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(54) **MODULAR BRIDGE**

(57) In the present invention a modular bridge structure (1) for a bridge is provided comprising two longitudinal elements (3) and a transversal deck element (5), each longitudinal element (3) having a first end (7), a central region (9), a second end (11), an arch section (13), an upper section (15) and two pillar sections (17), wherein a pillar section (17) each is arranged at the first end (7) and at the second end (11), wherein the arch section (13) and the upper section (15) are connected at the central region (9), wherein each of the pillar sections (17) connects an end of the arch section (13) with an end of the upper section (15) at the first end (7) and at the second end (11), wherein the deck element (5) is configured to be mounted on the upper sections (15) of the two longitudinal elements (3) such that the modular bridge structure (1) substantially comprises the shape of a π in cross section.

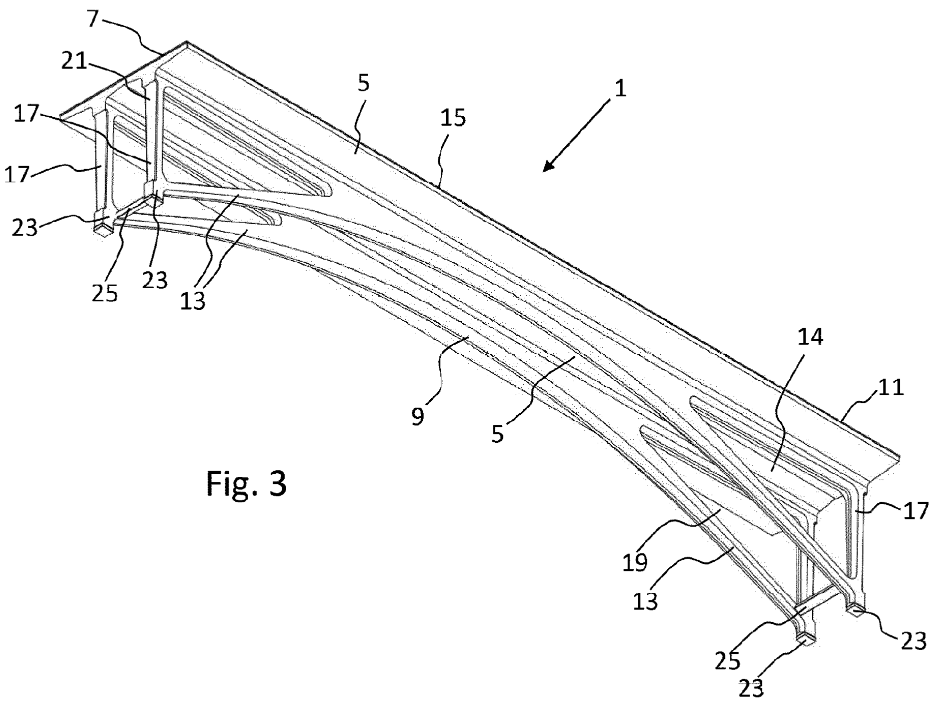

Fig. 3

EP 4 403 702 A1

Description

[0001] The present invention relates to a modular bridge structure, a bridge assembly and to a method of building a bridge involving the modular bridge structure and/or the bridge assembly.

INTRODUCTION

[0002] In geographical areas with islands, peninsulas, or other land regions between and around the sea or a lake, bridges and tunnels are often suitable structures enabling a land link for transportation between the respective regions of such topographies. As tunnel constructions are in most cases more complex and thus significantly more expensive, bridges are usually the most common structures for these requirements. For large spans across open water which may have a range between several hundred meters and several kilometers, modular bridges have been used.

[0003] However, known modular bridge structures are made of many single parts which must be produced and shipped to the bridge site. Pre-fabricating those structures and then transporting them to the bridge site is rather time-consuming and quite costly. Furthermore, fabricating all bridge components on site requires large amounts of material, energy and effort and often cannot ensure the necessary quality of the components. For these reasons, architects and engineers have abstained from designing aesthetically appealing modular bridge structures with components which comprise a more complex, off-standard structure.

SUMMARY

[0004] It is therefore the object of the present invention to provide a modular bridge structure which reduces the amount of material, saves cost, offers optically pleasing design alternatives and is thus more sustainable. Another object of the present invention is to provide an improved method of building a bridge which significantly decreases the overall construction cost, reduces the construction energy and time and is thus more sustainable compared with known methods.

[0005] This object is solved by the subject matter of claims 1 and 14. According to claim 1, a modular bridge structure for a bridge is provided comprising two longitudinal elements and a transversal deck element, each longitudinal element having a first end, a central region, a second end, an arch section, an upper section and two pillar sections, wherein a pillar section each is arranged at the first end and at the second end, wherein the arch section and the upper section are connected at the central region, wherein each of the pillar sections connects an end of the arch section with an end of the upper section at the first end and at the second end, wherein the deck element is configured to be mounted on the upper sections of the two longitudinal elements such that the modular bridge structure substantially comprises the shape of a π in cross section. In the context of the present invention, the term "the shape of a π in cross section" means that the two longitudinal elements are positioned parallel to each other in a predetermined distance with the deck element connecting the upper sections of the two longitudinal elements with each other, preferably and normally in an angle of 90° between the deck element and each longitudinal element. The edges of the deck element are usually not flush with one of the longitudinal elements but it is explicitly noted that such a flush configuration at least with one longitudinal element shall be included in that term.

[0006] Longitudinal in the sense of the present invention does not necessarily mean straight. In other words, the longitudinal elements and the deck element of the modular bridge structure may also be bent or curved so as to accommodate for a respective topology.

[0007] The components of such a modular bridge structure may be prefabricated in a plant facility at a first site, assembled there to at least partially obtain the modular bridge structure and then transported to a bridge site. This enables a higher fabrication quality compared to fabrication on site. Alternatively, the prefabricated components may separately be transported to the bridge site where the modular bridge structure is assembled. In any case, it's modular construction significantly reduces the amount of material used for a bridge and therefore reduces the overall costs of a bridge. Furthermore, its construction with the arch section enables a very stable framework and also an optically pleasing appearance.

[0008] In a preferred aspect of the invention, a void may be formed at the first end and/or at the second end of the longitudinal element between the upper section, the arch section and each of the pillar sections. Such a void further reduces the amount of material which in turn reduces the material costs. It is of course possible that the area between the upper section, the arch section and the pillar section of each longitudinal element may comprise more than one void. For example, a plurality of crossbeams may be arranged in the void dividing the area of the void into a plurality of partial voids.

[0009] In a further advantageous aspect of the invention, the void may comprise the shape of a triangle in cross section. In this case, the effort for the form work needed to implement the void in a triangular shape may be reduced. Alternatively, the cross-sectional shape of the void may be a polygon having at least one linear and/or at least one arched segment, a segment of a circle or an oval or a combination thereof.

[0010] According to a further aspect of the invention, each pillar section may comprise an upper end and a lower end, wherein at least one transverse beam connects the lower ends of each pillar at the first end and at the second end of the modular bridge structure. The transverse beam provides additional stability for the modular bridge structure. It is noted that on each pillar section there may be more than one transverse beam. Each transverse beam may also be integral with one pillar section or both pillar sections. It is conceivable that two or more transverse beams be aligned in form of diagonals, thereby acting as cross-bracing and/or diaphragm between the two longitudinal elements. The transverse beams could even extent over the full height as to form a wall between the pillar sections. The shape of the transverse beam may comprise straight and/or curved sections or a combination thereof. This additional flexibility increases the options for the engineers and architects.

[0011] According to another favorable aspect of the invention, each longitudinal element and the deck element may have a length of between 30 m and 70 m, more preferable between 40 m and 60 m, and/or that the deck element has a width of between 3 m and 10 m, more preferable between 6 m and 8 m. Longer and wider versions are possible but the above ranges have proven as preferred values in multi-lane bridges of several kilometers of overall length.

[0012] According to a further aspect of the invention, the deck element may extend in the transverse direction beyond the upper section of at least one of the longitudinal elements. As mentioned above, this refers to the π shape in cross section of the modular bridge structure and means that the deck element may not be flush with the upper section of a longitudinal element. As will be shown below, also combinations of parallel modular bridge structures may be possible, each of the parallel strings having a different configuration, for example.

[0013] In an additional aspect of the invention, the arch section of a longitudinal element may comprise at least one straight segment. This means that the arch section of a longitudinal element does not have to be a segment of a circle, an ellipse or another curved shape, but may also comprise one or more straight segments. This may facilitate the formwork of each longitudinal element due to the reduced complexity. Further, such a configuration may offer more constructional options while maintaining the structural behavior.

[0014] In another preferred aspect of the invention, the two longitudinal elements, the deck element or the transverse beam may at least partially be formed from reinforced concrete. Using reinforced concrete as a composite material for bridge components is well known in the art and one of the most common engineering materials with steel bars, also known as reinforcement bars or rebars, usually passively embedded in the concrete. Reinforced concrete may be used as precast or as cast-in-place concrete, and the modular bridge structure of the present invention may be preferably precast and assembled at an onshore construction facility such as a plant and then transported to an offshore bridge site where several modular bridge structures will finally form the bridge together with other components as will be explained below. It is noted that other reinforcement materials than steel such as glass fiber or other fibers of polymer, carbon, aramid or other high-strength fibers may also be used for the modular bridge structure.

[0015] Another aspect of the present invention relates to a bridge assembly. According to a preferred aspect of the invention, a bridge assembly may comprise at least two modular bridge structures as described above, wherein the at least two modular bridge structures may be arranged longitudinally adjacent to each other. By such an arrangement, long stretches over water between two or more land regions of up to several kilometers may be spanned with one or more bridge assemblies. As mentioned above, the modular bridge structures may also assume a bent or curved configuration in order to adapt the pathway of the bridge to the given topology. Together with the option of having different lengths of the modules, this offers an optimized flexibility when designing a bridge according to the given geographical circumstances.

[0016] According to a further preferred aspect of the invention, the adjacent pillar sections of two adjacent modular bridge structures are supported on at least one pier unit. The pier units form the base or the groundwork for the bridge assembly. There may also be more than one pier unit for adjacent pillar sections of two adjacent modular bridge structures. The pier units may also be prefabricated at a fabrication site and then transported to the bridge site. Alternatively, or in addition, the pier units may be fabricated directly at the bridge site where they may be immediately arranged and installed at their final location. The pier units may be comprised of a single component or of multiple components. Further, the pier units may be directly anchored in the ground or supported on a base member or foundation pad which represents the connection to the ground surface. It is further conceivable that the pier units are integrally formed and/or prefabricated with the foundation pad. Also, a pier unit may obtain a V-, Y- or T-shape wherein the two upper ends are connected to the pillar sections of a modular bridge structure and the lower end is either directly anchored in the ground or supported on a separate base member.

