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Phuly

(54) **FATIGUE REISTANT FOUNDATION SYSTEM**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 11/859,588, filed on Sep. 21, 2007.

(60) Provisional application No. 61/269,800, filed on Jun. 29, 2009, provisional application No. 61/284,901, filed on Dec. 28, 2009, provisional application No. 61/339,550, filed on Mar. 5, 2010, provisional application No. 60/826,452, filed on Sep. 21, 2006, provisional application No. 60/954,502, filed on Aug. 7, 2007.

Publication Classification

(51) **Int. Cl.**
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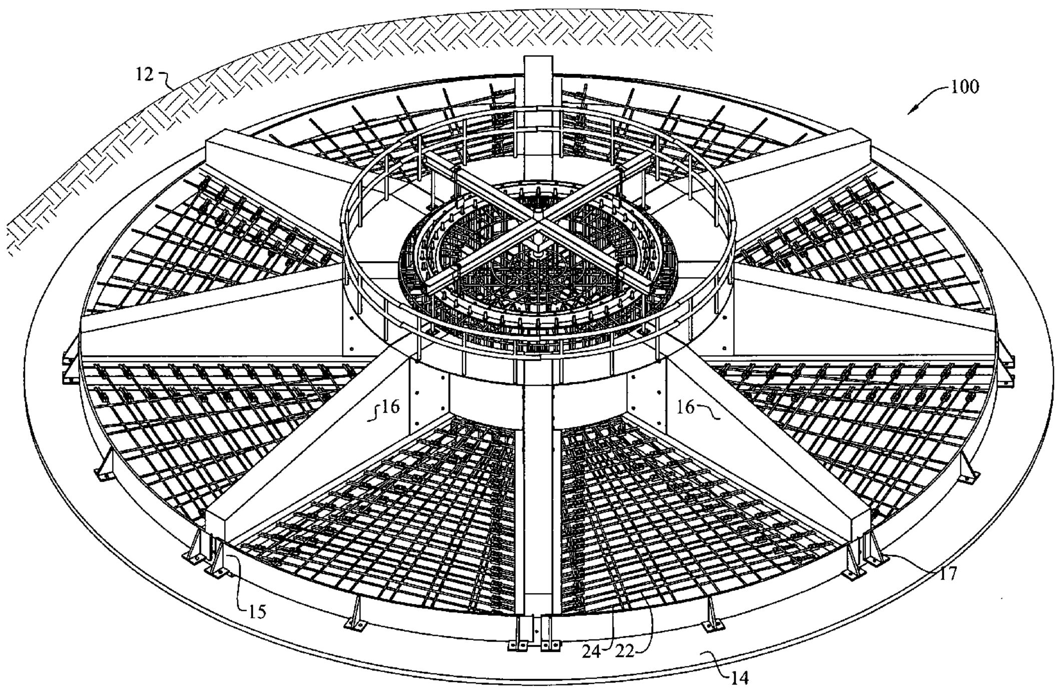
(52) **U.S. Cl.** **52/297**

(57) **ABSTRACT**

A fatigue resistant gravity based spread footing under heavy multi-axial cyclical loading of a wind tower having a central vertical pedestal, a substantially horizontal continuous bottom support slab with a stiffened perimeter, a plurality of radial reinforcing ribs extending radially outwardly from the pedestal and a three-dimensional network **500** of post-tensioning elements that keep the structural elements under heavy multi-axial post compression with a specific eccentricity that is intended to reduces stress amplitudes and deflections and allows the foundation to have a desirable combination of high stiffness and superior fatigue resistance. The foundation design reduces the weight and volume of materials used, reduces cost, and improves heat dissipation conditions during construction by having a small ratio of concrete mass to surface area thus eliminating the risk of thermal cracking due to heat of hydration.



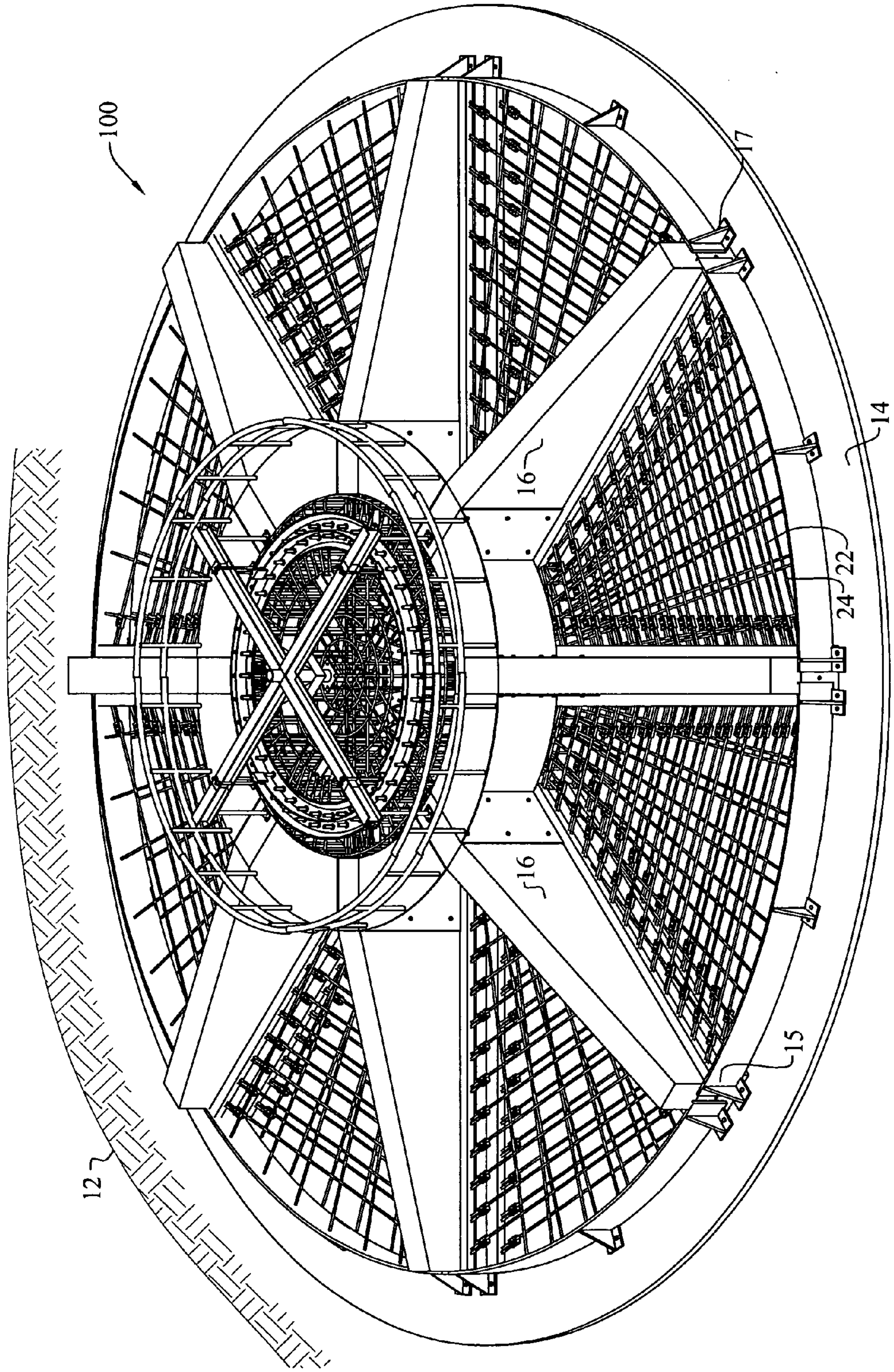


FIG. 1

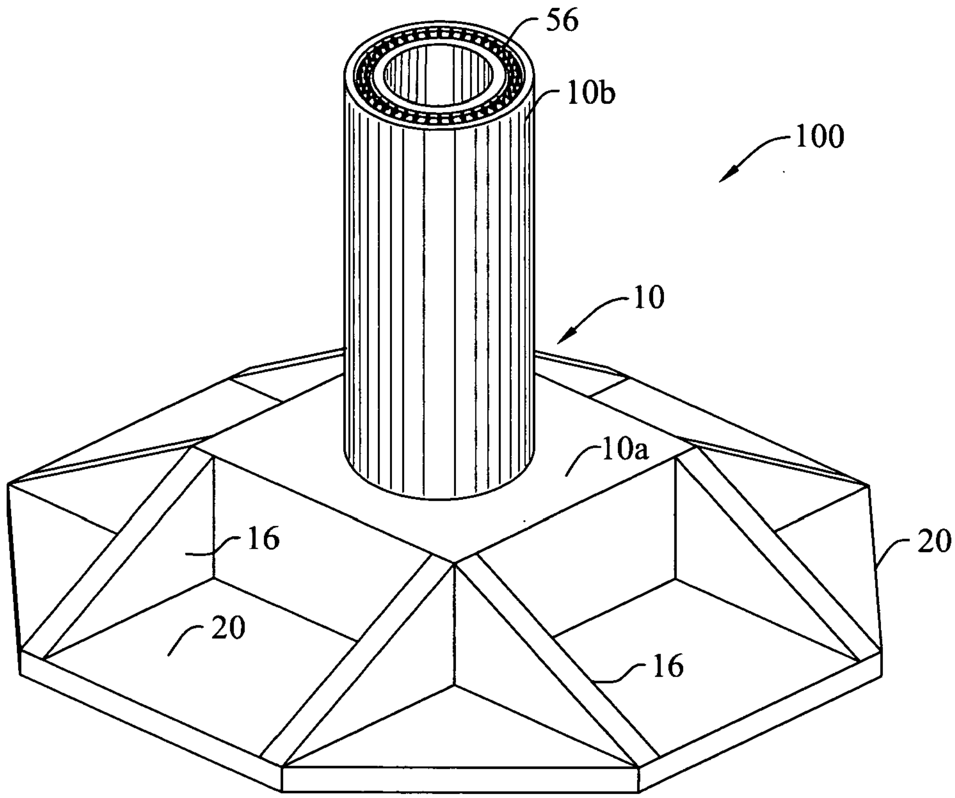


FIG. 2a

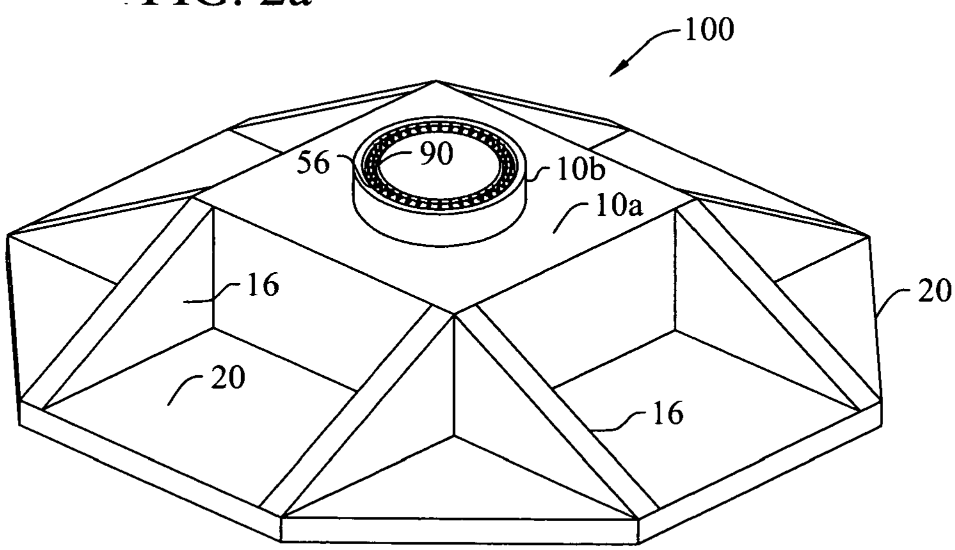


FIG. 2b

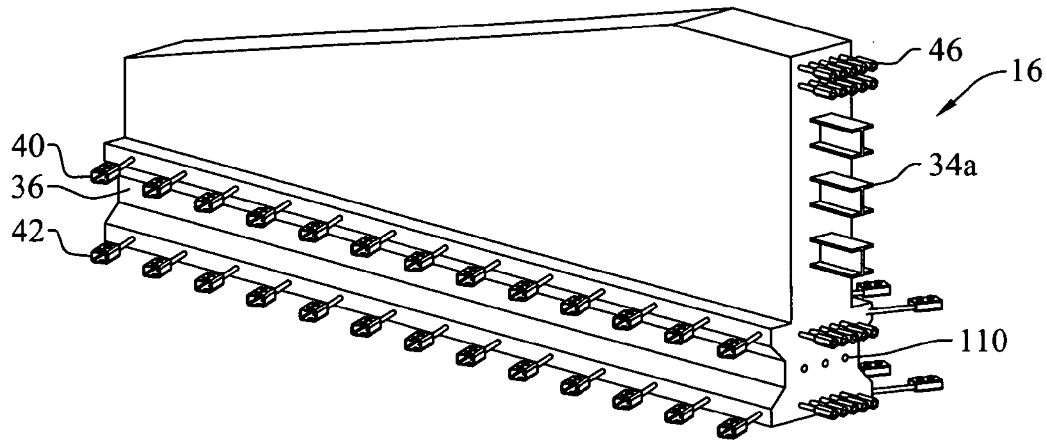


FIG. 3a

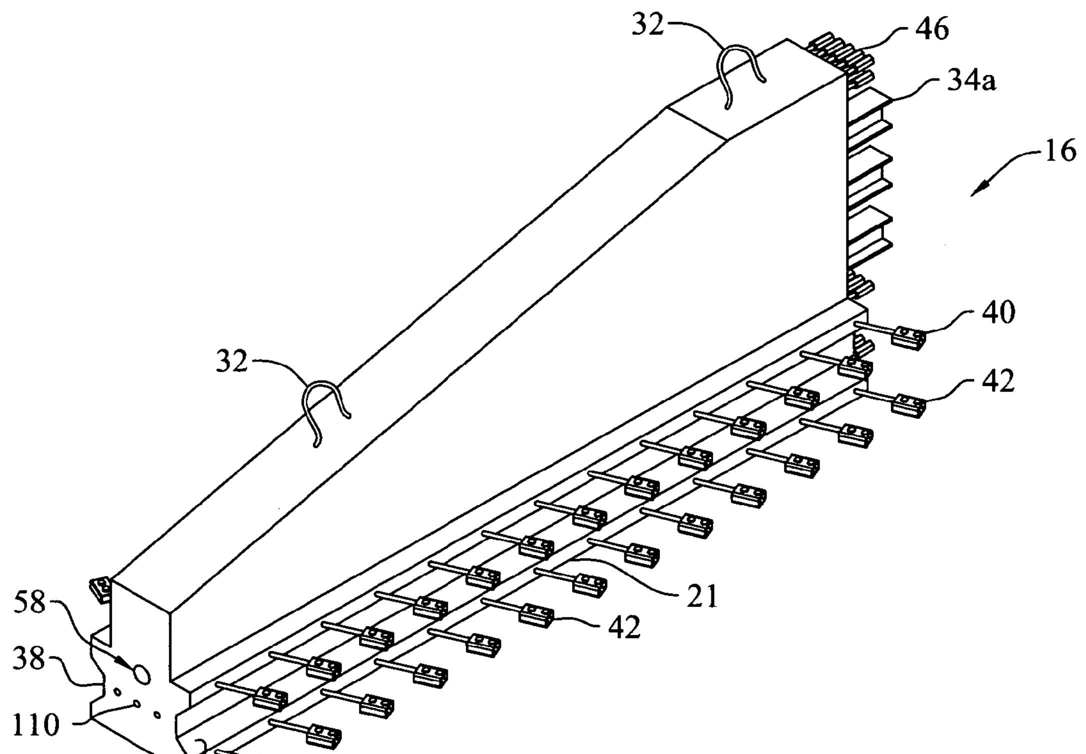
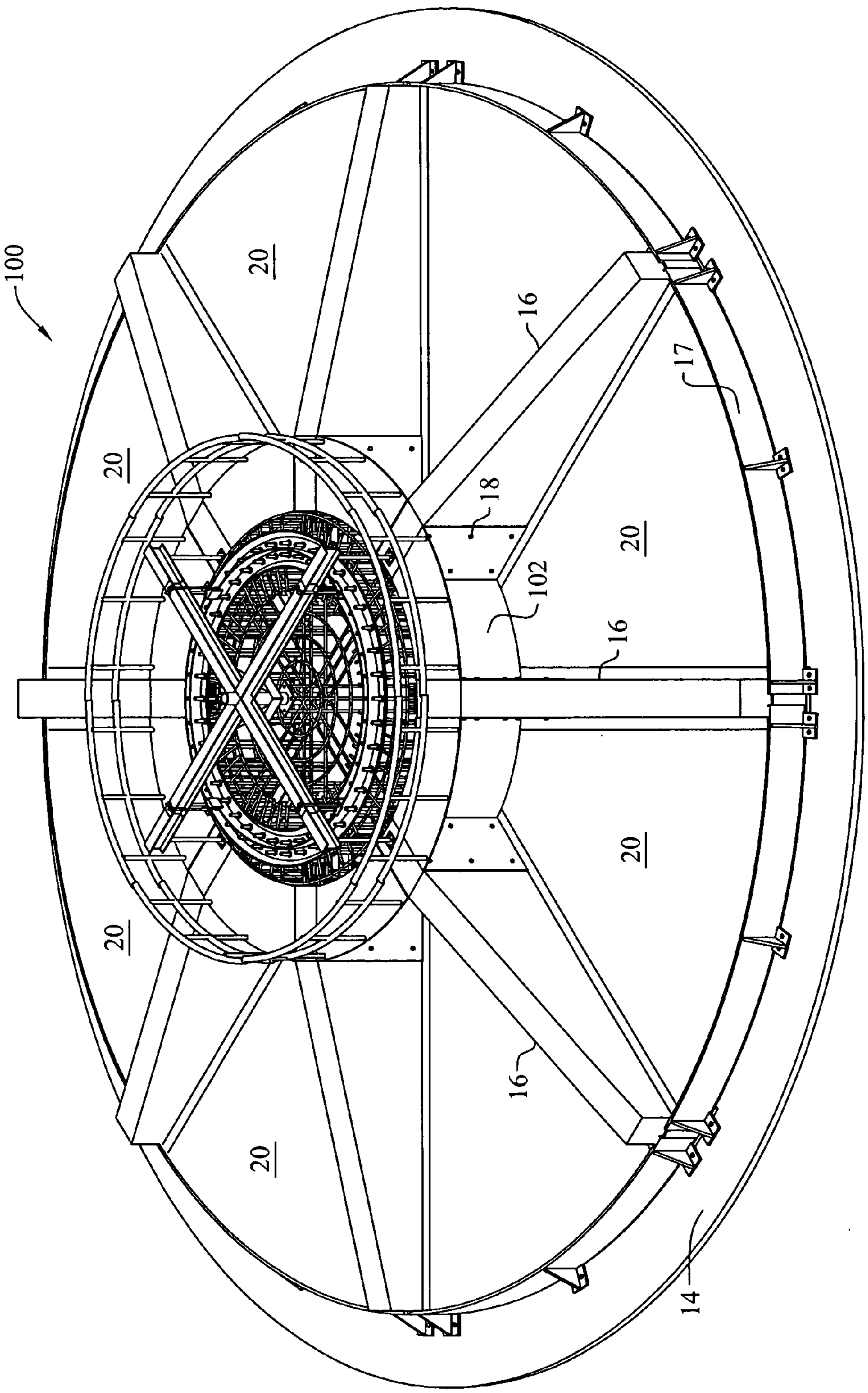


FIG. 3b



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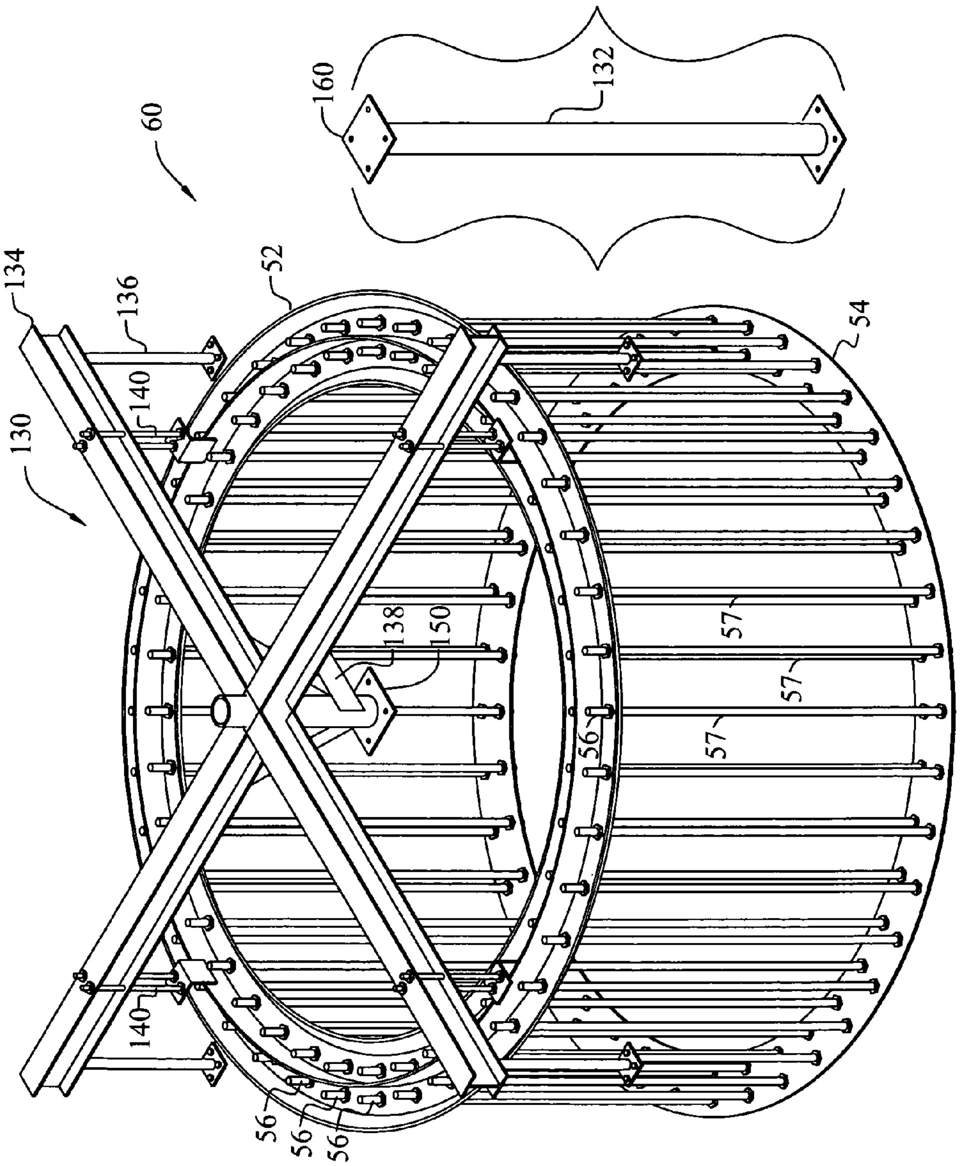

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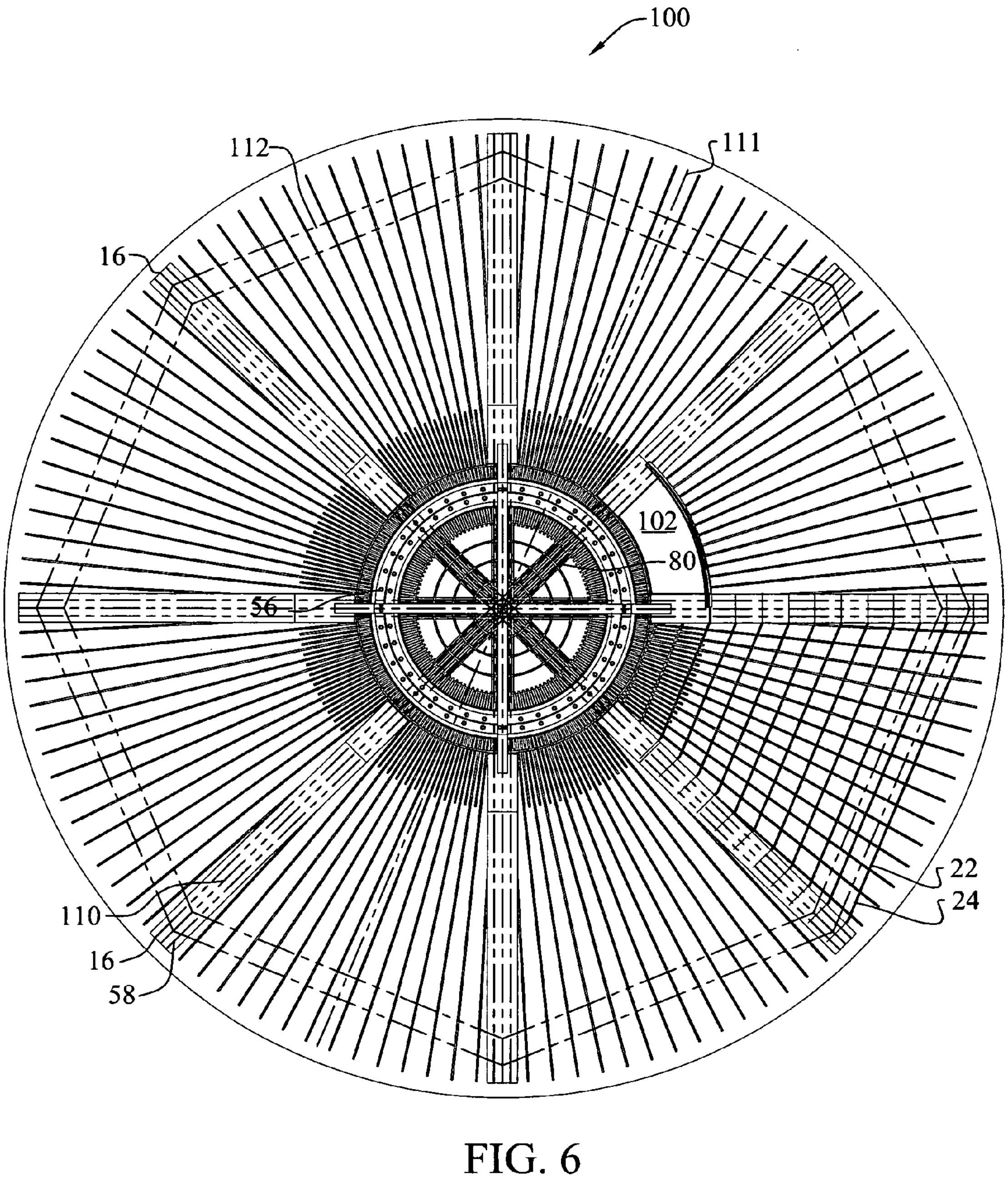

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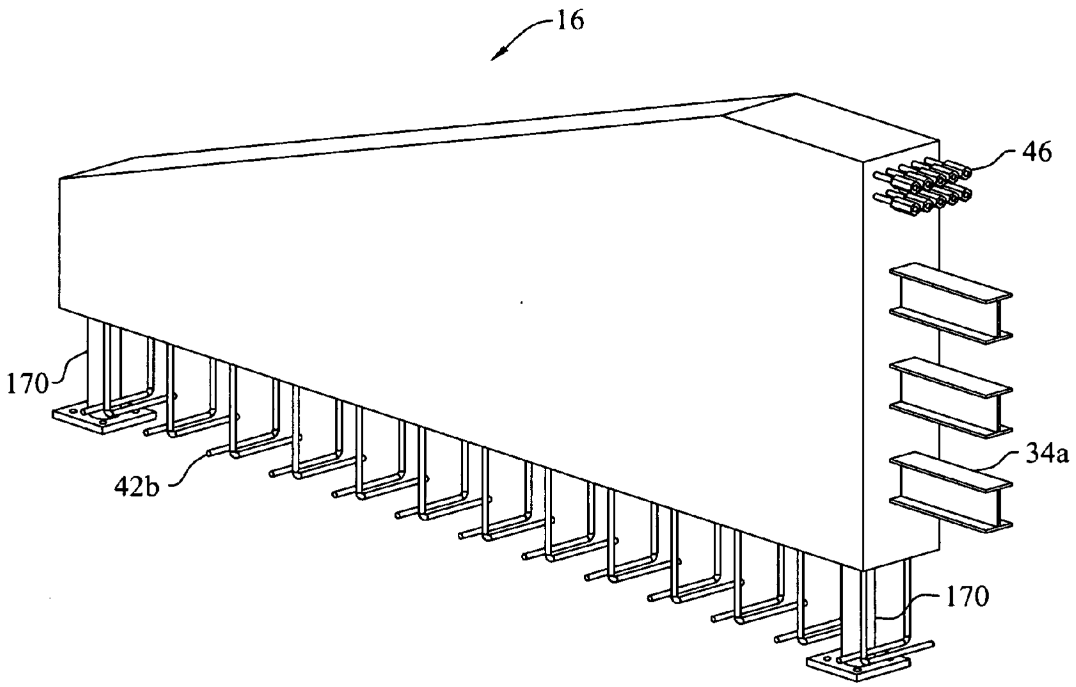

