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(54) MODULAR HYDROPOWER SYSTEMS AND METHODS WITH PUMPED STORAGE

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(22) Filed: Feb. 1, 2025

Related U.S. Application Data

(63) Continuation-in-part of application No. 18/924,991, filed on Oct. 23, 2024.

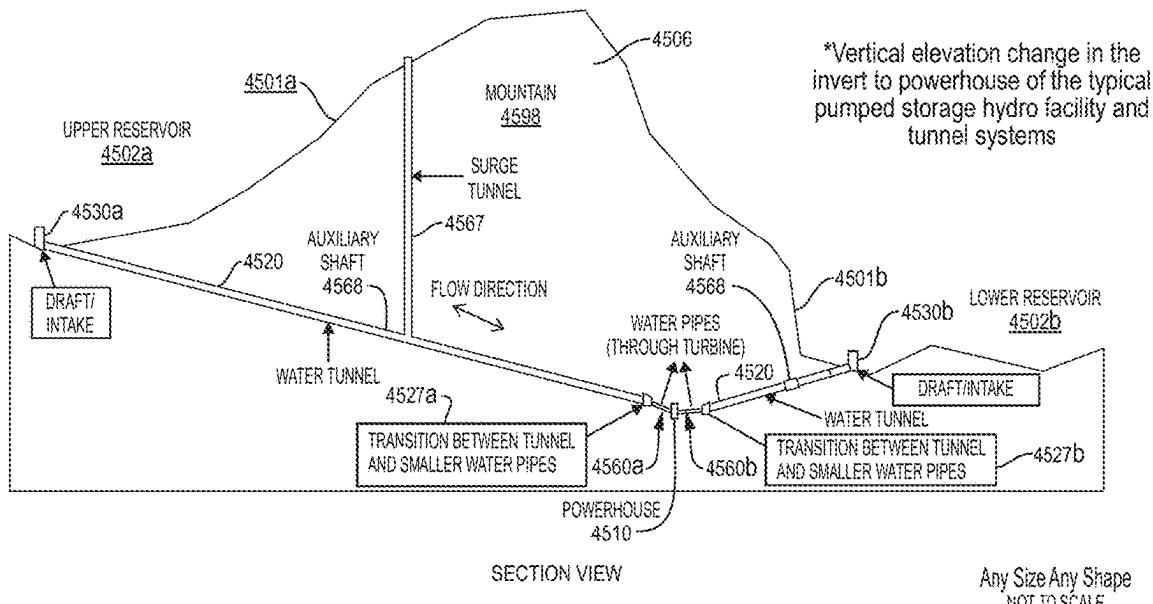
(60) Provisional application No. 63/718,561, filed on Nov. 8, 2024, provisional application No. 63/701,484, filed on Sep. 30, 2024, provisional application No. 63/552,655, filed on Feb. 12, 2024.

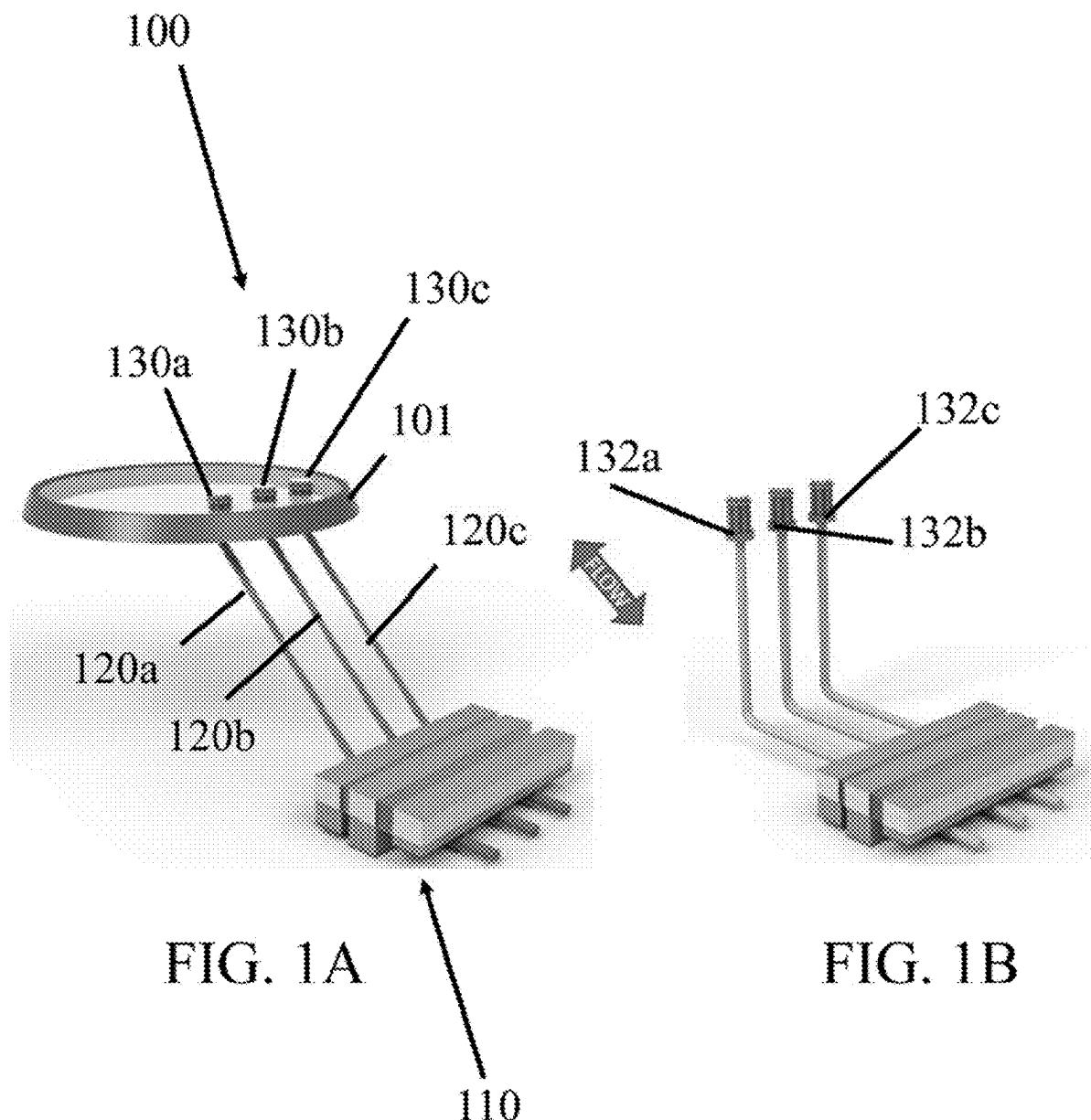
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F03B 17/06 (2006.01)
(52) U.S. Cl.
CPC F03B 17/06 (2013.01)

(57) ABSTRACT

A power generation system may include an impoundment structure at least partially defined by a plurality of precast segments. At least one of the precast segments may include a precast form and at least one precast infill block. The power generation system may include a powerhouse. At the powerhouse, a fluid conduit is coupled to an intake tube and a draft tube in respective transition regions to enable fluid to flow into a power generating module to produce electrical power, and transition collar(s) may be employed to secure connectivity between the fluid conduit and the intake tube and the draft tube. The power generating module may be arranged such that an intake port is elevated with respect to a draft port at the power generating module. Sensors may be employed to monitor integrity of elements of the power generation system.

Transition Between Larger Tunnel to Smaller Feeds
Precast Concrete Pumped Storage Hydro Facility



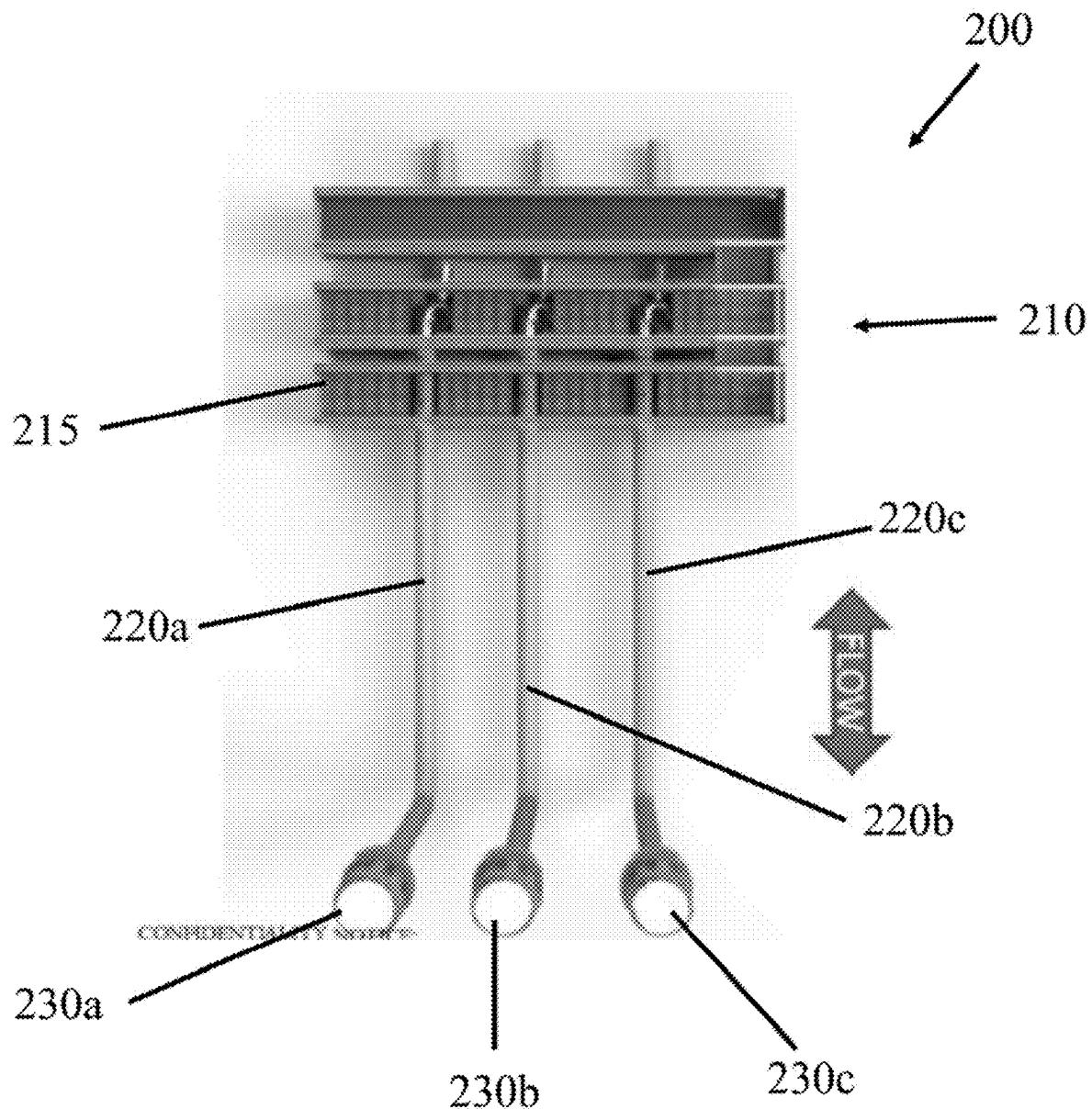
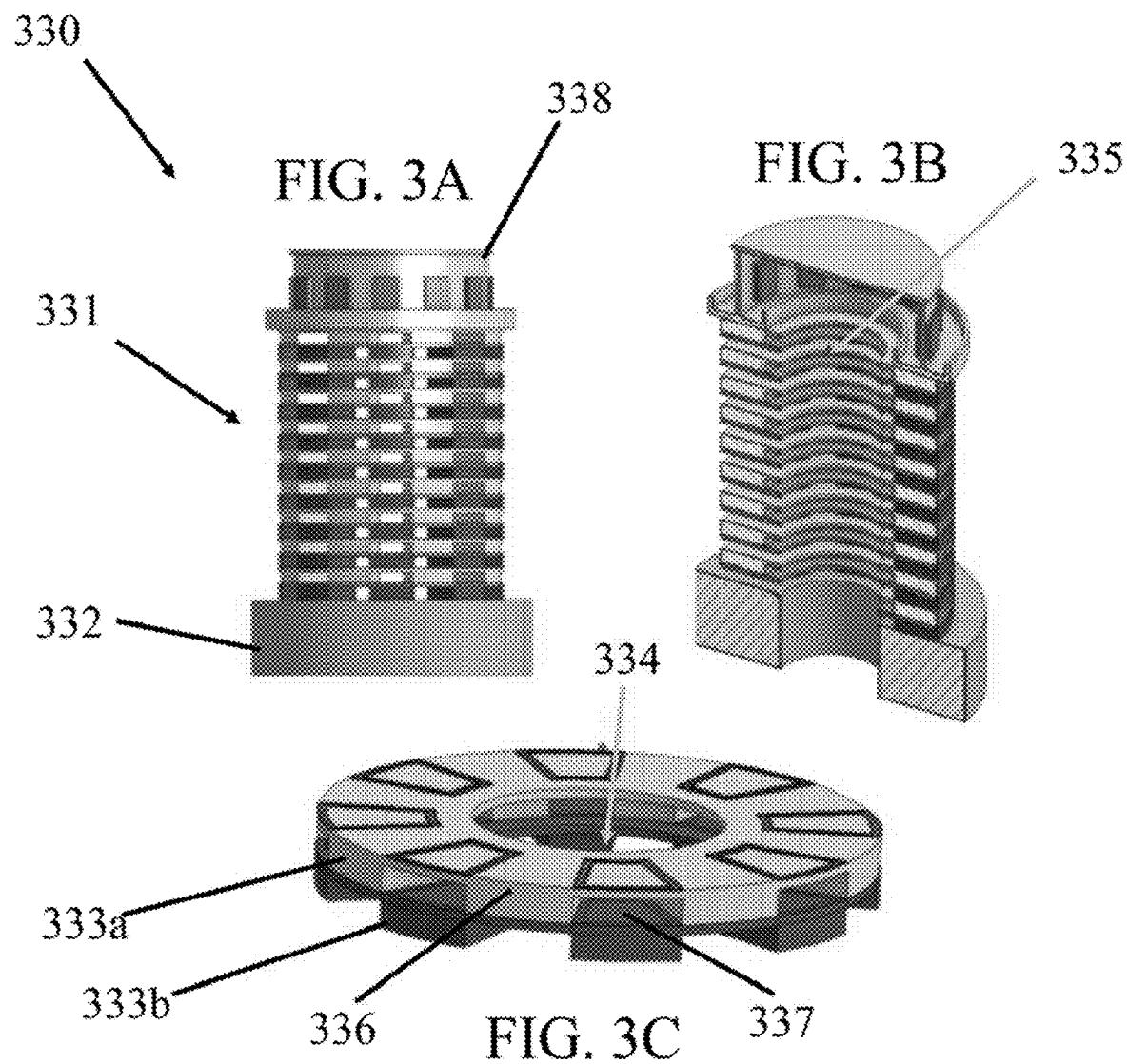


FIG. 2



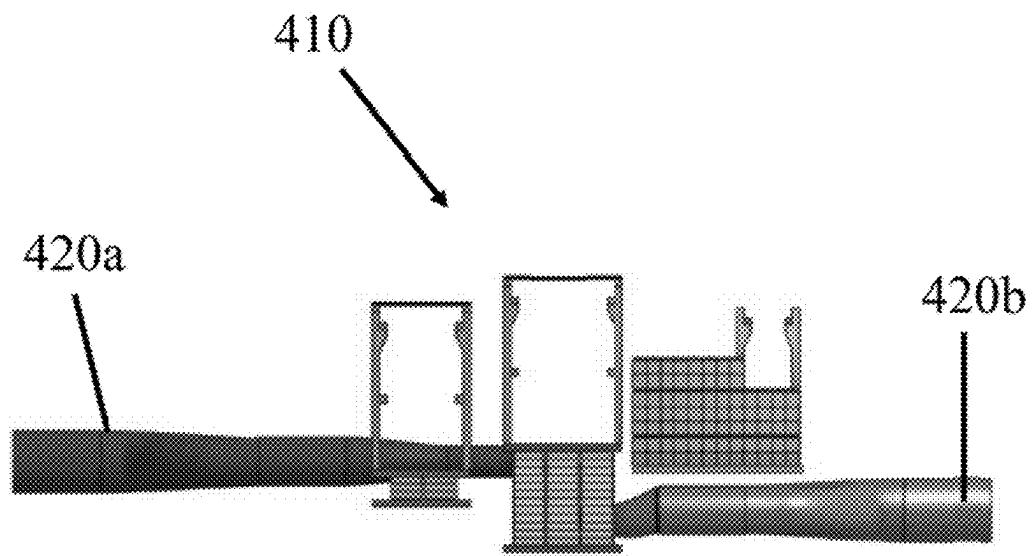


FIG. 4

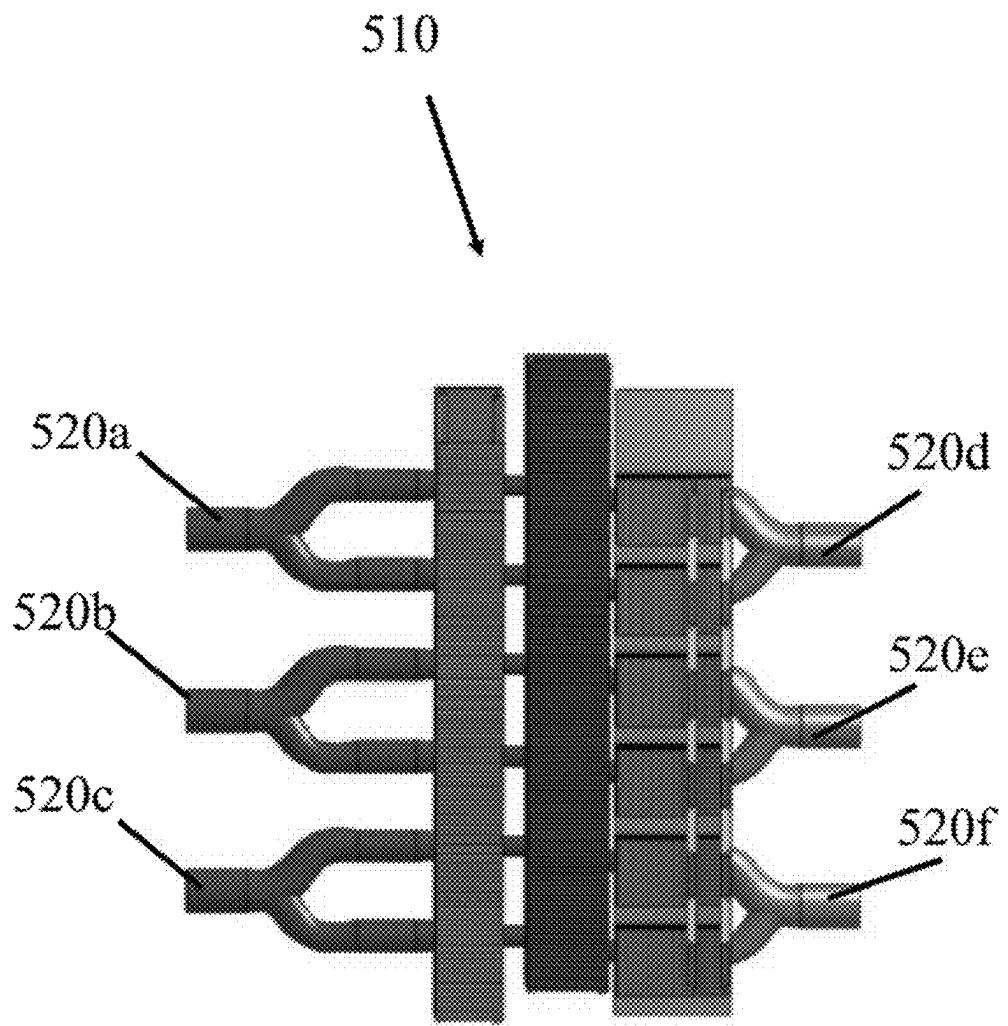


FIG. 5

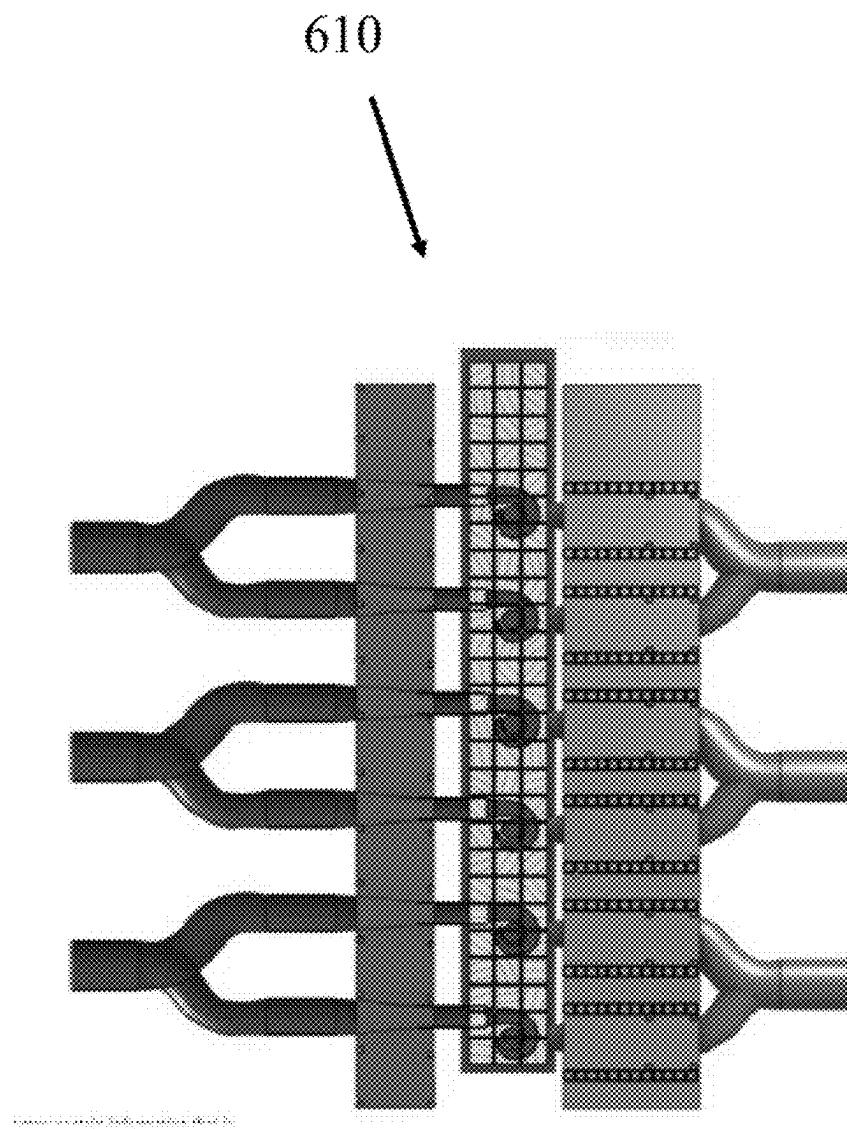


FIG. 6

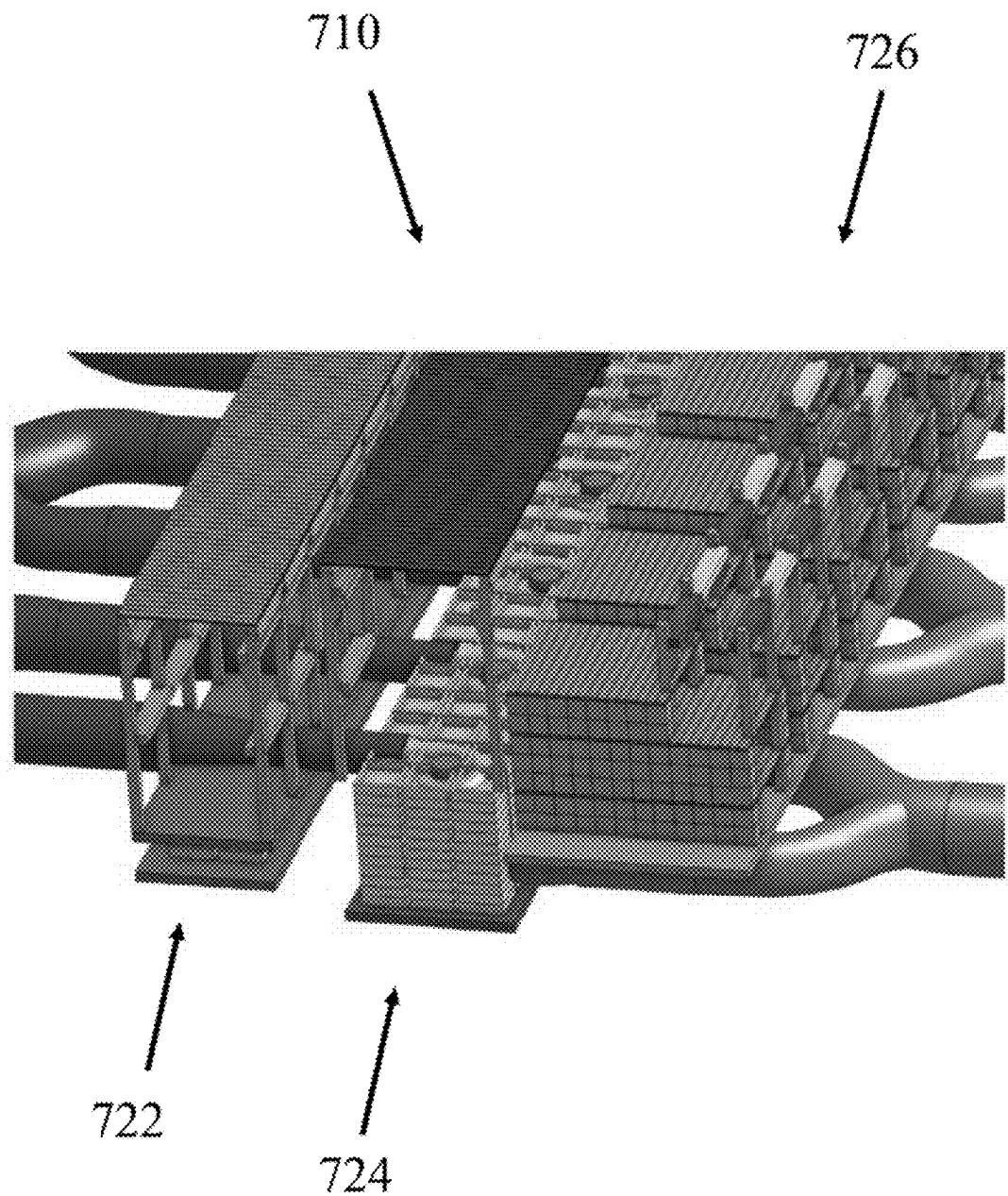


FIG. 7

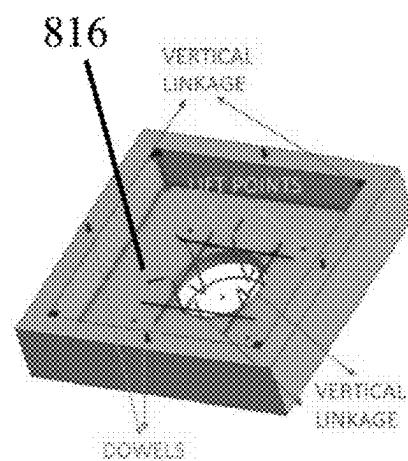
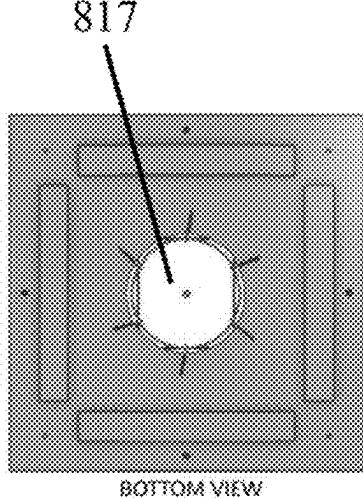
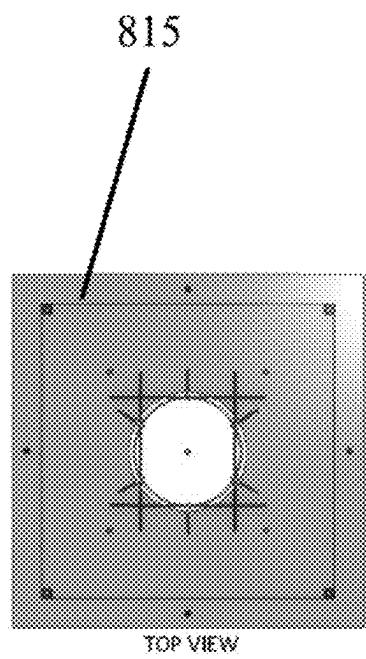


