliberately made flush with the top surfaces of the upper flanges of the two adjacent prefabricated deck panels 302, 304. This provides a virtually continuous, relatively smooth, upper surface for application thereon of a wearing surface 108 to support traffic.

The various bolt holes are pre-drilled into element 308 in the shop and then match-drilled in corresponding element 306 in the field. The only other field operations required are bolt installation and application of the wearing layer 108. This rapid field installation reduces traffic delays and overall project costs.

The L-shaped second splice element 308 is a simple solid shape free of any hollows. It requires an inexpensive extrusion die, and is thus less expensive to manufacture.

A groove is formed at the shear key 322 in the arm of the L-shaped second spliced element 308, and is shaped and sized to closely receive therein the upper outermost edge portion 319 of the first splice element

306. This allows for precise and easy fitting together of laterally adjoining deck panels in the field.

Fig. 3B relates to an alternative way of splicing together two longitudinally adjoining deck panels 302, 304 in the field. This is done by employing a first elongate, preferably extruded aluminum, splicing element 362 which has an upper flange 364, a lower flange 366 parallel to upper flange 364, a vertical web 368 which is perpendicular to parallel flanges 364 and 366, and an inclined web 370 which is integral with the upper flange 364 at one edge thereof and which joins with web 368 and lower flange 366 at a common junction 372. An elongate groove 374 is formed in web 368 at the junction 372 and may have any suitable cross-section, e.g., trapezoidal, semi-circular, square, etc.

A beveled surface 376 is provided at and along an uppermost edge portion where inclined web 370 and upper flange 364 join. This beveling preferably extends at an inclination (preferably of about 60° to the parallel flanges) and to a depth comparable to the beveling provided on the upper corner edge of the outermost longitudinal elongate element of deck 304. Beveled surface 376 cooperates with an adjacent beveled surface of the upper edge portion of deck 304 to form a V-shaped groove within which weld metal is deposited. Similarly, there is also provided a beveled edge portion 378 at an outer distal edge of lower flange 366, to cooperate with a counterpart adjacently located beveled surface of the lower flange of the outermost elongate element of deck 304. Accordingly, there is provided another elongate V-shaped space within which weld metal may be deposited to weld together the lowermost adjacently disposed flanges of deck 304 and splicing element 362 at 380. The welds at 380 (between the lower flanges) and 382 (between the upper flanges) serve to provide a very solid, secure and durable connection which maintains the essentially triangulated structure between splicing element 362 and deck 304. A ridge 406 shown in Fig. 3(B) is provided to the second splicing element 384, and is of a shape, size and location such as to closely fit into groove 374 of the first splicing element 362 to properly align adjacent deck panels 302, 304 to each other as shown in Fig. 3(B). Thus, after splicing elements 362 and 384 have been respectively welded to decks 304, 302, the fitting together of ridge 406 into groove 374 aligns the deck panels correctly for match drilling of holes (not numbered) to receive bolts 400 and 402 as shown.

In this embodiment, there is also provided a second and cooperating splicing element 384 which has a generally Z-shaped cross-section (seen in mirror image in Fig. (3B)). It comprises an upper flange 386, a parallel lower flange 388, and a transverse inclined web 390 connecting the two to form the Z-shape in cross-section. Beveled edge surfaces 392 and 394 are respectively provided at the junction of upper flange 386 and web 390 and at the outermost edge of lower flange 388. These have the same form and function as described earlier, i.e., to receive weld material. As seen in Fig. 3(B), the upper beveled surface 392 of splicing element 384 cooperates with a counterpart adjacent beveled surface of deck 302 to form a V-shaped place in which weld metal 396 is deposited to unite second splicing element 384 and deck 302. Similarly, the lower beveled edge surface 394 of lower flange 388 cooperates with the adjacent counterpart beveled surface of the lower flange of the outermost elongate element of deck 302 to form a second V-shaped region which may be filled with weld metal to form weld 398. The welds 396 and 398 thus provide solid, durable, and effective load-transmitting connections at the upper and lower flanges between the second splicing element 384 and deck 302.

As readily seen in Fig. 3(B), the sizing and shapes of the first and second splicing elements 362, 384 are selected so that the uppermost surface of upper flange 386 of the second splicing element 384 is coplanar with the upper surfaces of decks 302 and 304. Similarly, the lower outer surfaces of lower flanges 366, 388, of first and second splicing elements 362, 384, are also coplanar with the lower surfaces of decks 302, 304.

A plurality of suitably spaced-apart bolts 400, 400 are provided through field-matched holes drilled into the upper flanges 364, 386 of the first and second splicing elements to thereby unite decks 302, 304 at their upper portions. Similarly, pluralities of bolts 402, 402, passed through suitably spaced-apart and field-drilled holes may be employed to strongly connect lower flanges 366, 388 of the first and second splicing elements 362, 384 to a common elongate flat splicing plate 404, to thereby strongly unite the lower flanges of decks 302, 304 to each other. The heads of these bolts may be countersunk, if desired.

Alternative methods of splicing elements 302 and 304 by means of regular high strength steel bolts are also possible and may be considered.

A wearing layer 108 may then be applied, as previously discussed, on the top surface of the now united decks 302, 304 to provide a continuous, long-wearing, friction surface on which traffic may traverse the decks.

The purpose of strongly splicing together adjacent deck panels is to ensure that the desired isotropic performance of the total bridge deck is realized as closely as possible. Persons of ordinary skill in the art will appreciate that in both of the techniques for longitudinally splicing adjacent deck panels, as illustrated in Figs. 3(A) and 3(B) and as discussed above, the provision of suitably inclined and perpendicular transverse webs results in a light-weight structure capable of isotropically transmitting bending and shear loads through and between spliced-together adjacent deck panels in both the longitudinal (i.e., traffic) and transverse directions.

As best seen in Fig. 4, in deck panel 100 a number of longitudinally adjoining elongate elements 102, 102 are spliced together with their ends distributed in a staggered manner. Laterally adjoining elongate elements are welded at their respective upper and lower flanges by full penetration welds 104, 106. Fig. 5 shows details of how longitudinally adjoining elongate elements 102, 102 are shop-spliced to each other in forming each deck panel.

Individual elongate elements 102 may be pre-cut to specified lengths to create a desired deck panel layout. As shown in Fig. 5, in this particular embodiment, each elongate element 102 has an upper flange 502, a parallel lower flange 504, a web 506 perpendicular to the upper and lower flanges, and inclined webs 508 and 510 connecting the flanges as shown. This creates elongate, essentially triangular cross-sectioned voids 512 and 514. When two laterally adjoining elongate elements 102, 102 are welded by welds 104 and 106, there is also created an elongate essentially triangular cross-sectioned void 516. This plurality of webs and welded elongate elements creates a light-weight, stiff and structurally strong deck panel 100.

The ends of two longitudinally adjoining elongate elements 102, 102 are extended or shop-spliced together by, for example, inserting through their immediately adjacent ends a pair of essentially triangular cross-sectioned shear elements 518, 520. In Fig. 4, the disposition of the shear elements 518, 520 is indicated by broken lines. As best seen in the transverse cross-sectional view of Fig. 5, shear elements 518, 520 are shaped and sized to be closely received within the elongate voids 512, 514, respectively, of each of two longitudinally adjoining elongate elements 102, 102. In addition, there may be provided a flat bottom flange splice plate 522 directly beneath the end portions of the bottom flanges of the two longitudinally adjoining elements 102, 102.

Strong physical connection between shear elements 518, 520 and elongate elements 102, 102, as well as between the bottom flange splice plate 522 and the same elongate elements 102, 102, is provided by a plurality of connection elements such as bolts. Holes of suitable size to locate these bolts 524, 530 are provided through the upper flange 502 and the corresponding adjacent portion of each of shear elements 518, 520. To ensure that there is an essentially flat upper surface formed in the resulting deck panel, countersunk holes are formed in the upper flange 502 for tapered-head bolts 524. Other holes are provided for bolts 526 and 528 fitted through the inclined walls or webs, as shown in Fig. 5. These web connections may be made on one side of the splice only, prior to joining the ends of 102. Shear to the other element 102 may be transmitted by friction between tightly fitted elements or through the use of one-sided fasteners such as "HUCK" bolts. Holes are also provided for bolts 530 passed through bottom flange 504 and bottom flange splice plate 522. All of this is best done under shop conditions to ensure precise fitting together of the connected elements and to permit the necessary inspection to ensure quality control.

Elongate elements 102 typically are shorter than the final deck panel 100 formed therefrom. Longitudinal splicing of the elongate elements 102 in successive end-to-end connections by shear elements 518 and 520 and by bottom flange splice plate 522 creates elongate ribs of the desired length and these are then welded together by welds 104, 106, with elongate element ends in staggered array (see Fig. 4) to form the deck panels 100.

The above-described splicing is performed as many times as necessary, depending upon the desired length and width of the final deck panel to be formed. Since such deck panels can be easily made to a length of 100 ft. or longer, a single deck panel may suffice for a relatively short bridge without field splices. In the alternative, depending upon the chosen support system beneath the bridge deck, each deck panel may be oriented transversely to the direction of traffic and a number of such deck panels may be needed with the width of the bridge determined by the length of each deck panel. In any case, the end-to-end spliced elongate elements constitute shop-prefabricated ribs which are then welded together, also in the shop, at the top and bottom flanges 502 and 504 by full penetration welds 104 and 106, respectively, to form the prefabricated panel of selected length and width.

The thicknesses of upper and lower flanges 502, 504 of the elongate elements, if they are made of aluminum alloy, preferably are in the range 0.3-0.75 in. Full penetration welds 104, 106 therefore also are of comparable depth.

Splicing of elongate elements 102, 102 prior to welding allows easy visual access for inspection at both sides of the bottom flange and other regions of interest. Forming of holes to receive various bolts, and subsequent bolting together of the triangular cross-sectioned shear elements 518, 520 as described above is also facilitated. These shear elements allow for the transfer of shear forces between the ends of the pair of longitudinally adjoining elongate elements. Such easy access also allows the fabricator of the bridge deck to bolt the bottom splice plate to the bottom flanges of two laterally abutting elongate elements 102, 102 and provides additional bending strength to such a joint. Note that bolting together the top flanges 502 and the upper portions of the triangular cross-sectioned shear elements 518, 520 also adds to the strength of the structure when subjected to bending forces.

Since the entire above-described splicing and fabrication process is performed under shop conditions, allowing detailed inspection and consistent quality control, the resulting assembly and welding ensure that each deck panel has strong, weather resistant and dirt-impervious joints.

The interconnected deck panels forming the bridge deck must be securely mounted to support structures, e.g., a plurality of cooperating bridge girders. The top surfaces of steel girders are preferably coated with a protective coating to ensure against corrosive damage to the material of the deck panels due to bi-metallic effects wherever the girders make contact with the deck. If the aluminum is to make direct contact with uncured concrete it may need a protective coating. Aluminum girders could be provided in place of conventional concrete or steel girders, but when existing support structures are to be utilized, e.g., in replacing an existing deteriorated bridge deck or in expanding the same, steel girders are more likely to be encountered. It is desirable to entirely remove old concrete to which the previous bridge deck was anchored. To ensure a structurally sound and easily achievable connection compatible with existing girders, it is preferable to anchor the invented bridge deck to the tops of such girders via a flowable and curable medium capable of transferring shear, e.g., epoxies, resins, concrete, or grout. For secure load-transferring connection, a plurality of aluminum shear engagement devices such as studs or angle-section short metal elements may be used. Such aluminum shear engagement devices may also be coated with a protective coating to reduce corrosion and shortened life.

One form of the desired bridge deck-to-girder connection using a cured-in-place flowable medium for transferring loads from the prefabricated aluminum bridge deck 600 is best seen in Fig. 6. The cured-in-place medium, e.g., a known initially uncured and readily pumped flowable grout or concrete composition, is disposed between the bottom surface of the deck and the upper surfaces of the girders. Once it is cured, the medium connects the bridge deck to the bridge girders 602 each of which has a vertical web 604 and an upper horizontal flange 606. The desired structure is obtained by first attaching shear engagement elements 608, 608 to the top of girder flange 606. In redecking projects, these shear engagement elements 608 may already be in place. Similarly, a plurality of shear engagement elements 610, 610, spaced so as not to coincide or interfere with shear elements 608, 608, may be attached in any convenient manner to the bottom of bridge deck 600. They may even be part of element 102 wherein they are subsequently notched to create a shear interface.

Before bridge deck 600 is put in place, aluminum shear studs 610, 610 are attached to the bottom flange of the deck 600. Shear engagement elements 608, 608 are then attached to the upper flange 606 of girder 602. See Fig. 6. Leveling elements 616 are then secured to the tops of the girders in various locations for the purpose of setting the deck elevation. The heights of the leveling elements 616 are set in such a manner as to ensure that the prefabricated panel 600 when resting on the leveling elements 616 will be located at the proper elevation. Next, removable forms 612, 612, with compressible elements 614, 614 provided at the top thereof are attached to the upper flange 606 of girder 602. The goal is to form a temporary but well-sealed space between the upper surface of upper flange 606 of girder 602 and the bottom surface of bridge deck 600, with the various shear engagement devices disposed therebetween. The exact positioning of the bottom surface of deck 600 relative to the upper surface of upper flange 606 can be locally adjusted by any conventional leveling device such as 616 which is eventually left in place embedded in the cured flowable medium. Several such leveling devices may be used. By judicious use of such devices, even curved and/or crowned bridge deck profiles can be achieved.

Flowable medium 618 is then flowed into the void defined by the upper surface of upper flange 606 of girder 602 and the forms 612, 612 in sufficient quantity, i.e., to virtually the top of compressible elements 614, 614. The still uncured flowable medium is then preferably vibrated to settle within the formed volume. To minimize corrosion, flowable medium 618 may be a polymer-modified or magnesium phosphate based product. While the flowable medium 618 is still in its uncured and plastic state, the prefabricated aluminum deck 600, with shear engagement devices 610 attached thereto, is lowered into place so as to have its weight resting on the plurality of leveling devices 616 which have previously been adjusted as needed. The uppermost edges of the compressible elements 614, 614 will have been positioned so that they will deform slightly when deck 600 is in its final position initially resting on the top of the leveling devices 616. The goal is to ensure that the uncured flowable medium 618 makes extensive contact with the bottom surface of deck 600. This is facilitated by the compressible nature of compressive elements 614, 614 and proper adjustment beforehand of leveling devices 616. After a suitable period of time, once the flowable medium 618 has cured to its set state to form a rigid connection between bridge deck 600 and girder 602, the form elements 612, 612 may be removed.

Use of flowable medium 618 permits formation of complex bridge deck geometries without use of expensive and difficult-to-use shims and adjustment mechanisms, particularly under difficult field conditions and or where there are variations in girder heights/elevations. A deck cross-slope or crown is often necessary to ensure adequate drainage, and vertical curvature in bridge decks is often provided as a smooth continuation of a curved profile in the contiguous roadway but may be required for other reasons as well. Such geometric requirements can be readily met with simple leveling devices such as 616 and the ease of using a flowable medium 618 to establish the desired connection between bridge deck 600 and supporting girders 602.

Shear engagement devices such as elements 608 and 610 inexpensively and easily allow efficient transfer of shear force between bridge deck 600 and the supporting girders 602 positioned below. The final strong solid bond between them enables the bridge deck and the support system of girders to act compositely or in an integrated and unified manner, thereby increasing the strength of the overall structure. Ordinary studs, which are relatively inexpensive and are easily placed, may be used as the shear engagement devices 608, 610. Furthermore, since the shear engagement devices 610 according to this embodiment are attached to the bottom surface of the bridge deck 600, there is no need to strategically place the bridge deck so as to avoid the heads of conventional fasteners such as through-bolts. This will give the bridge engineer using this invention freedom to locate individual elongate shear elements 610 of the bridge deck in any selected location with respect to the supporting girders.

Shear engagement devices may readily be made of steel, hence they can be easily used for deck replacement on bridges which have existing shear studs located on the girder system which is to be retained. This avoids costly and time-consuming removal of existing shear connection devices during upgrading and/or extending of existing bridge facilities.

Use of compressible elements or strips 614, 614 at the tops of the removable forms 612, 612 ensures that flowed-in concrete or grout in its uncured state will be enabled to make intimate contact with the entire bottom surface of bridge deck 600, so that there will be sound well-distributed support by the cured concrete for the bridge deck 600 when the latter is put to use and carries its intended traffic loads.

If the existing girder support system is to remain for redecking, it must be prepared for attachment to the new bridge deck 600. Conventional attachment methods require significant drilling, in the field, through the top flanges of the girders. This is costly and time-consuming. Shear studs, however, can be applied rapidly and in many cases may already be present. Furthermore, since they are to be placed initially within the flowable medium, precise location of the shear studs is not required.

The above-described prefabricated bridge deck, when made of aluminum or aluminum alloy, is very light in weight (approximately 20 lbs. per sq. ft). The option therefore exists for the integrating connection between the bridge deck and underlying girders to be made in the shop when a new bridge deck and new steel or aluminum girders will be used. Entire bridge panels, including girders, could be so prefabricated, shipped to the final site of use, and installed quickly. With shop-construction, there will be improved inspection, quality control, safety assurance to the ultimate users of the bridge deck, and perhaps even lowered insurance premiums to the bridge builder and/or owner.

Fig. 14 is a transverse cross-sectional view of a bridge structure in which a bridge deck 1400 is securely mounted to the uppermost surfaces of horizontal compression flanges of a plurality of girders 1402. Along both outer edges of bridge deck 1400 are provided rail structures 1404, 1404. Other structure for supporting the girders 1402, 1402, may be of any conventional kind and is therefore not described further.

As indicated in Fig. 14, even where the bridge itself in its lengthwise direction and the road surfaces leading to it, are all substantially horizontal, it is customary to "crown" the bridge, i.e., to make its central portion a little higher than its outer edge portions to ensure drainage of rain water away from the uppermost surface of the bridge. A slight slope on both sides from the center of the roadway, typically only a few degrees downwardly from the local horizontal, is generally sufficient to facilitate effective drainage of rain water away from most of the traffic-contacted wear surface of the bridge. Such drainage of rain water also limits the formation of glaze ice in subfreezing weather and improves safety.

If a road surface approaching the bridge deck is sloped, or if the road is curved with or without a lengthwise slope and is banked to accommodate fast-moving traffic around a curve, the uppermost surface of the bridge deck may have to be inclined correspondingly with respect to the local horizontal.

A detailed description follows of a system for securely mounting a bridge deck incorporating elongate extrusion multivoid elements, including but not limited to the types discussed elsewhere in this application, to a system of supporting girders. The goal is to ensure that all forces related to loads causing shear and bending moments, and downward loads due to gravity (of both the bridge deck and traffic thereon), are transmitted between the bridge deck structure and the cooperating girders to enable them to act cooperatively in resisting both static and dynamic loads. Acting together as a composite structure they are better able to utilize metal and curable medium materials than is possible with conventional structures. This invention also economically facilitates precise crowning and/or banking of the bridge deck to suit specific design needs.

As best seen in Fig. 15, according to this invention a bridge deck is formed of a plurality of elongate multi-voided extrusion elements. It is securely mounted to cooperating girders to effectively transfer all static and dynamic forces between bridge deck 1500 and upper (compression) flange 1502 of an exemplary underlying girder 1504.

The bridge deck 1500 in a preferred embodiment is formed of a plurality of adjacent multivoid extrusion elements 1506, 1506 which are welded lengthwise to each other at upper welds 1508, 1508 and lower welds 1510, 1510 preferably as described earlier by one-side full-penetration welding. Each elongate extrusion element 1506 has a flat upper flange 1512 and a flat parallel lower flange 1514 between which extend a series of webs 1516, 1518 and 1520. The bottom edges of internal webs 1516, 1518 and 1520 meet in a junction 1522.

The procedure for forming the desired secure connection between bridge deck 1500 and flange 1502 of the support girder will now be described.

A plurality of leveling devices 1524, each preferably of a selected height, are placed in contact with the upper surface 1526 of flange 1502 at intervals along the length of girder 1504. The leveling devices do not have to be affixed to the girder for use as described, but affixation, e.g., by adhesive, spot welds, etc., to avoid their accidental displacement, would be advantageous. This is particularly true if the heights of individual spacing devices are selected to be different, e.g., to correct for unevenness of the girder flange, to obtain a desired curvature of the bridge deck, etc. Each such leveling device will serve as a local shim or spacer block, and may conveniently have the form of a short length of a hollow tube or pipe. The number and disposition of such leveling devices will depend on the length of the girder 1504 and a corresponding length of the bridge deck 1500 to be connected thereto while resting on the leveling devices. The leveling devices 1524 are preferably placed above and along the junction of flange 1502 and the underlying vertical web of girder 1504.