[0017] According to another aspect of the invention, the bridge assembly may comprise more than one modular bridge structure arranged in parallel to each other. This opens up possibilities to construct wide road structures with a plurality of lanes in parallel having a width of 20 m per direction or more. It is also possible to arrange more than two modular bridge structures in parallel such as one modular bridge structure for each driving direction and a further modular bridge structure therebetween serving as a bicycle lane or footpath. The two parallel modular bridge structures may be directly adjacent to each other or may have a gap between them.

[0018] According to a further aspect of the invention, the bridge assembly may comprise one or more road surface structures arranged on top of the deck elements of each modular bridge structure. Such road surface structures may be integrally formed with the deck elements or may be formed as separate components. They may be in the shape of concrete slabs or similar structures which may accommodate asphalt, other bituminous surfaces and other suitable road surface materials as well as waterproofing membranes. Further, these road surface structures may also be arranged between two parallel bridge assemblies using the modular bridge structures mentioned above so as to bridge the gap therebetween.

[0019] In a further aspect of the invention, a method of building a bridge at a bridge site comprises the steps of a) fabricating at a plant facility a plurality of longitudinal elements each having a first end, a central region, a second end, an arch section, an upper section and two pillar sections, wherein each pillar section is arranged at the first end and at the second end, wherein the arch section and the upper section are connected at the central region, wherein each of the pillar sections connects an end of the arch section with an end of the upper section at the first end and at the second end; b) fabricating at the plant facility a plurality of transversal deck elements; c) providing a plurality of pier elements at the bridge site; d) installing the plurality of pier elements at the bridge site; e) providing a plurality of π-shaped modular bridge structures at the bridge site, each modular bridge structure comprising two longitudinal elements and a deck element; f) arranging the plurality of modular bridge structures onto the plurality of installed pier elements; and g) connecting the plurality of modular bridge structures to form the bridge. The pier elements are configured to be anchored in the ground, be it below the waterline or on land, and may include vertically oriented pier units supported on base members. Alternatively, the pier units of the pier elements may be directly mounted as pillars or piles in the ground with or without an extra base member.

[0020] This method saves material, energy and costs and reduces the effort at the bridge site because the infrastructural capacities and technical possibilities at the plant facility are usually much more advanced than, for example, offshore at the bridge site. Furthermore, it enables an improved bridge construction which promotes to be of high manufacturing quality, aesthetically appealing, stable, and sustainable at the same time.

[0021] In advantageous embodiments, providing the plurality of π-shaped modular bridge structures at the bridge site in step e) comprises either e1) transporting the plurality of fabricated longitudinal elements and the plurality of deck elements from the plant facility to the bridge site and subsequently assembling each π-shaped modular bridge structures from two longitudinal elements and a deck element; or e2) assembling each π-shaped modular bridge structures from two longitudinal elements and a deck element at the plant facility and subsequently transporting the assembled π-shaped modular bridge structures from the plant facility to the bridge site. Option e1) may be particularly useful in situations where the bridge site is well accessible and offers sufficient infrastructure for the assembly of the modular bridge structure. The other alternative, option e2) may be beneficial in settings where the infrastructure at the bridge site cannot provide sufficient space, installations or resources.

[0022] According to a further aspect, providing the plurality of pier elements at the bridge site in step c) comprises either c1) fabricating at the plant facility the plurality of pier elements and subsequently transporting the plurality of pier elements from the plant facility to the bridge site; or c2) fabricating the plurality of pier elements directly at the bridge site. Option c1) may likewise be useful in situations where the infrastructure at the bridge site cannot provide sufficient space, installations or resources. The alternative, option c2) may be beneficial in settings where the bridge site is well accessible and offers sufficient infrastructure.

[0023] For example, options e2) and c1) may be applied in cases where the bridge is very extensive in its overall length and the installation location is rather far offshore.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] These and other advantages and benefits of the present invention may become apparent after a careful reading of the following detailed description of embodiments with appropriate reference to the accompanying drawings.

[0025] In the drawings:

Fig. 1	is an explosive, perspective view of a preferred embodiment of the modular bridge structure according to the invention,
Fig. 2	is an elevation view of the modular bridge structure of Fig. 1,
Fig. 3	is a perspective bottom view of the modular bridge structure of Fig. 1,
Fig. 4	is a perspective top view of the modular bridge structure of Fig. 1,
Fig.5	is a perspective bottom view of an embodiment of the bridge assembly according to the invention,
Fig. 6	is a perspective bottom view of a further embodiment of the bridge assembly according to the invention,
Fig. 7	is a perspective top view of yet another embodiment of the bridge assembly according to the invention,
Fig. 8	is a perspective bottom view of the bridge assembly of Fig. 7,
Fig. 9	is front view of the bridge assembly of Figs. 7 and 8,

Fig. 10 is an elevation view of a detail of the bridge assembly shown in Fig. 5,

Fig. 11 is a bottom view of yet a further embodiment of the bridge assembly according to the invention,

Fig. 12 is a perspective bottom view of the bridge assembly of Fig. 11,

Fig. 13 is a schematic view of a first fabrication state of an embodiment of the modular bridge structure of the present invention,

Fig. 14 is a schematic view of a second fabrication state of the embodiment of the modular bridge structure of Fig. 13,

Fig. 15 is a schematic view of a third fabrication state of the embodiment of the modular bridge structure of Fig. 13,

Fig. 16 is a schematic view of a final fabrication state of the embodiment of the modular bridge structure of Fig. 13, and

Figs. 17 to 21 show different steps of an embodiment of a preferred method of building a bridge according to the present invention.

DETAILED DESCRIPTION

[0026] Fig. 1 is an explosive, perspective view of a preferred embodiment of the modular bridge structure 1. The modular bridge structure 1 comprises two longitudinal elements 3 which are arranged substantially in parallel wherein each longitudinal element 3 comprises a first end 7, a central region 9, a second end 11, an arch section 13, an upper section 15 and two pillar sections 17 at the first end 7 and the second end 11, respectively. The arch section 13 and the upper section 15 of the longitudinal element 3 are connected at the central region 9. In the shown embodiment, the arch section 13 and the upper section 15 merge at the central region 9. Each of the pillar sections 17 connects an end of the arch section 13 with an end of the upper section 15 at the first end 7 and at the second end 11, respectively. A void 19 is formed at the first end 7 and at the second end 11 of the longitudinal element 3. Each void 19 is enclosed by the upper section 15, an arch section 13 and a pillar section 17.

[0027] The modular bridge structure 1 further includes a transversal deck element 5 having an upper surface 6 and a lower surface 8. On the lower surface 8 there are two parallel slab thickenings 10 having a support surface configured for a mating or a complementary arrangement of an upper section 15 of the longitudinal element 3. The slab thickenings 10 may have a flat surface in a preferred embodiment. However, in further embodiments it may be possible that the slab thickenings 10 comprise at least partially an uneven surface, e.g. an undulated surface. In such an embodiment, the upper section 15 of the longitudinal element 3 may have a matching surface which corresponds to the surface of the slab thickenings 10. It is noted that the slab thickenings 10 are optional. Thus, the lower surface 8 of the deck element 5 may also be essentially plane or flat.

[0028] In this embodiment, a transverse beam 25 is arranged between the two lower ends 23 of the first end 7 and the two lower ends 23 of the second end 11 of the two parallely arranged longitudinal elements 3. It is possible that further transverse beams are arranged between the two longitudinal elements 3 to reinforce and stabilize the structure. It may also be envisioned that the transfers beam 25 is not arranged at the lower end 23 but further up on the pillar section 17 or even at a predetermined distance from the lower end at the arch section 13.

[0029] In the elevation view of Fig. 2 it can be seen that the modular bridge structure 1 is essentially symmetric with respect to a vertical plane located in the central region 9 dissecting the structure into a right and left portion. This symmetry is not mandatory but helpful as it reduces the complexity of the fabrication process and of the handling of the modular bridge structure 1. Further, it should be noted that the area between the upper section 15, the arch section 13 and the pillar section 17 on each side of one longitudinal element 3 may comprise more than one void. For example, a plurality of crossbeams may be arranged in the void dividing the area of the void into a plurality of partial voids. In the embodiment shown in Fig. 2, the void 19 has an essentially triangular shape in cross-section, here optionally with its edges rounded. This shape has proven beneficial as the formwork is less complex with its linear segments of the triangle instead of curved ones.

[0030] Figs. 3 and 4 are prospective bottom and top views, respectively, of the preferred embodiment of the modular bridge structure 1 already described with respect to Figs. 1 and 2. Here, the transverse beams 25 between the lower ends 23 may be seen fully connecting and stabilizing the two longitudinal elements 3.

[0031] Both Fig. 3 and Fig. 4 show an important aspect of the present invention which is the shape of the cross-section of the modular bridge structure 1 embodied as a π: in Fig. 3 it is the left side which shows the π-shape, and in Fig. 4 it is the right side or second end 11 which shows the π-shape in cross-section. As can be seen from the previously described Figs. 1 to 4, the transversal deck element 5 is symmetric in the longitudinal direction, i.e. the longitudinal edges of the deck element 5 protrude by the same predetermined amount to the side starting from each slab thickening 10 on the underside of the deck element 5. The deck element 5 thus extends in the longitudinal direction beyond the upper section 15 of each longitudinal element. It is noted that other asymmetric configurations of the deck element 5 are possible. For example, the deck element 5 may only cover the area between the two longitudinal elements 3, or the deck element 5 may only protrude on one side. Of course, other asymmetric configurations are possible, too. Also, the protrusions on both edges do not have to be continuous. In other words, there may be smaller portions on the edges which protrude further, or indentations, for example for lamp installations or other infrastructural components.

[0032] Fig. 5 is a perspective bottom view of an embodiment of a bridge assembly 20 according to the invention wherein two modular bridge structures 1 are arranged next to one another in the longitudinal direction. In other words, the front ends of each modular bridge structure 1 abut with each other such that the upper surfaces 6 of each deck element 5 form a smooth transition. The neighboring lower ends 23 of two longitudinal elements 3 are arranged on pier unit 27. In the present embodiment, one pier unit 27 supports two lower ends 23 on either side of the modular bridge structure 1. Two pier units 27 are arranged on a base member 29 to support the four lower ends 23 of two abutting modular bridge structures 1. It should be noted that other pier or basic structures are also feasible in other embodiments, for example, instead of two cylindrically shaped pier units 27, a single larger pier member may be used spanning the entire width between the longitudinal elements 3. It is also possible that there is no base member at all, i.e. the pier units 27 may be directly anchored in the ground.

[0033] It will be apparent to those skilled in the art that two or more modular bridge structures 1 may be arranged longitudinally next to one another forming a very long bridge assembly which could, for example, span several hundred meters or even several kilometers. For the shown embodiments, a typical length of the modular bridge assembly 1 is between 30 m and 70 m, more preferably between 40 m and 60 m while the typical width of the deck element may be between 3 m and 10 m, more preferably between 6 m and 8 m. Depending on the used material and the conditions at the bridge site, other dimensions may also be used.