FIG. 8A

FIG. 8B

FIG. 8C

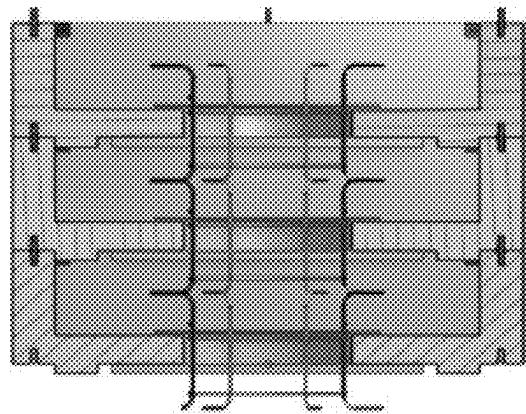
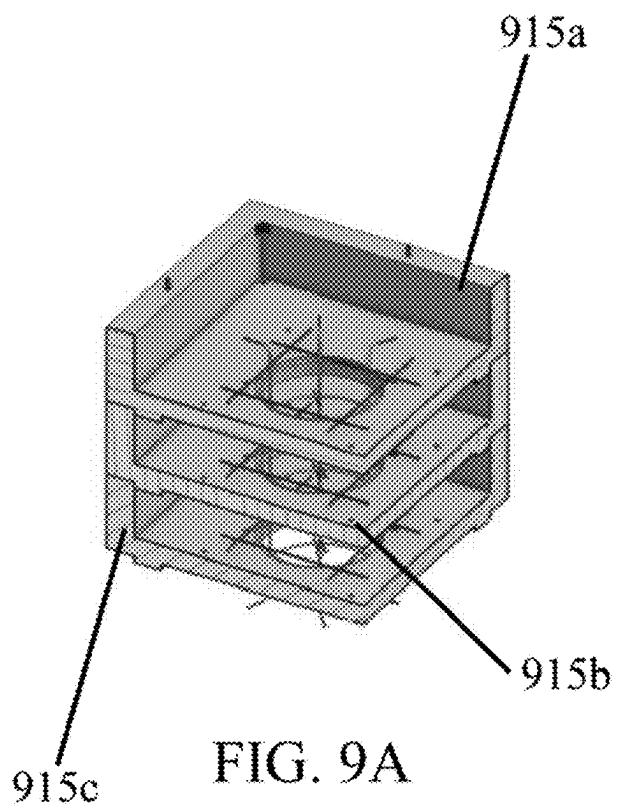
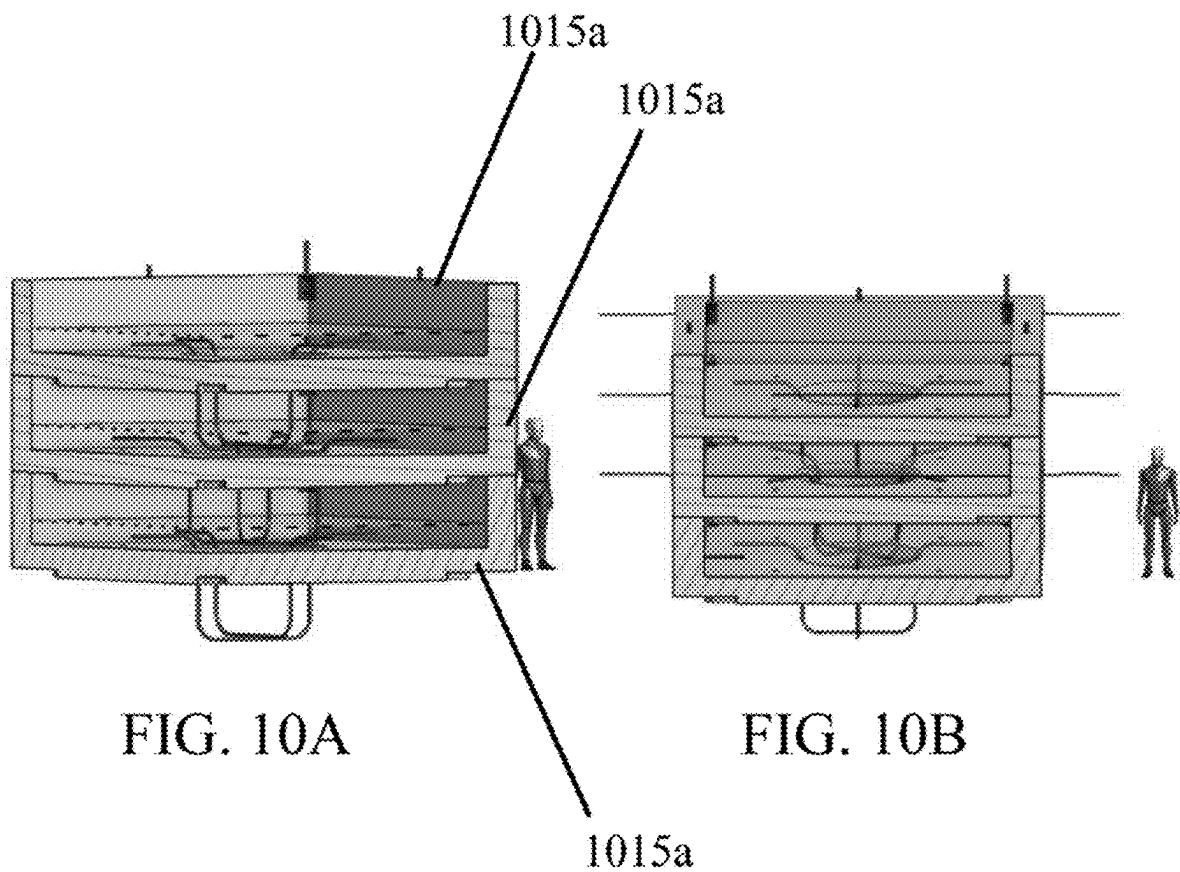


FIG. 9A

FIG. 9B



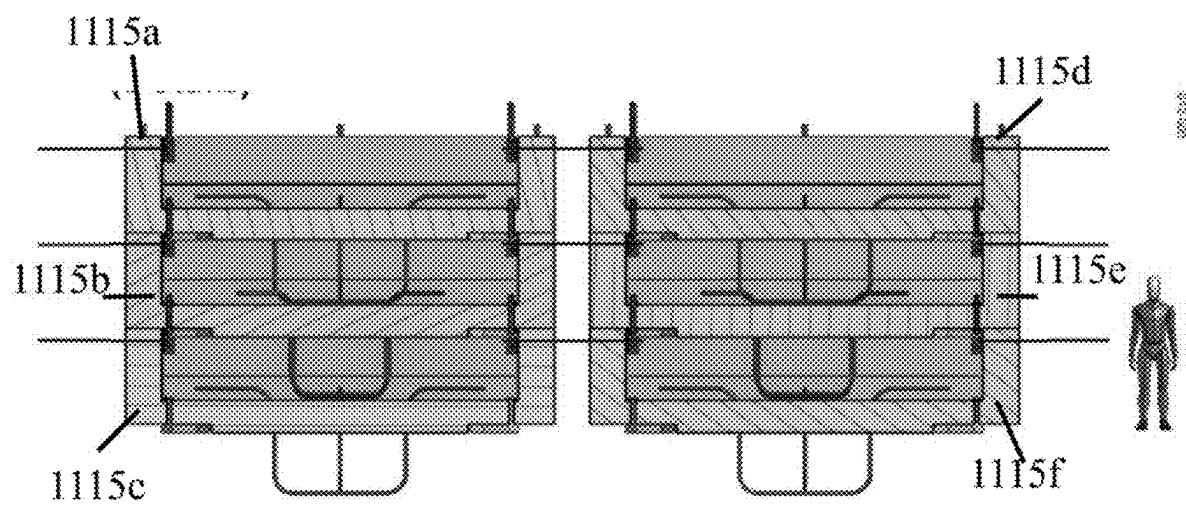


FIG. 11

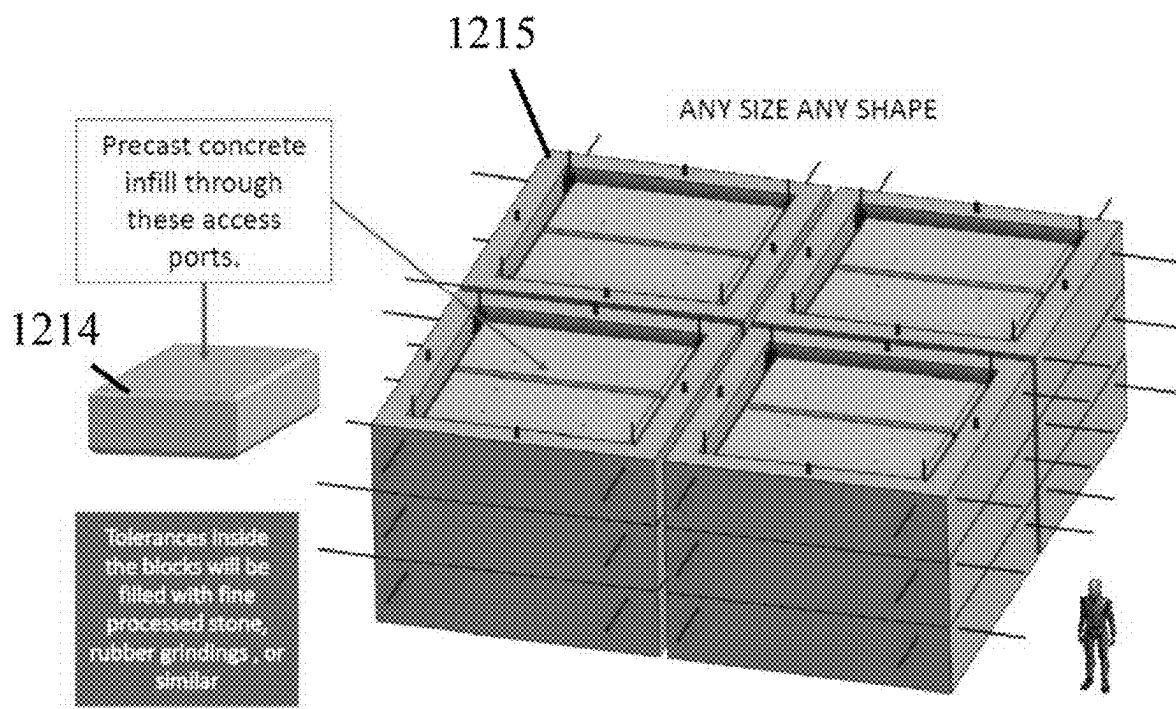


FIG. 12

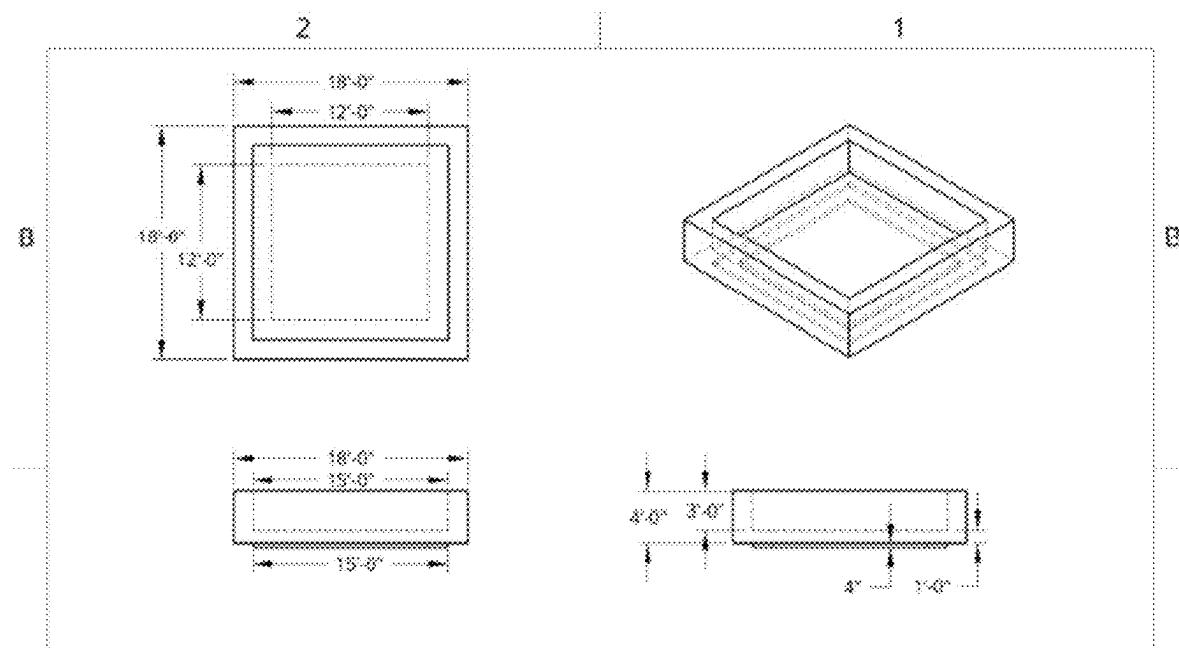


FIG. 13

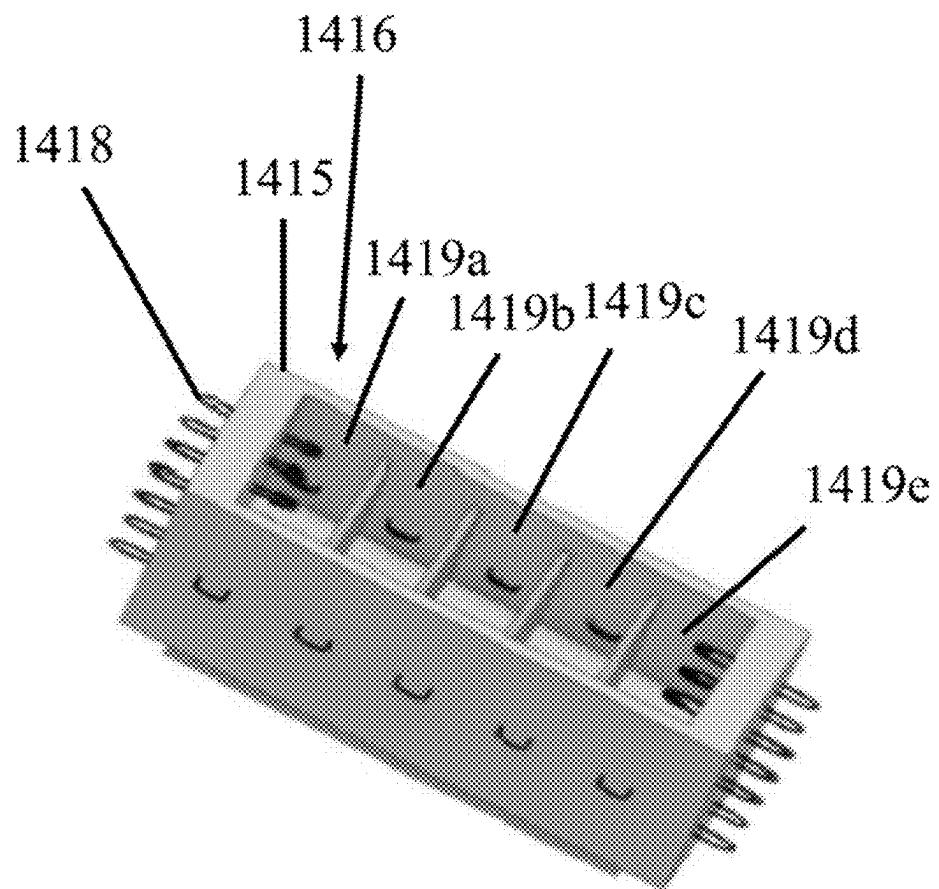
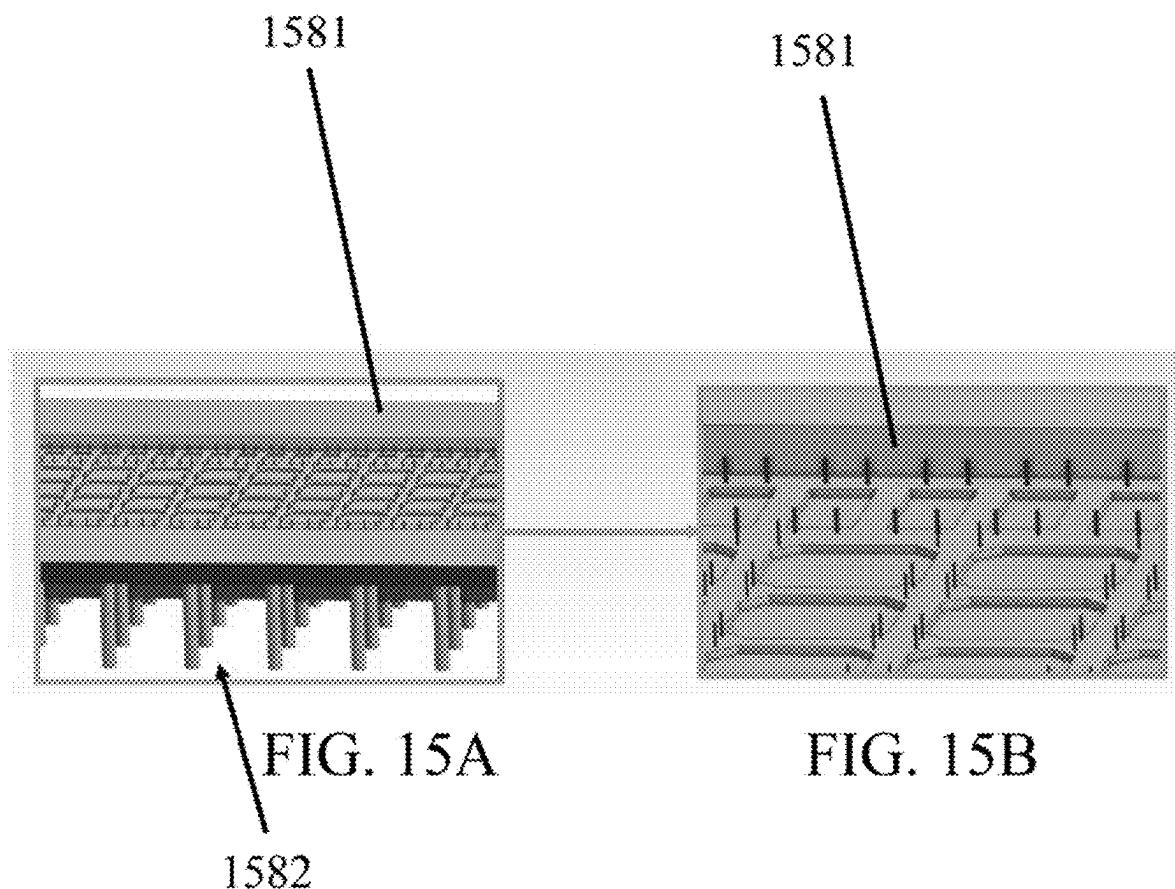