On opposite sides of the line of leveling devices are preferably provided a plurality of paired, spaced-apart studs 1528, 1528 mounted upwardly of the top surface of the girder 1504. Each stud 1528 has a distal head 1530, 1530. When girder flange 1502 is made of steel, studs 1528 preferably are also made of steel and are welded perpendicular to the upper surface 1526 of the flange 1502 in a selected distribution and spacing relative to the leveling device 1524 and along the length of flange 1502. This welding can be done in the field if necessary, and may also be done in the shop if desired. The overall length of each stud 1528 and its head 1530 in an axial direction must be selected so that there is a small space between an inside surface of the adjacent upper flange 1512 and the distal end surface of stud head 1530 when the bridge deck 1500 is placed in contact with leveling devices 1524 above flange 1502 as illustrated in Fig. 15.

In order to receive studs 1530 into the voids which are to be later filled with the flowable/curable medium, suitably sized holes, having diameters larger than the diameters of the stud heads 1530, 1530, are drilled in the bottom of the bridge deck at a plurality of locations corresponding to and preferably exceeding the numbers of the studs 1528, 1528. This is best done by a known device, e.g., a hole saw, preferably in the shop, to drill holes 1532, 1532 in the lower flanges 1514, 1514 and holes 1534, 1534 coaxial therewith through inclined flanges 1518 and 1520. With these holes, bridge deck 1500 can be placed above flange 1502 to rest on spacing devices 1524 so that studs 1528, 1528 respectively extend into the holed elongate elements 1506, 1506 substantially centrally of corresponding holes 1532 and 1534.

Fig. 16 is a view of part of the bottom surface of the bridge deck 1500 as used in the structure of Fig. 15. Holes 1532, 1532 are formed through the bottom flange portion of one of the constituent elongate elements, of a size large enough to allow easy passage therethrough of the heads 1530, 1530 of corresponding studs 1528, 1528. The holes 1532, 1532 are most easily made in the shop (although they can be made in the field) to a selected pattern. It may also be desirable to form a larger number of holes 1532, 1532 than the anticipated number of studs 1528, 1528 to allow for addition of more studs during assembly of the bridge. The initially flowed and eventually cured-in-place medium will cure-in-place in the finished structure as a contiguous bonded mass extending via all the holes 1532, 1532.

Two elongate removable forms 1536, 1536 may be positioned to contact outer edges of flange 1502 so that their upper edges contact the undersurface of bridge deck 1500. These forms may be thin plates made of metal, plastic or wood. They may be forcibly held in firm contact with the outer edges of flange 1502 by any suitable means, e.g., a plurality of elongate form ties or threaded rods 1538 passed through the forms and fastened by nuts 1540, 1540 as shown in Fig. 15. Removable forms 1536, 1536 define an elongate space between the bridge deck 1500 and the upper surface 1526 of the upper flange 1502 of girder 1504, of a height determined by the leveling devices and of a length determined by the lengths of the forms themselves.

This still leaves openings at both ends of the bridge deck 1500, leading to the voids therein above leveling devices 1524, and between bridge deck 1500 and upper surface 1526 of flange 1502. The temporarily defined elongate space preferably is of at least the length of the bridge deck 1500, i.e., of the longitudinally attached extruded elements. It is necessary to substantially close-off these end openings (not numbered) to define an enclosed space into which a controlled flow of the initially substantially fluid but curable-in-place medium is to be flowed in.

As best seen in Fig. 17, an end plate 1702 to temporarily enclose an end opening of the space to be filled in may be of a generally rectangular shape. It should have a width larger than the width of the girder flange 1502 and a height extending at least from the top surface of girder flange 1502 to the bottom of the bridge deck. A plurality of holes 1704, preferably three each of about 1 1/2 in. diameter may be provided at locations corresponding to the uppermost corners of the voids in the elongate elements 1506, 1506 which are to be temporarily closed-off by end plate 1702. The purpose of these holes 1704 is to enable flow-in therethrough of the initially fluid uncured medium into each of the voids near the uppermost portions thereof. Rubber or plastic like 1562 or 1564 as shown in Fig. 15, of a size corresponding to holes 1704, may be inserted to temporarily seal off the holes after the medium has been flowed-in and while it sets to its cured state.

Sufficient curable material must be poured in, with efficient bleeding out of air from the enclosed space, to completely fill the spaces in the voids between the internal webs 1516, 1518 and 1520 and the annular spaces around studs 1528, 1528 and the surrounding holes in the inclined webs 1518, 1520 as well as the bottom flanges 1514, 1514. External vibration means may be applied in known manner to vibrate the elongate member being filled in to ensure good flow with escape of the air being displaced. A plurality of such bleed holes 1560, 1560, preferably at selected heights relative to the enclosed space being defined between the bottom of the deck 1500 and the top surface 1526 of the girder, may be provided in the removable forms and plugged with rubber or plastic plugs 1562, 1562. The bleed holes are selectively unplugged open to allow air to escape. One or more pluggable bleed holes 1564 and plugs 1566 therefore may also be provided in the upper flange 1506 of the elongate element, preferably at the highest points thereof, to facilitate final bleed-off of air.

As indicated by the array of marks or dots in Fig. 15, the initially uncured but subsequently cured-in-place medium material 1542 must essentially fully fill the space defined by the inside surfaces of upper flanges 1512, 1512, internal webs 1516, 1518 and 1520, lower flanges 1514, 1514, the upper surface 1526 of girder flange 1502, and the inside surfaces of removable forms 1536, 1536. The medium 1542 is flowed in, under controlled pressure and vibrated if required, and held in place until it is adequately cured. Once the medium has cured-in-place, removable forms 1536, 1536 are removed and the cured medium is inspected to detect visible surface voids, cracks, or other imperfections so that they may be treated as described below.

Suitable curable mediums which are initially fluid and can be cured to be put into a solid state are widely available commercially. Among these are "928 Grout" and "Set 45", products manufactured by Master Builders, Inc. of 23700 Chagrin Blvd., Cleveland, Ohio. The "Set 45" product has, as its cementitious base, magnesium phosphate instead of the traditional Portland cement. The presence of magnesium phosphate causes the initially flowable medium to have a pH value in the range 7-8. This is a substantial improvement over conventional grouts which typically have a pH of about 13 in their uncured state, which tends to create adverse reactions with structural aluminum and aluminum alloys. Often, even after setting, the pH of conventional grouts will return to high, undesirable levels when the grout becomes wet. This is not the case with "Set-45", which maintains its relatively low pH level at all times. The "Set 45" product also meets recognized criteria for a "non-shrink" grout, which is desirable for the contemplated use, since intimate contact between parts after the medium has cured the strength and durability of the connection. High compressive and shear strengths are other desirable characteristics of "Set 45" for bridge construction purposes.

Desirable qualities of the medium include ease of handling, consistency of physical parameters of interest, cost, and availability. It must be flowable under prevailing conditions, e.g., in desert heat or at relatively cold temperatures. It must be of a consistent quality and readily available when and where it is needed.

As will be appreciated, given a large enough facility and adequate in-shop equipment, it should be a matter of design choice whether a particular bridge deck is attached as described above, namely via studs, removable forms, and flowable medium cured-in-place, in a shop. If some or all the metal elements, i.e., the bridge deck, the studs, and the girders, are made of aluminum or aluminum alloy (a material which includes aluminum), the completed structure with the bridge deck made virtually integral with the girders may not be too heavy to be transported to its intended site of use. If, instead, an old bridge deck has been removed and the underlying support girders are to be reused for placement of a new deck thereon, some or all of the studs may have to be welded in the field, the removable forms attached in the field, the deck assembled on the leveling devices in the field, and the curable medium poured in the field.

Once the material is cured, nuts 1540, 1540 can be readily removed by the use of conventional wrenches and the like, and the removable forms 1536 tapped loose and also removed. Bars 1538 will now be solidly embedded into the cured medium 1542, as will the leveling elements 1524. A careful inspection must then be made of the exposed surfaces of the cured-in-place medium where it cured in contact with inside surfaces of removable forms 1536, 1536. By applying a conventional vibrating device to the girder as the initially fluid uncured medium is poured in, it should be possible to shake loose and remove bubbles of air that might otherwise become trapped within the enclosed space being filled by the medium. Nevertheless, small bubbles and local cracks may occasionally be detected. If the medium includes an epoxy compound, the presence of such small bubble voids, local cracks, etc., should not seriously compromise its structural integrity when cured-in-place, and should not compromise its ability to safely support the weight of the bridge deck and all anticipated traffic. Commercially available protective compounds may be applied to the surface of the cured-in-place medium 1542 between the lower surface of the bridge deck and the upper surface of flange 1502 to weatherize, seal, and protect the exposed surfaces.

To ensure against corrosion damage by chemical interactions between the medium and the material of the bridge deck, it may be desirable to treat those surfaces which contact the uncured medium. This may be important where chemically non-reactive, magnesium phosphate-based initially flowable medium is not available or is otherwise impractical to use. The protective treatment may include the steps of initially washing the surfaces with a suitable detergent, drying them and then spraying the surfaces if this is convenient, or otherwise painting the surfaces with a suitable corrosion-resistant primer-type material. Various commercially available materials are suitable for this purpose, including bitumen. Such a material must adhere strongly to the clean exposed surfaces to which it is applied, whether on the aluminum or aluminum alloy bridge deck elements or on the exposed upper surface of flange 1502 of old or new steel girder 1504. It is also desirable, although not necessary, that when the coating layer is dry it should have an inherent small scale roughness on its exposed surface so that the initially uncured fluid flowable medium will attach very strongly thereto and, when cured-in-place, become very strongly bonded to the metal via the corrosion-resistant coating 1550.

When shear forces are to be transmitted between the bridge deck 1500 and the girder 1504 after integration of the bridge deck with the girder, the load will initially be experienced by the bridge deck, transmitted to the cured-in-place medium 1542, then to studs 1528, 1528, and through them to the upper or compression flange 1502 of girder 1504.

It is essential to note, as it represents an innovative and previously untried component of this invention, that the transfer of shear forces between the bridge deck 1500 and the cured flowable medium is highly facilitated by the provision of the openings 1532, 1532 in the bottom flanges 1514 and internal webs 1516, 1518 and 1520. This is the primary reason for providing openings 1532, 1532 even where shear studs 1528, 1528 will not protrude. The initially flowable medium 1542, after curing, forms a contiguous, solid, strong mass, which exists in and around the openings and thus acts as an interference mechanism to resist any shear forces applied by the deck. Therefore, because of this interference, any horizontal or vertical load transmitted to or existing in the deck 1500 will be transmitted in turn to the cured medium 1542. Similarly, loads or forces from the cured medium 1542 will be transmitted to the deck 1500. The controlling criteria in determining the strength of this connection include the number of openings 1532, 1534, the sizes of these openings, and the shear strength of the flowable medium 1542 after it has cured.

It follows that the number and size of openings 1532, 1534, may be varied as needed accommodate the anticipated loading for the bridge. Similarly, the size and spacing of the shear studs 1528, 1528, are matters of design choice to suit the requirements and loading of any particular bridge.

As noted earlier, when a large number of studs 1528 are to be accommodated through corresponding holes 1532 and 1534, due to errors in measurement or alignment the annular gap between the outer surface of a stud 1528 and its surrounding hole 1532 or 1534 may not be even all around. A preferred diameter for such studs is in the range about 13 mm - 22 mm, and a preferred size of the corresponding hole in the multivoid element to receive such a stud is in the range about 38 mm - 64 mm, so that an open annular gap around a perfectly located stud is at least about 6.5 mm and preferably in the range about 6.5 mm - 19 mm. Even if there is only a relatively thin layer of the cured-in-place medium 1542 at any location between a stud 1528 and a surrounding adjacent edge of hole 1532 or 1534, there need not be any significant destruction of the relatively small amount of the cured medium 1542 thereat when the bridge is under load. The reason is that transmission of shear forces between bridge deck 1500 and cured-in-place medium 1542 is accomplished via a plurality of openings 1532, 1534, both at the locations the shear studs 1528, 1528 and elsewhere.

Also, because cured-in-place medium 1542 makes contact with a large surface area of the elongate multivoid elements 1506, 1506 (which are welded together by elongate welds 1508 and 1510 to create the space to be filled by the cured medium 1542), there will be a very large bonding force between the cured medium 1542 and all the surfaces contacted thereby. While this is not the primary means of transmitting shear forces between bridge deck 1500 and the cured flowable medium, it provides additional strength, redundancy, and an additional factor of safety. Therefore, even if there is actual physical contact between a hard steel stud 1528 and a relatively soft aluminum or aluminum alloy portion of the bridge deck, once the medium 1542 is cured-in-place, transmission of all forces between the bridge deck and the studs, and thus to the girder below, can be accomplished with a very high factor of safety over a prolonged period of time. This represents an inherent structural advantage of the present invention over other known ways of attaching a metal bridge deck to a support girder.

Note that once the enlarged heads of the studs are surrounded by cured-in-place medium the studs will be available to carry tensile loads as well. Such tensile loading and oppositely directed compressive loading along the axes of individual studs may arise due to rolling loads on the bridge deck, temperature-induced differential expansions, etc., which could cause time-varying bending moments to be generated in the bridge structure.

In utilizing an existing support girder system to support a new bridge deck it may happen that the upper surfaces of the upper flanges of the girders may have had holes previously drilled through them during the original construction (to receive nuts or rivets during their earlier use), or there may be left over studs or other bits of metal (e.g., distorted, distressed surface portions, uneven surface spots due to rust, stubs of studs knocked off or cut off to remove the old deck, etc.). Because the present invention ensures that there is a two-inch gap between the lower surface of the bridge deck and the upper surface of an underlying upper flange of a girder, the initially uncured fluid medium will flow over, around, and into such uneven portions of the girder as required. This also is an inherent advantage of the present invention over other known techniques.

The medium must be flowed into all the voids and spaces which it must fill. Holes may be made in removable forms 1536, 1536 at different heights and initially plugged close with flexible plugs made of rubber or plastic. Individual plugs can be pulled out at different heights so that air and the initially fluid uncured medium leak or seep out from the opened holes, and the holes then reclosed as the medium rises higher.

If there is an imperfect fit between the upper edges of removable forms 1536, 1536 and the undersurface of the bridge deck contacted thereby, some of the medium may seep out from any gaps. The forms can be tapped upward to obtain the best possible contact. Adhesive tape, e.g., common duct tape, may also be used to seal any gaps that remain. Then, as the initially fluid uncured medium is poured in and rises to that level it will push on any air that is left there. This air can be released by removing the tape as needed. Such techniques for checking the complete filling-in of the space with the initially fluid uncured medium should be easy to use even under field conditions.

An important aspect of the present invention is the generation of a bridge structure which includes a relatively large deck panel from simple elongate extruded aluminum elements 102 by connecting them to each other by longitudinal one-side, full-penetration welds. This feature of the invention is best understood with reference to Fig. 11 which also illustrates and explains a preferred mechanical device for forming such welds efficiently, rapidly and to consistently high standards.

In Fig. 11 the two longitudinally adjoining elongate elements 102, 102 which are to be welded together are shown "upside-down" as compared to the view in Fig. 10. If the welding takes place in a "shop", there is no special limitation generated by the terms "up" and "down", but when the completed deck panel is to be assembled into the bridge deck it is important to have the upper surface of each panel at the top.

In Fig. 11 there are seen in transverse cross-section only the relevant portions of two longitudinally adjoining but unwelded elongate elements 1100a and 1100b. As seen in transverse cross-section, they have first flanges 1102a and 1102b and second flanges 1104a and 1104b which have respective outer flat surfaces 1106a, 1106b and 1108a, 1108b. At their outer flange edges, elongate elements 1100a, 1100b are respectively provided with chamfer surfaces 1110a, 1110b and 1112a, 1112b, respectively. Accordingly, when two elongate elements 1100a and 1100b are placed in side-by-side contact with each other they generate two local V-shaped elongate grooves 1114 and 1116 into which are to be formed the so-called "one-side, full penetration welds" as discussed above.

Secure positioning of two cooperating but unwelded elongate elements 1100a and 1100b is readily accomplished. It is important, however, to avoid loss of deposited molten weld material through the bottoms of the unclosed V-shaped grooves 1114 and 1116 (when each is disposed with its apex downward to receive molten weld material) while the welds are being formed. To significantly reduce such throughflow of weld material, and to ensure high quality longitudinal welds, a backing bar 1118, made of a material such as anodized aluminum or stainless steel, is inserted below the apex of the upper V-shaped groove, i.e., 1116 in the arrangement per Fig. 11. Backing bar 1118 is temporarily held in place by any suitable means, e.g., a cylinder (pneumatic or hydraulic) 1120 generating an upward force on a piston 1122 immediately beneath backing bar 1118. A better controlled and stronger weld is obtained by providing a shallow groove 1124 in the outer surface of backing bar 1118, positioned directly beneath the apex of the V-shaped groove 1116. Thus, molten weld metal deposited into V-shaped groove 1116 melds with the material of flanges 1104a, 1104b at the inclined surfaces 1112a, 1112b thereof. Some weld metal will fall through the apex of the V-shaped groove 1116 and will be caught in the shallow groove 1124 therebelow, form a weld bead reinforcement, and become part of the weld between the flanges 1104a, 1104b. Most of the weld metal will blend in with the parent metal of the two adjacent flanges that are being welded together, and will fill the initially open V-shaped groove therebetween.

The exemplary apparatus 1150 which comprises backing bar 1118, cylinder 1120, and piston 1122, also includes a base element 1142 of trapezoidal cross-section on which pneumatic cylinder 1120 is mounted by bolts 1126 on an intermediate base 1128 which has two outwardly extended inclined arms 1130a, 1130b. Small rounded slider contacts 1132a and 1132b are provided on extensions 1130a, 1130b, respectively, and are sized and positioned so as to make light sliding contact with inclined inner surfaces 1134a, 1134b of inclined webs 1136a, 1136b.

Directly beneath base element 1142 there is provided a second backing bar 1138 which has a rounded surface containing a shallow groove 1140 which is positioned immediately adjacent to the apex of V-shaped groove 1114. As will be immediately apparent, shallow groove 1140 is intended to perform precisely the same kind of function as shallow groove 1124 in backing bar 1118, i.e., to form the weld metal that melts through the apex of the V-shaped groove 1114 into a reinforcing weld bead when welding is being done between inclined surfaces 1110a, 1110b.

Pneumatic cylinders are preferably utilized, and a conventional pneumatic hose (not shown) may be employed with a shop supply of compressed air to pressurize pneumatic cylinder 1120 after the apparatus 1150 has been pushed into the space between the adjacently held elongate elements 1100a, 1100b. Application of pneumatic pressure to pneumatic cylinder 1120 will then cause piston 1122 to push upward on backing bar 1118 and, simultaneously, will cause the other backing bar 1138 to press in the opposite direction. Relief of pneumatic pressure will have the opposite effect and some retraction of the backing bars and will permit the operator to pull the apparatus 1150 out once the welds have been made. Instead of pneumatic pressure with compressed air one may substitute water pressure, e.g., using a conventional fire hose and mains water pressure. In addition, an especially useful mechanism is a fire hose (or equivalent) pneumatically inflated and guided for longitudinal movement by spring-loaded bearing to ensure correct positioning of the backup bars.

As a practical matter, backing bars 1118 and 1138 can be consumable shop elements which may be disposed of after a certain amount of use, and the metal therein may be recycled if desired. The key is that backing bars 1118 and 1138 can be conveniently made to any required length. This means the apparatus 1150 can be inserted from either end of the essentially triangular cross-sectioned space defined between two adjacently placed elongate elements 1100a, 1100b. High quality, continuous full-penetration welds 1114, 1116 can thus be readily provided between elongate elements. It may be necessary to use more than one pneumatic cylinder like 1120 to hold backing bars 1118 and 1138 in their desired positions, particularly if relatively long elongate elements 1100a, 1100b are to be welded together as described.