[0034] Fig. 6 is a perspective bottom view of a further embodiment of the bridge assembly 20 wherein the modular bridge structures 1 are arranged in parallel and connected via a plurality of transversal deck members 31. Such an arrangement is particularly useful in cases where a very wide road surface shall be achieved. Also here, the modular bridge structures 1 reside on base units formed by pier units 27 and base members 29. The inner edges of the two parallel modular bridge structures 1 are spanned by the deck members 31 which may have a length corresponding to the distance between the two modular bridge structures 1 and a predetermined width, for example between 2 m and 8 m. Preferably, the longitudinal edge of the deck member 31 is flush with the front end of a deck element 5 so that a plurality of bridge assemblies 20 as shown in Fig. 6 may be arranged next to each other in the longitudinal direction as schematically shown in Fig. 5. It is understood that two longitudinally arranged bridge assemblies 20 as shown in Fig. 6 may likewise share the base unit with the two peer units 27 and the base member 29.

[0035] Figs. 7 and 8 are a perspective top and bottom views, respectively, of another embodiment of the bridge assembly 20 wherein a plurality of modular bridge structures 1 are arranged in parallel and partly connected via a plurality of transversal deck members 31. In principle, the embodiment of Figs. 7 and 8 represents a combination of two bridge assemblies 20 as shown in Fig. 6 combined with a central bridge assembly 20 according to the embodiment of Fig. 5 wherein only one modular bridge structure 1 is shown. The embodiment of Figs. 7 and 8 may, for example, be used in a setting where two motorway or highway bridge structures, one for each direction, are divided in the middle by a central cycle and/or footpath bridge structure. As can be seen, there is no connection between the cycle and/or footpath bridge structure and the other bridge structures which provides traffic security for the cyclists/pedestrians which under normal circumstances may not come into contact with the traffic on the motorway or highway lanes of the bridge. It is understood, that the bridge structures shown here are usually arranged one after the other in the longitudinal direction in the same fashion as shown in Fig. 5. In other words, the base units including the base member or foundation pad 29 and two pier units 27 are configured to accommodate the adjacent modular bridge structure 1. Those skilled in the art will appreciate that other combinations of one or more bridge assemblies may be arranged next to each other and in the longitudinal direction so as to offer a full flexibility for architects, bridge engineers and designers. Particularly, a road bridge structure may comprise a narrower or wider deck member 31 or may comprise three or more parallel modular bridge structures 1 with or without narrow or wide deck members 31 arranged in between. As can be seen, these arrangements of multiple modular bridge structures 1 benefit most from the modularity presented herein as the number of different components is reduced and very limited.

[0036] Fig. 9 is a front view of the bridge assembly shown in Figs. 7 and 8. Here, it can be seen that the deck elements 5 of the left and right motorway or highway bridge structures are different from the deck element 5 of the cycle and or footpath bridge structure shown in the middle. In this embodiment, the deck members 31 form a transverse connection between the two modular bridge structures 1 described as motorways or highways. It should also be mentioned that the pier units 27 may have different lengths depending on the circumstances of the ground surface where the base members 29 are positioned.

[0037] Fig. 10 shows a partial side elevation view of a detail of the bridge assembly 20 shown in Fig. 5. The detail relates to the frontal connection between two modular bridge structures 1 wherein the surfaces of the deck elements 5 form a smooth transition. The upper part of the pier unit 27 forms a head portion 28 which supports the lower ends 23 of the pillar sections 17 of each longitudinal element 3. The surfaces of the head portion 28 and the lower ends 23 may be configured e. g. with a positive fit by means of indentations and/or protrusions such that the connection is supported. Additional fixing means may also be used such as bolts, concrete connectors and the like. In the shown embodiment, there is a gap 39 formed between the pillar sections 17 of two abutting longitudinal elements 3. However, there may be other configurations without such a gap or, alternatively, with a plurality of gaps along the lengths of the pillar sections 17. Further, in the present embodiment, the mating surfaces of the two frontally connected modular bridge structures 1 are essentially plane. It is also possible that the surfaces comprise a slanted, serrated, undulated or otherwise designed shape which matches the opposing surface and thus supports the connection between the two components.

[0038] Fig. 11 is a bottom view of yet a further embodiment of a bridge assembly 20 wherein the modular bridge structures 1 have a slightly curved configuration. Such a configuration may be desirable in areas where the geographical circumstances dictate a bent or curved bridge path which, for example, cannot be compensated by using modular bridge structures which are rather short in length but are frontally connected with each other out of a central line. This is also very helpful in situations where shorter bridge modules may not be used, for example because of geographic or aesthetic reasons. In the shown embodiment, the deck elements 5 of the two modular bridge structures 1 comprise a non-straight configuration: in this case, the deck elements 5 comprise an outer radius R2 which may be different from or equal to a central radius R which also may be different from or equal to an inner radius R1. The longitudinal elements 3 are straight in this embodiment but it may also be envisaged that they comprise a curved configuration with a radius R3. The fact that the deck elements 5 are curved but the longitudinal elements 3 are not has the effect that the connections areas and elements of the modular bridge structures 1 above the base members 29 must be configured accordingly. Here, the surface areas of the head portion 28 of the pier units 27 are sufficiently dimensioned so that the lower ends 23 of the pillar section 17 of each longitudinal element 3 are from both sides fully supported on the head portion 28. In the shown embodiment, the distance between the facing lower ends 23 from both longitudinal elements 3 is not equal. It should be mentioned that other curved configurations of the bridge assemblies are possible, in particular also curved longitudinal elements 3. However, due to the complexity of fabrication of curved versus straight longitudinal elements 3, such a curved configuration is less likely to be used. By contrast, the fabrication of curved deck elements 5, even with different radii R1, R2 and R3, is less cumbersome.

[0039] Fig. 12 is a perspective bottom view of the bridge assembly of Fig. 11 wherein the slight curvature of the deck elements 5 can be seen from below.

[0040] Figs. 13 to 21 shall provide support of a detailed description of the method of building a bridge at a bridge site according to the invention. Figs. 13 to 16 are related to the fabrication process of a modular bridge structure 1 as mentioned and shown above, e. g. with respect to Figs. 1 to 4.

[0041] The preferred material for the essential components of the modular bridge structure and the bridge assembly is reinforced concrete. Reinforced concrete, its usage as a composite material for bridge components and the fabrication at or near a construction site is well known in the art. Usually, the concrete is reinforced with steel bars, also known as reinforcing bars or rebars, which are passively embedded in the concrete. Reinforced concrete may be used as precast or as cast-in-place concrete, and the modular bridge structure of the present invention may be precast and assembled at a construction facility at a predetermined distance from a bridge site and then transported to the bridge site where several modular bridge structures will finally form the bridge together with other components. This embodiment of the method will be explained below with respect to Figs 13 to 16.

[0042] Fig. 13 shows in perspective view a first form 33 for the longitudinal element 3. The first form 33 may be made from wood, aluminum or steel or any other suitable formwork material, e.g. plastic. On the upper section 15 of the longitudinal element 3, a plurality of rebars 35 protrude. Some of the rebars are formed as lifting hooks 36. Once the longitudinal element 3 has sufficiently cured it can be taken out of the formwork 33 and arranged as can be seen in Fig. 14. There, two longitudinal elements 3 are arranged parallel to each other with transverse beams 25 located between them. Formwork props 37 support the upright standing two longitudinal elements. The arrangement in Fig. 14 is an intermediate position. Fig. 15 shows the subsequent position wherein the second form 34 has been placed on the upper sections 15 of the longitudinal elements 3 so that concrete may be cast. Again, props are added to stabilize the entire formwork as needed. It should be noted that other forms of arrangement of the two longitudinal elements 3 are possible. For example, the deck element 5 could be cast first, and then the two longitudinal elements 3 could be cast and then connected with the deck element 5. It is also envisaged that the entire modular bridge structure 1 is (pre-)cast in one piece, i.e. in one casting procedure. Fig. 16 shows the completed modular bridge structure 1 without the formwork and other support material. In this cured condition, the modular bridge structure 1 is prepared for being transported to the bridge site and for being installed as will be explained below.

[0043] In the shown embodiment, there are four lifting hooks 36 protruding from the upper surface 6 of the deck element 5 which serve for lifting and/or transporting purposes. The iron loops of the lifting hooks 36 are configured as sufficiently strong so that the entire modular bridge structure 1 can be carried, for example by a crane 41 at least two hooks of which engage with the iron loops or lifting hooks 36 as shown in Fig. 17. The crane 41 will lift and then deposit the completed modular bridge structure 1 or a plurality of modular bridge structures 1 on a barge 43 as depicted in Fig. 18. The barge 43 which may, of course, carry more than one modular bridge structure 1 is pushed by a tug boat 44 as seen in Fig. 19. However, other transport vessels or a train or any other suitable transport means may be used to transport the modular bridge structure(s) onshore, offshore and over the air or a combination thereof to the bridge site.

[0044] Figs. 20 and 21 show schematically how a bridge with a plurality of modular bridge structures 1 may be assembled at a bridge site. In the shown embodiment, a bridge as depicted in Fig. 5 shall be installed at an offshore bridge location. At least two modular bridge structures 1 have already been installed on the respective pier units 27 and base members 29 which are shown as already under water in Fig. 20. A crane 41 mounted on a smaller barge 43 is in the process of lifting a further modular bridge structure 1 from the transport barge 43 to its installation location and of installing it on the top portions of the pier units 27 which protrude out of the water. Once installed, two lines of modular bridge structures 1 positioned longitudinally one after the other each form one side of a bridge assembly 20 as shown in Fig. 21. A plurality of precast deck members 31 have been transported from the precast facility to the bridge site on a barge 43. A crane 41 standing on the deck element 5 of an already installed modular bridge structure 1 has lifted a deck member 31 from the barge 43 and is in the process of installing the deck member 31 between the two parallel deck elements 5 of the respective modular bridge structures 1. It can bee seen that a plurality of deck members 31 have already been installed parallel to each other spanning the gap between the deck elements 5 of the modular bridge units 5 so as to form a smooth bridge surface.

[0045] It should be noted that in the shown embodiments, the road surface of the bridge assemblies still must be mounted. The road surface may include prefabricated modular components, or may be installed in a traditional way having an asphalt layer and one or more additional layers. Other combinations with a concrete road surface or a mixture with any of the above mentioned materials are possible.

[0046] With the subject matter presented in this description a modular bridge structure is provided which reduces the amount of material, saves cost, offers optically pleasing design alternatives and is thus more sustainable. Further, the improved method of building a bridge significantly decreases the overall construction cost, reduces the construction energy and time and is thus more sustainable compared with known methods.