FIG. 14



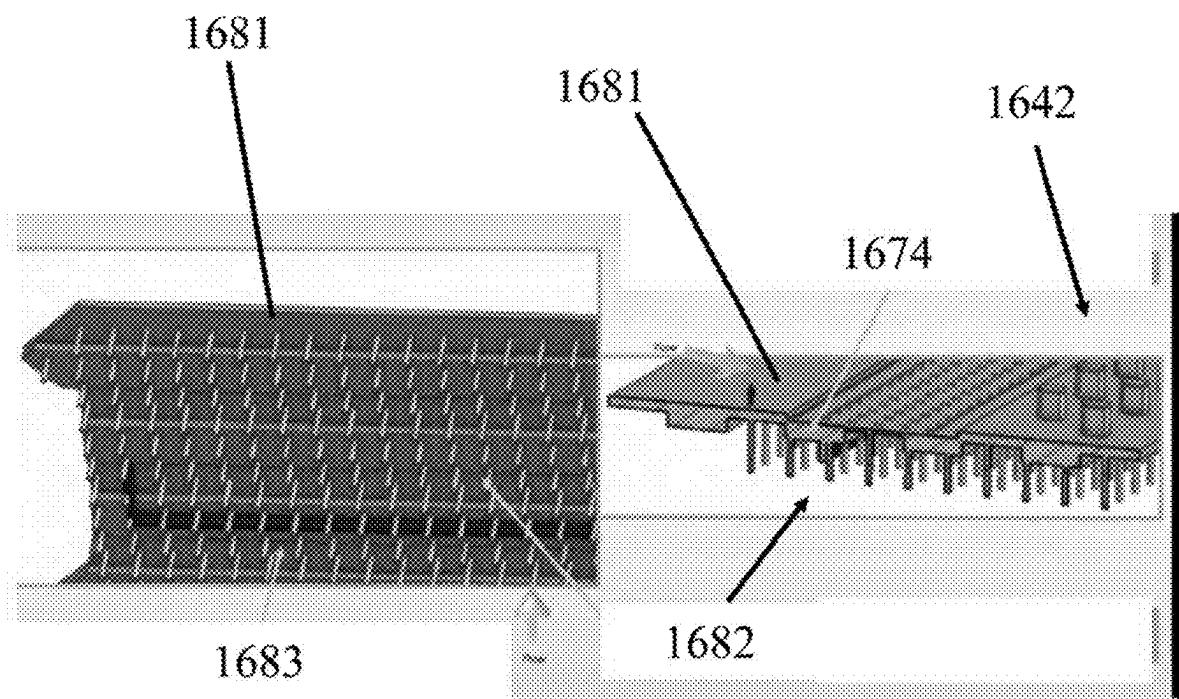


FIG. 16A

FIG. 16B

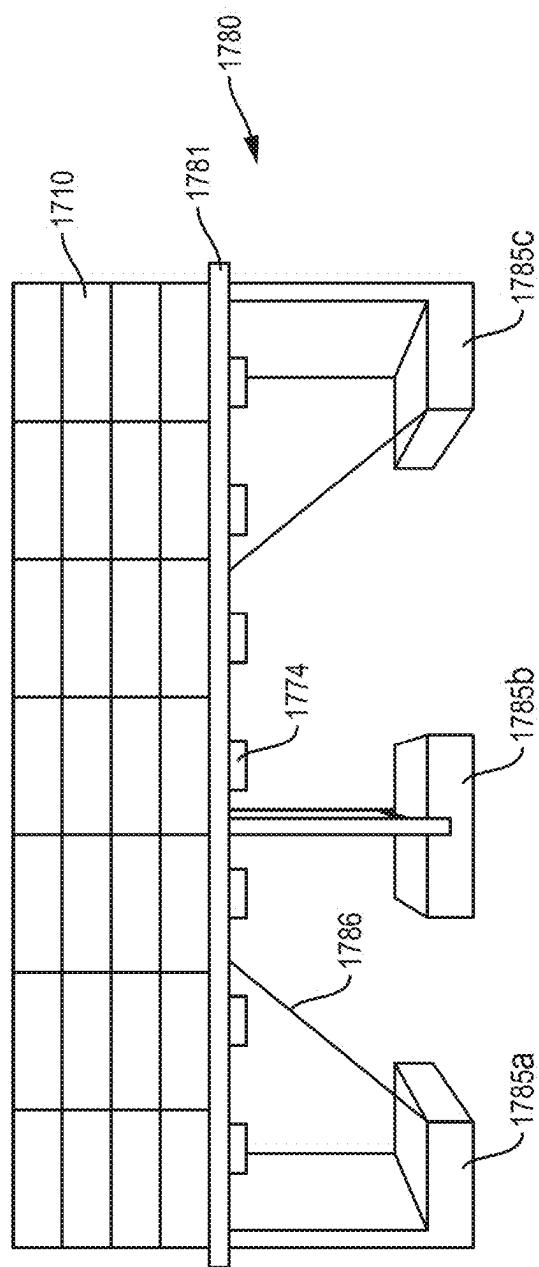


FIG. 17

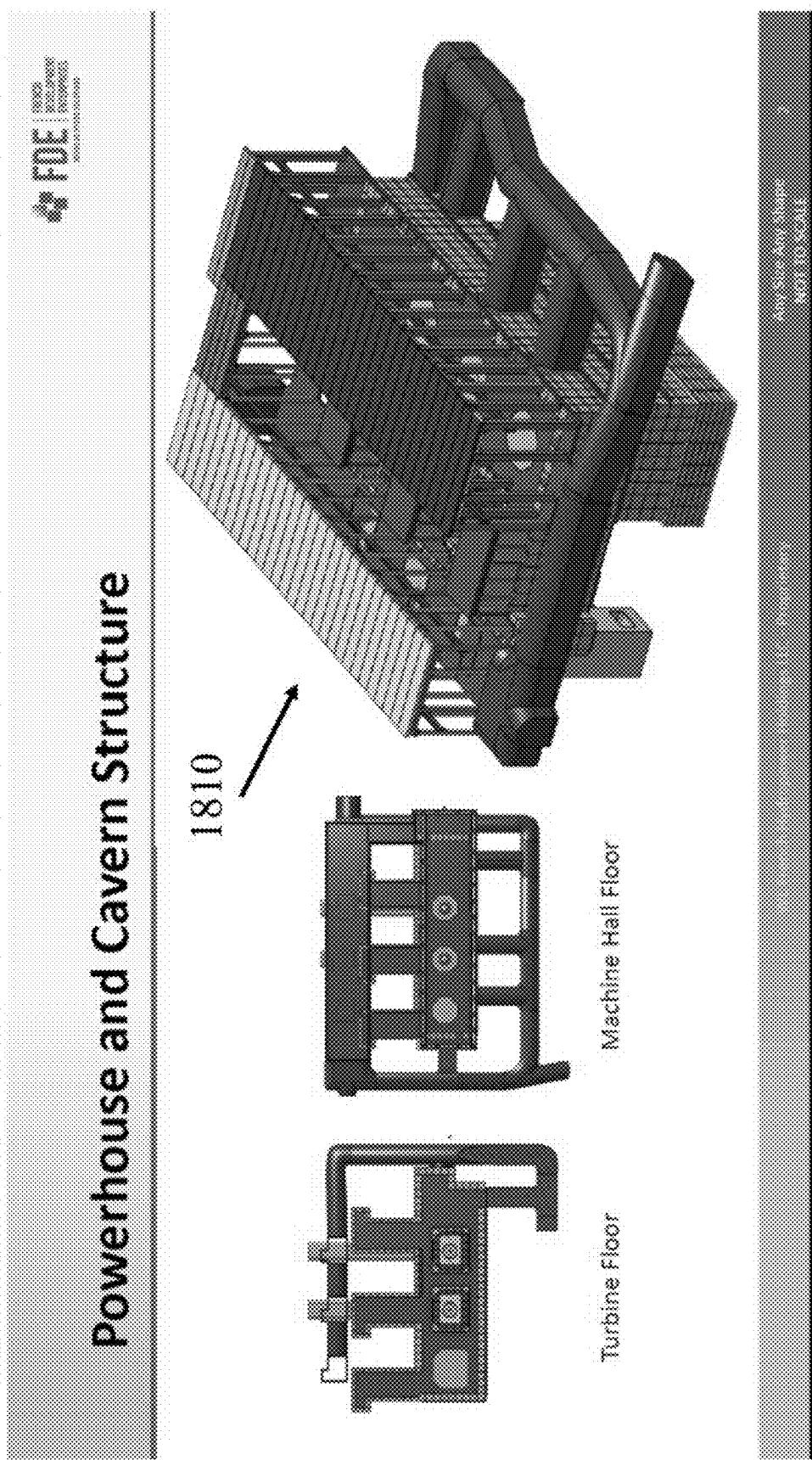


FIG. 18

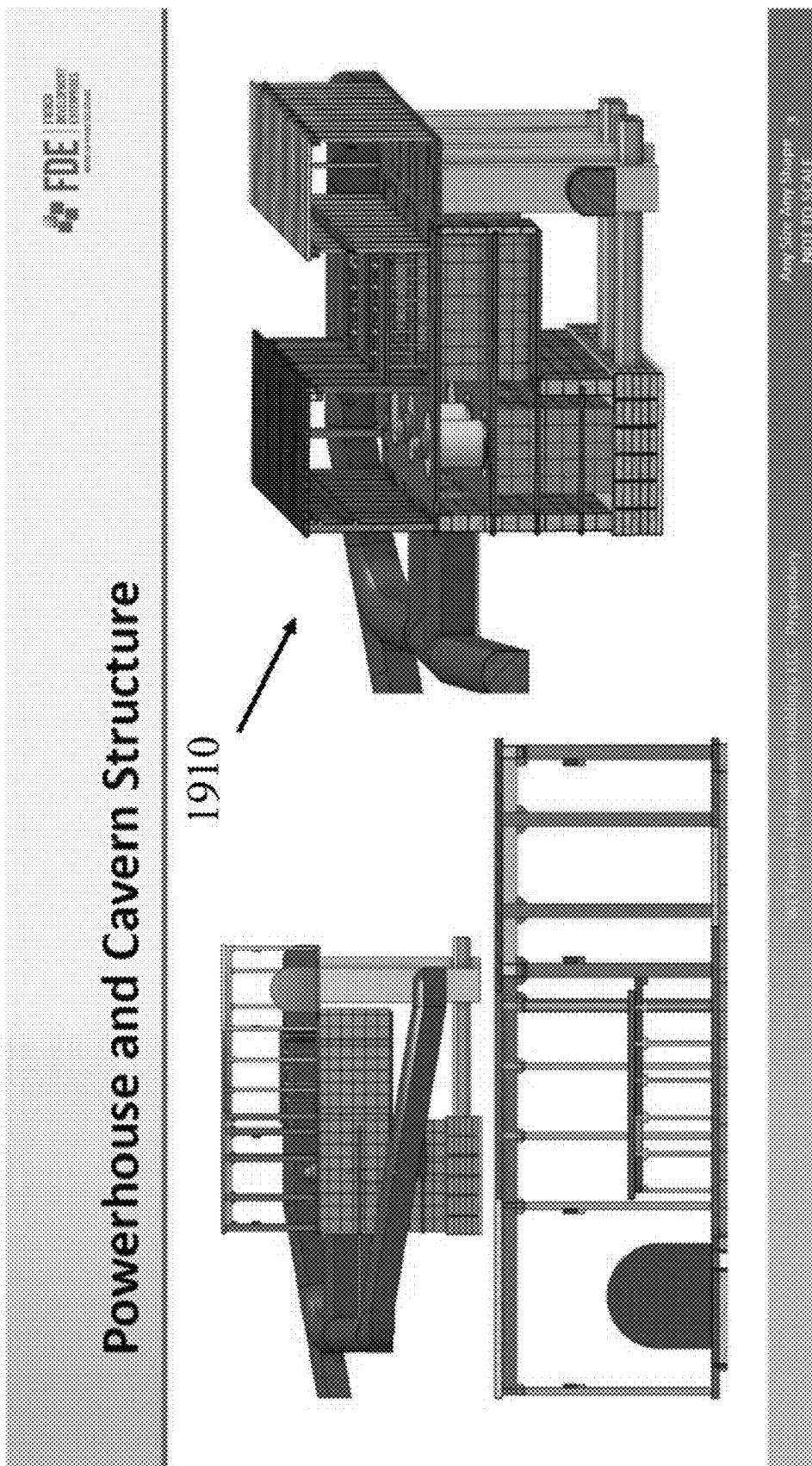


FIG. 19

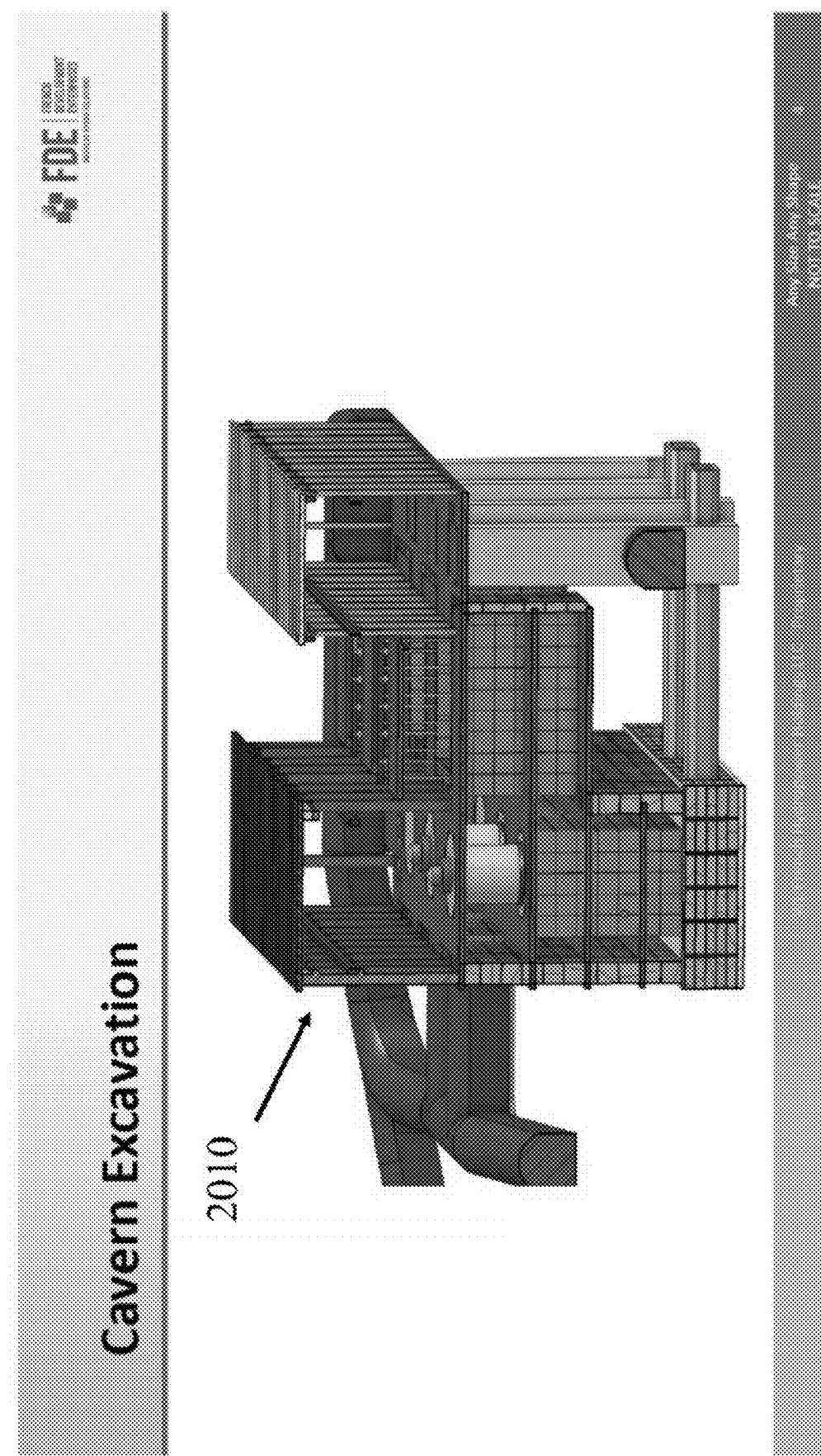


FIG. 20

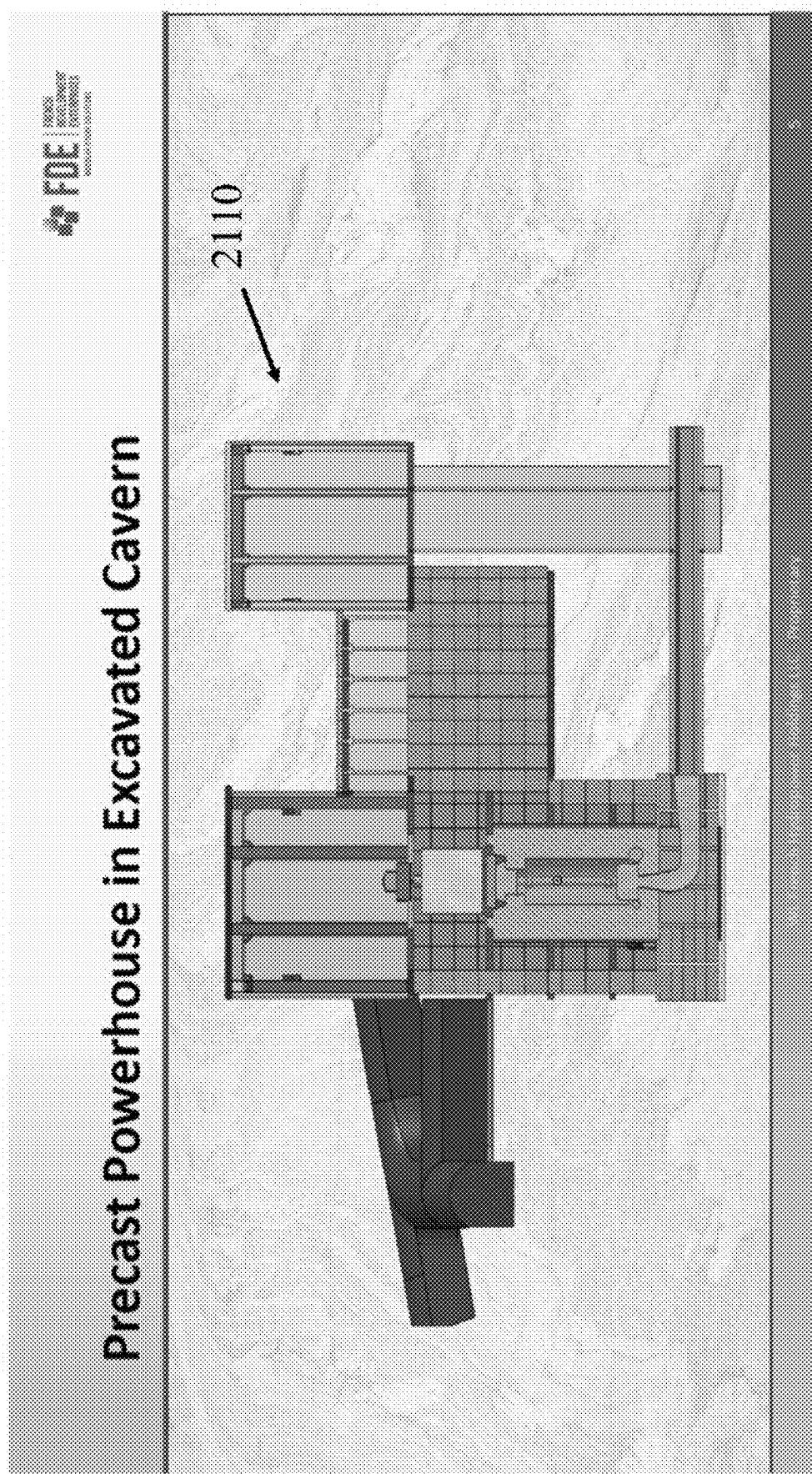


FIG. 21

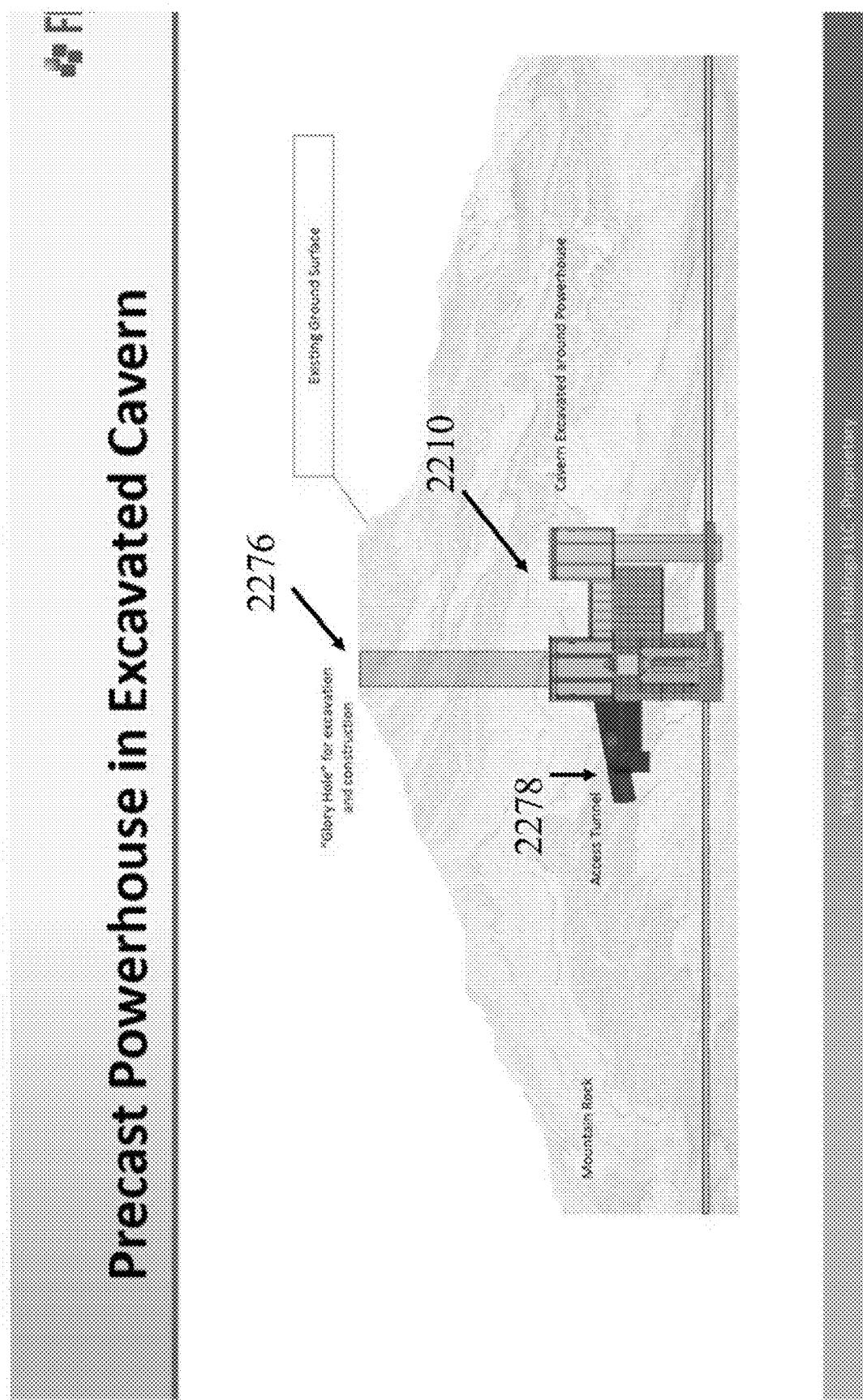


FIG. 22

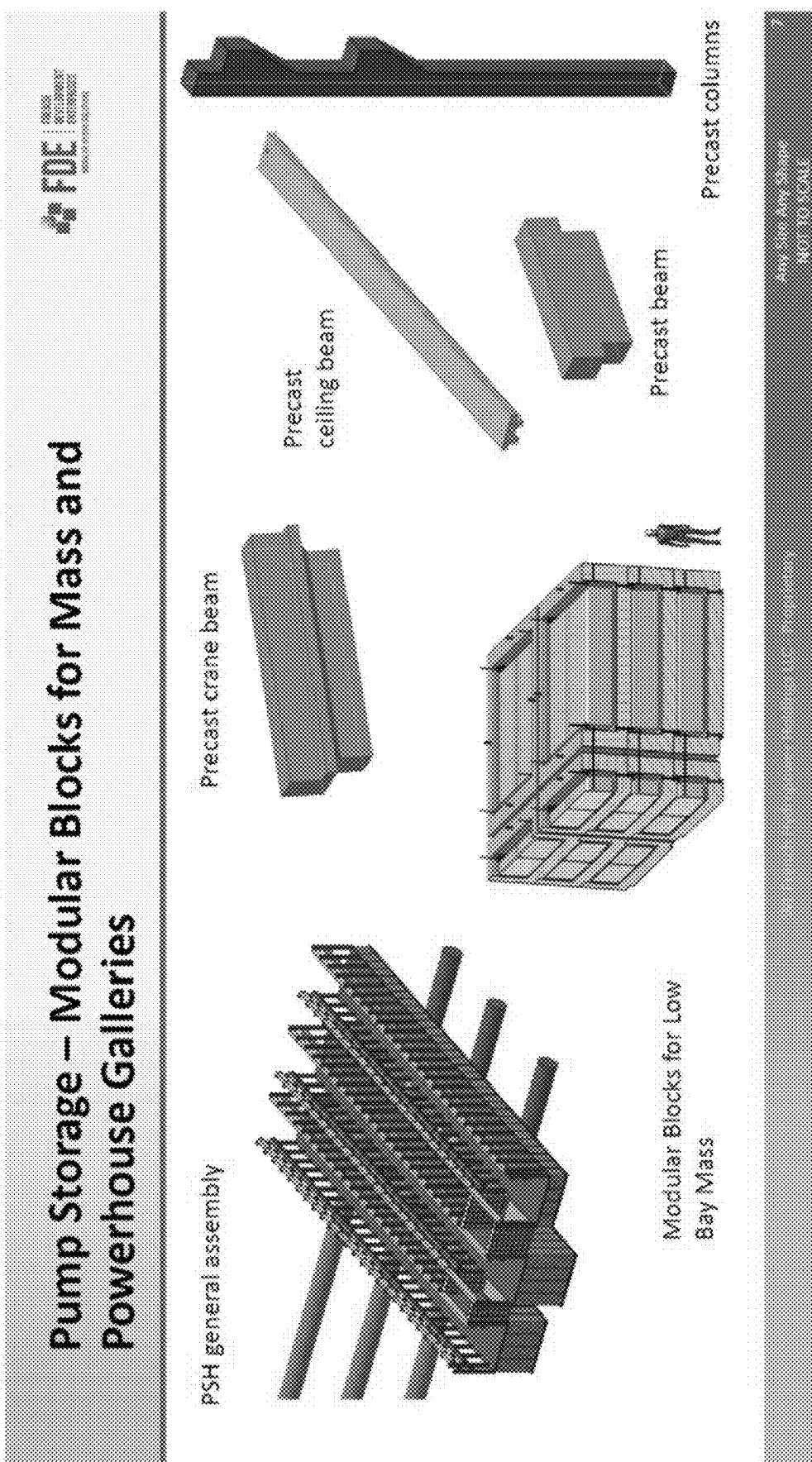


FIG. 23

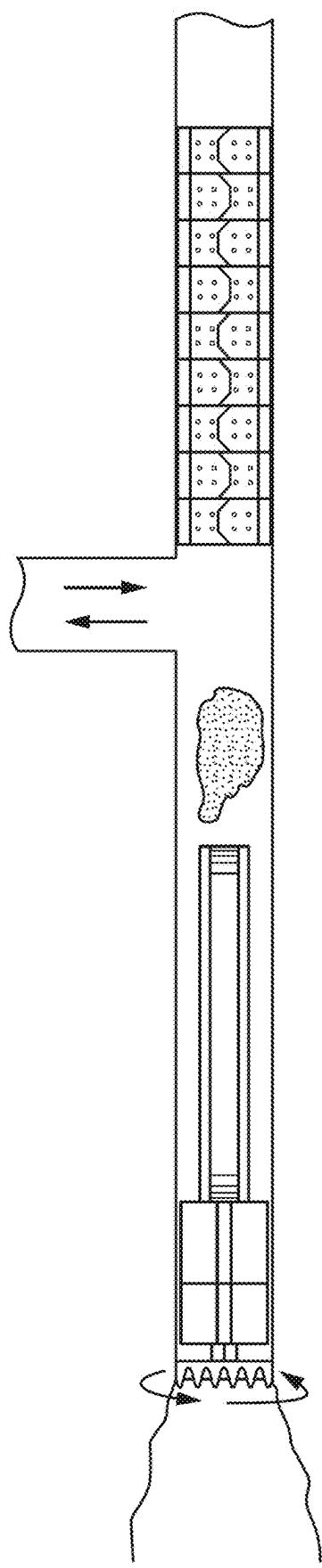


FIG. 24A

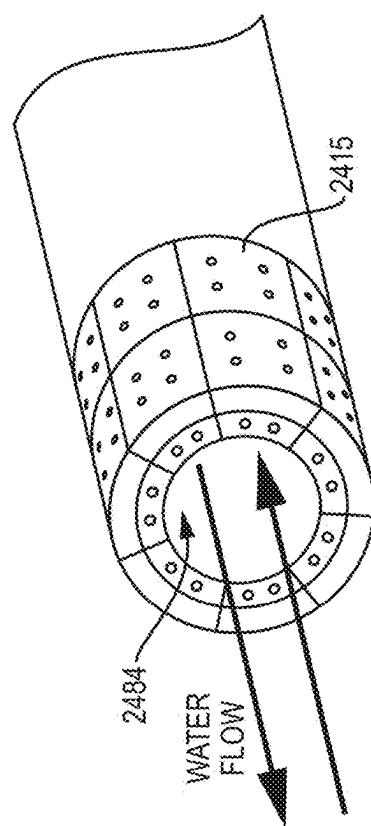


FIG. 24D



FIG. 24C

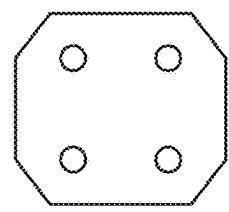


FIG. 24B

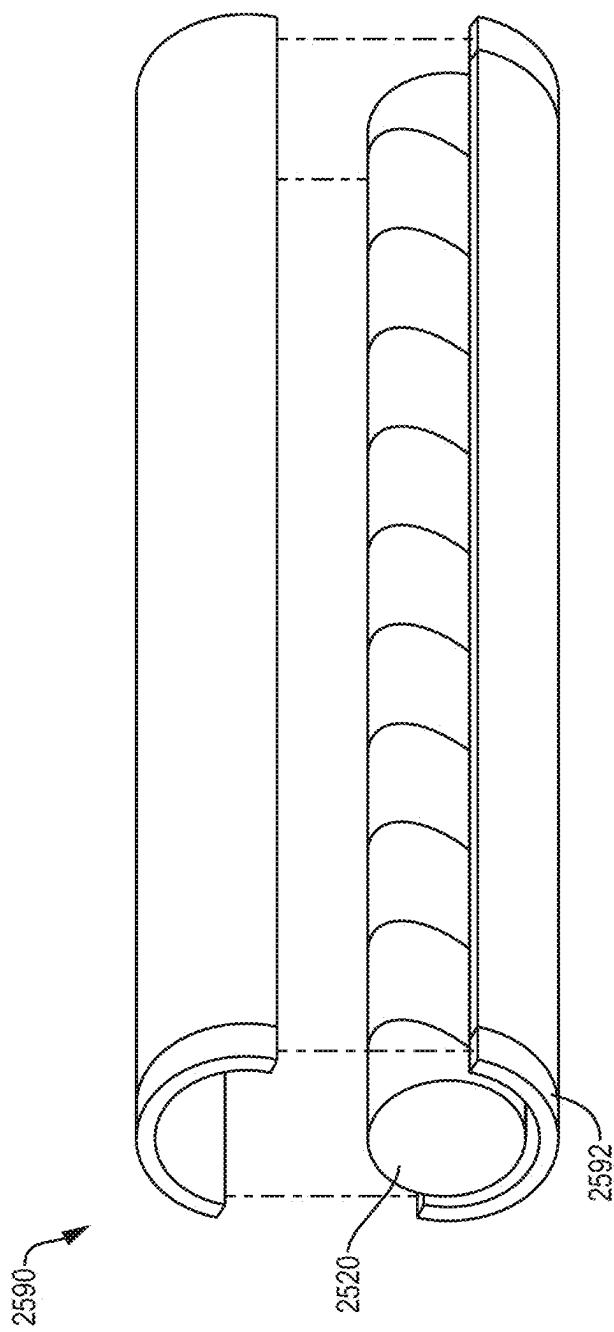


FIG. 25

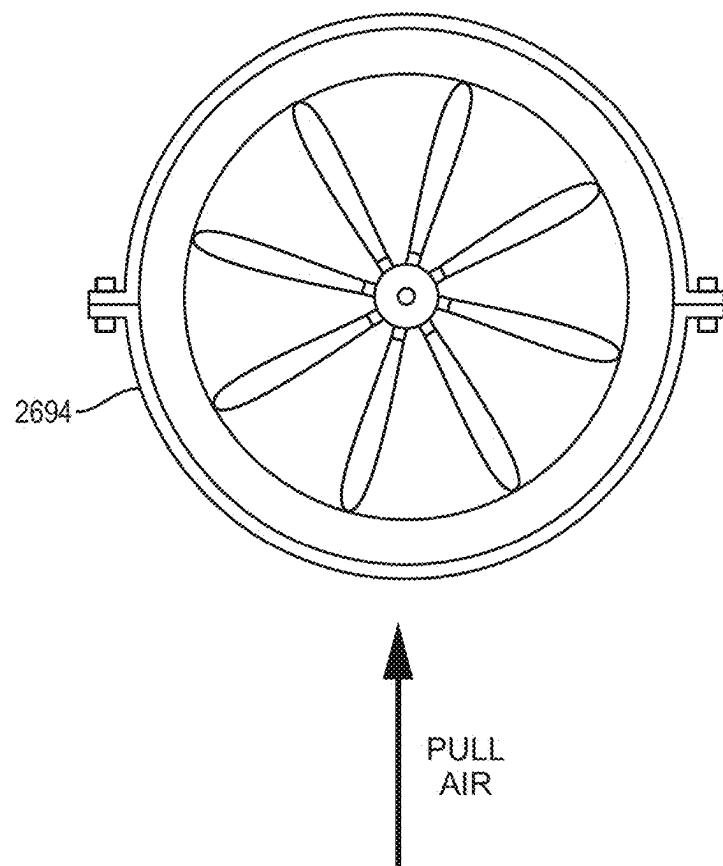


FIG. 26A

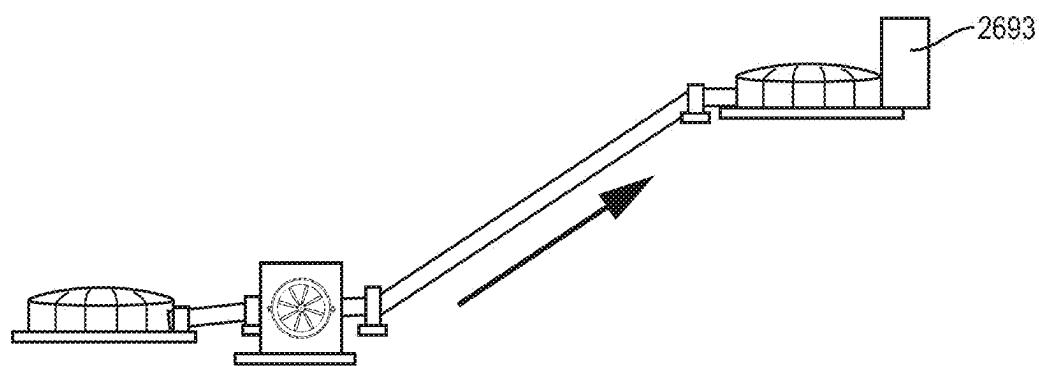