Fig. 12 is a transverse cross-sectional view of an alternative for the previously-discussed form of the basic elongate element such as 102 as discussed above and as illustrated in Fig. 10. In the embodiment per Fig. 12, the basic structural element 1200 has an upper flange 1202 which on both sides has cantilevered end portions 1204, 1204. At the distal edges of these cantilevered portions, about half way through the thickness of the flange, there are provided beveled surfaces 1206, 1206. Thus, when two of these elongate elements are placed side-by-side the corresponding beveled surfaces create a V-shaped groove into which weld metal may be deposited to unite the two elongate elements. Note that in elongate element 1200 there is no transverse web (like 110 in Fig. 10) which is perpendicular to flange 1202. Such perpendicular webs are found to contribute significantly to the stiffness and reduced deformation of the bridge deck upper surface in use. Instead, one additional inclined web is provided. This, in turn, ensures more durable bonding of a wearing layer applied to the top surface of the bridge deck.

In element 1200, there is also provided a lower second flange 1208 of substantially uniform thickness. The outermost surfaces 1210, 1212 of the first and second flanges 1202, 1208 are planar and parallel. Between first and second flanges 1202, 1208 there are provided four webs 1214, 1216, 1218 and 1220, inclined as indicated in Fig. 12. As shown, webs 1214 and 1220 incline inwardly from their bottoms immediately adjacent the distal edges of second flanges 1208, to join first flange 1202 at junctions 1222, 1224. Internal inclined webs 1216 and 1218 meet each other and the lower flange at a shared lower junction 1226 and they also respectively join first flange 1202 at junctions 1222 and 1224.

In element 1200 there are thus provided three substantially triangular voids, having rounded corners primarily to accomplish smooth transition of stresses with the central triangle having a curved base. Such an element is welded, preferably in the shop, to an adjacent similar elongate element by welds provided at the upper beveled surfaces 1206, 1206 and similar lower beveled surfaces 1228, 1228. Substantially triangular voids will then be formed between the welded elements, each having a curved base virtually the same in shape and size as the central void of each individual element 1200. As discussed earlier, provision of such uniformly distributed webs between inclined webs generates a very lightweight and easy-to-handle but stiff deck having isotropic load-distribution.

The area of the top flange immediately below the wheel of a truck will experience higher local bending than adjacent areas further away. These local bending moments are highest at junctures 1222 and 1224. It is therefore desirable to thicken the top flange 1202 at these junctures in order to reduce locally induced bending stress. This increased top flange thickness is labeled as "T_1", and the smaller thickness located at the midpoint 1230 and distal edges 1206 of the top flange 1202 is labeled as "t_1". This results in "arching" of the top flange 1202. As a practical matter, this is an option available only with extruded products such as aluminum.

Fig. 13 is a cross-sectional view of yet another form of a basic elongate element from which deck panels may be made. In this embodiment, there is provided an upper flange 1302 of substantially uniform thickness and a first width, with cantilevered end portions 1304, 1304 which are provided with beveled edge surfaces 1306, 1308 as shown. Element 1300 also has a lower flange 1310 having a substantially uniform thickness in its central portion, two inclined outer webs 1312, 1314, and two inclined inner webs 1316, 1318. Lower flange 1310 is narrower than upper flange 1302.

If element 1300 is made of an extruded alloy material, the three triangular voids formed by the webs will have rounded corners. Also, the thickness "H" at the outer edge portions of lower flange 1310 will be greater than the thickness "h" of the central portion of lower flange 1310. The outer edge portions of lower flange 1310 are therefore extremely strong and provide good rigid support to the inclined webs intersecting thereat.

Shown in broken lines through both the upper and lower flanges and the inclined webs therebetween are neutral surfaces as follows: 1320 is the neutral surface for upper flange 1302, 1322 is the neutral surface for lower flange 1310, 1324, 1326, 1328 and 1330 are the respective neutral surfaces for inclined webs 1312, 1314, 1316 and 1318. An important aspect of element 1300 is that neutral surfaces 1322, 1324 and 1328 all intersect at a single straight line 1332 which would be perpendicular to the plane of Fig. 13, i.e., in the longitudinal direction of element 1300. Similarly, neutral surfaces 1322, 1326 and 1330 also all intersect at a single straight line 1334 which would be parallel to line 1332. In the same manner, neutral surfaces 1320, 1328 and 1330 also all intersect at a third straight line 1336 parallel to lines 1332 and 1334.

The term "neutral surface" of an element or portion thereof is meant to identify a surface which contains the centroidal or neutral axis of the element. This aspect of the selected shape is called "perfect triangulation", and is considered to be a feature which is singularly effective in enabling such an element under load to cope with and distribute forces and bending moments while acting as a truss.

When a deck panel is formed from elements 1300, because of welding at beveled faces 1306, 1308, there will be a continuous welded upper surface formed of the welded-together upper flanges 1302 of the various elements. However, there will not be a continuous lower surface as in the embodiment employing elongate elements 102 or 1200. This lack of a continuous lower surface makes the embodiment of Fig. 13 an orthotropic rather than an isotropic bridge deck. However, for certain applications, the use of elements such as 1300 provides very advantageous deck panels for bridges and other structures. This is particularly true where the deck is required to span and possess substantial strength characteristics in one direction only.

Fig. 18 illustrates in transverse cross-section how an isotropic deck structure like that of Fig. 12 may be strongly mounted to an upper flange of a girder of I-beam cross-section with a plurality of studs and an initially fluid curable medium cured-in-place.

In Fig. 18, an isotropic multivoid deck structure 1800 comprises a plurality of elongate multivoid elements 1802, 1802 welded together longitudinally at upper welds 1804, 1804 and lower welds 1806, 1806. Girder 1808 has an upper flange 1810 with a substantially flat upper surface 1812 positioned beneath an under surface 1814 of bridge deck 1800. A vertical separation, preferably not less than about 51 mm between the bottom surface 1814 of bridge deck 1800 and upper surface of 1812 of girder 1808, is obtained by disposing a plurality of spacer elements 1830 therebetween at locations longitudinally of flange 1810 of the girder. Spacer elements 1830 may be spot welded or otherwise adhered to the top surface 1812 of the girder flange 1810. They may preferably be aligned directly above the central web of girder 1808.

A plurality of studs 1816, 1816 are preferably welded to extend upwardly perpendicular from top surface 1812 of girder 1808, in a manner similar to that in which studs 1528 illustrated in Fig. 15. Each stud has an enlarged head 1818 at its distal end, of any suitable shape. To permit reception of these studs 1816, 1816 and their distal heads 1818, 1818 into corresponding voids of the bridge deck 1800, a plurality of sufficiently large holes 1820, 1820 are formed into the voids through the bottom surface 1814. The studs 1816, 1816, their distal head 1818, 1818, and the holes 1820, 1820 to receive them, may be sized in the same manner as were their counterpart studs 1528, 1528, distal heads 1530, 1530, and holes 1532, 1534, in the structure illustrated in Fig. 15.

Also, as shown in Fig. 18, removable elongate substantially flat plate-like forms 1822, 1822 may be temporarily attached to outer elongate edges of upper flange 1810 of girder 1808 by form ties or threaded bars 1824, 1824, the latter being secured by end nuts 1826, 1826, respectively tightened over washers 1828, 1828.

End plates (not shown) generally similar in form and function to end plates 1702, 1702 may be employed at opposite ends of the temporary enclosed space being defined cooperatively between the inner surfaces of removable forms 1822, 1822, the upper surface 1812 of girder 1808, the bottom surface 1814 of bridge deck 1800, inside surfaces of the end plates, and the inside surfaces of internal webs 1214, 1216, 1218 and 1220. The deployment and use of the end plates (not numbered) of this embodiment is exactly the same as in the embodiment described with reference to Fig. 17 earlier.

The bridge deck 1800 is suitably spaced above the upper surface of girder 1808, and removable forms and end plates appropriately located. A quantity of an initially fluid curable medium is flowed in as air initially contained within the temporarily enclosed space for receiving the medium is bled out through suitable air-bleed holes (not shown) provided in removable forms 1822, 1822. The medium 1850 is then allowed to cure-in-place. The removable forms and end plates are then removed, and exposed portions of the cured-in-place medium 1850 carefully examined. Surface treatment provided as necessary, and the desired secure connection is obtained between the bridge deck and the girder.

As with the embodiment of Fig. 15, the cured-in-place medium 1850 will be contiguously distributed in close contact with and will bond when cured to various internal surfaces of the voids of bridge deck 1800, studs 1816, 1816, around distal heads 1818, 1818, and the space between the bottom surface 1814 of bridge deck

1800 and the upper surface 1812 of girder 1808. In this manner, a bridge deck comprised of extruded elongate elements having cross-sections as shown in Fig. 12 can be readily rendered composite with, i.e., integrated to a girder in a manner which permits reliable transfer of shear forces, static and dynamic loads of all kinds, and to forces generated by bending moments experienced due to loading of the bridge deck, changes in weather conditions, wind, snow and ice collections, etc.

Figs. 15 and 18 illustrate a system of studs and cured-in-place medium distributed contiguously into voids of a multivoid bridge deck and a space defined between the bridge deck and an upper surface of an underlying girder, for two of a number of possible multivoid sections of the bridge deck itself. There is yet another way by which a multivoid bridge deck structure can be connected to an underlying girder to create a very strong bond therebetween.

As best seen in Fig. 19, bridge deck 1900 is formed of a plurality of elongate multivoid extruded elements 1902, 1902 connected by longitudinal upper welds 1904, 1904 and lower welds 1906, 1906. A generally I- cross-section beam or girder 1908 is disposed below bridge deck 1900 with an upper flange 1910 having its uppermost substantially flat surface 1912 is spaced from a bottom surface 1914 of bridge deck 1900 by a plurality of spacer elements 1916. These spacer elements 1916 may be spot welded, adhered, or otherwise located on upper surface 1912 of girder 1908 prior to lowering thereon of bridge deck 1900.

A pair of elongate removable forms 1922, 1922 bracketing opposite longitudinal edges of upper flange 1910 of girder 1908 are temporarily held in place by form ties or threaded bars 1924, the latter being tightened in place by nuts 1926, 1926 over washers 1927, 1927.

The removable forms may be relatively thin and made of metal, plastic or other suitable material or may be simply planks of suitable cross-section and length. In the embodiment illustrated in Fig. 19, it is long flat wooden planks of suitable rectangular cross-section which are employed. These may be compared to the relatively thin flat plate-like removable forms 1536, 1536 in Fig. 15 or 1822, 1822 in Fig. 18. When relatively thick wooden planks such as 1922, 1922 are so utilized, it may be helpful to also use sealing strips 1928, 1928 between the bottom surface 1914 of bridge deck 1900 and the upper edges of removable forms 1922, 1922.

There may be circumstances when the bridge deck may have to be banked, crowned, or otherwise made locally not quite horizontal. If the upper surface of the underlying support girder is essentially horizontal, the gap defined between the bottom surface of the bridge deck and the upper surface of the underlying girder may then not be exactly the same at all locations. Fig. 19 shows a circumstance in which the spacing at the left side is smaller than the spacing at the right side between the bottom surface 1914 of bridge deck 1900 and the upper surface 1912 of girder 1908 in the space between the removable forms 1922, 1922. Use of sealing strips 1928, 1928 can help seal the temporarily enclosed space to receive initially fluid curable medium.

End plates of generally rectangular cross-section, substantially as described earlier, may be used with removable forms 1922, 1922 to define a temporarily enclosed space with inlets for initially flowing in the fluid curable medium. Air-bleed holes 1930, 1930 may be provided in removable forms 1922, 1922 as well as in the end plates (not shown). Small air-bleed holes may also be formed in the bottom flanges of the bridge deck to allow bleed-off of air as the initially fluid curable medium is flowed into the temporarily enclosed space.

One important respect in which the structure illustrated in Fig. 19 differs from that illustrated in Figs. 15 and 18 is in how force transfer is obtained, principally in shear, between the bridge deck and the girder.

In the structure of Fig. 19, elongate perforated plates 2000, each have perforations 2002, 2002 (best seen in Fig. 20) formed longitudinally therein. Plates 2000 are welded essentially perpendicular to and longitudinally of the bridge deck bottom surface 1914. It is preferred that when two such plates 2000, 2000 are so employed, they be spaced apart by less than the width of the underlying girder and be substantially parallel, as indicated in cross-sectional view in Fig. 19.

A similar plate 2004, having its own plurality of elongately distributed apertures 2006 is similarly connected, preferably by welding, perpendicular to upper surface 1912 of girder 1908. More than one such plate may be so utilized, although when only one is used it is preferably located above and along the central web of girder 1908 (generally as indicated in Fig. 19). If perforated plates 2000 or 2004 are so employed, they should terminate at the opposite ends of the bridge deck length. End plates as described earlier may be utilized to enclose the space to be filled with the initially fluid curable medium. Air bleeding is performed as described earlier to eliminate air displaced by the medium. The medium subsequently cures in a mass extending contiguously around spacer elements 1916 and through apertures 2002 provided in plates 2000, 2000 (attached to the bottom surface of bridge deck 1900) and through the apertures 2006 of the elongate perforated plate 2004 (attached to extend upwardly of girder 1908).

Once medium 1940 has cured-in-place, nuts 1926 are loosened and removable elongate forms 1922, 1922 removed. The end plates may also be removed at that time, as may be the sealing elements 1928, 1928. The exposed portion of the cured-in-place medium 1940 is carefully examined and local repairs and painting done to protect the cured medium.

The structure per Fig. 19, because it may be easier to provide long welds along the edges of perforated plates 2000 or 2004 than weld a larger number of studs, may be easier to make/use. Also, since it would be unnecessary to drill holes through the bottom surface of the bridge deck, the overall expense may possibly be lower with plates than with the other described techniques and structures. Elongate perforated plates 2000 or 2004 are made of metal and are securely welded respectively to the bottom surface of the bridge deck and to the top surface of the cooperating girders through corresponding welds. It is therefore necessary only that force be transmitted between elongate perforated plates 2000 and 2004 to ensure the desired strong connection between the bridge deck and the girder. Once the cured medium is contiguously distributed through the perforations 2002 of plates 2000 and perforations 2006 of plate 2004, shear force will be transmitted between plates 2002 and 2004 through the cured-in-place medium material extending through the respective perforations 2002, 2006. As a result, bridge deck 1900 and girder 1908 will act cooperatively with each other for transmittal of shear and other forces.

The controlling criteria for determining the shear strength according to such a connection are: the thickness and strength of the perforated plates 2000, 2004; the strength of the respective welds by which the perforated plates are attached either to the bottom surface of deck 1900 or the top surface of the underlying girder; the shear strength of the flowable medium 1940 after it has completely cured-in-place; the sizes of the perforations 2002 in plates 2000, 2000, and the comparable perforations 2006 in plate 2004. Any or all of these parameters can be adjusted by the bridge design engineer to meet the anticipated loading requirements with appropriate factors of safety. The dimensions of the perforated plates, depending on whether the material is aluminum or steel, diameters of the respective perforations, and the spacing between adjacent perforations, are all matters of design choice. For many applications, the preferred dimensions are as follows: thickness of aluminum or steel perforated plates 2000 and 2004 in the range about 6.5 mm - 13 mm; diameters of the perforations 2002 and 2006 in the range about 25 mm - 50 mm; width of the perforated plates 2000 and 2004 in the range about 50 mm - 100 mm; and vertical spacing between the bottom of the bridge deck and the top of the girder flange in this embodiment anywhere from about 76 mm - 254 mm. All or some of the materials may be aluminum or steel for most normal uses, although suitable alloys may also be considered.

Advantages of the Present Invention

The low dead load of the aluminum deck taught herein facilitates widening of existing bridges without the need to build new substructures. Existing substructures may simply be extended with the use of corbels or similar widening techniques at the top to receive girders for the widened bridge. The low dead load of the bridge deck also results in lower seismic loads acting on the bridge, since seismic forces are directly proportional to the mass of the bridge.

Because the centerlines or neutral surfaces of the web elements of the selected transverse cross-sections of the basic elongate extended elements define triangles, this deck is very strong and stiff in the transverse direction. A triangle is the only shape that can resist loads applied to the points of intersection of the legs without bending at those points or in the legs. The legs of the triangle resist the load by forces directed axially along the legs. Such structural webs are much stiffer against axial forces than they are against bending.

The deck is attached securely to the bridge girders so securely that the deck and girders act compositely.

The disclosed deck has no horizontal areas under the deck where dirt may accumulate or birds roost.

It may also be made with continuous top and bottom flanges, so that it acts much more like a truly isotropic deck with similar structural properties, such as strength and stiffness, in both the transverse and longitudinal directions rather than an orthotropic deck which has different properties in different horizontal directions.

Although the drawing figures and related detailed description of the structures shown therein all relate to bridge deck applications, this is not intended to be limiting. Persons of ordinary skill in the art will immediately recognize the general utility of the invention in other applications where lightweight modular support is desired, e.g., floors in buildings, mobile homes and for truck beds, temporary platforms as for band-stands and helicopter landing pads, gangways, and portable or re-usable bridges, and the like. The key to such a broad usage of the invention is that aluminum extruded elements are employed to maximum advantage to create extended support elements, largely in a controlled shop environment.

Fig. 21 is a cross-sectional view of yet another embodiment of this invention, in which adjacent deck panels formed by welding of elongate multivoid elements are readily interconnected to each other and made composite with an underlying support girder in a manner which provides significant advantages.

Bridge structure 2100 includes a support girder 2102 having an upright web 2104 and a top flange 2106 having a flat substantially horizontal upper surface 2108 to support a bridge deck.

In Fig. 21, a first deck panel 2110 is formed of a plurality of welded multivoid, preferably extruded aluminum, elements having a first cross-section. The second deck panel 2112 connected thereto is similarly formed of welded elongate, preferably extruded aluminum, elements having a different cross-section. This embodiment is thus capable of integrating to each other and to the supporting girder bridge deck panels of essentially the same thickness or height (as determined between respective upper and lower surfaces of the deck panels) regardless of the cross-sections of the constituent multivoid elongate elements. The particular cross-sectional structures for the first and second deck panels 2110, 2112 in Fig. 21 are intended to be merely exemplary and not limiting. In fact, this embodiment is inherently capable of accommodating some difference in the overall height or thickness dimensions of adjacent deck panels.

Elongate element 2114 of first deck panel 2110 has a pair of parallel upper and lower flanges 2116, 2118 separated by integral inclined webs 2120, 2122 and perpendicular webs 2124 located therebetween. Deck panel

2110 thus has an upper elongate edge where upper flange 2116 intersects inclined web 2122. This edge is provided a beveled surface 2126. Lower flange 2118 also has an edge provided with a beveled surface 2128 beneath beveled surface 2126.

Second deck panel 2112 has upper and lower flanges 2130, 2132 which have respective outer upper and lower parallel surfaces, respectively. Upper flange 2130 has an elongate edge provided with a beveled surface 2134. Lower flange 2132, where it intersects with an inclined web 2136, has an elongate edge provided with a beveled surface 2138. In a manner similar to that discussed in relation to the earlier embodiments, beveled surfaces 2126, 2128, 2134 and 2138 are all intended to cooperate with adjacent beveled surfaces to define generally V-shaped groove-like regions into which weld material is deposited to form strong welded connections as described earlier.

In the embodiment of Figs. 21 and 22, there is provided a first connection element 2140 which is preferably formed of a material comprising aluminum, e.g., an aluminum alloy, by a conventional extrusion process for economy, consistency of manufacturing quality, and close control over dimensions and surface finish. The extrusion industry is believed to be capable of producing such extrusions using correspondingly shaped relatively inexpensive extrusion dies and ancillary equipment of known kind.

First connection element 2140 has a base flange 2142 which is integral with an upright flange 2144 perpendicular thereto. A height determined from the external surface of base flange 2142 to the upper end surface of upright flange 2144 is selected to be essentially the same as the height between the upper and lower internal surfaces of parallel flanges 2116 and

2118 of first deck element 2110. An exterior edge of base flange 2142 is provided a beveled surface 2146 which cooperates with beveled surface 2128 to form the desired generally V-shaped groove region into which weld material of weld 2152 is deposited to cause welding of lower flange 2118 and base flange 2142. Similarly, the upper end of upright flange 2144 is provided a beveled surface 2148 which cooperates with beveled surface 2126 of upper flange 2116 to define another generally V-shaped groove region into which weld material 2150 is deposited to connect first deck element 2110 and first connection element 2140. Upper and lower welds 2150 and 2152 preferably are one-side, full-penetration welds of the type discussed earlier.