List of reference numbers

[0047]

1	modular bridge structure
3	longitudinal element
5	deck element
6	upper surface
7	first end
8	lower surface
9	central region
10	slab thickening
11	second end
12	vertical plane
13	arch section
15	upper section
17	pillar section
19	void
20	bridge assembly
21	upper end
23	lower end
25	transverse beam
27	pier unit
28	head portion
29	base member
31	deck member
33	first form
34	second form
35	rebar
36	lifting hook
37	formwork prop
39	gap
41	crane
43	barge
44	tug boat

Claims

1. Modular bridge structure (1) for a bridge comprising:

two longitudinal elements (3) and a transversal deck element (5),

each longitudinal element (3) having a first end (7), a central region (9), a second end (11), an arch section (13), an upper section (15) and two pillar sections (17), wherein a pillar section (17) each is arranged at the first end (7) and at the second end (11),

wherein the arch section (13) and the upper section (15) are connected at the central region (9),

wherein each of the pillar sections (17) connects an end of the arch section (13) with an end of the upper section (15) at the first end (7) and at the second end (11),

wherein the deck element (5) is configured to be mounted on the upper sections (15) of the two longitudinal elements (3) such that the modular bridge structure (1) substantially comprises the shape of a π in cross section.

2. Modular bridge structure (1) according to claim 1, **characterized in that** a void (19) is formed at the first end (7) and/or at the second end (11) of the longitudinal element (3) between the upper section (15), the arch section (13) and each of the pillar sections (17).

3. Modular bridge structure (1) according to claim 2, **characterized in that** the void (19) comprises the shape of a triangle in cross section.

4. Modular bridge structure (1) according to any of the previous claims, **characterized in that** each pillar section (17) comprises an upper end (21) and a lower end (23), wherein at least one transverse beam (25) connects the lower ends (23) of each pillar section (17) at the first end (7) and at the second end (11) of the modular bridge structure (1).

5. Modular bridge structure (1) according to any of the previous claims, **characterized in that** each longitudinal element (3) and the deck element (5) have a length of between 30 m and 70 m, more preferable between 40 m and 60 m, and/or that the deck element (5) has a width of between 3 m and 10 m, more preferable between 6 m and 8 m.

6. Modular bridge structure (1) according to any of the previous claims, **characterized in that** in the transverse direction the deck element (5) extends beyond the upper section (15) of at least one of the longitudinal elements (3).

7. Modular bridge structure (1) according to any of the previous claims, **characterized in that** the arch section (13) of a longitudinal element (3) comprises at least one straight segment.

8. Modular bridge structure (1) according to any of the previous claims, **characterized in that** the two longitudinal elements (3) and the deck element (5) are at least partially formed from reinforced concrete.

9. Bridge assembly (20) comprising at least two modular bridge structures (1) according to any of the previous claims, **characterized in that** the at least two modular bridge structures (1) are arranged longitudinally adjacent to each other.

10. Bridge assembly (20) according to claim 9, **characterized in that** the adjacent pillar sections (17) of two adjacent modular bridge structures (1) are supported on at least one pier unit (27).

11. Bridge assembly (20) according to any of claims 9 to 10, **characterized in that** it comprises more than one modular bridge structure (1) arranged in parallel to each other.

12. Bridge assembly (20) according to any of claims 9 to 11, **characterized in that** it comprises one or more road surface structures arranged on top of the deck elements (5) of each modular bridge structure (1).

13. Method of building a bridge at a bridge site comprising the following steps:

a) fabricating at a plant facility a plurality of longitudinal elements (3) each having a first end (7), a central region (9), a second end (11), an arch section (13), an upper section (15) and two pillar sections (17), wherein each pillar section (17) is arranged at the first end (7) and at the second end (11), wherein the arch section (13) and the upper section (15) are connected at the central region (9), wherein each of the pillar sections (17) connects an end of the arch section (13) with an end of the upper section (15) at the first end (7) and at the second end (11);
b) fabricating at the plant facility a plurality of transversal deck elements (5);
c) providing a plurality of pier units (27) at the bridge site;
d) installing the plurality of pier units (27) at the bridge site;
e) providing a plurality of π-shaped modular bridge structures (1) at the bridge site, each modular bridge structure (1) comprising two longitudinal elements (3) and a deck element (5);
f) arranging the plurality of modular bridge structures (1) onto the plurality of installed pier units (27); and
g) connecting the plurality of modular bridge structures (1) to form the bridge.

14. Method according to claim 13, **characterized in that** providing the plurality of π-shaped modular bridge structures (1) at the bridge site in step e) comprises either

e1) transporting the plurality of fabricated longitudinal elements (3) and the plurality of deck elements (5) from the plant facility to the bridge site and subsequently assembling each π-shaped modular bridge structures (1) from two longitudinal elements (3) and a deck element (5); or
e2) assembling each π-shaped modular bridge structure (1) from two longitudinal elements (3) and a deck element (5) at the plant facility and subsequently transporting the assembled π-shaped modular bridge structure (1) from the plant facility to the bridge site.

15. Method according to claim 13 or 14, **characterized in that** providing the plurality of pier units (27) at the bridge site in step c) comprises

c1) either fabricating at the plant facility the plurality of pier units (27) and subsequently transporting the plurality of pier units (27) from the plant facility to the bridge site;
c2) or fabricating the plurality of pier units (27) directly at the bridge site.

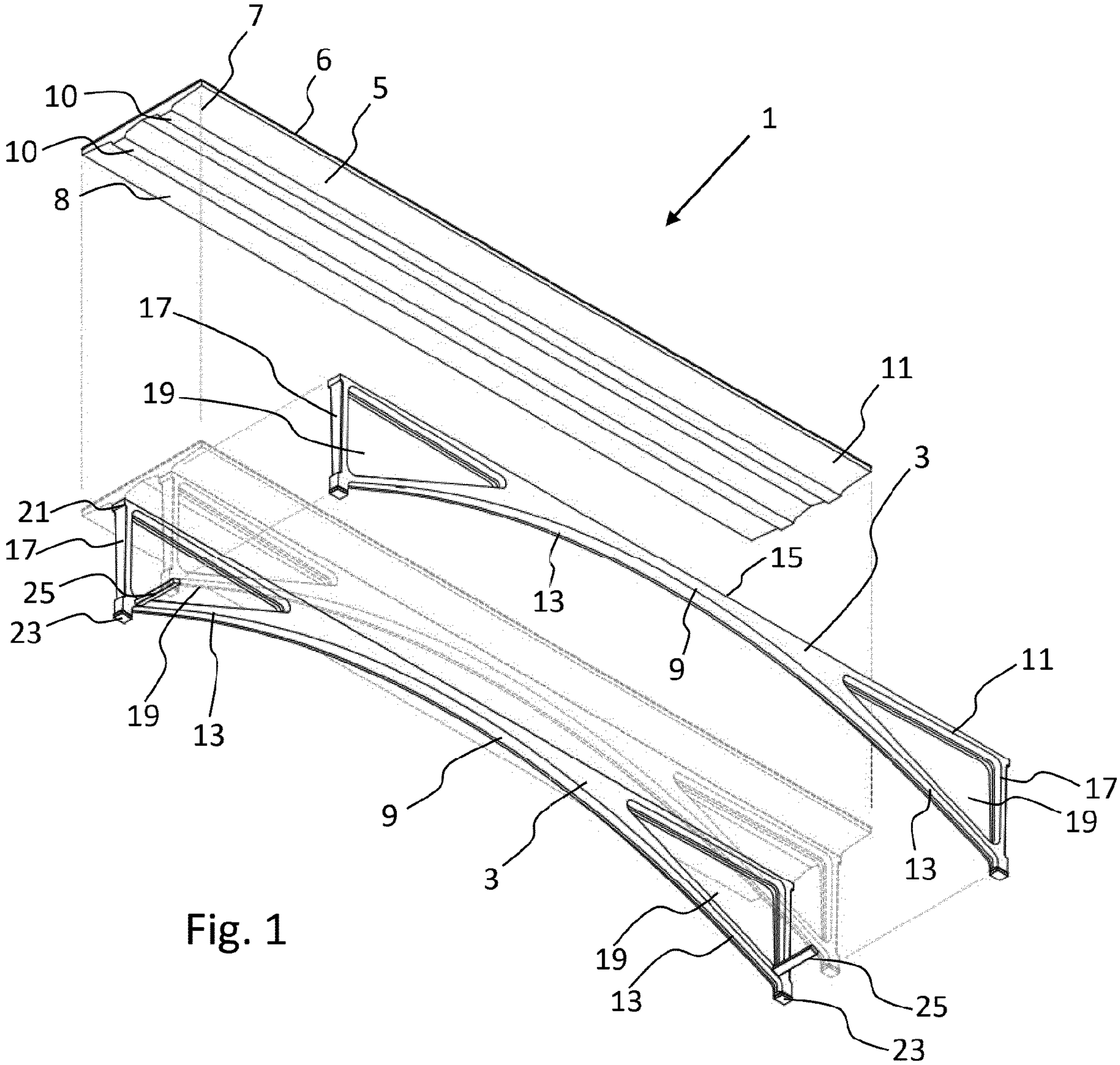
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Fig. 1

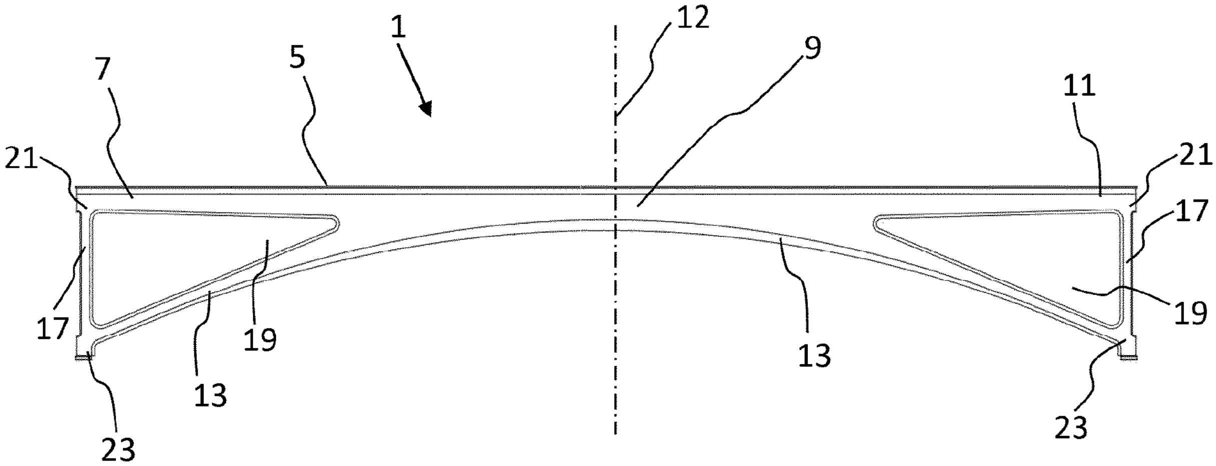
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Fig. 2

