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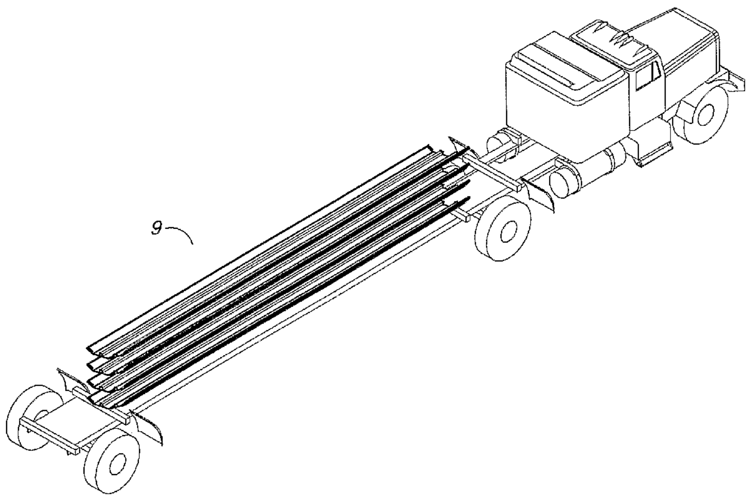
(54) Title: LATTICE-SKIN HYBRID TOWER



(57) Abstract: A tower having internal legs and an external skin providing a hybrid of lattice type towers and tubular type towers. The internal legs and the external skin share tower loading in a manner that optimizes the structural design of the tower, thereby providing benefits of both lattice and tubular type towers. A unique pin connection between tower sections is used to transmit loads smoothly and aid in section alignment. Tower sections are constructed from radial segments which may be nested for shipping such that transportation logistical barriers can be overcome for very large or tall wind turbine towers. The tower sections are then assembled on site using a specialized section assembly system which holds segments from both ends while consecutive segments are added to form a complete cylindrical or tapered section. The section assembly system includes a pair of frames that support the tower segments and align them properly during assembly. The section assembly system may be used to assembly a tower section in either a horizontal or a vertical orientation.

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Lattice-Skin Hybrid Tower

Field of the Invention

Embodiments of the invention relate to metal towers. Specifically to towers of the kind used for deployment of large wind turbines.

Background of the Invention

The global wind power industry continues to grow rapidly. In 2004, the sizes of wind turbines are averaging 80 meters in rotor diameter with tower heights reaching 80 meters. Larger rotors and taller towers have already been demonstrated and will soon be in the market. Tubular towers are now used almost exclusively in all designs by all manufacturers. Numerous problems in manufacturing and transportation of tubular towers have been encountered, and will be compounded with the anticipated larger units.

Typical tubular tower construction consists of rolled plate steel formed in rings, with those rings welded at their seams until a full tower section is achieved. Typical plate thickness of these tower skins exceeds 25 mm for tower bases sections. Thick cross-section flanges are welded at each end of the tower sections to accommodate joining of the sections together with fasteners. Typical cross-section thickness of flanges now exceeds 50 mm.

Tower section lengths (heights) vary according to manufacturer preferences, but currently range in 20 meter to 30 meter lengths. Manufacturers strive to minimize the number of required sections to minimize the number of flanged connections. The limiting factors are typically maximum shipping weights and lengths.

An example of a commercially available wind turbine tower is shown in US Patent Number 6,532,700, incorporated herein by reference. This tower utilizes nontapered ring sections with a single tapered section in the center of the tower. Other commercially available wind turbine towers utilize ring sections that are all slightly tapered.

Towers have grown in size such that tower diameters are now limited by shipping requirements. The largest diameter tubular tower known to be in use in the United States is 4.2 meters. It is possible that tower diameters up to approximately 4.4 meters in diameter could be used with specialized transportation equipment and with appropriate permits. Tower diameter is limited due to overhead clearances required for transportation. It is likely that the tower diameter limitation will vary depending on the specific country, state, and locality due to different road regulations and different heights for bridges and utility lines.

Tubular towers are preferred in large wind turbine applications due to their predictable structural, fatigue, and dynamic characteristics. The towers must withstand the mass of the wind generator, extreme wind loading, and dynamic interaction of the wind turbine. Fatigue life requirements typically must exceed 25 years.

Few structural problems have been encountered in the use of tubular towers. However, as the size of wind turbines increases, numerous problems have emerged in their manufacture and transportation. Thick plate steel for the tower skins is increasingly more specialized due to the volume required. Specialized steel rolling equipment is needed to form the skins. The heavy weight of completed sections requires manufacturers to have specialized overhead crane and in-factory handling equipment. Specialized painting chambers of the sizes necessary are rare. There are currently fewer than ten tower suppliers that have been used in the supply of any significant quantity of wind turbine towers in the United States. This has led to supply bottlenecks during periods of aggressive market activity and forces upward pressure on costs to wind turbine suppliers. The lack of capable tower suppliers has resulted in importation from Asia and Europe on several occasions.

Tower flanges have also been a source of difficulty in the supply of tubular towers. Flanges are typically flame cut from a single slab of plate steel resulting in significant waste. Welding of the flanges to the skins commonly results in warping of the flange, and post-welding machining of the flanges is required to assure proper flatness for mating to other section flanges. The availability of these thick plate slabs has resulted in their being manufactured in Asia and transported for assembly and machining in the United States.

Transportation of completed tower sections has also become a source of difficulty in the use of tubular towers. Tower designers seek to keep section diameters larger to better manage bending loads and foundation structural requirements. However, tower diameters are limited by overhead clearances on highways. As wind power markets move east of the Mississippi River, these overhead clearances begin to decrease due to standards used in the intestate and local highway system. Non-direct routing of towers manufactured in the West and Midwest has resulted in significant increases in transportation costs. The availability of specialized low-boy style of trailers needed for the extreme weights and lengths are quite limited during periods of peak market activity.

It would be advantageous to provide a tower solution which could attain larger diameters than current tubular towers and yet be easily shippable. It would provide further benefit if this solution were easily manufactured with more commonly available tools and materials than needed for prior art tubular towers, thus costing less while providing similar structural reliability to tubular towers.

One type of tower which, for smaller wind turbines, has been used is the lattice tower. Lattice tower construction consists of three or four primary load bearing "leg" structures made of either small diameter steel tubing, or angle cross-sections. These leg structures are connected by horizontal and diagonal angle cross-members forming the open-sides of the tower sections resulting in either triangular or square towers. Tower sections are fastened with leg flanges (feet) welded to the ends of tubular legs. Angle iron leg sections are connected by fastening overlapped portions of the angle legs.

Lattice towers were frequently used during the 1980s on wind turbines ranging in size from 12 meters to 17 meters in rotor diameter. Tower heights ranged from 20 meters to 40 meters. Several attempts have been made to continue use of lattice towers on machines with 50 meter diameter rotors on towers 40 to 65 meters in height. The last known major deployment of these larger lattice towers was in the late 1990s.

The key benefit in using lattice towers has been their cost due to a significantly lower useage of material. Lattice towers also lend themselves to lower costs and greater supply options due to the standard shapes and thicknesses of steel that are typically used. Transportation is greatly simplified due to flat-stacking or nesting of materials. The lack of transportation constraints also allows the design of towers with a larger base area which reduces the concentration of tower overturning forces and promotes lower cost foundations. A larger base foot print relative to the transportation constricted base diameter of tubular towers results in a further reduction in material and weight requirements due to significantly lowered overturning loads being distributed over a larger base area.

The structural interaction between wind turbines and lattice towers has had a checkered history. Even the smaller 13 – 20 meter diameter machines had been reported to fail tower leg sections or tower top interfaces (to wind turbines). Earlier and therefore smaller wind turbines utilized free or passive yaw orientation systems. As the wind turbines grew larger, active yaw systems became common. Active yaw systems can transmit very high torsional forces from the point of machine-to-tower interface into the upper portions of the towers. Lattice towers under torsional bending provide stress concentrations at the diagonal or horizontal cross-member connection points.

It would be beneficial to provide a tower with the benefits of a lattice tower while avoiding the structural problems associated with stress concentrations at points of connection of diagonal or horizontal cross-members.

Several modified towers are known to have been designed in the past to attempt to overcome the limitations of conventional tubular and lattice towers. The first attempt was a tubular tower that was used on a Micon 250 kW wind turbine at a wind farm owned by Cannon Power Corporation in Tehachapi, California in the late 1980s. The Micon wind turbine utilized tower sections that were divided into smaller sized radial segments that were bolted together in the field. The tower segments were formed of press broken sheet steel. It is believed that Micon used similar towers on wind turbines up to 750 kW in size in India in the 1990s. The Micon towers were on relatively small turbines (by 2005 standards) and were not intended to overcome overland transportation logistic limitations being experienced with today’s larger machines. Rather, it is believed that the Micon towers were fabricated in segments in order to allow the towers to be galvanized and to utilize bolted connections in place of weldments for the purpose of improving fatigue resistance. Micon also sought to ease transatlantic shipping, as their towers were manufactured in Denmark. The Micon towers did not have any lattice or leg elements to carry part or all of the tower loads and all of the loads were carried by the press broken tower skins.

The next modified tower was built in the mid 1990s by Kenetech Windpower. It utilized a set of lattice legs for a lower portion of the tower and the lattice legs transitioned into a conventional tubular tower for the upper portion of the tower. The Kenetech tower was known in the wind energy industry as the so-called Kenetower. It was intended to reduce potential perching locations for birds while allowing a spread out foundation suitable for a lattice tower. The intent of the design was to minimize tower and foundation costs while meeting certain objectives for reducing bird mortality. The lattice portion of the tower and the tubular portion of the tower did not share loads. The lattice portion of the tower bore all of the loads in the lower portion of the tower and the tubular portion of the tower bore all of the loads in the upper portion of the tower.

Another modified tower was developed by a Dutch company called Mecal. Mecal designed a hybrid tower that includes a concrete base and a tubular steel tower set atop the base. The base section is pre-cast and is divided into several radial segments. This overcomes some of the transportation logistics associated with conventional tubular towers and allows the use of taller towers. The concrete tower base also exhibits favorable structural dynamic behavior. However, the Mecal tower does not utilize any aspects of a lattice tower and the concrete and tubular steel tower sections bear the entire load that is applied to the tower. The tubular steel portion of the Mecal tower is subject to all of the typical manufacturing and quality control issues associated with conventional tubular towers, such as ensuring that the tower section flanges are flat, ensuring that weld strength is sufficient, and ensuring that bolt torque and bolt strength for connections between tower sections is sufficient.

Recently, Valmont Industries introduced a sectioned tubular tower where each section is constructed from a number of radial tower segments. The tower was described in the September 2004 issue of North American Windpower magazine. Relatively few details of the Valmont tower are known and so it is not clear what elements are included in this tower or how it works. The tower appears to be made of a number of press broken radial segments that are fastened together in the field, much like the Micon tower mentioned above that was installed at the Cannon Power Corporation wind farm in Tehachapi, California in the early to mid 1990s. The motivations for Valmont's tower include overcoming transportation logistic challenges of conventional tubular tower and allowing the tower segments to be galvanized. Applicant does not admit that the Valmont tower constitutes prior art for the present invention. The Valmont tower does not appear to utilize any aspects of a lattice tower and all of the tower loads are fully borne by the press broken skin segments. The North American Windpower article states that the tower segments are "bolted together onsite using a forklift or a small all-terrain crane." Therefore, the Valmont tower concept does not appear to include any system, method, or apparatus for assisting with on-site assembly of the tower segments. From the limited material available, the Valmont tower also appears to use conventional flanges for making the section connections.

Summary of the Invention

The following outlines an alternative tower design referred to herein as a Lattice-Skin Hybrid tower that exhibits similar structural and dynamic characteristics as tubular towers, and that is less costly, easier to transport, employs easier to procure materials, and that avails itself to greater supplier options.

As the name suggests, the Lattice-Skin Hybrid tower utilizes a combination of features of tubular and lattice towers. It consists of primary load bearing legs similar to a lattice tower, but has steel skins welded or otherwise bonded to the primary legs to form a complete shell. The combination allows the use of lighter weight skins that distribute torsional loads more evenly than do lattice cross-members. A novel element of the Lattice-Skin Hybrid is that a significant portion of bending loads is borne by the leg portions of the structure.

The specific features of this design include segments that may have faceted or press-broken skins attached to the primary leg structures. Each of these segments has a press-broken flange along its longitudinal sides. Each of these longitudinal flanges has holes drilled or other features which will accommodate interior tower fastening to adjacent or mating segments. An alternative to the press-broken flange would be to attach an angle iron to each tower segment so that adjacent segments can be fastened together. Tower base diameter will determine the number of segments per section, and a minimum of four are envisioned although fewer than four are possible, especially for smaller turbines. Non-faceted rolled section segments could also be used with this concept, however, non-faceted skins are more susceptible to buckling loads and either thicker skin sections or more primary legs would be required. One of ordinary skill in the art would be capable of designing details of the tower such as the number of tower segments, the number of primary load-bearing legs, the thickness of the tower segment skins, the thickness of legs, and the method of forming the tower segments in terms of whether they are faceted or non-faceted. Factors that control the design include the size and weight of the wind turbine, the desired hub height (hub height is the height above ground of the center of the wind turbine's rotor), overturning moment loads, torsional loads, and structural dynamics. Fatigue and buckling are both important possible failure modes, and both should be considered when designing a Lattice-Skin Hybrid tower. Optionally, it is conceived that the majority of bending loads in the tower are borne by the load bearing legs and that the majority of torsional loads are borne by the tower skins. However, there may be situations in which it is desirable, for instance, to have the skins bear more of the tower bending loads than the legs bear. One of ordinary skill in the art would be able to determine the optimum load sharing between the legs and the skins.