Upright flange 2144 is formed to have an integral elongate first anchoring element 2154 which may be generally parallel to base flange 2142 on a side away from the beveled surfaces relative to upright flange 2144. If desired, all or different portions of inner anchoring flange 2154 may be nipped, i.e., provided local cuts, and/or bent as depicted by broken lines immediately below the solid line depiction of inner anchoring element 2154. This enhances the integration of the cure-in-place material and the connection elements.

Between the upper end of upright flange 2144 and base flange 2142 there is provided an integral inner connection flange 2156 parallel to and preferably of about the same width as the underlying portion of base flange 2142. A plurality of holes, shown as elongate slotted holes 2158 and 2160, are formed in inner connection flange 2156 and base flange 2142, respectively, each oriented perpendicular, i.e., transverse, to the elongate direction of upright flange 2144. These holes (which may be made slotted) are best made in the shop.

A counterpart to first connection element 2140 is a second connection element 2162 which has many points of geometric and functional similarities. Thus, second connection element 2162 has a base flange 2164 provided with a beveled surface 2166 which cooperates with beveled surface 2138 of the second deck element to define a generally V-shaped groove into which weld 2168 is formed to connect second connection element 2162 to second deck panel 2112. Perpendicular to base flange 2164 and integral therewith is second upright flange 2170 which has a height matching the height of second deck panel 2112. Above base flange 2164 and on a side opposite to the beveled surface 2166 relative to upright flange 2170 there is provided an integral second inner anchoring element 2172. As with first inner anchoring element 2154, nips or cuts may be provided and portions of second inner anchoring element 2172 may be bent as indicated generally by broken lines immediately beneath second inner anchoring element 2172.

A weld 2135 is formed between beveled surface 2137 of the upper flange of second connection element 2162 and beveled surface 2134 of the second deck panel.

The adjective "inner" is used in the present context as indicative of a location within a space between adjacent deck panels which are to be connected solidly and compositely not only to each other but also to the underlying support girder 2102.

Above second inner anchoring element 2172 and integral with second upright flange 2170 is provided a second inner connection flange 2174 at the same height relative to base flange 2164 as is first interconnection flange 2156 relative to its base flange 2142. Both base flange 2164 and second interconnection flange 2174 are provided with a plurality of somewhat oversized bolt holes 2176 and 2178, respectively, to receive elongate shank portions of connection bolts. Exemplary bolt 2180 forms part of a bolt assembly including upper and lower washers 2182, 2184 and nut 2186.

Because it may be somewhat difficult to appreciate these structural details at the scale of Fig. 21, the just described structure is illustrated to a somewhat enlarged scale in Fig. 22. Subsequent discussion will therefore recite Fig. 22 wherever appropriate. The same numerals are utilized to identify the same elements in Figs. 21 and 22.

At the uppermost end portion of upright flange 2144 of the first connection element 2140 there is formed an elongate upward inner lip 2188 which serves as a dam for a layer of wearing material 2190 which is preferably applied in the shop after welding together of first deck panel 2110 and first connection element 2140. Similarly, second connection element 2162 is provided with an elongate inner lip 2192 extending upwardly to a height matching that of lip 2188 on the first connection element. This second lip 2192 serves as a dam or a layer 2194 of wearing material applied to the upper surface of the second deck panel and the uppermost surface of second connection element 2162, preferably in the shop.

To the upper surface 2108 of the support girder 2102 are welded a plurality of upward shear elements 2200, which preferably have enlarged heads at their distal ends (not numbered). The material, dimensions, number, and distribution pattern of shear elements 2200 is a matter of design choice, hence no particular values or ranges of values can realistically be quoted. The key is that the shear elements must cope with all forseeable loads and stresses generated by traffic loads, weather and temperature variations, earthquakes and wind forces. This includes static and dynamic loads, bending moments, or vibration, and the resultant stresses must be distributed and transmitted between the bridge deck and the underlying support girder to effect composite action without structural damage over a prolonged period of time. Accordingly, if the underlying support girder 2102 is made of steel, it may be most convenient to weld steel shear elements 2200 thereto. On the other hand, if the underlying support girder is made of aluminum or some other alloy, shear elements 2200 could be selected and connected thereto in appropriate manner.

As in earlier-described embodiments, a plurality of spacer elements 2202, e.g., short cylinders or square shims, are placed on top of upper surface 2108 to support on their respective upper ends the lower flanges 2142 and 2164 of the first and second connection elements 2140, 2162. Support elements 2202 are preferably at least about 51 mm high, although this is not intended to be limiting. Support elements 2202 need not all be selected to be of the same size if it is desired to bank or crown the bridge deck. By selecting support elements 2202 to be of carefully graduated sizes it should be easy to tilt the portion of the bridge deck directly above the girder to a small degree relative to the substantially horizontal upper surface 2108 of support girder 2102, or to correct camber errors in support girder 2102.

First and second connection elements 2140 and 2162 are connected to each other by a plurality of upper and lower interconnection elements 2204, 2206, respectively. These are essentially flat aluminum or steel pieces which may be provided with transverse anchoring element portions 2208 or 2210 oriented as shown in Fig. 22. These need not be perpendicular to the major portion of the interconnection elements but may be nipped, cut, or bent as generally indicated by broken lines (not numbered). Other forms for such connection elements, e.g., as corrugated plates, may also be considered.

Both the upper and lower interconnection elements 2204, 2206 are provided with holes 2212, 2214 (which may be elongate/slotted and oriented parallel to and) along the lengthwise direction of the first and second connection elements 2140, 2162. Each of the upper and lower interconnection elements is made of relatively short length, so that a worker may reach between adjacent interconnection elements to position and tighten respective bolt assemblies including bolts such as 2180. Provision of the holes shown as slotted holes 2212 and 2214 in upper interconnection element 2204 significantly facilitates location of the respective bolt shanks in a manner which will be well understood by persons of ordinary skill in the art. Provision of the holes shown as slotted holes 2216 and 2218 in lower interconnection elements 2206 similarly facilitates location and tightening of corresponding bolt assemblies (not shown).

An important advantage of these structural features is that formation of such bolt holes can be completed in the shop before the respective deck elements are moved out into the field yet there is considerable tolerance of small errors in positioning and alignment of adjacent deck elements relative to each other. An advantage of not slotting the holes, i.e., providing round holes, is that a stronger joint is obtained. In either case, the entire system is inherently forgiving of small dimensional errors and positioning, which greatly facilitates quick and effective assembly in the field under adverse weather conditions.

Once the deck panels are interconnected by bolting together of the respective upper and lower pluralities of interconnection elements, flat-sided plates or forms (not shown but of a type generally described earlier) may be positioned between the upper surface 2108 of girder 2102 and respective undersurfaces of deck panels 2110, 2112 to define a temporarily enclosed space. Into this is supplied an initially pourable and subsequently curable medium 2260, e.g., a selected concrete composition or the like, held until cured. It is poured from the top into the gap between first and second connection elements 2140, 2162 to a level essentially the same as that of the upper surfaces of interconnected deck panels 2110, 2112. Depending on the choice of this material, curing is effected in a short time, the temporary forms may be removed left in place, and a layer of wearing material 2222 is deposited between lips 2188 and 2192 of first and second connection elements 2140, 2162. See Fig. 22. The wearing material thickness (if any is applied) is selected to ensure a contiguous upper load-bearing surface of wearing material 2190 over the entire bridge deck.

A surface coating or treatment may be provided to those portions of elements made of metal, e.g., the upper surface of the girder, shear elements 2200, base flanges 2142 and 2164, etc. to inhibit/prevent corrosive deterioration thereat by interaction of metal with components of the pourable material or with moisture which may permeate the cured material. Coating the exposed surfaces of the cured material between the girder and the lower surfaces of the deck elements, e.g., with an epoxy paint or the like, is also considered desirable.

The above-described embodiment provides significant advantages. It is a highly economical and effective method of splicing together prefabricated modular deck panels in the field. It is also a very effective means for securely attaching a bridge deck to an underlying girder. In both respects, it provides a rigid connection capable of transferring diverse loads between cooperating elements which may be made of different materials. Because of the nature of the structure, there is provided a maximum stiffness at the joint between adjacent deck panels, i.e., there is no local flexibility which is likely to cause cracking and/or detachment of the wearing layer upon which traffic traverses. A very high shear strength is provided through the spliced joint, because the various anchoring elements and shear elements are integrated into a rigid, non-compressible matrix of the cured material, e.g., concrete grout. This ensures excellent shear engagement between adjacent deck panels. Very high bending strength through the joint between adjacent deck panels is provided by strong bolting together of the upper and lower interconnection elements. This system inherently is also relatively forgiving of small errors and misalignments which can, of course, be reduced by appropriate sizing and shop fabrication of slotted bolt holes. The system provides smoothly a continuous and contiguous wearing surface of an essentially constant thickness.

By appropriate selection of the support elements, which eventually become integrated into the set cured material, mild variations in horizontal and vertical profiles of the deck relative to the support girders are readily obtainable and/or corrected as appropriate.

The bolt holes can all be drilled in the shop, and the only field operations required are fit-up, perhaps some field drilling of holes, bolt installation, grouting, (i.e., pouring of initially pourable and subsequently cured material), and application of the wearing surface layer over the cured grout material. This allows for rapid field installation, and reduces traffic delays and overall project costs. The connection elements and interconnection elements are all readily extrudable solid shapes free of hollows, and their manufacture therefore requires relatively inexpensive dies.

Stresses are partially resisted by the aluminum of the deck panels and connection elements through the shear engagement elements, i.e., the interconnection elements and shear elements welded to the underlying girder. There is a composite connection between the bridge deck and the girder, which gives each of the individually combined elements greater strength when acting together than would be possible with other known techniques for integrating them. Finally construction techniques needed to realize the benefits of this embodiment are all conventional and relatively simple, hence no special equipment or training of personnel is needed, which allows quality workmanship at low cost.

Aluminum or aluminum alloy bridge decks pose unique problems, different from those encountered with steel or concrete decks, in securely bonding thereon a wearing material layer on which traffic travels. An efficient technique has been developed for ensuring an excellent bond between the layer of wearing material and the underlying aluminum material.

In this technique, at least a portion of the weld-containing aluminum alloy bridge deck surface is buffed in conventional manner to obtain a substantially uniform surface finish and texture over the entire buffed area, preferably with the use of a nylon buffing material such as a "Scotch Brite™" type pad.

The buffed surface is then cleaned with a mild alkaline cleaner, preferably an 8% solution of "OAKITE NST" in 120°F tap water to remove all discrete particles of foreign material, particularly organic material.

It is then rinsed to create a "water break free surface", i.e., a clean surface which when rinsed with water does not generate substantial beading of water. In other words, the water covers the bridge deck surface as an almost unbroken sheet so that virtually no discrete water droplets are formed. If water droplets or beads are noticed, it indicates that residual contaminants still remain on the bridge deck surface and may interfere with the desired secured bonding. In this case, the cleaning step should be repeated. The rinsing step may be performed with ordinary tap water and the water applied in any known manner. Softened water is preferable, but is not considered essential.

Following the rinsing step, a conversion coating is formed on the cleaned deck surface. This involves converting the aluminum bridge deck upper surface from a natural oxide outer layer to an oxide mixture including non-aluminum oxides such as zirconium oxide, molybdenum oxide, chromium oxide, titanium oxide, or silicon oxide. Typically, the top thirty to forty Å thickness of the natural oxide is converted during formation of the conversion coating. One intended result of developing this conversion coating is the generation of a layer having better chemical resistance than is available with just the natural aluminum oxide layer present on the bridge deck surface. Such a conversion coating, containing non-aluminum oxides, significantly reduces or eliminates the potential of destructive interaction between water and aluminum oxide.

The conversion coating is typically formed by making an aqueous solution of a conversion coating material and applying it to the bridge deck surface using known techniques, e.g., spraying, immersion, roll-coating, or the like. Preferably, the conversion coating aqueous solution is applied while the bridge deck surface is still covered by residual rinse water. This enhances the wetting of the bridge deck surface with the conversion coating solution. Cleansing after application of the conversion coating may be required to removed excess coating solution and to reduce undesired reaction products. A preferred conversion coating is a 1% aqueous solution of DC1903R, a conversion coating material manufactured by Betzdearborn, Laboratories of Trevose, Pennsylvania. This is a solution conveniently applied with a paint roller.

After the conversion coating is applied, it is allowed to dry under either ambient conditions or by convection drying. Once the conversion coating is formed, dried, and inspected, the wearing material is applied directly thereto to form the desired wear layer 2190 (best seen in Fig. 22).

Although any known wearing material can be utilized and will bond securely to the conversion coating, a polymer concrete-type material is preferred. Typically, such polymer concrete materials comprise polyester-based, methylacraylate-based and epoxy resin-based systems. Although any of these types of polymer concretes can be utilized with the instant invention, the epoxy resin-based system is preferred. It typically comprises a two-part system, a first part being an epoxy hardener and the second part being the epoxy base. The polymer concrete material, as applied, must also include an aggregate material which may be of any known type but typically is a silica, alumina or basalt. The aggregate is mixed with the two-part epoxy resin-based system and then applied to the conversion coated bridge deck upper surface by any known method. Typically, the polymer concrete is applied in thicknesses of up to ½ inch. Once the polymer concrete is so applied and evened out over the bridge deck surface, a further aggregate layer can then be broadcast over the surface prior to curing the polymer concrete material. A preferred polymer concrete is a Flexolith polymer concrete system manufactured by Tamms Industry of Mentor, Ohio. In this system, a combination of a BIS-A epoxy resin and 2 ethylxhexyl glycidyl ether is preferably used as the base and a combination of ethanol, a diethylene triamine polyamide resin and a modified aminophenol is used as a hardener. The aggregate is preferably sized such that 100% thereof passes through a #6 sieve, 65-90% is retained on a #10 sieve, and 20-35% is retained on a #20 sieve. Once the polymer concrete is applied, it is best left to cure under ambient conditions for between one and seven days.

The above-described method is conveniently applied to individual bridge deck panels in a shop environment. This permits excellent control of quality, environmental hazards from the different materials used, etc. The completed bridge deck panels, on which the material is dammed by lips 2188, 2192 at the top of connection elements 2140 or 2162, are then transported to the site.

In the structure per Figs. 21 and 22, when the grout material has cured between the two interconnected cooperating deck panels and the underlying support girder, a quantity of the same wearing material may be applied to fill the gap between the two adjacent lips 2188 and 2192, as best seen in Fig. 22. Concrete grout material will not require treatment with the same conversion coating as is considered desirable when coating aluminum surfaces. The net result, as indicated in Figs. 21 and 22, should be a substantially uniform thickness of well-bonded wearing material to provide a long-lasting wear surface for traffic. Note that because of the conversion coating treatment applied to the upper surface of the aluminum deck, including both sides and the top surface of each of the elongate lips 2188, 2192, there will be bonding of the wearing material deposited on the cured-in-place material between the decks and those portions of the treated surfaces of lips 2188, 2192 making contact therewith.

It may sometimes be necessary to apply wearing material to a deck panel where a portion of the shop-applied wearing material has been broken or knocked off in the course of handling the deck panel during its installation. In this event, the following steps are preferably performed in the field to effect a cure:

1) buff the exposed bridge deck upper surface where the wearing material is damaged;
2) clean the thereby exposed bridge deck upper surface, e.g., by careful sweeping away of discrete particulate matter;
3) rinse the exposed bridge deck upper surface, in the same manner as was done in the shop in applying the original (now removed, damaged or broken) layer;
4) form a conversion coating on the exposed bridge deck upper surface, as in the shop;
5) dry the applied conversion-coated surface; and
6) apply additional wearing material to the dry, conversion-coated, exposed surface of the bridge deck to a level sufficient to make it smoothly contiguous with the surrounding undamaged cured wearing material, and allow the newly applied wearing material to cure-in-place to become integrated with the surrounding cured material and firmly bonded to the re-treated bridge deck upper surface.

Another situation that may arise after the bridge deck has been used for its intended purpose over a period of time is that it may become necessary to apply additional wearing material, e.g., because the previously applied wearing material has worn unevenly as may happen where vehicular wheels traverse the wearing surface most frequently. The problem faced by those seeking to deposit additional wearing material, such as an epoxy concrete containing an epoxy material and aggregate, is that new uncured epoxy does not bond well to already-cured old epoxy. In other words, a "new epoxy concrete-to-old cured epoxy concrete" bond is extremely difficult to obtain. A preferred solution to this problem includes the following steps:

1. buff the accessible surface of the old cured-in-place wearing material layer where new material is to be added- on, to such an extent that a significant amount of the surface area of the old aggregate material is exposed and becomes available for adherence thereto of the epoxy component in the newly-applied epoxy-containing wearing material;
2. remove any loose particulate matter from the buffed "old" wearing material, and particularly from the newly-exposed surfaces of the aggregate portion thereof; and
3. apply a quantity of new, uncured, wearing material to the buffed and cleaned surface of the old, cured-in-place wearing material, to obtain a direct bond between the epoxy content of the newly applied wearing material and the buffed and cleaned surfaces of the aggregate component of the old, cured-in-place wearing material.

In summary, in the "repair" work described in the immediately preceding paragraphs, a strong bond is obtained between the epoxy content of the newly applied wearing material and the buffed and cleaned exposed surfaces of the aggregate component of the old, cured-in-place, wearing material (not between uncured epoxy and old cured epoxy). This technique ensures a strong and durable bond between the newly applied wearing material and the residue of the previous, partially worn wearing material layer.

Although the present invention has been described and illustrated in detail, it should be clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

WHAT IS CLAIMED IS:

1. A modular bridge deck system supported on a plurality of cooperating girders, comprising:

a plurality of prefabricated deck panels which are longitudinally field-spliced together, each deck panel being formed by longitudinally shop-welding a plurality of elongate, multi-void, extruded aluminum elements which are transversely end-spliced in a staggered arrangement; and

a plurality of field-bolted mutually engaging extrusions enabling said longitudinal field-splicing of adjacent panels to each other,

wherein said longitudinal shop-welding comprises one-side, full-penetration, longitudinal top and bottom welds between respective top and bottom flanges of adjoining elongate extruded aluminum elements, whereby the welded top flanges of said field-spliced panels provide a substantially continuous upper surface.

2. The bridge deck system according to claim 1, further comprising:

a wearing layer applied over said substantially continuous upper surface.

3. The bridge deck system according to claim 1, further comprising:

means for positively connecting the deck panels to a support system comprising cooperating girders in a manner enabling the deck panels to act compositely with the girders.

4. A system for field-splicing of two adjacent prefabricated deck panels each formed by longitudinally shop-welding a plurality of elongate, multi-void elements which are transversely end-spliced in a staggered arrangement, wherein each multi-void element

has an upper flange connected by a plurality of webs to a lower flange, the field-splicing system comprising:

a first splice element having upper and lower flanges, longitudinally shop-welded to the upper and lower flanges of an outermost multi-void element of a first deck panel by respective full-penetration upper and lower shop-welds;

a second splice element having an upper flange and an arm, longitudinally welded to the upper and lower flanges of an outermost multi-void element of a second deck panel by respective full-penetration upper and lower shop-welds;

a flat elongate splice plate; and

a plurality of fastener elements field-fastening the upper flanges of the first and second splice elements to each other, a lower flange of the first splice element to the splice plate, and the splice plate to the lower flange of the outermost multi-void element of the second panel.

5. The field-splicing system according to claim 4, wherein:

the multi-void elements and the first and second spliced elements are all formed of extruded aluminum, said first splice element having a cross-section comprising one vertical and two inclined webs connecting the upper and lower flanges thereof, said second splice element having a generally L-shaped cross-section wherein said arm is perpendicular to the upper flange thereof and a shear key formed on an inside surface of said arm to cooperate with a correspondingly shaped and sized end portion of the first spliced element fitted thereto.

6. The field-splicing system according to claim 5, wherein:

the first and second splice elements and the splice plate are shop-fitted to each other and are provided a plurality of holes match-drilled through the upper flanges of the first splice elements, and additional holes provided between the splice plate and the lower flange of the first splice element and also between the splice plate and the lower flange of the outermost multi-void element of the second deck panel, subsequently match-drilled in the field; and

said fastener elements are respectively fitted into said match-drilled holes to provide secure connections thereat.