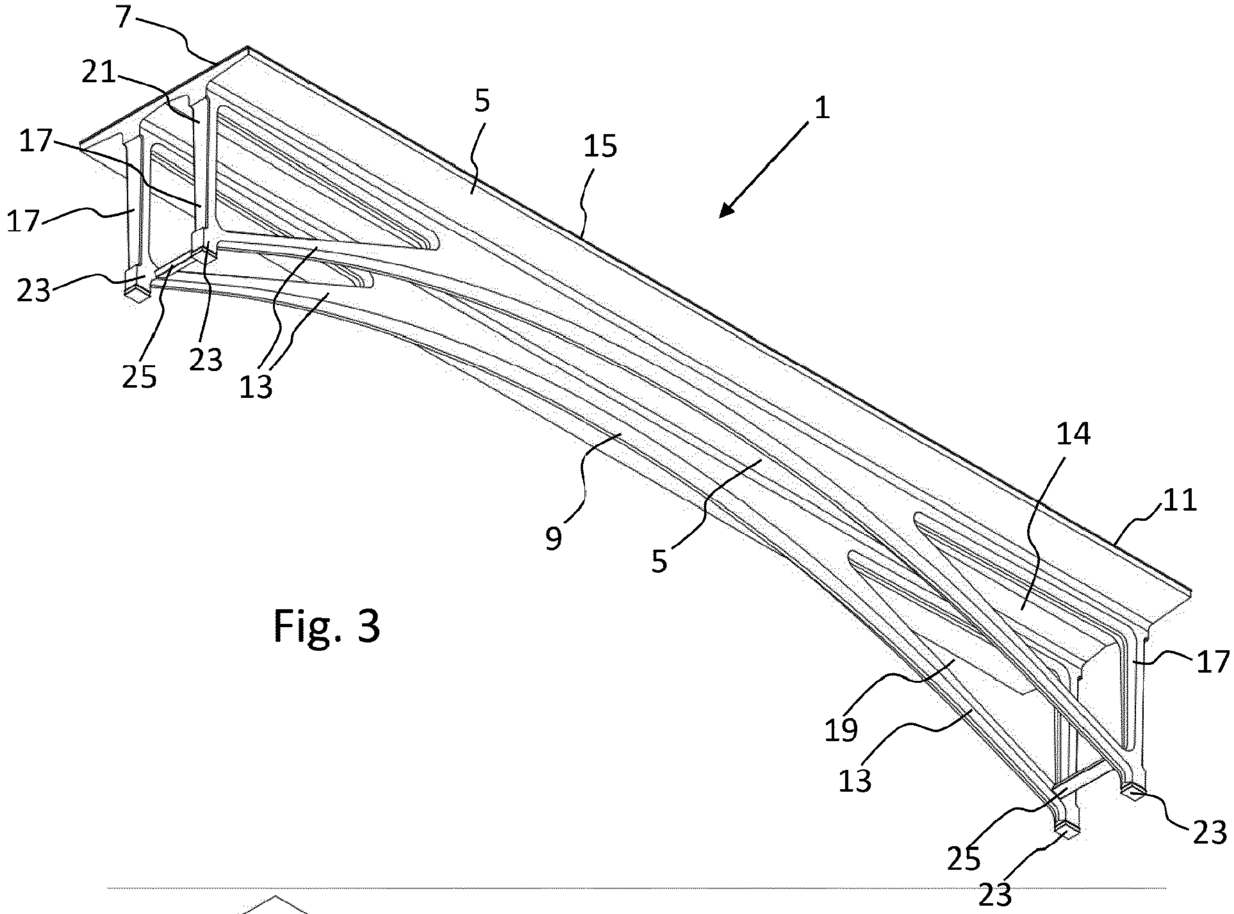
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Fig. 3

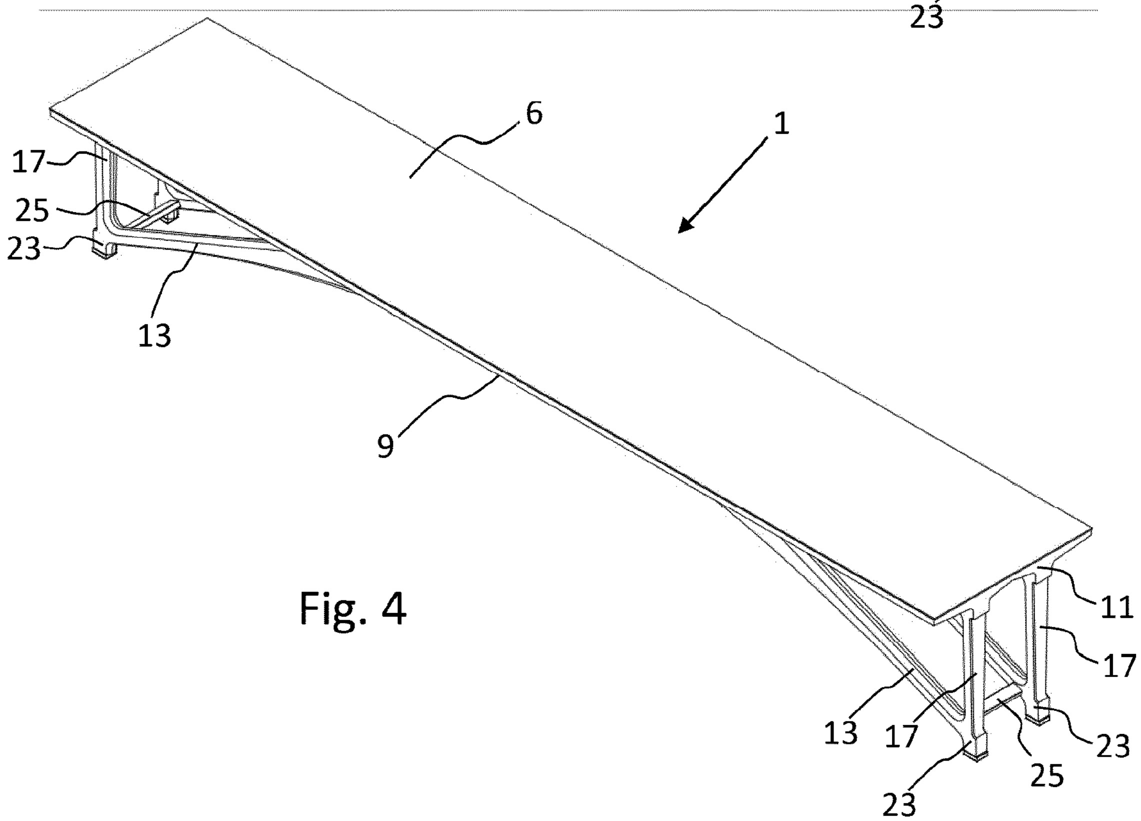
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Fig. 4

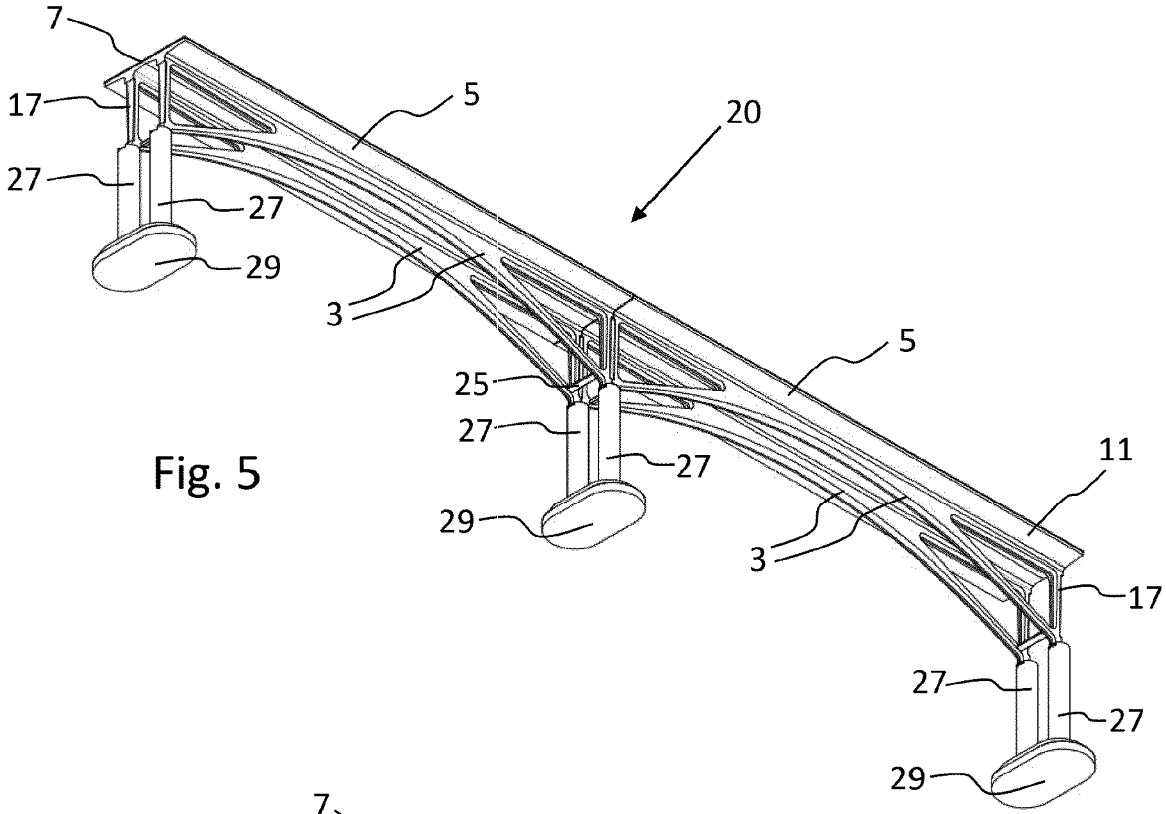
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Fig. 5