A unique feature of the Lattice-Skin Hybrid design is the method of connecting the tower sections together. A tapered pin is welded or otherwise fastened to the top side of each of the section legs. The underside of each section leg has a mating taper-pin receiver similarly fastened to each leg. As the upper section is lowered onto the already installed lower section during tower assembly, these pins serve to provide alignment to accommodate swift assembly. Final securing of the sections together is accomplished with a transverse tapered pin that slips through both the underside pin receiver, and upper side pin. Because the pins are directly in-line with the primary load bearing leg structures, there is a near perfect transfer of tension and compression loads directly at the joint. By contrast, flange type tower section connections require massive flange thicknesses to accommodate the load path diversion from the skins to the interior of the flange, and back out to the skins. The elimination of the flanges provides for significant cost reduction in both materials and manufacturing processes. Elimination of flange connections also relieves many of the quality control concerns that exist during assembly of conventional tubular towers. Attachment of two flange sections requires a connection that includes numerous high strength bolts. These bolts must be pre-tensioned to a level that is near their yield strength for the bolts to achieve sufficient fatigue resistance. Pre-tensioning to this level requires sophisticated tensioning systems that must be calibrated, monitored, and verified to ensure a high quality tower connection. In contrast, the tapered pin design for tower connection that is contemplated for use with the present invention allows for the use of a single transverse bolt on each pin wherein the transverse bolt does not need to be particularly high strength nor does it need to be pre-tensioned to a precise tolerance. Optionally, the Lattice-Skin Hybrid tower sections can be fastened together by using overlapping pieces of steel that are bolted together, analogously to the manner in which conventional lattice tower sections are fastened together. For the lattice tower type method for connecting tower sections, the internal legs would need to be fabricated in such a way that they have pieces of steel that may overlap with corresponding leg pieces from the adjacent tower section. For instance, the load bearing legs could be fabricated out of angle iron in such a way that pieces of angle iron from adjacent tower sections overlap each other and may be bolted together.

There are several significant cost trade-offs to be considered when comparing the Lattice-Skin Hybrid with tubular towers. While manufacturing and transportation costs of the Lattice-Skin Hybrid are reduced, each tower section must now be assembled in the field in contrast to tubular tower sections which are completely assembled and transported as one unit. An efficient method of field assembly is preferred to fully realize the value of the Lattice-Skin Hybrid concept. Also, not all Lattice-Skin Hybrid tower sections necessarily need to be field assembled. Top sections of wind turbine towers are typically small enough in diameter and light enough in weight to not require specialized transportation and may be assembled at the factory if this proves to be most cost effective.

A Lattice-Skin Hybrid Section Assembly System is contemplated to accommodate accurate and fast field assembly of the segments into complete tower sections. The system consists of two similar fixtures that support the Lattice-Skin Hybrid section segments on both ends to facilitate assembly. Each fixture consists of a main horizontal axle mounted to a riser-pedestal that allows adequate elevation for the completed section to clear the ground, i.e. elevation greater than the largest radius of the tower section. Attached to the axles are struts that connect to a double H frame, or a mating hub and spoke type structure that aligns with the pins and serves to hold the tower shape during post-assembly transport and lifting operations. Thus, the struts serve as universal hubs to connect to the various sizes of double H frames/lifting structures. The double H frames can either be fixed, dedicated devices or adjustable telescoping devices. The double H frames could also be integrated into the permanent tower structure, or alternatively serve as structures that would support ancillary systems such as climbing and rest platforms.

The Section Assembly System axles would allow rotation of hubs in either direction. A method of securing the axles against movement is required due to off-center loading during assembly of a tower section. The rotation can be provided by an on-site lifting crane, or by indexing hydraulic or mechanical drives located at the axles. Only one drive system may be necessary for one of the axles.

Two methods in which to apply the Section Assembly System are described. One is to truck-bed mount the Section Assembly System. Precision alignment of the two units would be accomplished with an adjustable (likely hydraulic) traverse mechanism that accommodates movement in the X (horizontal and transverse to the tower section centerline), Y (vertical and transverse to tower section centerline), and Z (along or in-line with section centerline) axes. Similar devices are used in the assembly of very large cranes and are commonly referred to as Boom Launching Trailers. The other method would be to mount a rail system on the ground to provide a fixed X axis and an adjustable (via rail) Z axis. The Y axis adjustment would be provided with hydraulic or manual screw drive extension/retraction.

The assembly of the section segments may use an on-site crane to lift the double H frame fixtures to the hub. The crane would then lift the first tower segment onto the Section Assembly System, and crews would secure it to the ring. The Section Assembly System would then rotate about the tower section centerline axis and be locked into position to receive the next segment. At this point the segments would be secured to each other via fasteners through the holes along the longitudinal flanges. This process is repeated for the remaining segments until a complete tower section is formed. Upon completion of a tower section, it would be lifted from the Section Assembly System by the on-site crane. The Section Assembly System would then be ready for assembly of the next tower section.

An alternative Section Assembly System is contemplated in which the tower segments are oriented vertically during assembly and the final assembled tower section is vertical when completed. This system requires less space at the turbine installation location. A vertically oriented Section Assembly System also allows the use of only a single crane to assemble tower segments into tower sections and then, using the same crane, the tower sections can be installed until a complete wind turbine tower is complete.

Additional features and advantages according to the invention in its various embodiments will be apparent from the remainder of this disclosure.

Brief Description of the Drawings

Features and advantages according to embodiments of the invention will be apparent from the following Detailed Description taken in conjunction with the accompanying drawings, in which:

FIG 1 shows three different tower types standing side by side, a tubular tower, a lattice tower, and a Lattice-Skin Hybrid tower according to an embodiment of the present invention.

FIG 2 shows Lattice-Skin Hybrid tower sections loaded on a trailer according to an embodiment of the present invention.

FIG 3 shows the structure of a single Lattice-Skin Hybrid tower section according to an embodiment of the present invention.

FIG 4 shows a tapered pin connection according to an embodiment of the present invention.

FIG 5a through 5i show the operation of a Section Assembly System according to an embodiment of the present invention in which the tower section is assembled in a horizontal orientation.

FIG 6 shows one Section Assembly System spindle carriage according to an embodiment of the present invention.

FIG 7 shows an arm assembly according to an embodiment of the present invention.

FIG 8 shows another embodiment of the Section Assembly System of the present invention in which a tower section is assembled in a vertical orientation.

Detailed Description of the Drawings

Figure 1 shows three different towers: a tubular tower 1, a lattice tower 2, and a Skin-Lattice Hybrid tower 3. The tubular tower 1 is constructed of multiple, optionally tapered, tubular segments 5 fastened vertically atop one another via bolts through a massive interior flange. The tubular tower's 1 base diameter D_1 is limited by transportation height limits such that approximately 4.4 meters is currently the maximum diameter practical. The precise limitation on tower diameter is determined by local transportation restrictions. Allowable load heights may vary in different states or localities, and likely varies in different countries. The lattice tower 2 is constructed of many smaller elements 6, such as steel angles or tubes, bolted together. Since the elements 6 of the lattice tower 2 can be optionally stacked flat and assembled on site, the base width D_2 is not limited by transportation height. The lattice tower is not only easier to transport but uses less material and therefore costs less than the tubular tower 1. There exists significant stress concentration however at the points of connection of the elements, especially under torsional forces, such that lattice towers 2 have been found unreliable for large wind turbines. Furthermore the smooth solid appearance of tubular towers 1 is considered more aesthetically pleasing than that of lattice towers 2. Also, there is evidence that avian mortality is lower for wind turbines mounted on tubular towers than for turbines mounted on lattice towers.

A Lattice-Skin Hybrid tower 3 uses elements from both tubular towers 1 and lattice towers 2. The Lattice-Skin Hybrid tower 3 consists of internal legs 10 (visible in Figure 3 but not visible in Figure 1) covered by an external skin 12. The legs 10 are constructed of a series of leg members 11 connected one on top of another. The skin is constructed of a patchwork of skin sheets 13 connected to each other via flanges and fasteners. Lattice-Skin Hybrid towers 3 are built by stacking multiple cylindrical or tapered sections 7 similar to tubular tower 1 construction. A big difference in Lattice-Skin Hybrid towers is that each section 7 is composed of several vertical segments 9. The vertical segments 9 can be stacked flat during shipping, as shown in Figure 2, and then assembled on site. Four such segments 9 are shown per section 7 within this disclosure but more or fewer segments 9 per section 7 may be used. Maximum width of the segments 9 for transportation combined with the desired tower base diameter D_3 is the major deciding factor in choosing the number of segments 9 into which the sections 7 will be divided. Other factors may also determine the number of segments 9 in each tower section 7, such as the size capability of equipment being used to form, paint, or galvanize each segment 9. In the case of a tapering Lattice-Skin Hybrid tower 3 it is further conceived that lower sections 7 of the tower may be divided into more segments 9 than higher sections 7. Indeed the top most sections 7 may be either pre assembled, or formed as a single piece at the point of manufacturing since the decreased size and weight of such sections 7 may lend themselves to conventional transport.

It is possible that the Lattice-Skin Hybrid tower could be constructed with diagonal cross members attached to the tower's legs 10, but inside of the skin 13. In this way, some or all of the tower's torsional loads could be borne by the diagonal cross members in the way that they are on a conventional lattice tower. However, the skin 13 would provide cladding to prevent birds from perching on the cross members. In the case where the Lattice-Skin Hybrid includes diagonal cross members, the skin 13 also serves to provide protection from the weather for service personnel climbing the tower and to provide a more uniform and pleasing visual appearance to the tower. Also, some torsional loads, as well as some bending loads, could still be borne by the tower skin, thereby relieving stress concentrations and fatigue issues associated with convention lattice towers.

Figure 3 shows the basic structure of the Lattice-Skin Hybrid tower segments 9 according to an embodiment of the present invention. There are two main structural components of each segment, leg members 11 and a skin sheet 13. The skin sheet 13 is optionally press broken sheet steel. A continuous curved shape and other alternative shapes for the skin 13 can be used and are considered to be within the scope of this disclosure. The form shown provides desirable structural attributes and will be shown throughout this disclosure. The leg members 11 are optionally formed of structural steel. The leg members 11 shown in the Figures are of square tube cross section but any cross section deemed suitable by one skilled in the art could be used, including, I beams, C or U channels, triangular or circular channels, etc. The leg members 11 may be attached in the middle of a ‘face’ of a press broken skin sheet 13, as shown in Figure 3, for a strong structure or may optionally be placed in another location. Each leg member 11 may be welded onto the skin 13 of a tower segment 9, or the leg members 11 may be bolted onto the skin 13 or attached by any other suitable method. If it is desired to bolt the leg members 11 onto the skins 13, then it may be desirable to weld ears, such as lengths of angle iron, onto the skins 13 that can be pre-drilled with holes for bolting the legs 11. There are two leg members 11 in the segment 9 shown in Figure 3 but any number of leg members 11 is conceived. The leg members 11 are substantially aligned with a longitudinal axis of a tower segment 7. In the context of the disclosure of the leg design, the term “substantially aligned” is intended to allow for a certain amount of taper in the tower segment such that the leg members 11 are not necessarily exactly parallel with the tower segment longitudinal axis, but rather are within approximately 3 degrees of parallel. Aligning the leg members 11 in this way causes them to bear principally vertical tower loads as would be developed from tower bending.

The skin sheet 13 of a segment 9 is attached to an adjacent segment via a press broken flange 15 on the vertical edge of each section 9 with holes drilled periodically along the length for a bolted connection. Optionally, rather than press breaking the flanges 15, the flanges may be provided by welding angled tabs with pre-drilled holes onto the skin sheets 13. Other connection solutions, such as a field-welded connection, are conceived and could be devised by one of ordinary skill in the art. Skin sheets 13 of one section 7 are attached to skin sheets 13 of another section 7 by an inward flange 17 on the top and bottom ends of each segment 9. The flange 17 used in the Lattice-Skin Hybrid tower 3 is much smaller than the flange mentioned in use with a prior art tubular tower 1 since the loads it is required to bear are substantially less. The flange 17 may in fact be simply constructed by press breaking the skin sheet 13 material itself, with no need for special machining or welding, or, the flange 17 may be constructed by attaching a piece of angle iron with drilled holes to allow connection to the flange 17 on the skin sheet 13 of the adjacent tower segment 9. In some cases, it is possible that the primary structural connection between adjacent tower sections 7 may be achieved entirely through the leg members 11 and the flanges 17 may not be required.

At each end of the leg members 11 is a male pin connector 19 or female pin connector 21 for connecting to the segments 7 above and below the segment in question. Throughout this disclosure the male pin connector 19 will be at the top of the leg and the female connector 21 at the bottom although the reverse could also work and is considered to be within the scope of this disclosure. Special terminations of the legs 10 may be employed at the top and bottom of the Lattice-Skin Hybrid tower 3 for connecting to a turbine or a foundation respectively. Alternatively, the foundation and turbine interface may be built to accept the pin connections thus directing forces directly into the legs 10.