7. A modular deck panel formed of interconnected multi-void extruded elongate elements, comprising:

a plurality of elongate ribs, comprising a plurality of multi-void extruded elongate elements which are each at most equal in length to a length of the deck panel and having a common cross-sectional shape comprising elongate upper and lower flanges joined to each other by a plurality of webs defining a plurality of elongate voids;

a plurality of elongate shear elements, shorter than said elongate elements and having a cross-section shaped and sized so as to be closely fitted simultaneously into corresponding voids of two of said elongate elements disposed longitudinally in a staggered end-to-end manner;

first connection means for connecting the shear elements to said two elongate elements at said upper flanges and selected webs thereof;

second connection means for simultaneously connecting to the lower flanges of said two elongate elements to connect them to each other; and a plurality of full-penetration welds for welding together respective upper flanges and lower flanges of the elongate elements of adjacent positioned ribs.

8. A method of connecting a prefabricated bridge deck to a support girder, comprising the steps of:

mounting first shear force transfer elements to extend from an upper surface of the girder in a first arrangement;

mounting second shear force transfer elements to extend from a bottom surface of the bridge deck in a second arrangement different from said first arrangement;

providing a plurality of leveling elements extending from the upper surface of the girder to define a selected spacing between the upper surface of the girder and the lower surface of the bridge deck;

providing a set of forms along said upper surface of the girder to define a space which contains the first shear force transfer elements and the leveling elements, the forms including compressible upper edge portions;

pouring a quantity of a flowable and curable medium into said space so as to surround the first shear force transfer elements and the leveling elements;

placing the bridge deck so as to support the same by said leveling elements in a manner such that the second shear force transfer elements are submerged in the flowable medium and the bottom surface of the bridge deck contacts the compressible portions of the forms to an extent sufficient to obtain extended contact between the bottom surface of the bridge deck and the uncured flowable medium; and

curing the flowable medium, to thereby form a strong shear force transmitting vertical and horizontal support and connection between the girder and the bridge deck.

9. A mechanism for facilitating formation of long, one-side, full-penetration welds between two adjacently placed elongate elements each having parallel upper and lower flanges with chamfered outer edges, each pair of flanges being interconnected by respective transverse webs, comprising:

a cylinder having a pneumatically or hydraulically actuated piston, mounted on a base slidable along adjacent webs of the two elongate elements between the upper and lower flanges thereof; and

a first backing bar having a first shallow longitudinal groove, movable by said piston so that the first shallow groove is pressed along and under the apex of a first V-shaped groove defined by cooperating chamfered edges of the upper flanges of the elongate elements to thereby limit flow of weld metal deposited in the first V-shaped groove to weld the elongate elements thereat to each other.

10. The mechanism according to claim 9, further comprising:

a second backing bar having a second shallow longitudinal groove, mounted beneath said base of the cylinder and positioned such that the second shallow groove is pressed immediately along and under the apex of a second V-shaped groove defined by cooperating chamfered edges of the two lower flanges of the elongate elements.

11. A multi-void elongate structural element, comprising:

first and second parallel flanges each having a respective thickness and a flat elongate outer surface, and each having chamfers along outer edges over substantially the entire flange thickness;

webs that define essentially triangular structures between the flanges.

12. The elongate element according to claim 11, made of extruded aluminum.

13. The elongate element according to claim 26, with an additional vertical web that bisects the angle between two inclined webs.

14. A bridge structure including a multi-void hollow element securely mounted to an underlying girder, comprising:

a plurality of studs connected at selected locations substantially perpendicular to an upper surface of the girder;

a plurality of holes formed through an undersurface of the hollow element, some of said holes being positioned to receive respective studs therethrough into a void of the hollow element; and

a medium filling said void and all of said holes, extending around said received studs in said same holes where said studs are present, and extending contiguously through all of said holes into a space defined between the undersurface of the hollow element and the upper surface of the girder.

15. The bridge structure according to claim 14, further comprising:

leveling means for supporting the undersurface of the hollow element at a selected separation from the upper surface of the girder, said separation corresponding to at least a predetermined minimum height of said space.

16. The bridge structure according to claim 14, wherein:

a substantially annular gap, defined between an outer surface of the stud and an adjacent edge of a corresponding hole through which the stud is received, has a minimum value of about 6.5 mm.

17. The bridge structure according to claim 14, wherein:

the predetermined minimum height of the space when the space is filled with the medium, is about 25 mm.

18. A method of securely mounting a multi-void hollow element to an underlying girder, comprising the steps of:

connecting at least one stud to an upper surface of the girder to extend substantially perpendicularly thereto at a selected location;

providing a plurality of holes in a bottom of the hollow element, at least one of the holes being sized and located to receive the at least one stud therethrough into a void of the hollow element;

applying spacing means to support a lower surface of said hollow element at a selected spacing relative to the upper surface of said girder;

forming a temporarily enclosed space between a portion of said bottom of said hollow element containing said holes and said upper surface of said girder, with a height of said space corresponding to said selected spacing, said space communicating with said void through said hole;

providing a flowable initially uncured medium into said void and said temporarily enclosed space to contiguously fill the same through said holes and surrounding the at least one stud in said at least one hole; and

curing said flowable initially uncured medium.

19. The method according to claim 18, wherein:

the step of providing the holes comprises the step of drilling from an undersurface and through a bottom flange of the element and through an adjacent inclined inside web defining said void in said hollow element.

20. The method according to claim 18, wherein:

the step of forming the temporarily enclosed space comprises the step of temporarily attaching space defining means to enclose a volume having a length corresponding to a length of the hollow element and a cross-section defined substantially by a width of the girder and the selected spacing.

21. An aluminum bridge structure including a deck element and an underlying girder, comprising:

a first elongate perforated plate connected at a lower edge to an upper surface of the girder to extend perpendicularly upward thereof;

at least one of a second elongate perforated plate connected at an upper edge to an undersurface of the bridge deck to extend perpendicularly downward thereof and adjacent the first elongate plate; and

a medium filling a space defined between the undersurface of the bridge deck and the upper surface of the girder and extending contiguously through respective perforations of the first perforated plate and the second perforated plate to enable transfer of a shear force thereby between the deck element and the girder.

22. The bridge structure according to claim 21, further comprising:

at least one spacer element for supporting the undersurface of the bridge deck at a selected separation from the upper surface of the girder, said separation corresponding to at least a predetermined height of said space and exceeding a respective width of each of said first and second perforated plates.

23. The bridge structure according to claim 41, wherein:

the bridge deck comprises a plurality of multivoid elongate elements longitudinally welded at respective upper and lower flanges to adjacent elongate multivoid elements to provide an essentially isotropic load bearing structure.

24. The bridge structure according to claim 21, wherein:

the predetermined minimum height of the space, when the space is filled with the medium, is 25 mm.

25. The bridge structure according to claim 21, wherein:

the medium is initially fluid in an uncured state and is cured-in-place so as to extend contiguously through the perforations of each of said first and second perforated plates to thereby connect them to each other in a manner enabling the transfer of a shear force therebetween through the cured-in-place medium.

26. A method of securely mounting a bridge deck to an underlying girder, comprising the steps of:

connecting an elongate perforated plate to an upper surface of the girder so as to extend substantially perpendicularly upward thereof;

connecting at least one of a second elongate perforated plate to an under surface of the bridge deck to extend substantially perpendicularly downward thereof;

providing at least one spacing element to support the under surface of the bridge deck at a selected separation above to the upper surface of the girder;

forming a temporarily enclosed space between the under surface of the bridge deck and the upper surface of the girder, a height of said space corresponding to said selected separation, said space including said first and second elongate perforated plates and said spacing element;

providing a flowable initially uncured medium into said temporarily enclosed space to contiguously fill the same while extending through respective perforations in each of said first and second elongate perforated plates; and

curing said flowable initially uncured medium to a cured state thereof, to enable transfer of a shear force between the bridge deck and the girder via the cured medium extending though said perforations.

27. A bridge structure, comprising:

an elongate first deck panel having a first thickness defined between outer surfaces of a first pair of parallel upper and lower deck panel flanges separated by a first plurality of longitudinal webs;

an elongate second deck panel having the same thickness as said first deck panel, said thickness being defined between outer surfaces of a second pair of parallel upper and lower deck panel flanges separated by a second plurality of longitudinal webs;

a first elongate connection element, having a first base element with a first outer edge and a first inner edge, a first upright flange perpendicular to the first base flange and integrally connected to the first base between the first inner and first outer edges, a first inner anchoring element integral with the first upright flange and extending therefrom above the first base flange, a first inner connection flange integral with the first upright flange above the first inner anchoring element and parallel to the first base flange, wherein the first upright flange has a first upper end flange, both the first upper end flange and the first base have respective outer elongate beveled surfaces, and each of the first base flange and the first inner connection flange have respective slots oriented parallel to the first upright flange for receiving respective connection bolts therethrough;

a second elongate connection element, having a second base element with a second outer edge and a second inner edge, a second upright flange perpendicular to the second base flange and integrally connected to the second base between the second inner and second outer edges, a second inner anchoring element integral with the second upright flange and extending therefrom above the second base flange, a second inner connection flange integral with the second upright flange above the second inner anchoring element and parallel to the second base flange, wherein the second upright flange has a second upper end flange, both the second upper end flange and the second base flange have respective outer elongate beveled surfaces, and each of the second base flange and the second inner connection flange have respective slots oriented parallel to the second upright flange for receiving respective connection bolts therethrough;

a plurality of upper interconnection elements each having a first width, a first length, at least one bolt hole for bolted connection thereat above and to one of the first and second inner connection flanges while extending immediately over the other of the first and second inner connection flanges, and at least one elongate longitudinally oriented slot extending over a corresponding slot of said other of the first and second inner connection flanges for bolted connection thereat;

a plurality of lower inner connection elements each having a width equal to said first width, a second length, at least one bolt hole for bolted connection thereat above and to one of the first and second base flanges while extending immediately over the other of the first and second base flanges, and at least one elongate longitudinally oriented slot extending over a corresponding slot of said other of the first and second base flanges for bolted connection thereat;

a plurality of bolt assemblies sized to be respectively bolted via corresponding slots of the first and second elongate connection elements and the upper and lower inner connection elements extended therebetween,

wherein the second deck panel and the second connection element are welded to each other by a third weld extending between an end of the second upper flange of the second deck panel and the second upper end flange of the second elongate connection element, and a fourth weld between the lower flange of the second deck panel and the second base of the second elongate connection element; and

wherein a plurality of bolt assemblies sized to be respectively bolted via corresponding slots of the second and second elongate connection elements and the upper and lower inner connection elements extended therebetween,

wherein the first deck panel and the first connection element are welded to each other by a first weld extending between an end of the first upper flange of the first deck panel and the first upper end flange of the first elongate connection element, and a second weld between the lower flange of the first deck panel and the first base of the first elongate connection element, and

a quantity of initially pourable material is flowed into fill a space defined at least between adjacent surfaces of the first and second elongate connection elements, said material being contained until cured.

28. The bridge structure according to claim 27, further comprising:

a support girder having a substantially horizontal upper surface beneath the first and second deck panels bolted to each other via said first and second elongate connection elements and said upper and lower inner connection elements and separated therefrom by a first spacing;

a plurality of shear studs affixed to said upper surface of said girder and extending upwardly therefrom, each shear stud having a respective distal end located between the upper and lower inner connection elements and interspersed between adjacent ones of said lower interconnection elements,

wherein the initially flowable material is contained in part within a space defined between said upper surface of said girder and respective bottom surfaces of said first and second elongate connection elements until cured, whereby said cured material extends contiguously from said upper surface of said girder, through said slots provided in said first and second elongate connection elements and said plurality of upper and lower interconnection elements to a level approximately adjacent to the first and second upper end flanges of said first and second elongate connection elements.

29. The bridge structure according to claim 27, wherein:

the upper interconnection elements are each provided with downwardly extending engagement portions and said lower interconnection elements are each provided with upwardly extending engagement elements.

30. The bridge structure according to claim 28, wherein:

the first and second upper end flanges are each formed to have an elongate upward inner lip.

31. The bridge structure according to claim 30, further comprising:

a layer of a wearing material is applied to an upper surface of each of said first and second deck panels and over said first and second upper end flanges to extend to said first and second elongate lips thereof.

32. The bridge structure according to claim 31, further comprising:

a treatment layer provided to said upper surfaces of said first and second deck panels and said first and second upper flanges of said first and second connection elements welded thereto, said wearing material being applied over said treatment layer.

33. The bridge structure according to claim 32, further comprising:

additional wearing material desposited over said cured material between said first and second lips of said first and second elongate connection elements to a thickness such as to provide a smoothly contiguous upper layer of said wearing material extending over and between said connected first and second deck panels.

34. A method of preparing an aluminum or aluminum alloy deck panel surface, for secure bonding thereto of a wearing material, comprising the steps of:

buffing at least a portion of a surface of the deck panel;

cleaning the buffed deck surface to remove any discrete particulate material present thereon;

rinsing the buffed and cleaned deck surface to form an essentially water break free deck surface; and

forming a conversion coating on the water break free deck surface to enable a strong bond thereat with applied wearing material.

35. The method according to claim 34, comprising the further step of:

applying a wearing material to the conversion coating on the deck surface to a selected thickness to produce a bonded wearing material layer; and

allowing the bonded wearing material layer to cure in place.

36. The method according to claim 34, wherein:

said cleaning step comprises washing the deck surface with an alkaline soap aqueous solution.

37. The method according to claim 34, wherein:

said rinsing step comprises the application of water to remove any residue from the cleaning step, leaving water on the water free break surface to facilitate the step of forming the conversion coating.

38. The method according to claim 34, wherein: said forming step comprises applying a conversion coating aqueous solution containing at least one of zirconium oxide, molybdenum oxide, chromium oxide, titanium oxide or silicon oxide to said water-covered water break free deck surface.

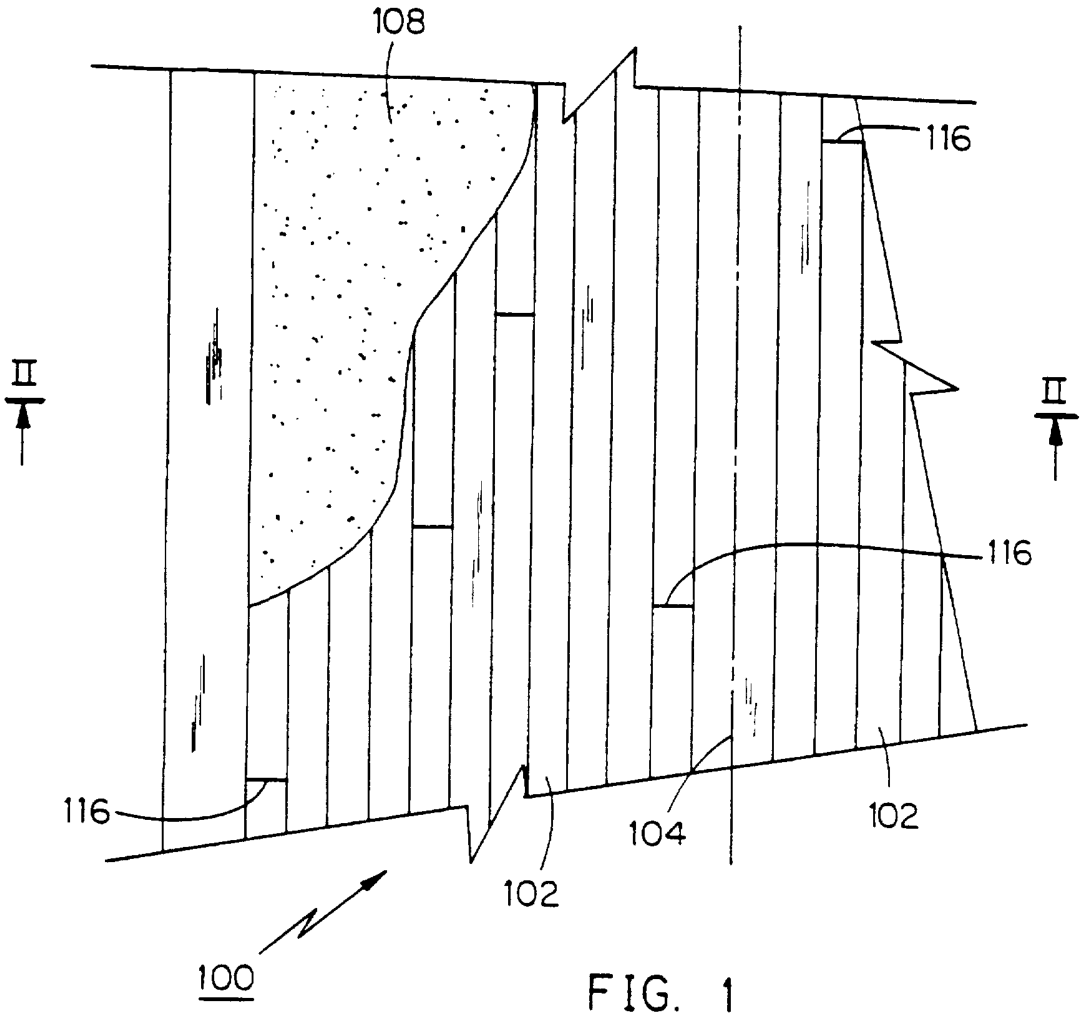

108
116
II
II
116
116
104
102
102
100

FIG. 1

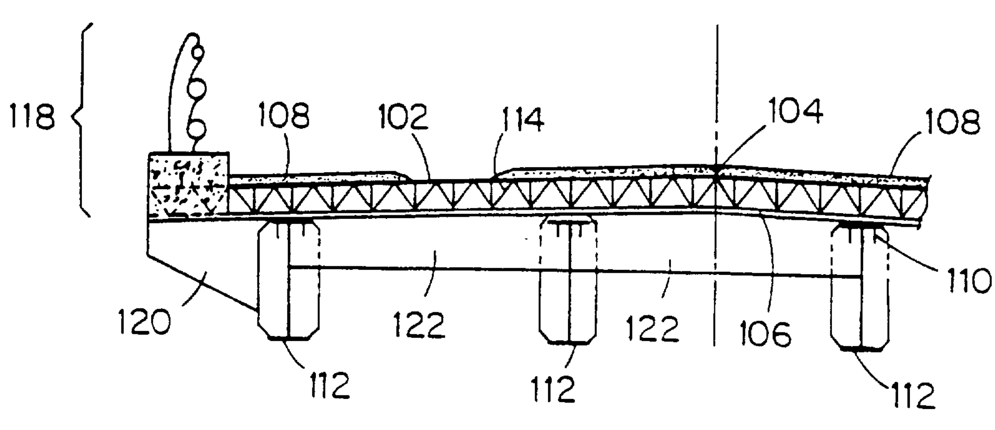

118
108
102
114
104
108
110
120
122
122
106
112
112
112

FIG. 2

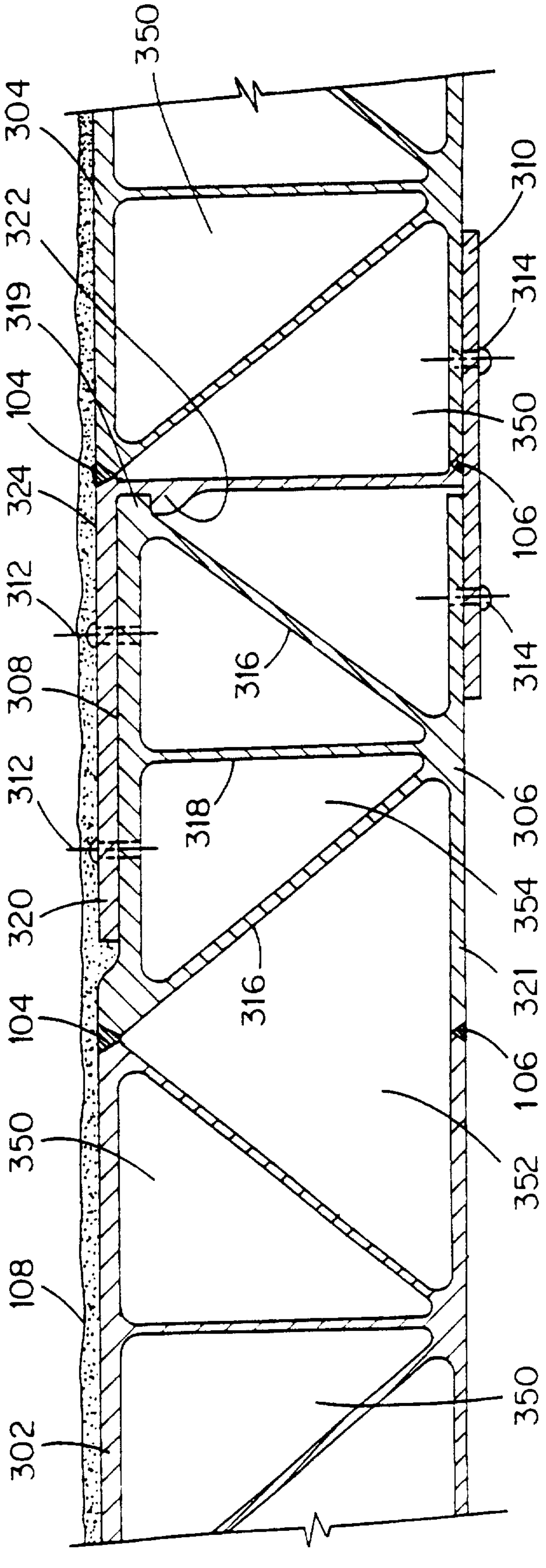

350
304
310
322
314
319
104
350
324
106
312
316
314
308
318
306
312
354
320
316
321
104
106
350
352
108
350
302