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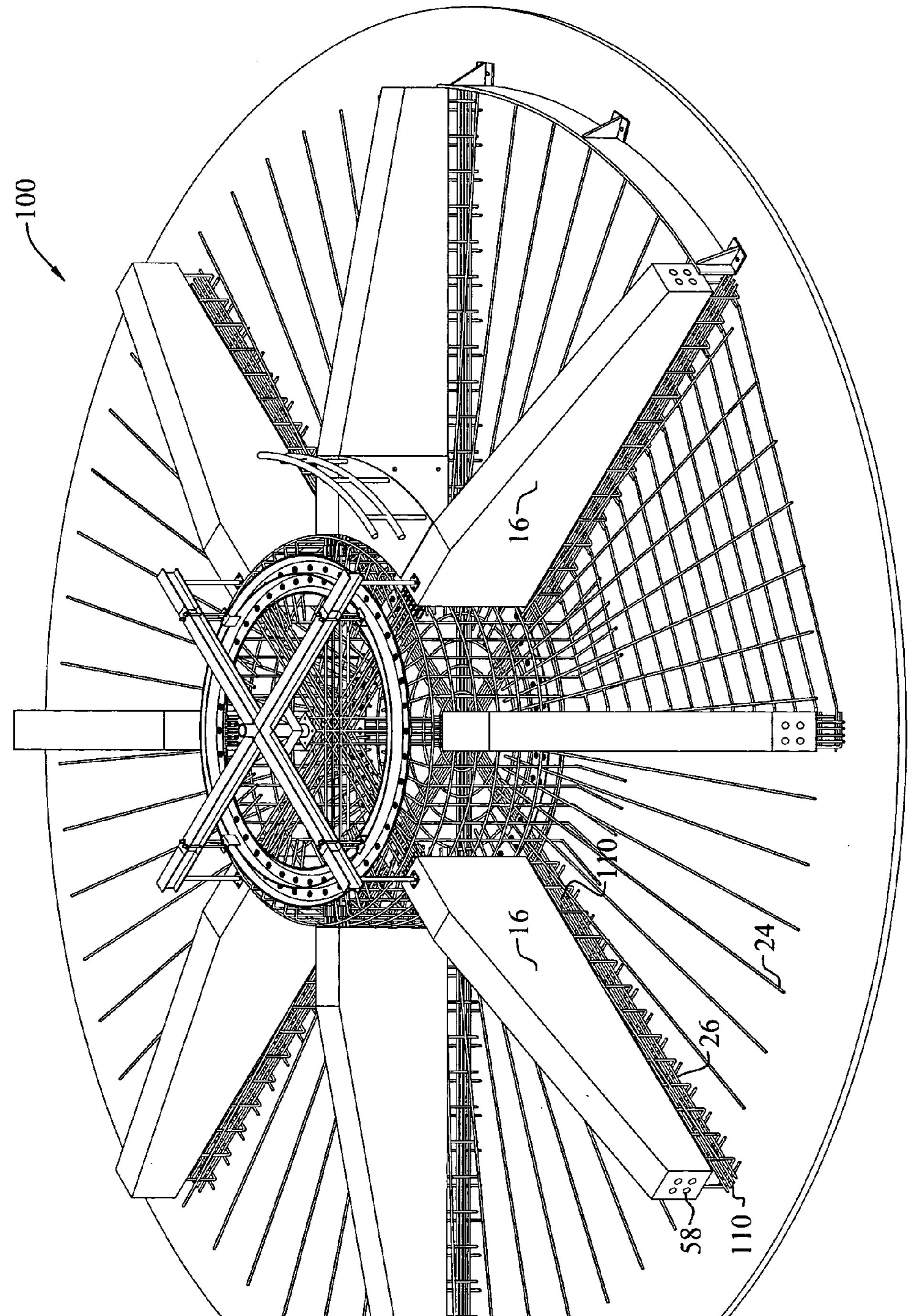

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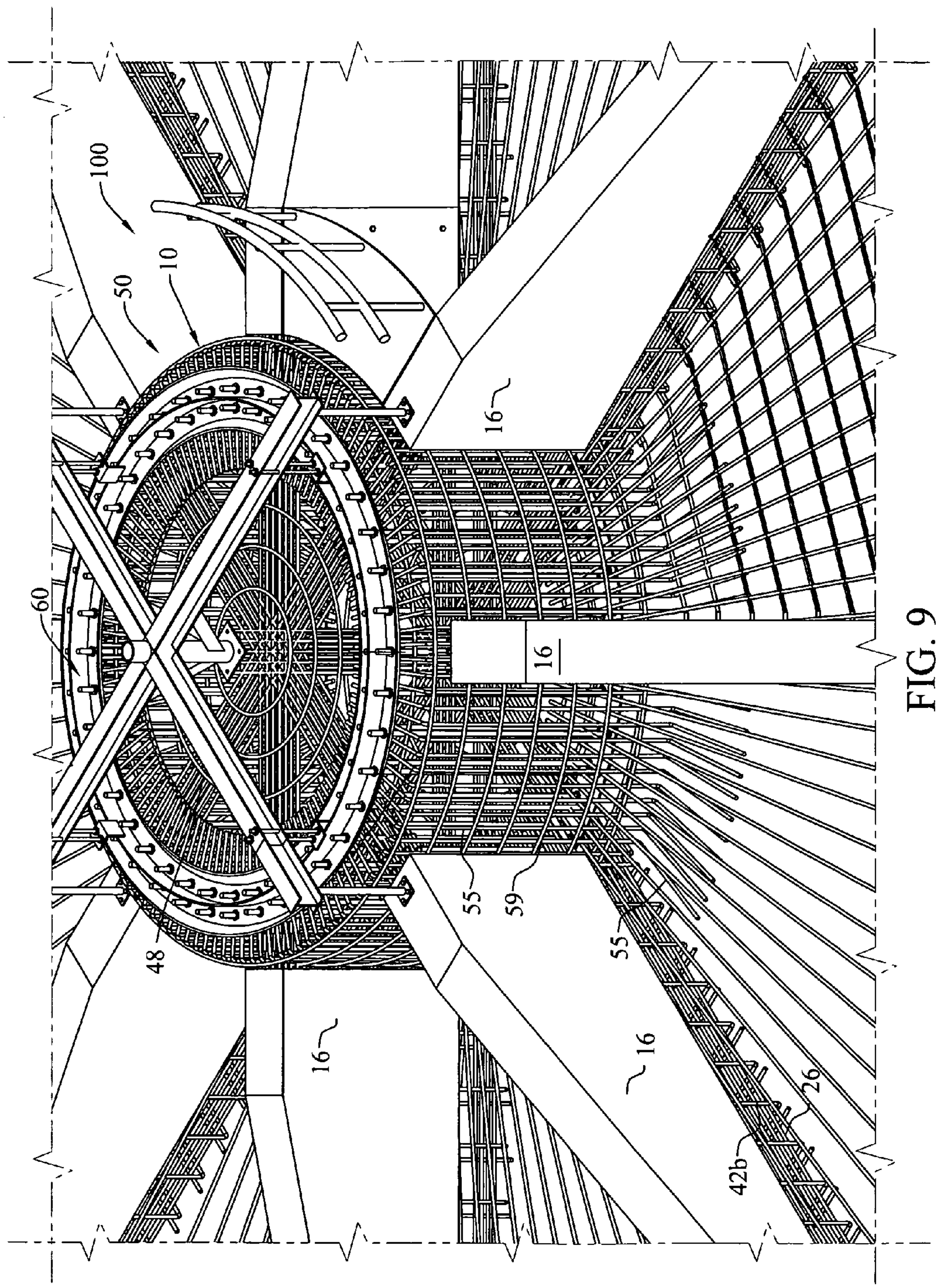

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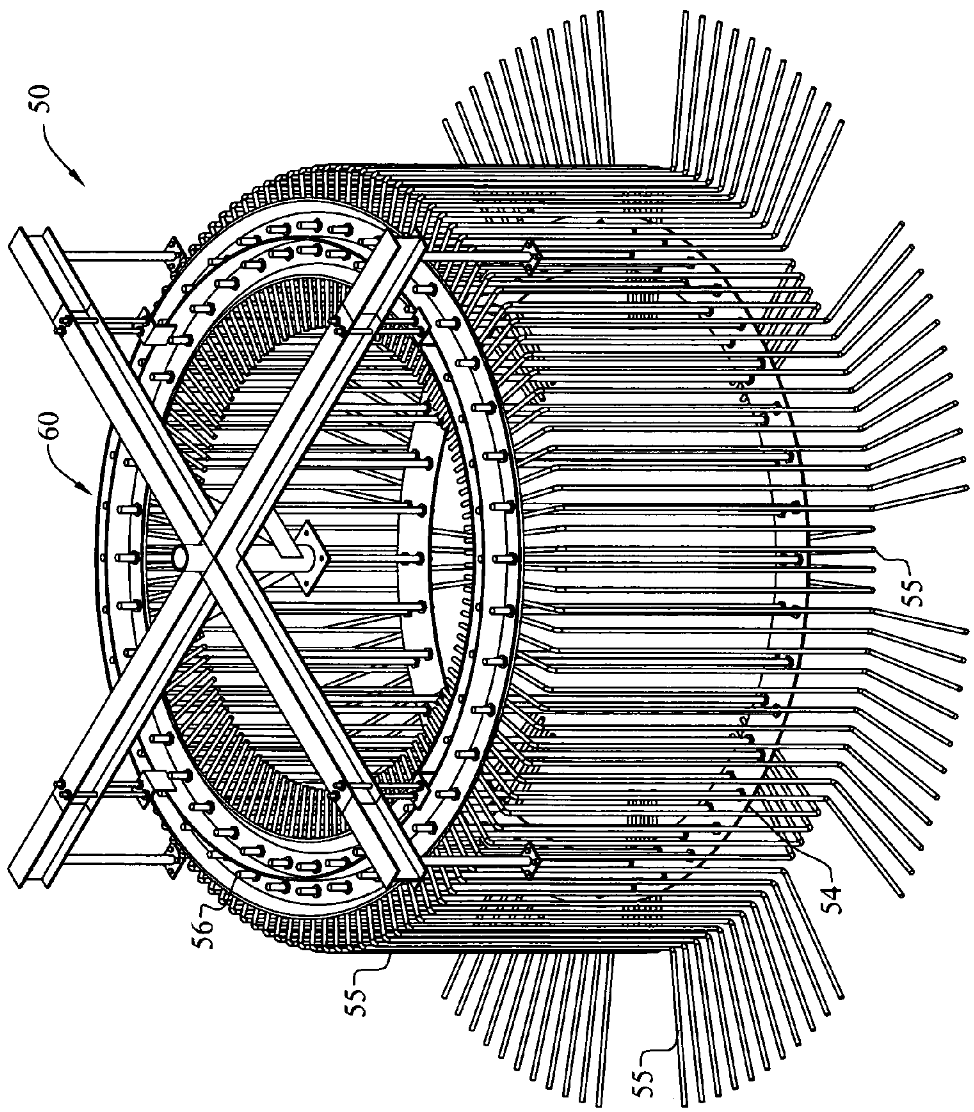

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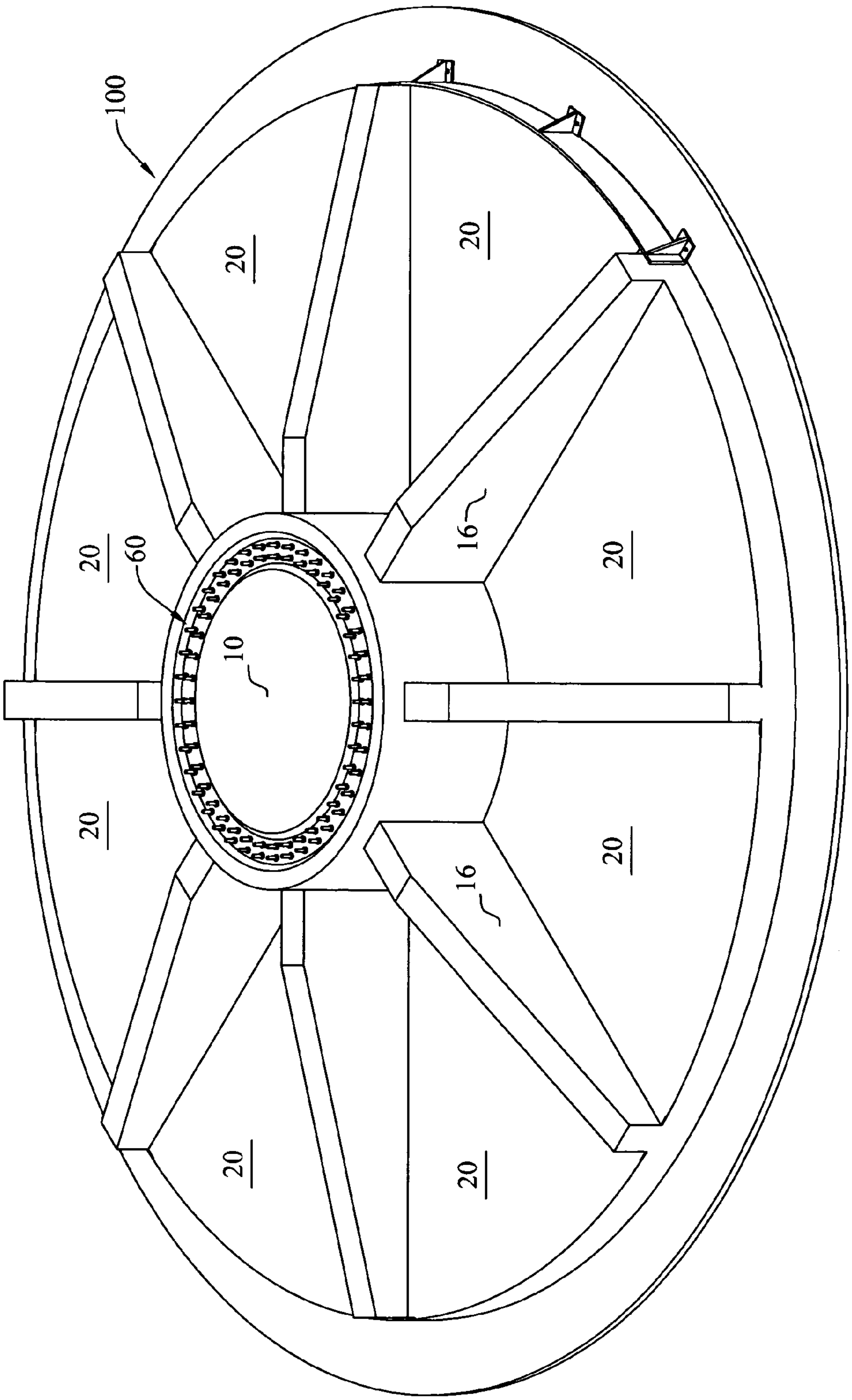


FIG. 11

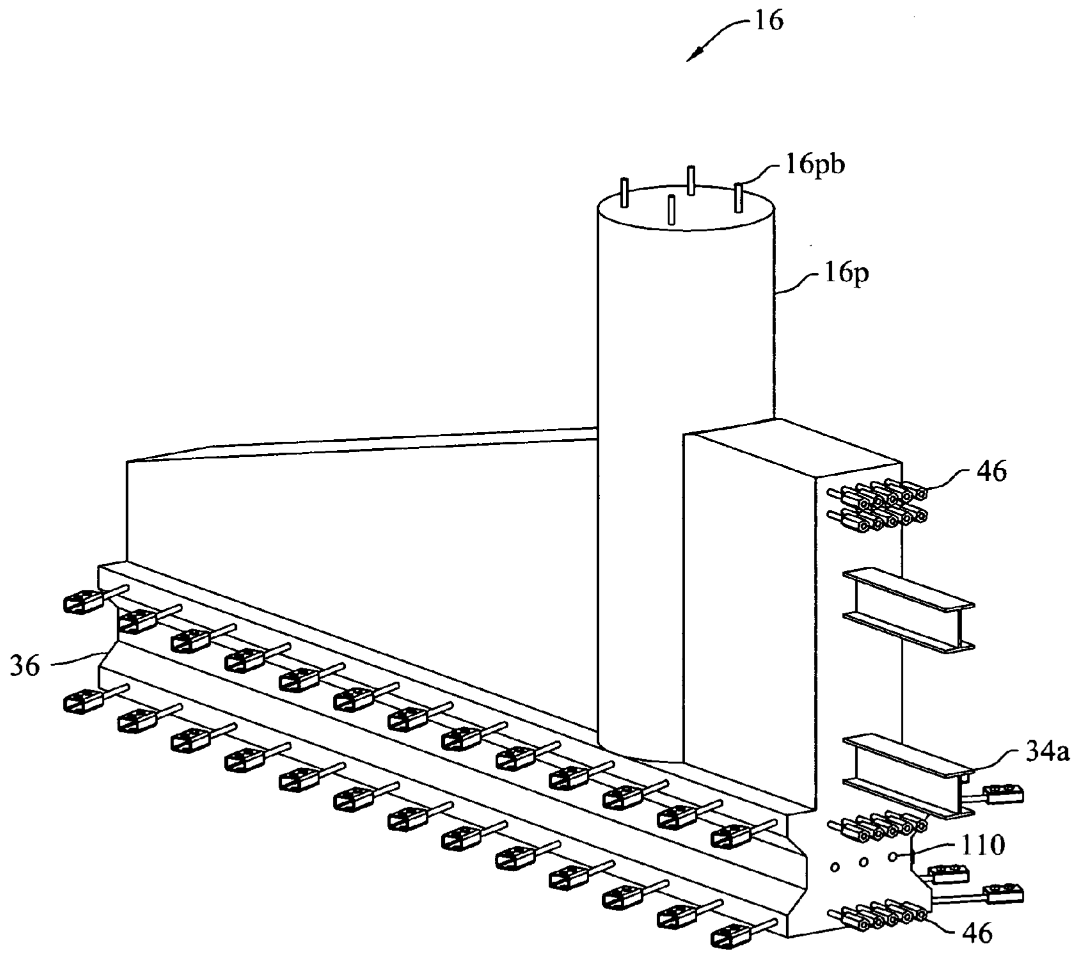
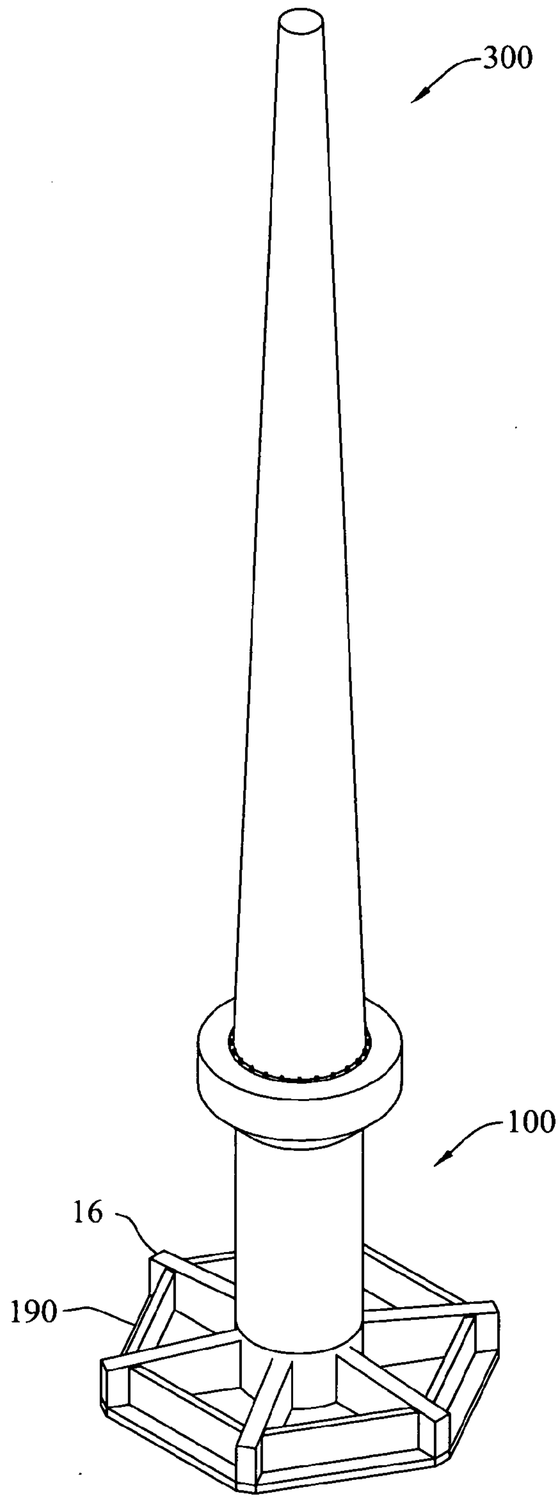


FIG. 12



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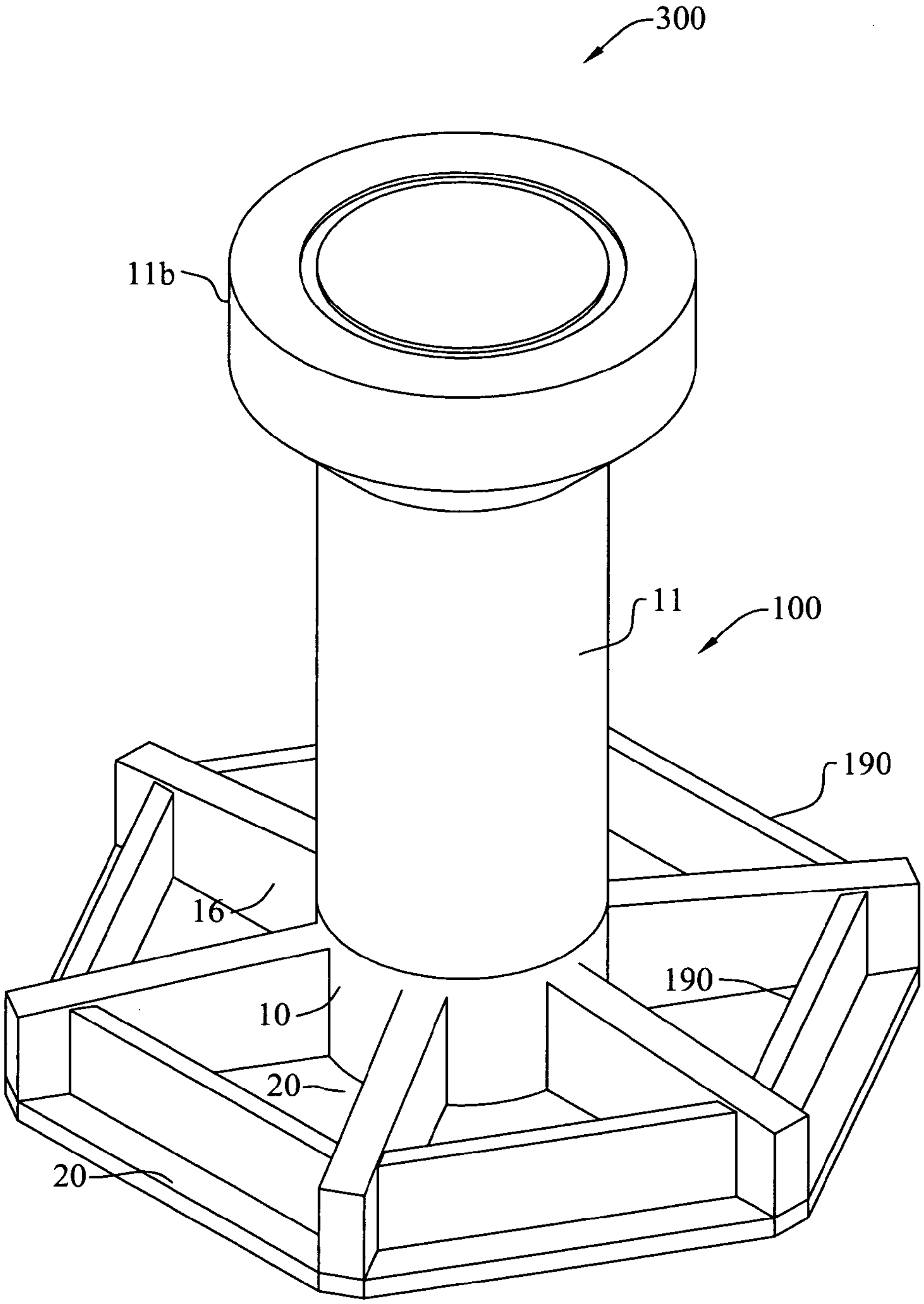

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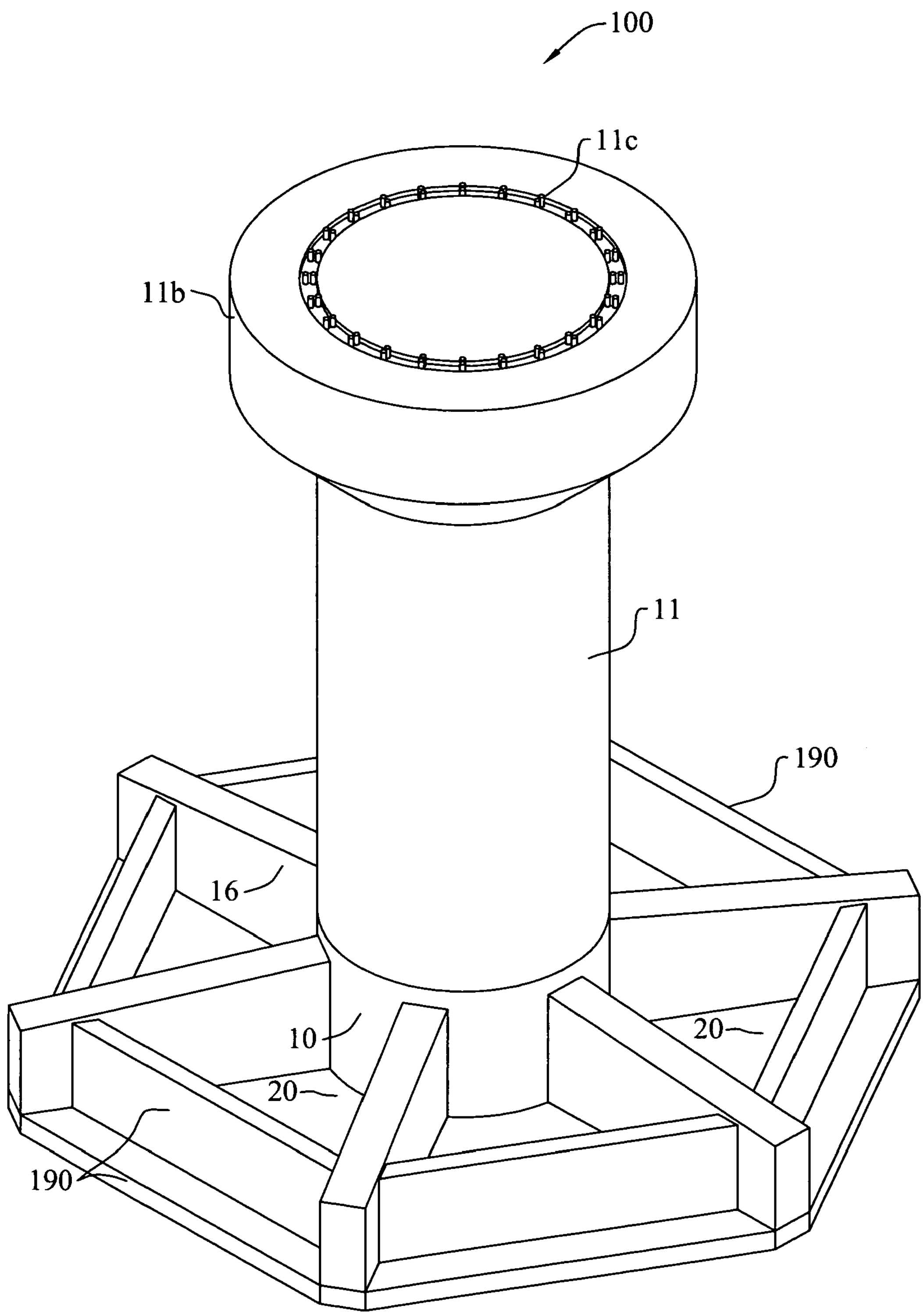