Figure 4 is a close up view of a single male pin connector 19 and a single female pin connector 21 and a locking pin 23. The male pin connector consists of a body 25, a shoulder area 27 a tapered pin 29, and a locking pin hole 31. The female pin connector 21 consists of a body 33, a shoulder area 35, a tapered pin receiving cavity 37, and a locking pin hole 39. The body 25, 33 of each connector 19, 21 is attached to a leg member 11 such that forces are evenly transmitted from one leg member 11 to another without local stress concentrations. In the embodiment shown, solid square cross section bodies 25, 33 are inserted and attached inside the square channel of the leg member 11 with enough length of body 25, 33 to evenly transmit the forces from one leg member 11 to the next. The pin connectors 19, 21 are formed such that when seated, the shoulder areas 27, 35 are in firm contact, the locking pin holes 31, 39 are aligned, and the tapered pin 29 is firmly pressed against the sides of the tapered pin receiving cavity 37 thus preventing any sideways movement and effectively transmitting compression forces. A tapered locking pin 23 is inserted in the locking pin holes 31, 39 and secured on the far side by a nut, cotter pin or other method as could be devised by one skilled in the art. The locking pin 23 is designed to effectively transmit tension forces from one leg member 11 to another. It should be noted that the tension forces are typically much lower than compression forces in almost all applications.

It should be noted that the pin connection herein described is disclosed as an inventive element of the Lattice-Skin Hybrid tower 3. It should be further noted that other connection techniques may be used with a tower having internal legs 10 and an external skin 12 and are still within the scope of the present invention. Furthermore such a tapered pin connection may be used for construction of tubular, lattice, Lattice-Skin Hybrid, or other types of towers.

Additional information about determination of tower loads can be found in *Guidelines for Design of Wind Turbines* published by Det Norske Veritas and Riso National Laboratory in 2002, *Wind Energy Handbook* written by Burton, Sharpe, Jenkins, and Bossanyi and published by John Wiley & Sons in 2001, *Wind Power Plants: Fundamentals, Design, Construction and Operation* written by Gasch and Twele and published by James & James in 2002, *Wind Turbine Engineering Design*, written by Eggleston and Stoddard and published by Van Nostrand Reinhold in 1987, *Windturbines*, written by Hau and published by Springer in 2000, *Wind Turbine Technology*, edited by Spera and published by ASME Press in 1994, and *Wind Energy Conversion Systems*, written by Freris and published by Prentice Hall in 1990, all of which are incorporated herein by reference. It is important to consider both static and dynamic loads when designing the tower. It is also important to consider all relevant load cases, including operating loads and loading under high wind conditions when the wind turbine is not operating. Design loads for specific commercially available wind turbines can be obtained from the wind turbine manufacturers.

The Skin-Lattice Hybrid tower segments 9 are assembled into sections 7 using a Section Assembly System 41. The Section Assembly System 41 allows for easy, accurate, on-site assembly. A Section Assembly System according to an embodiment of the present invention can be seen in Figures 5a through 5i. The Section Assembly System 41 consists of 3 major components, two arm assemblies 43, two spindle carriages 45, and a rigid spanning structure 47. The rigid spanning structure 47 can take the form of a rail system fixed to leveled ground, the bed of a special trailer, or other convenient structure to secure the two spindle carriages 45 at their appropriate positions. Tower assembly can optionally be performed adjacent to the towers' foundation such that the tower may be installed immediately after assembly, or it can be performed at a central staging area where all towers for a particular wind project are assembled. Optionally, tower assembly may also take place off-site at an assembly shop from which the towers may be transported to the project site. If the towers are assembled off-site, it is important to ensure that there are no impediments to transportation of the assembled tower from the shop to the project site.

In Figure 5a, a first tower segment 9 is being lifted by an assembly crane from a truck used to transport the tower segments 9 onto the Section Assembly System 41. The tower segment 9 is then bolted onto the arm assemblies 43 of Section Assembly System 41 as shown in 5b. The tower segment can be secured to the arm assemblies 43 by any suitable manner. An example of a suitable attachment would be to bolt the flanges 17 on the ends of the tower segment 9 onto mating bolt holes on the arm assemblies 43 of Section Assembly System 41. After the tower segment 9 is secured to the arm assemblies 43, the arm assemblies can then be rotated, or indexed, by 90 degrees (or some other appropriate angle if there are other than four tower segments 9 in a tower section 7) as shown in Figure 5c to allow an adjacent tower segment 9 to be assembled. The arm assemblies 43 can be rotated between the position shown in Figure 5b and that shown in 5c by using the assembly crane or by building an indexing mechanism into the arm assemblies 43. After the arm assemblies 43 have been rotated to the position shown in 5c, another tower segment 9 can be lifted by the assembly crane into the Section Assembly System 41, as shown in Figure 5c. The second tower segment 9 is then secured to the arm assemblies 43 of the Section Assembly System 41 as shown in Figure 5d. At this point, the longitudinal flanges 15 of adjacent tower segments 9 can be bolted or otherwise fastened together to securely connect the adjacent tower segments 9. At this point, the arm assemblies 43 of Section Assembly System 41 are rotated by another 90 degrees to the orientation shown in Figure 5e. Then, the assembly crane can lift a third tower segment 9 from the truck to the Section Assembly System, as shown in Figure 5e. The third tower segment 9 is secured to the arm assemblies 43 of the Section Assembly System 41 as shown in Figure 5f and the flanges 15 of the second and third tower segments are fastened together. Next, the arm assemblies 43 of Section Assembly System 41 are rotated by another 90 degrees to the orientation shown in Figure 5g and the fourth tower segment 9 is lifted into place. Finally, the fourth tower segment 9 is secured to the arm assemblies 43 of the Section Assembly System 41 as shown in Figure 5h. At this point, the flanges 15 of the fourth tower segment 9 may be secured to the flanges 15 of the first and third tower segments 9 and a tower section 7 is completely assembled. After assembly of the tower segments, it is possible to install any ancillary equipment that must be assembled on site, such as ladders, lights, cable trays, or work platforms.

Once the tower section 7 has been assembled, the assembly crane can be attached to the arm assemblies 43 and the tower section 7 can be lifted out of the Section Assembly System 41. The section 7 is then lifted vertical and hanging a little above ground level. The bottom arm assembly 43 is then removed and the section 7 is lifted into position atop a foundation or atop another tower section 7. The tapered shape of the pin connections 19, 21 help to guide the tower section 7 into position. Once seated, the locking pins 23 are secured into place and the inward flanges 17 are bolted together. It may be that a final tightening of the vertical flange 15 bolts is performed at this time. The upper arm assembly 43 is then detached from the section 7 and brought to the ground by the assembly crane and the process of lifting the next section 7 is initiated. After detachment from the tower section 7, the arm assemblies 43 may be taken back to the Section Assembly System 41 for use on the next tower section 7.

Figure 6 shows details of a spindle carriage 45. The principal function of the spindle carriage 45 is to provide a mechanism that can support the tower segments 9 and provide the necessary movement for adjustments to allow alignment while they are being assembled into a tower section 7. The spindle carriage 45 should ideally provide capability for translation in three directions as well as rotation around the tower section's longitudinal axis. One of ordinary skill in the art would be capable of designing a suitable mechanism to provide the necessary adjustments and alignments. By way of example, one design of a spindle carriage 45 is described herein with reference to Figure 6. A carriage base 53 is connected to and may move on the rigid spanning structure 47. The arm assembly 43 is fastened to a spindle 55 which is optionally driven by a spindle drive 57. The spindle drive 57 may be any of a number of devices as would be apparent to one skilled in the art. As an example, a ratcheting hydraulic drive would work well as spindle drive 57. The spindle drive 57 needs to be able to rotate an unbalanced load and hold it firmly in place. A safety lock is preferably included to positively prevent rotation of the spindle drive 57 in a fail-safe manner while workers are fastening tower segments together. It may be that the spindle 57 drive is only required on one end of the Section Assembly System 41 and thus the other end would have a bearing instead of a spindle drive 57. The Spindle drive is held above the carriage base 53 by a goose neck 59 which holds the spindle 55 and arm assembly 43 away from the carriage base 53 to keep the segments 9 being assembled from interfering with the spindle carriage 45. The spindle carriage 45 must provide for adjusting the placement of the arm assembly 43 in three degrees of freedom; longitudinally or along the Z axis, parallel to the center line of the horizontal section 7, vertically, or along the Y axis perpendicular to the center line of the horizontal section 7, and laterally, or along the X axis also perpendicular to the center line of the horizontal section 7. Near perfect alignment of these three degrees of freedom are necessary to ensure the sections 7 are not assembled askew and that the arm assembly

43 mates appropriately with the flanges 17, and that the final tower sections 7 are properly aligned to each other when assembled as a complete tower. The Z axis mobility may also be used to withdraw the spindle carriage 45 to release the arm assemblies 43 and completed section 7 when the assembly crane 49 lifts the segment 7 away. Alternatively, such a release can be achieved by providing the goose neck 59 with the ability to tilt away from the arm assembly 43.

Figure 6 shows a hydraulic telescoping mechanism 61 incorporated into the goose neck 59 to provide the Y axis degree of freedom in an embodiment of the present invention. A manual or power screw mechanism or hydraulic ram 63 at the base of the goose neck 59 provides the X axis of freedom in the embodiment shown. The Z axis of freedom in the embodiment shown in Figure 6 is gained by a positioning and locking mechanism 65 which allows the spindle carriage 45 to travel on a short section of track 67 built into the rigid spanning structure 47 for the embodiment shown. The positioning and locking mechanism 65 could be a relatively complex active drive, such as a rack and pinion system, or it could be as simple as a cable and winch to pull the spindle carriage 45 along the track 67. The positioning and locking mechanism 65 should preferably include a locking device to prevent movement of the spindle carriage 45 during assembly of a tower section. A laser leveling device 69 may be built into the spindle carriage to aid in alignment.

An embodiment of an arm assembly 43 is shown in Figure 7. The principal function of the arm assembly 43 is to provide a frame that can support the tower segments 9 while they are being assembled into a tower section 7. The frame structure must be either adjustable to accommodate various diameters of tower sections (i.e. the bottom tower section will typically have a larger diameter than the top tower section) and designs, or there must be multiple designs of the frame structure to accommodate different tower section diameters and designs. One or ordinary skill in the art would be capable of designing a suitable frame structure to accommodate the tower contemplated in the present invention, or to allow assembly of other designs of segmented towers.

By way of example, one design of an arm assembly 43 is described herein with reference to Figure 7. The central portion of the arm assembly 43 forms a hub 71. On the spindle side of the hub 71 are a plurality of connectors 73 which are fastened to the spindle 55 during assembly of a segment 7 and which are un-fastened when the completed section 7 is removed from the Section Assembly System 41. Radiating from the hub 71 is a plurality of arms 75. The arm assembly 43 shown has eight arms 75 although other numbers of arms 75 could also work. Each arm 75 terminates in a pin connector 77 which may be male or female depending on at which end of the segment 7 the arm assembly 43 is intended. The pin connectors 77 shown in Figure 7 are male and are intended for mating with female pin connectors 21 at the end of a segment 9 leg member 11. There may be as many arms 75 as leg members 11 in the section 7 being assembled.

The embodiment of the present invention most explicitly illustrated within this disclosure has eight leg members 11 per section 7 but any number three or greater is conceivable and falls within the intended scope of the disclosure. One skilled in the art could design an arm assembly 43 for any number of arms 75. The arms 75 are connected to the hub 71 using a hinge pin 79 and hold pin 81. When a new segment 9 is being placed in the Section Assembly System 41 the appropriate arms 75 have their hold pin 81 removed and the arms 75 are allowed to swing back, hinged on the hinge pin 79, away from the segment 9. Once the segment 9 is in place, the arms 75 are swung inward to seat their pin connectors 77 with the pin connectors 19, 21 of the segment 9 and locking pins 23 are inserted. Once the connectors 77 are seated, the hold pins 81 are replaced rigidly fixing the arms. Alternatively, instead of devising the arm assemblies 43 to mate with the pin connectors 19, 21 of a tower segment, the arms 75 can have a set of bolt holes (as shown in Figure 6) that mate with flanges 17 on the ends of tower segments 9. One skilled in the art could devise other methods of operating the essential functions of an arm assembly 43 without departing from the scope of that disclosed in this invention.

An alternative assembly method is described with reference to Figure 8. The assembly system shown in Figure 8 maintains the tower segments in a vertical orientation while a tower section is being assembled. This has the advantage of requiring less space on site. However, it also increases the complexity of accessing the tower section during assembly. As with the horizontal assembly system, tower assembly may take place adjacent to a wind turbine foundation, at a wind project staging area, or in an assembly shop near the project site.

The vertical Section Assembly System shown in Figure 8 comprises a small inexpensive foundation 101 that may be either permanent or temporary. Optionally, a support structure could be used rather than using a foundation. A support structure would serve the same purpose as the foundation, but would be temporarily placed on the surface of the ground rather than buried below ground level. The support structure could consist of pre-cast concrete elements, or it could be fabricated from steel beams. Outboard of the foundation 101, there are a set of assembly braces 102 that correspond with leg structures

11 in a tower section 7. The assembly braces 102 include jacks or other mechanisms for raising and lowering them relative to the ground for the purpose of leveling the system. The ground under the jacks may be compacted and covered with gravel to provide a solid surface for supporting the leveling jacks. It may also be necessary to provide cribbing for the leveling jacks if the ground is not level. Assembly braces 102 connect at their center to a tower structure 103 which may be lattice or tubular, although lattice is preferred for weight advantages and to allow the tower to be climbed if necessary.