FIG. 3(A)

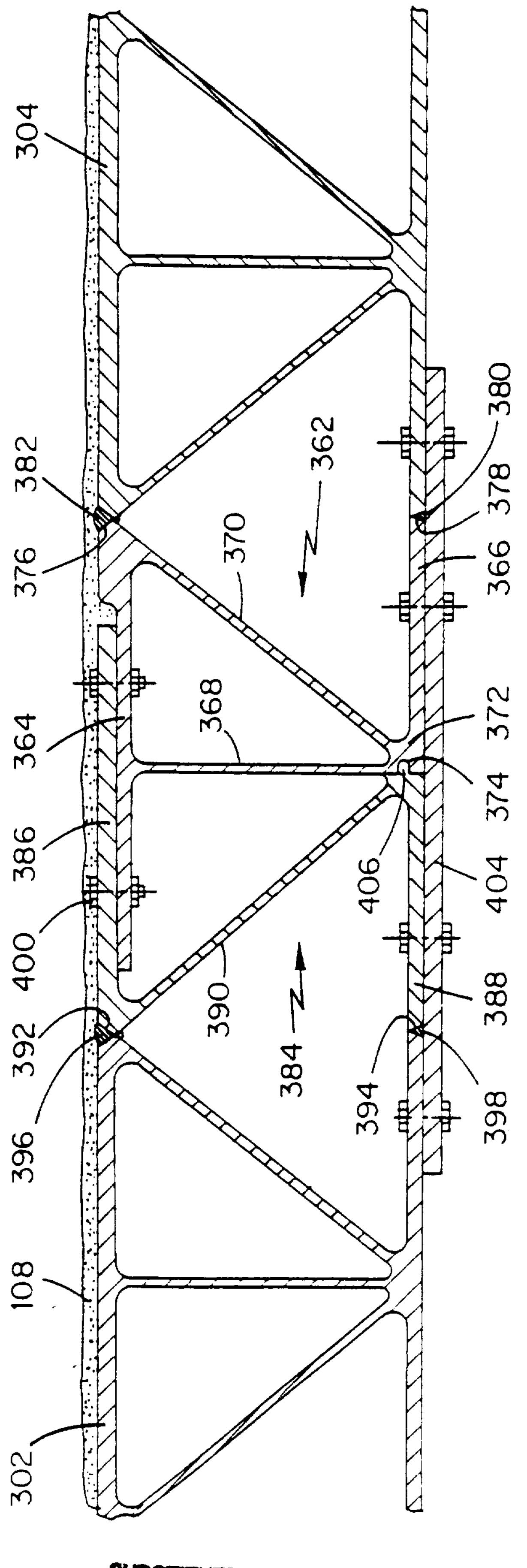

304
382
376
364
386
400
392
396
108
302
362
370
368
390
384
406
372
374
380
378
366
404
388
394
398

FIG. 3(B)