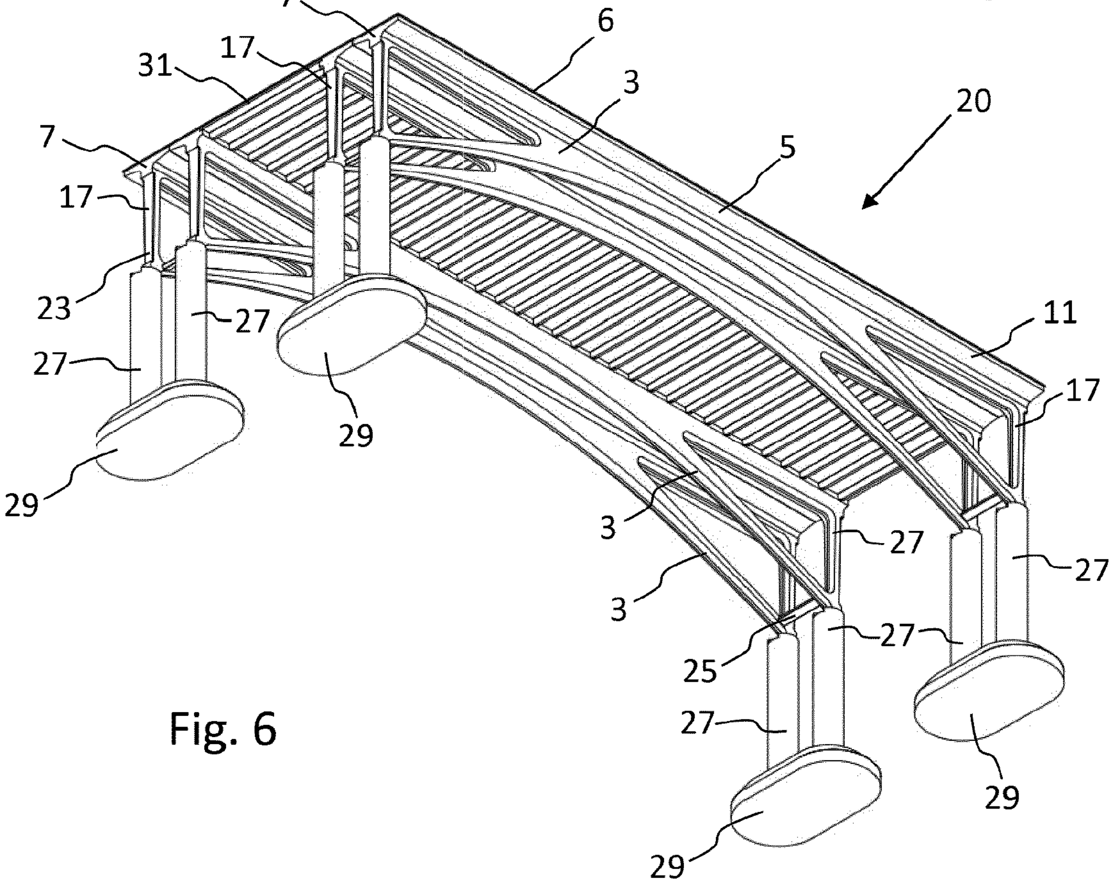
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Fig. 6

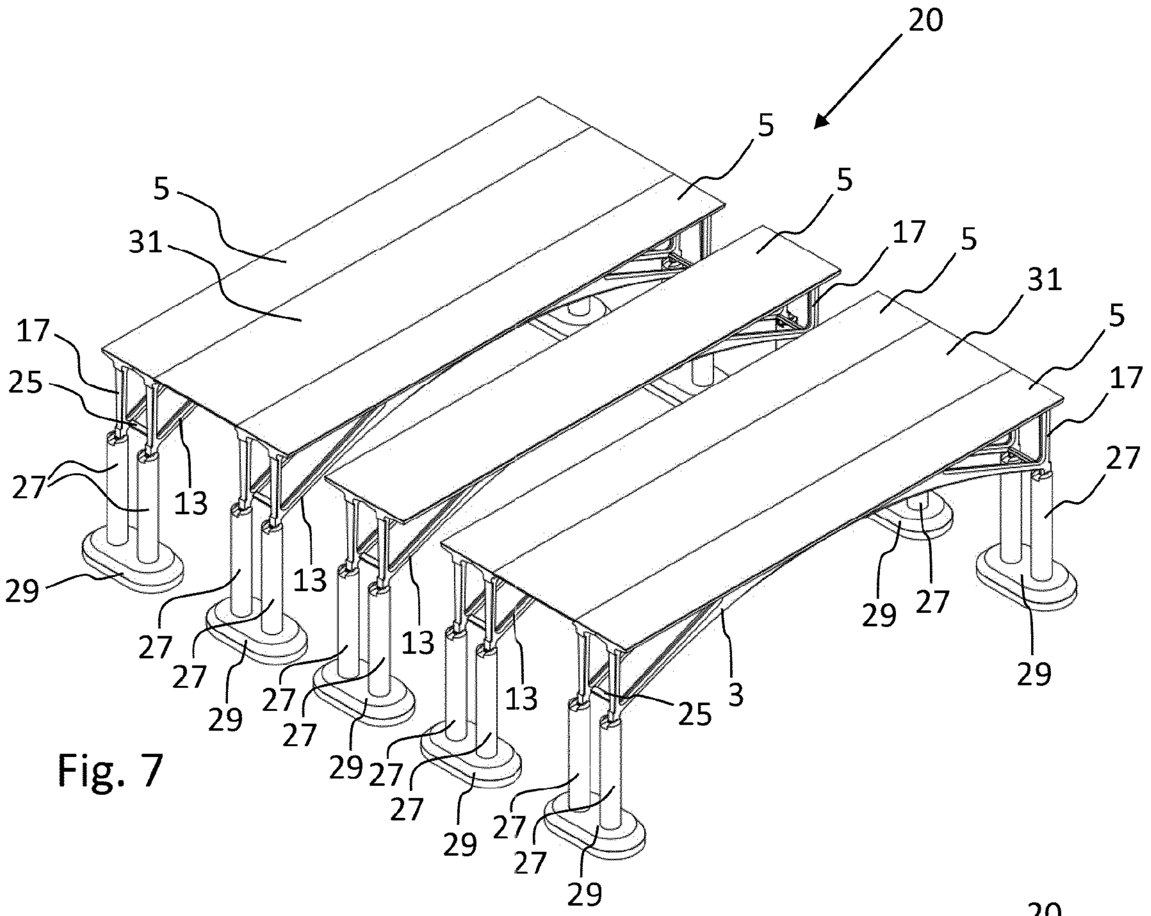
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Fig. 7

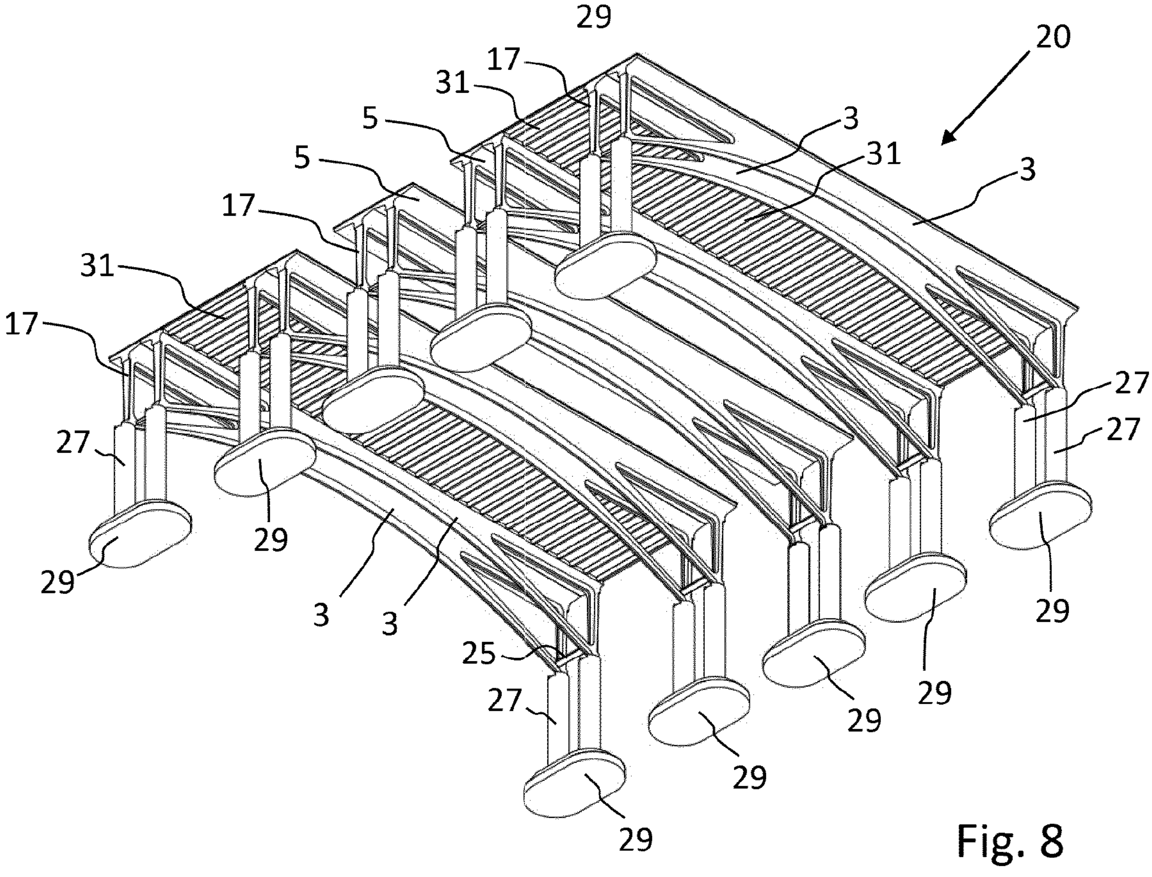
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Fig. 8

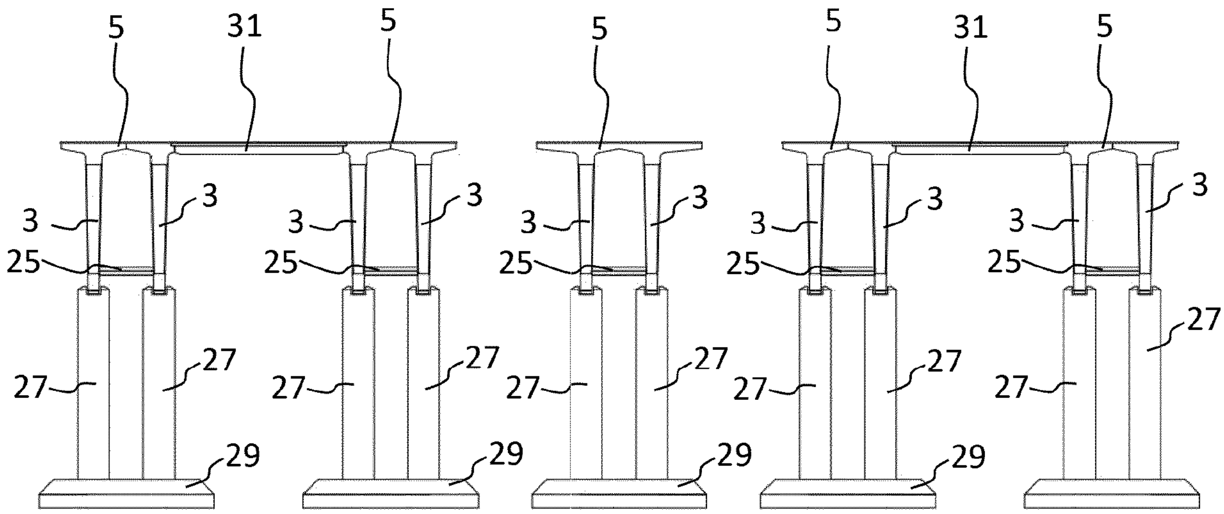
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Fig. 9