On the top of the tower structure 103 are mounted an upper set of assembly braces 104 that are similar to the lower braces 102. Both the lower braces 102 and the upper braces 104 are telescopic with a variety of bolt holes to allow the length of the braces to be adjusted for different diameter towers. Note also that the ends of the lower braces 102 include transverse adjustments 112 that allow the width of the ends of the braces 102 to be adjusted. Bolted or pinned to the central tower structure 103 is a set of climbing ladders 104 that are spaced and oriented to allow access to the seams 15 between two adjacent tower segments. In Figure 8 only two such climbing ladders 105 are shown to prevent clutter in the drawing, although four would be useful for the tower embodiment described herein that includes four segments 9 per section 7. It could also be possible to provide only one ladder 105 for the entire Section Assembly System in which case the ladder 105 would need to be moved during assembly of various tower segments. The ladders 105 include safety cages or other fall-prevention equipment to prevent personnel from falling while working on the seams between tower segments.

At the ends of the upper assembly braces 104 are a set of receiving brackets 106 that include one half of a female pin connector. A male pin connector 19 on a tower segment 9 is adapted to fit within the half of a female pin connector on a receiving brace. At the ends of the lower assembly braces 102 are a set of receiving brackets 107 that include male pin connectors. The male pin connectors on the ends of lower receiving brackets 107 are adapted to fit within the female pin connectors 21 on the lower end of a tower segment 9. By adjusting the width of the transverse adjustments 112, the distance between adjacent lower receiving brackets 107 can be modified to accommodate towers with different diameters or different leg spacing. With the tower segment pin connectors 19, 21 attached to the receiving brackets 106, 107, a tower segment 9 may be secured to the Section Assembly System.

Because the upper receiving brackets 106 only include a half of a female pin connector, the first tower segment 9 will need to be secured to the central tower structure 103 with a rope, cable, or a strap. After one tower segment 9 has been secured to the Section Assembly System, additional segments 9 can be secured. After two segments 9 have been secured in the Section Assembly System, personnel can climb up the ladders 105 to secure adjacent segments 9 to each other by bolting their flanges 15 together.

The Section Assembly System shown in Figure 8 includes several features to make it easy to transport and quick and easy to assemble on site. The lower assembly braces 102 are attached to the central tower structure 103 via hinges, as indicated by numeral 109 in Figure 8. The hinges allow the assembly braces 102 to be folded alongside the central tower structure 103 to create a compact structure for transportation. It is intended that all connections on the Section Assembly System are preferably pinned connections to allow for quick and easy assembly.

During assembly of the Section Assembly System, a crane lifts the central tower structure 103, along with lower assembly braces 102 onto the foundation 101. The lower assembly braces 102 are then hinged down into their correct position. At this time, the entire structure is leveled and adjusted with jacks that are placed between the ground and lower assembly braces 102. Then, someone climbs the central tower 103 and the crane lifts upper assembly braces 104 into place where they are pinned onto the central tower 103. Then, the ladders 105 are pinned into their correct position and the Section Assembly System is ready to use. Because the upper assembly braces 104 are pinned onto the central tower structure 103, it is expected that they could be unpinned from the tower structure 103 after a tower section 7 is completed so that the upper assembly braces 104 can be removed. After removal of the upper assembly braces 104, a lifting device similar to the double-H shaped spindle 55 shown in Figure 6 would be attached to the top of the tower section. The lifting device would attach to tabs 17 on top of the tower section, or to another suitable location with adequate structural strength to support the tower section, to provide a pick point for the crane. The crane can then lift the completed tower section and place it on the adjacent wind turbine foundation or on the next lower tower section.

While embodiments of the invention have been shown and described, it will be apparent to those skilled in the art that various modifications may be made in these embodiments without departing from the scope of the invention. Therefore, the invention is not limited to the particular embodiments described and illustrated herein.

What is claimed is:

1. A wind turbine tower comprising:

a tower section having a longitudinal axis comprising a plurality of leg structures spaced around a periphery of said tower section and substantially aligned with said longitudinal axis; and

a skin attached to said leg structures wherein loads applied to said tower are shared by said leg structures and said skin.

2. The wind turbine tower of claim 1 wherein said leg structures and said skin are fabricated out of steel and wherein said skin is welded to said legs.

3. The wind turbine tower of claim 1 wherein said skin is fabricated out of press broken sheet steel.

4. The wind turbine tower of claim 1 wherein said tower section is divided into at least two segments along seams that are substantially aligned with said longitudinal axis.

5. The wind turbine tower of claim 4 wherein said segments are attached to each other by a plurality of bolts along said seams.

6. The wind turbine tower of claim 4 wherein said tower comprises at least two said tower sections and wherein at least one said tower segment is divided into at least two segments.

7. The wind turbine tower of claim 1 wherein said tower comprises at least two said tower sections.

8. The wind turbine tower of claim 7 wherein said at least two said tower sections fasten to each other with a plurality of mating tapered pin and cavity connectors.

9. The wind turbine tower of claim 8 wherein one mating tapered pin and cavity connector is located at the end of each leg structure.

10. The wind turbine tower of claim 9 wherein said mating tapered pin and cavity connectors comprise:

a tapered pin attached to a first tower section with a transverse hole provided in said pin;

a body attached to a second tower section with a tapered cavity for receiving said tapered pin with a transverse hole provided in said body; and

a bolt inserted through the transverse holes in said pin and said body to fasten said pin and said body together.

11. A device for attaching two sections of a wind turbine tower comprising:

a tapered pin attached to a first tower section with a transverse hole provided in said pin;

a body attached to a second tower section with a tapered cavity for receiving said tapered pin with a transverse hole provided in said body; and

a bolt inserted through the transverse holes in said pin and said body to fasten said pin and said body together.

12. The device of claim 11 wherein said tapered pin is seated in firm contact with said tapered cavity when said bolt is inserted through said transverse holes.

13. The device of claim 12 wherein compressive forces are transmitted between said two sections of a wind turbine tower by said tapered pin pressing against said tapered cavity.

14. The device of claim 13 wherein tension forces are transmitted between said two sections of a wind turbine tower through shear stress in said bolt.

15. A method of assembling a wind turbine tower comprising the steps of:

providing a tower section that is divided into a plurality of radial segments;

providing a frame that is capable of supporting said radial tower segments;

attaching said radial tower segments to said frame; and

fastening said radial tower segments to each other.

16. The method of claim 15 wherein the step of providing a frame that is capable of supporting radial tower segments comprises the provision of two frame structures for supporting both ends of said radial tower segments.

17. The method of claim 16 further comprising the steps of:

providing a mechanism for adjusting the positions said frame structures; and

adjusting said two frame structures relative to each other to align adjacent tower radial tower segments relative to each other during assembly.

18. The method of claim 15 further comprising the steps of:

providing a mechanism for rotating said frame about a longitudinal axis;

attaching said radial tower segments to said frame one at a time; and

rotating said frame about said longitudinal axis after attaching each said radial tower segment.

19. The method of claim 18 wherein each of said radial tower segments has a predetermined radial circumference and said frame is rotated by an angle substantially equal to the radial circumference of each said radial tower segment after attaching each said radial tower segment.

20. The method of claim 15 wherein said step of providing a frame that is capable of supporting said radial tower segments further comprises providing said frame in a horizontal orientation.

21. The method of claim 15 wherein said step of providing a frame that is capable of supporting said radial tower segments further comprises providing said frame in a vertical orientation.

22. The method of claim 15 further comprising the step of:

removing said tower section from said frame.

23. An assembly device for a wind turbine tower wherein said tower comprises a plurality of radial segments, said assembly device comprising:

a first frame for supporting a first end of each said radial segment of said tower;

a second frame for supporting a second end of said radial segment of said tower; and

a mechanism for adjusting said first frame relative to said second frame whereby said radial segments may be properly aligned during assembly.

24. The assembly device of claim 23 further comprising a measuring device that measures the alignment of said radial tower segments and wherein said mechanism for adjusting said frame makes adjustments based on said measured alignment of said radial tower segments.

25. The assembly device of claim 23 wherein said assembly device orients said radial tower segments in a substantially horizontal orientation during assembly.

26. The assembly device of claim 23 wherein said assembly device orients said radial tower segments in a substantially vertical orientation during assembly.

27. The assembly device of claim 23 wherein said first frame and said second frame are adjustable to accommodate tower sections of varying size and geometry.

28. A method of assembling a wind turbine tower comprising the steps of:

providing a tower section that is divided into a plurality of radial segments;

supporting each of said tower segments substantially horizontally;

aligning said tower segments relative to each other; and

fastening said radial tower segments to each other.

29. The method of claim 28 further comprising the step of:

providing a frame to support said tower segments during assembly.

30. A method of assembling a wind turbine tower comprising the steps of:

providing a tower section that is divided into a plurality of radial segments;

supporting each of said tower segments substantially vertically;

aligning said tower segments relative to each other; and

fastening said radial tower segments to each other.

31. The method of claim 30 further comprising the step of:

providing a frame to support said tower segments during assembly.

32. An assembly device for a wind turbine tower wherein said tower comprises a plurality of radial segments, said assembly device comprising:

a frame for supporting said radial segments in a substantially horizontal orientation; and

a mechanism for adjusting the alignment of said radial segments relative to each other during assembly.

33. An assembly device for a wind turbine tower wherein said tower comprises a plurality of radial segments, said assembly device comprising:

a frame for supporting said radial segments in a substantially vertical orientation; and

a mechanism for adjusting the alignment of said radial segments relative to each other during assembly.

34. A wind turbine tower comprising:

a plurality of load bearing leg structures; and

a skin attached to said leg structures to provide cladding for said tower.

35. The wind turbine tower of claim 34 wherein said skin eliminates potential perching locations for birds on said tower.

36. The wind turbine tower of claim 34 wherein said leg structures are substantially aligned with a longitudinal axis of said tower and wherein said skin bears a substantial portion of torsional loads applied to said tower.

37. The wind turbine tower of claim 34 wherein a first set of said leg structures are substantially aligned with a longitudinal axis of said tower to bear bending loads applied to said tower and wherein a second set of said leg structures are attached to said first set of leg structures in a diagonal orientation to bear torsional loads applied to said tower.

38. The wind turbine tower of claim 34 wherein said leg structures define a first load path and wherein said skin defines a second load path in parallel with said first load path and wherein bending loads applied to said tower are shared between said first load path and said second load path.

39. The wind turbine tower of claim 38 wherein a majority of bending loads are borne by said first load path.

40. The wind turbine tower of claim 34 wherein said leg structures define a first load path and wherein said skin defines a second load path in parallel with said first load path and wherein torsional loads applied to said tower are shared between said first load path and said second load path.

41. The wind turbine tower of claim 40 wherein a majority of torsional loads are borne by said second load path.

42. The wind turbine tower of claim 34 wherein said leg structures define a first load path and wherein said skin defines a second load path in parallel with said first load path and wherein both bending and torsional loads applied to said tower are shared between said first load path and said second load path.

43. The wind turbine tower of claim 42 wherein wherein a majority of bending loads are borne by said first load path and wherein a majority of torsional loads are borne by said second load path.

44. The wind turbine tower of claim 34 wherein said load bearing legs bear substantially all of the loads applied to said tower and wherein said skin does not bear a significant portion of the loads applied to said tower.

45. The wind turbine tower of claim 34 wherein said skin is formed of press-broken sheet steel.

46. A frame for supporting a wind turbine tower section during assembly wherein said tower section comprises a plurality of radial segments, said frame comprising:

a pair of frame structures disposed opposite each other to support opposite ends of said tower section wherein each of said frame structures comprises attachment points for attaching each said tower segment; and

a mechanism for adjusting said frame structures relative to each other whereby said tower segments can be aligned during assembly of said tower section.

47. The frame of claim 46 wherein said mechanism for adjusting said frame structures comprises a mechanism for translating at least one of said frame structures in three orthogonal directions.

48. The frame structure of claim 47 wherein said mechanism for adjusting said frame structures further comprises a mechanism for rotating said frame structures about a longitudinal axis.

49. The frame structure of claim 46 wherein said frame structures are disposed to maintain said tower section in a substantially horizontal orientation during assembly thereof.

50. The frame structure of claim 46 wherein said frame structures are disposed to maintain said tower section in a substantially vertical orientation during assembly thereof.

51. The frame structure of claim 46 wherein said frame structure is adjustable to accommodate tower sections of various sizes and geometries.