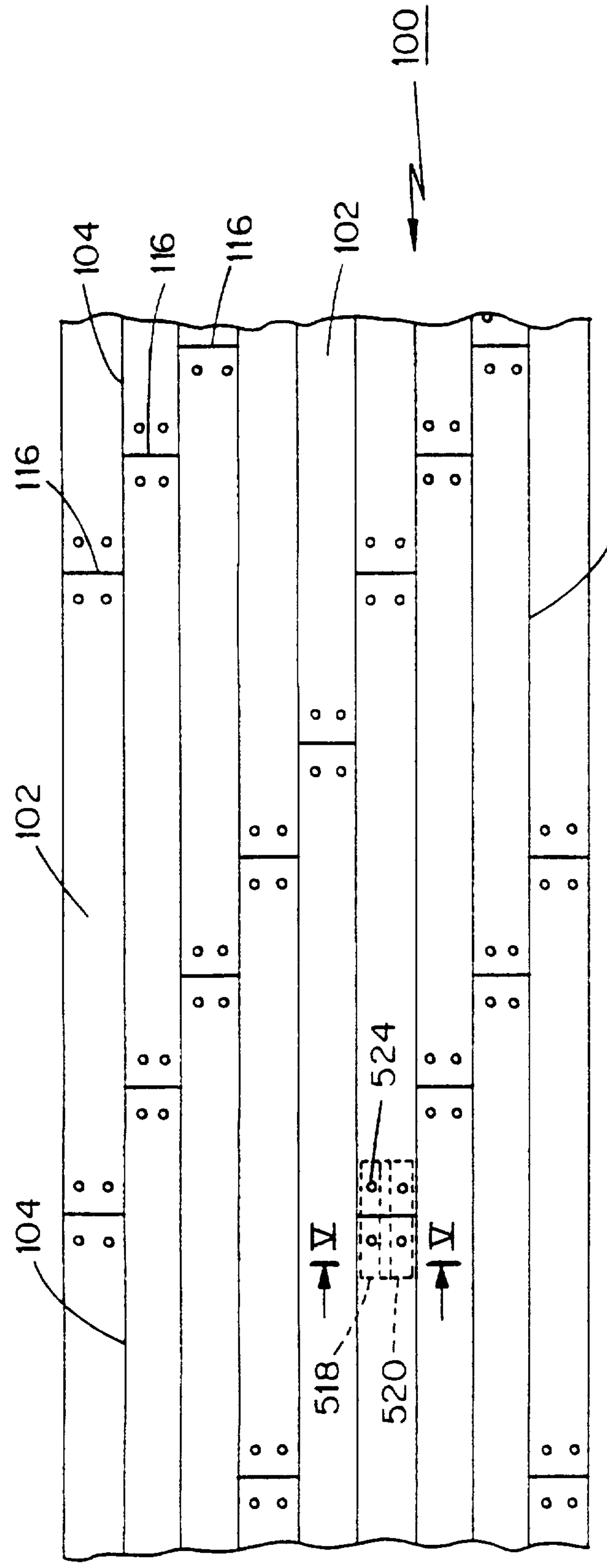

100
102
104
116
518
520
524
V

FIG. 4

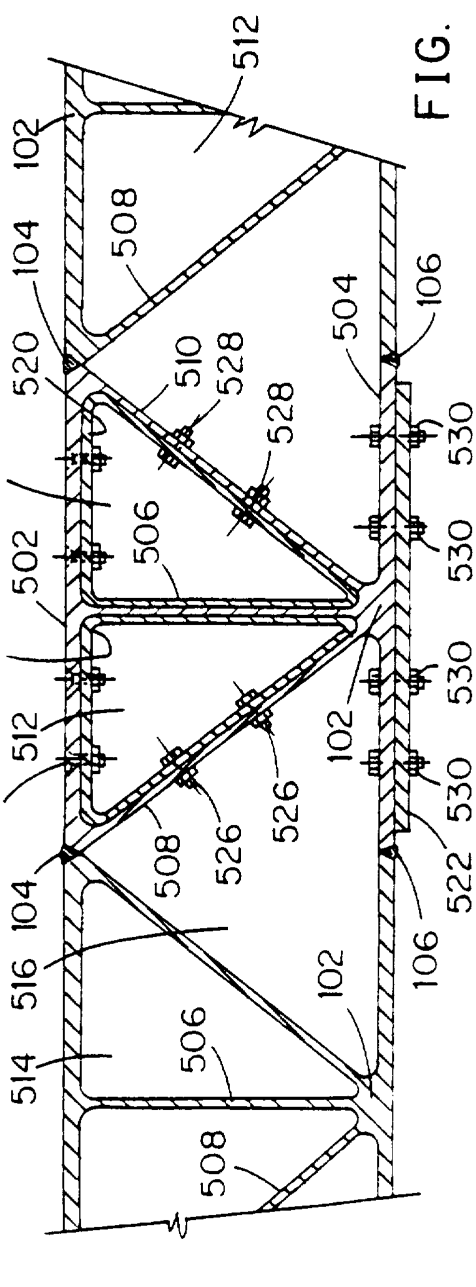

102
104
106
502
504
506
508
510
512
514
516
518
520
522
524
526
528
530

FIG. 5

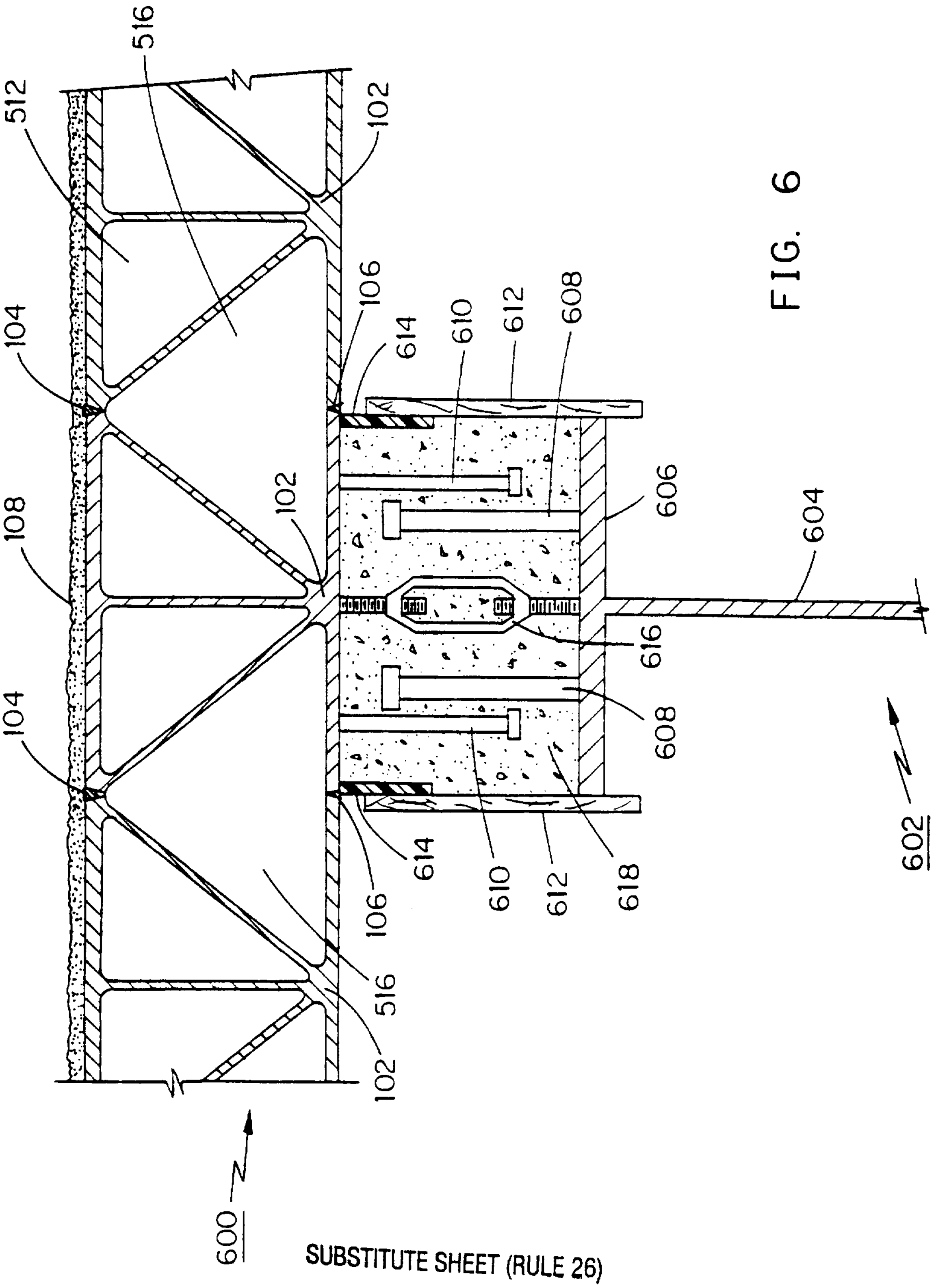


FIG. 6

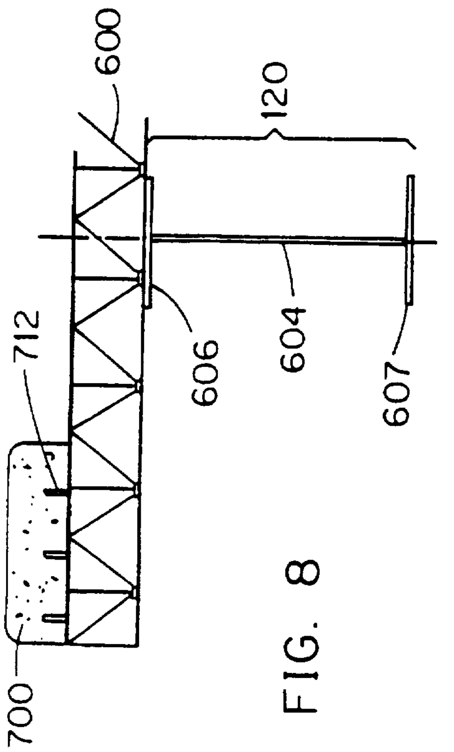


FIG. 8

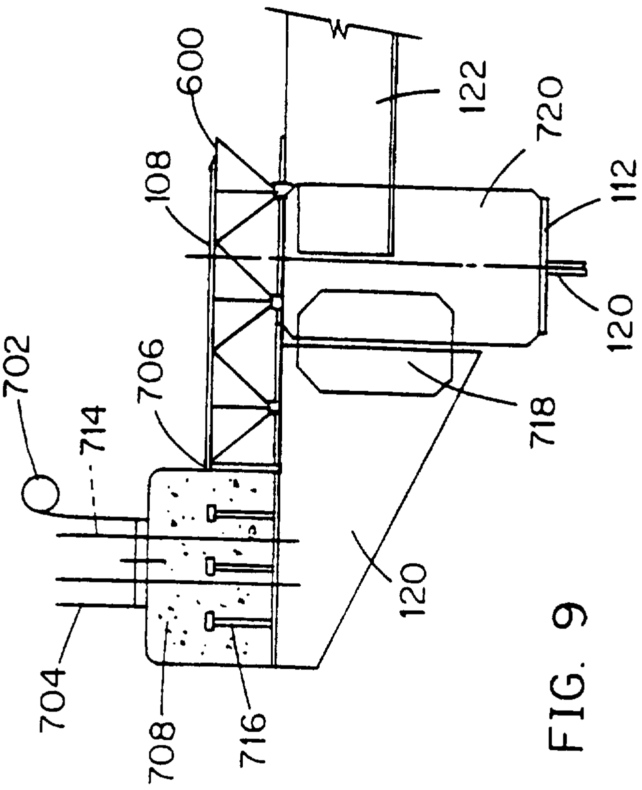


FIG. 9

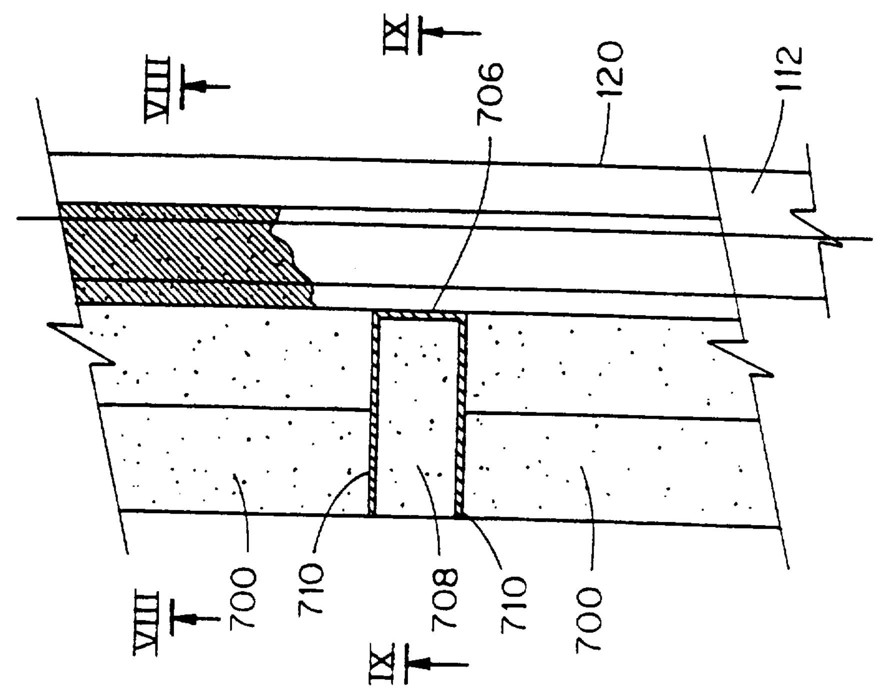


FIG. 7

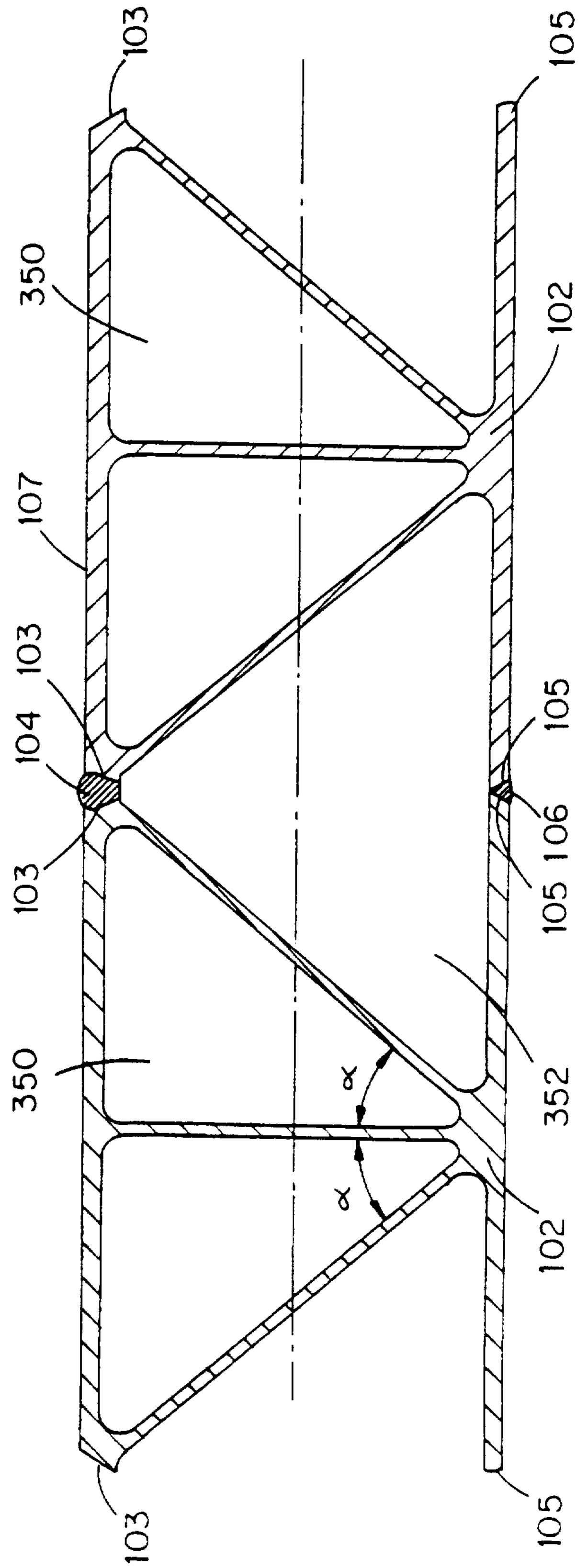

103
105
350
102
107
103
104
103
105
106
105
350
352
α
α
102
103
105

FIG. 10

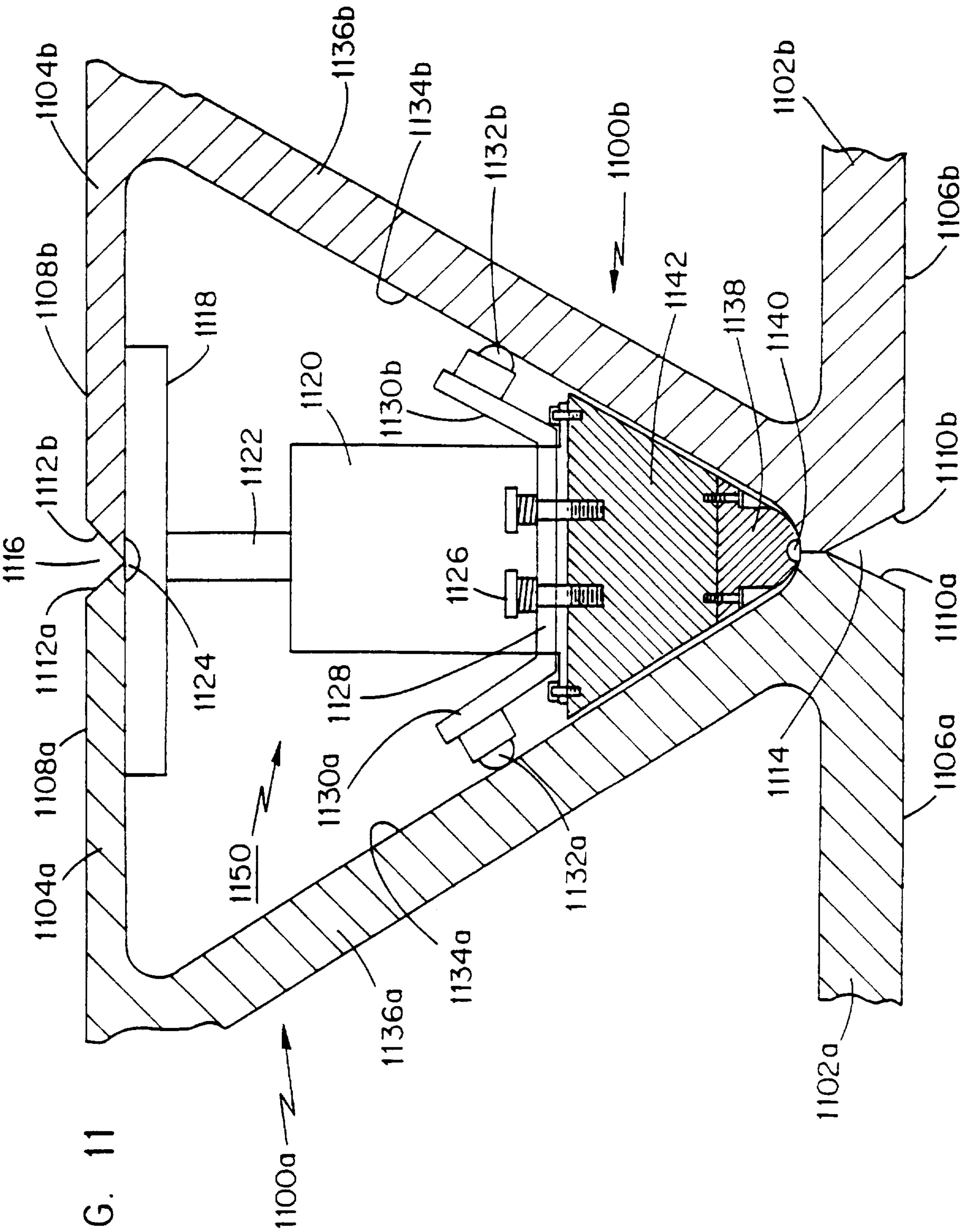

1104b
1136b
1134b
1132b
1100b
1102b
1106b
1108b
1118
1120
1130b
1142
1138
1140
1110b
1112b
1122
1116
1126
1112a
1124
1128
1110a
1108a
1130a
1150
1114
1106a
1104a
1132a
1134a
1136a
1102a
1100a

FIG. 11

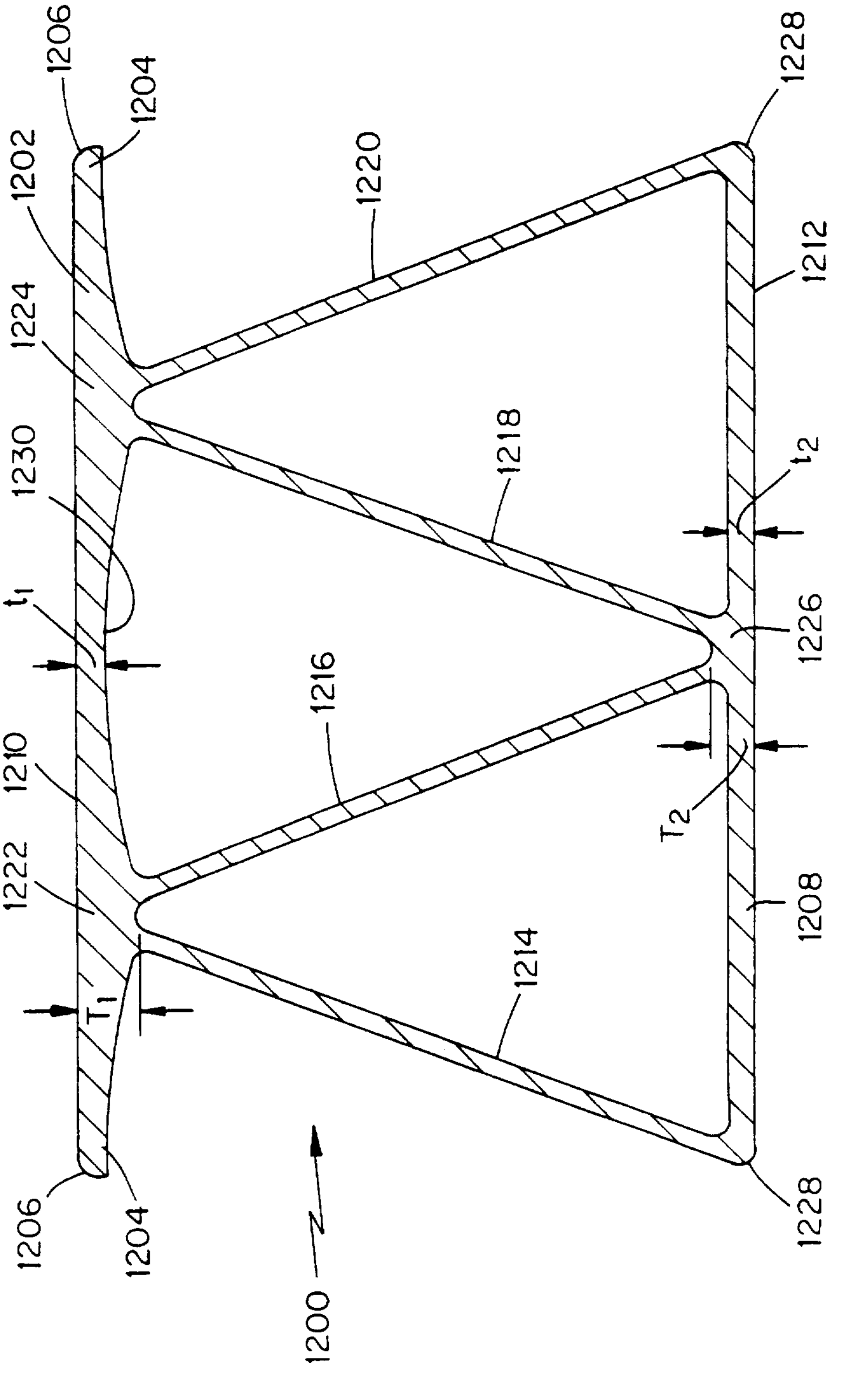

1200
1202
1204
1204
1206
1206
1208
1210
1212
1214
1216
1218
1220
1222
1224
1226
1228
1228
1230
t_1
T_1
t_2
T_2

FIG. 12

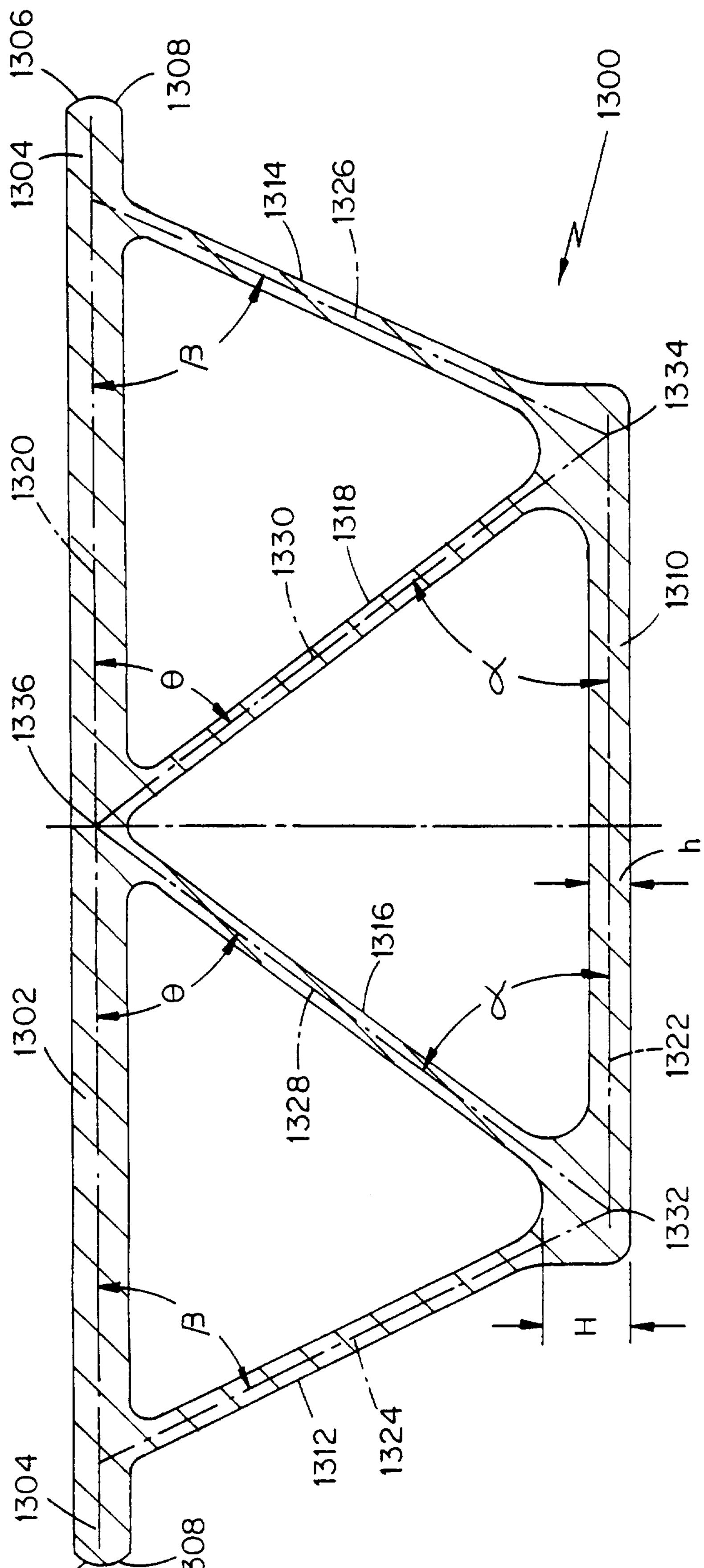

1300
1302
1304
1306
1308
1310
1312
1314
1316
1318
1320
1322
1324
1326
1328
1330
1332
1334
1336
H
h

FIG. 13

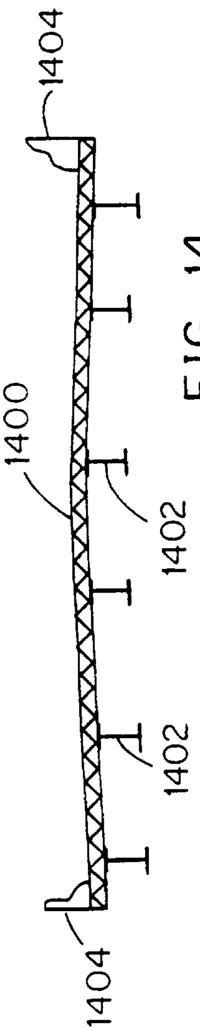

1400
1402
1402
1404
1404

FIG. 14

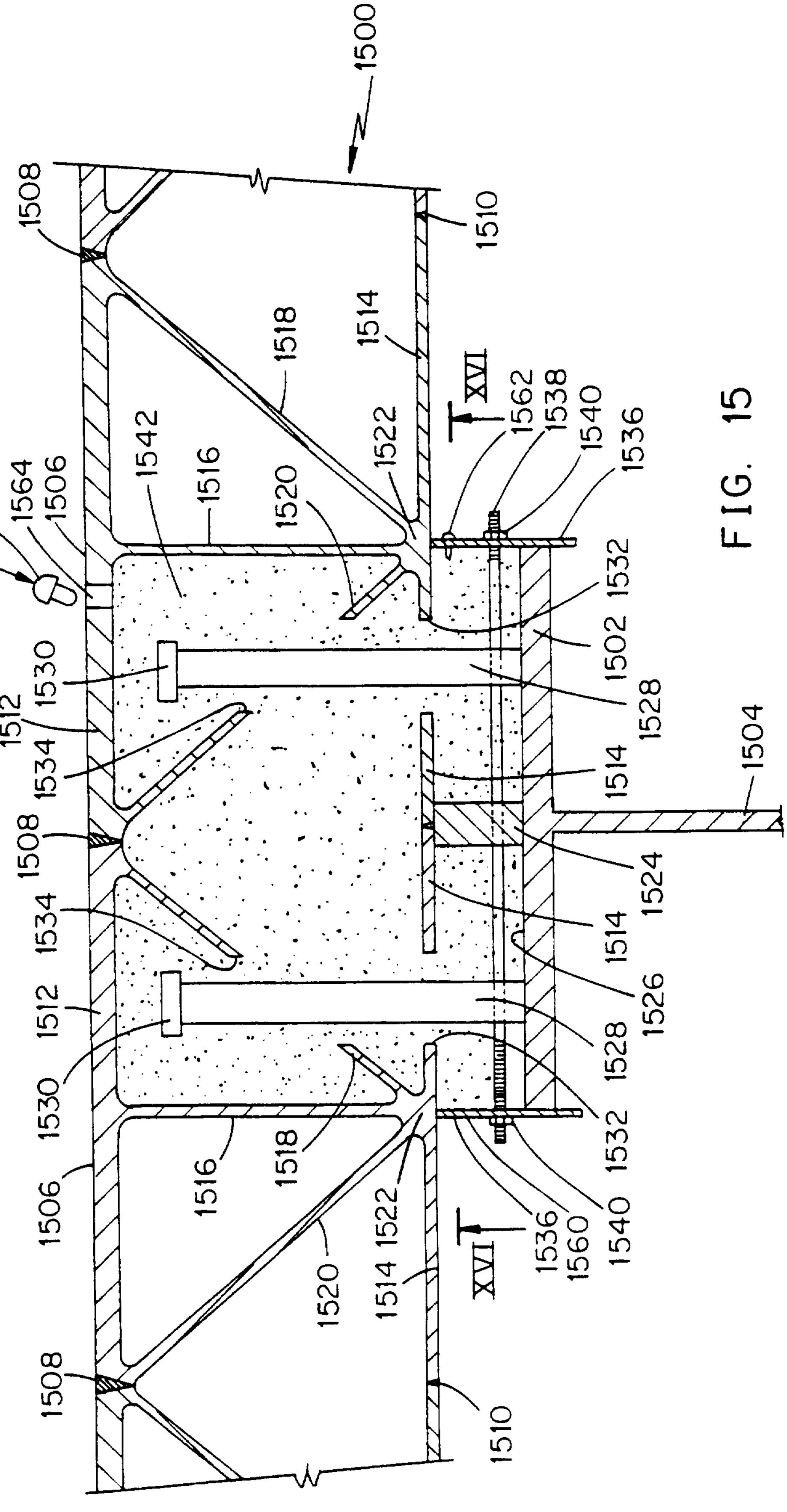

1500
1502
1504
1506
1506
1508
1508
1508
1510
1510
1512
1512
1514
1514
1514
1514
1516
1516
1518
1518
1520
1520
1522
1522
1524
1526
1528
1528
1530
1530
1532
1532
1534
1534
1536
1536
1538
1540
1540
1542
1560
1562
1564
1566
XVI
XVI

FIG. 15

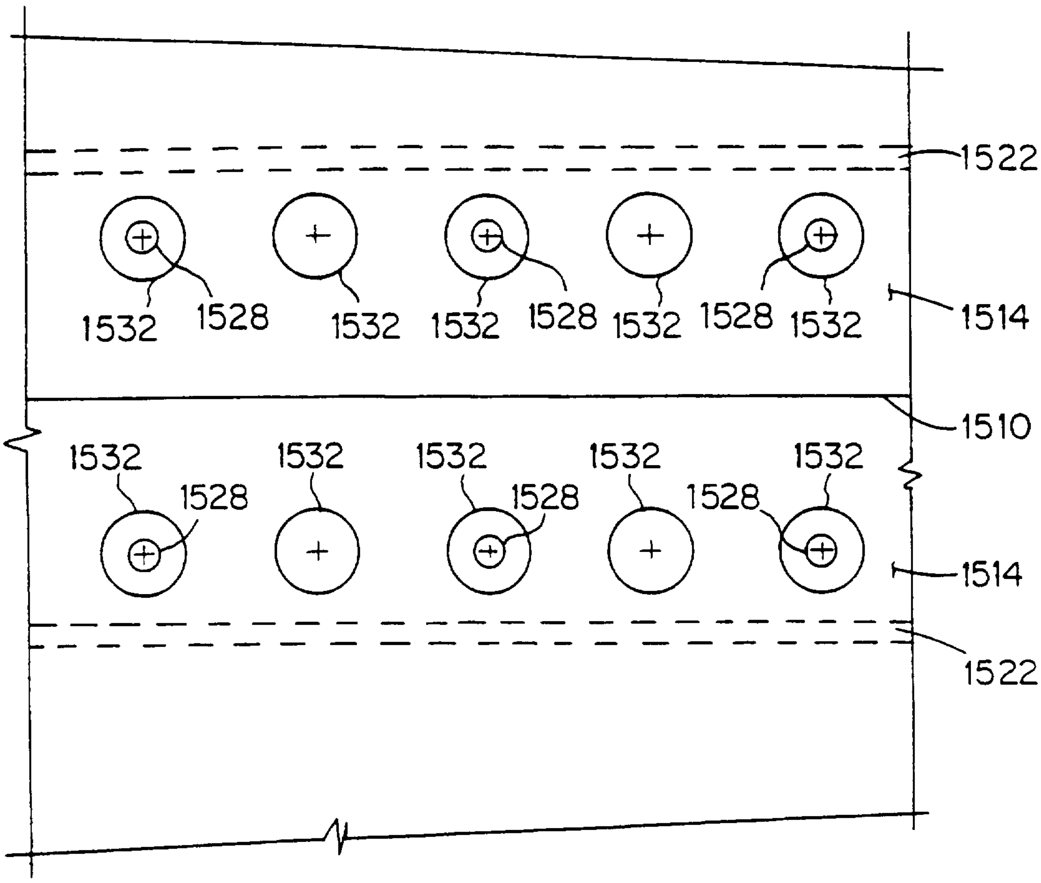

1522
1532
1528
1532
1532
1528
1532
1528
1532
1514
1510
1532
1532
1532
1532
1532
1528
1528
1528
1514
1522