FIG. 26B

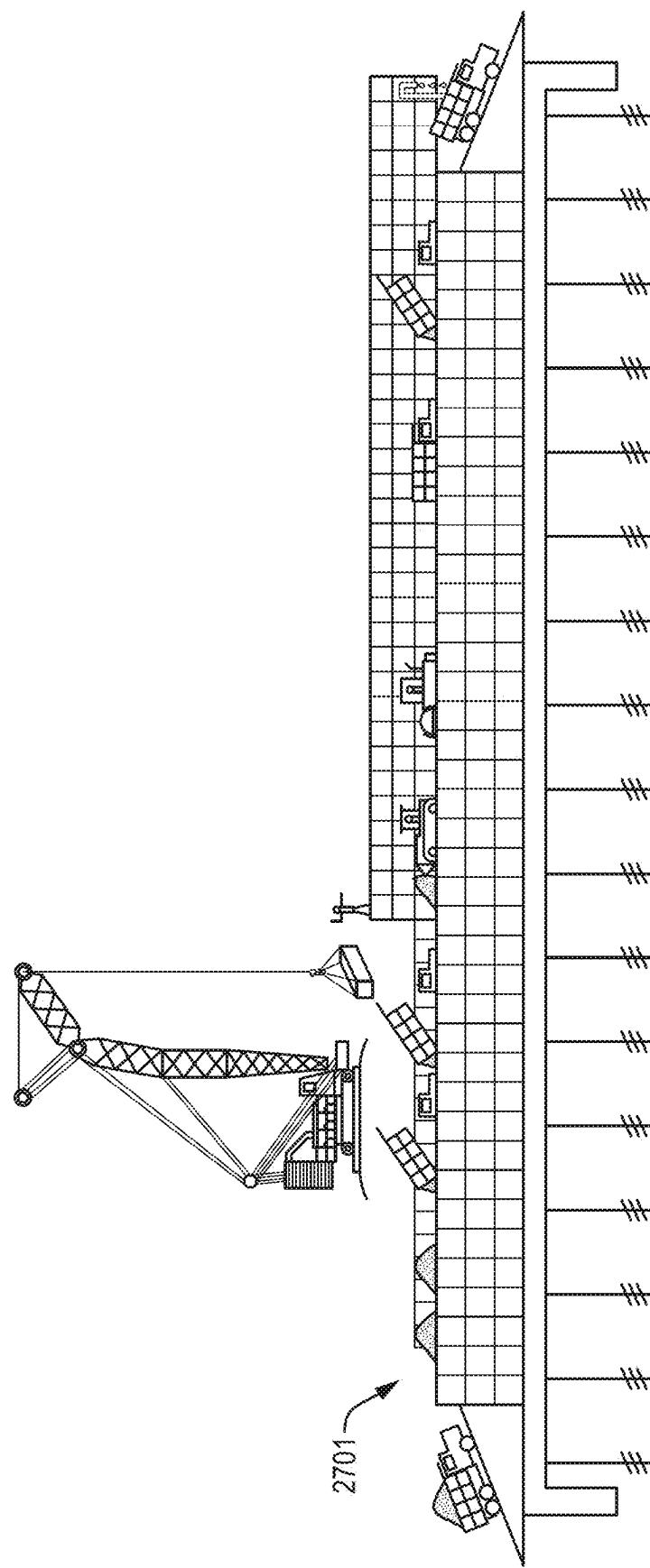


FIG. 27

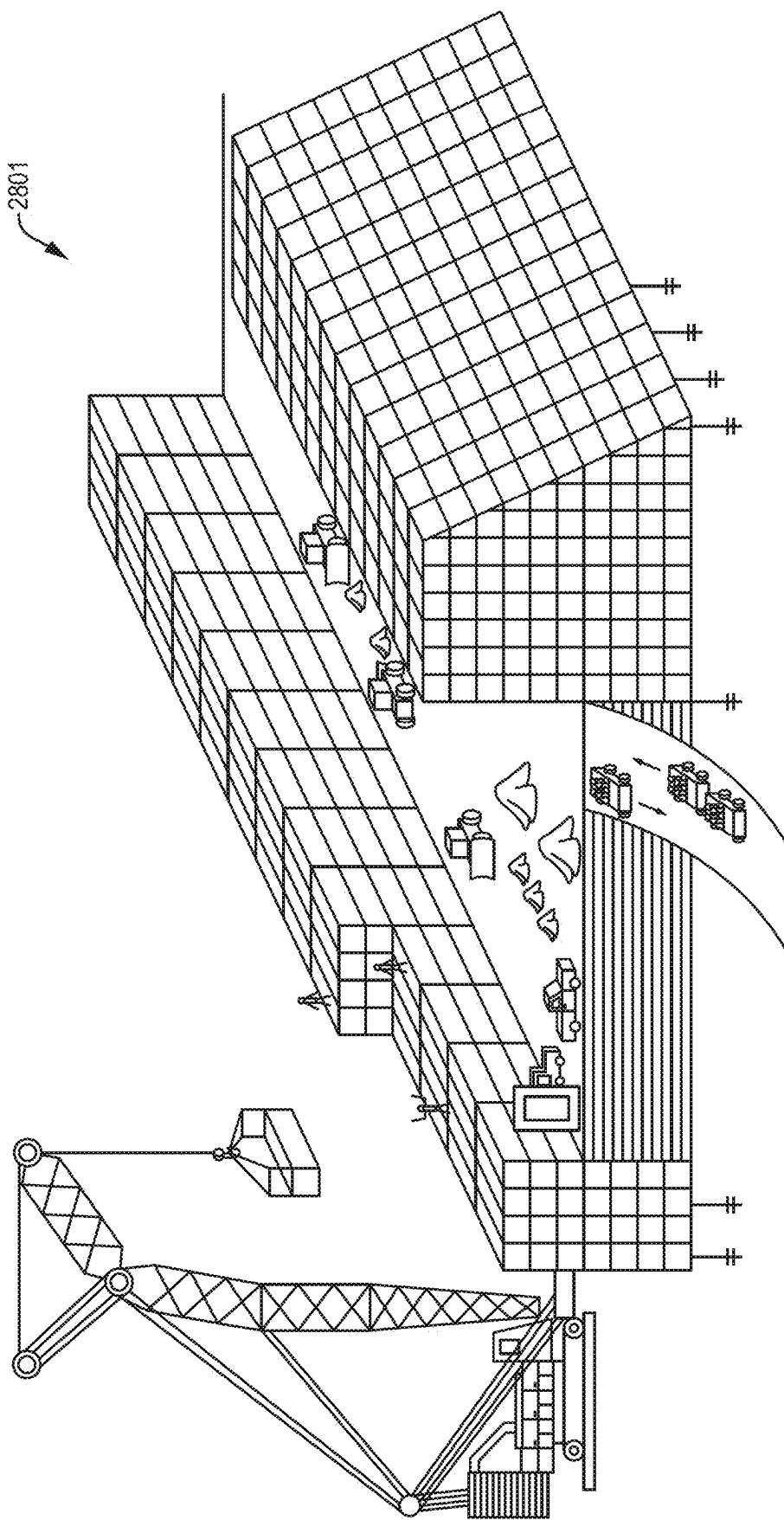


FIG. 28

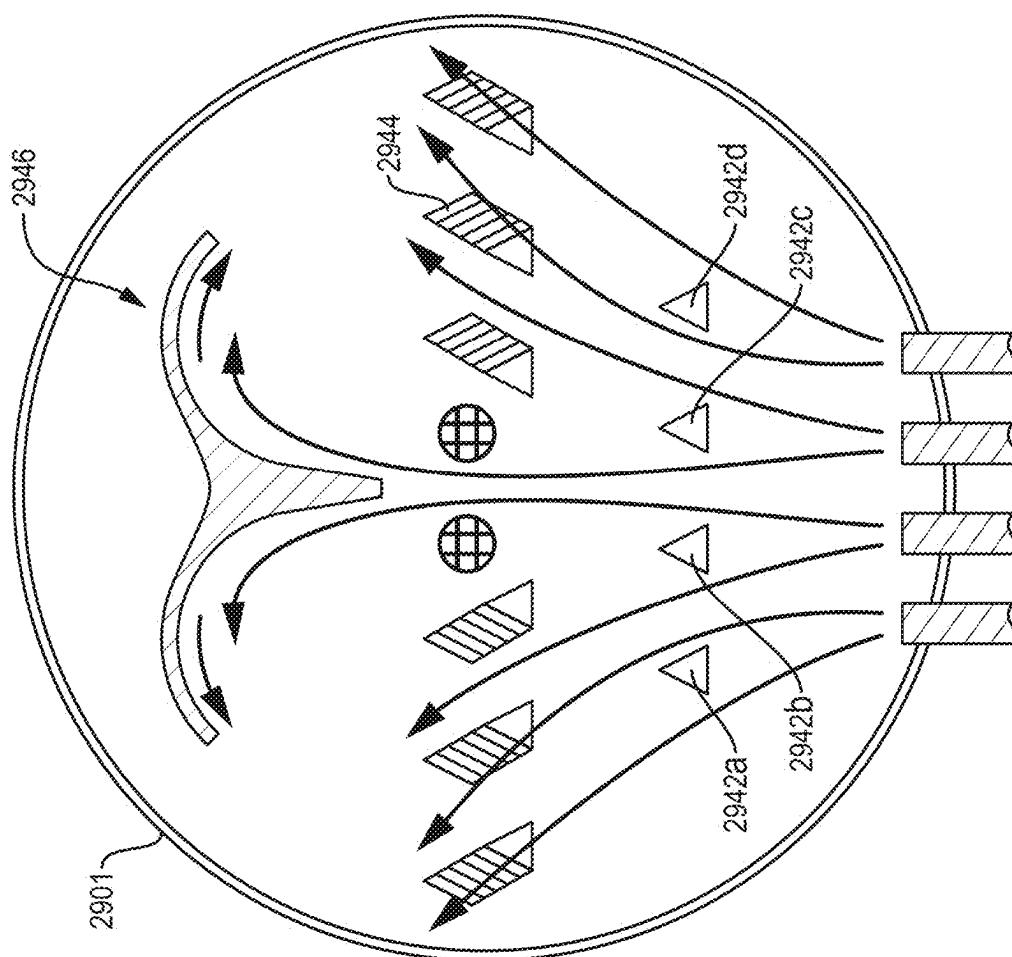


FIG. 29

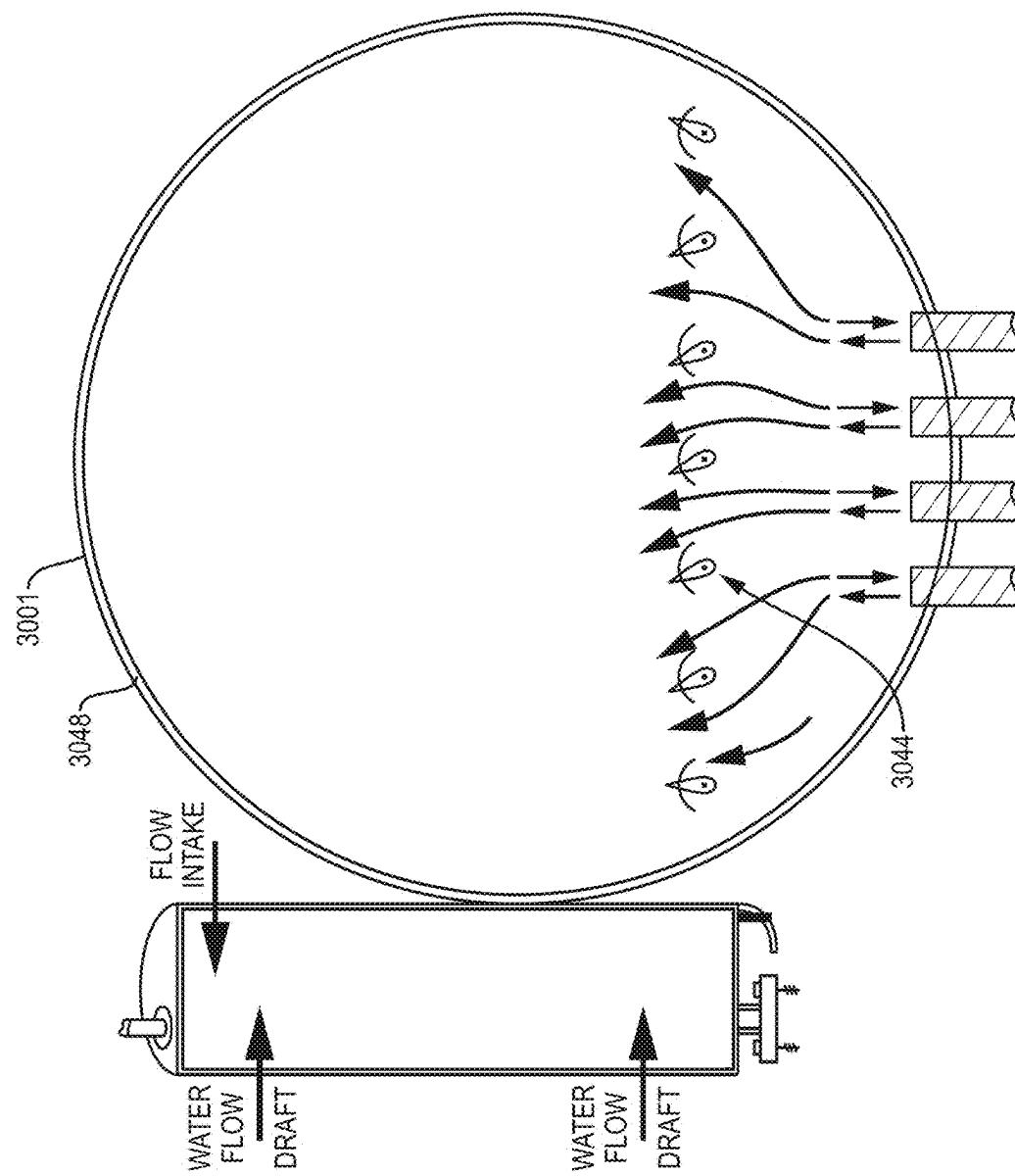


FIG. 30

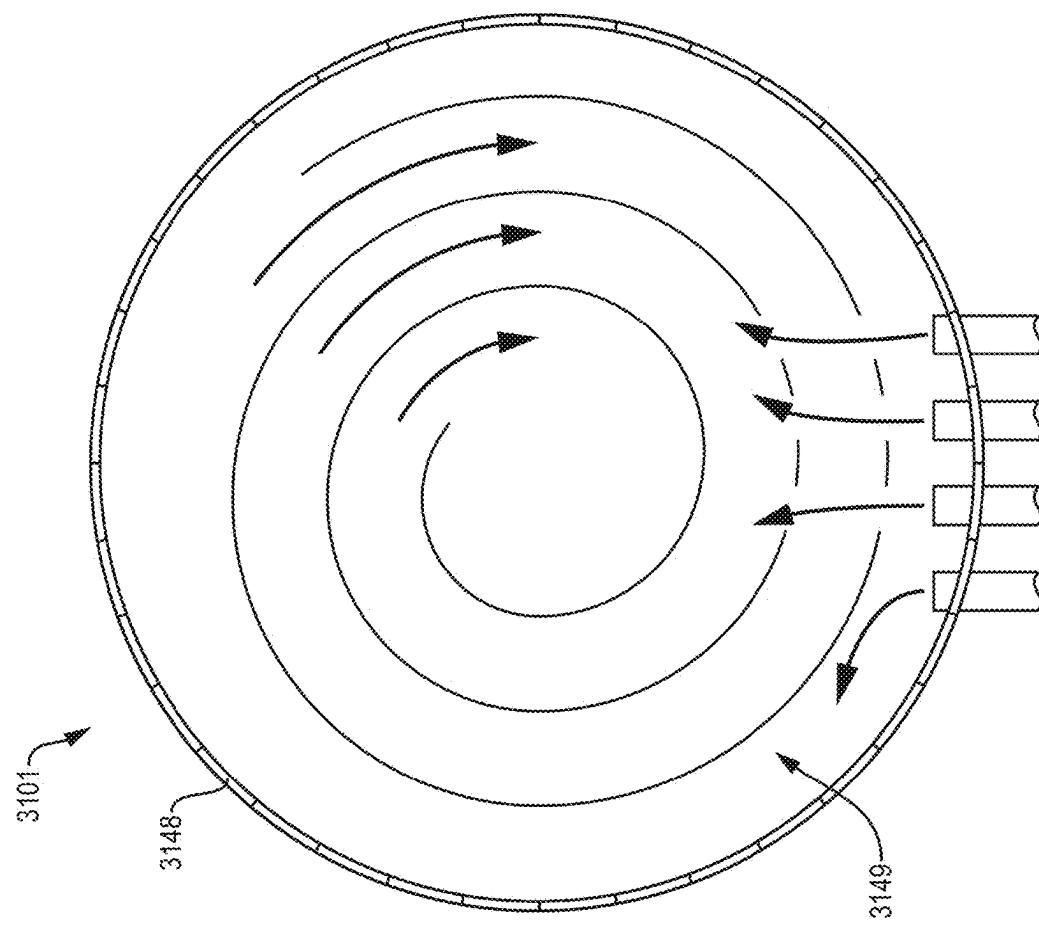


FIG. 31

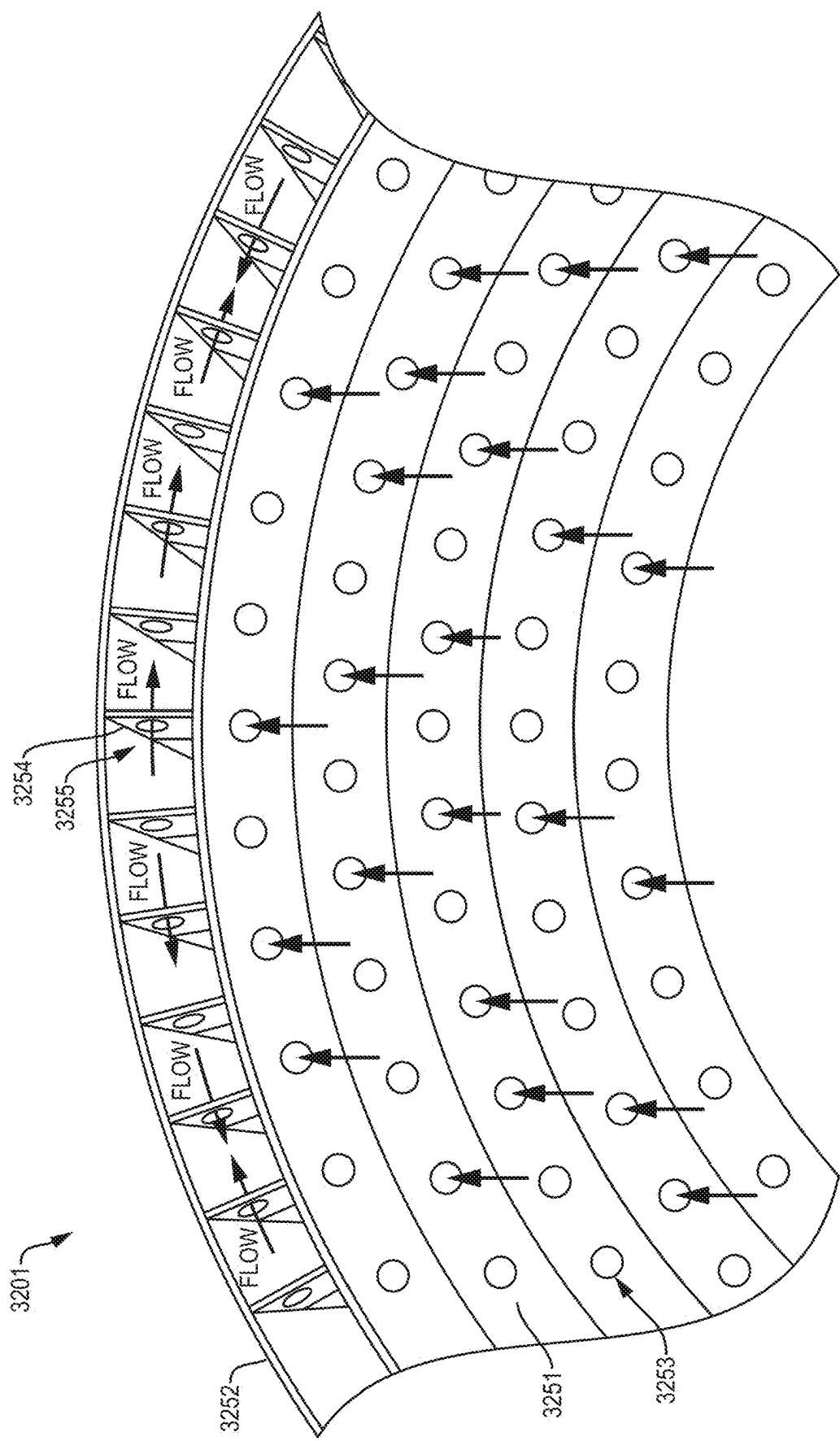


FIG. 32

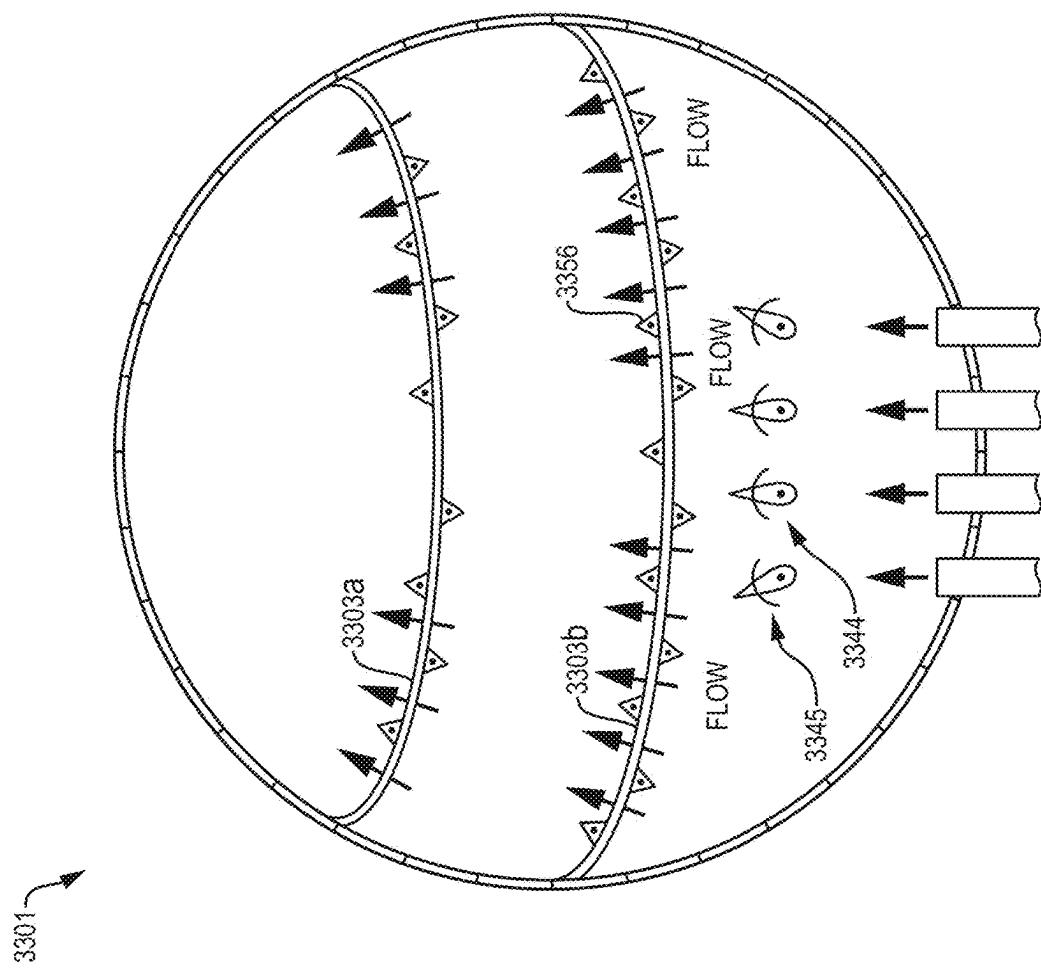


FIG. 33

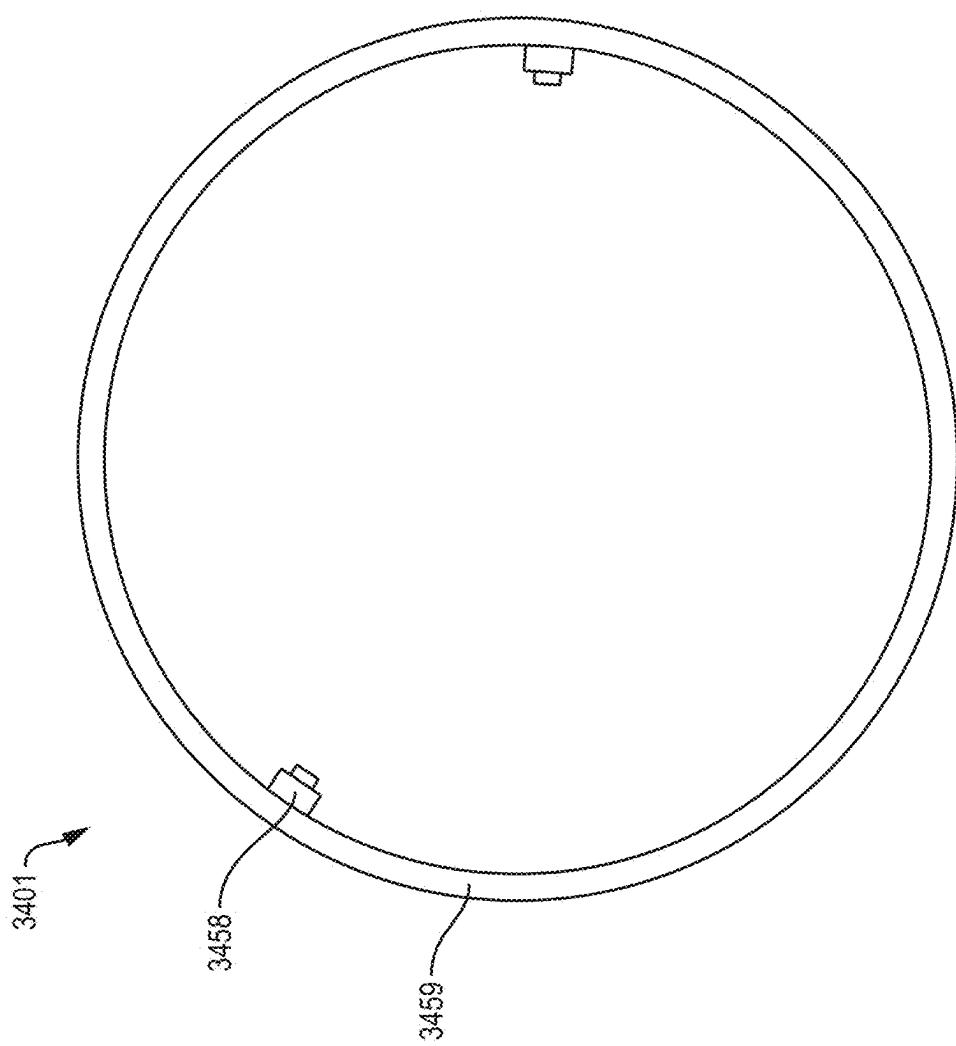


FIG. 34

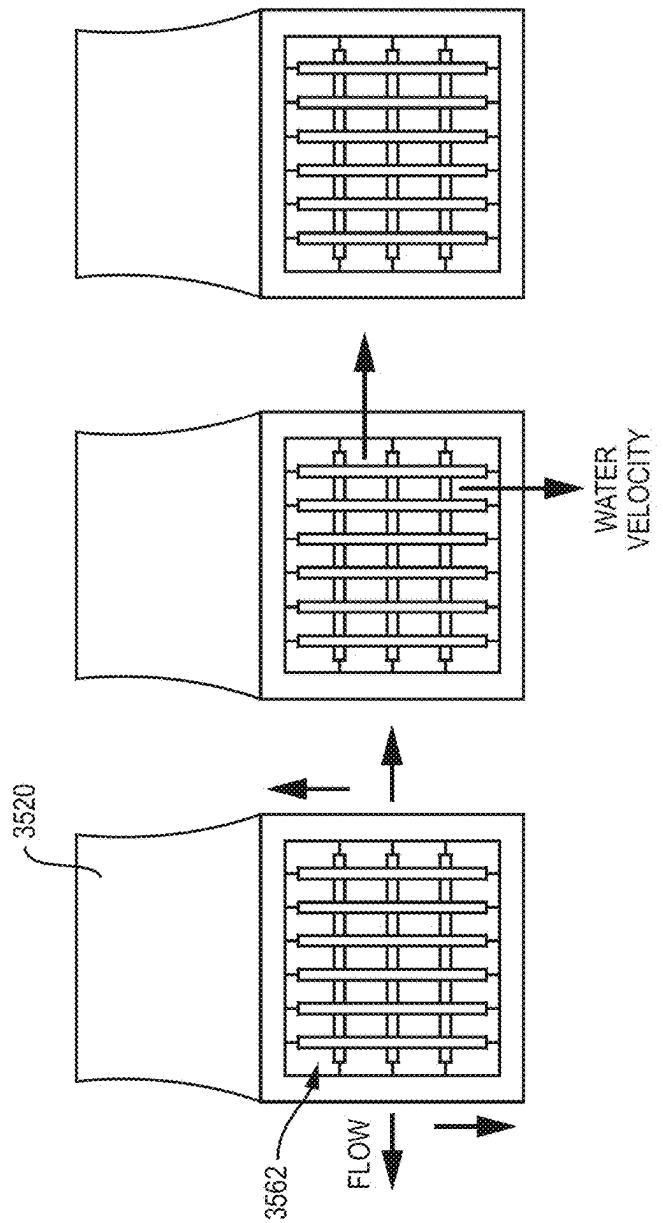


FIG. 35A

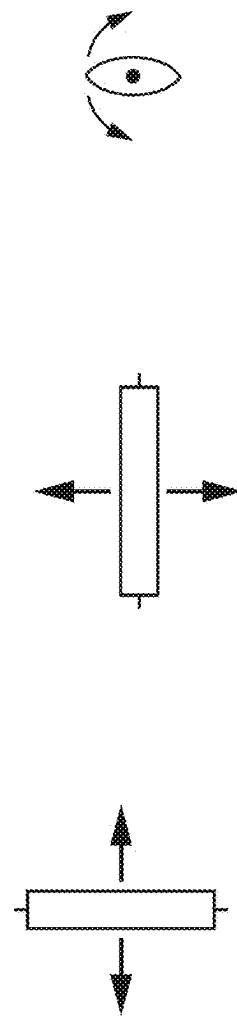


FIG. 35B

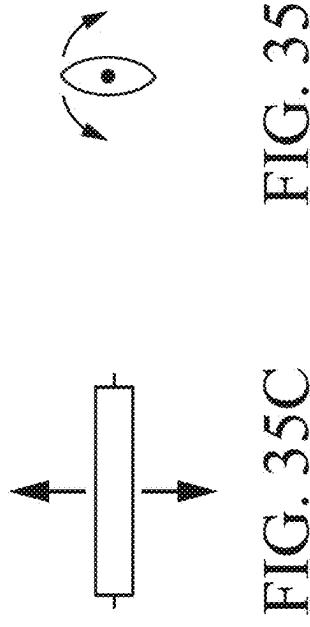


FIG. 35C

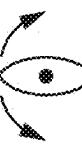


FIG. 35D

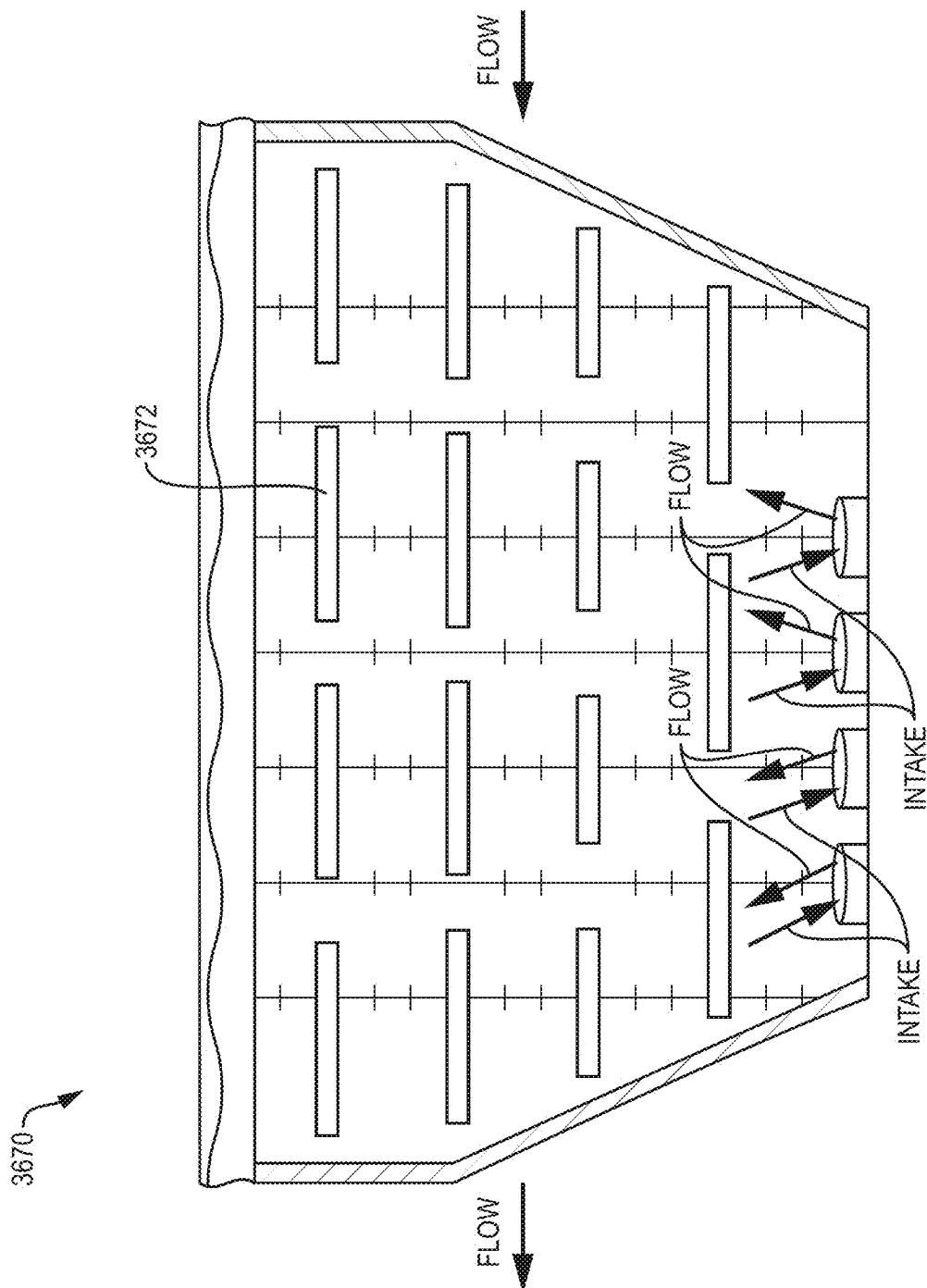
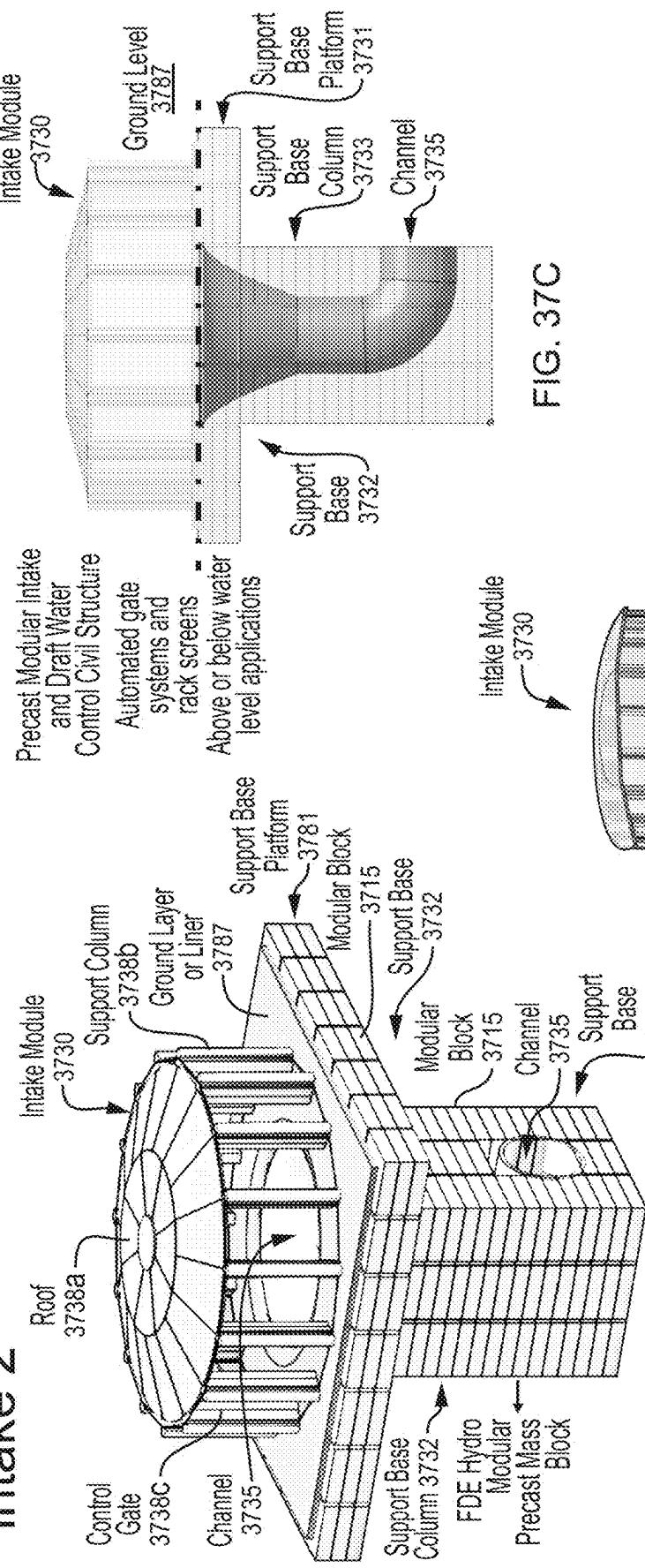