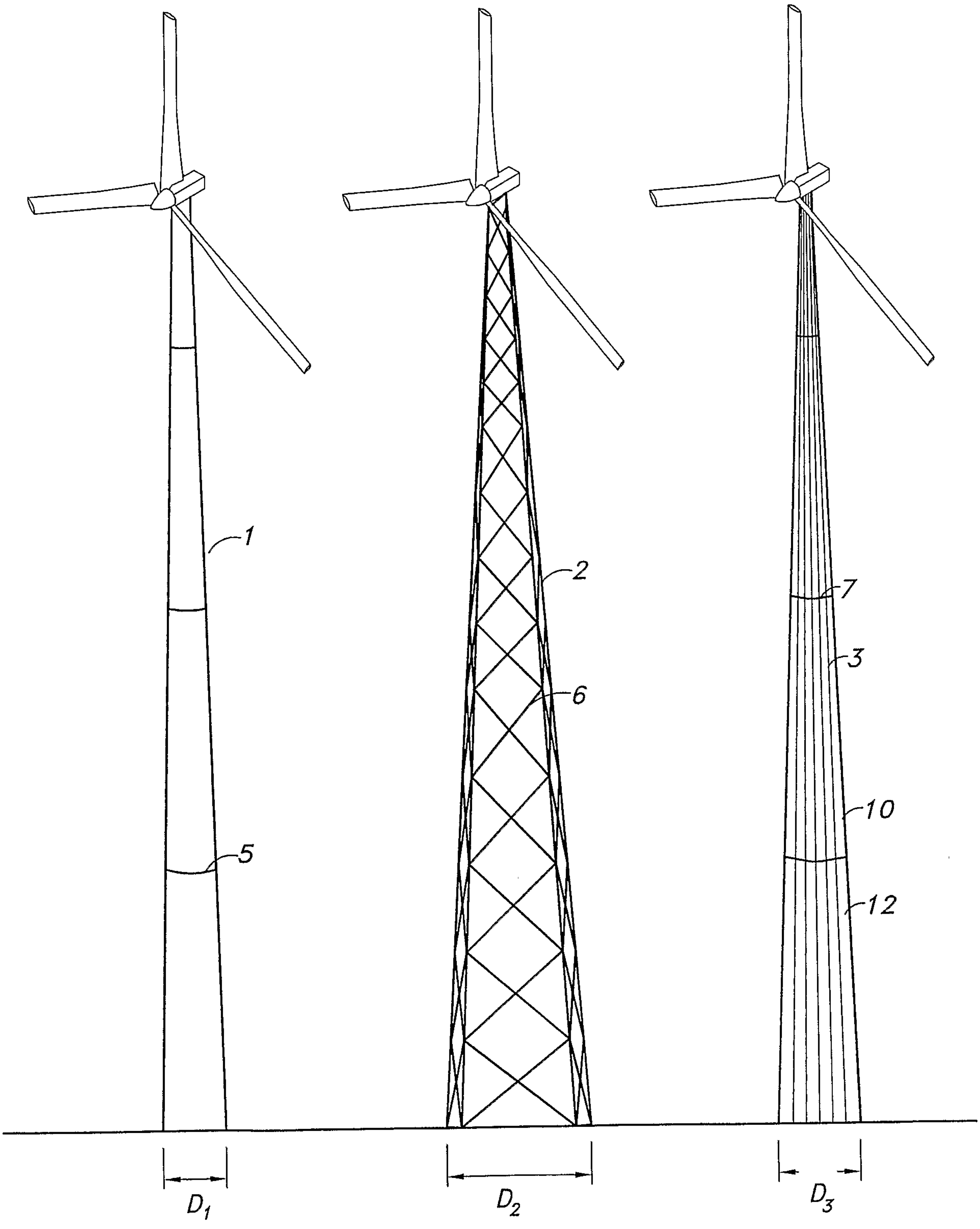

Figure 1

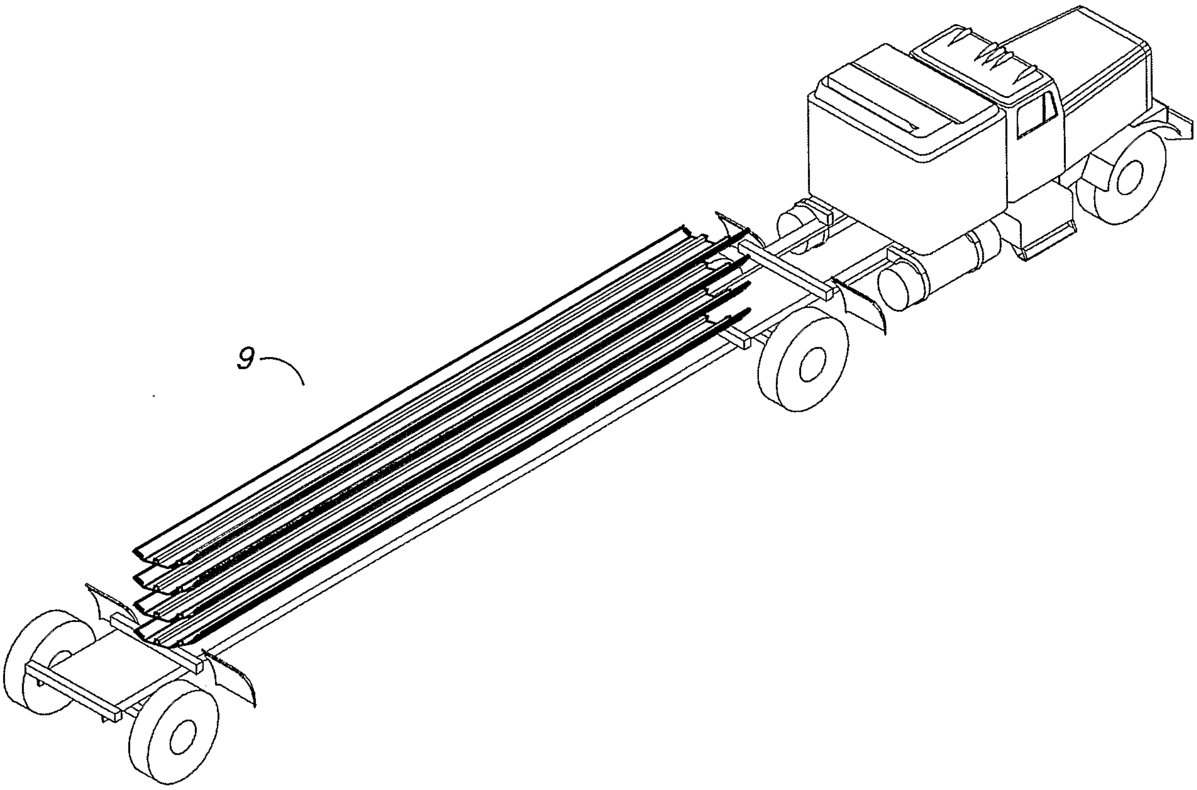

Figure 2

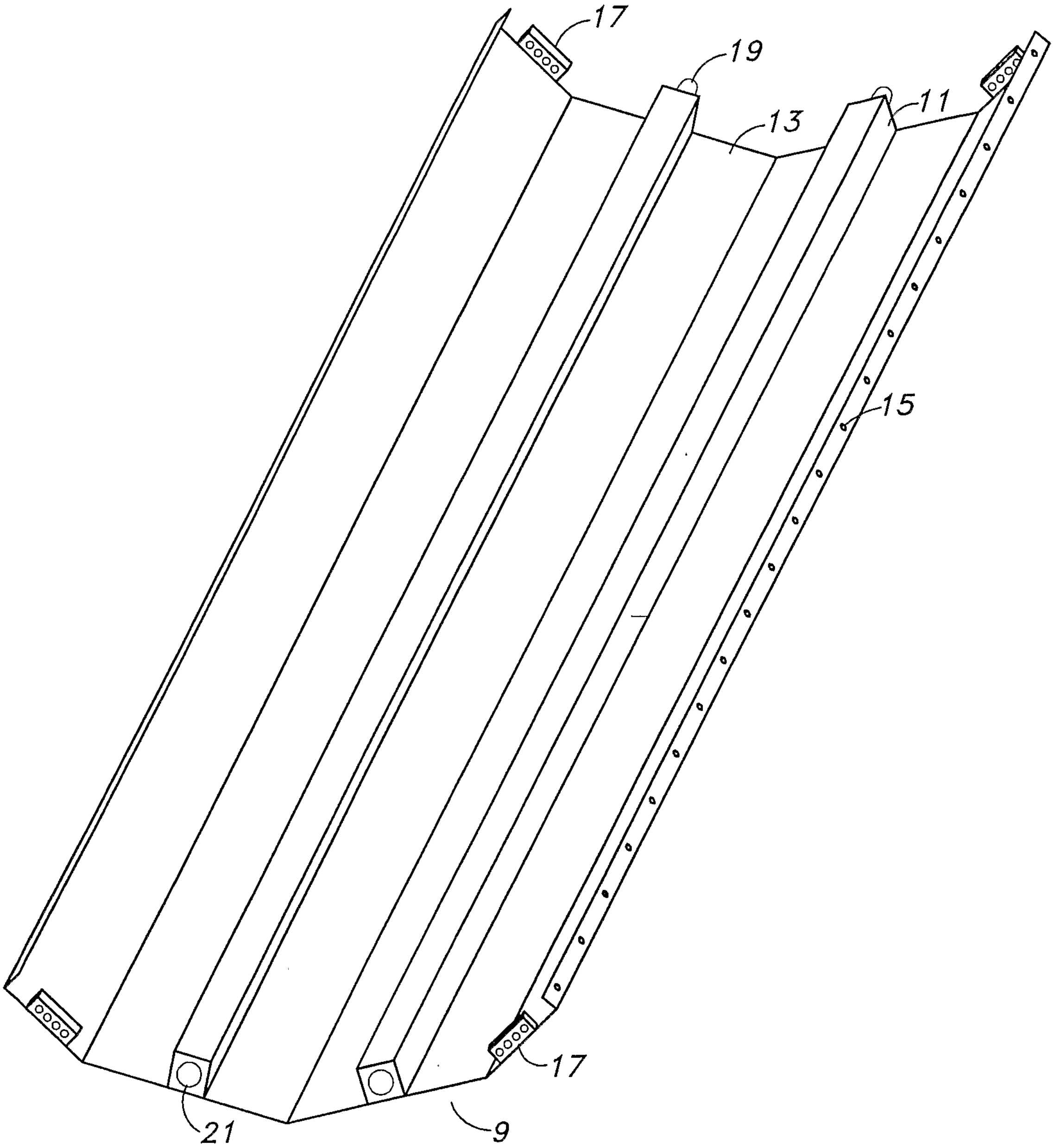

Figure 3

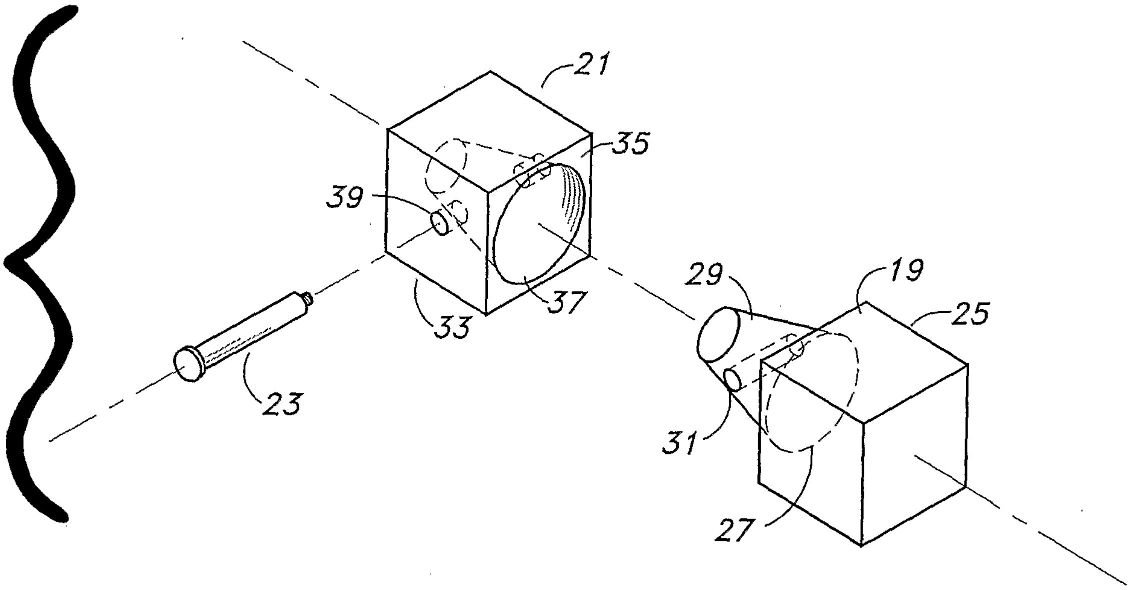

Figure 4