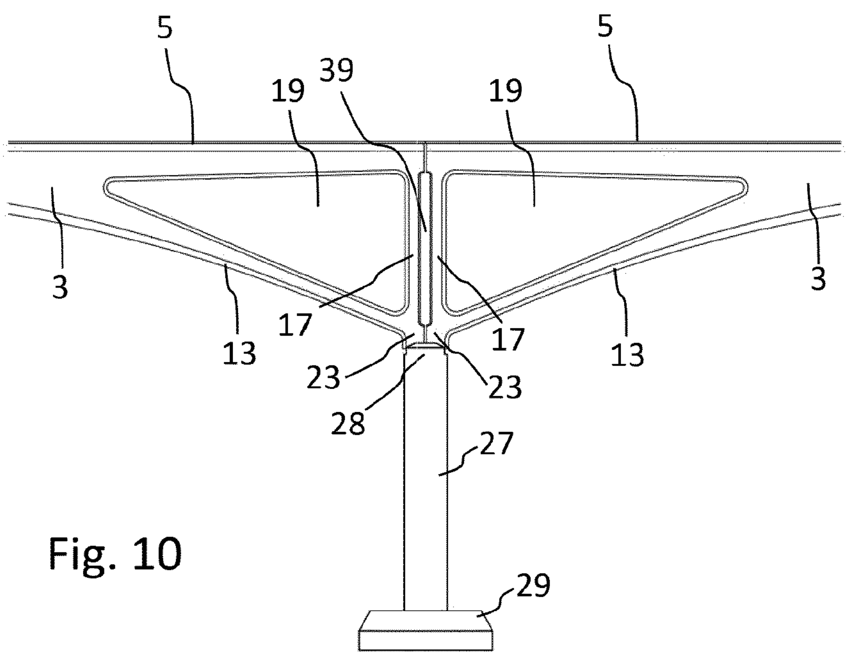
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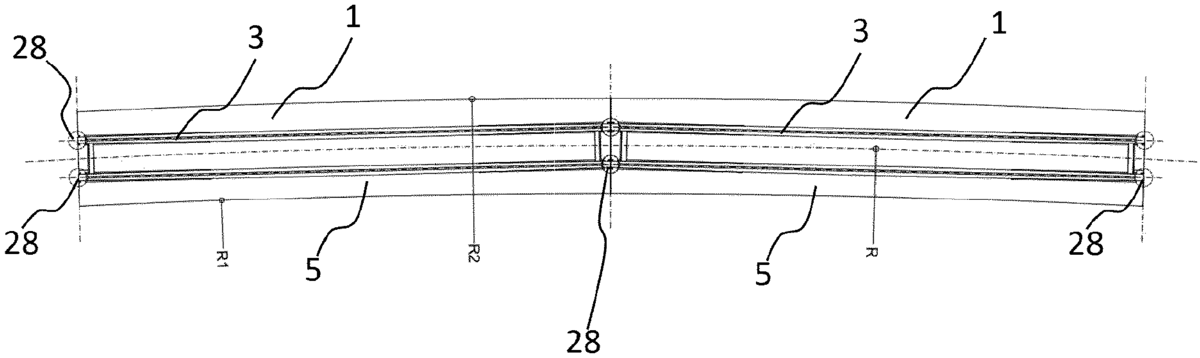
Fig. 10



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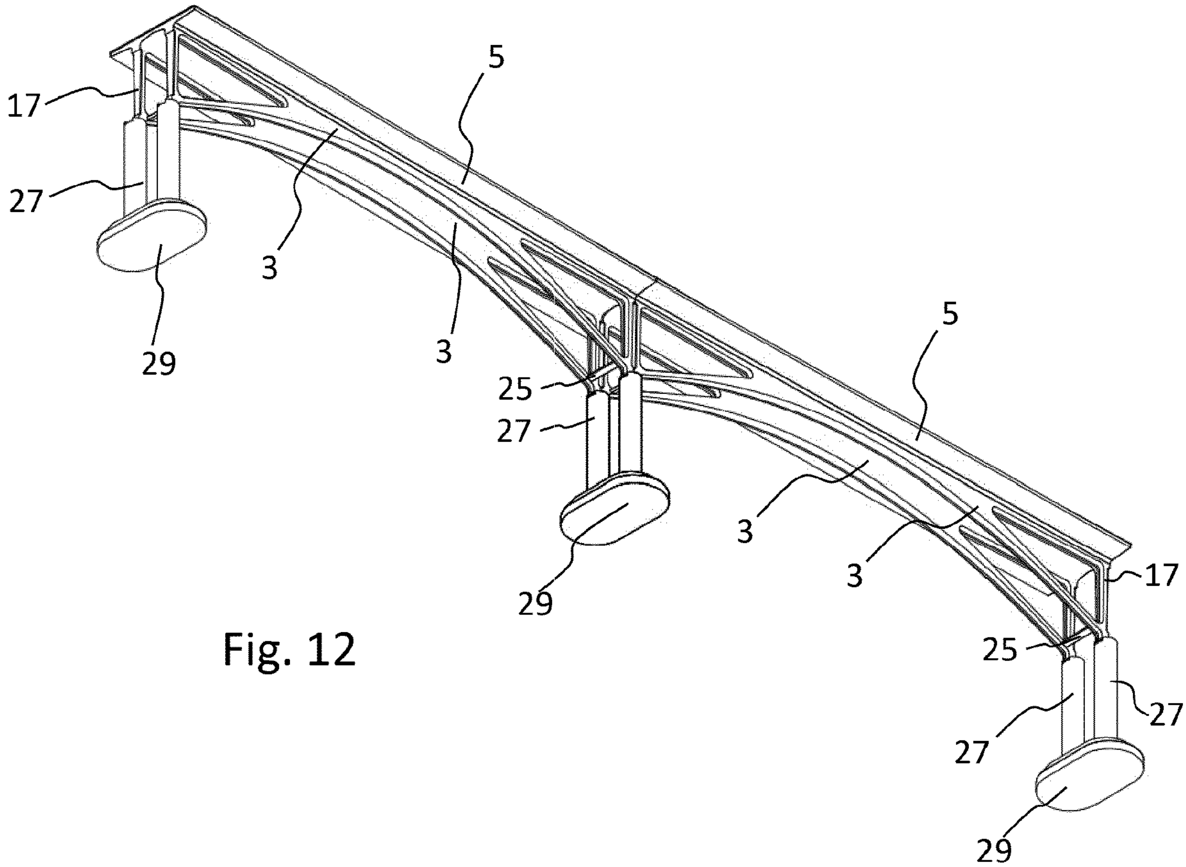

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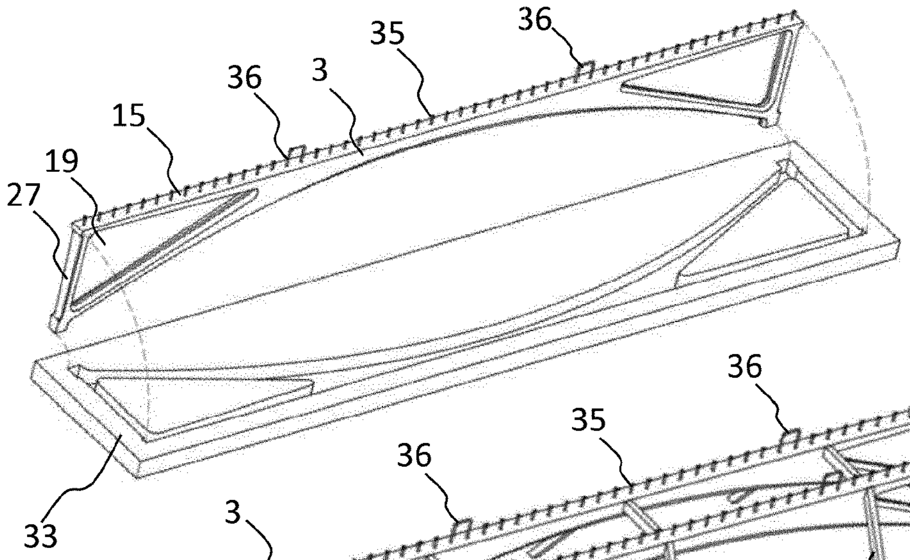


Fig. 13

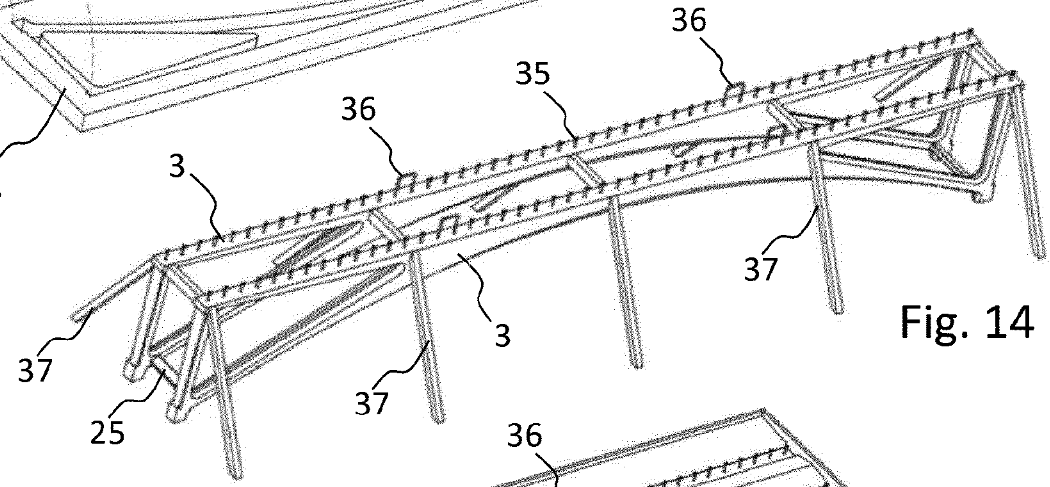
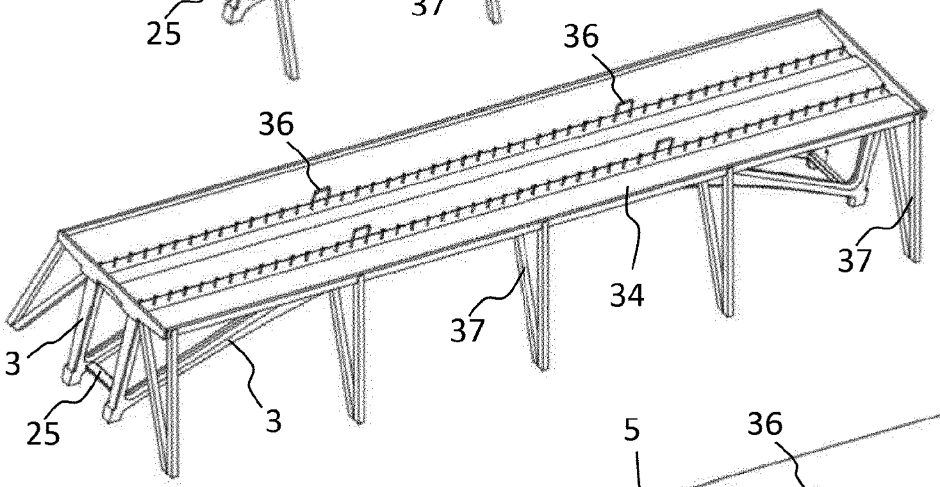