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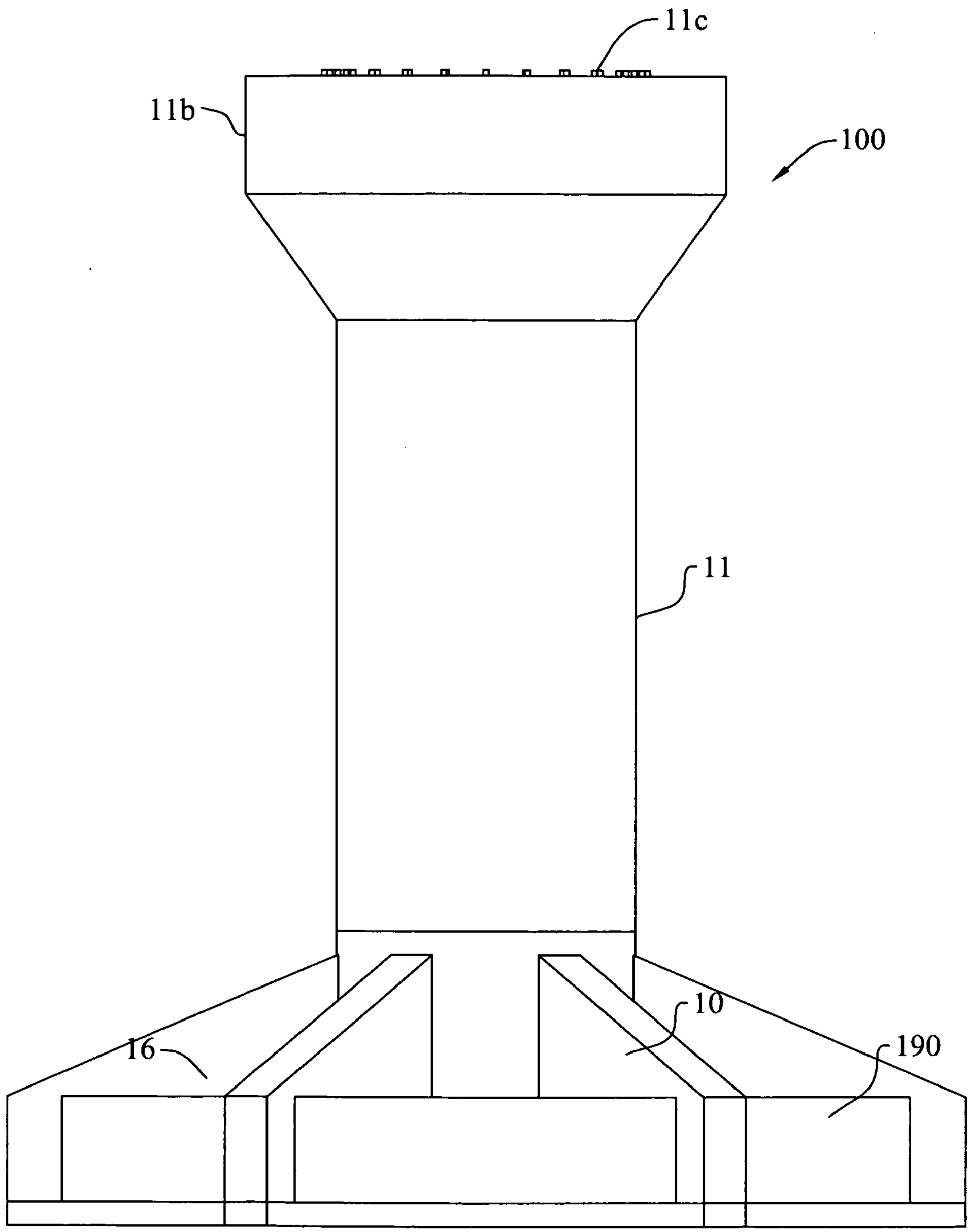

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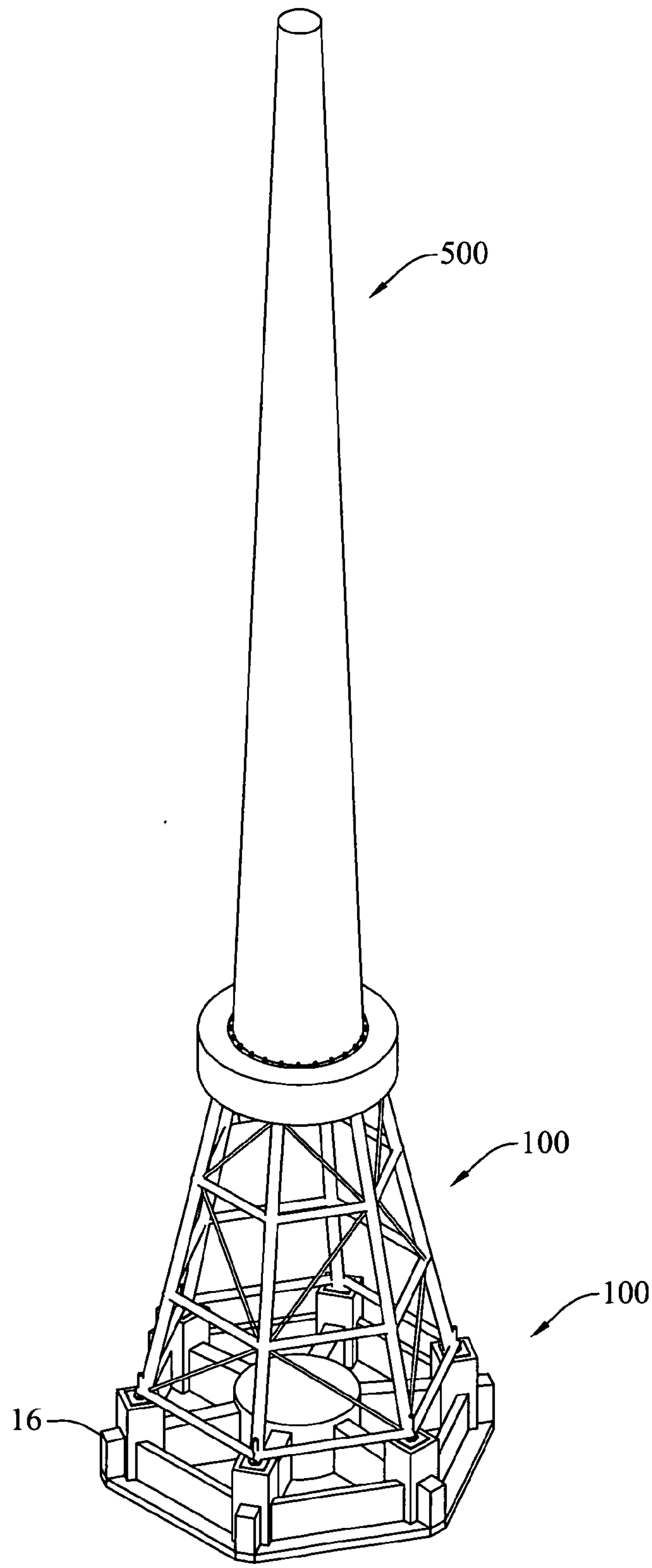

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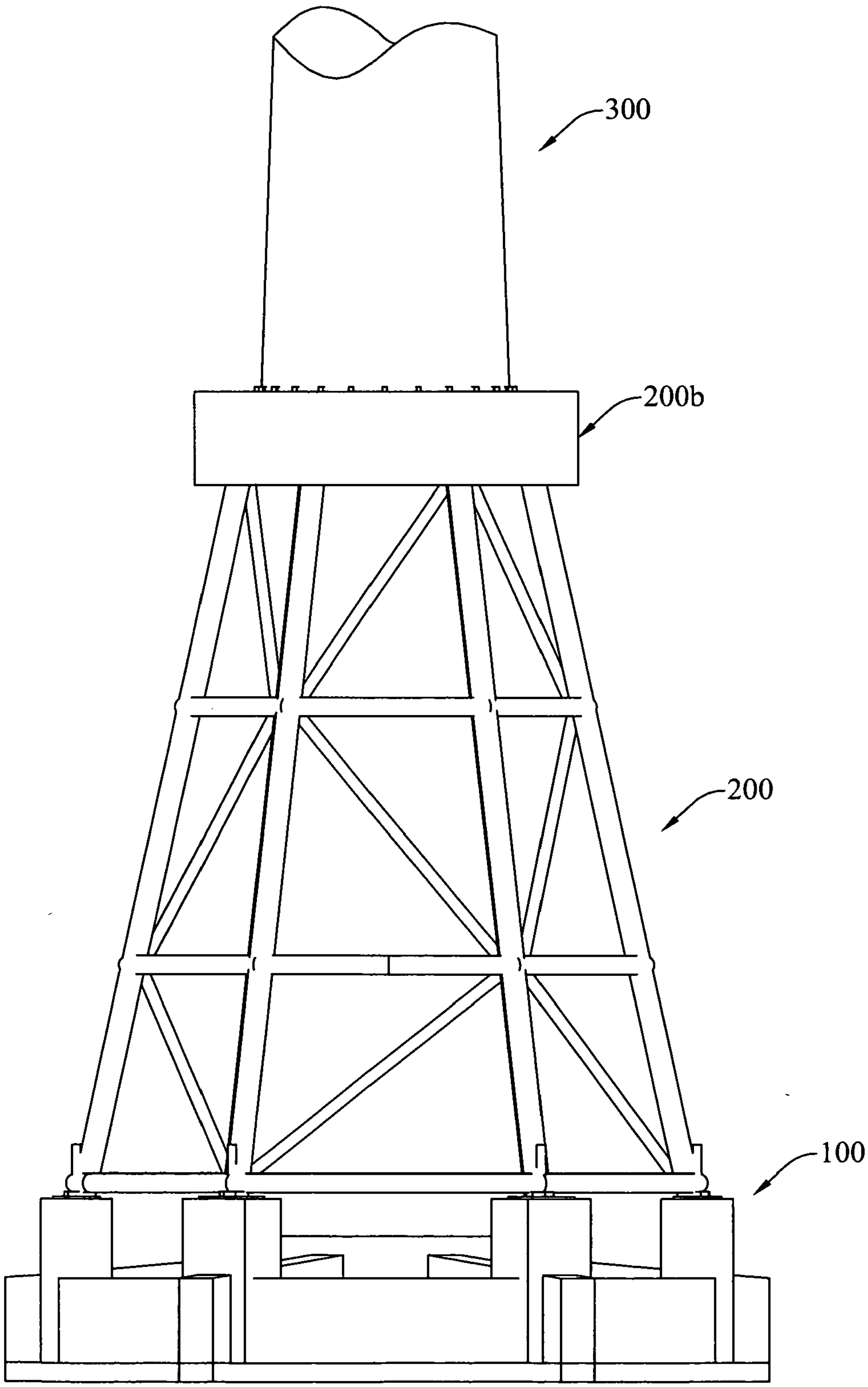

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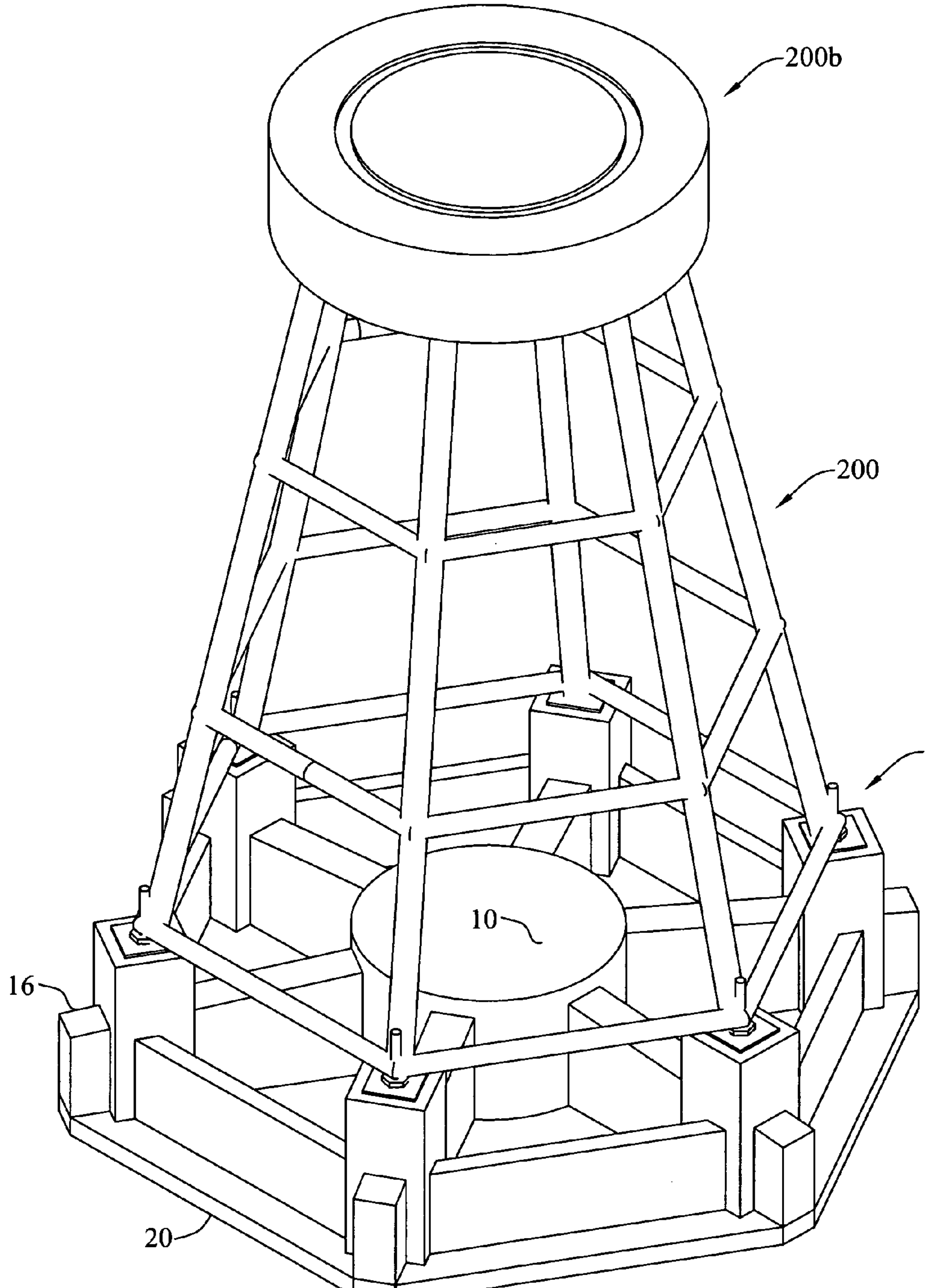


FIG. 19

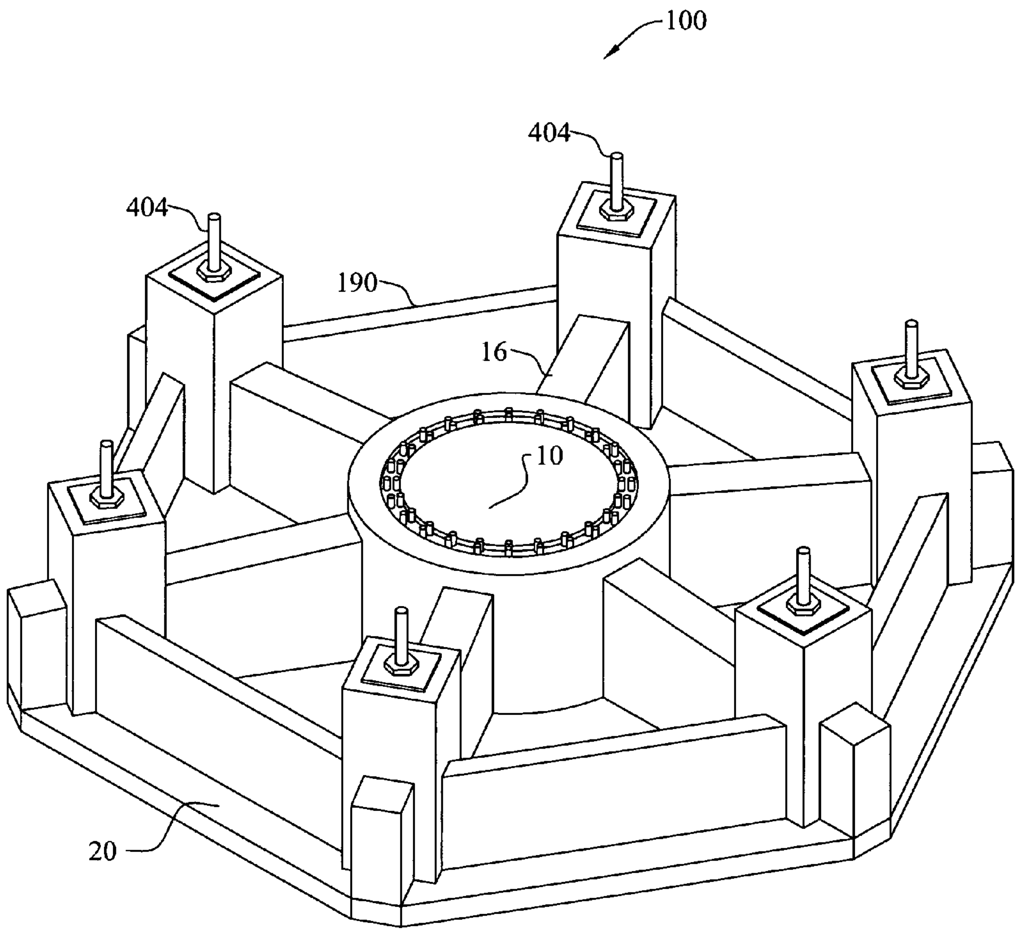
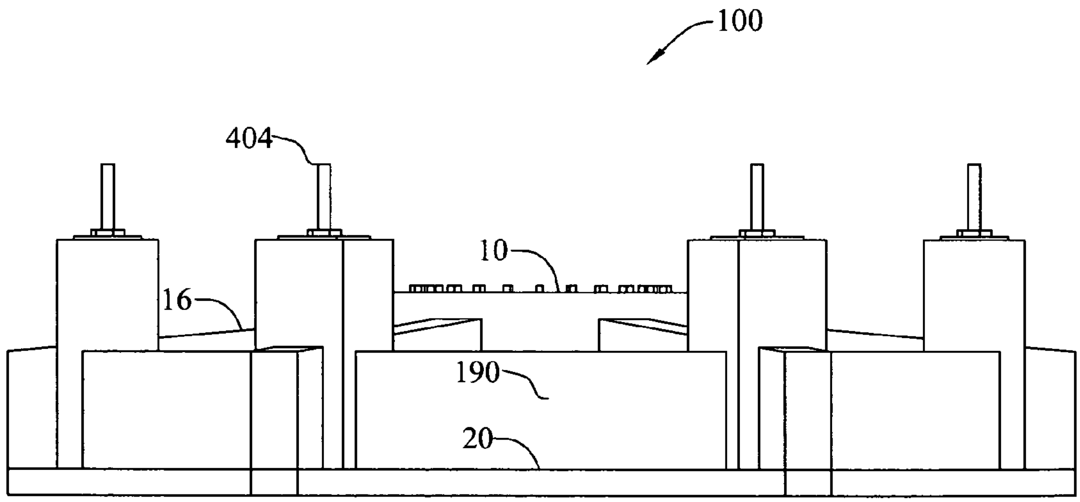


FIG. 20



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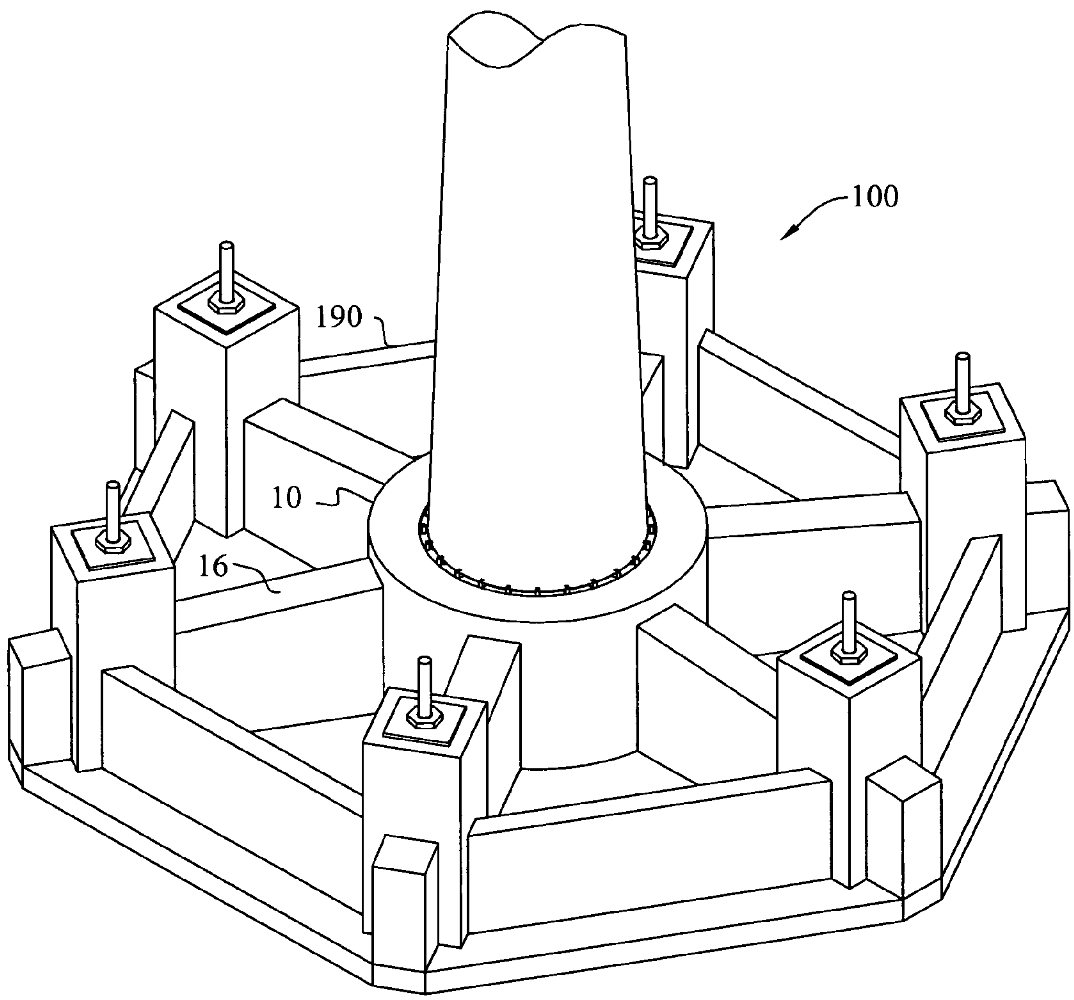

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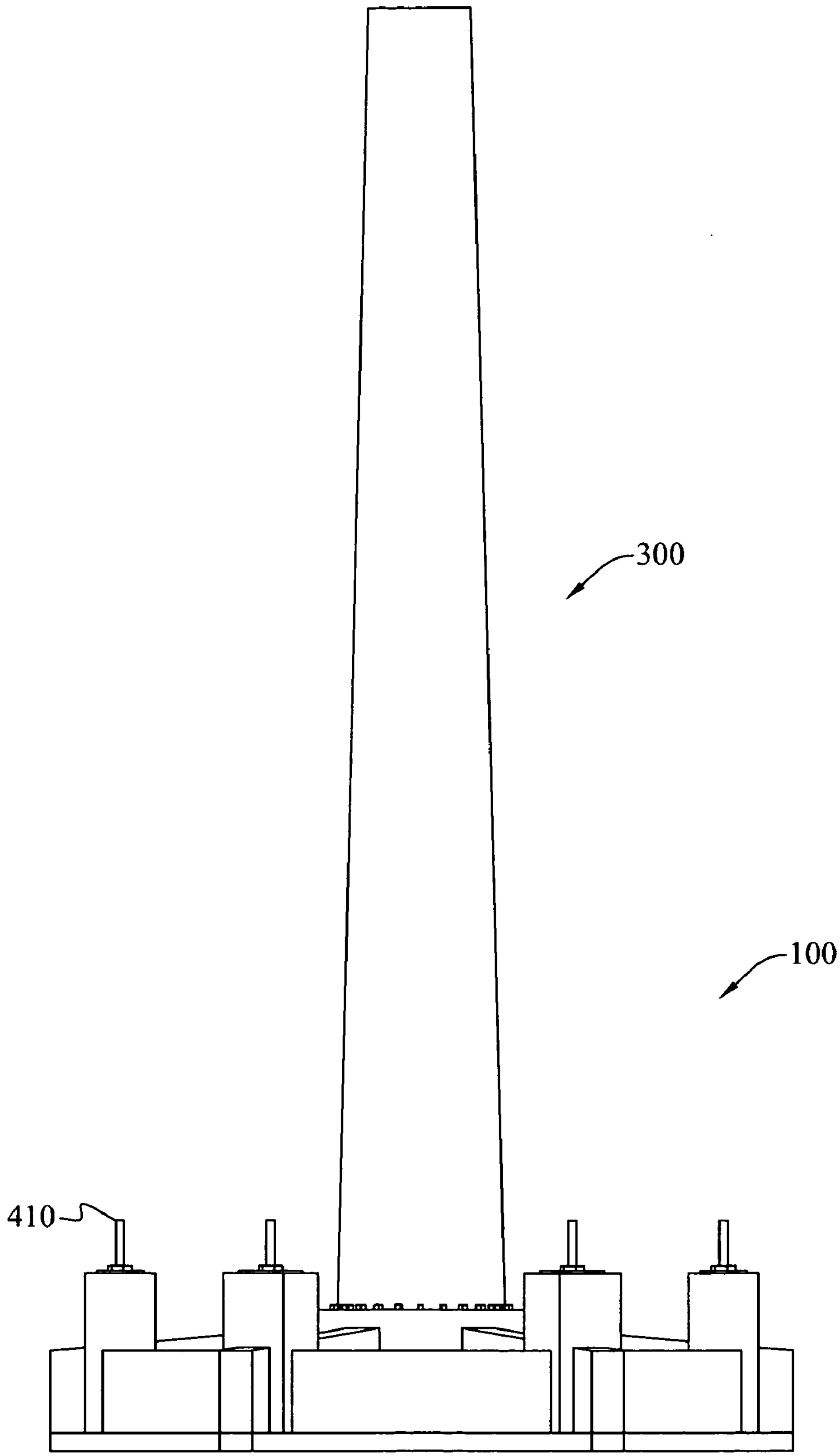