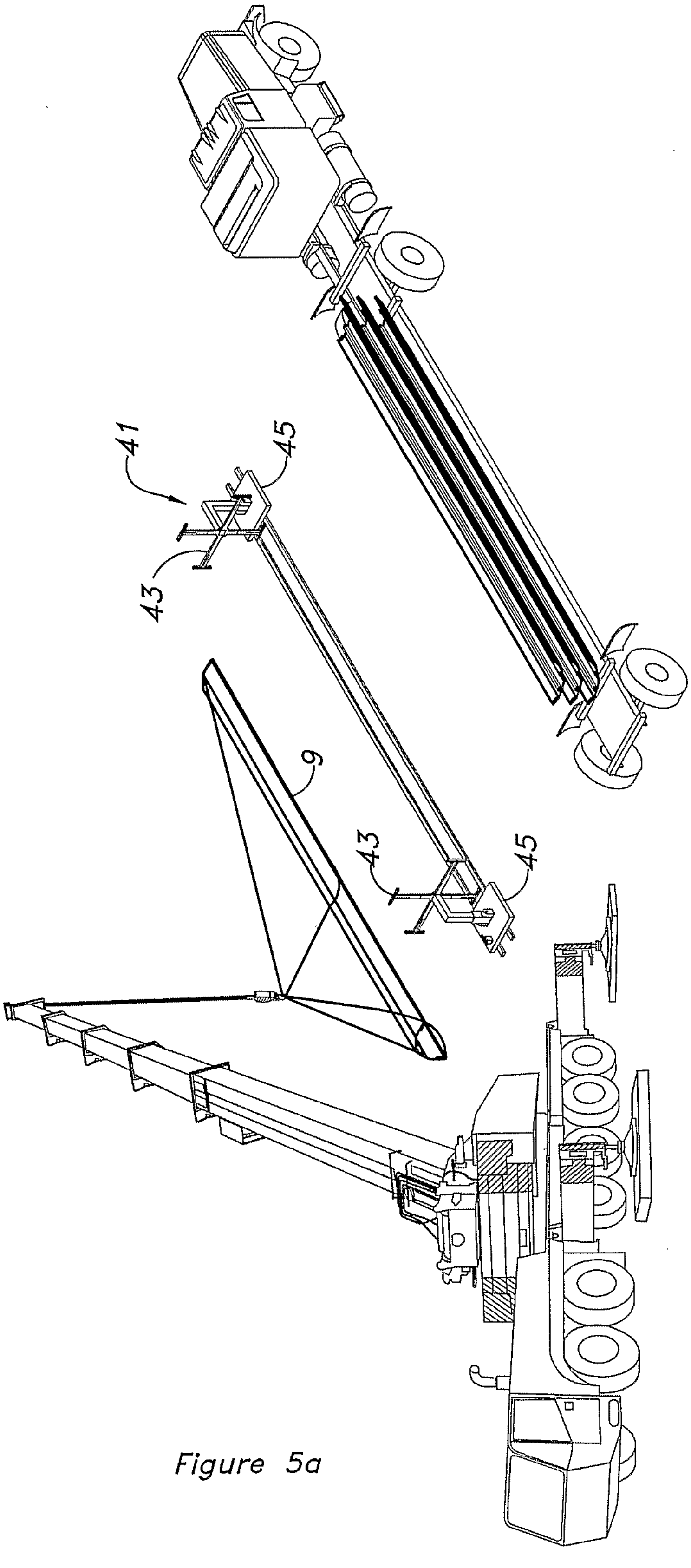

Figure 5a

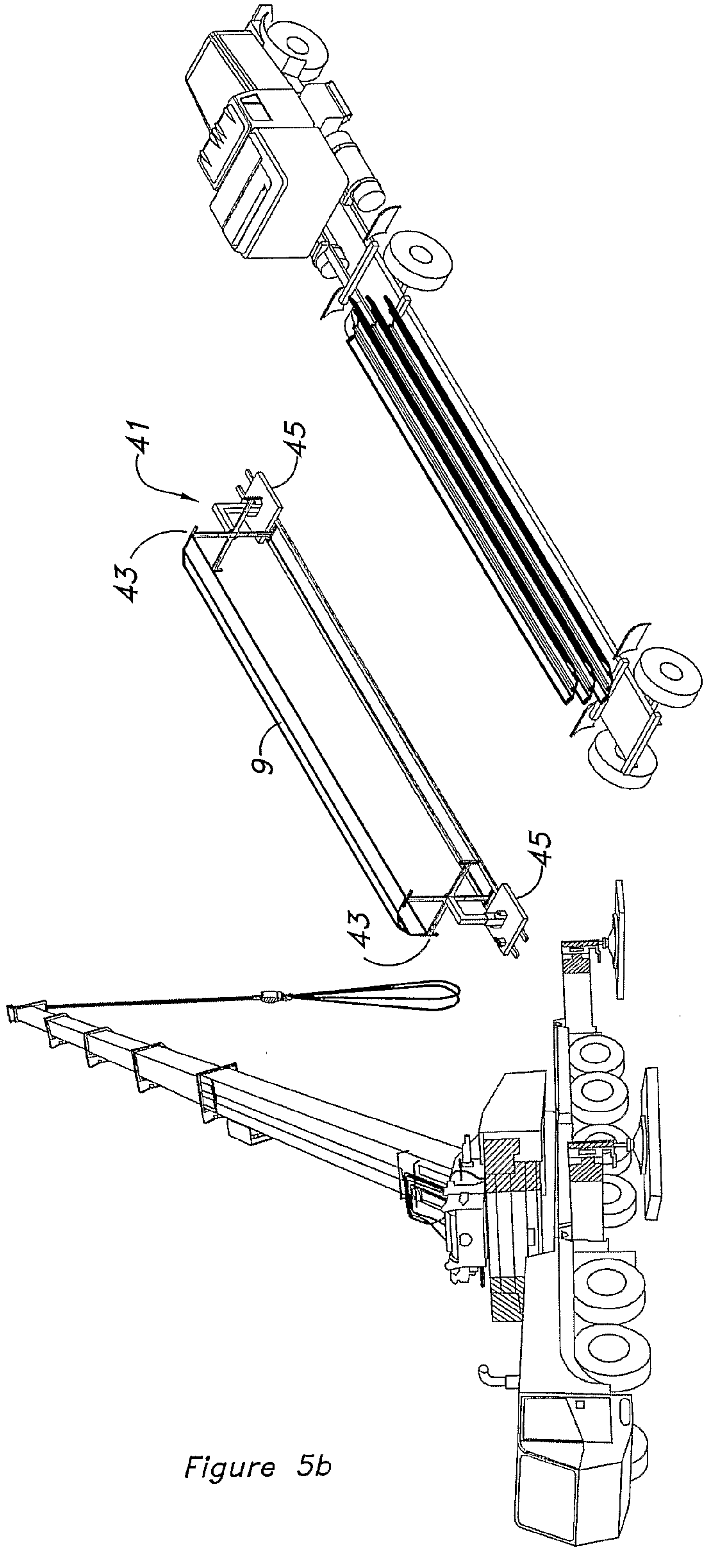

Figure 5b

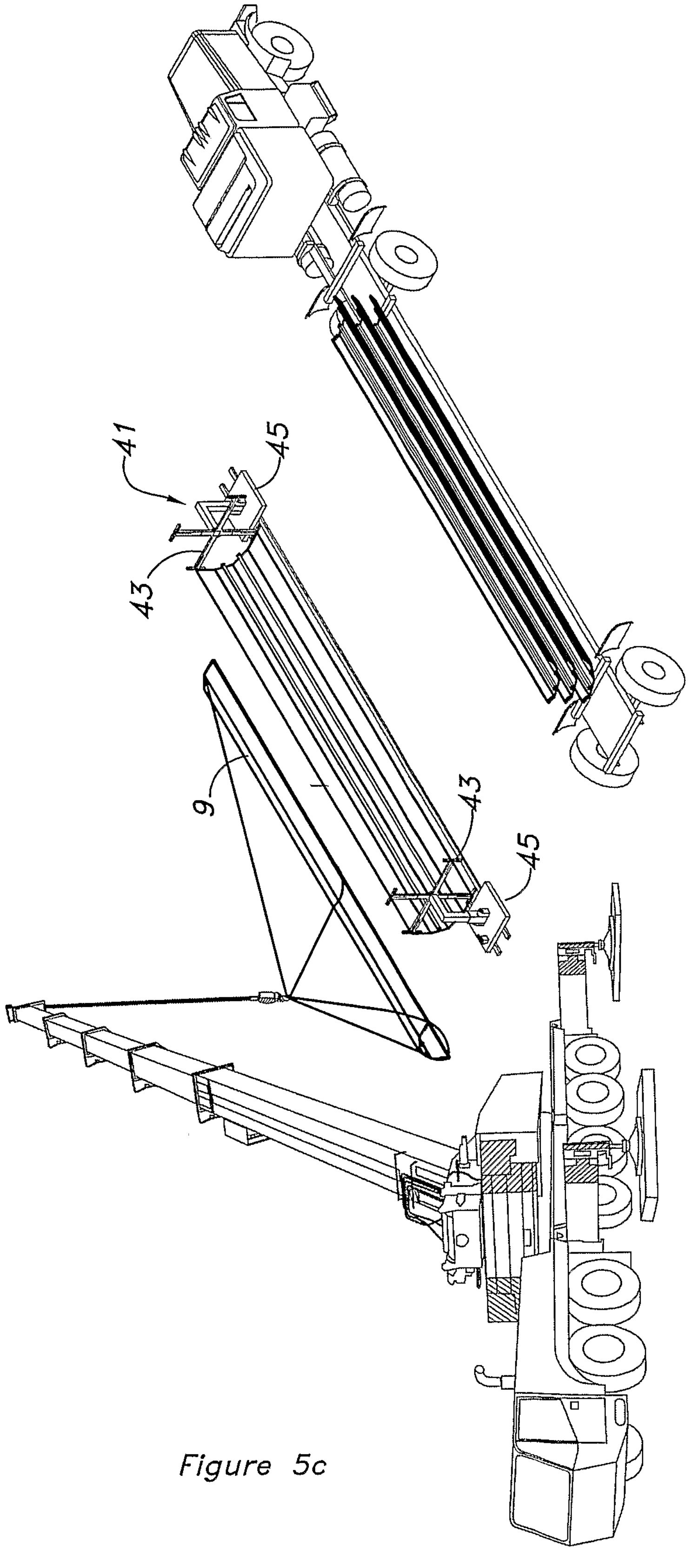

Figure 5c

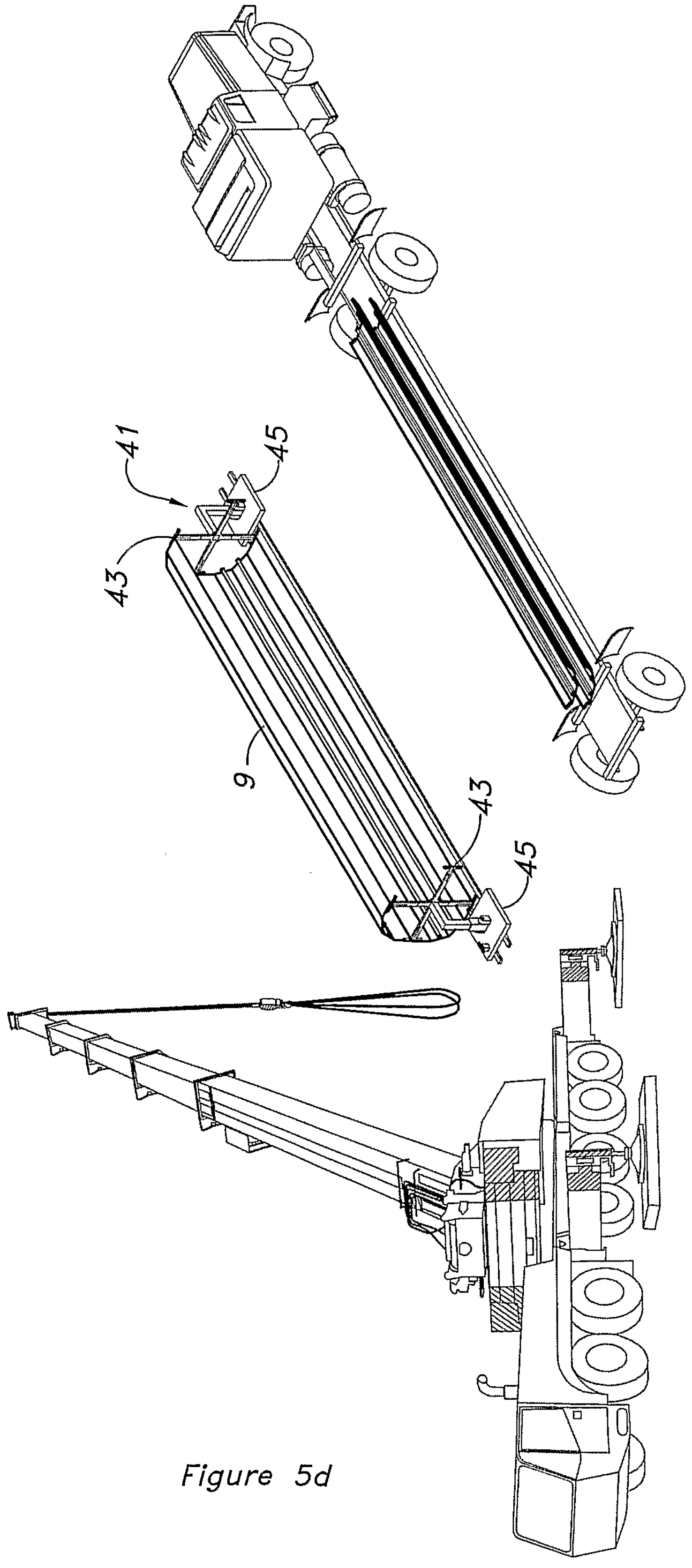

Figure 5d