Fig. 14



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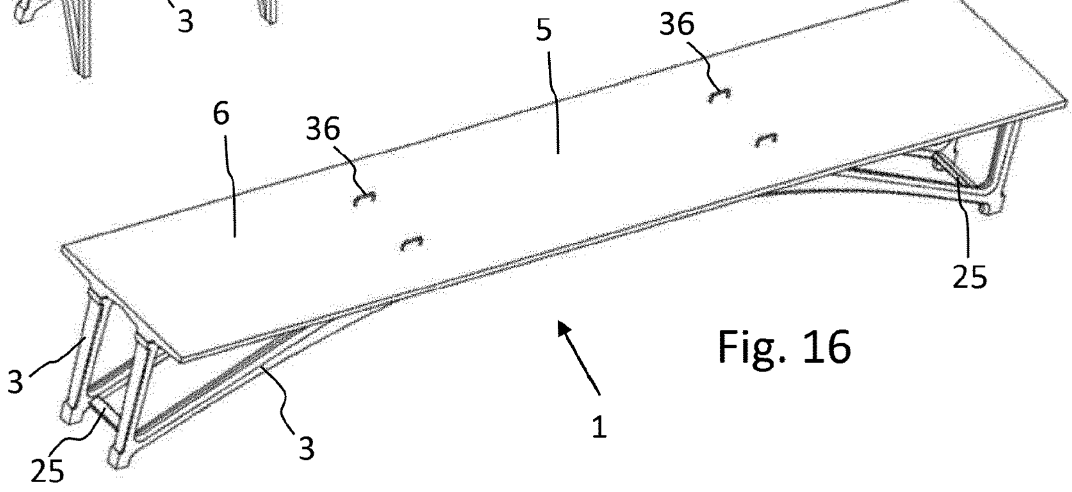

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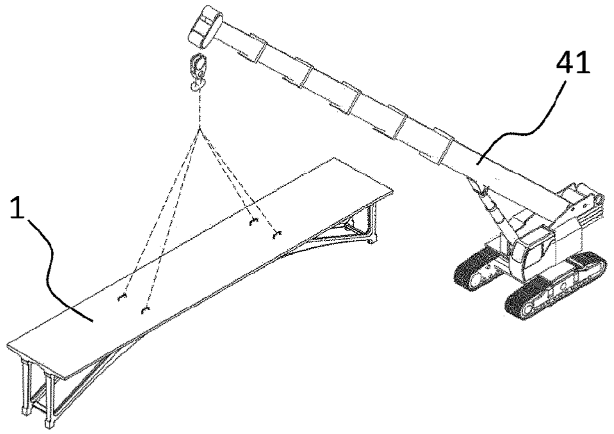


Fig. 17

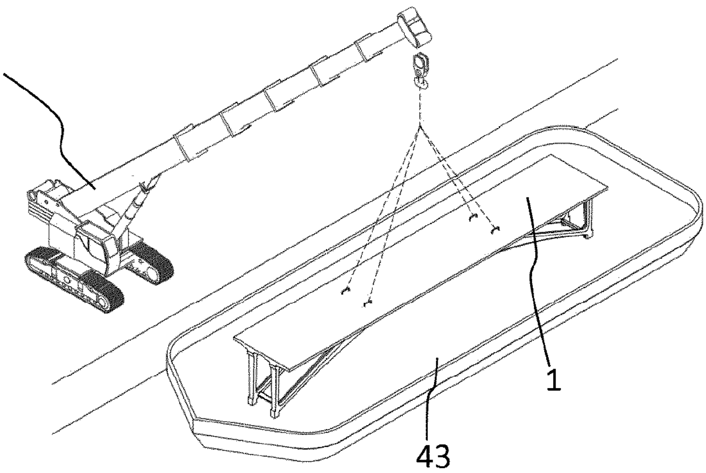
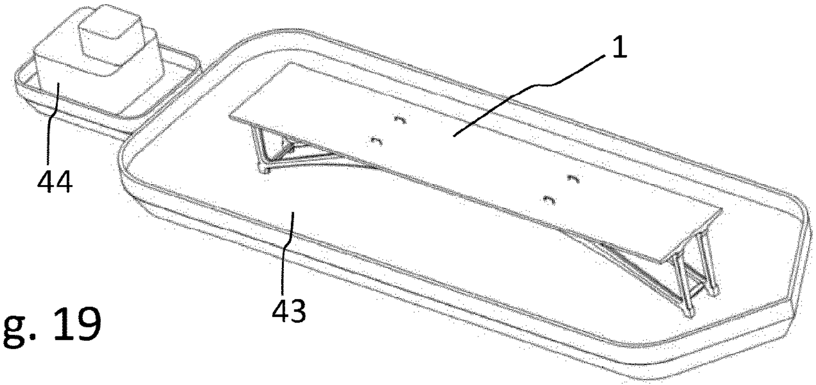


Fig. 18



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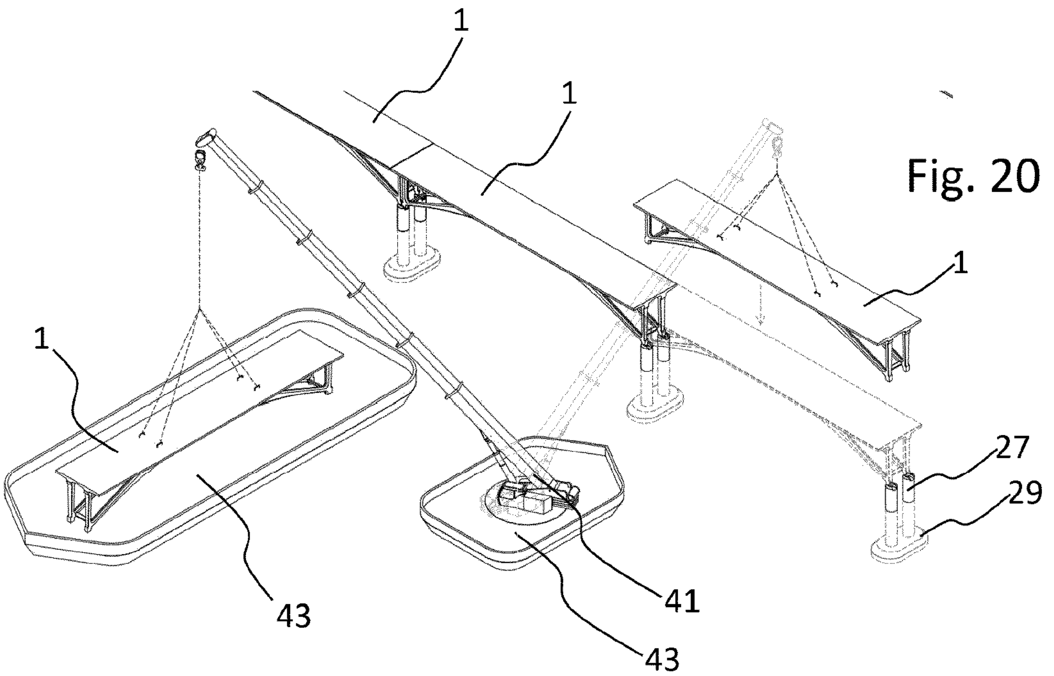

Fig. 20

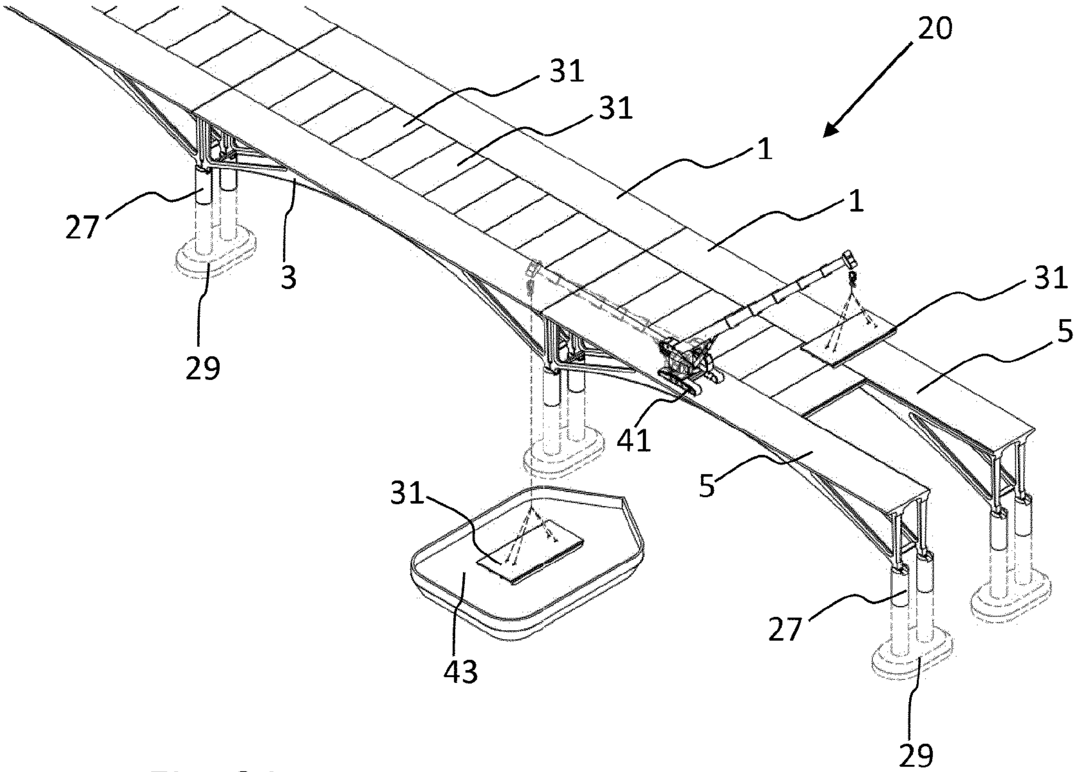

Fig. 21

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EUROPEAN SEARCH REPORT

Application Number
EP 23 15 2955

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	CN 114 438 869 A (UNIV HUNAN) 6 May 2022 (2022-05-06) * the whole document * -----	1,2,4-6, 8-15	INV. E01D4/00 E01D15/12
X	CN 109 024 225 B (UNIV HUNAN) 4 May 2021 (2021-05-04) * the whole document * -----	1-3,7	
X	CN 113 863 171 A (CCCC ROAD & BRIDGE SPECIAL ENG CO LTD) 31 December 2021 (2021-12-31) * the whole document * -----	1	
A	KR 2011 0062073 A (UNIV DONG A RES FOUNDATION [KR]) 10 June 2011 (2011-06-10) * the whole document * -----	1-13	

TECHNICAL FIELDS SEARCHED (IPC)

E01D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	26 June 2023	Beucher, Stefan

CATEGORY OF CITED DOCUMENTS

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26-06-2023

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KR 20110062073 A	10-06-2011	NONE	

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