FIG. 36

Draft-Intake Modular Precast Structures Intake 2



Control water intake to tunnels/powerhouse
FIG. 37A

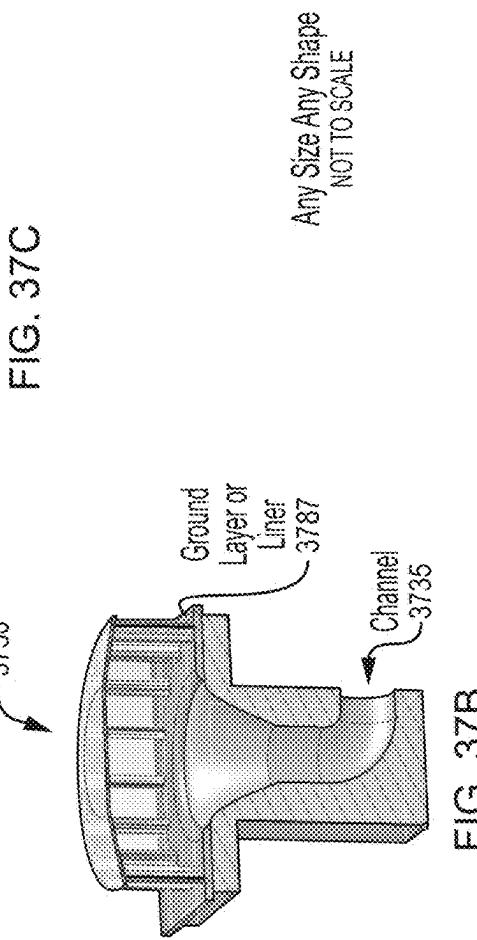


FIG. 37B

FIG. 37C

Any Size Any Shape
NOT TO SCALE

Transition Between Larger Tunnel to Smaller Feeds

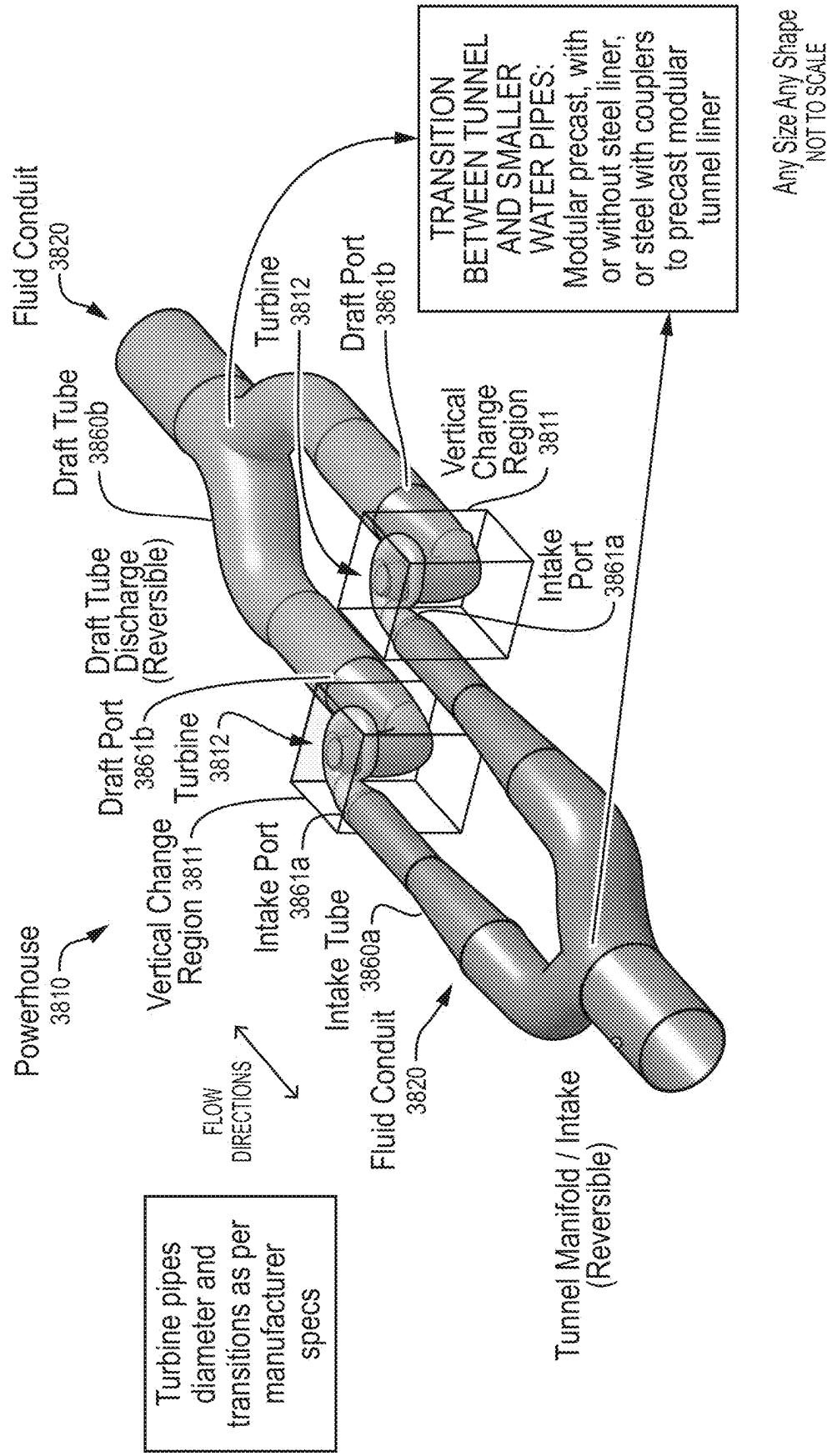


FIG. 38

Top View Two Options (Precast Over or Inside the Steel Liner)

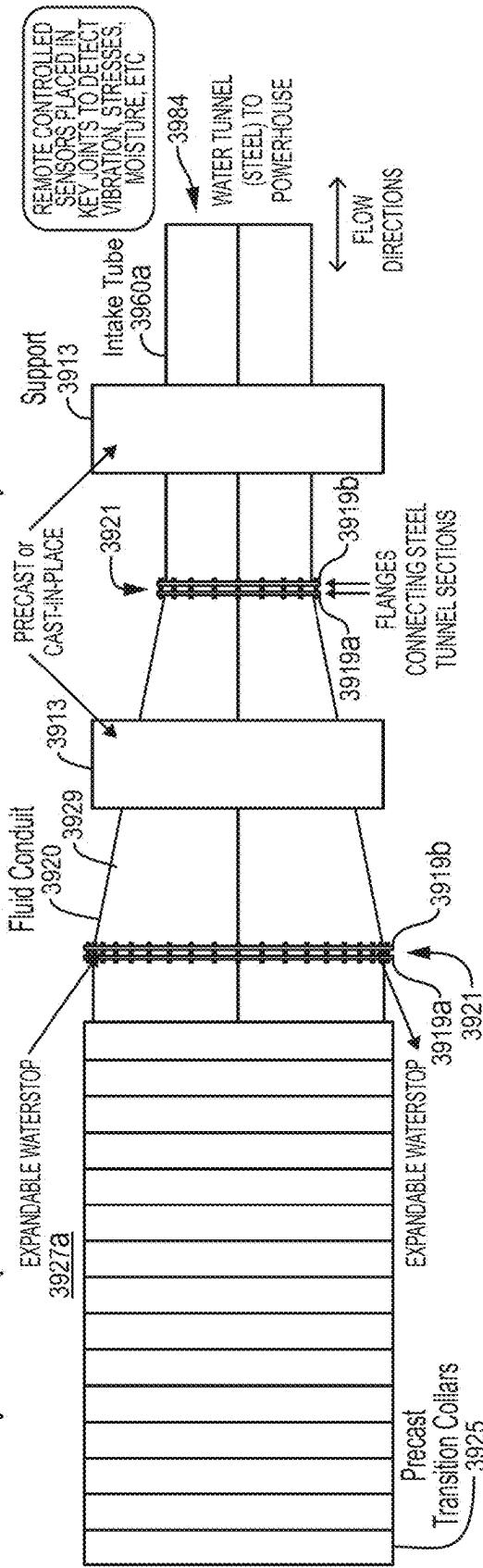


FIG. 39A

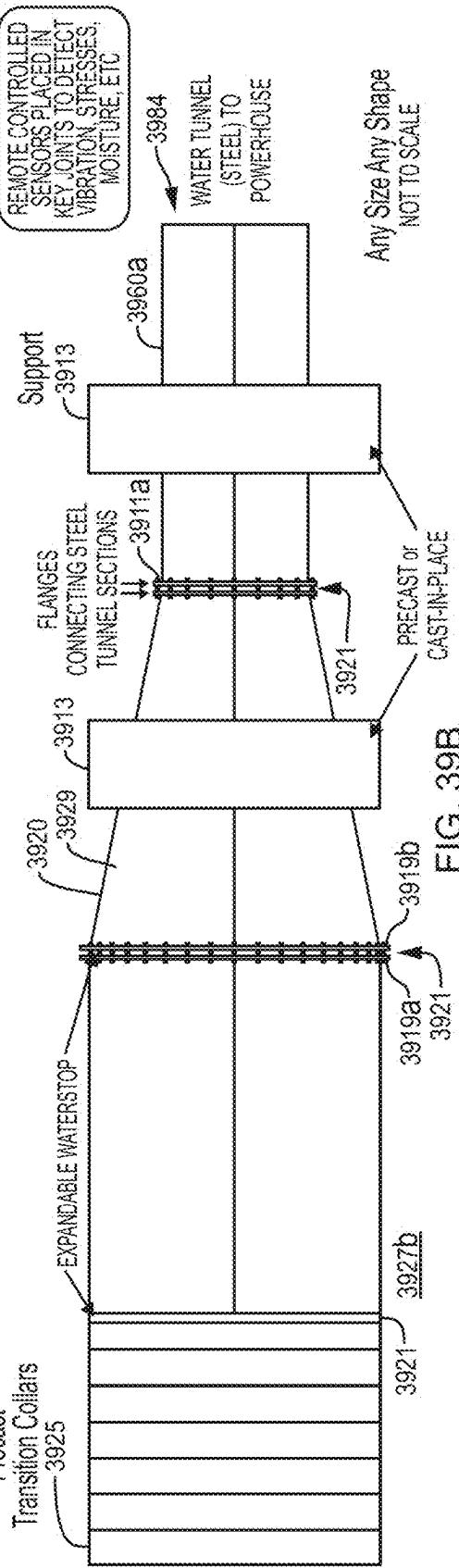


FIG. 39B

Top View Two Options (Precast Over or Inside the Steel Liner)