FIG. 16

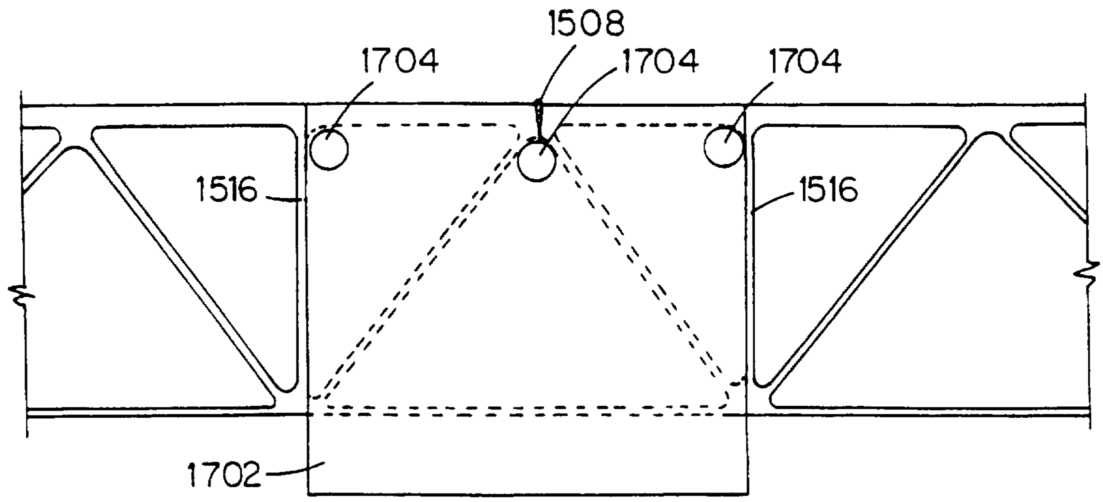

1508
1704
1704
1704
1516
1516
1702

FIG. 17

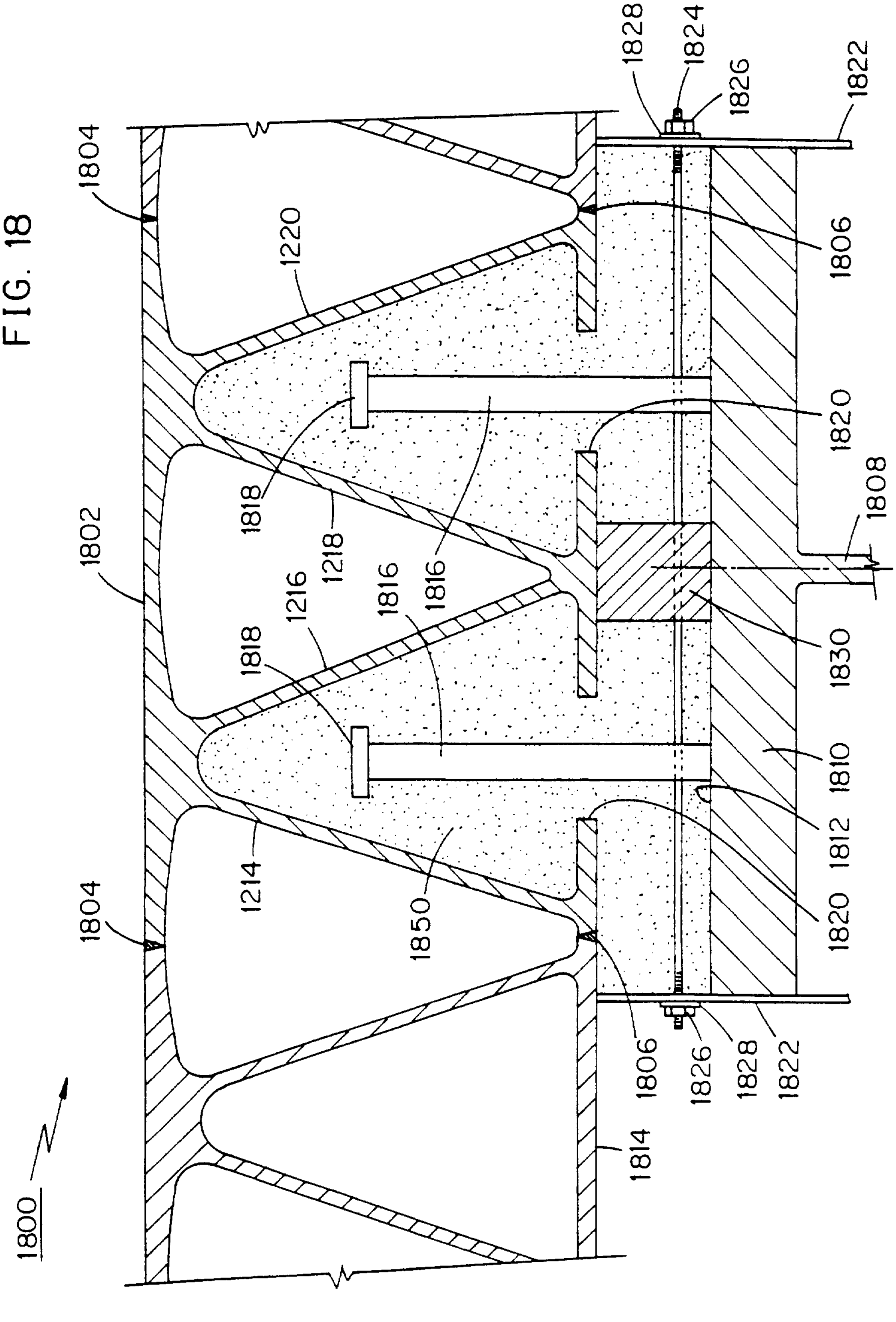

1800
1802
1804
1806
1808
1810
1812
1814
1816
1818
1820
1822
1824
1826
1828
1830
1850
1214
1216
1218
1220

FIG. 18

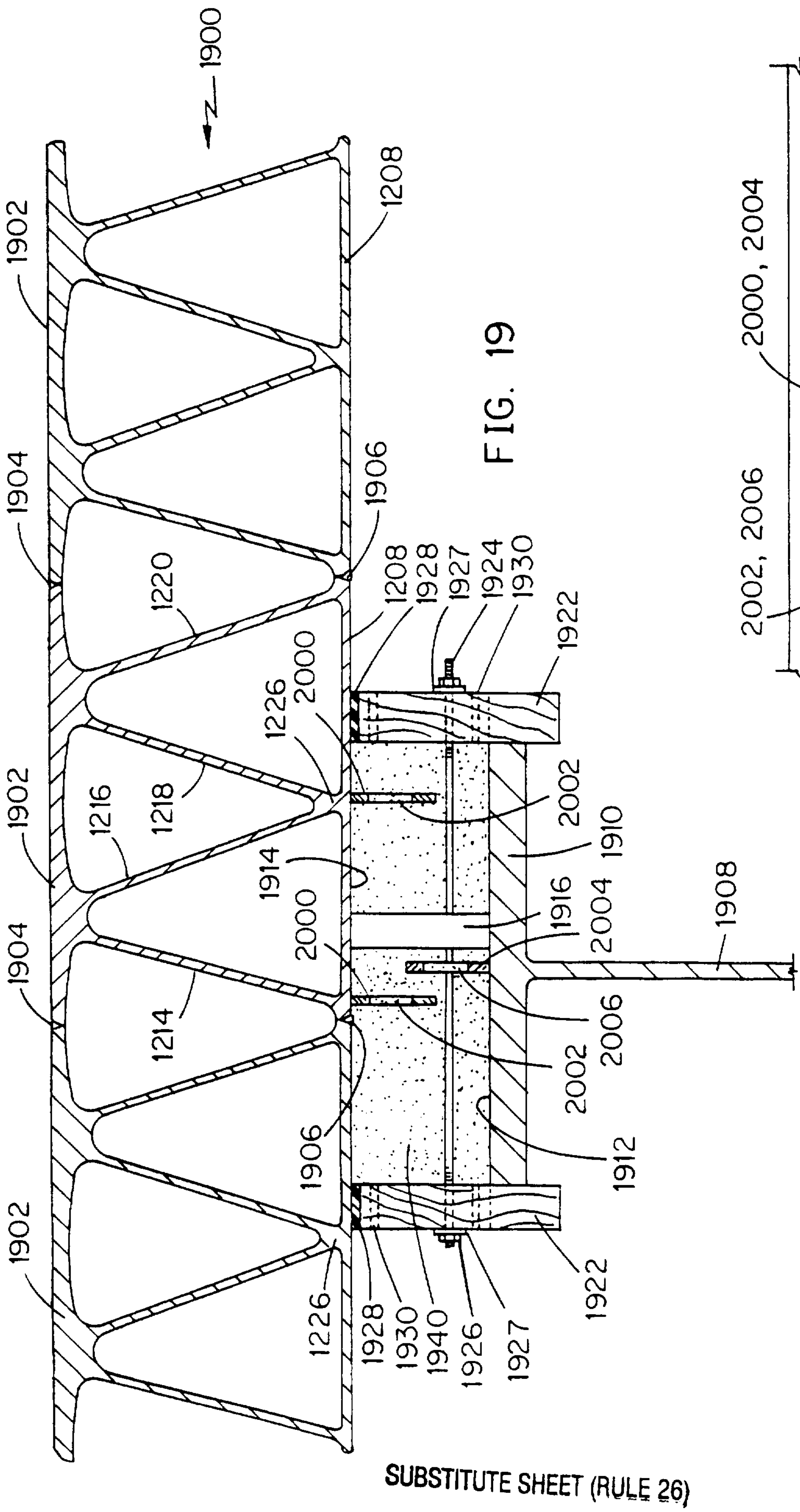

1900
1902
1904
1906
1208
1220
1226
2000
1928
1927
1924
1930
1922
1216
1218
2002
1910
1914
1916
2004
1908
2006
1214
1912
1940
1926

FIG. 19

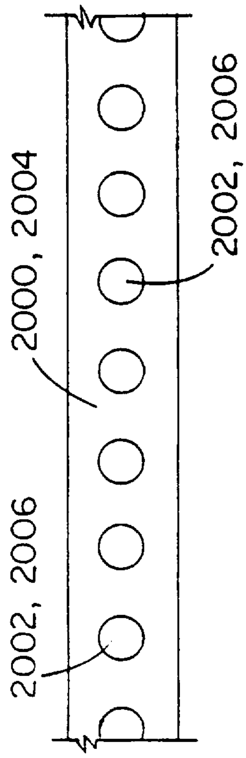

2000, 2004
2002, 2006

FIG. 20

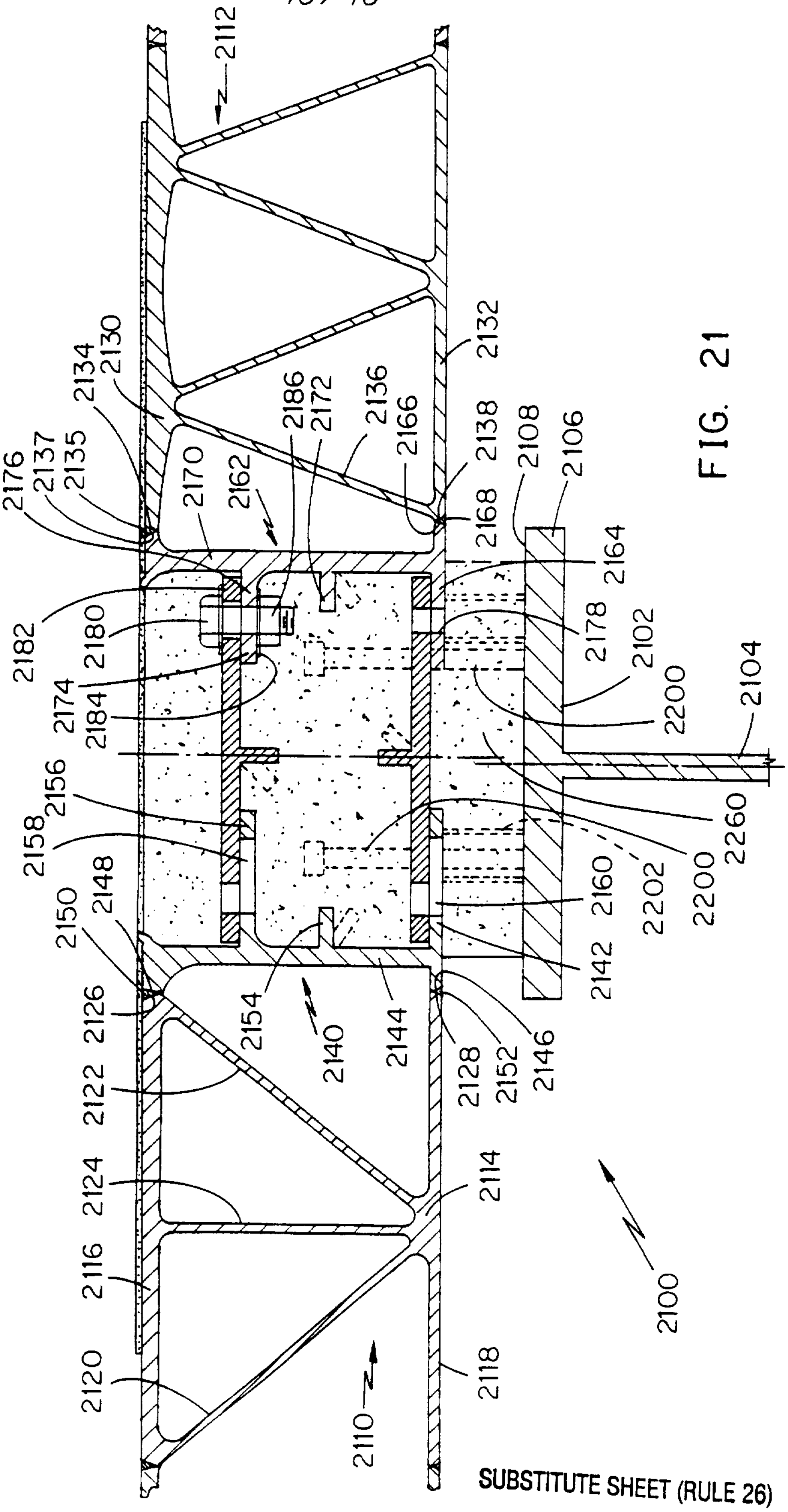

2112
2132
2130
2134
2176
2137
2135
2170
2162
2186
2172
2136
2166
2138
2168
2108
2106
2164
2182
2180
2178
2102
2174
2184
2200
2104
2260
2156
2158
2202
2148
2150
2160
2142
2126
2154
2140
2144
2128
2152
2146
2122
2124
2114
2116
2100
2120
2110
2118

FIG. 21

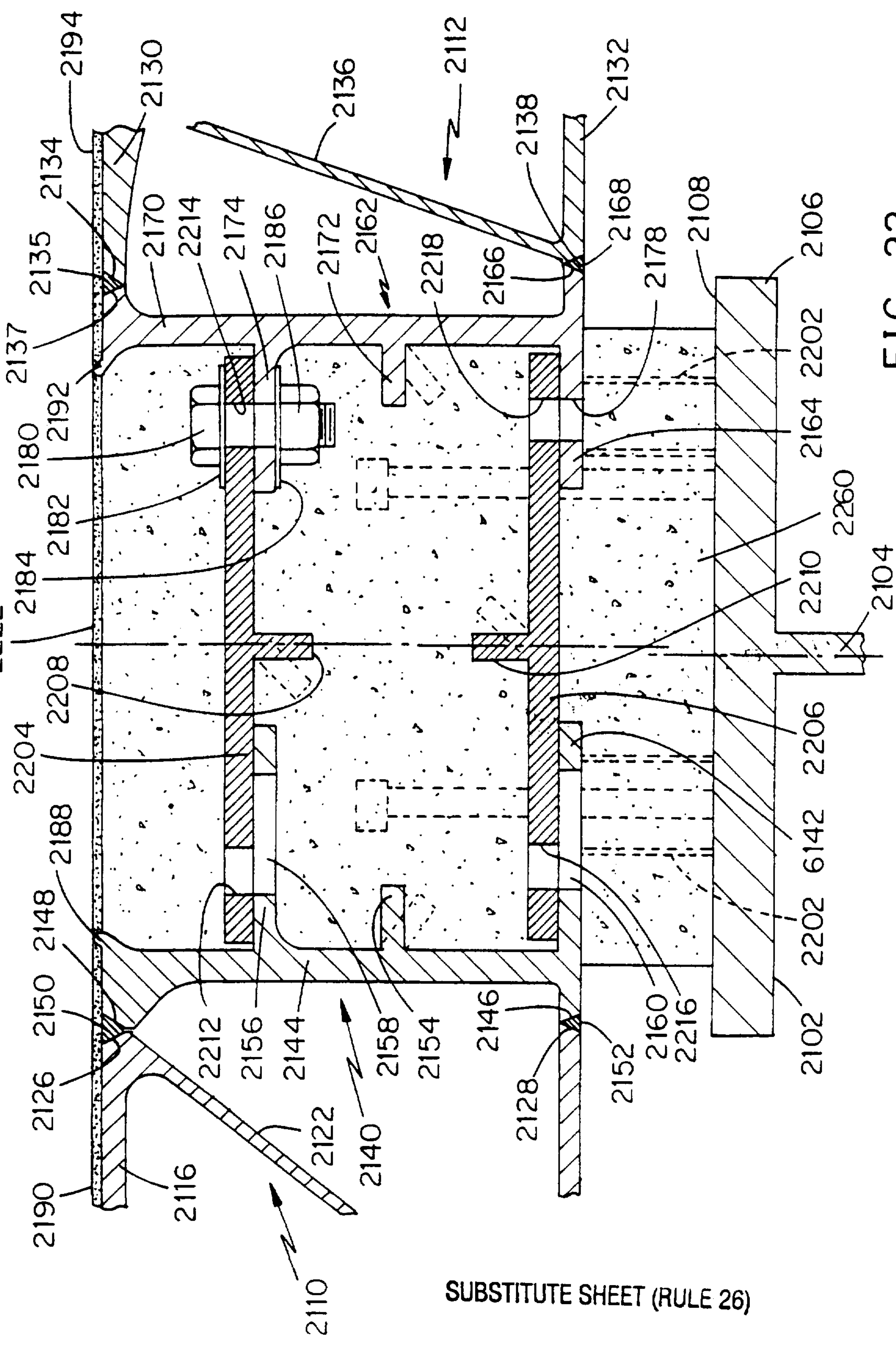

2194
2130
2134
2135
2137
2192
2180
2182
2184
2222
2208
2204
2188
2148
2150
2126
2190
2116
2110
2122
2140
2212
2156
2144
2158
2154
2146
2128
2152
2160
2216
2102
2202
6142
2206
2210
2104
2260
2164
2202
2106
2108
2178
2168
2166
2218
2162
2172
2186
2174
2214
2170
2136
2112
2138
2132

FIG. 22

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/18367

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :E01D 19/12
US CL :14/6, 73, 77.1; 52/588.1; 228/50
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 14/3, 4, 6, 73, 73.1, 74, 77.1, 52/581, 582.1, 588.1, 782.1, 783.1; 228/25, 26, 27, 50; 244/124, 235, 131

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,243,288 A (NAGIN) 31 May 1966 (31.05.66), see the entire document.	1-3 and 31-33
A	US 3,253,289 A (NAGIN) 31 May 1966 (31.05.66), see then entire document.	2-3, 31-33
A	US 4,289,420 A (DAVIS et al) 15 September 1981 (15.09.81), see especially column 3, lines 20-25.	1-3
A	US 4,972,537 A (SLAW, Sr.) 27 November 1990 (27.11.90), see the entire document.	3 and 14-33
X ---- Y	US 5,033,147 A (SVENSSON) 23 July 1991 (07.23.91), see the entire document.	11-12 ------- 13

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 JANUARY 1997	14 FEB 1997

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	JAMES A. LISEHORA
Facsimile No. (703) 305-3230	Telephone No. (703) 308-2168

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,450,996 A (HELTON et al) 19 September 1995 (19.09.95), see the entire document.	9-10
A	GB 1,587,224 A (BRITISH ALUMINIUM LTD) 01 APRIL 1981 (01.04.81), see the entire document.	1-3
Y	FR 2,510,154 A (MINISTERE DES TRANSPORTS) 28 January 1983 (28.01.83), see the entire document.	13