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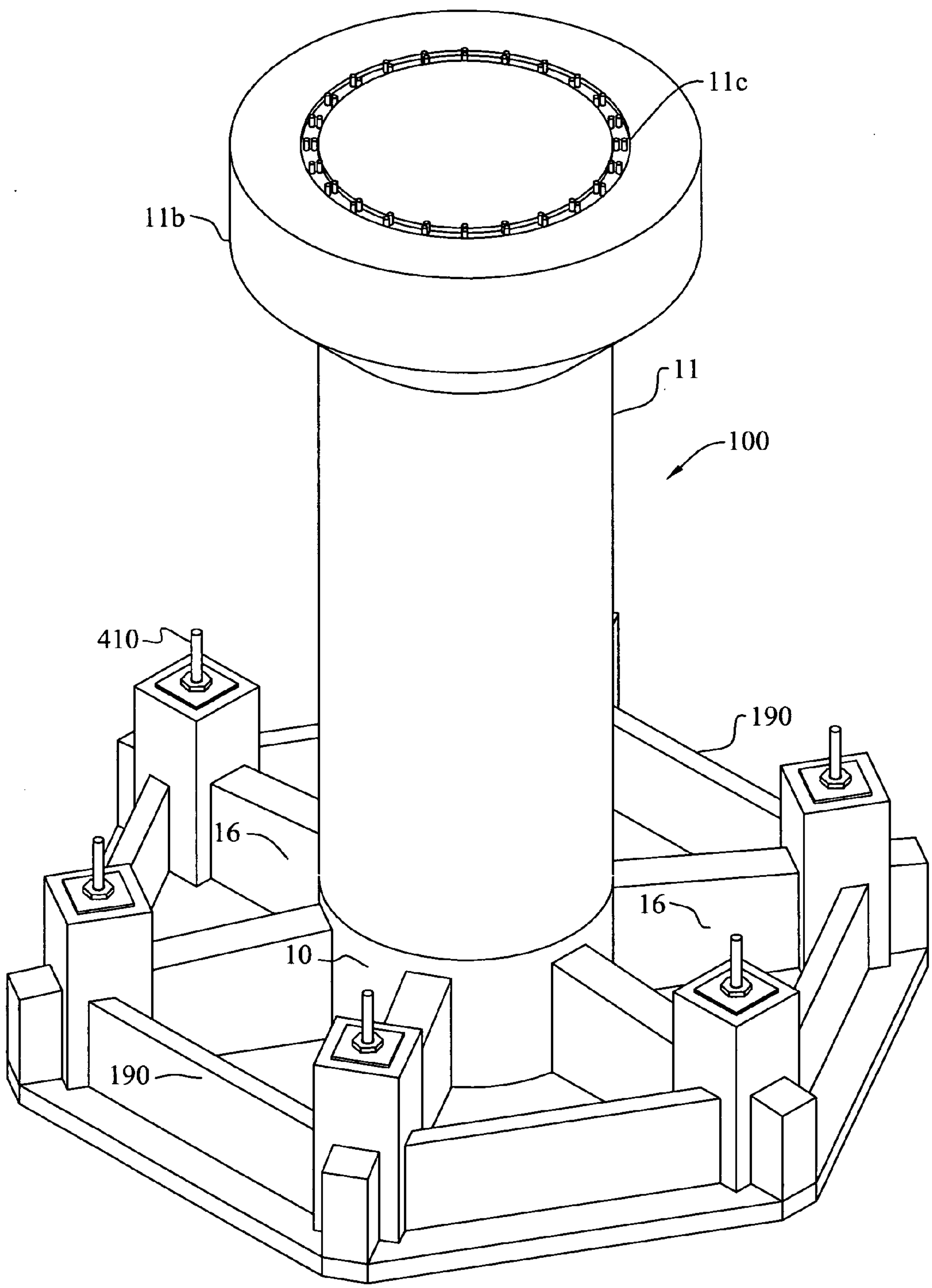
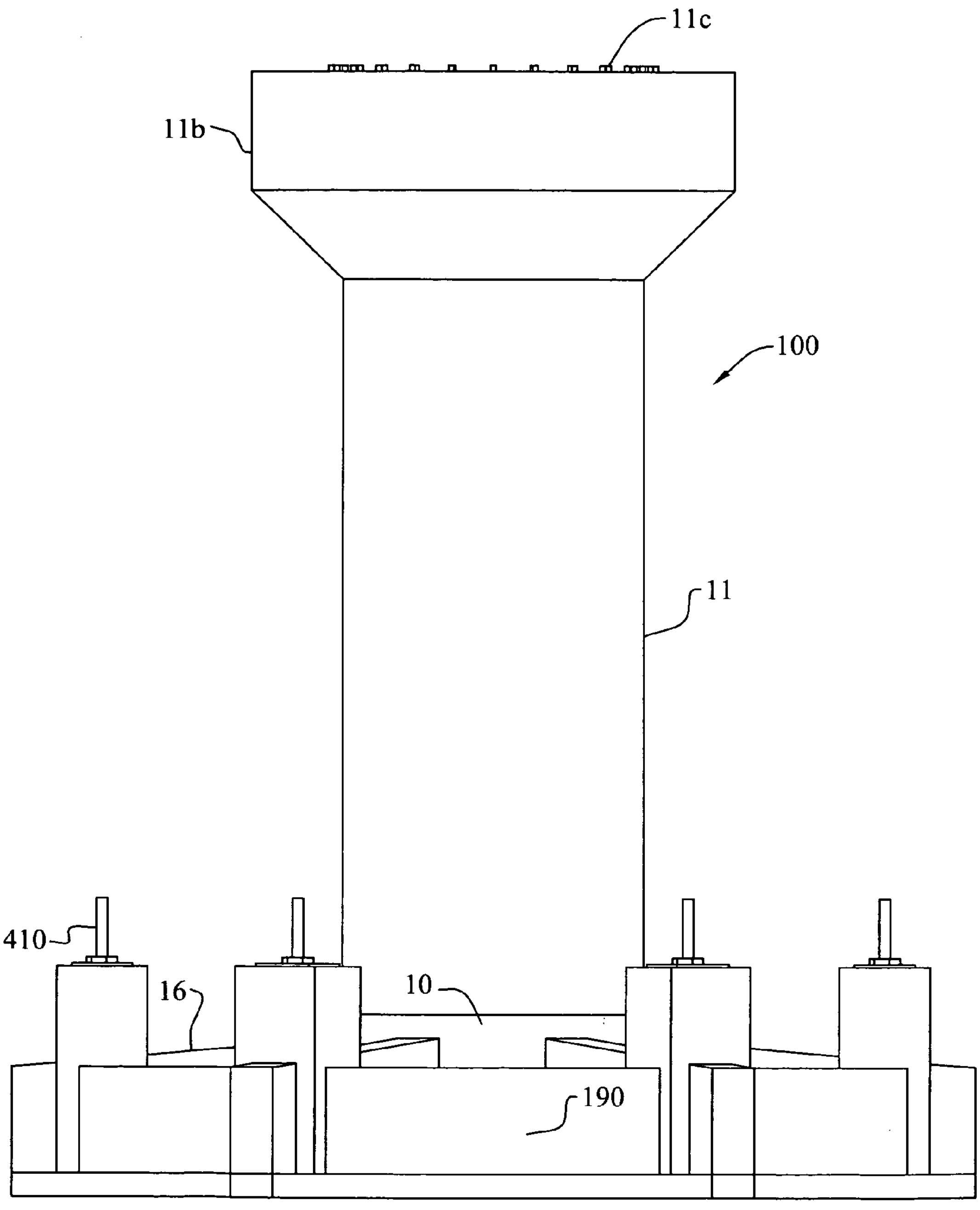


FIG. 24



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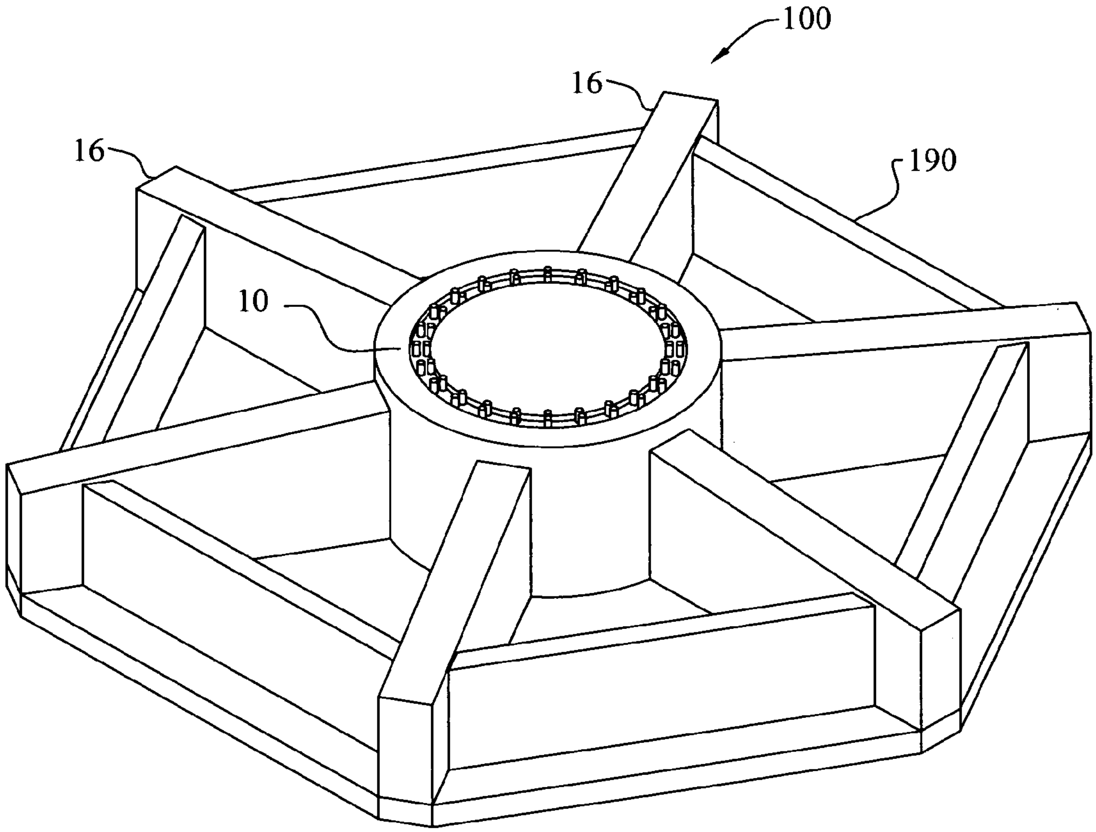


FIG. 26

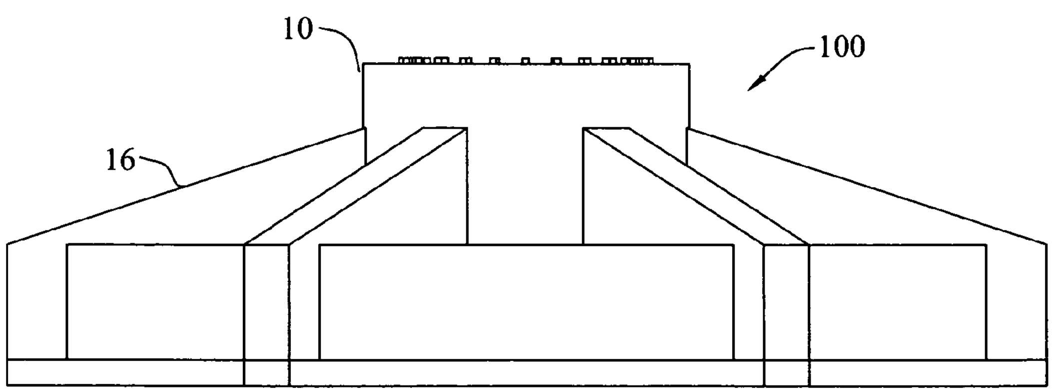
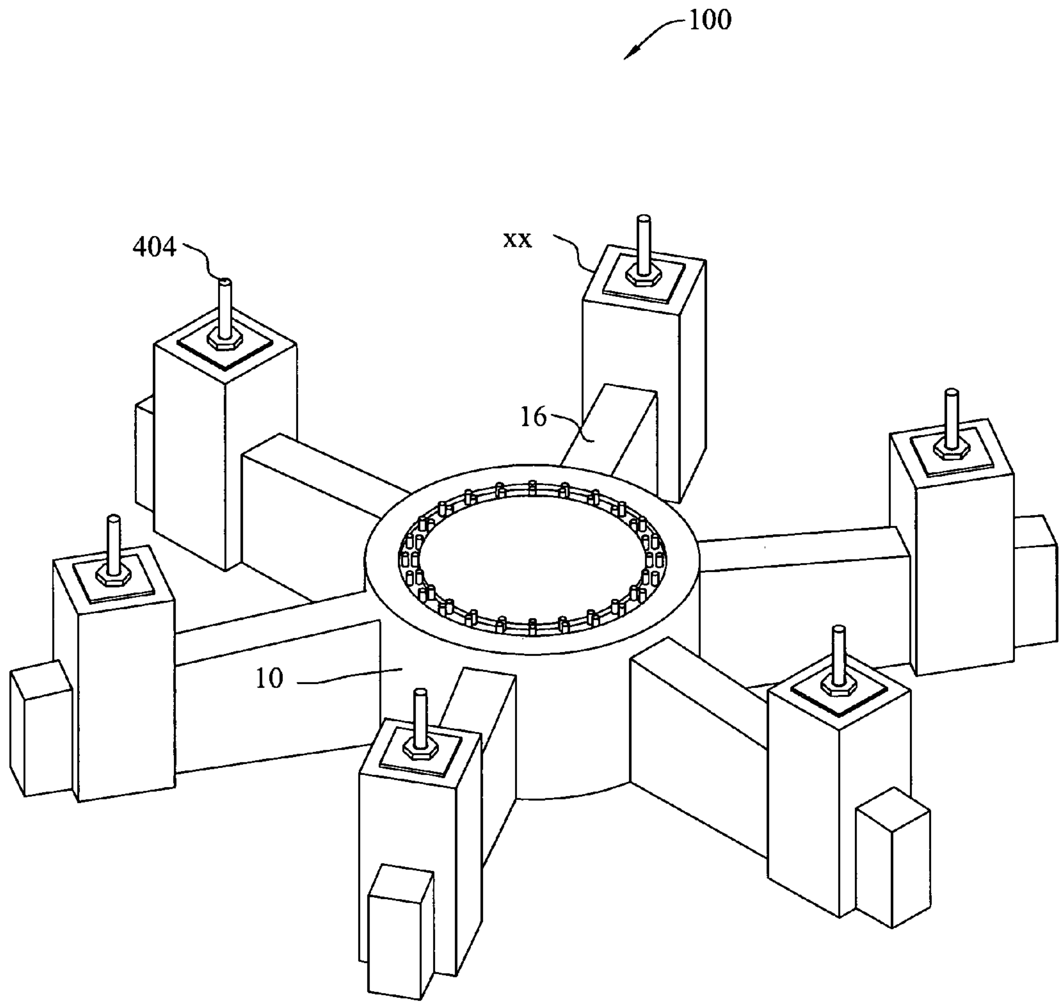


FIG. 27



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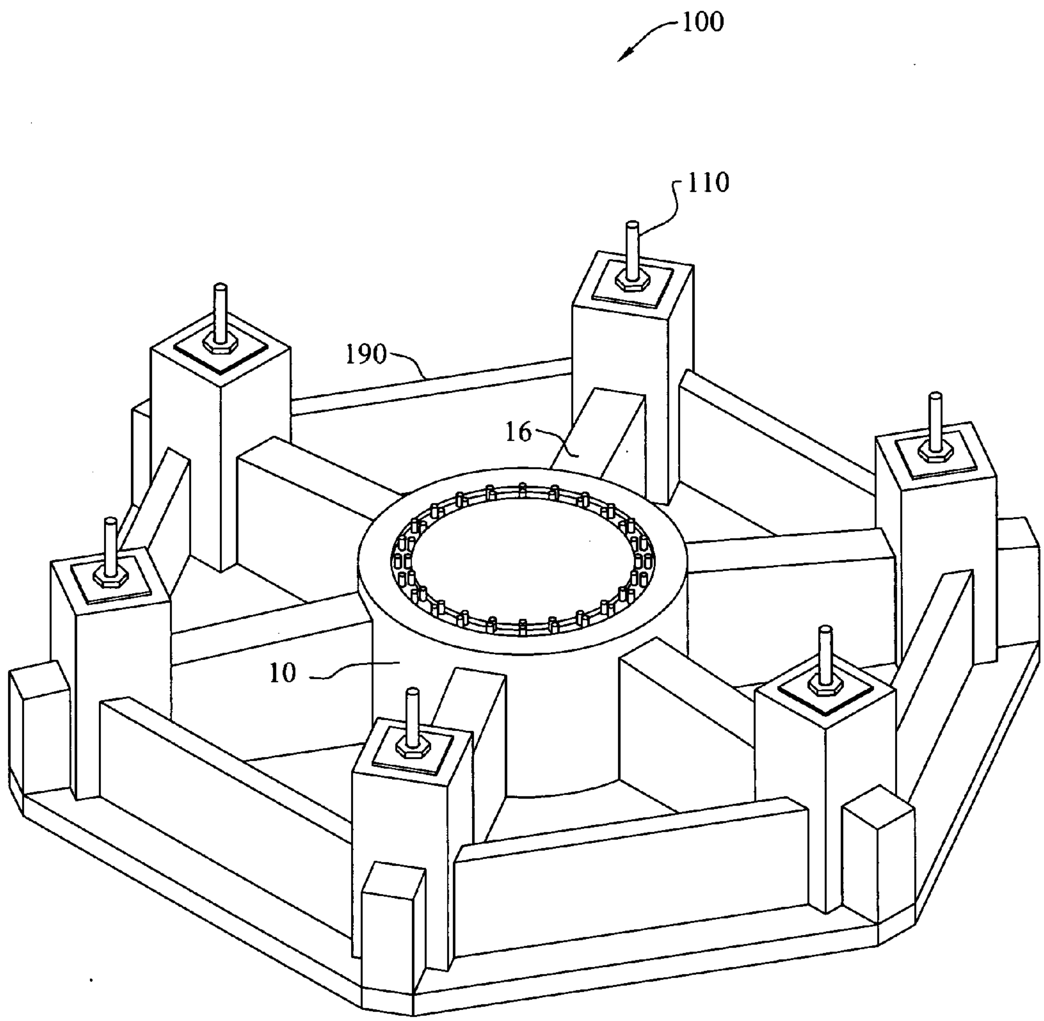


FIG. 29

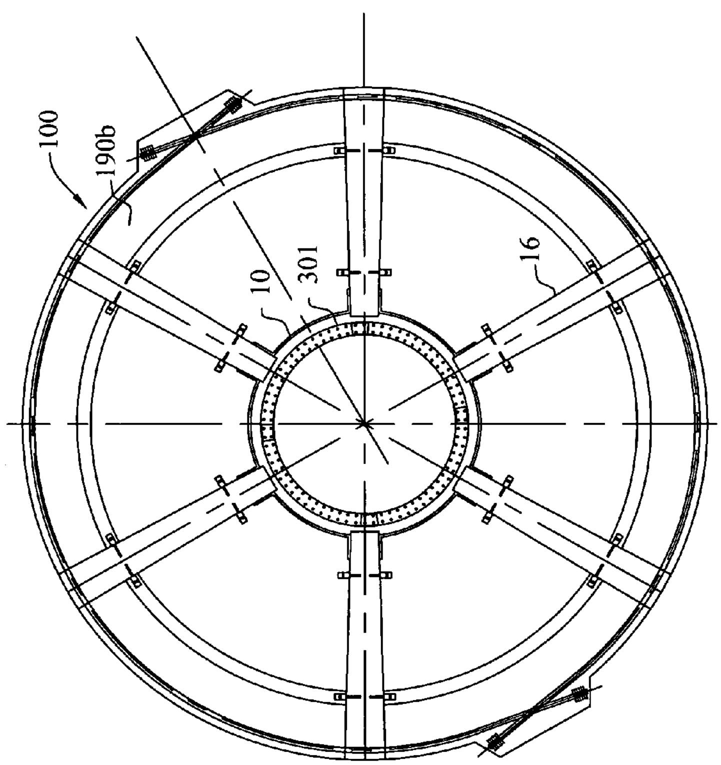


FIG. 30b

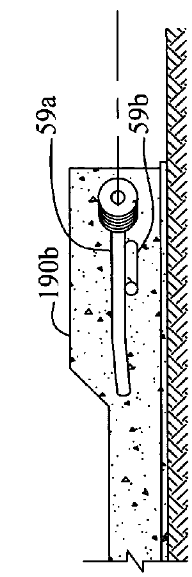


FIG. 30d

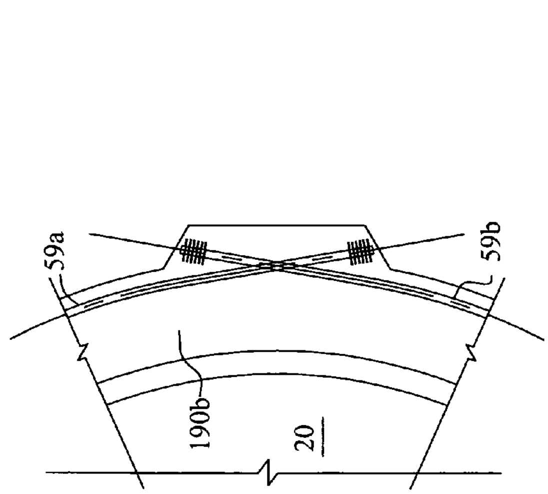


FIG. 30a

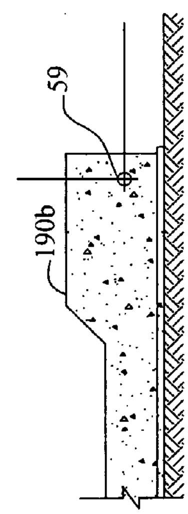


FIG. 30c

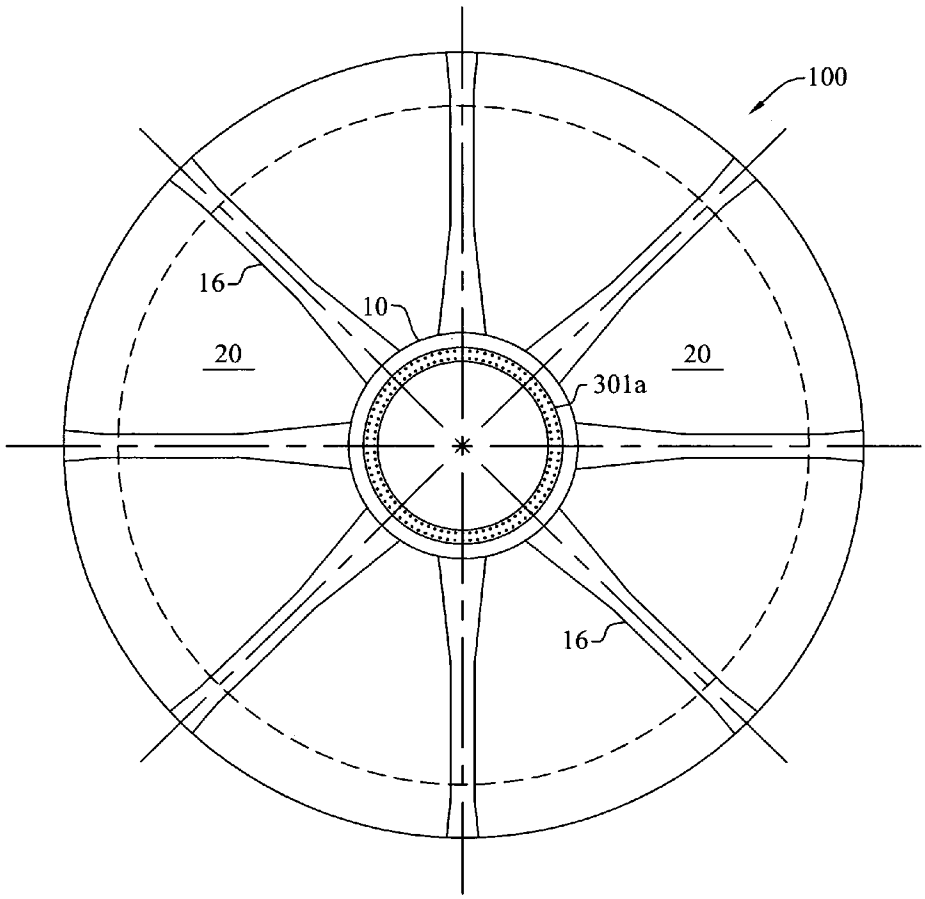


FIG. 31a

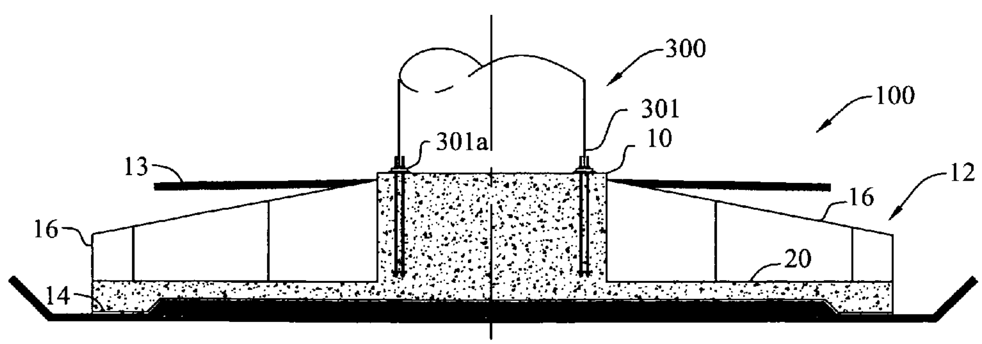


FIG. 31b

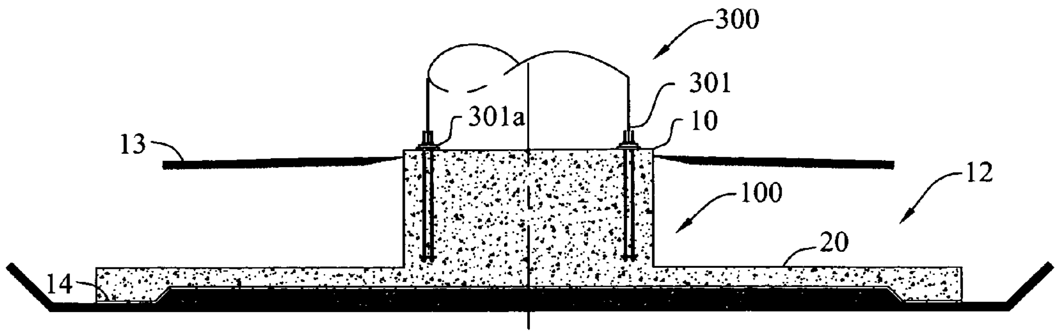


FIG. 32a

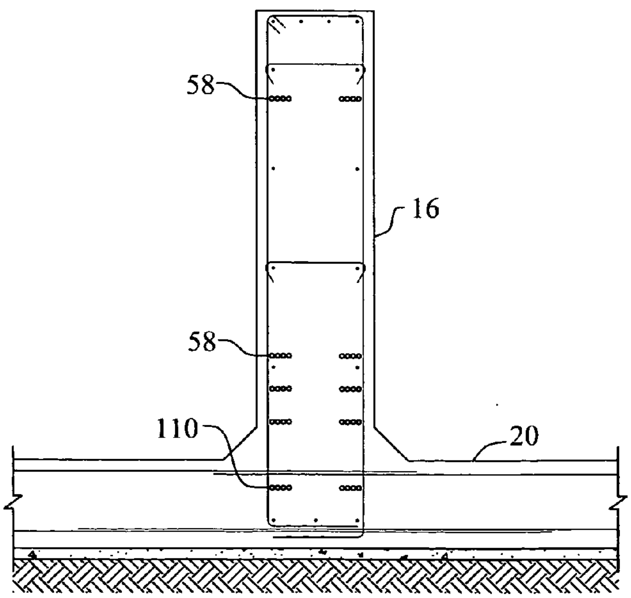


FIG. 32b

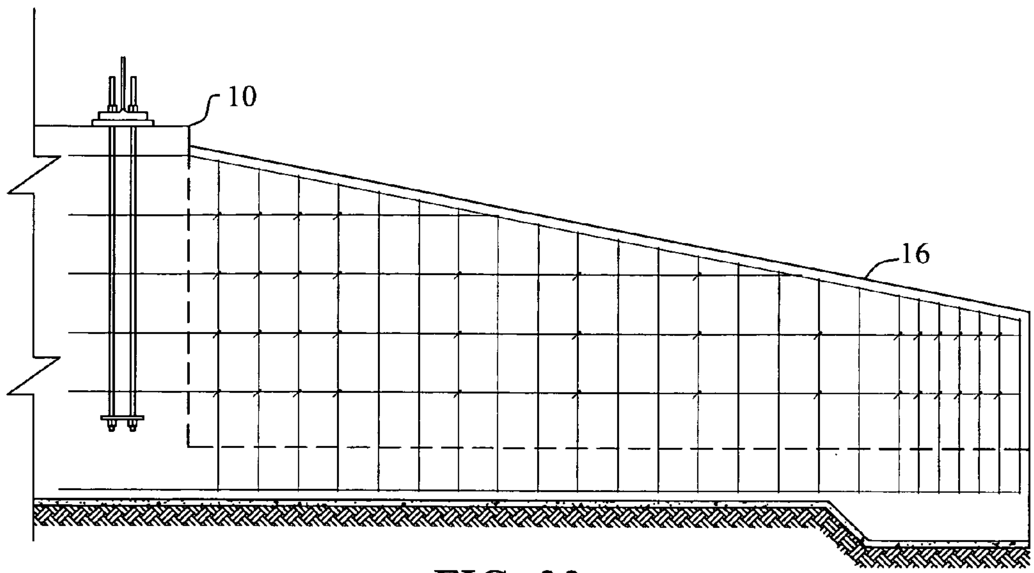


FIG. 33a

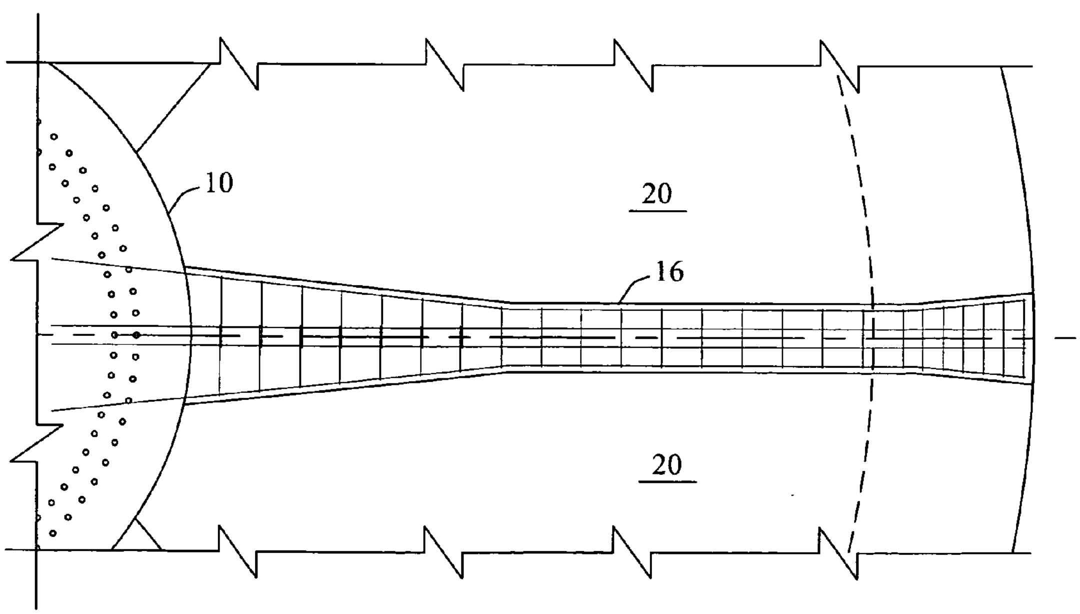
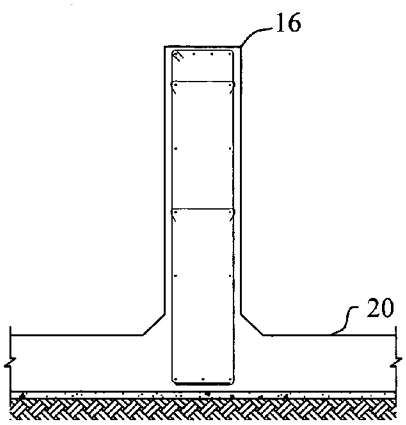