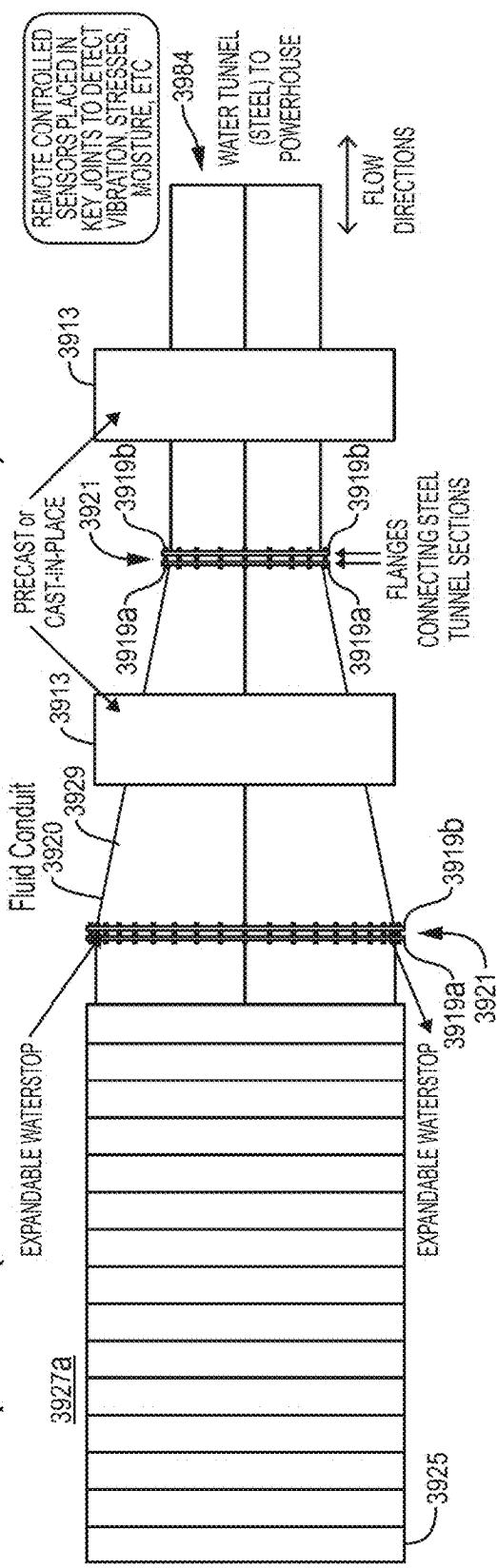


FIG. 39C

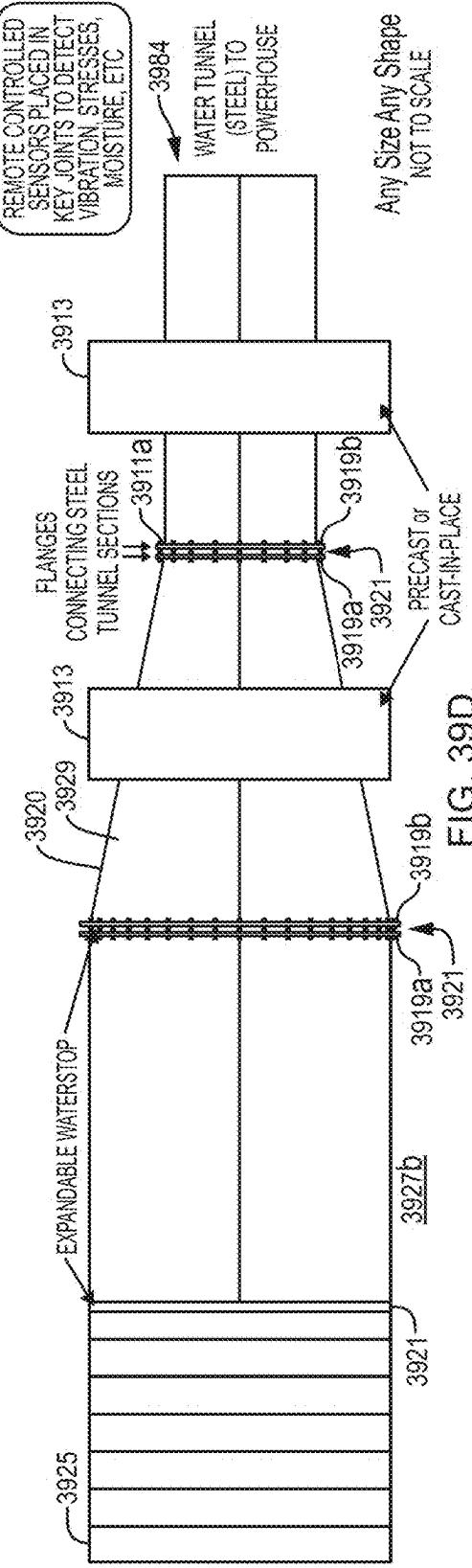


FIG. 39D

Section Through

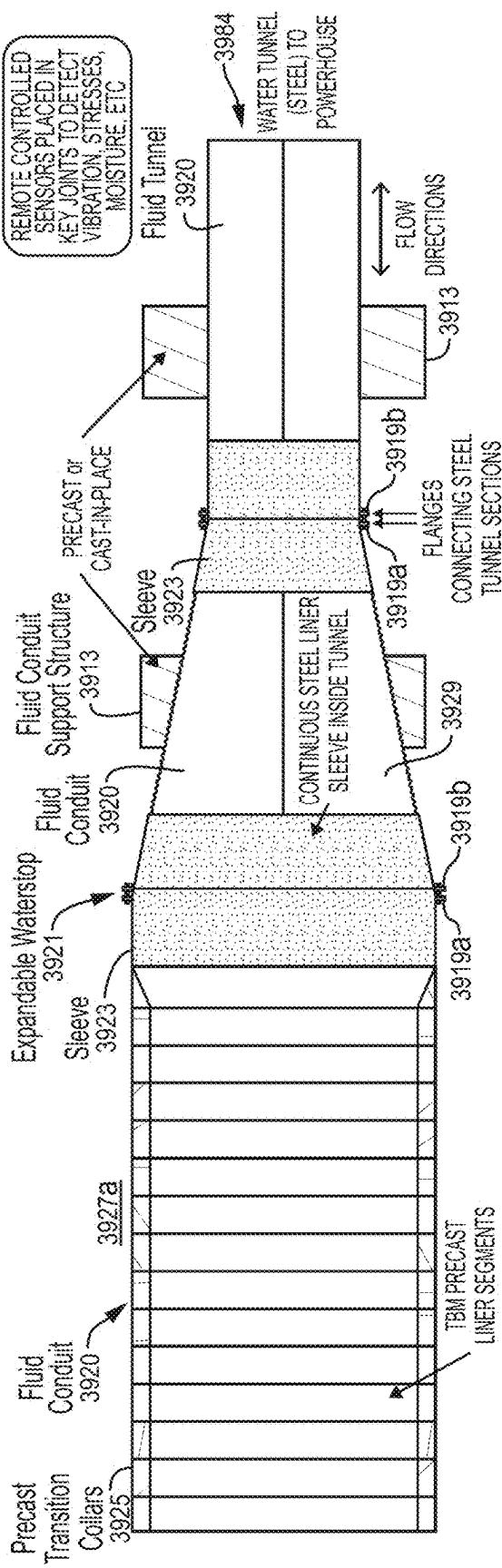


FIG. 39E

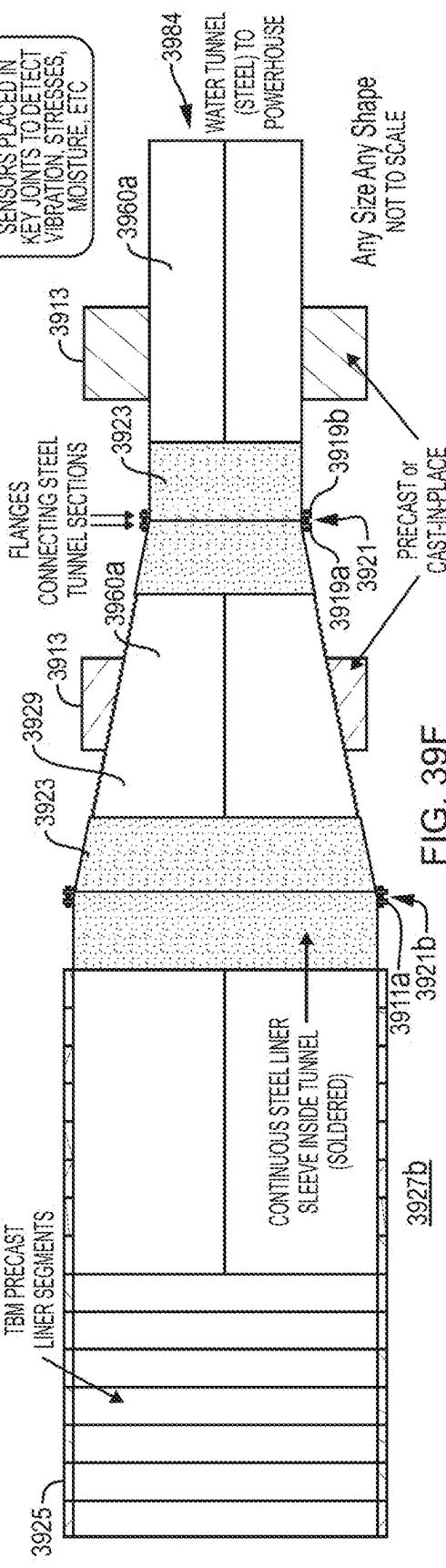


FIG. 39F

PRECAST TBM OVER STEEL LINER

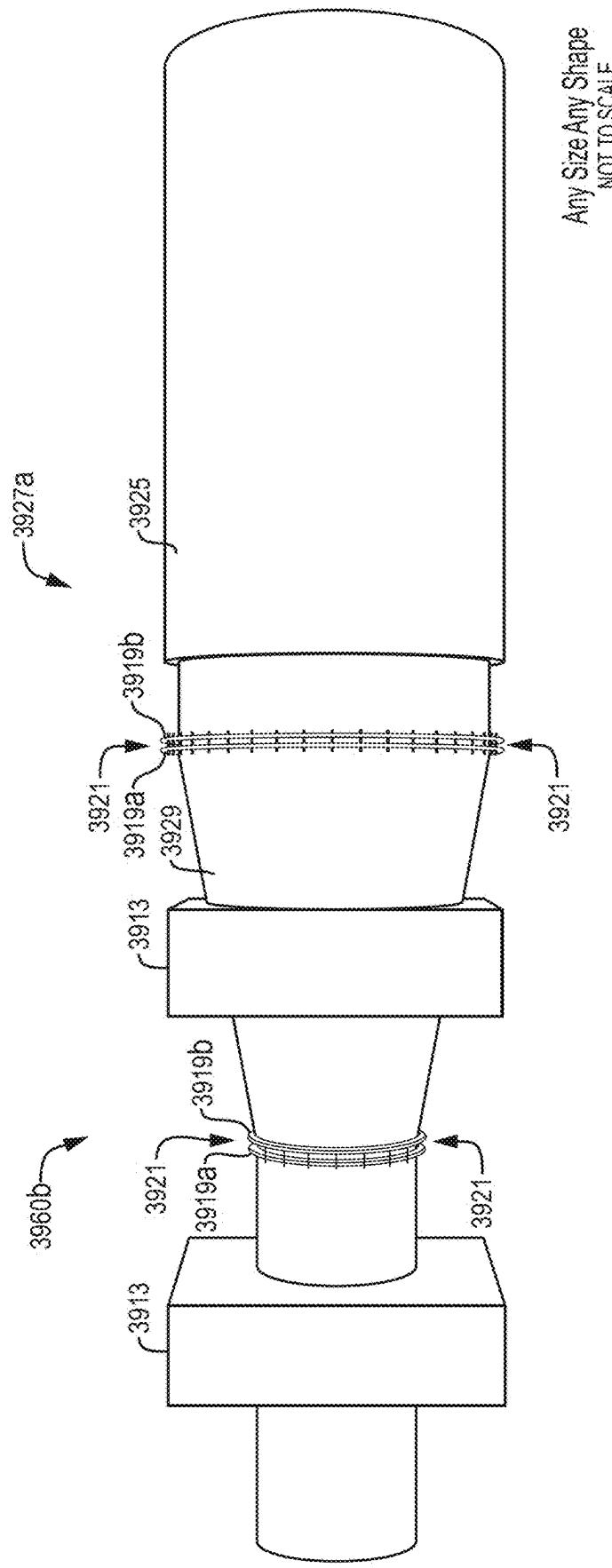


FIG. 39G

Any Size Any Shape
NOT TO SCALE

PRECAST TBM OVER STEEL LINER

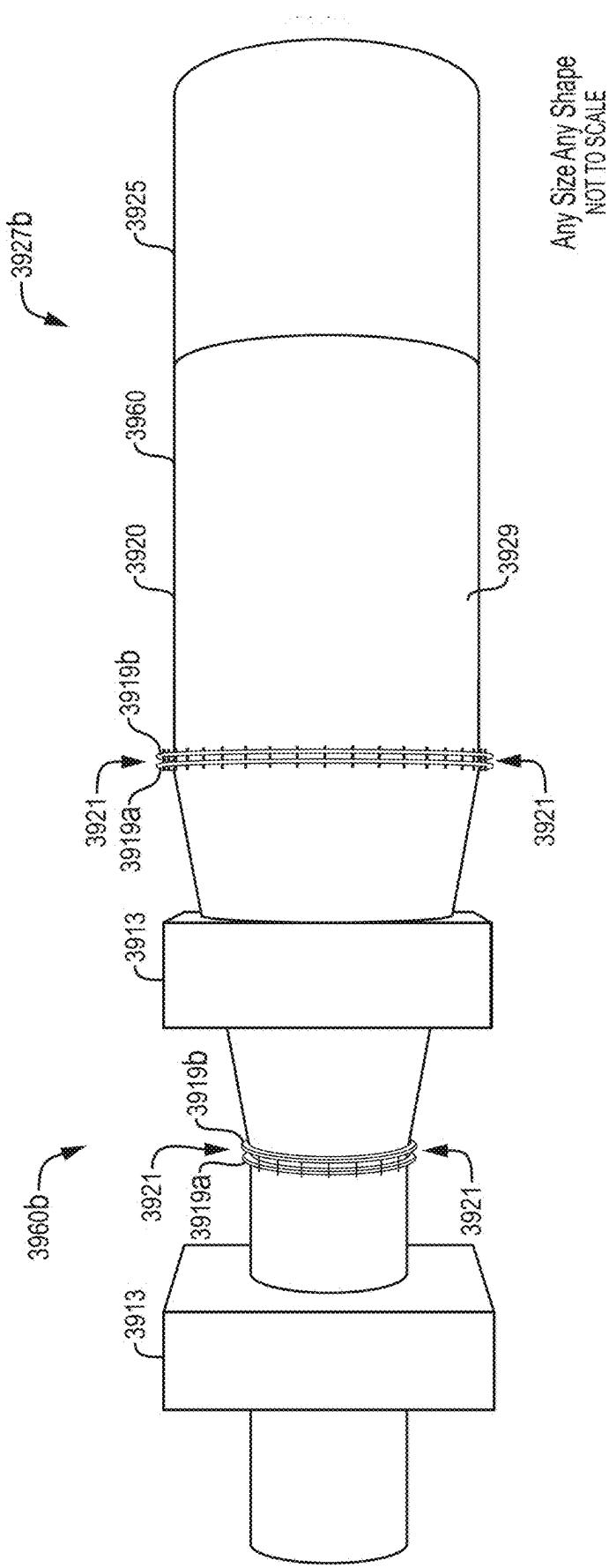


FIG. 39H

Any Size Any Shape
NOT TO SCALE

Linkage and Steel Liner Details TBM Precast OVER Steel Liner

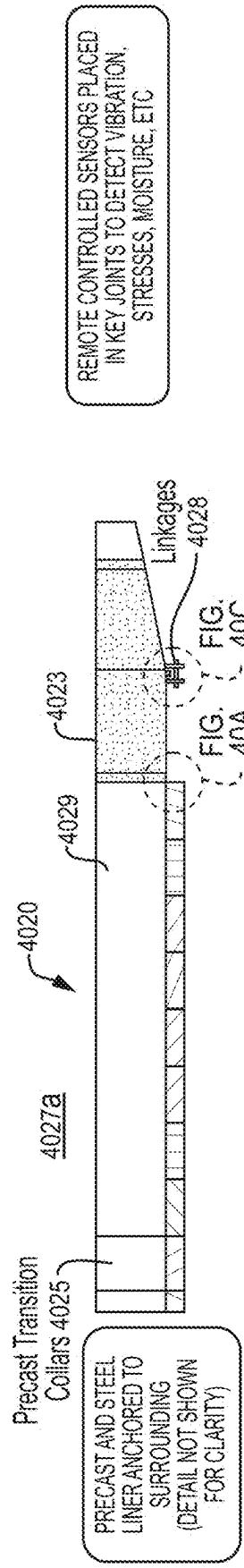


FIG. 40B

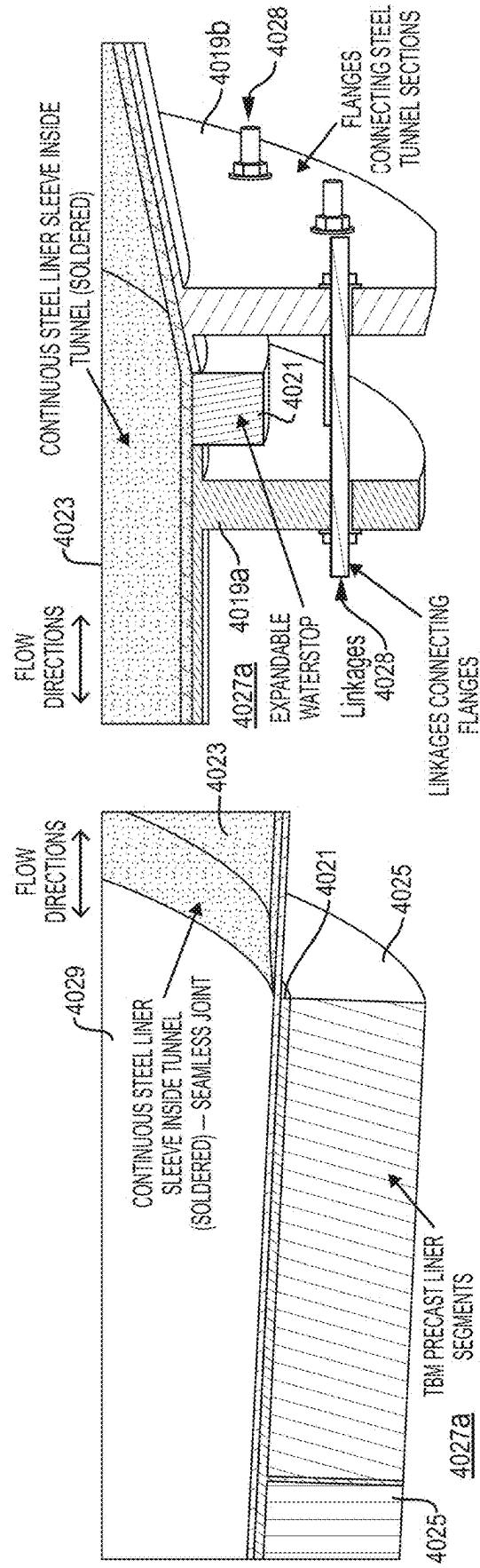


FIG. 40A

Any Size Any Shape
NOT TO SCALE

FIG. 40C

Linkage and Steel Liner Details TBM Precast INSIDE Steel Liner

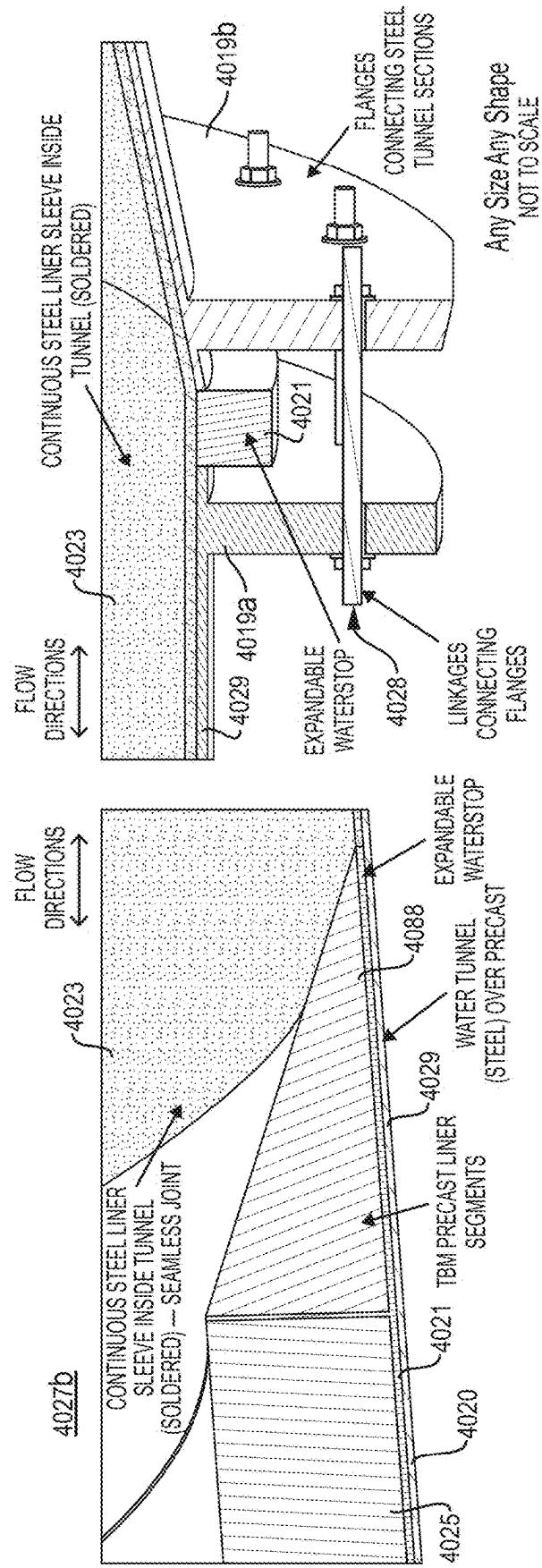
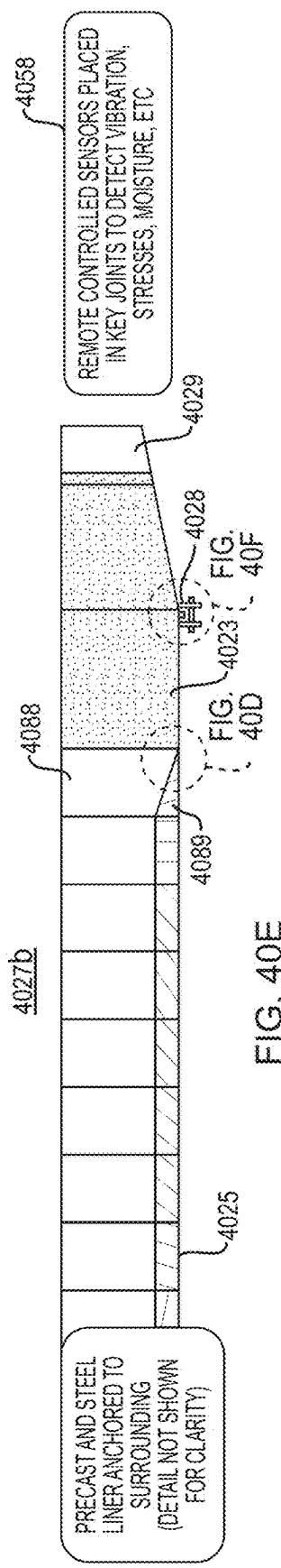


FIG. 40F

Isometric View



FIG. 41B

FIG. 41D

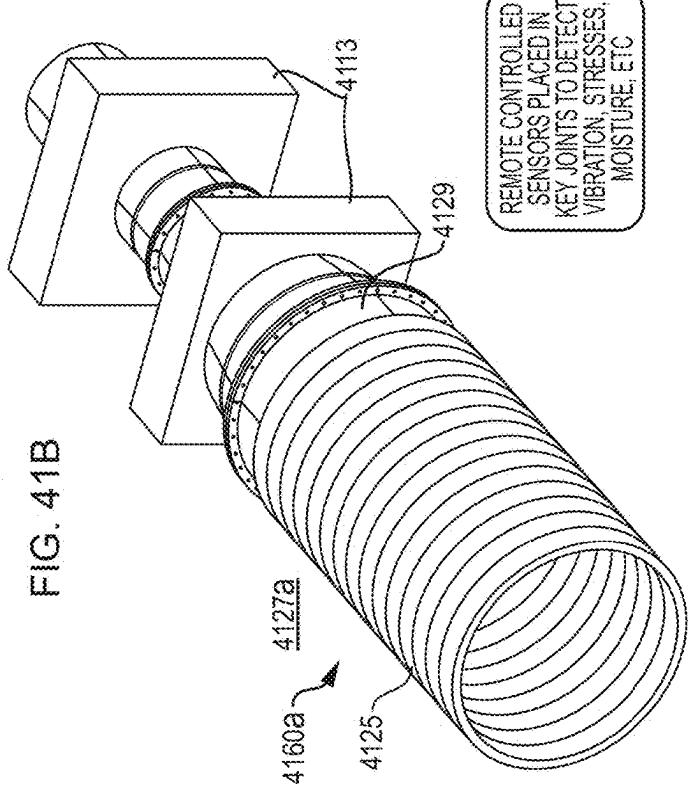


FIG. 41A

4127b

4113

4120

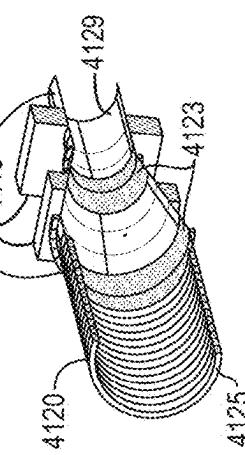
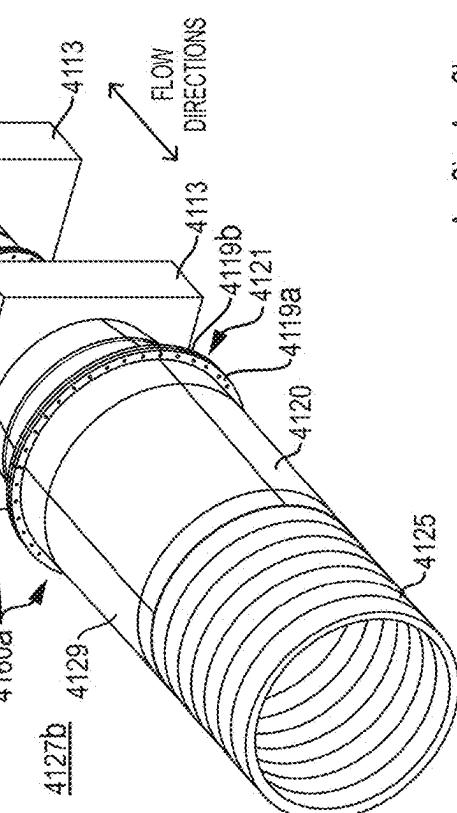


FIG. 41C

Any Size Any Shape
NOT TO SCALE



4113

FLOW DIRECTIONS

4113

4119b

4119a

4121

4120

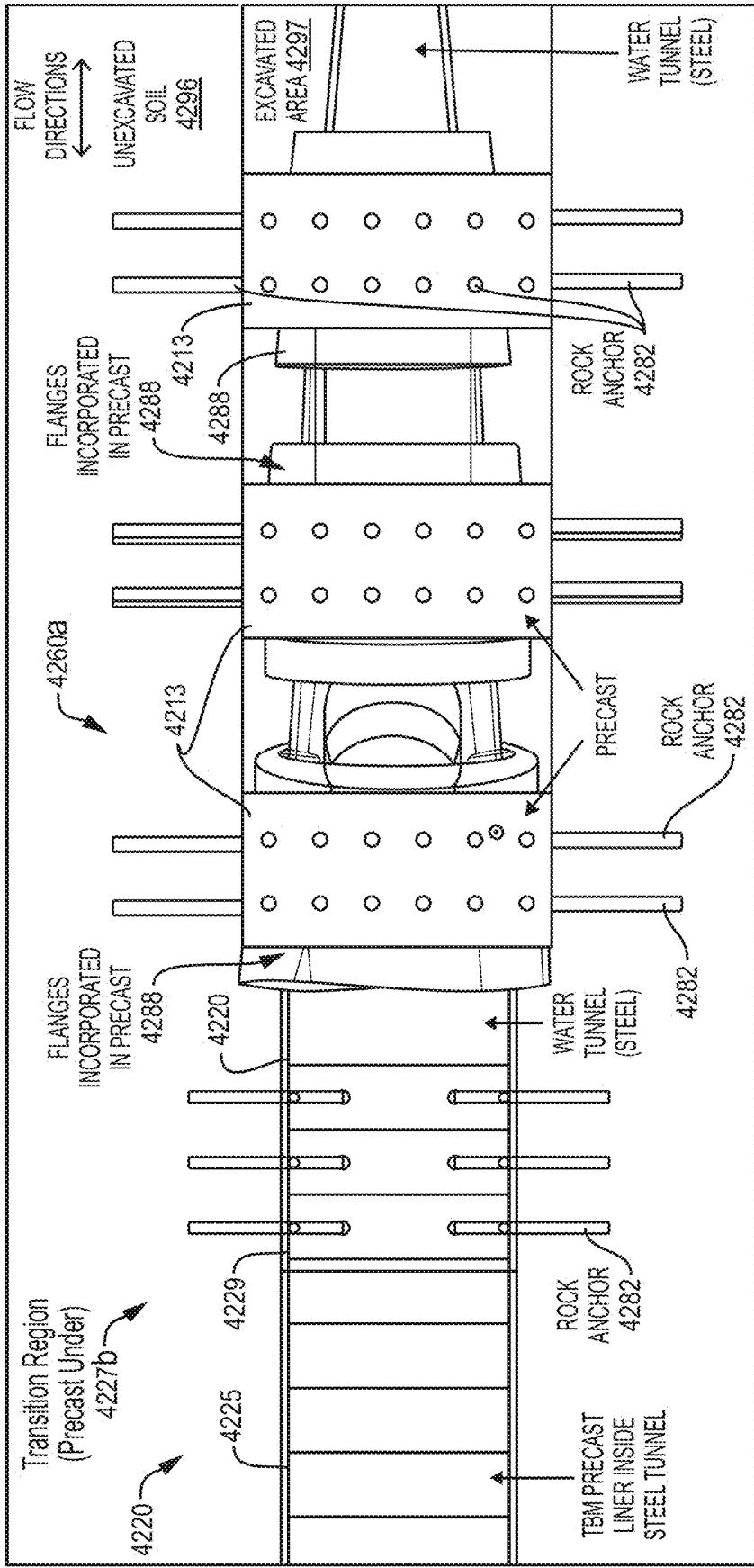
4125

4127b

4129

FIG. 41D

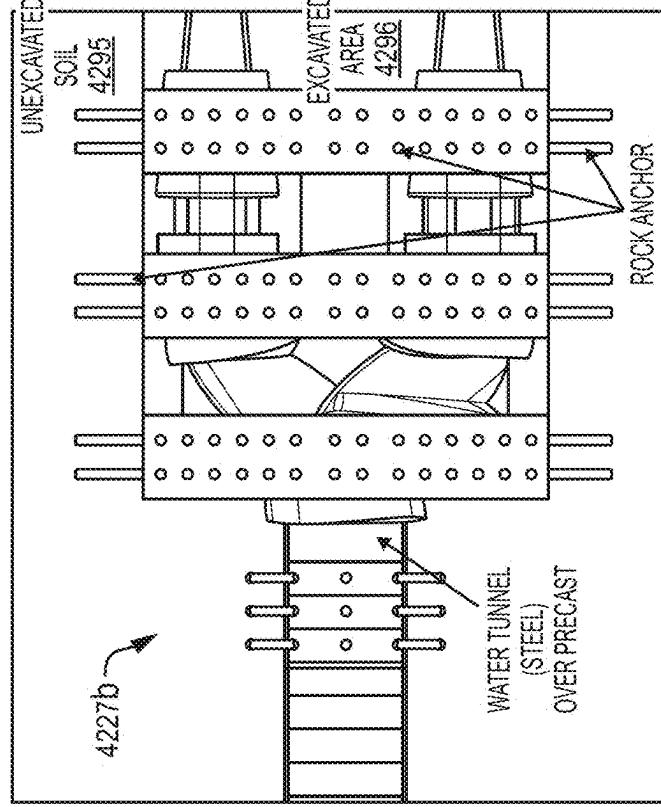
Side View of the Transition Section



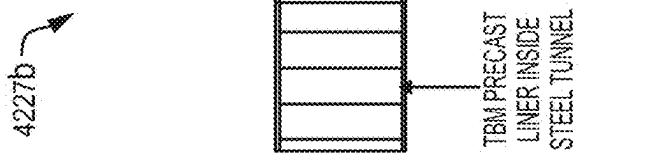
Any Size Any Shape
NOT TO SCALE

FIG. 42A

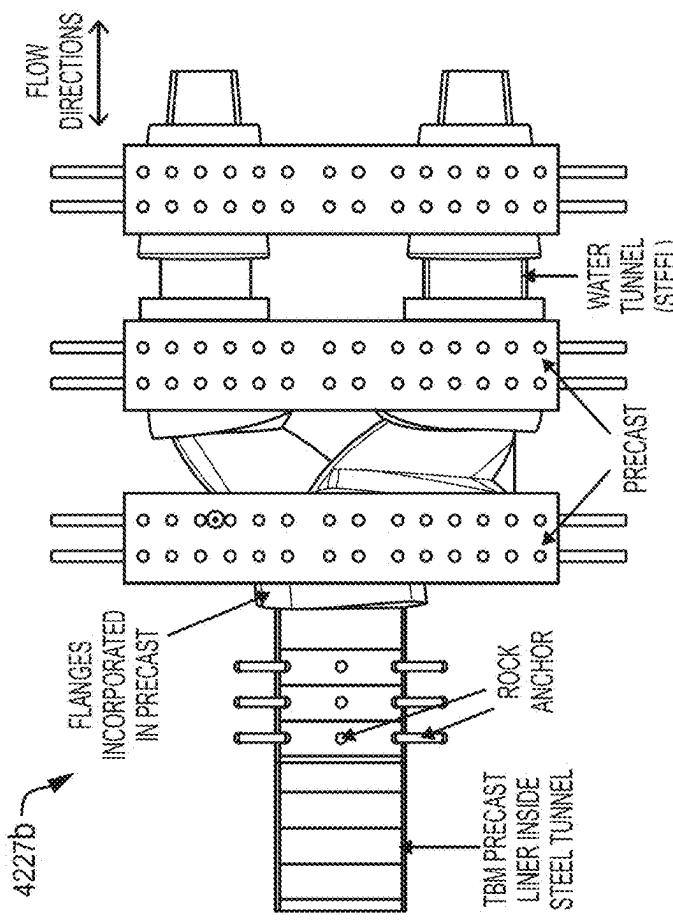
Top View of the Transition Section



(TOP VIEW) Excavation Detail



(TOP VIEW) (Excavation omitted)



Any Size Any Shape
NOT TO SCALE

FIG. 42C

(TOP VIEW) Excavation Detail

FIG. 42B

Transition Manifold with Precast Thrust Blocks
And Precast Tunnel Liners

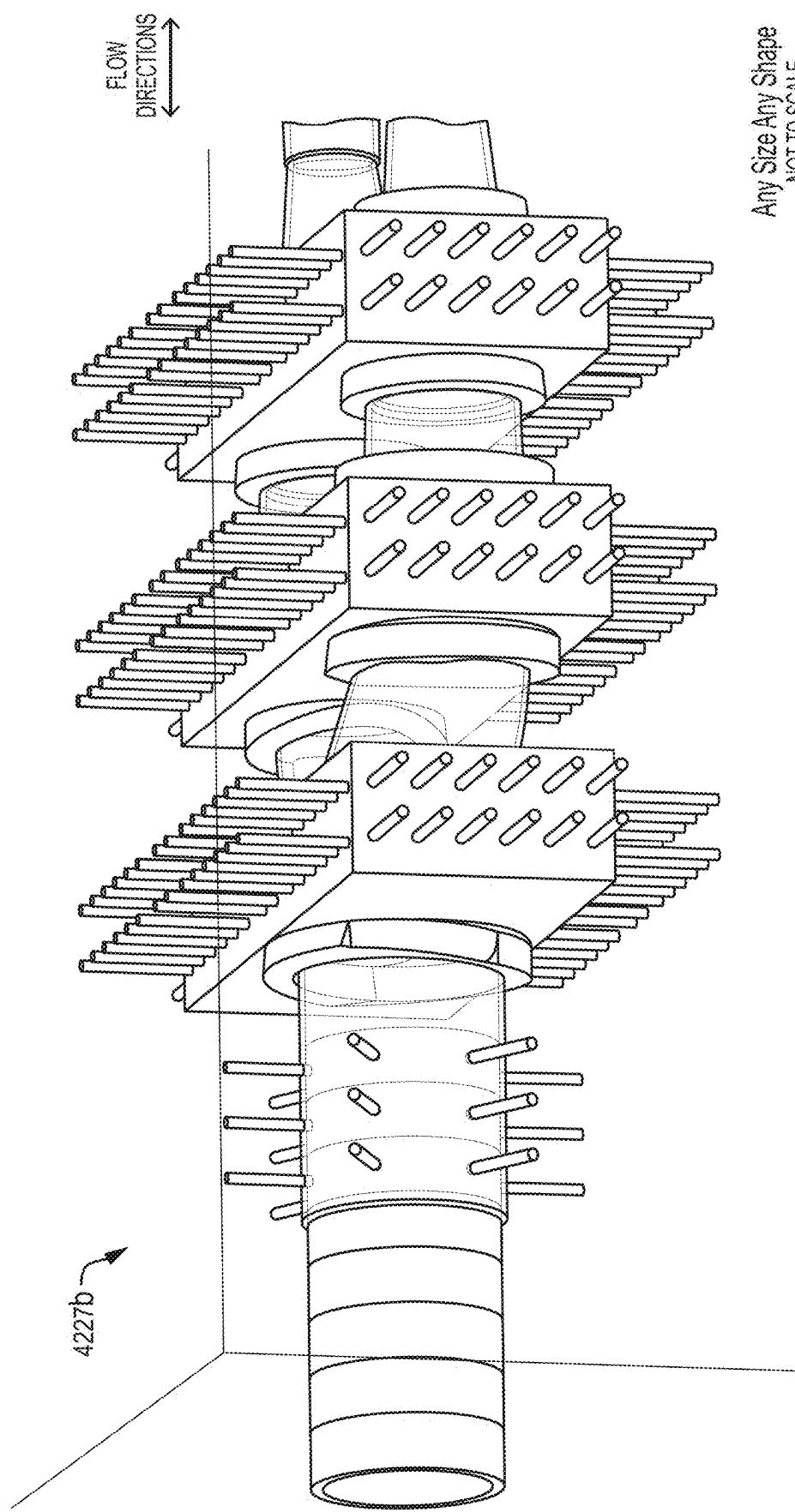
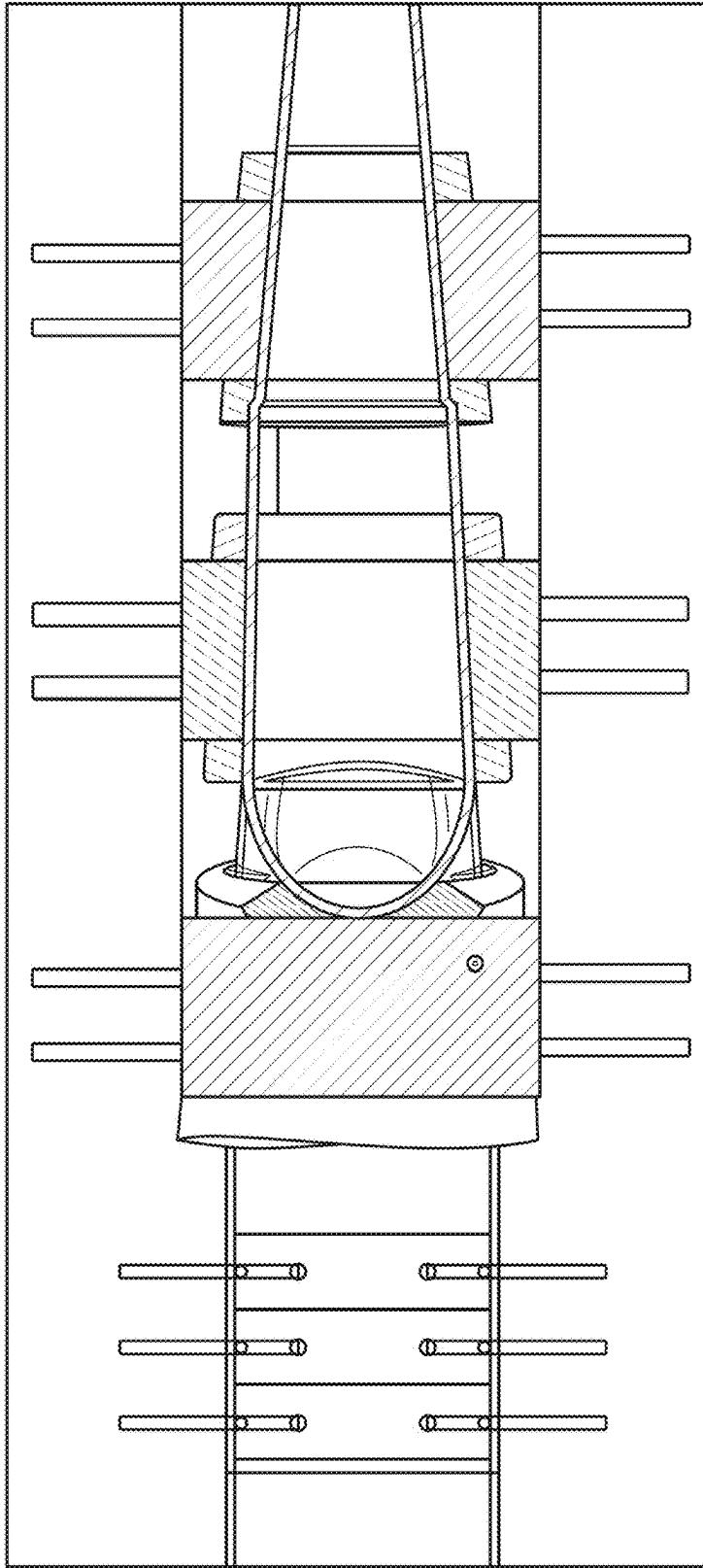