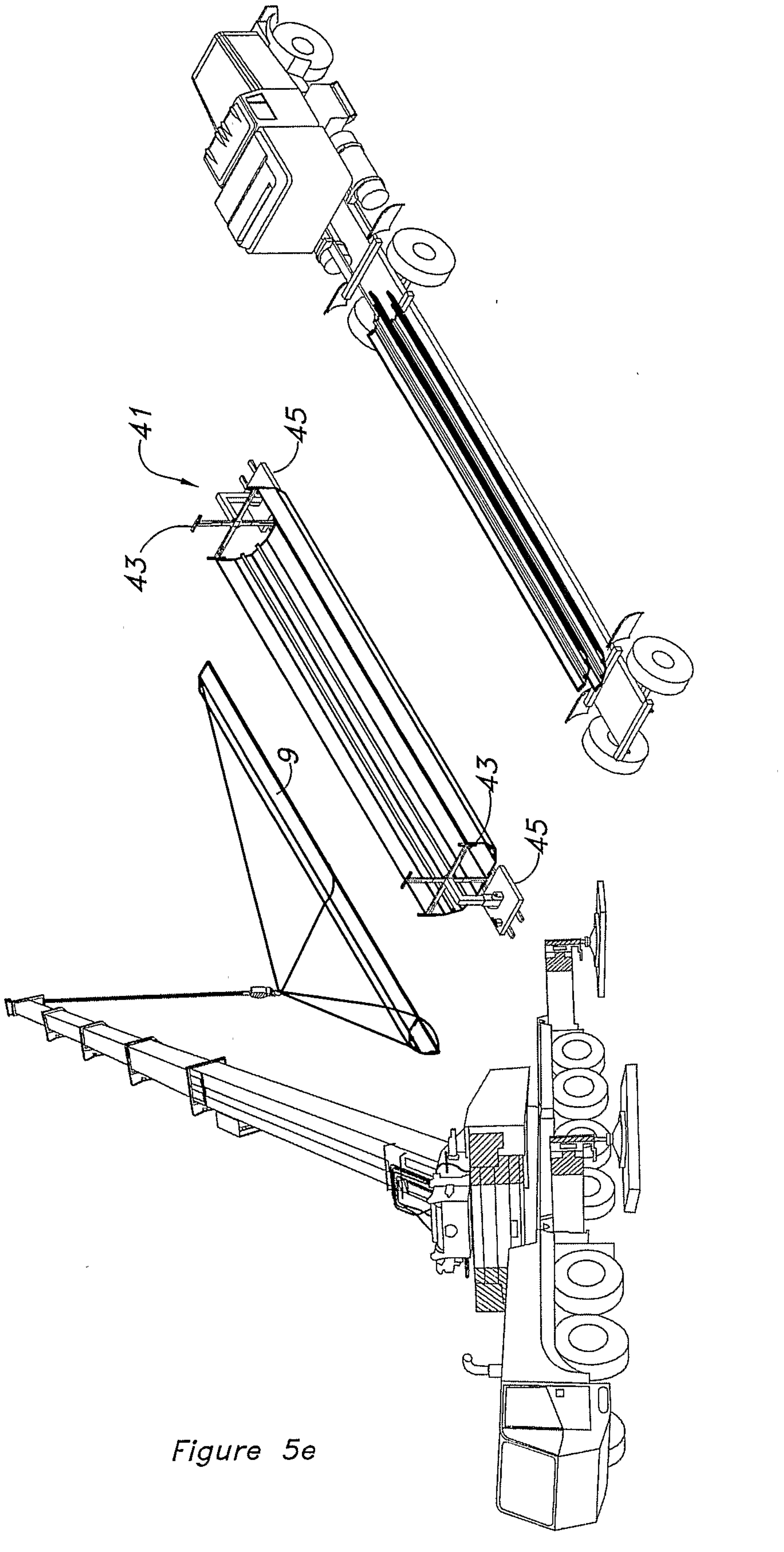

Figure 5e

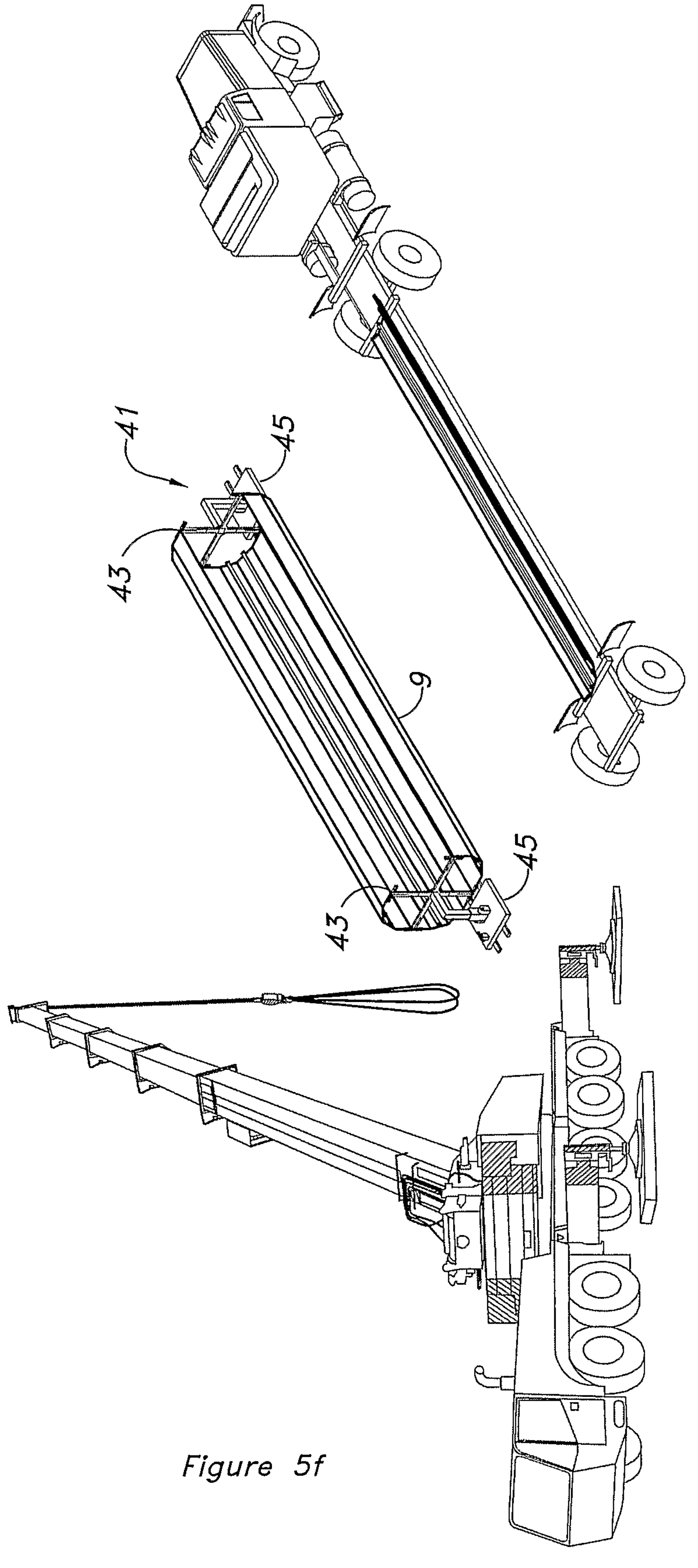

Figure 5f

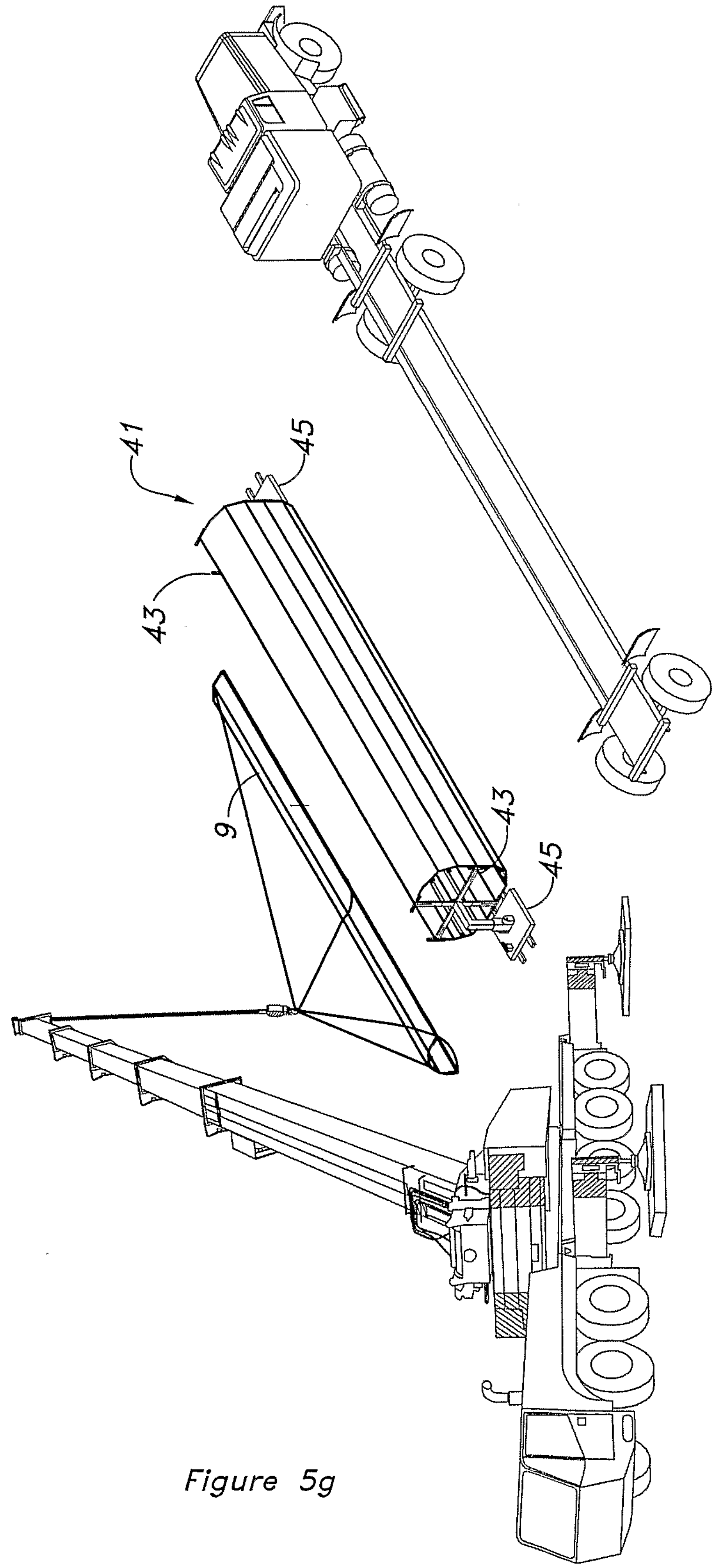

Figure 5g

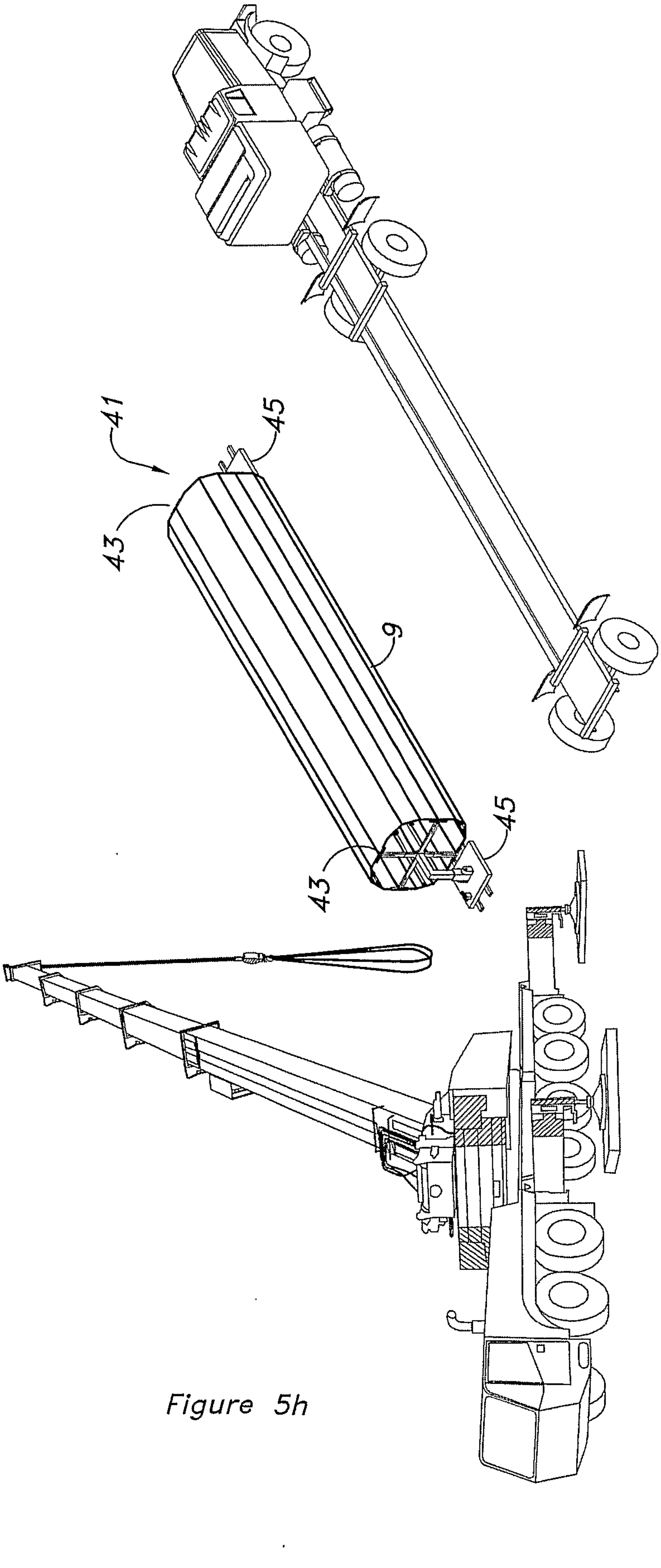

Figure 5h