FIG. 33b



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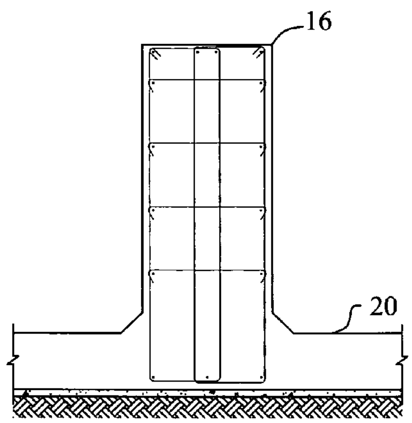


FIG. 34b

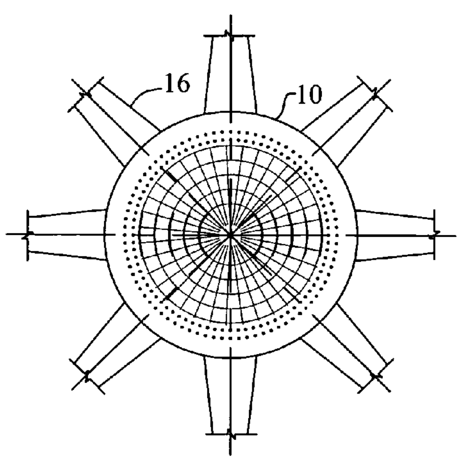


FIG. 34c

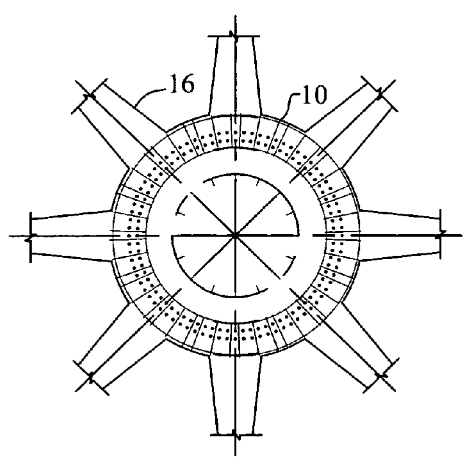


FIG. 34d

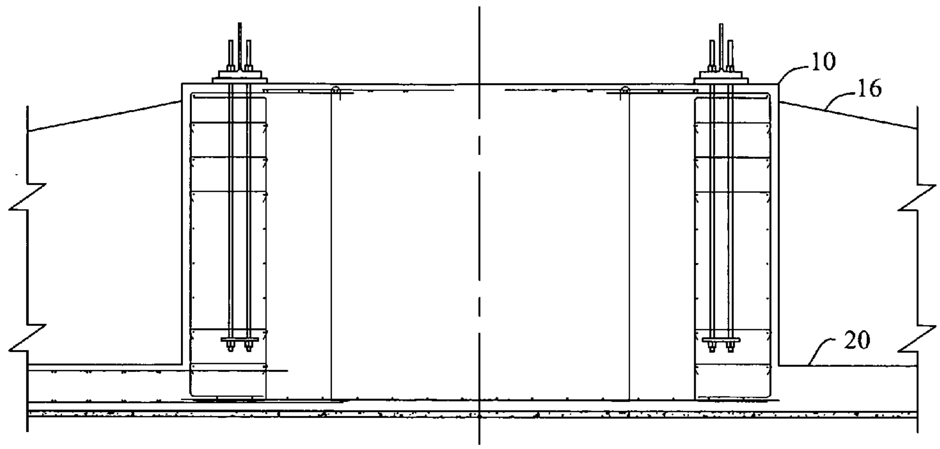
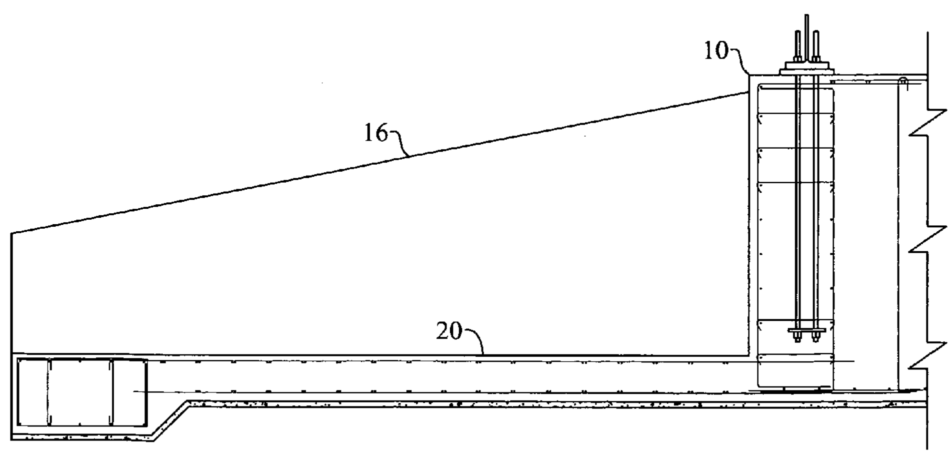


FIG. 35a



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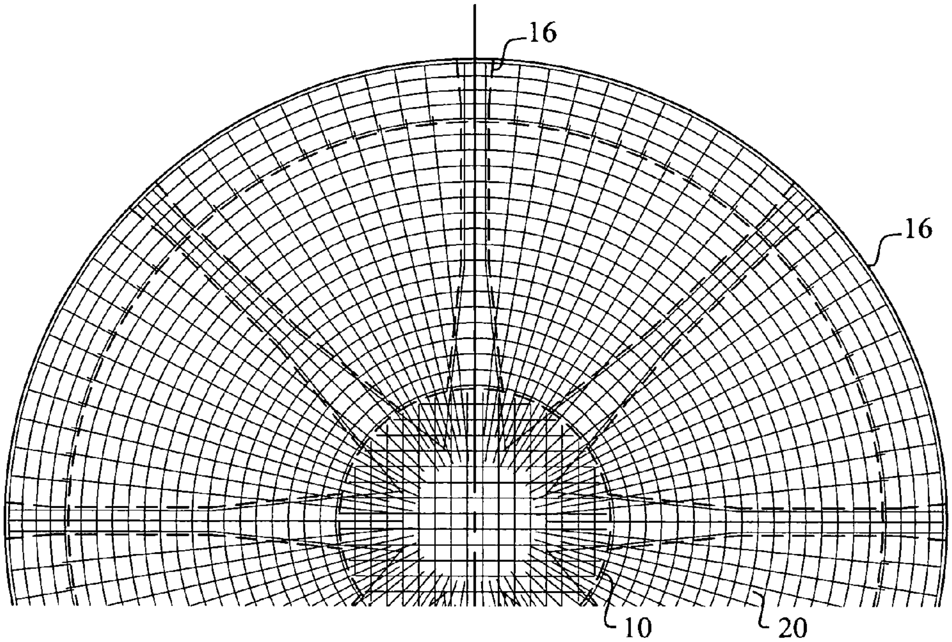


FIG. 36a

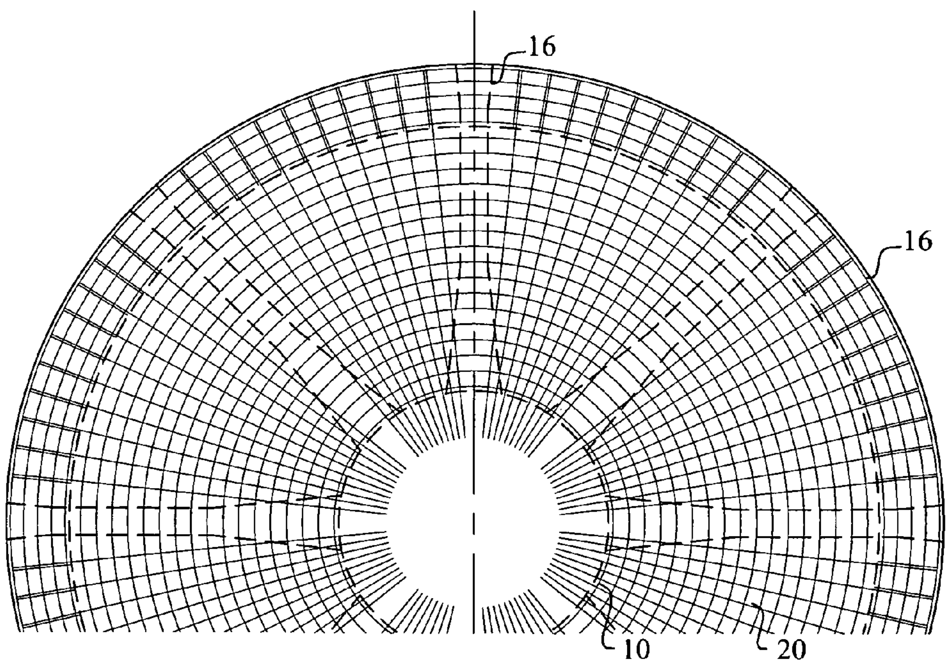
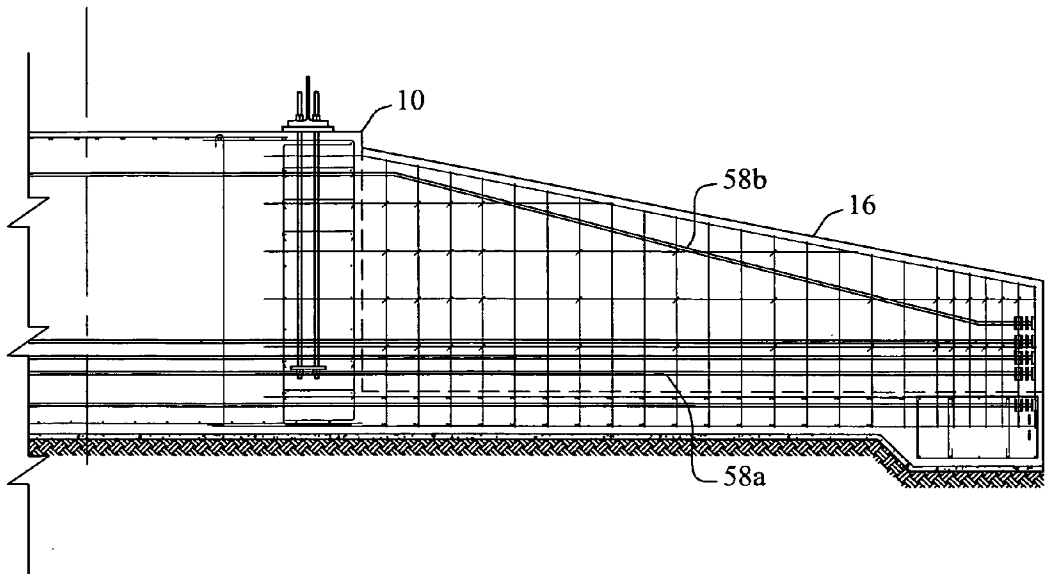


FIG. 36b



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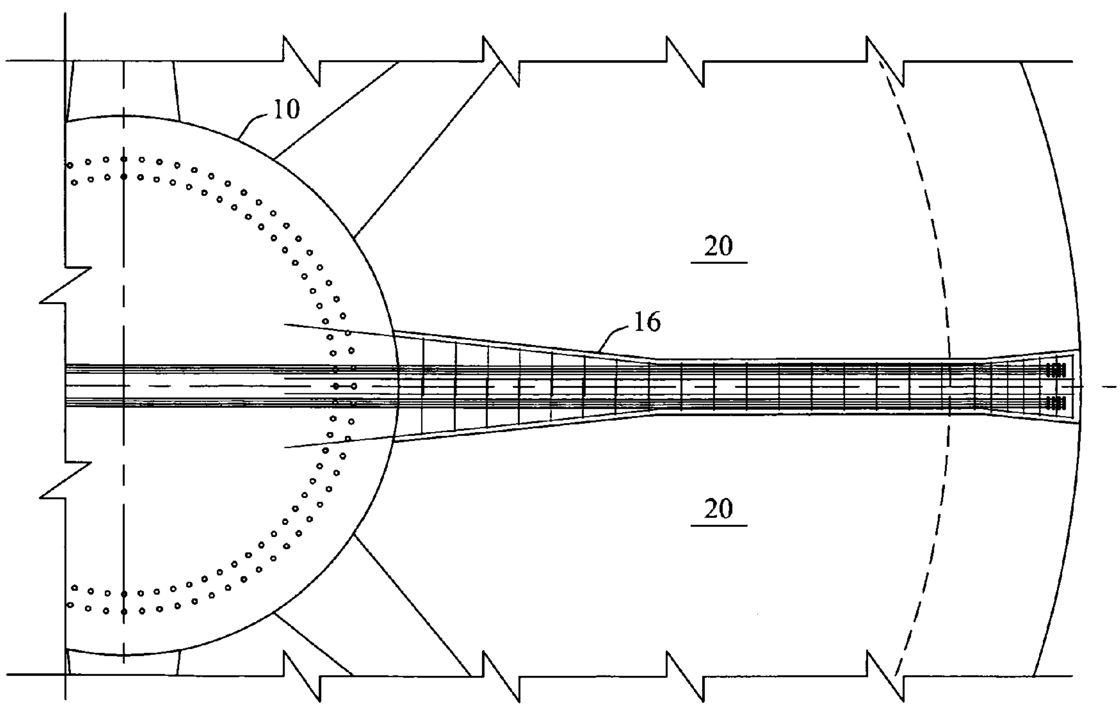


FIG. 37b

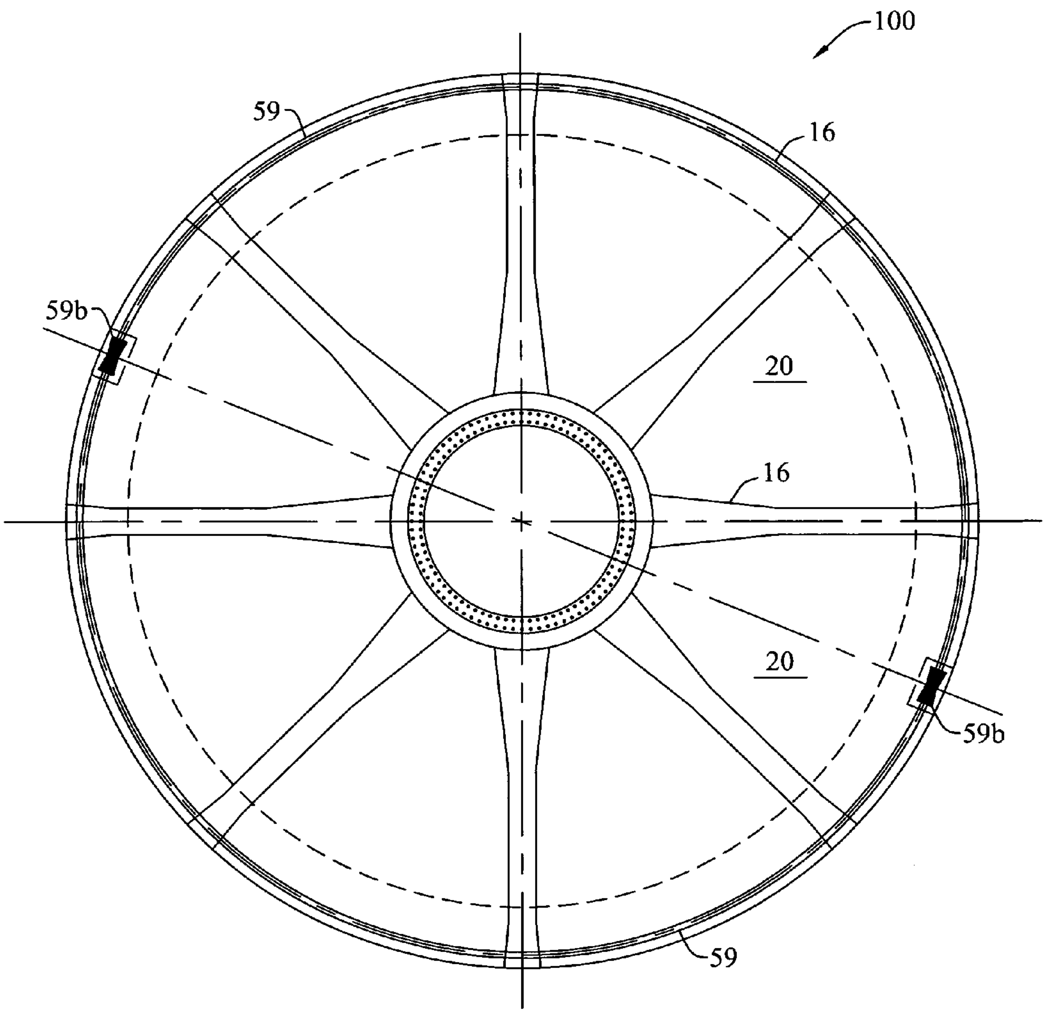


FIG. 38

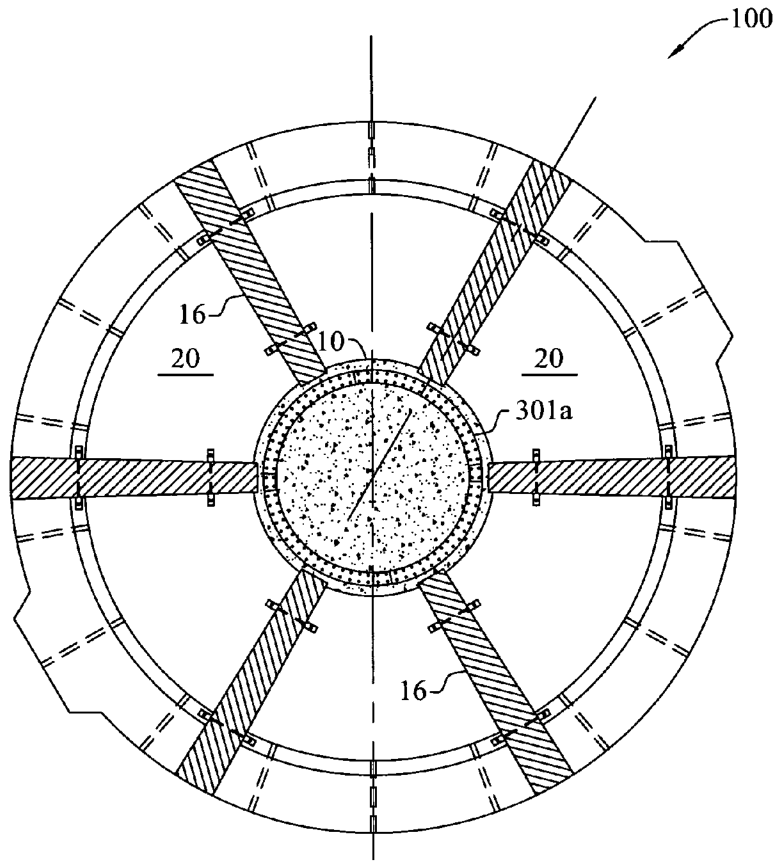


FIG. 39a

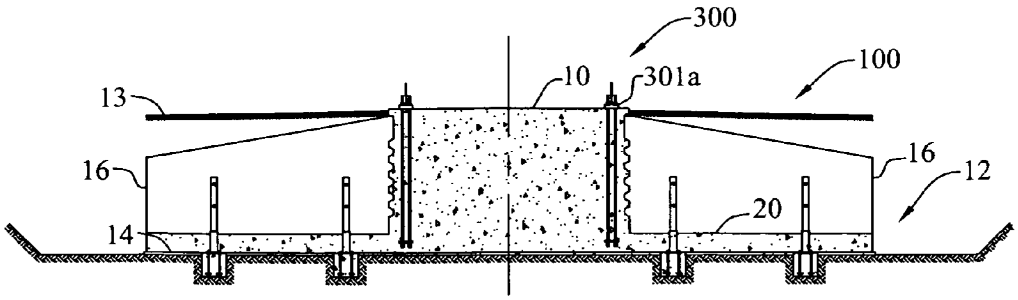


FIG. 39b

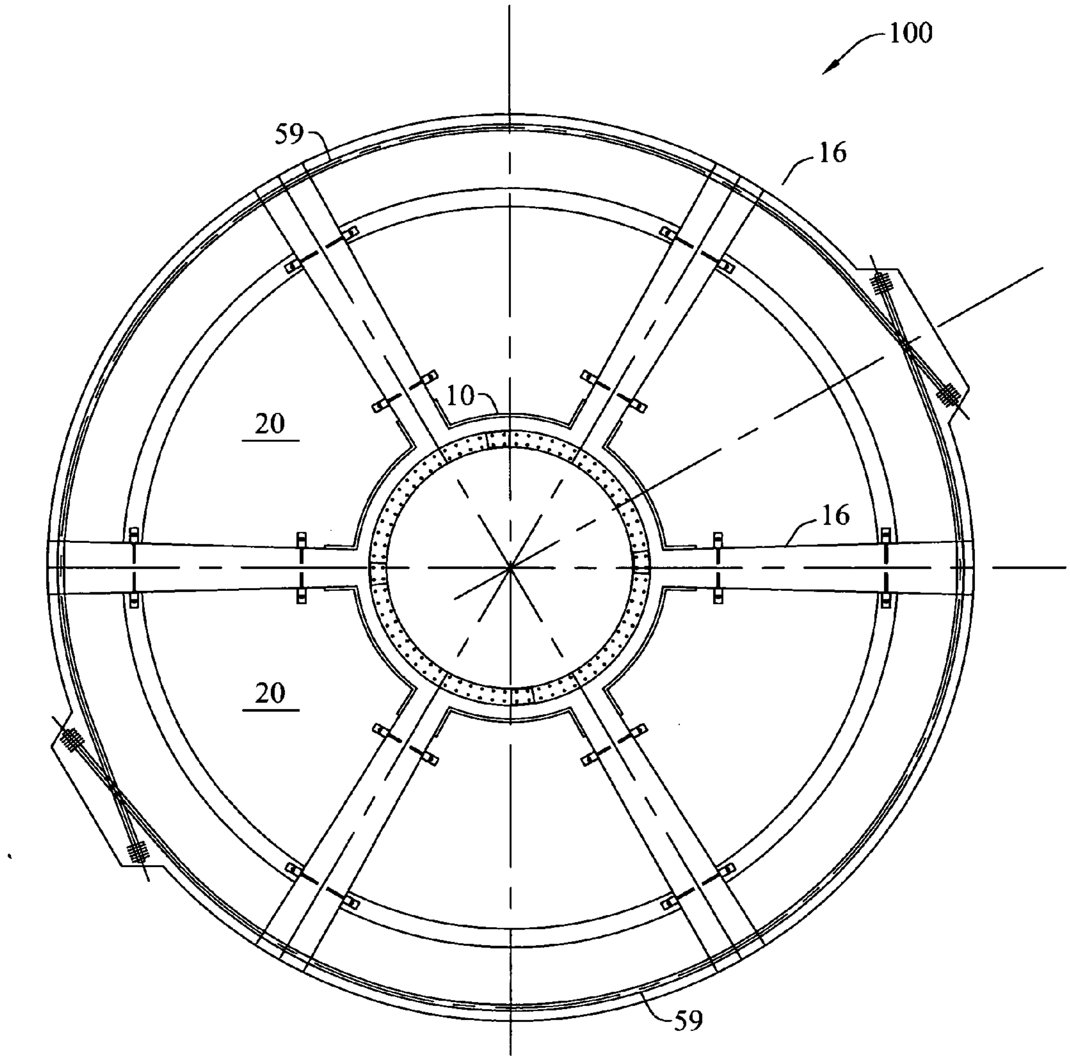


FIG. 40

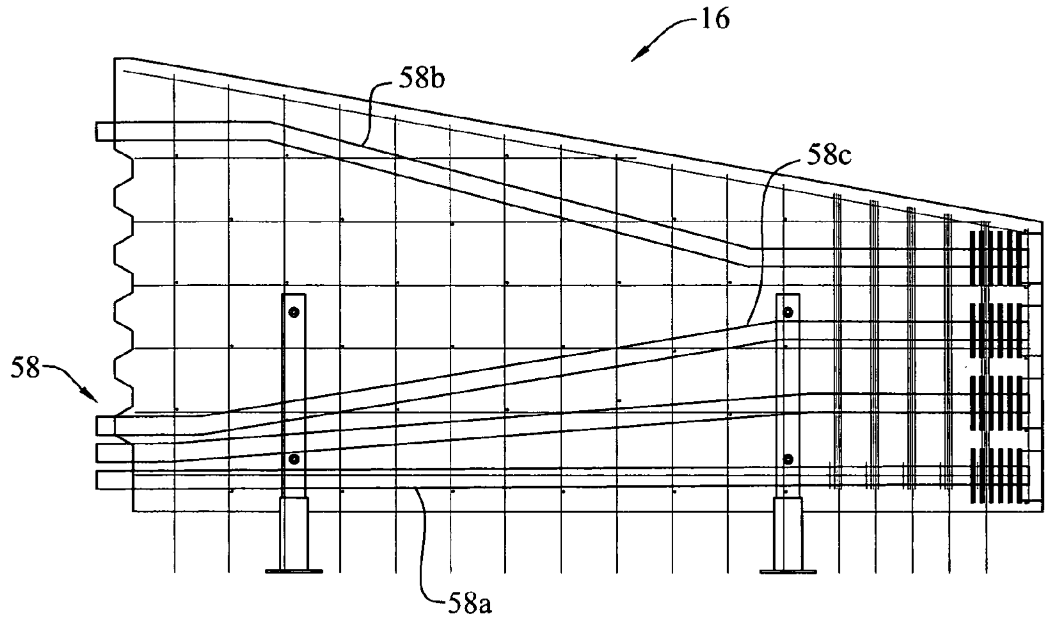
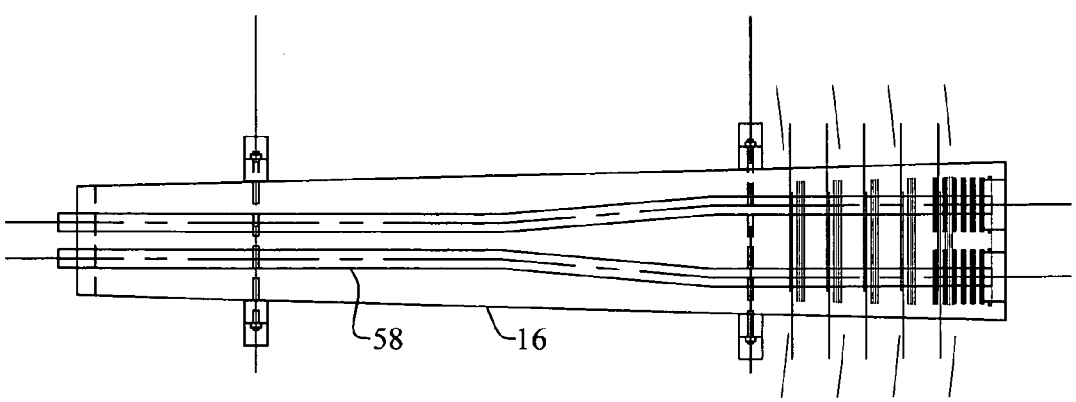


FIG. 41a



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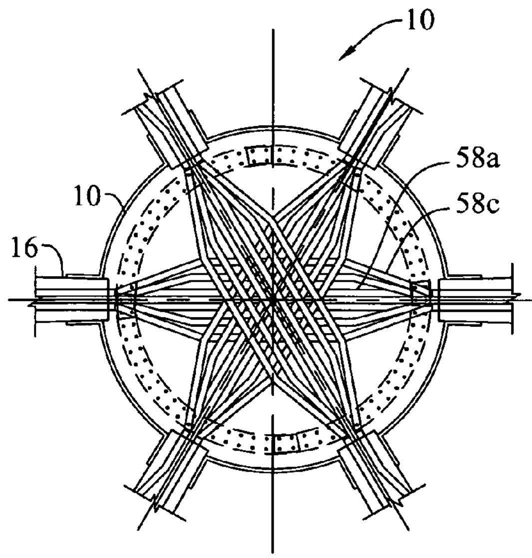

FIG. 42a

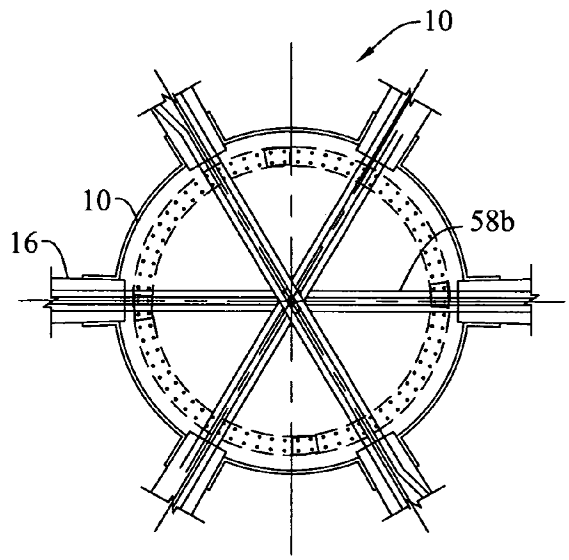

FIG. 42b

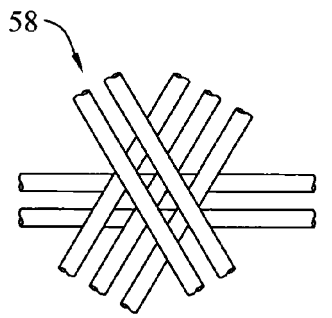

FIG. 42d

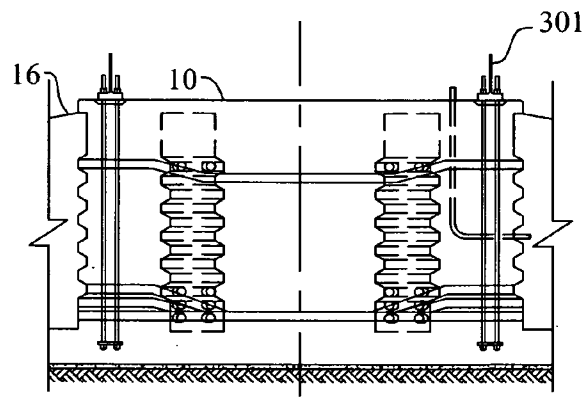

FIG. 42d

FATIGUE REISTANT FOUNDATION SYSTEM

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] This invention relates to a method for building fatigue resistant foundations for supporting columns, towers and structures under heavy cyclical loads such as wind turbines towers for onshore and offshore installations.