FIG. 42D

Section Through Turbine Pipes

FLOW
DIRECTIONS
↔



Any Size Any Shape
NOT TO SCALE

FIG. 42E

Section Through Tunnel Transition

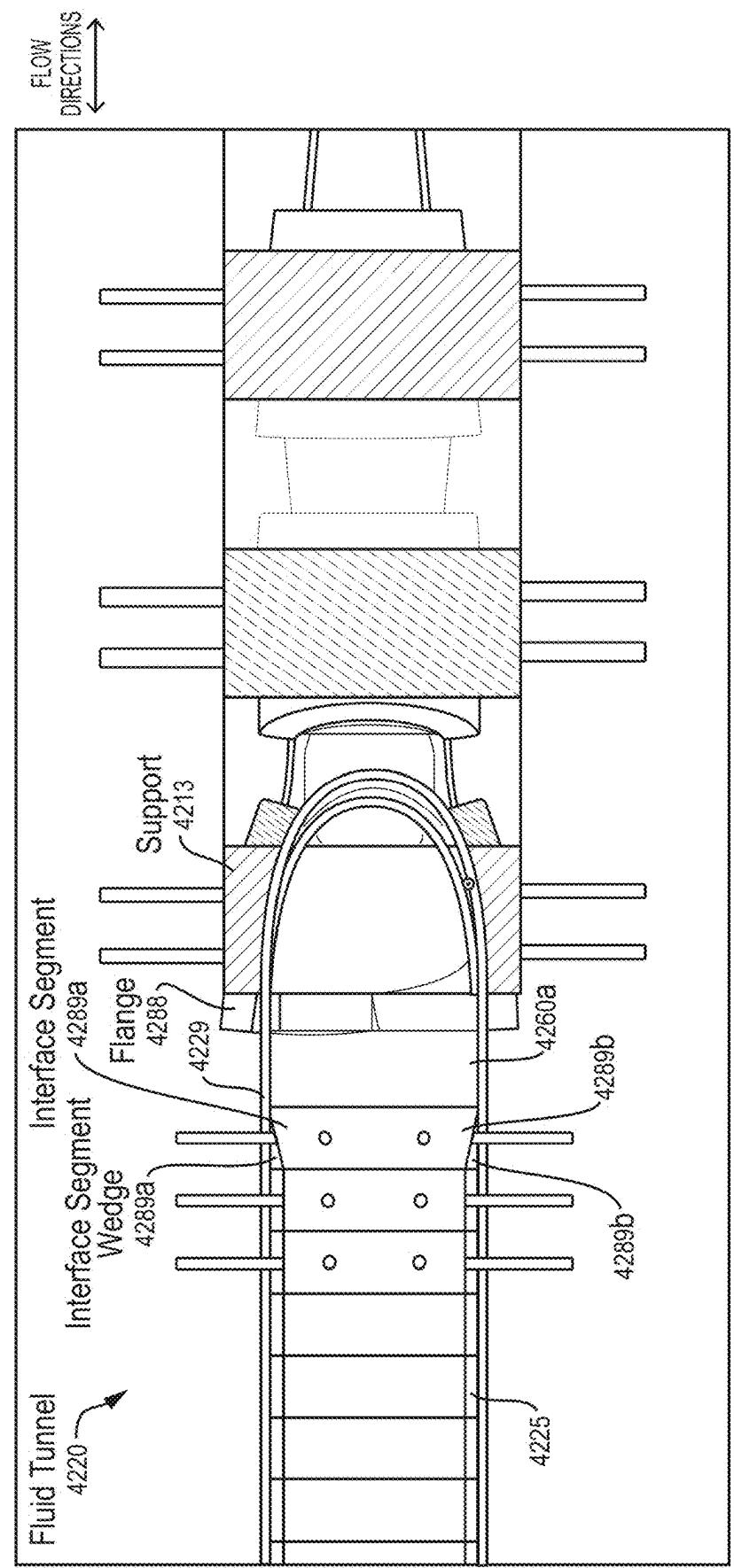
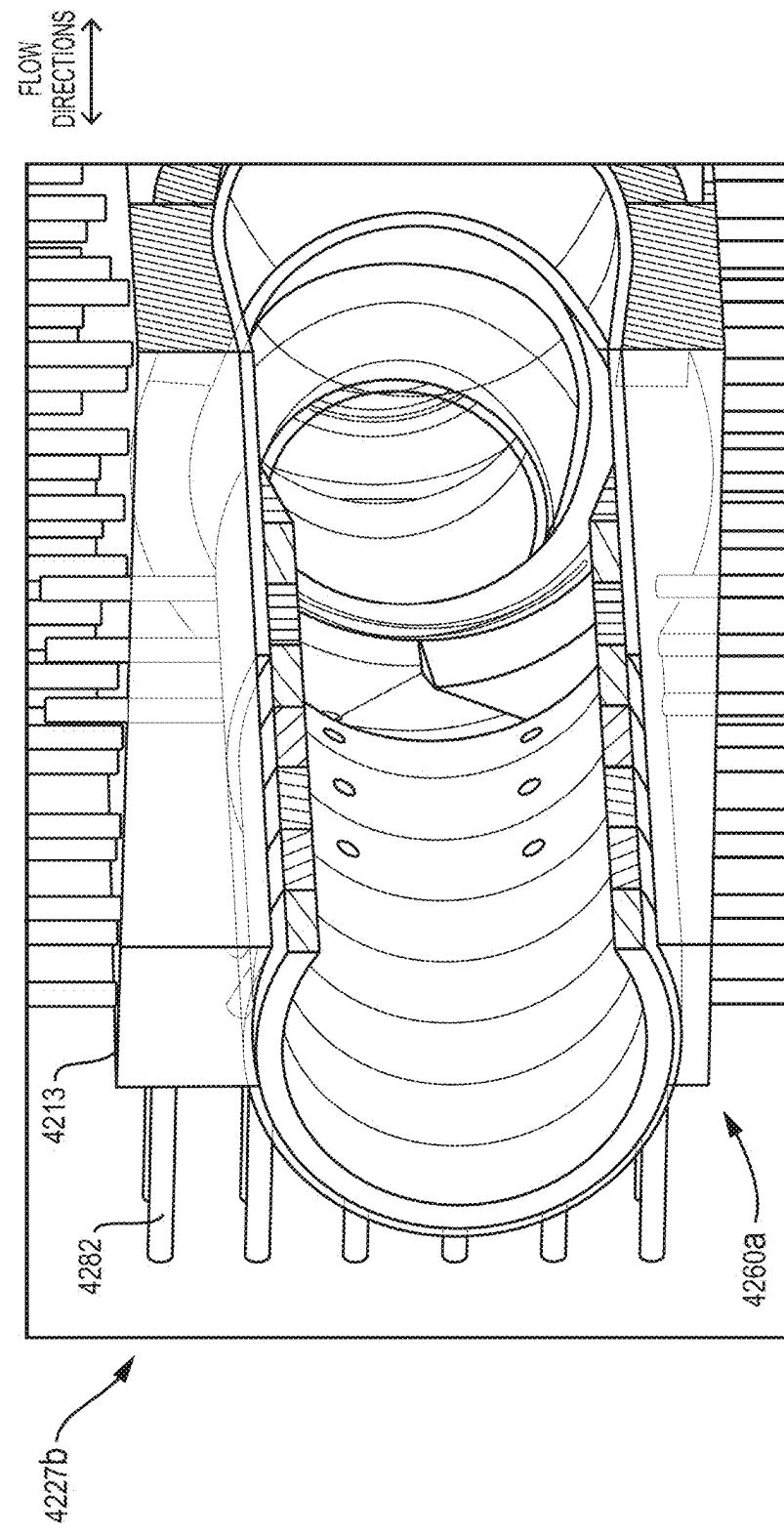


FIG. 42F

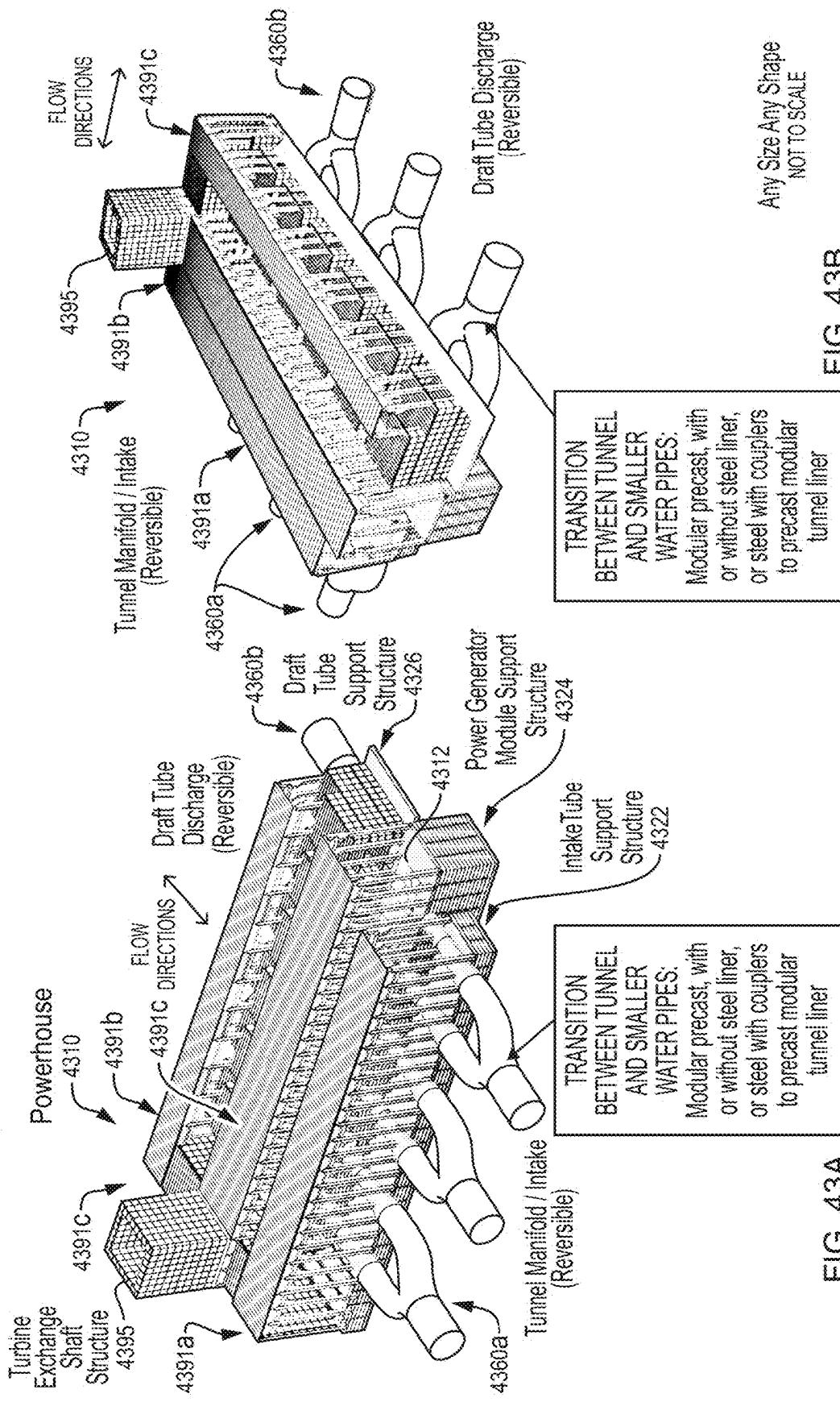
Section Through Tunnel Transition



Any Size Any Shape
NOT TO SCALE

FIG. 42G

Tunnel Manifolds and Draft Tube Typical Pumped Storage Hydro



Tunnel Manifolds and Draft Tube Typical Pumped Storage Hydro

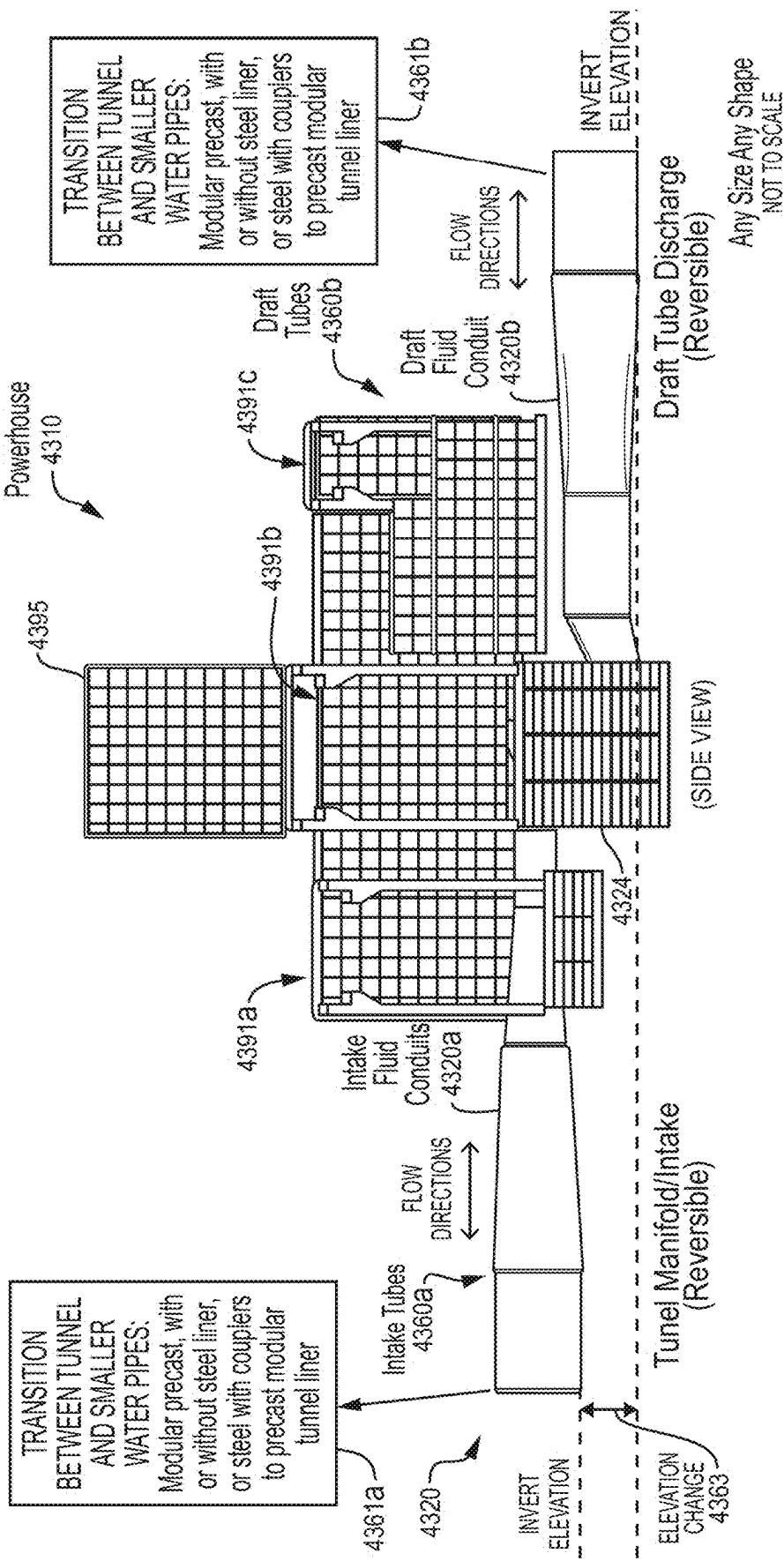


FIG. 43C

Tunnel Manifolds and Draft Tube Typical Pumped Storage Hydro

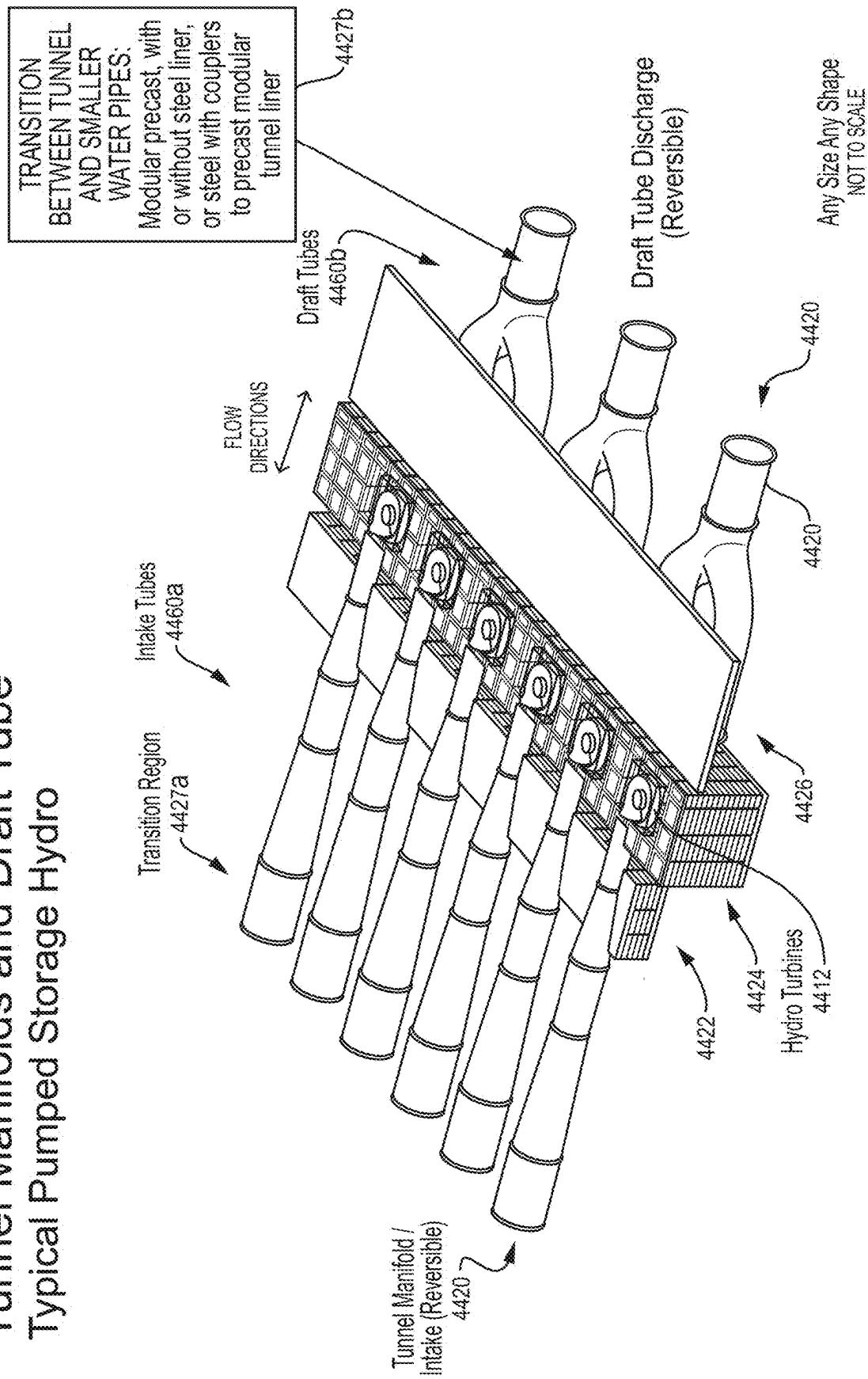
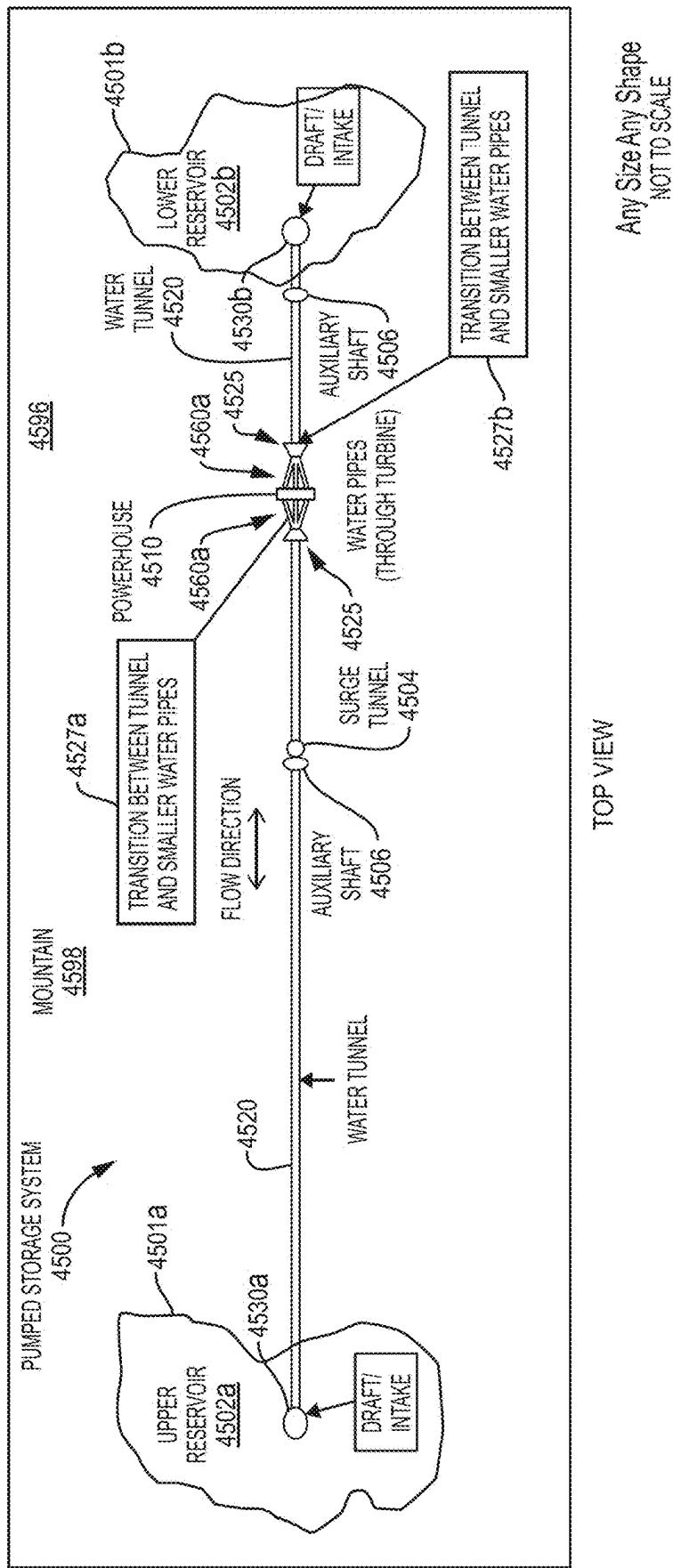


FIG. 44

Transition Between Larger Tunnel to Smaller Feeds



TOP VIEW

FIG. 45A

Transition Between Larger Tunnel to Smaller Feeds Precast Concrete Pumped Storage Hydro Facility

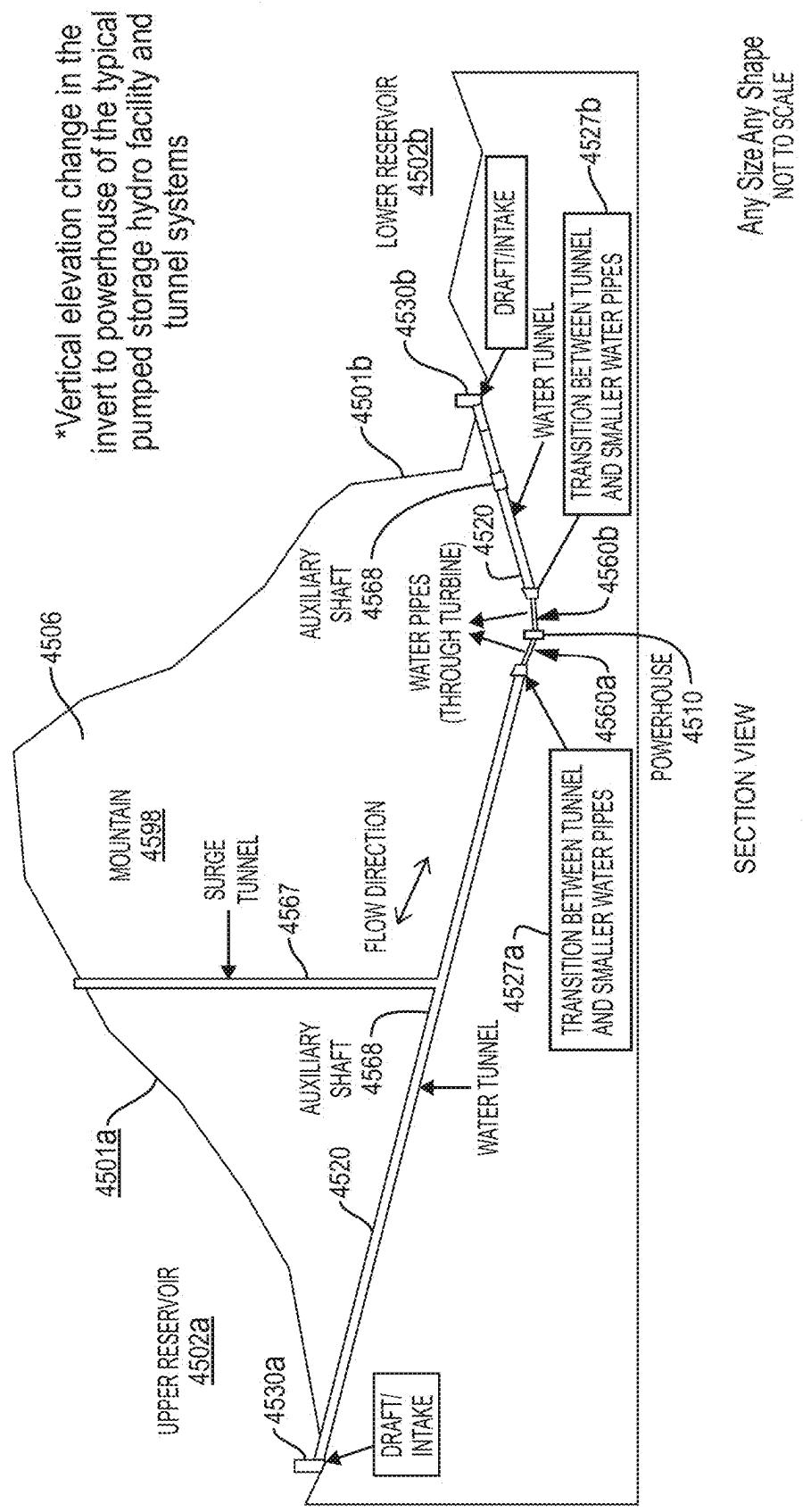


FIG. 45B

MODULAR HYDROPOWER SYSTEMS AND METHODS WITH PUMPED STORAGE

RELATED APPLICATIONS

[0001] This application is a continuation-in-part application of U.S. Non-Provisional application Ser. No. 18/924,991, filed on Oct. 23, 2024. This application claims the benefit of U.S. Provisional Application No. 63/718,561, filed on Nov. 8, 2024. This application also claims the benefit of U.S. Provisional Application No. 63/701,484, filed on Sep. 30, 2024. This application also claims the benefit of U.S. Provisional Application No. 63/552,655, filed on Feb. 12, 2024. The entire teachings of the above applications are incorporated herein by reference.

BACKGROUND

[0002] Pumped storage hydropower systems produce electrical power from the kinetic energy of running water. Pumped storage hydropower systems typically include two water reservoirs, one water reservoir being located at a higher elevation than the other. Power is generated (via a turbine or other power generation components) as water moves from the upper reservoir to the lower reservoir. The system is "recharged" by pumping water from the lower reservoir to the upper reservoir. There is a need for improved hydroelectric power generation systems.

SUMMARY

[0003] A power generation system may include an impoundment structure at least partially defined by a plurality of precast segments. At least one of the precast segments may include a precast form and at least one precast infill block.

[0004] In some example embodiments, the impoundment structure may define an intake or egress configured to receive or output fluid with a fluid supply via a flow path.

[0005] In some example embodiments, the power generation system may further include a power generation module configured to pump fluid from the fluid supply and into the impoundment structure via the flow path.

[0006] In some example embodiments, the power generation system may further include a power conversion module configured to convert kinetic energy of fluid released from the impoundment structure and travelling through the flow path into electric energy.

[0007] In some example embodiments, the power conversion module may include an intake support structure, a power generator support structure, and a draft support structure. The intake support structure may be configured to support at least one intake tube, the intake tube at least partially defining a flow path. The intake support structure may be at least partially constructed of precast segments. The power generator support structure may be configured to support weight of a power generator in an arrangement operably disposed within the flow path. The power generator support structure may be at least partially constructed of precast segments. The draft support structure may be configured to support at least one draft tube, the at least one draft tube at least partially defining the flow path. The draft support structure may be at least partially constructed of precast segments positioned above the at least one draft tube.

[0008] In some example embodiments, the power generation system may further include a flow path structure

coupled to the impoundment structure, the flow path structure at least partially defining the flow path. The flow path structure may include at least one precast segment.

[0009] In some example embodiments, the precast infill block may be fixedly coupled to the precast segment.

[0010] A power generation system may include an impoundment structure. The impoundment structure may include a containment wall and at least one inner wall. The containment wall may define at least a portion of a boundary of a containment volume. The containment volume may be configured to store a volume of fluid. The at least one inner wall may be positioned within the containment volume and offset from the containment wall. The at least one inner wall may define at least one aperture.

[0011] In some example embodiments, the impoundment structure may include at least one precast segment. The at least one precast segment may include a precast form and at least one precast infill block.

[0012] In some example embodiments, the power generation system may further include one or more supports coupling the containment wall with the inner wall.

[0013] In some example embodiments, one or more of the one or more supports may define at least one aperture configured to allow fluid to pass therethrough.

[0014] In some example embodiments, the power generation system may further include at least one energy dissipation element disposed within the impoundment structure. The at least one energy dissipation element may be configured to redirect the flow of the pumped fluid entering the-impoundment structure.

[0015] In some example embodiments, the at least one energy dissipation element disposed within the impoundment structure may cause the flow of the pumped fluid to be redirected to be in a circulating direction between inner wall and outer wall.

[0016] In some example embodiments, the containment wall or the at least one inner wall may be at least partially defined by a plurality of precast segments.

[0017] In some example embodiments, at least a subset of the plurality of precast segments may be interconnected via complementary coupling elements.

[0018] A power generation system may include a powerhouse. The powerhouse may include an intake support structure, a power generator, and a draft support structure. The intake support structure may be configured to support at least one intake tube, the intake tube at least partially defining a flow path. The intake support structure may be at least partially constructed of precast segments.

[0019] The power generator support structure may be configured to support weight of a power generator in an arrangement operably disposed within the flow path. The power generator support structure may be at least partially constructed of precast segments. The draft support structure may be configured to support at least one draft tube, the at least one draft tube at least partially defining the flow path. The draft support structure may be at least partially constructed of precast segments positioned above the at least one draft tube.

[0020] In some example embodiments, the at least one precast segment may include a precast form and at least one precast infill block.

[0021] The power generation system may further include a stabilization system. The stabilization system may include at least one support structure configured to be positioned

below a lower surface of the powerhouse; and an attachment mechanism configured to couple the at least one support structure with the powerhouse.

[0022] A power generation system may include a water intake structure configured to intake fluid and configured for fluid communication with a powerhouse via a flow path. The water intake structure may be at least partially constructed of precast segments.

[0023] The power generation system may further include a flow path structure configured to facilitate fluid communication between the water intake structure and the powerhouse. A first end of the flow path structure may be coupled to the water intake structure and a second end of the flow path structure may be coupled to the powerhouse.

[0024] In some example embodiments, the water intake structure may include one or more layers. Each layer may include one or more precast segment.

[0025] In some example embodiments, each layer may include at least one protrusion.

[0026] In some example embodiments, at least one of the precast segments may include a precast form and a precast infill block.

[0027] Another example embodiment of the power generation system comprises a powerhouse including a power generating module disposed therein; an intake tube coupled to the power generating module at an intake port and a draft tube coupled to the power generating module at a draft port; and a fluid conduit defining a fluid flow path and including at least one transition collar at a transition region between the fluid conduit and the intake tube, the draft tube, or both.

[0028] In this other example embodiment, the fluid conduit may be defined by at least one precast segment of cementitious material and at least one of the intake tube or draft tube is of non-cementitious material.