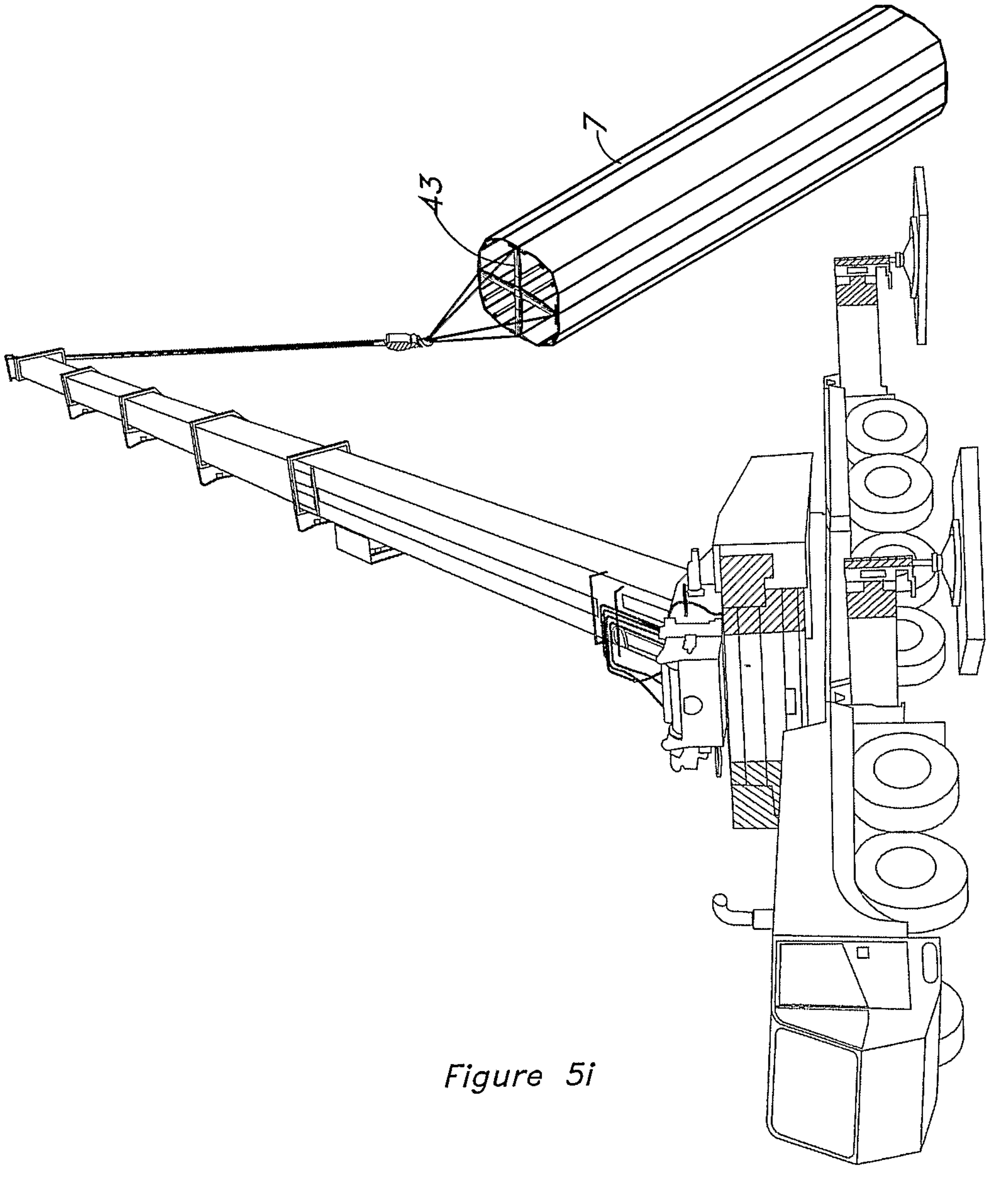

Figure 5i

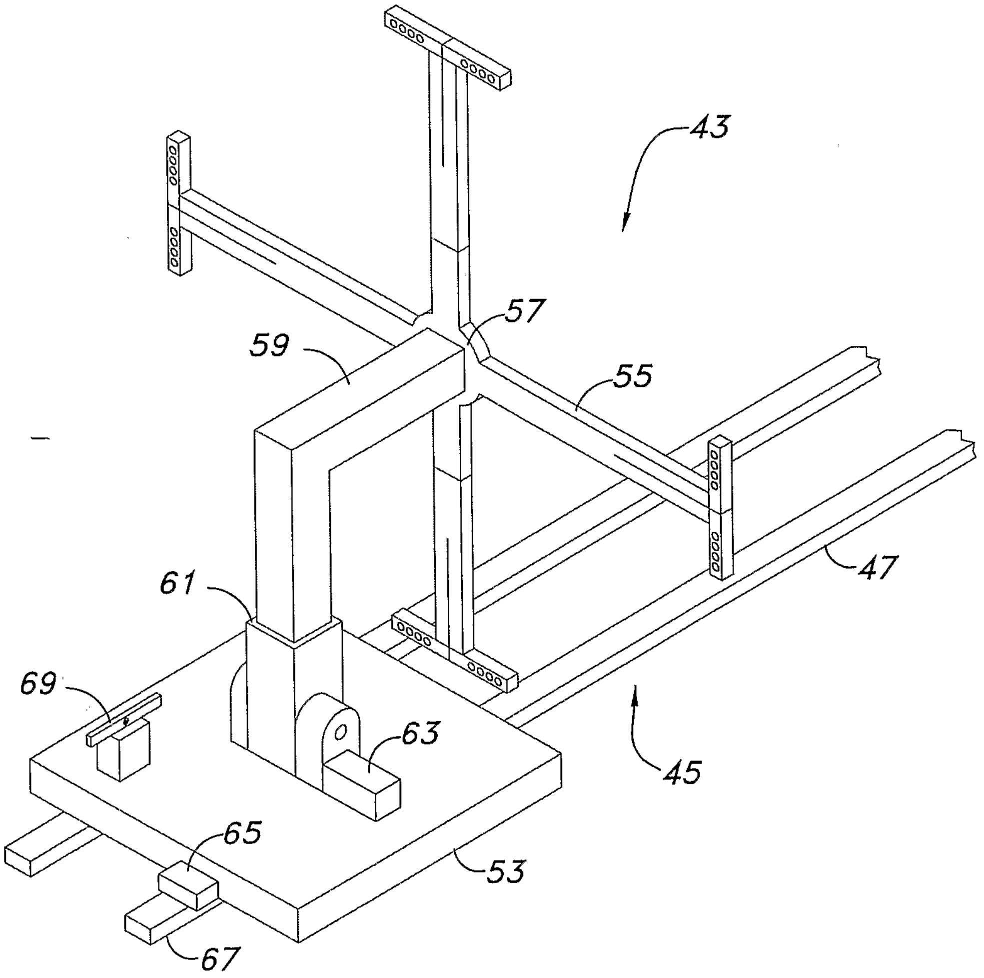

Figure 6

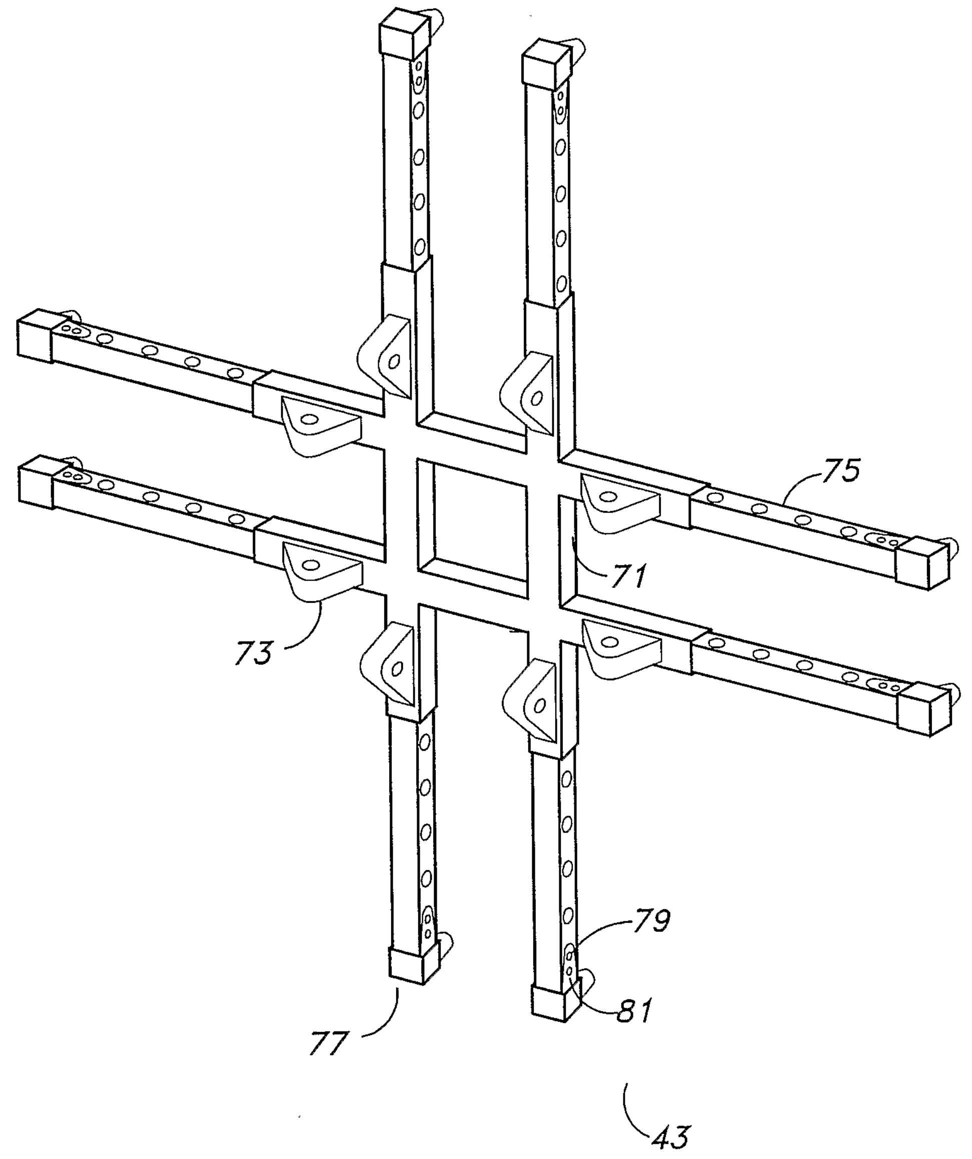

Figure 7

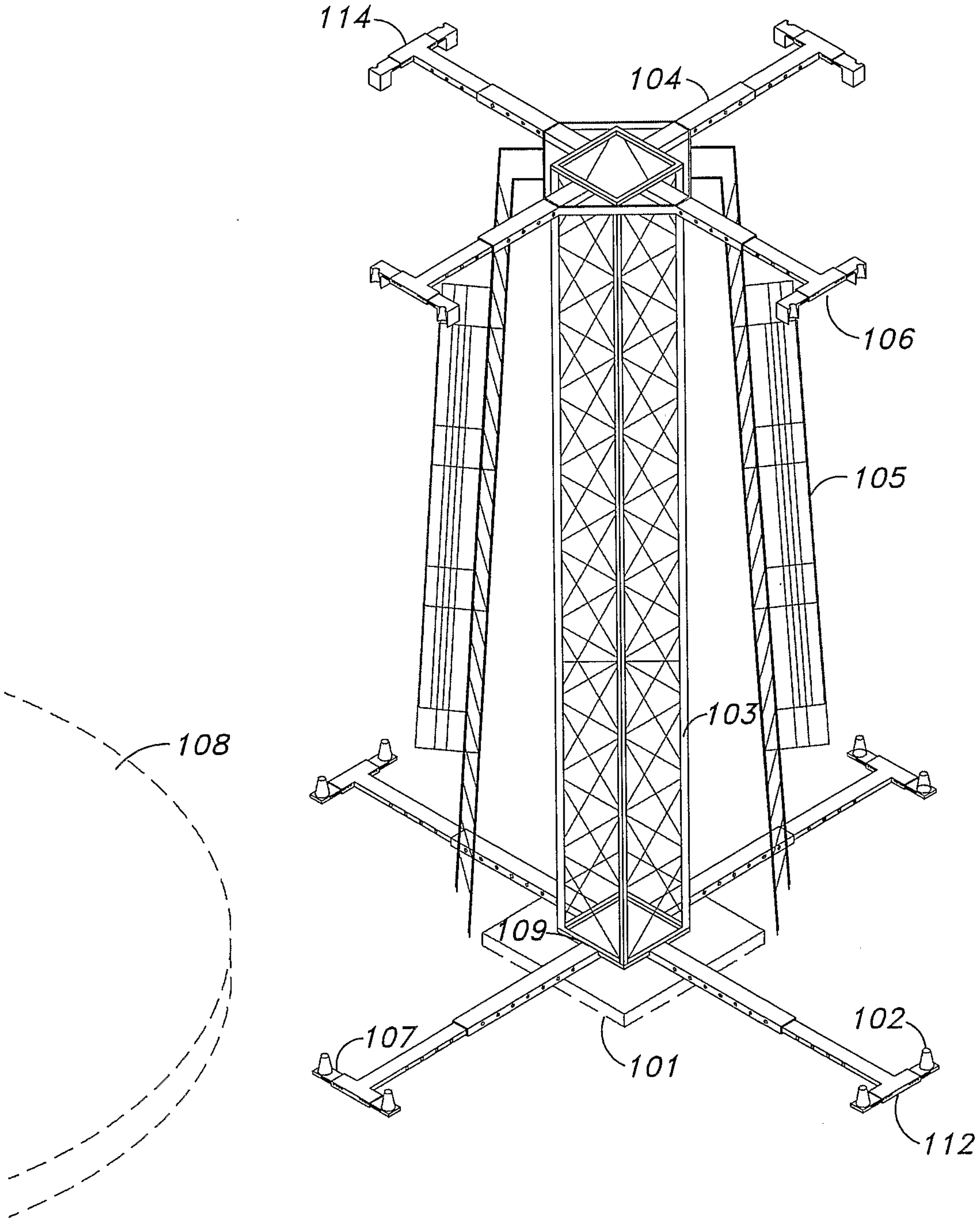

Figure 8