[0003] The proposed foundation system will be used specifically for the Multi-Megawatt class wind turbines. Several wind turbine manufacturers have successfully developed large wind turbines with rated power ranging from 1.5 to 10 MW. Several wind turbine manufacturers are planning mass production of large multi Megawatt turbines for onshore and offshore installations. The installation of the E-126 model turbine by Enercon with a 7 MW rated power required a xx meter diameter circular foundation with 1,400 cubic meters of concrete and xx tons of rebar. The installation of the 5M turbine by RePower with a 5 MW rated power required a 23 meter diameter circular foundation with 1,300 cubic meters of concrete and 180 tons of rebar. The task of building such large foundations is monumental and requires a great deal of construction planning and logistics. The proposed foundation designs and their associated construction methods provide cost-effective solutions for such challenging foundation projects.

[0004] Several wind turbine foundations, that have been constructed in the last 10 years in the US and Europe, have structural problems stemming from thermal cracking during construction or from fatigue cracking and required repairs. The present invention improves the geometry of the foundation in order to enhance dissipation conditions for the due to the typical temperature rise after casting and also provides a cost effective fatigue resistant design.

[0005] 2. Description of the Related Art

[0006] Conventional gravity style foundations for large wind turbine usually comprise a large, thick, horizontal, heavily reinforced cast in situ concrete base; and a vertical cast in situ cylindrical pedestal that is installed over the base. There are several problems that are typically encountered during the construction of such foundations.

[0007] Fatigue resistant of such conventional footings is achieved by over sizing the structural concrete elements and the reinforcing elements such that the resulting stress amplitudes are small enough for the structural elements to bass fatigue design checks.

[0008] The main problem is the monumental task of managing large continuous concrete pours, which require sophisticated planning and coordination in order to pour more than four hundred cubic yards of concrete per footing, on average, in one continuous pour, without having any cold joints within the pour.

[0009] Another problem is logistics coordinating with multiple local batch plants the delivery plan of the large number of concrete trucks to the job site in a timely and organized manner.

[0010] A further problem is the complexity of installing the rebar assembly into the foundation which requires assembling two layers of steel reinforcing meshes that are two to six feet apart across the full area of the foundation, while maintaining strict geometric layout and specific spacing. This rebar assembly is made of extremely long and heavy rebar which requires the use of a crane in addition to multiple workers to install all components of the assembly. The rebar often exceeds forty feet in length, thus requiring special oversized shipments which are very expensive and usually require special permits. That labor intensive and time consuming task requires large number of well trained rebar placing workers.

[0011] Another important problem is the fact that majority of the construction process consist of field work which could be easily compromised by weather conditions and other site conditions.

[0012] Another problem is thermal cracking of concrete due to overheating of the concrete mass. When concrete is cast in massive sections for wind tower foundations, temperature can reach high levels and the risk of thermal cracking becomes very likely. Thermal cracking often compromises the structural integrity of the foundations as reported in many projects in Europe and North America.

[0013] Multi-cell caissons used in offshore installations always lack multi-axial post-tensioning elements and their fatigue resistant rely completely on heavily reinforced oversized concrete elements which involves expensive and labor intensive construction.

BRIEF SUMMARY OF THE INVENTION

[0014] It is desired to have cost-effective foundation system that can reduce construction materials and labor for large wind turbines. The wind turbine foundations can then be built to the standards of the Fatigue Resistant Foundation System which uses concrete rib stiffeners, with a cast in place slab on grade element and a central pedestal to build an integral foundation that will behave structurally as a monolithic foundation structure. Other concrete components can be included such as secondary and perimeter beams, diaphragms, or intermediate stiffeners and rib stiffened or flat slab sections. The foundation system relies on the use of many prefabricated components including rebar meshes and cages, pedestal cage assembly, pre cut post-tensioning strands, preassembled strand bundles, pre-cut post-tensioning duct sections and prefabricated concrete forms.

[0015] The present invention pertains to a fatigue resistant foundation for wind towers which comprises a plurality of components, namely a central vertical pedestal, a substantially horizontal continuous bottom support slab with stiffened perimeter, a plurality of radial reinforcing ribs extending radially outwardly from the pedestal and a three-dimensional network of vertical, horizontal, diagonal, radial and circumferential post-tensioning elements embedded in the footing that keeps all the structural elements under heavy multi-axial post compression, reduces stress amplitudes and deflections and allows the foundation to have a desirable combination of high stiffness and superior fatigue resistant while improving heat dissipation conditions during construction by having a small ratio of concrete mass to surface area thus eliminating the risk of thermal cracking due to heat of hydration.

[0016] Although the application is written for a wind turbine tower as the column being supported by the foundation, any tower or column can be used on the foundation including but not limited to, antennas, chimneys, stacks, distillation columns, water towers, electric power lines, bridges, buildings, or any other structure using a column.

[0017] In one embodiment, the present invention pertains to a wind turbine foundation having a plurality of components, namely a central vertical pedestal, a substantially horizontal bottom support slab, and a plurality of radial reinforcing ribs extending radially outwardly from the pedestal. The ribs are prefabricated and transported to job site, but the pedestal and support slab are poured in situ at the site out of concrete. The prefabricated ribs are equipped with load transfer mechanisms, for shear force and bending moment, along the conjunctions with the cast in situ support slab. The prefabricated ribs are also equipped at their inner ends with load transfer mechanisms, for shear force and bending moment, along the conjunctions with the cast in situ pedestal. The ribs are arranged in a circumferentially spaced manner around the outer diameter of the pedestal cage assembly before or after slab reinforcing steel is installed. Forms are then arranged for the pedestal and support slab. The support slab is cast in situ by pouring concrete into the forms and then pedestal concrete is poured over the slab into the pedestal form. When the concrete cures the support slab is united to the prefabricated ribs and the ribs are also united to the pedestal. The final result is continuous monolithic polygonal or circular foundation wherein loads are carried across the structure vertically and laterally through the continuous structure by the doweled and spliced reinforcing steel bars which are integrally cast into the pedestal, ribs and support slab. The combination of the high stiffness of the ribs, solid pedestal and continuous slab construction across the pedestal, and through or under ribs, allows the slab to behave structurally as a continuous slab over multiple rigid supports resulting in small bending and shear stresses in the slab, reducing deflections and increasing the stiffness of the foundation, improving fatigue conditions as well as allowing for the benefits of an economical design. Support slab reinforcing steel covers the entire footprint of the foundation and extends, without interruption, across the slab area and into the pedestal to improve the structural performance of the foundation under different loading conditions. Perimeter beams or thickened slab edges around the perimeter add stiffness and strength to the foundation and provide the benefits of a two-way slab system. Circumferential post-tensioning of slab edge is used to increase the structural capacity of the ribs and the pedestal by creating eccentric post compression in the ribs and by reducing stress amplitudes in the slab, ribs and pedestal.

[0018] The foundation of the present invention substantially reduces the amount of concrete used in wind turbine foundation of spread footing style, simplifies the placement of rebar and concrete in the foundation, allows for labor and time savings and shortens foundation construction schedule when compared to conventional designs.

[0019] This invention provides the wind energy industry with a foundation system suitable for utility scale wind turbines including 1.5 MW through 10 MW and even larger, wherein the amount of cast in situ concrete work is limited, and the number of concrete trucks required for the foundation is small and manageable level and the amount of rebar used in the foundation is 60% less than conventional footings.

[0020] In one embodiment, the present invention relies on using prefabricated components that meet size and weight limits for standard ground freight shipping through typical roads and highways, without resorting to special permitting for oversize or overweight shipments, keeping in mind that the foundation width for large turbines can easily exceed sixty feet in width.

[0021] In another embodiment, the present invention uses specific combinations of precast components with cast in situ components designed to speed up construction without compromising the rigidity and structural continuity and optimization of the foundation. The combination of high strength, high stiffness prefabricated ribs, solid pedestal construction and continuous slab construction across the pedestal, and through or under ribs, allows the slab to behave structurally as a continuous slab over multiple rigid supports resulting in small bending and shear stresses in the slab, reducing deflections and increasing the stiffness of the foundation, substantially reducing fatigue as well as allowing for the benefits of rapid construction and economical design.

[0022] The present invention improves the geometry of the foundation in order to enhance dissipation conditions for the heat of hydration due to the typical temperature rise after casting. This design feature is achieved by reducing the thickness of the support slab and the ratio of concrete mass to surface area, thus reducing the risk of thermal cracking and protecting the structural integrity of the foundations.

[0023] The present invention optimizes the design support slab by configuring slab reinforcing to span between supporting ribs and allowing it to continue under or across the ribs. Each slab panel is triangular or pie-shaped and is prestressed along all three sides such that a multi-axial prestress is generated in slab panel. Slab panels with radial and perimeter post tensioning elements form a robust horizontal trussed diaphragm and as a result, the required slab thickness is optimized and the amount of cast in situ concrete is reduced.

[0024] The present invention reduces the maximum rebar length for field installation to roughly 7.6 meters (twenty five feet), which is significantly shorter when compared to conventional footing that may requires 15.2 to 18.3 meters (fifty to sixty foot) long reinforcing bars.

[0025] The present invention allows rib dowels, or post tensioning tendons, extending inwardly into the pedestal at one end, to continue without interruption between distal ends of the foundation. As a result each pair of ribs on opposite ends of the pedestal will behave structurally as one continuous beam across the width of the foundation.

[0026] The present invention reduces fatigue for concrete and rebar in the foundation by minimizing stress concentrations through appropriately configured connections and component geometry. The solid and deep construction of the pedestal allows for great reduction of stresses across the pedestal and at the conjunctions between the pedestal and surrounding. Dowels into the pedestal are relatively deep to reduce stresses near the surface zone of the pedestal. The solid pedestal offers generous bearing conditions for the tower base plate and improves geometry as needed to minimize fatigue.

[0027] The present invention employs prestressing and/or post tensioning techniques in order to maximize the performance of the foundation, or to extend its life span. Besides the vertical tensioning of anchor bolts, tensioning of horizontal and diagonal tendons along the length concrete ribs and across the pedestal besides circumferential **112** and radial **111** post tensioning strands imbedded in the slab are employed. Post-tensioning of the ribs is done in an eccentric manner to counter balance and reduce the stresses from the dead loads on the foundation. This can be accomplished by setting an eccentric post tensioning load pattern in the ribs with higher axial force at the bottom than at the top of the rib. The circumferential post tensioning load in the slab provides additional desirable eccentric prestressing of the ribs and the pedestal and helps increase rib load capacity and rib fatigue resistance.

OBJECTS OF THE INVENTION

[0028] An object of this invention is to provide the wind energy industry with a fast, reliable, yet cost-effective foundation system that is suitable for most wind energy projects, including projects using the largest utility scale turbines and tallest towers, while providing a foundation lifespan that is longer than conventional foundation systems.

[0029] Another object of this invention is to reduce the cost of wind energy projects by realizing savings in the areas of rebar quantity, form work, concrete trucking service, concrete pouring and finishing, logistics, man-hours and crane operations.

[0030] It is the object of this invention is to provide foundation system suitable for large wind turbines including utility scale turbines ranging from 1.5 MW to 10 MW and larger, wherein the amount of cast in situ concrete work is limited and the number of concrete trucks and the amount of rebar required for the foundation are reduced to a manageable level when compared to conventional gravity style foundations.

[0031] Another object of this invention is to improve dissipation conditions for the heat of hydration and the typical temperature rise after casting. That goal is achieved by reducing the ratio of concrete mass to surface area. When concrete is cast in massive sections for wind tower foundations, temperature can reach high levels and the risk of thermal cracking becomes very high unless cooling techniques or special admixtures are applied. Thermal cracking often compromises the structural integrity of the foundations.

[0032] A further object of this invention is to improve foundation structural properties due to fabrication of some structural components in a fully controlled environment of a precast concrete plant or a suitable facility at or near project site and to utilize benefit from advancement in concrete construction in areas such as concrete admixtures, special cements and fiber reinforcement.

[0033] Still another object of this invention is to utilize desirable features and benefits associated with mass production of precast concrete such as high reliability and uniform consistency and high compressive strength.

[0034] Another important object of this invention is to minimize chances for errors in bar placement, spacing and layout by providing pre-marked spacing for splicing slab rebar with existing dowels extending from ribs.

[0035] A further object of this invention is to use light weight, small diameter, short and easy to handle rebar for the cast in situ concrete.

[0036] A further important object of this invention is to provide the wind energy industry with a solution for all weather foundation construction.

[0037] Still another important object of this invention is to improve safety and accessibility around foundations under construction, and reduce hazardous conditions for construction crew.

[0038] A further significant object of this invention is to increase productivity and increase the number of footing that can be built in a given time frame using the same number of workers, when compared to conventional foundation designs built under similar conditions.

[0039] Another object of this invention is to employ prestressing and/or post tensioning techniques in order to maximize the performance of the foundation, improve its fatigue resistant and extend its life span.

[0040] Another object of this invention is to provide the wind energy industry with reliable and readily available designs, and prefabricated components, for every wind energy project wherein foundation designs are pre-approved by and coordinated with turbine manufactures and certification agencies.

[0041] A further object of this invention is to use standard designs to reduce engineering work and simplify the permitting process, as well as improve project construction schedule.

[0042] Still another object of this invention is to speed-up construction by using many prefabricated components including rebar meshes and cages, bolt cage assembly, pre cut post-tensioning strands, preassembled post-tensioning bundles, pre-cut post-tensioning duct sections and prefabricated concrete forms.

[0043] It is also the object of this invention is to provide wind energy developers with the ability to select pre-approved complete foundation designs for wind turbine foundation based on project and site variables including turbine model and tower height; site geotechnical characteristics; and desired foundation style such as gravity, anchored or piling.

[0044] Another object of this invention is to provide foundation contractors with the convenience and economy of using commercially available prefabricated components with complete assembly and detail drawings that can be delivered to any project site with short lead time.

[0045] A further object of this invention is to improve the quality and productivity of foundation construction due to experience gained from practicing standard construction techniques with repetitive production steps.

[0046] Still another object of his invention is to produce foundation designs suitable for shallow and deep offshore installations.

[0047] Another object of this invention is to use the modular foundation system for other tower structures such as chimneys, stacks, distillation columns and telecommunication towers.

[0048] Yet another object of the foundation is to improve tower base bearing resistant in concrete pedestals supporting wind towers such that it become possible to build the pedestal and the foundation with concrete having the same compressive strength without increasing the diameter of the pedestal.

[0049] Another object of the invention is to build wind tower foundation in one continuous concrete pour.

[0050] The final object of the invention is to independently produce prefabricated components for offshore foundations that can be assembled on a barge without having the critical path of completing to a first component before a second component can be constructed.

[0051] Other objects, advantages and novel features of the present invention will become apparent from the following description of the preferred embodiments when considered in conjunction with the accompanying drawings.

DETAILED DESCRIPTION OF THE DRAWINGS

[0052] FIG. **1** is a perspective view of the foundation showing the rebar before pouring the concrete.

[0053] FIG. **2**A is a perspective view of a pedestal and ribs in a second embodiment with a pier for off shore applications.

[0054] FIG. **2**B is a perspective view of a pedestal and ribs.

[0055] FIG. **3**A is an inner perspective view of a rib showing connections to the pedestal and the slab.

[0056] FIG. **3**B is an outer perspective view of a rib showing connections to the pedestal and the slab.

[0057] FIG. **4** is a perspective view of a rib and forms for forming the pedestal and slab.

[0058] FIG. **5** is a perspective view of the bolt assembly and alignment apparatus.

[0059] FIG. **6** is a top view of the foundation prior to pouring the concrete showing the rebar and template for the anchor bolts and post tensioning elements.

[0060] FIG. **7** is a perspective view of a raised rib having means for raising the rib above the slab.

[0061] FIG. **8** is a perspective view of the foundation showing the alignment apparatus and a pedestal forming section.

[0062] FIG. **9** is a perspective view of the foundation showing the rebar and rebar cage.

[0063] FIG. **10** is a perspective view pedestal cage assembly with anchor bolt and reinforcing.

[0064] FIG. **11** is a perspective view of the foundation.

[0065] FIG. **12** is a perspective view of the rib for supporting a lattice style tower.

[0066] FIG. **13** is a perspective view of the foundation for offshore installation.

[0067] FIG. **14** is a perspective view of the foundation for offshore installation.

[0068] FIG. **15** is a perspective view of the foundation for offshore installation.

[0069] FIG. **16** is an elevation view of the foundation for offshore installation.

[0070] FIG. **17** is a perspective view of the foundation for offshore installation.

[0071] FIG. **18** is a perspective view of the foundation for offshore installation.

[0072] FIG. **19** is a perspective view of the foundation for offshore installation.

[0073] FIG. **20** is a perspective view of the foundation with rock anchors.

[0074] FIG. **21** is a perspective view of the foundation with rock anchors.

[0075] FIG. **22** is a perspective view of the foundation with rock anchors.

[0076] FIG. **23** is an elevation view of the foundation with rock anchors.

[0077] FIG. **24** is a perspective view of an offshore foundation with micro-piles.

[0078] FIG. **25** is an elevation view of an offshore foundation with micro-piles.

[0079] FIG. **26** is a perspective view of the foundation.

[0080] FIG. **27** is an elevation view of the foundation.

[0081] FIG. **28** is a perspective view of rock anchored foundation.

[0082] FIG. **29** is a perspective view of rock anchored foundation.

[0083] FIG. **30***a*-**30***d* show circumferential post tensioning view of the foundation.

[0084] FIG. **31***a* is a plan view of the foundation.

[0085] FIG. **31***b* is a section view of the foundation.

[0086] FIG. **32***a* is a section view of the foundation.

[0087] FIG. **32***b* is a section view of the rib **16**.

[0088] FIG. **33***a* is an elevation of rib reinforcing details.

[0089] FIG. **33***b* is a plan view of rib reinforcing details.

[0090] FIG. **34***a* and FIG. **34***b* are section views of the rib **16**.

[0091] FIG. **34***c* and FIG. **34***d* are pedestal reinforcing details.

[0092] FIG. **35***a* and FIG. **35***b* are section views of the pedestal.

[0093] FIGS. **36***a* and **36***b* are slab **20** reinforcing plans.

[0094] FIG. **37***a* and FIG. **37***b* are elevation and plan views of a rib with unbounded post tensioning elements.

[0095] FIG. **38** FIG. is a plan view showing circumferential post tensioning in the foundation.

[0096] FIG. **39***a*-FIG. **41***b* show details of the a foundation with prefabricated ribs.

[0097] FIG. **42***a*-FIG. **42***d* show tendon duct arrangements in a pedestal **10**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0098] The present invention pertains to a wind turbine foundation for wind turbines. The foundation comprises a plurality of components, namely a central vertical pedestal, a substantially horizontal bottom support slab, and a plurality of radial reinforcing ribs extending radially outwardly from the pedestal. The ribs may be prefabricated and transported to job site, but the pedestal and support slab are poured in situ at the site out of concrete. Alternatively the ribs may be cast in situ.

[0099] The present invention pertains to a fatigue resistant foundation **100** for wind towers which comprises a plurality of components, namely a central vertical pedestal, a substantially horizontal continuous bottom support slab with a stiffened perimeter, a plurality of radial reinforcing ribs extending radially outwardly from the pedestal and a three-dimensional network **500** of vertical, horizontal, diagonal, radial and circumferential post-tensioning elements embedded in the footing that keeps all the structural elements under heavy multi-axial post compression, reduces stress amplitudes and deflections and allows the foundation **100** to have a desirable combination of high stiffness and superior fatigue resistance while improving heat dissipation conditions during construction by having a small ratio of concrete mass to surface area thus eliminating the risk of thermal cracking due to the heat of hydration.

[0100] A construction site is prepared by excavation and flattening and preparation of soil for the foundation **100**. The foundation **100** may be set on pilings, on piers, or have anchors (soil anchors or rock anchors **404** or micro-piles **401** or other types) in a conventional manner. The present invention ensures good contact between foundation **100** and soil, or sub-base, by casting.

[0101] The foundation **100** is cast against prepared soil, or crushed stone sub-base, or a mud slab or a membrane sheet in case of offshore foundations assembled on a barge or in dry docks. Known grouting and leveling techniques under precast elements can be employed for ensuring plumb installation and good soil contact.

[0102] In one embodiment of the invention the foundation **100** may be set on a mud slab **14** or on compacted granular fill. The mud slab **14** is often a thin plain concrete layer intended to provide a clean and level base for foundation installation. After the foundation site has been prepared, a plurality of three or more precast stiffener ribs **16** are placed on the mud slab **14** or compacted granular fill inside of the excavation pit **12**. The precast concrete stiffener ribs **16** may have means for leveling or other leveling techniques can be employed for level and plumb installation. If desired, grouting techniques can be used to ensure complete rib base contact with the mud slab or sub-base. The precast concrete stiffener ribs **16** may have bases **21** with left shear key **38** and/or shear connectors and right shear key **36** and/or shear connectors. The precast concrete stiffener ribs **16** may also have a vertical shear key

34. The shear keys **34**, **36** and **38** and associated dowels **40**, **42** and **46** are to ensure continuous connections, with complete transfer of shear and bending loads, between the precast concrete rib stiffener **16** and the cast in place concrete which is to be poured into the foundation **100**. The precast concrete stiffener ribs **16** have upper dowels **40** and lower dowels **42** extending on the right and left sides of the base **21** which interconnect with and spliced to upper mesh rebar **22** and lower mesh rebar **24** installed between the ribs **16** and connected to dowels **40**, **42** to form reinforcement for the slabs of foundation **100** when the concrete is poured. The base **21** of rib **16** and the top of rib **16** also have dowels **46** radially entering the pedestal **10** in the center of the foundation.

[0103] Doweling of rebar between ribs and foundation components can be achieved rebar dowels extending from the prefabricated elements or by using rebar couplers, bar extenders or any mechanical rebar splicing system.

[0104] Arrays of grout or epoxy filled sleeves arranged in the slab **20** could receive corresponding arrays of vertical dowels extending from the bottom of prefabricated ribs or perimeter beams **190** or other prefabricated components.

[0105] Shear keys can be replaced with, or combined with, corbels or shear studs, or other shear connectors such as angled rebar or embedded steel shapes.

[0106] In another embodiment an array of steel beams, are encased into the web of the rib and extend inwardly into the pedestal cavity at the inner most end of ribs, and serve as a suitable shear force transfer mechanism between the rib and the pedestal.

[0107] In another embodiment the foundation **100** comprises a steel frame fully is encased in concrete and has a central tower receiving metal cylinder fixed to an array of radially extending steel girders encased in concrete beams and rigidly connected at their outer ends to an array of perimeter beams **190** encased in the concrete foundation and a reinforced concrete slab-on-grade **20** covering the foot print of the foundation **100** and connected to the said steel frame.

[0108] In one embodiment the ribs are treated with concrete bonding agent along surfaces where cast in place concrete is received.

[0109] In another embodiment the foundation **100** is provided with drains around the perimeter and the top surface of the slab **20** is slightly sloped towards the said drains such that water is drained away from foundation **100**.

[0110] In another embodiment the ribs or other foundation elements are covered or coated with protective material for extending the life span of the footing.

[0111] In one embodiment the ribs **16** are placed on the mud slab **14** first and then the pedestal cage **50** made of an array of rebar, preferably Z or C shaped rebar and circumferential rebar is assembled around anchor bolt assembly. Alternatively the pedestal cage **50** is assembled first or a preassembled pedestal cage **50** dropped into place first and then the ribs **16** with dowels **46** are slid into place so that dowels **46** and shear connectors fit between the elements of pedestal cage **50** rebar assembly.

[0112] As best seen in FIG. **3***b*, the precast concrete stiffener rib **16** has lifting lugs **32** to help place the stiffener rib **16** into the excavated construction area. The base **21** has a flat bottom surface such that the ribs may stand on their own on the mud slab **14** or compacted granular fill or during transportation from precast plant to foundation site. The precast concrete stiffener ribs **16** have prestressing elements **58** running through the ribs **16** radially from the outside of the ribs **16** and through pedestal **10**. The radial prestressing elements **58** (or post tensioning elements) may be anchored to the opposite side of the pedestal or optionally run through the opposing precast concrete stiffener **16** on the other side of the pedestal **16** and anchored at the end of the opposite rib **16**. Once the ribs **16** and the pedestal cage **50** are in place, the dowels **46** extending radially inward from ribs **16** may be connected to, or spliced with, corresponding dowels arranged in the pedestal cage. Inside of a cage **50** are additional rebar dowels **48** which will facilitate the continuity of the structural components through the pedestal **10** as well as resist bearing, shear and bending loads.

[0113] Also inside of pedestal reinforcement cage **50** is a bolt assembly **60** comprising a bolt template **52** an embedment ring **54** and anchor bolts **56** protected by a PVC sleeve **57** or wrapped with a material to prevent bonding between the anchor bolts **56** and concrete to be poured. The anchor bolts **56** have a top portion which is used to attach the base flange **301** of a tower or column to the pedestal **10**. A grout trough template **52** at the bottom of the bolt template **52** may be used to create a grout trough **90** to ensure a good connection of the tower or column to the pedestal **10**. The grout trough **90** will be formed by removing the bolt template **52** from the anchor bolts **56** after the concrete has been poured. Radial dowels, prestressing elements or shear connectors at the inner end of ribs **16** should be spaced to clear anchor bolts # and other reinforcement arranged in pedestal cage **50**.

[0114] In a preferred embodiment, for fully cast in place foundations, slab forms may sit directly on the mud slab and rib forms **16***b* are supported and kept elevated above slab **20** elevation by means of adjustable and reusable support legs arranged in the rib forms **16***b*. Small footings or thickened mud slab areas could be used under rib form support legs. Pedestal forms **102** can be supported by rib forms **16***b* or by separate support legs.

[0115] When ribs **16** are prefabricated, the bolt assembly **60** is held in place and the anchor bolts **56** are properly oriented by an alignment apparatus **130** can be utilized. The alignment apparatus **130** has a central post **132** with arms **134** attached perpendicularly to the center post and having legs **136** for attachment to the top of the ribs **16** to provide added stability, and bolt circle proper alignment during construction. The legs **136** have an adjustable height relative to the arms **134**.

[0116] The arms **134** may have braces **138** attached to the central post **132** for holding the arms **134** straight. The central post **132** may also have rod supports **135** for holding reinforcement rebar such as reinforcement rebar **80** which are spliced to dowels **46**. The alignment apparatus **130** also has adjustable support members **140** for attachment between the arms **134** and the bolt template **52** to align the anchor bolts **56** so they are upright. The alignment apparatus **130** can support the bolt assembly **60** without the central post **132** by relying on the legs **136** supported by ribs **16**, which allows the lower portion of the central post **132** to be removed if desired. Alignment apparatus **130** can be used as a template to ensure proper location, elevation and orientation of ribs **16**.

[0117] The ribs **16** can be of any shape or size depending on the specifications of the tower and loads thereon. For example the ribs **16** may be trapezoidal, rectangular, tee shaped or I beam shaped. The ribs **16** may have intermediate stiffener plates or diaphragms for improved structural performance. The ribs **16** or rib forms **16***b* may receive ramps or catwalks thereon for easy access to the forms during construction.

[0118] Ribs **16**, or rib forms **16***b*, may have means for receiving and supporting perimeter forms **18**, such as bolts or threaded inserts for receiving and supporting the pedestal forms **102**. The ribs **16**, or rib forms **16***b*, may also have attachment means **15** for holding base forms **17**. The pedestal forms **102** may be equipped with platform sections for allowing access around the pedestal and the rest of the footing.

[0119] With all the rebar, ribs **16**, pedestal **100**, bolt assembly frame **80** and optional alignment apparatus **130** in place concrete forms may be attached such that concrete can be poured to form the pedestal and base of the foundation. Pedestal forms **102** may attach to the ribs **16**, or rib forms **16***b*, by bolts **18** or by any other means. Similarly the base perimeter forms **17** may be attached to the ribs **16**, or rib forms **16***b*, by bolts **15** or by any other means. Alternatively the base perimeter forms may be supported to the ground or the mud slab.

[0120] With all the parts assembled all the rebar in place and the conduit for the prestressing tendons or rods of the foundation in place, concrete is ready to be poured into the pedestal **10** and between the ribs **16**. The pouring of the concrete can be accomplished quickly and slab areas between the ribs **16** can be finished as the pedestal **10** concrete is still being poured. The concrete may be used to build the pedestal **10** and the slab **20** in one pour. Alternatively the base for the entire foot print of the footing can be poured in a first pour then the pedestal **10** can be formed in a second pour.

[0121] When bonded multi-strand post tensioning system is used in the foundation **100**, the prefabricated components will be fitted with ducts and anchor hardware according to design specifications. The cast in place components will be fitted with matching ducts to facilitate the continuity of tendons across the foundation **100**. After the jacking of tendons, duct grouting is carried out as required. If the un-bonded, bundled mono-strand system is employed, no duct or grouting is required.

[0122] The structural load capacity of the foundation **100** is increased significantly by the combination or radial (or diametric) and circumferential post tensioning **59**. Circumferential post tensioning **59** creates a desirable symmetric bi-axial post compression in the slab **20**. Circumferential post tensioning **59** is applied at an elevation well below the neutral axes of the ribs **16** thus creating eccentric post compression in the ribs **16** and the pedestal **10** and resulting in increased nominal moment and shear capacity of the ribs **16** as well as improvement in multi-axial fatigue resistant of the pedestal **10**, ribs **16** and the slab **20**. Radial or diametric post tensioning elements **58** extend from rib to opposite rib across the pedestal **10**. Radial post-tensioning is applied with an eccentric load pattern, with higher post compression below the neutral axis of the rib. When all the prestressing elements are jacked, the foundation **100** is kept under heavy multi-axial eccentric post compression stress, thus increasing rib structural capacity to resist soil support reaction and providing low deflections, high stiffness and low stress amplitudes resulting in high fatigue resistant and high durability. Backfill is added over the foundation **100** for increased stability and stiffness of the foundation **100**.

[0123] After the concrete sets, post tensioning is carried out and the foundation **100** is backfilled with compacted granular fill to stabilize the foundation **100** against overturning.

[0124] Alternately the bolt assembly can be replaced by a tower section **56***b* embedded in pedestal **10** concrete and the embedded section **56***b* having means **56***c* for receiving a tower base by means of a bolted connection arranged at the top of the section. The embedded metal cylindrical tower section **56***b* encased in pedestal **10** concrete is provided with holes for rebar and post tensioning tendons **58** to extend through the metal cylinder. Post tensioning **58** tendons can extend through holes arranged in the cylinder and across the pedestal **10**, through the ribs **16** to be anchored on distal ends of the foundation.

[0125] Pedestal **10** can be any size or shape, round, triangular, square, polygon or other shape depending on the specifications of the tower and loads thereon. The ribs **16** can be in any pattern around the pedestal **10**. In one embodiment shown in FIG. **2** the foundation **100** may have a square pedestal **10** and ribs **16** at the corners parallel to the faces of the pedestal. The pedestal **10** may have a stepped construction with an enlarged lower cross section to reduce the length of the cantilevered ribs **16**.

[0126] Pre-assembled reinforcement sections (meshes) of the slab **20** components can be lowered into place in the slab **20** to speedup construction. All rebar dowel or metal shear connectors extending through a construction joints may be galvanized or Epoxy coated to prevent corrosion. The use of mechanical couplers in the foundation **100** shall be limited or avoided. Specified mechanical couplers must be tested and certified for the number of load cycles in the life span of the foundation **100**.

[0127] In another preferred embodiment, the ribs are cast in place in reusable rib forms **16***b*. The ribs **16** are cast in place jointly with the pedestal **10** in one continuous pour over the slab. Optionally, the ribs **16**, the pedestal **10** and the slab **20** are all jointly cast in one pour. All rib internal components including rebar assembly with dowels and prestressing elements are placed inside the forms then cast in place concrete is poured into the rib forms **16***b* as well as into pedestal **10** and slab **20** forms.

[0128] Rib reinforcing cages can be assembled above grade and lowered into the foundation in one or more sections.

[0129] In a preferred embodiment rib forms **16***b* with internal rib reinforcing cages are preassembled and lowered into the foundation by cranes to mesh with slab reinforcing sections already placed in the foundation. The radial reinforcing panel of the slab **20** enables the meshing rib dowels between slab reinforcing without geometric interference.

[0130] Ribs **16** can also be made in segments and eventually united by means doweling or by using segmented post-tensioned construction techniques. Rib anchor zone with anchor trumpets and hardware can be prefabricated separately of higher strength concrete than the rest of the rib.

[0131] Prefabricated perimeter beams **190** with post tension ducts could serve as perimeter forms become part of the structure. An array of precast, rectangular or L-shaped beams with means for connecting to the slab **20** and the ribs **16** can be used. The perimeter (edge) beams can rest directly on the mud slab and connect to the slab **20** using horizontal dowels and shear key arranged at its inner side. Optionally the perimeter beam is elevated and connects to the top of the slab **20** using dowels extending from its bottom. The precast perimeter beams **190** may have dowels and shear keys extending from their sides ends for connecting to the ribs **16**. In this case the ribs **16** will have corresponding dowels and shear keys for receiving and supporting perimeter beams **190**. The connection between ribs **16** and perimeter beams **190** is established using closure pours in small cavity at the conjunctions.

[0132] In another embodiment the foundation **100** pertains to hybrid gravity based and rock anchored foundation system.

Ribs **16** can be made with arrangement, mechanisms and connecters for receiving piles **400** or micro-piles **401** or anchors **404** in different configurations. Vertical through holes in the ribs **16** can provide means for receiving a pile or an anchor. Bearing elements and grouting are arranged on top of each rib to establish the required structural connection. An array of bearing plates **404***b* with tensioning nuts **404***c* on each soil/rock anchor is used to compress the foundation **100** against supporting soil. Vertical through holes with corrugations for the anchor extend through the foundation. Bearing plates **404***b* with tensioning nuts **404***c* can be placed on top of the pedestal **10** or in the foundation **100**. If desired ribs **16** may have piers extending vertically from the ribs **16** and the top of pier elevation is raised above grade to make anchor bolts accessible for tensioning and testing. Typical rock or soil anchor construction and grouting methods can be utilized. Another option is to house rock anchor bolts and bearing plates **404***b* and tensioning nuts **404***c* in accessible corrosion protection compartments above the foundation **100**.

[0133] In another embodiment the invention pertains to a foundation **100** that comprises the following elements:

[0134] 1. A vertically extending pedestal **10** that is cast in situ, out of concrete, the pedestal **10** serving to receive and support the tower structure;

[0135] 2. A substantially horizontal support slab **20** that is cast in situ out of concrete, the support slab **20** covering an area of ground larger than that covered by the pedestal **10**;

[0136] 3. A plurality of radial ribs **16** extending radially outwardly from the pedestal **10** and spaced around the pedestal **10**, each rib is being joined along the base thereof to the support slab **20** being joined along an inner side thereof to the pedestal **10**, each rib has means for receiving a rock or soil anchor;

[0137] 4. An optional plurality of perimeter beams **190**, or stiffened slab edge **190***a*, spanning continuously, near the perimeter of the foundation, between ribs **16** and supporting the slab **20** may be employed;

[0138] 5. An array of soil or rock anchors **404** extending through the foundation **100**, preferably through the ribs **16**, may extend down into the ground below the foundation, each anchor having a bearing element in or above the foundation **100** and compressing the foundation against support soil when the anchors are tensioned.

[0139] The prefabricated components can be molded at a facility under controlled conditions for good quality concrete setting and controlled rebar spacing which is superior to what can be obtained on a job site and at a lower cost. The ribs **16**, acting as deep stiff horizontal cantilever support, allow the base of the foundation slabs to have a relatively small thickness using less cast in place concrete and rebar thus lowering the cost for each foundation.

[0140] Alternatively ribs **16** can have reusable temporary supports **170**, or other means, arranged at the ribs **16** to hold the ribs **16** in place, maintain them plumb during construction and elevate them at a predetermined height over slab reinforcing. This style of ribs **16** is intended to be raised above the ground or mud slab **14** so that the foundation support slab **20** can be poured in place continuously under ribs. Dowels and shear connectors for this style may be arranged at the bottom of the rib for connecting with base slab **20** which extends under the raised rib. When the concrete cures the continuous support slab **20**, extending under the ribs, is united to the prefabricated ribs **16** and the ribs **16** are also united to the pedestal **10**. The rib inner ends will be partially encased in the pedestal **10** to increase rib torsional end resistance. The final result is continuous monolithic foundation wherein loads are carried across the structure vertically and laterally through the continuous structure by the doweled and spliced reinforcing steel bars which are integrally cast into the pedestal, ribs **16** and support slab **20**. The combination of the high stiffness of the ribs **16**, solid pedestal **10** and continuous slab **20** construction across the pedestal **10**, and under ribs **16**, allows the slab **20** to behave structurally as a continuous slab **20** over multiple rigid supports resulting in small flexural and shear stresses in the slab **20**, reducing deflections, improving fatigue conditions and increasing the stiffness of the foundation as well as allowing for the benefits of an economical design.

[0141] Cast in situ concrete can be shielded from extreme weather, including heat, cold, rain and snow, by simply extending blankets, covers or shields between ribs **16** during construction, and then using heaters or fans as required to regulate temperature, humidity of concrete to allow for proper setting and curing conditions.

[0142] Another embodiment of the present invention pertains to a leveling technique that simplifies the tower base leveling process and shortens the number of steps required for grouting under a tower base. The bolt template is provided at the very top of the bolt assembly with at least three sets of additional bolts and corresponding threaded bolt inserts suitable for embedment in the concrete. Such leveling bolts **53** and inserts **53***b* will be located outside or inside the bolt circle of tower base, but directly under tower base flange. This allows for continuity of grout bed construction and provides an easy access to leveling bolts **53**. Small cutouts at leveling bolt locations may be used. Another benefit of this leveling technique is having the ability to apply continuous grout bed that is free of cold joints, under tower base flange in one session as well as having the ability to tension all anchor bolts in one work session.

[0143] The foundation design can be reconfigured to support lattice towers comprising multiple columns connections to foundations in a spaced array. The ribs **16** will be provided with column receiving components including embedded anchor bolts (or grouting around embedded element) and an integrated pier design into the rib. The rib geometry may be widened and enlarged at the integral pier. The array of said integrated piers ribs **16** are fitted with means for receiving and supporting the legs or the columns of the lattice tower **200**. The integrated piers can extend above final grade elevation, while the top of pedestal **10** may stay below final grade elevation. For this foundation style, pedestal elevation may be depressed and tower receiving components may not be required in the pedestal **10**. This configuration may also be used in offshore applications wherein a prefabricated gravity foundation **100** is connected to lattice tower structure **200** that is fitted with a wind tower receiving component at its top. The foundation **100** will be installed over prepared seabed and filled with a suitable backfilling material **13**, and surrounded with scour protection **13***b*.

[0144] In permafrost conditions, the foundation **100** may be supported on an array of concrete piers deeply embedded and frozen into the ground. Anchors can be used to secure the ribs **16** to their supporting piers around the perimeter of the foundation. If a slab **20** is incorporated in the design, the slab **20** bottom elevation may be set above grade elevation.

[0145] This invention pertains to a fatigue resistant gravity based spread footing for use under heavy multi-axial cyclical loading of a wind tower **300** which comprises a plurality of components, namely a central vertical pedestal **10**, a substantially horizontal continuous bottom support slab **20** with stiffened perimeter, a plurality of radial reinforcing ribs **16** extending radially outwardly from the pedestal **10** and a three-dimensional network of vertical, horizontal, diagonal, radial (or diametric) and circumferential post-tensioning elements that keep the structural elements under heavy multi-axial post compression with specific eccentricities and orientations that are intended to reduces stress amplitudes and deflections and allows the foundation **100** to have a desirable combination of high stiffness and superior fatigue resistance while improving heat dissipation conditions during construction by having a small ratio of concrete mass to surface area thus eliminating the risk of thermal cracking due to heat of hydration.

[0146] Vertical prestressing of the pedestal **10** can be carried out independently of tower receiving elements. A pedestal **10** may have an array of vertical post tensioning elements **56** that does not connect to a tower **300**, and an embedded tower section **56*b*** bolted to a tower structure **300**.

[0147] Radial post-tensioning **58**, extending across the foundation **100**, in pairs of ribs **16**, allows for the desirable structural continuity and the direct transfer of loads from a downwind ribs **16** into the pedestal **10** and then into the opposing upwind ribs **16**. Radial and circumferential post compression stresses in the slab **20** and/or perimeter beams **190** allows for a desirable reduction in stress amplitudes the structural continuity between slab **20** spans and/or perimeter beam **190** spans, across the ribs **16**, thus creating a desirable load sharing mechanism between adjacent ribs **16** by forcing more ribs **16** to be engaged in resisting tower loads.

[0148] The invention pertains to a durable, high-stiffness, fatigue-resistant foundation structure **100** for onshore wind tower installations which comprises:

[0149] 1. a central pedestal **10** that is made of cast-in-place concrete with concentric vertical prestressing elements and eccentric multi-axial horizontal and/or radial post-tensioning elements;

[0150] 2. an array of cast-in-place eccentrically post-tensioned radial ribs **16**;

[0151] 3. a cast-in-place slab **20** with heavily post-tensioned thickened slab edge **190*a***.

All components are made of high strength reinforced concrete and are rigidly connected to each other to behave as a monolithic spread foundation structure. The structural components are rigidly connected with arrays of rebar dowels (passive reinforcing) or post-tensioning elements extending through the conjunctions. The slab **20** functions as a two-way slab system that is free of construction joints across the footprint of the foundation and spans continuously over multiple ribs **16**. Perimeter post tensioning **59*a*** or circumferential post tensioning **59** of the slab **20** is applied at an elevation well below the neutral axes of the ribs **16** to cause eccentric loading of the ribs **16** and the pedestal **10**. Radial post-tensioning elements with an eccentric load pattern, with higher post compression at the bottom of the rib, extend from rib end to opposite rib across the pedestal **10**, or to the opposite end of the pedestal **10**. When all the prestressing elements are jacked, the foundation **100** is kept under heavy multi-axial eccentric post compression stress, thus increasing rib structural capacity to resist soil support reaction and providing low deflections, high stiffness and low stress amplitudes resulting in high fatigue resistant and high durability. Backfill **13** is added over the foundation **100** for increased stability and stiffness of the foundation **100**.

[0152] Soil support reaction under the slab **20** is transferred from the slab **20** to the ribs **16** and thickened slab edge **190*a*** (or perimeter beams **190**) as in two-way slab systems with more load distribution going to the ribs **16** in the primary span. Perimeter or circumferential post-tensioning are applied, perpendicular to the ribs **16**, in the orientation of the primary span that effectively reduces stress amplitudes and deflections in the slab **20** by keeping the slab **20** under heavy post-compression in the directions of primary slab spans around the foundation. The size, distribution, eccentricity and location of post tensioning elements **58** in the ribs **16** and the slab **20** are used, by the engineer, to dictate the natural frequencies of the foundation **100** to be in a safe range relative to operating frequencies of the wind generator according to turbine manufacturer recommendations.

[0153] The said vertical, radial and circumferential post-tensioning in the foundation keep all the structural components (Pedestal **10**, ribs **16**, slab **20**, thickened slab edges (or integral edge beams)) under multi-axial post compression confinement resulting in lower stress range amplitudes thus yielding higher stiffness, more effective crack control, lower deflections and improved fatigue resistance. Superior fatigue resistance and long life-span are achieved by keeping most of the structural elements of the foundation **100** under multi-axial compression while resisting operating loads or even during normal and abnormal extreme loads from the supported structure (wind power generator).

[0154] In a preferred embodiment, rib post-tensioning requirement are reduced by engaging fully developed bar dowels from the rib into the pedestal connection as well as extending fully developed radial rebar dowels of the slab **20** into the pedestal **10**, thus allowing passive reinforcing to participate in the said connection especially under extreme loads. Radial slab reinforcing pattern with tapered rib width was found to be very cost effective as the rib to pedestal connection benefits from a large number of top and bottom radial slab reinforcing bars participating in the said connection, as the rib width widens, thus reducing the number of bottom post-tensioning strands required for the said connection.

[0155] The structural configuration of the foundation **100** reduces the overall cumulative deflections in the structure under tower loads and significantly improves the rotational stiffness of the foundation **100** which is a key factor in determining the size of foundations in wind turbine installations. The rotational stiffness is also improved by the interlocking between surrounding soil (after backfilling) and the multiple surfaces and vertical faces of the foundation structure. The horizontal stiffness is improved by the passive earth pressure on the multiple faces of the structure. Both rotational and horizontal stiffness achieved by this design are much higher than conventional tapered inverted-T gravity spread footings especially for onshore foundations installed below grade in an excavated pit because of the increased interlocking surface area and increased passive earth pressure and increased friction on the multiple faces of the fatigue resistant foundation **100**.

[0156] The solid-core pedestal **10** comprises a continuous reinforcing cage and a tower receiving component, such as anchor-bolt assembly, with a cylindrical array of bond protected high strength post-tensioning bolts, for connecting to wind tower base flange **301**. In another embodiment and the tower receiving component may comprise an embedded cylindrical metal tower section **56***b* with means **56***c* for connecting to a tower section such as a flange with bolt holes for receiving bolts at its top and with an array of holes to allow the passing of rebar and post tension tendons. The anchor bolt assembly ensures structural continuity between the tower **300** and the pedestal **10**. The post-tensioning forces of the anchor bolts are selected by the engineer to insure that the tower base flange **301** remains in contact with the pedestal **10** under extreme normal and abnormal load conditions. The bolt assembly includes, at its bottom end, a bearing element that may consist of an embedment ring plate that is made of segments that are welded together.

[0157] Radial post-tension tendons and rebar reinforcing elements extending from the ribs **16** and the slab **20** pass through the pedestal reinforcing cage, or through holes in the embedded metal tower section.

[0158] As shown on the drawings, post-tensioning elements are flared horizontally, profiled vertically, arranged in matrix groups, spaced and draped in a manner that allows for optimum utilization of post-tensioning and ease of installation while avoiding tendon congestion and stress concentrations as tendons crisscross in the pedestal **10**. The regrouping of tendons to form flat and wide matrix along each axis was found to be effective in avoiding tendon congestion especially in the pedestal **10**. The said flat and wide matrix of tendons is placed as high or as low as possible to maximize their moment arms and optimize their contributed moment capacity. For corrosion protection, bonded (multi-strand and grouted) or un-bonded encapsulated (mono-strand) post-tensioning elements and their associated construction techniques can be used in the foundation **100**.

[0159] The rib's thickness can be gradually increased at the connection to the pedestal **10** to increase rib flexural, shear and torsional capacity and enhance pedestal confinement. The post-tensioning requirements can be reduced by engaging dowels at rib-to-pedestal connection and by extending fully developed radial dowels from the rib and the slab **20** deep into the pedestal, thus allowing passive reinforcing to participate in the connection.

[0160] In another embodiment, ribs **16** top surface can be tapered to a substantial slope extending vertically to an elevation near the top of pedestal allowing the ribs **16** to benefit from diaphragm action at their inner zone and also provide lateral support for the full height of the pedestal **10** and to provide concrete confinement at the highly stressed zone at the top of pedestal under tower base flange **301**.

[0161] The foundation may have a circular or polygonal foot print. The thickened slab edge **190***a* **190***a* (perimeter beam) may extend above or below the foundation. A shallow perimeter beam profile should be selected for ease of backfilling and improved accessibility for roller compactors during the backfilling of the foundation **100**. A thickened slab ring beam **190***a* may be designed to be at an offset distance away from the slab edge allowing the slab segment, outside the ring, to behave as a cantilever. This configuration reduces slab span and deflections as well as the volume of concrete required in the foundation **100**.

[0162] As shown on the drawings the size of the slab **20** and its continuous reinforcing including that of the thickened slab is configured to create a rigid composite connection to the ribs **16** with high stiffness which is sufficient to allow adjoining ribs **16** to participate more in resisting the loads and thus reducing local deflections and increasing overall foundation stiffness in addition to reducing the unsupported length of cantilever radial ribs **16**.

[0163] In a preferred embodiment, as shown on the drawings, the pairing of the ribs **16** on distal ends and the continuous perimeter beam construction yield a cost effective layout of post-tensioning that uses a small number of tendons and corresponding anchors as well as reduces friction losses by avoiding sharp turns in tendon layout. The tendons of the ribs **16** are anchored in a matrix array at the outer end of the rib and extend horizontally and diagonally along the rib to split into at least two groups **58***a* and **58***b* one near the bottom and the other near the top of the rib as it connects to the pedestal **10**. The tendons are more concentrated at the bottom than at the top in a concentric prestressing pattern that is intended to maximize the structural capacity of the foundation and meet the flexure and shear demand of the governing load cases.

[0164] Ribs **16** may have thickened flanges, at their connection to the pedestal **10**, that may also house post tensioning anchors for tendons **58** extending from ribs **16** on the opposite side of pedestal. The ribs **16** may also have post tensioning anchors along their sides or tops if tendon curtailment methods are applied in the design. The ribs **16** may also have embedded loop anchors if looping of tendons is used in the design. Loop anchors could also be used in the pedestal **10** to support precast concrete towers **300***b*.

[0165] As shown on the drawings the tendons in ribs **16** extend horizontally and diagonally to be split into three distinctive groups as they enter the pedestal. The first group **58***a* with more tendons is placed at the bottom of ribs **16** or in the slab to create camber for reducing deflections and improving foundation soil contact as well as meet the high flexural demand from the governing load cases, and the second group **58***b* slope up diagonally to follow the geometry of the top of the rib as they enter the pedestal **10**. The third group **58***c* is in the middle and it starts horizontal at rib anchor block and diagonally slopes down towards the bottom of the rib to enter the pedestal **10** for optimum use of the tendons. Tendons in the pedestal **10** are fanned and flared into groups to simplify the installation and maximize their utilization by increasing their moment arms measured from the top or the bottom of the structural concrete. Additional post-tensioning groups for shear resistance can be provided by providing tendons that traverse the shear failure plane in the ribs **16**.

[0166] In another embodiment the post-tensioning in the ribs **16** consist of three distinctive groups:

[0167] 1. A bottom group **58***a* that is horizontal at the bottom of the rib **16** and in the slab **20** and may be grouped with slab post tensioning,

[0168] 2. A top group **58***b* that is diagonally sloped upward to follow the geometry of rib top,

[0169] 3. An optional middle group **58***c* that starts horizontal at rib outer edge and is diagonally sloped down towards the bottom of the rib to eliminate dead load deflections and keep the ribs **16** and pedestal under post compression during normal operating conditions and also provide the high demand of post-tensioning capacity required at the bottom of the rib for downwind load cases, and traverse the shear failure plane for ribs **16** in the governing downwind load cases and provide additional shear resisting capacity in each rib,

such that the number of strands in the bottom of the rib and the pedestal **10** is much higher than that at the top thus causing a multi-axial, heavy, eccentric horizontal post compression in the foundation after the tendons are jacked.

[0170] Anchor-blocks for perimeter or circumferential post-tension tendons can be placed at perimeter beams **190**, (ring beams) or thickened slab or at the edge of the foundation or on top of perimeter beams **190** or on sides of ribs **16**. A preferred layout with two anchor blocks on opposite sides of the foundation and with semi-circular (180-degree) tendon arrangement is shown on drawings. Ring tendons with ring anchors **59***b* (such as dog-bone anchors) can be used to avoid having blisters on the foundation **100**. Styrofoam block-outs **59***c* can be placed in the foundation **100** according to anchor manufacturer recommended dimensions. When the concrete reaches the sufficient strength ring tendons are jacked and ring anchors grouted.

[0171] The foundation is made of a network of prestressed concrete elements that can be structurally analyzed, with the strut and tie method, as to a three-dimensional structure made of an array of vertically and horizontally oriented truss-girders joined at the center, with major tension chords reinforced with prestressing tendons, based on both upwind and downwind load cases wherein tension forces in the structure are resisted largely by prestressing elements and passive reinforcing and compression forces are resisted largely by the concrete elements. The structure can be analyzed as a circumferential array of vertically oriented trusses that are fixed at their inner ends to the central pedestal **10** and are laterally stabilized at their bottom by a horizontal trussed diaphragm formed by perimeter post tensioning **59***a*, in the slab or perimeter beam, and radial bottom tendons **58** in the ribs **16** or the slab **20**.

[0172] In another embodiment the fatigue resistant foundation **100** comprises a circumferential array of vertically oriented eccentrically prestressed cantilevered girders that are fixed at their inner ends to a central pedestal **10** that is laterally supported and confined through most of its height by rib concrete, and the ribs **16** and pedestal **10** are laterally stabilized at their bottom by a horizontal prestressed concrete trussed diaphragm, with a continuous slab **20**, and the prestressing is provided by radial tendons in the ribs **16** (or the slab **20**) and circumferential post tensioning elements **59**. The radial and circumferential tendons provide eccentric prestressing in the ribs **16** and the pedestal **10**. The pedestal is vertically prestressed and is structurally fixed to a tower base **301** of a pylon.

[0173] In a preferred embodiment the construction of the foundation **100** may utilize pre-assembled perimeter beam reinforcing cages, built in segments with overlapping spliced bars at their ends, and each having an array of shear resisting vertical ties and flexure resisting horizontal bars as well as local reinforcing at anchor locations as shown on FIG. X.

[0174] As shown on the drawings, the foundation has specific reinforcing groups. The ribs **16** have flexure reinforcing concentrated at the bottom and the top, vertical stirrups for shear reinforcing that are tightly spaced at high shear zone along rib inner end, rib skin reinforcing on ach face and bursting and splitting reinforcing made of horizontal hairpins extending between the said rib skin reinforcing, as well as straight or U-shaped horizontal dowels for embedment into the pedestal **10** and vertical dowels, at the bottom, for composite action with the slab **20**. As shown on the drawings the vertical stirrups also function as dowels for composite action of the slab **20**. The said dowels are spaced such that they could mesh between slab reinforcing bars without geometric interference, if the rib reinforcing is built in preassembled cages and placed over the slab reinforcing. In order to maximize shear capacity vertical stirrups are placed side-by-side, in pairs, at the inner rib zone where the shear demand is high.

[0175] Anchor zones are provided with heavy reinforcing with trim bar and ties. The ribs **16** may also have horizontal reinforcing dowels, perpendicular to the ribs **16**, to facilitate the structural continuity of the supported perimeter beams **190** or the thickened slab, across the width of the rib, by means of splicing the said dowels with perimeter reinforcing.

[0176] The pedestal **10** has a horizontal mesh at the top and skin reinforcing at all faces as well as at least one cage, around the anchor bolt assembly, comprising vertical tightly meshed anti-bursting reinforcing including two cylindrical meshes confining the anchor bolts each comprising horizontal hoops and either C or Z-Shaped bars and a radial array of horizontal hair-pins or stirrups tying both cylindrical meshes or spirals stirrups each housing a number of anchor bolts. The pedestal **10** cage assembly may comprise two concentric tightly meshed cages surrounding the anchor bolts one from the inside and the other from the outside with radial array of anti bursting and splitting resistant hairpins extending between the two cages # and #. Additionally an array vertically oriented pedestal vertical anti bursting and splitting resistant reinforcing group, comprising circumferentially spaced vertical hairpins extending between said top horizontal mesh and a horizontal bottom reinforcing mesh in the pedestal **10** or slab **20**, is included in the pedestal cage. The vertical hairpins # also function as supports to secure tendons in the pedestal **10** during construction.

[0177] Upper and lower slab reinforcing meshes may have any pattern such as a square grid, a circular array with radial pattern or overlapping pie-shaped segments. Additionally, an array of slab reinforcing locally arranged beneath the ribs **16** and being oriented parallel to the ribs **16** and extending into the pedestal **10** to facilitate composite action. The slab **20** may also be reinforced with post-tensioning elements in any pattern including radial, circumferential, perimeter or a square grid.

[0178] The foundation system relies on the use of many prefabricated components including rebar meshes and cages, pedestal cage assembly, pre cut post-tensioning strands, preassembled post-tensioning bundles, pre-cut post-tensioning duct sections and prefabricated concrete forms.

[0179] Reusable rib forms **16***b* are utilized to form foundation perimeter, the ribs **16** and the pedestal. Forms can be made to be segmented, universal, expandable and adjustable to work for different foundation sizes. As shown on FIG. X rib forms **16***b* can be made with adjustable supports to elevate the forms above the wet slab concrete during construction if the foundation is built in one pour. Rib forms **16***b* may sit directly on the hardened concrete slab **20** if the foundation is built in two pours. Rib forms **16***b* may be made with two side-panels of stiffened non-stick plates and an array of adjustable horizontal spacers between the panels to maintain proper geometry and resist the lateral pressure of wet concrete. Rib and pedestal forms **102** may be fitted with lifting lugs or means for receiving and supporting ladders, catwalks and work platforms to allow for access around the foundation. The forms may have means for securing post-tension anchors and hardware at specific spacing during construction. The forms may also have means for hanging an supporting rib reinforcing cages.

[0180] The foundation **100** may be supported on piles, or micro-piles **401** or piers **402** or rammed-aggregate piers **405**. The foundation **100** may receive rock anchors **404** or soil-anchors in a conventional manner. A construction site is prepared by excavation and flattening and preparation of soil for the foundation. The foundation **100** may be set on a mud slab or on compacted granular fill. The mud slab is a thin plain concrete layer intended to provide a clean and level base for foundation installation.

[0181] In one embodiment, After the foundation site has been prepared, slab reinforcing is placed inside slab forms and the slab is poured in place with dowels extending up from the slab **20** to receive ribs **16** and pedestal in a second pour. Rib and pedestal rebar and cage placement with post-tension tendons (or duct) placement are accomplished and forms are installed in place and a second pour is carried out. Alternatively the foundation **100** can be poured in a single pour with the use of accelerators in the concrete mix and by following a well designed concrete pour sequence. A set of small footings, placed within the mud slab, can be used to support and elevate the rib forms **16***b* and pedestal forms **102** during construction. Slab **20**, pedestal and rib reinforcing elements are assembled in the foundation **100**. Forms are placed in the foundation around the perimeter, the ribs **16** and the pedestal and the concrete is poured into the foundation in a carefully designed pour sequence. One option is to start with slab **20** and the bottom part of the ribs **16** and the pedestal with accelerator in the concrete mix to seal the bottom of rib and pedestal forms **102** by the time the slab **20** concrete is finished, the ribs **16** and the pedestal are poured jointly in small lifts.

[0182] When the concrete hardens to certain strength, post-tension elements are jacked and grouted as required. The tower base flange **301** is then attached to the pedestal **10** and grouted, and the tower anchor bolts are tensioned after the grout reaches sufficient strength.

[0183] In a preferred embodiment, the invention relates to a high stiffness, fatigue resistant, wind turbine foundation **100**, supporting a wind generator with a multi-megawatt rating and subjected to extremely high cyclical upset loads that comprise the following components:

[0184] 1. a substantially massive and wide central pedestal **10** with substantially solid core concrete construction that is kept, through most of its height, under a combination of lateral structural concrete supports and confinement, high vertical post-compression stress and high eccentric multi-axial lateral horizontal post-compression stress across its width, provided by said lateral supports and post-tensioning elements that traverse the width of the pedestal **10**, through non-segmented concrete construction, along multiple axes in a concentric pattern, and having a set of upright, circumferentially spaced anchor bolts, for providing the said high vertical post-compression stress, extending through said pedestal **10**, and having lower ends anchored relative to an anchor ring and upper ends projecting upwardly from said top end of said pedestal, said anchor bolts being substantially bond protected along their length, said upper ends of said bolts project upwardly from the said pedestal **10** through a base flange of an annular tower structurally fixed atop the said pedestal **10**, and also having an upright heavily reinforced cage of tightly meshed rebar, and concentrically arranged around both sides of the anchor bolt cage with opening to allow the passing of lateral load transfer elements,

[0185] 2. a support slab-on-grade **20**, cast-in-situ out of concrete against the soil, in an excavation pit, of continuous construction and covering a footprint substantially larger than that of the pedestal **10** and having a thickness that is much smaller than the depth of the pedestal **10** and having thickened edge made of concrete integral with the support slab **20** and having horizontal post-tensioning elements to keep the slab **20** under heavy multi-axial post compression,

[0186] 3. an array of concentrically arranged ribs **16** made of deep girder construction, integral with the pedestal and support slab **20**, and jointly cast-in-situ with said pedestal **10**, and extending vertically, above the slab **20**, to an elevation near the top of pedestal **10** such that the pedestal **10** is laterally supported and substantially confined below the said tower base flange **301**, and having a width that is substantially smaller than that of the said pedestal, and being arranged such that pairs of ribs **16** outwardly extend from opposite sides of the pedestal with post-tensioning elements inwardly extending from the distal ends of the ribs **16** through the pedestal,

[0187] 4. reinforcing rebar and prestressed dowels extending from the ribs **16** deep into the core of the pedestal **10** from distal ends, and arrays of dowels, made of rebar, extend between the slab **20** and each of the ribs **16** and the pedestal along their conjunctions,

[0188] 5. a suitable backfill material **13** placed over the foundation **100**, to stabilize the foundation **100** against overturning, followed by tower base installation and grouting,

the foundation **100** is kept under heavy multi-axial post-compression such that tower loads are resisted by pairs of ribs **16**, on distal ends of the pedestal **10**, wherein each pair of ribs **16** form a high stiffness continuous, non-segmented, laterally supported, post-tensioned girder extending between distal ends of the foundation **100** with continuous uninterrupted composite action from the slab-on-grade **20**.

[0189] In another embodiment, slab post-tensioning can be arranged at any combination of perimeter, radial or diametric, or other patterns.

[0190] In another embodiment, composite action is further facilitated with radially oriented, reinforcing bars locally arranged in the slab **20**, beneath the ribs **16**, and extended deep into the pedestal **10**, in addition to an array of vertical dowels extending between the rib and the slab **20** that function as shear connectors.

[0191] In a preferred embodiment, the invention pertains to a foundation **100** for supporting a wind generator with a multi-megawatt rating and subjected to extremely high cyclical upset loads, with increased stiffness and improved fatigue resistant comprising:

[0192] 1. a support slab-on-grade **20** of non-segmented continuous construction with a circular integral perimeter beams **190** with circumferential post tensioning elements **59** made of two 180-degree tendon segments forming a 360-degree circle, with anchors at the opposite sides of the foundation,

[0193] 2. a central cylindrical pedestal **10** integral with the support slab-on-grade of solid non-segmented construction and having vertical post-tensioning elements,

[0194] 3. ribs **16** integral with the support slab and the central pedestal **10**, on top of the slab **20**, with three or four pairs of ribs **16** radially extending from opposite sides of the pedestal **10** and post tensioning elements extending axially and diagonally from anchors placed at the distal ends of the ribs **16** through the pedestal **10**, such that the ribs **16** and the perimeter beams **190** function as a prestressed trussed diaphragm structure with infill panels, and pairs of ribs **16** on distal ends of the pedestal **10** function continuous post-tensioned girder, that is free of construction joints, with continuous composite action from the slab **20** and the foundation **100** is kept under eccentric multi-axial horizontal and concentric vertical post-compression, and circumferential post-tensioning in the slab **20** effectively reduces stress amplitudes and deflections in the slab **20** by keeping the slab **20** under heavy post-compression in the direction of primary slab spans which is roughly perpendicular to the ribs **16**.

[0195] In a preferred embodiment, the rib extends vertically from the bottom of the foundation to an elevation near the bottom of the tower base flange **301** to enable the ribs **16** to participate in resisting bearing loads under the tower base flange by increasing the area of the cross-section involved in bearing resistance under the tower base flange **301** and increasing the permissible bearing strength under the base flange or the grout bed by increasing the bearing area measured at the surrounding faces of the concrete. The geometric configuration and the improvement in bearing resistance, in this invention, allow the engineer to specify concrete with only one relatively low compressive-strength for the entire foundation structure. In contrast, high bearing stresses under the tower base flange **301** in conventional gravity spread footings, force the engineer to specify concrete with higher compressive strength for the pedestal and a lower compressive strength for the base.

[0196] The proximity of inner rib ends to the tower base flange **301** allows the inner zones of the ribs **16** to remain under vertical compression stresses caused by vertical post-tensioning forces between embedment ring **54** and tower base flange **301**. The said vertical compression stress zones improves confinement conditions and fatigue resistance in rib inner zones.

[0197] Bonded and grouted multi-strand system was found to be expensive and lengthy and requires an additional step of grouting and may not be economical for some onshore installations. It is preferable to use un-bonded, encapsulated mono-strands, arranged in bundles and installed in the foundation reinforcing prior to concrete casting, which would reduce construction costs and improve construction schedule.

[0198] In a preferred embodiment post-tensioning in the foundation **100** is made eccentric, to create cambers in the foundation **100** that could result in reduced deflections and improved foundation-soil contact. As an example, the eccentric prestressing of the ribs **16** creates a convex shaped camber in the foundation **100** that helps reduce the deflections under turbine weight and operating loads. Similarly cambers can be used in perimeter beams **190** and slab sections to reduce slab deflections and improve foundation-soil contact conditions by ensuring a more uniform bearing pressure under the foundation.

[0199] The vertical profile (elevation) of circumferential tendons in the foundation **100** may be adjusted at mid spans and under supporting ribs **16** to optimize their utilization.

[0200] In another embodiment gradual transition of geometry at the conjunction of the structural elements is employed to prevent stress concentration and fatigue related problems. As an example the use of fillets and curved transition is desirable at the conjunctions between ribs **16**, pedestal **10** and the slab **20**.

[0201] In a preferred embodiment, as shown on FIG. X, the inner ends of the ribs **16** are tapered to become wider as the rib connects to the pedestal, in order to satisfy the high flexural, torsional and shear demands at the inner zone of the ribs **16**, and to distribute the multi-axial compression over large surface area to help reduce splitting and bursting reinforcing at the sides of the pedestal **10**.

[0202] In another embodiment low relaxation post-tensioning strands are used to reduce post tension losses over time. Concrete accelerators and plasticizers and otter admixtures may be utilized in the concrete mix design. The small thickness of the structural elements may allow for on-site steam curing of concrete.

[0203] A hollow pedestal **10** cross-section may be used, however it can be problematic. Hollow pedestal above the frost depth where there is elevated water table is problematic. Hollow pedestal results in reduced stiffness, stress discontinuity, indirect load transfer and stress concentration with local deformation in the shell resulting in poor performance under heavy flexural and torsional loads from the cantilevered rib, as well as additional problems stemming from stresses caused by frost forming and freezing of ground water in the foundation.

[0204] In another embodiment the cross-section of the rib may change and dimensions along its length may change. For example, the section may start rectangular and gradually a top flange may be enlarged to reduce stresses in the upper zone of the rib.

[0205] In another embodiment the pedestal **10** may have an enlarged cross-section at the top followed by a transition into a smaller cross-section below. The upper enlarged cross-section may help with improve bearing strength at the top of the pedestal below tower base flange **301**, or bearing washer plate, and the high strength grout bed according to American Concrete Institute design guidelines.

[0206] The present invention pertains to a foundation design that overcomes the thermal cracking problem stemming from heat of hydration, in large foundation pours for large multi-megawatt rated turbines, by using a structural configuration coupled with post-tensioning techniques that reduce the thickness of the structural elements, while increasing the surface area of concrete pours, thus improving heat dissipation conditions and causing a the ratio of concrete mass to surface area to be roughly 40% to 50% less than in conventional design for foundations for the same turbine under the same loading and geotechnical conditions.

[0207] The present invention uses a tower base leveling and grouting method without using tower anchor bolts for leveling, or having to use leveling shims which cause undesirable stress concentration at shim locations which could lead to localized fatigue failure at shim locations. This task is achieved by providing the bolt template at the very top of the bolt assembly with at least three sets of additional bolts and corresponding threaded bolt inserts suitable for embedment into concrete. The said leveling bolts **53** and inserts **53***b* are be located outside or inside the bolt circle of tower base, but directly under tower base flange. This allows for continuity of grout bed construction and provides an easy access for leveling bolts **53**. Small cutouts at leveling bolt locations connected can be used. Another benefit of this leveling technique is having the ability to apply grout a continuous grout bed that is free of construction joints, under tower base **301** in one session and to also have the ability to tension all anchor bolts in one session.

[0208] The present invention improves safety and accessibility around foundations during construction, and reduces hazardous conditions for construction crew. That goal is achieved by using reusable form sections that are fitted with platform sections for forming a access platforms around the foundation, and connect to at least one access ramp extending beyond the edge of the foundation. The platform and the ramp are fitted with slip-resistant walking surface and elevated ramps all provided with guardrails and designed to applicable industry safety standards. The relatively thin slab thickness minimizes the risk of worker injury during construction.

[0209] Transformer pad can be supported on precast concrete posts extending vertically from the foundation.

[0210] Pedestal forms **102** will have openings for running electrical and communication conduits thus preventing problems stemming from randomly placing the conduits in areas that could compromise the structural design.

[0211] The ribs **16** may have means for receiving and supporting prefabricated trays (or electrical duct banks) for housing power and communication cables.

[0212] This foundation design can also be adapted for offshore wind turbine projects. In this case the foundation **100** may be assembled on a barge or dry dock then transported or floated to its destination, then lowered into a prepared seabed location. The foundation can be weighed down in place by backfilling it with suitable material. The offshore foundation **100** may be configured to receive any type of offshore piers **404**, suction piers **403**, piles **400**, micro-piles **401**, anchors **404** or any combination of the above.

[0213] The invention relates to an offshore concrete foundation **100** with high stiffness and improved fatigue resistant comprising:

[0214] 1. a support slab-on-grade **20** of non-segmented continuous construction covering the entire footprint of the foundation and having (horizontal) diametric and perimeter post-tensioning elements,

[0215] 2. a central pedestal **10** integral with the support slab-on-grade **20** of solid non-segmented construction and having vertical post-tensioning elements and also having reinforcing elements of rebar to carry loads diametrically across the pedestal **10**;

[0216] 3. a cylindrical or conical stem **11** extending vertically above the pedestal **10** and being fixed to the pedestal **10**, and having a hollow cross section, of equal size or smaller than that of the pedestal **10**, and may be constructed with segmented or non-segmented construction methods and could be made with typical cast in place over the pedestal **10** by using typical construction methods for tall cylindrical concrete structures such as continuous forming, successive pours, segmental construction with precast concrete panels or other known construction methods used conventionally for cylindrical concrete structures such as chimneys, and the stem **11** is kept under heavy concentric vertical post-compression stress by an array of circumferentially arranged vertical post-tensioning elements, and the stem **11** may have an ice cone **11***b* integral with the top of stem **11**, and the stem **11** having means for fixing a tower base **301** of a wind tower **300**, the stem **11** and the ice cone **11***b* are vertically and circumferentially prestressed with vertical and circumferential post tensioning elements,

[0217] 4. ribs **16** integral with the support slab **20** and the central pedestal **10**, on top of the slab-on-grade, with pairs of ribs **16** radially extending from opposite sides of the pedestal **10** with post-tensioning elements extending radially and diagonally from the distal ends of the ribs **16** through the pedestal **10** and keeping the ribs **16** and the pedestal **10** under heavy eccentric post compression stress and reinforcing dowels extending from the ribs **16** into the pedestal **10** and spliced with pedestal **10** reinforcing,

[0218] 5. deep perimeter beams **190** extending continuously around the foundation, made of concrete integral with the support slab-on-grade **20** and the ribs **16** and having continuous perimeter or circumferential post tensioning elements,

When the concrete sets, the said post-tensioning elements are jacked and the anchor bolts are post-tensioned the foundation is kept under heavy multi-axial post-compression.

[0219] The offshore foundation **100** is constructed on a barge or in a dry dock and then floated or transported to an offshore installation site and lowered to be places over a prepared sea bed, a suitable backfill material **13** placed over the foundation **100** to stabilize the foundation against overturning. Scour protection measures **13***b* are provided around the foundation. The foundation is built with marine cement and marine grout and is kept under heavy multi-axial horizontal and vertical pre-stress using bonded and grouted post tensioning systems rated for double corrosion protection and suitable for marine environment.

[0220] An offshore foundation for wind turbines comprising the following elements:

[0221] 1. A vertically extending pedestal that is cast in situ, on a barge, out of concrete, the pedestal has an integral long stem **11** for receiving and supporting a tower structure;

[0222] 2. A substantially horizontal support slab **20** that is cast in situ, on a barge, out of concrete, the support slab **20** covering an area of ground larger than that covered by the pedestal **10**;

[0223] 3. A plurality of radial ribs **16** extending radially outwardly from the pedestal **10** and spaced around the pedestal **10**, each rib being prefabricated and being joined along the base thereof to the support slab **20** when the support slab **20** is cast in situ and being joined along an inner side thereof to the pedestal **10** when the pedestal **10** is cast in situ;

[0224] 4. A plurality of prefabricated perimeter beams **190** spanning continuously, near the perimeter of the foundation, between ribs **16** and supporting the slab **20**;

[0225] 5. Backfill **13** for weighing down the foundation, resisting tower loads and providing scour protection **13***b*.

when the concrete sets, the precast components will become integral with a cast-in-place components. Radial post-tensioning tendons extend from rib ends opposite rib ends across the pedestal **10**. Vertical post-tensioning is arranged in the pedestal **10** as well. The stem **11** and the ice cone **11***b* may also benefit from circumferential post-tensioning.

[0226] The pedestal **10** has means for receiving and supporting a tower **300** or pylon. The upper portion of the pedestal **10** (the stem **11**) may be made in multiple consecutive cast in situ pours, depending on its height. Alternatively, the stem **11** may also be made by joining precast segments with circumferential and vertical post-tensioning to form the stem **11**.

[0227] In another embodiment of the invention, a wind turbine is fabricated on a barge with precast concrete element as following. The barge surface is prepare with a non bonding agent or a thin membrane at the foot print where the foundation to be built. Lower slab reinforcing mesh sections are assembled and placed and the pedestal cage reinforcing is assembled at the center of the foundation. Upper slab reinforcing mesh sections may follow after slab post tension duct is placed. Precast concrete ribs **16** are placed in a radial array around the pedestal cage and precast concrete perimeter beams **190** are arranged around the perimeter of the foundation. Post tensioning ducts in the pedestal space and at perimeter beam-to-rib connections are placed to pair with corresponding duct in the precast members. Forms for pedestal and for closure pours at rib-to-perimeter beam connections are installed. Slab concrete is poured followed by pedestal **10** concrete and closure pours at rib-to-pedestal connections. Stem **11** is fabricated possibly in multiple consecutive pours depending on pedestal height. Stem **11** design may incorporate an ice cone **11***b* at its top. Post tensioning tendons are installed, the jacking and grouting of tendons is carried out. Some pylon sections could be installed earlier prior to transportation. The finished foundation **100** is transported to its offshore installation site using a suitable means of transportation such as towing the barge.

[0228] In another embodiment of the invention relates to an offshore foundation for wind turbines comprising the following elements:

[0229] 1. A vertically extending pedestal **10** that is cast in situ, on a barge or dry dock, out of concrete;

[0230] 2. A substantially horizontal support slab **20** that is cast in situ, on a barge or dry dock, out of concrete, the support slab **20** covering an area of ground larger than that covered by the pedestal **10**;

[0231] 3. A plurality of radial ribs **16** extending radially outwardly from the pedestal **10** and spaced around the pedestal **10**, each rib being prefabricated and being joined along the base thereof to the support slab when the support slab **20** is cast in situ and being joined along an inner side thereof to the pedestal **10** when the pedestal is cast in situ, each rib has an integral pier for receiving a leg of lattice lower;

[0232] 4. A plurality of perimeter beams **190** spanning continuously, near the perimeter of the foundation, between ribs **16** and supporting the slab **20**, optionally each perimeter beam can be prefabricated;

[0233] 5. A lattice tower **200** having a plurality of legs structurally connected to the integral piers **180** in the ribs **16**, the lattice tower **200** has, at its top, means for receiving and structurally supporting a pylon or a tower **300**;

[0234] 6. Suitable offshore backfill **13** for weighing down the foundation, resisting tower loads and providing scour protection **13***b*.

[0235] When the concrete sets, the pre-cast components will become integral with a cast-in-place components. Radial post-tensioning tendons extend from rib ends opposite rib ends across the pedestal **10**. Vertical post-tensioning is arranged in the pedestal **10** as well. The structural behavior is improved by the added compression in all ribs **16**, edge beams, slab **20** and center pedestal.

[0236] The lattice tower **200**, preferably incorporating 3-dimentional trusses, transfers the pylon loads down to the concrete foundation **100**. The lattice tower **200** may get connected to the concrete foundation prior to transportation or it can be connected to the foundation at final offshore installation site.

[0237] In another embodiment of the invention, a wind turbine is fabricated on a barge with precast concrete element as following. The barge surface is coated with a non-bonding agent or covered with a thin membrane at the foot print where the foundation to be built. Lower slab reinforcing mesh sections are assembled and placed and the pedestal cage reinforcing is assembled at the center of the foundation. Upper slab reinforcing mesh sections may follow after slab post tension duct is placed. Precast concrete ribs **16** are placed in a radial array around the pedestal cage and precast concrete perimeter beams **190** are arranged around the perimeter of the foundation. Post tensioning ducts in the pedestal space and at perimeter beam-to-rib connections are placed to pair with corresponding duct in the precast members. Forms for pedestal and for closure pours at rib-to-perimeter beam connections are installed. Slab concrete is poured followed by pedestal concrete and closure pours at rib-to-pedestal connections. A lattice tower **200** structure is prefabricated and mounted atop the concrete foundation **100**. The foundation is transported to installation site using a suitable means of transportation. Seabed is prepared for receiving the foundation by placing a sub-base of suitable material such as crushed stone. The foundation is backfilled and scour protection measures **13***b* are installed.

[0238] In another embodiment of the invention, the stem **11** is prefabricated separately and provided with means for connecting to the pedestal **10**, preferably an array vertical post tensioning dowels extended between the pedestal and the stem or other segmental post tensioning joining methods. The pedestal may be fitted with means for receiving the prefabricated stem based on segmental post tensioning and grouting construction methods.

[0239] Piles **400**, Micro-piles **401** or piers **402** or suction piers **403** or anchors **404** can be used with the offshore foundation **100** in a similar manner describe in the application. In this case vertical sleeves will be arranged in the foundation to receive an array of piles **400** or anchors extending through the foundation, and allow for additional loading capacity and improve stability of foundation. Piles **400** are secured to the foundation by filling the sleeves with marine grout.

[0240] Under some conditions, the use of piles **400**, piers or suction piers or anchors may eliminate the slab **20** and/or the perimeter beams **190** from the design.

[0241] Obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that, within the scope of the invention.

1. A foundation comprising:

a concrete support slab having horizontal rebar therein,

a concrete pedestal integral with the support slab having vertical rebar therein,

a plurality of concrete ribs on top of and integral with the support slab and integral with the pedestal, the ribs being radial to pedestal, and having connection elements extending from the ribs into the pedestal and from the ribs into the slab,

post tensioning elements extending from the distal end of the ribs through the pedestal and, a perimeter beam in the slab having a post tensioning element therein.

2. A foundation as in claim **1** wherein,

the ribs positioned in pairs on opposite sides of the pedestal and having the tension elements extending from the distal ends of the ribs through the pedestal.

3. A foundation as in claim **2** wherein,

the post tensioning elements in the ribs are eccentrically arrayed for eccentric loading.

4. A fatigue resistant foundation comprising:

a horizontally prestressed concrete slab having a structurally continuous horizontal rebar grid for reinforcing the slab and a plurality of horizontal post tensioning elements therein for prestressing the slab, and a perimeter beam proximate the perimeter of the slab,

a vertically extending central concrete pedestal having a plurality of vertical post tensioning elements, the pedestal integrally connected to the slab,

a plurality of reinforced concrete ribs on top of and integrally connected to the slab with structural continuity between the rib and the slab, the ribs integrally connected to the pedestal, with structural continuity between the rib and the pedestal,

at least one post tensioning element running through each rib and the pedestal for providing post tensioning stress in the ribs and pedestal and for connecting the ribs to the pedestal under post compression stress,

such that the pedestal, slab and the ribs are connected to each other to form a monolithic foundation with a three dimensional network of post tensioning elements in the slab, pedestal and ribs keeping the foundation under multi-axial compression while resisting operating loads, and during normal and abnormal extreme loads, thus linking the slab and the ribs to the pedestal under vertical, and horizontally eccentric post compression stress, with reduced multi-axial stress range amplitudes in the concrete and steel reinforcing.

5. A foundation as in claim **4** wherein,

the perimeter beam comprises a thickened perimeter slab portion.

6. A foundation as in claim **5** wherein,

the thickened perimeter slab portion comprises a plurality of slab perimeter reinforcing cages, each cage having a plurality of continuous horizontal bars housed in an array of vertical stirrups extending between the horizontal bars for reinforcing the perimeter slab portion and having a perimeter post tensioning element extending through the plurality of perimeter reinforcing cages to further post tension the perimeter slab portion.

7. A foundation as in claim **4** wherein,

the pedestal has a vertical inner reinforcing cage and an outer reinforcing cage with the plurality of vertical post tensioning elements therebetween, the pedestal also having a horizontal bottom reinforcing mesh, and a horizontal top reinforcing mesh, with an array of vertical reinforcing hairpin bars extending therebetween for reinforcing the core of the pedestal.

8. A foundation as in claim **4** wherein,

the pedestal has pairs of ribs on opposing sides of thereof and post tensioning elements extending from the distal ends of the ribs though the pedestal to hold the ribs to the pedestal under post compression stress.

9. A foundation as in claim **7** wherein,

the pedestal has a vertical inner reinforcing cage and an outer reinforcing cage with the plurality of vertical post tensioning elements therebetween, the pedestal also having a horizontal bottom reinforcing mesh, and a horizontal top reinforcing mesh, with an array of vertical reinforcing hairpin bars extending therebetween for reinforcing the core of the pedestal.

10. A foundation as in claim **9** wherein,

the pedestal has pairs of ribs on opposing sides of thereof and post tensioning elements extending from the distal ends of the ribs though the pedestal to hold the ribs to the pedestal under post compression stress.

11. A foundation as in claim **4** wherein,

the ribs are cantilevered and have a neutral axis, and the post tension elements in the perimeter beam and in the ribs and through the pedestal are spaced relative to the neutral axis of the cantilevered ribs to provide a three dimensional post compression load pattern in the foundation to counter influence the multi-stage and multi-axial fatigue loading of the forces of a wind tower supported thereon when the post tensioning elements are tensioned to the desired stresses.

12. A foundation as in claim **4** wherein,

the ribs have a neutral axis and the post tension elements in the perimeter beam, in the ribs and through the pedestal are spaced relative to the central axis of the ribs to provide a camber pattern in the foundation to counter the deformation due to the dead loads on the foundation from self weight, soil weight and the weight of a wind tower supported thereon when the post tensioning elements are tensioned to the desired stresses.

13. A foundation as in claim **4** wherein,

the ribs are cantilevered and have a neutral axis such that when perimeter post tensioning elements in the slab are tensioned at an elevation below the neutral axis of the cantilevered ribs it causes an eccentric loading of the cantilevered ribs and the pedestal to satisfy the governing load case of ribs under downwind loading during extreme normal and abnormal load cases when the post tensioning elements are tensioned to the desired stresses.

14. A foundation as in claim **4** wherein,

the pedestal is laterally confided by the ribs and the vertical post tensioning elements in the pedestal, and the pedestal further comprises a plurality of bond-protected anchor bolts extending vertically from an embedment ring near the bottom of the pedestal through the top of the pedestal for securing a base flange of a tower in full contact under compression for providing vertical post compression stress in the foundation when the anchor bolts are tensioned.

15. A foundation as in claim **4** wherein,

a backfilling material placed over the foundation adds stability and stiffness to the foundation.

16. A foundation as in claim **4** wherein,

the size, distribution, eccentricity and location of post tensioning elements in the ribs and the slab are selected to dictate the natural frequencies in the foundation for a desired safety range selected for the operating frequencies of the wind tower and generator supported on the pedestal.

17. A foundation as in claim **4** wherein, the ribs are prefabricated.

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