[0029] The at least one transition collar may be a precast segment of cementitious material and at least one of the intake tube and draft tube may be non-cementitious, and wherein waterstop material may be disposed between the at least one transition collar and the intake tube, draft tube, or both.

[0030] The power generation system may further comprise a structural material disposed between the at least one transition collar and the intake tube or draft tube in a coaxial arrangement, the structural material forming a flange external from the at least one transition collar or the intake tube or draft tube having the larger dimension.

[0031] The power generation system at the transition region may include at least one transition collar that defines a circumference of the fluid conduit and the intake tube and the draft tube define respective circumferences, the at least one transition collar and intake tube and draft tube may be coupled together in a coaxial arrangement, and wherein the circumference of the fluid conduit may be larger than at least one of a circumference of the intake tube or the draft tube or smaller than at least one of a circumference of the intake tube or the draft tube, or the precast segment at the interface region has a thickness of cementitious material and wherein the circumference of the intake tube or the draft tube is within an outer circumference and inner circumference of the precast segment.

[0032] In the example embodiment, the power generation system may further comprise a liner sleeve coupled circumferentially to an interior or exterior of the fluid conduit at the interface region and extends at least a portion of at least one

precast segment. The liner sleeve may be disposed between the at least one precast segment and a corresponding intake tube or draft tube. Waterstop material may be coupled to at least one of an inner surface or outer surface of the liner sleeve.

[0033] The power generation system may include multiple segments that compose at least one of the intake tube and draft tube and wherein adjacent segments may be coupled together by complementary flanges. Waterstop material may be disposed between the complementary flanges. At least one of the complementary flanges may include a guide dowel or off-centered bolt, and the other complementary flange may include a complementary feature to accept the guide dowel or off-centered bolt.

[0034] The intake tube and draft tube may be made of metal or other material of sufficient strength to contain water pressure corresponding to a pressure of the fluid conduit filled with a fluid for a vertical distance between the powerhouse and a fluid intake structure at a respective fluid supply.

[0035] The power generation system may further comprise at least one support segment coupled to at least one of the intake tube or the draft tube between the respective portion of the fluid conduit and the powerhouse. The at least one support segment may be configured to secure the intake tube or the draft tube to a structural feature to support or resist displacement force on the intake tube or the draft tube caused by fluid flow therein.

[0036] The at least one support segment may include extenders that project outward from the at least one support segment configured to be coupled to at least one natural structural feature.

[0037] The intake tube and draft tube may be split into a corresponding number of subtubes to direct fluid to a corresponding number of power generating modules within the powerhouse.

[0038] Multiple precast segments may form the fluid conduit between an upper fluid supply and the powerhouse or a lower fluid supply and the powerhouse, and wherein an interior surface of the fluid conduit may have a smoothness with a tolerance that controls creation of turbulence within the fluid conduit, and further wherein the fluid conduit may be coupled at an interface region to the intake tube or the draft tube in a manner defining a substantially continuous surface internally in the fluid flow path. The interior surface may be coated with a hydrophobic compound.

[0039] The powerhouse may be disposed beneath a surface of the ground, and, in an example embodiment, multiple precast segments that define a maintenance shaft may extend from a surface of the earth location to the powerhouse to enable replacing of a power generating module. Further, multiple precast segments may define an auxiliary shaft with an opening arranged to enable access to the fluid conduit. Still further, multiple precast segments may define a surge tunnel fluidically coupled to the fluid conduit and sized to relieve at least 5% of the pressure within the fluid conduit between a fluid supply and the powerhouse.

[0040] In an example embodiment of the power generation system, the power generating module is oriented in a vertical arrangement, the intake port and the draft port define an elevation differential at least a height of the power generating module in the vertical arrangement. The elevation differential may have a distance of multiple feet, multiple tens of feet, or multiple hundreds of feet.

[0041] The power generating module may include multiple power generating modules configured to operate in parallel within the powerhouse.

[0042] Sensors may be employed and arranged to sense an indication of a reduction in integrity relative to a desired performance, the indication being at least one of vibration, stress, or moisture.

[0043] In another example embodiment, a power generation system may include a powerhouse configured to support a power generating module disposed therein and further include an intake tube coupled to the power generating module at an intake port and a draft tube coupled to the power generating module at a draft port, the intake port elevated with respect to the draft port.

[0044] In this example embodiment, the power generation system may include a power generating module support structure and a power generating superstructure with at least one crane coupled thereto, the at least one crane having a capacity to deploy and extract the power generating module from the power generating module support structure.

[0045] The power generation system may further comprise an intake tube support structure with corresponding superstructure, a draft tube support structure with corresponding superstructure, and at least one crane coupled to at least one of the intake tube superstructure and draft tube superstructure. At least one of the power generating module support structure, intake tube support structure, and draft tube support structure may include multiple precast segments coupled together.

[0046] The power generation system may further comprise a turbine exchange shaft structure defining a shaft of dimensions to enable a power generating module to be deployed and extracted therethrough.

[0047] The power generation system may further comprise at least one sensor configured to detect an operational parameter of the power generating module or an operational parameter (e.g., structural integrity) of at least one of the intake tube or draft tube. A controller may be communicatively coupled to the at least one sensor, the controller further communicatively coupled to an operational element within the power generation system to cause the operational element to adjust a fluid flow associated with the intake tube, draft tube, or both.

[0048] In still a further example embodiment, a power generation system may comprise means for securing an intake tube of a powerhouse to a first section of a fluid conduit; means for securing a draft tube of the powerhouse to a second section of the fluid conduit; and means for converting fluid flow to electrical power within the powerhouse, said means for converting being deployed at a location fluidically between the intake tube and draft tube.

BRIEF DESCRIPTION OF THE DRAWINGS

[0049] The foregoing will be apparent from the following more particular description of example embodiments, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating embodiments.

[0050] FIG. 1A shows a schematic of an example embodiment of a pump storage system.

[0051] FIG. 1B shows a schematic of an example embodiment of a pump storage system.

[0052] FIG. 2 shows a top view of an example embodiment of a pump storage system comprising three intake modules, each being coupled to a powerhouse via a fluid conduit.

[0053] FIG. 3A shows a side view of an example embodiment of an intake module.

[0054] FIG. 3B shows a perspective sectional view of an example embodiment of an intake module.

[0055] FIG. 3C shows a perspective view of an example embodiment of a layer of an intake module.

[0056] FIG. 4 shows a side view of a schematic of a portion of an example embodiment of a powerhouse.

[0057] FIG. 5 shows a top view of a schematic of a portion of an example embodiment of a powerhouse.

[0058] FIG. 6 shows a top view of a schematic of a portion of an example embodiment of a powerhouse.

[0059] FIG. 7 shows a perspective view of a schematic of a portion of an example embodiment of a powerhouse.

[0060] FIG. 8A shows a top view of an example embodiment of a modular block.

[0061] FIG. 8B shows a bottom view of the example embodiment of a modular block of FIG. 8A.

[0062] FIG. 8C shows a bottom view of the example embodiment of a modular block of FIG. 8A.

[0063] FIG. 9A is a perspective view of an example embodiment of three modular blocks in a stacked configuration.

[0064] FIG. 9B is a side view of the example embodiment of FIG. 9A.

[0065] FIGS. 10A-10B are perspective views of an example embodiment of three modular blocks in a stacked configuration and shows example levels to which the cavity of each modular block may be filled.

[0066] FIG. 11 shows an example embodiment of two stacks of modular blocks, the two stacks being coupled together laterally.

[0067] FIG. 12 shows an example embodiment of four stacks of modular blocks and precast concrete infill blocks.

[0068] FIG. 13 shows example dimensions for an example embodiment of a modular block.

[0069] FIG. 14 shows an example embodiment of a rectangular modular block.

[0070] FIG. 15A shows a perspective of an example embodiment of a working platform coupled to rock anchors.

[0071] FIG. 15B shows a close-up view of the example embodiment of a working platform of FIG. 15A.

[0072] FIG. 16A shows a perspective view of an example embodiment of a working platform coupled to multiple rock anchors.

[0073] FIG. 16B shows a perspective view of an example embodiment of a working platform coupled to multiple cleats, rock anchors, and diffusers.

[0074] FIG. 17 shows an example embodiment of an earthquake prevention system.

[0075] FIG. 18 shows an example embodiment of a powerhouse configured to be at a cavernous subterranean location underground.

[0076] FIG. 19 shows an example embodiment of a powerhouse configured to be at a cavernous subterranean location underground.

[0077] FIG. 20 shows an example embodiment of a powerhouse configured to be at a cavernous subterranean location underground.

- [0078] FIG. 21 shows an example embodiment of a pre-cast powerhouse configured to be at a cavernous subterranean location underground.
- [0079] FIG. 22 shows an example embodiment of a pre-cast powerhouse in an excavated cavern.
- [0080] FIG. 23 shows example embodiments of modular blocks for mass and powerhouse galleries.
- [0081] FIG. 24A shows an example embodiment of a water storage tunnel.
- [0082] FIG. 24B shows a top view of an example embodiment of a tunnel precast module.
- [0083] FIG. 24C shows a side view of an example embodiment of a tunnel precast module.
- [0084] FIG. 24D shows a perspective view of an example embodiment of a water storage tunnel.
- [0085] FIG. 25 shows an example embodiment of a seismic relief fluid conduit system.
- [0086] FIG. 26A shows an example of a fan configured to provide suction to pull fluid to the upper impoundment structure.
- [0087] FIG. 26B shows an example configuration for pulling fluid to an upper impoundment structure.
- [0088] FIG. 27 shows an example of an assembly of an example embodiment of an impoundment structure.
- [0089] FIG. 28 shows an example of an assembly of an example embodiment of an impoundment structure.
- [0090] FIG. 29 shows an example embodiment of an impoundment structure comprising energy dissipation elements (also referred to as diffusers).
- [0091] FIG. 30 shows an example embodiment of an impoundment structure or tank comprising energy dissipation elements.
- [0092] FIG. 31 shows an example embodiment of an impoundment structure or tank comprising energy dissipation elements.
- [0093] FIG. 32 shows an example embodiment of an impoundment structure comprising energy dissipation elements.
- [0094] FIG. 33 shows an example embodiment of an impoundment structure or tank comprising energy dissipation elements.
- [0095] FIG. 34 shows an example embodiment of an impoundment structure comprising a sensor system configured to monitor conditions in the impoundment structure.
- [0096] FIG. 35A shows an example embodiment of tube gates at fluid conduits.
- [0097] FIG. 35B is a side view of an example embodiment of gates configured to translate in the direction of the arrows.
- [0098] FIG. 35C is a side view of an example embodiment of gates configured to translate in the direction of the arrows.
- [0099] FIG. 35D is a top view of an example embodiment of gates configured to translate in the direction of the arrows.
- [0100] FIG. 36 is an example embodiment of an environmental protective system.
- [0101] FIGS. 37A-37C are diagrams of an alternative embodiment of an intake modular precast structure relative to the intake modular precast structure of FIGS. 1A-3C.
- [0102] FIG. 38 is a diagram of aspects of a powerhouse that includes intake tube(s) and draft tube(s).
- [0103] FIGS. 39A through 39H are diagrams that illustrate example embodiments of transition regions in a proximal location of a powerhouse.

[0104] FIGS. 40A, 40B, and 40C are diagrams of the transition region that illustrate details of an embodiment of an assembly.

[0105] FIGS. 40D, 40E, and 40F illustrate an embodiment in which precast transition collars are located inside a steel liner.

[0106] FIGS. 41A, 41B, 41C, and 41D are isometric views consistent with the embodiment of FIG. 39B.

[0107] FIGS. 42A-42G are views of an example embodiment of a transition region that may be located beneath the surface of the ground.

[0108] FIGS. 43A-43C are diagrams of a powerhouse illustrating the flow tubes and draft tubes in context with other aspects of the powerhouse.

[0109] FIG. 44 is a diagram similar to FIGS. 43A-C that shows the elements of FIGS. 43A-C with more visibility of the hydro turbines.

[0110] FIGS. 45A and 45B are scene diagrams of a pumped storage system from a top view and section view, respectively.

DETAILED DESCRIPTION

[0111] A description of example embodiments follows.

[0112] Traditional pumped storage facilities typically require complex custom civil designs that are expensive to build, especially in remote mountainous areas. Blasting, excavating, embankment building, and rock-tunneling are examples of costly and time-consuming civil construction activities typically involved in building traditional pumped storage facilities, and these activities leave permanent environmental scars on the landscape. Accordingly, there is a need for improved pumped storage systems.

[0113] Systems, devices and methods described herein may involve pumped storage hydropower (PSH) systems that include components constructed from precast segments. As used herein, the term “precast segment” refers to precast modules of particular shape and size formed of a structural material, such as, concrete. Precast segments can include coupling elements to enable the segments to be interconnected during construction of a structure, such as a reservoir or impoundment module. Precast segments can be manufactured off-site, providing for increased control over manufacturing conditions, thereby providing for more robust and uniformly constructed segments for forming a structure, as compared with a structure formed by on-site concrete pouring. For some construction projects, a temporary facility may be constructed to manufacture precast segments on-site, whereby the temporary facility itself may be formed of precast segments.

[0114] Hydroelectric power generation systems described herein can provide for more versatile and facile construction than existing hydroelectric power systems, and with less environmental impact. Such systems can be constructed with precast segments, which can provide for faster construction with more robust structural components, and which can provide for construction in areas that would otherwise be inaccessible or that would require more environmentally-destructive construction.

[0115] In various embodiments, a power generation system may include a reservoir or impoundment structure that is at least partially defined by a plurality of precast segments. At least a subset of the precast segments may be interconnected via complementary coupling elements. The reservoir or impoundment structure may be elevated with respect to a

fluid supply. The system may further include a flow path providing fluid communication between the reservoir or impoundment structure and the fluid supply, a power generation module configured to pump fluid from the fluid supply and into the reservoir via the flow path, and a power conversion module configured to convert kinetic energy of fluid released from the reservoir and travelling through the flow path into electric energy.

[0116] The power generation system can be an open-loop system or a closed-loop system. For example, for an open-loop system, the fluid supply can be a natural water supply, such as a river or lake or rain. For a closed-loop system, the system can further include a lower reservoir or impoundment structure that houses the fluid supply.

[0117] The reservoir(s) or impoundment structures of the system can include energy dissipation elements that are configured to disrupt a direction of fluid flow and/or reduce a velocity of flowing fluid that is being pumped into the reservoir or impoundment structure. Such energy dissipation elements can be auxiliary precast segments, or can be at least partially defined by one or more auxiliary precast segments. Optionally, an auxiliary precast segment can include a coupling element for mechanical coupling to a precast element of the reservoir or impoundment structure. The energy dissipation elements can be disposed substantially vertically with respect to a base of the reservoir or impoundment structure and, optionally, provide for the multifunction purpose of supporting a roof that permanently covers or selectively covers the reservoir or impoundment structure. Vertically-disposed auxiliary precast segments can be further supported by auxiliary precast segments that extend between the vertically-disposed auxiliary precast segments. For example, auxiliary precast segments with a non-vertical orientation can be disposed between the vertically-disposed auxiliary precast segments. The energy dissipation elements can comprise perforated structures, such as defined by one or more precast segments. Energy dissipation elements can also be disposed in a fluid supply for an open-loop system. For example, energy dissipation elements can be disposed in an area at which water is released back to the natural water supply, so as to reduce impact of the flowing water on natural structures and on wildlife.

[0118] The reservoir(s) or impoundment structure(s) of the system can each include a continuous base, with precast segments forming the reservoir impoundment structure configured to couple to an upper surface of the base. Precast segments forming the reservoirs or impoundment structures can include precast segments having at least two opposing surfaces of a substantially triangular or truncated triangular shape. Such shape can provide for the precast segments to be alternately arranged to define a wall of the reservoir/impoundment structure and/or to define a buttress structure to support a wall of the reservoir/impoundment structure. Other shapes that define straight or curvilinear edges that enable adjacent arrangement to define a buttress structure may also be employed.

[0119] The flow path(s) of the system can be defined by at least two fluid conduits that are individually selectable for fluid transfer between the fluid supply and the reservoir/impoundment structure. For example, one of the fluid conduits can be utilized for upward flow, and the other for downward flow, with an option to alternate direction in each conduit. At least one dedicated pump can be included at each of the at least two fluid conduits. The fluid pump(s) of the

system can be disposed at varying elevations. For example, at least two fluid pumps can be disposed at a conduit that defines a flowpath, the fluid pumps disposed at varying elevations. Optionally, one or more intermediary reservoirs/impoundment structures can be included, where the intermediary reservoirs/impoundment structures may include aspects constructed through the use of precast segments, such as any of the precast segments described herein. The inclusion of multiple fluid pumps for a flow path and intermediary reservoirs/impoundment structures along the flow path can provide for a configuration in which work is distributed throughout the system rather than performed by a single pump. Similarly, intermediate reservoirs/impoundment structures can be included along the flow path for downward flow, so as to not overwhelm a lower reservoir/impoundment structure or naturally water supply during periods of power generation.

[0120] In some embodiments, the fluid pump(s) may be used to force fluid to an upper reservoir/impoundment structure to retain the pumped fluid as potential energy and convert kinetic energy of fluid flowing downward into electrical power. For example, in one embodiment, the power generation module and power conversion module may be integrated into a single module that includes a turbine configured to rotate in a first direction to pump the fluid from the fluid supply and into the reservoir via the flow path and to rotate in a second direction to convert the kinetic energy of fluid released from the reservoir into electric energy.

[0121] Various configurations of precast segments can be used to construct or define the system. Precast segments can be provided for foundation segment(s) of the reservoir(s)/impoundment structure(s), as impound segments configured to encase infill to at least partially define the reservoir(s)/impoundment structure(s), and/or as fluid conduit segments to define the flow path(s) of the system. The reservoir(s)/impoundment structure(s) can include one or more precast segment(s) defining an outlet port for fluid released from the reservoir/impoundment structure and defining an inlet port for fluid pumped into the reservoir/impoundment structure. One or more inlet and/or outlet ports can be included. The inlet port can be disposed at a higher elevation than the outlet port.

[0122] The power generation system may have the power generation module and power conversion module integrated into a single module that includes a turbine configured to rotate in a first direction to pump the fluid from the fluid supply and into the reservoir/impoundment structure via the flow path and to rotate in a second direction to convert the kinetic energy of fluid released from the reservoir/impoundment structure into electric energy.

[0123] The power generation system may further comprise material flowed and coupled to a precast segment. The material may be positioned over a seam between adjacent precast segments or define an energy dissipation element.

[0124] The power generating system may comprise a three-dimensional (3D) material printing system coupled to a precast segment on a base of or at an upper surface of the reservoir/impoundment structure. In such an embodiment, the 3D material printing system may access material from a source of material located at the reservoir/impoundment structure and transfer the material to a different precast segment via a boom.

[0125] A power generation method includes, with a power generation system, transferring fluid from the fluid supply to the reservoir/impoundment structure via the flow path, releasing fluid from the reservoir/impoundment structure to the fluid supply via the flow path, and storing energy converted by the energy conversion component during fluid release.

[0126] In various embodiments, transferring of water from the water supply to the reservoir/impoundment structure can occur during a period of low-energy use by a community associated with a power grid that may supply power to or receive power from the power generation system such that the cost of energy is low while water is being pumped upward to the reservoir. Releasing of water from the reservoir/impoundment structure to the water supply occurs during a period of high-energy use such that power generated by the power generation system is available to serve the community via the power grid.

[0127] FIG. 1A shows a schematic of an example embodiment of a pump storage system 100. In various embodiments, such as the one shown in FIG. 1A, a pump storage system 100 may comprise an impoundment structure 101, at least one fluid conduit 120, and a powerhouse 110. The powerhouse 110 may be above ground or below ground. In various embodiments, the powerhouse may be mounted on a foundation that doesn't penetrate the ground. The pump storage system 100 may also be referred to as a power generation system herein.

[0128] The impoundment structure 101 is constructed and arranged to store a volume of fluid. In various embodiments, each impoundment structure 101 is composed of at least one precast segment. The at least one fluid conduit 120 (also referred to as a flow path structure) may be coupled to the impoundment structure 101 and the powerhouse 110 such that the fluid can flow from the impoundment structure 101 to the powerhouse 110 and then to a second location. In some embodiments, the second location is a second storage location, for example a second impoundment structure. In various embodiments, at least one of the fluid conduits comprises at least one precast segment. In some example embodiments, the impoundment structure includes a roof. In some example embodiments, the impoundment structure does not include a roof.

[0129] In various embodiments, such as the one shown in FIG. 1A, the pump storage system 100 comprises at least one intake module 130, each intake module 130 being configured to receive or emit fluid. Each of the at least one intake module 130 is coupled to a corresponding fluid conduit 120. In the embodiment shown FIG. 1A, the pump storage system 100 comprises three intake modules 130a-130c. In alternative embodiments, the pump storage system comprises a different number of intake modules.

[0130] In the embodiments shown in FIG. 1A the three intake modules 130a-130c are arranged in a row. In alternative embodiments, the different intake modules may be arranged differently.

[0131] In various embodiments, such as the one shown in FIG. 1A, the intake modules 130a-130c are located at an upper impoundment structure 101. In various embodiments, at least one intake module may be located at a lower impoundment structure or natural fluid storage location (e.g., a river, lake, pond, etc.).

[0132] In the embodiment shown in FIG. 1A the pump storage system comprises three fluid conduits. In alternative

embodiments, the pump storage system may comprise a different number of fluid conduits. The fluid conduits may be arranged in different configurations. For example, the fluid conduits shown in FIG. 1A are straight. In alternative embodiments, one or more of the fluid conduits may be arranged differently. In some example embodiments, one or more of the fluid conduits may have a circular cross-section. In alternative example embodiments, one or more fluid conduits may have a cross-section of a different shape, for example square, rectangular, triangular, etc. In some example embodiments, one or more fluid conduits may include a precast segment.

[0133] In some example embodiments, one or more fluid conduits may be open (i.e., configured such that a fluid in the fluid conduit is exposed to the environment). In some example embodiments, one or more fluid conduits may be closed. In some example embodiments, precast structures define a flowpath.

[0134] In some example embodiments, one or more structures may secure the position of one or more fluid conduits. In some example embodiments, one or more of the one or more structures may include at least one precast segment. In some example embodiments, one or more of the structures may be configured to be secured to the ground for stability.

[0135] FIG. 1B shows a schematic of an example embodiment of a pump storage system 100. In FIG. 1B the impoundment structure has been removed for clarity. In some embodiments, such as the one shown in FIG. 1B the fluid conduits are configured at a right angle.

[0136] In various embodiments, such as the ones shown in FIGS. 1A-1B, each intake module 130 comprises a support base 132. In alternative embodiments, one or more of the intake modules may not comprise a support base. In various embodiments, each intake module comprises an axial channel and the axial channel is coupled to the at least one of the fluid conduits such that fluid passes down to the powerhouse.

[0137] In the example embodiment shown in FIGS. 1A and 1B, the powerhouse 110 includes three houses. In alternative embodiments, the powerhouse may include a different number of houses.

[0138] In some example embodiments, the powerhouse includes at least one valve house. The valve house may include at least one valve coupled with a fluid conduit. In some example embodiments, a house closest to the impoundment structure is a valve house.

[0139] In some example embodiments, the powerhouse includes at least one electric house. In some example embodiments, a house farthest from the impoundment structure is an electric house.

[0140] In some example embodiments, the powerhouse includes at least one turbine house. The turbine house may include at least one turbine. In some example embodiments, a turbine house is between a valve house and an electric house.

[0141] FIG. 2 shows a top view of an example embodiment of a pump storage system 200 comprising three intake modules 230a-230c, each being coupled to a powerhouse 210 via a fluid conduit 220a-220c. The impoundment structure is not shown in this view. In various embodiments, such as the one shown in FIG. 2, the powerhouse 210 comprises three turbines. In alternative embodiments, the powerhouse may comprise a different number of turbines. In those embodiments in which the powerhouse is underground, the

associated fluid conduits may also be underground. In various embodiments, the pump storage system may comprise more than one powerhouse.

[0142] In various embodiments, such as the one shown in FIG. 2, the powerhouse may comprise one or more modular blocks. In various embodiments, the modular blocks are precast.

[0143] FIG. 3A shows a side view of an example embodiment of an intake module.

[0144] FIG. 3B shows a perspective sectional view of an example embodiment of an intake module.

[0145] FIG. 3C shows a perspective view of an example embodiment of a layer of an intake module.

[0146] One or more of the intake modules 330 may be constructed using precast components. In various embodiments, an intake module 330 may comprise a support base 332 and an at least one intake region 331. In the embodiment shown in FIG. 3A, the intake module 330 comprises one intake region 331. In alternative embodiments, the intake module may comprise more than one intake region coupled to a support base.

[0147] In various embodiments, the intake region 331 may comprise one or more layers 333. One or more of the one or more layers 333 may comprise precast segments. A portion of a layer may be a precast segment. An entire layer may be a precast segment. Multiple layers may together be a precast segment.

[0148] One or more of the one or more layers may comprise one or more apertures. In the embodiment shown in FIGS. 3A-3C, each layer 333 comprises one circular central aperture 334 and the circular aperture 334 is positioned at the center of the layer 333. In alternative embodiments, one or more of the layers may not comprise an aperture. In alternative embodiments, one or more of the layers may comprise more than one aperture. In alternative embodiments, one or more of apertures may comprise a different shape. In alternative embodiments, one or more of the apertures may be positioned off-center at the corresponding layer.

[0149] One or more apertures of the layers may form one or more axial channels 335 through the intake region 331 of the intake module 330. In the embodiment shown in FIGS. 3A-3C, the intake region 331 comprises one channel 335. In alternative embodiments, the intake region may comprise more than one channel.

[0150] The axial channel of the intake region may be aligned with an axial channel of the support base. The axial channel of the support base may be aligned with a channel of a fluid conduit.

[0151] One or more of the one or more layers 333 may comprise one or more protrusions 336. In various embodiments, a first layer 333a and a neighboring second layer 333b may be arranged such that the arrangement of protrusions 336 create apertures 337 at the sides of the intake region 331. These apertures 337 are configured to allow fluid to enter the intake module 330 and flow to an axial channel 335. In various embodiments, the protrusions 336 may be configured differently than the configuration shown in FIGS. 3A-3C.

[0152] In some example embodiments, one or more of the apertures 337 may be at least partially blocked with a cover (not shown). One or more of the one or more covers may be in communication with a controller. The controller may control the opening and/or closing of one or more of the

covers. In some instances, the covers may all be opened and/or closed together. In some instances, some of the covers may be opened and/or closed selectively. In some instances, the covers at a specific layer may be opened and/or closed together. One or more of the covers may be opened and/or closed using any suitable mechanism, for example pneumatic controls, electromagnetic controls, and/or one or more screw drive actuators.

[0153] In some example embodiments, a user may control the opening and/or closing of covers using the controller. In some example embodiments, a user may control the opening and/or closing of covers using a local interface. In some example embodiments, a user may control the opening and/or closing of covers using a remote interface. In some example embodiments, the opening and/or closing of covers may be controlled automatically. In some example embodiments, the opening and/or closing of covers may be controlled based, at least in part, on environmental conditions, for example fluid levels.

[0154] In some example embodiments, the intake module may be in communication with one or more powerhouses. In some example embodiments, the intake module may be in wireless communication with one or more powerhouses. In some example embodiments, the intake module may be in wired communication with one or more powerhouses. In some example embodiments, communication between one or more intake modules and one or more powerhouses may determine settings at one or more intake module or one or more powerhouse. For example, flow control gate configurations at a powerhouse may be based, at least in part, on information from an intake module.

[0155] In the embodiment shown in FIGS. 3A-3C, each layer 333 comprises a circular shape. In alternative embodiments, one or more of the layers may comprise a different shape. In the embodiment shown in FIGS. 3A-3C each support base 332 comprises a circular shape. In alternative embodiments, the support base may comprise a different shape.

[0156] In some embodiments, the top of the intake region comprises a cover 338. In alternative embodiments, the top of the intake region may comprise at least one aperture. In various embodiments, at least one aperture of the at least one aperture at the top of the intake region may be aligned with at least one axial channel. In various embodiments, the cover of the intake region may comprise one or more precast components.

[0157] One more intake module may be located in or near an upper impoundment structure, a lower impoundment structure, an intermediary impoundment structure, a dam, or a natural water source (e.g. a river, lake, pond, etc.). In various embodiments, the intake module may be constructed using cast in place techniques.

[0158] FIG. 4 shows a side view of a schematic of a portion of an embodiment of a powerhouse 410. In various embodiments, such as the one shown in FIG. 4, the fluid conduit into the powerhouse (420a, left) may be at a different height than the fluid conduit leaving the powerhouse 420b. In various embodiments, one or more of the fluid conduits may comprise a steel lining. In some example embodiments, the fluid conduit may include at least one penstock. In at least some instances, a flow path structure may be a fluid conduit. In at least some instances, an intake tube may be a fluid conduit. In at least some instances, a draft tube may be a fluid conduit.

[0159] FIG. 5 shows a top view of a schematic of a portion of an example embodiment of a powerhouse **510**. As shown in FIG. 5, the fluid conduits into the powerhouse (**520a-520c**, left) may comprise Y-junctions. As shown in FIG. 5, the fluid conduits out of the powerhouse (**520d-520f**, right) may comprise Y-junctions. In alternative embodiments, the fluid conduits into and/or out of the powerhouse may not comprise Y-junctions.

[0160] FIG. 6 shows a top view of a schematic of a portion of an embodiment of a powerhouse **610**. In embodiment, the intake fluid conduits **620a** and draft fluid conduits **620b** are coupled to six turbines **612**. In alternative embodiments, the powerhouse may comprise a different number of turbines. In the embodiment shown in FIG. 6 the turbines **612** are arranged in a row. In alternative embodiments, the turbines may be arranged differently.

[0161] FIG. 7 shows a perspective view of a schematic of a portion of an embodiment of a powerhouse **710**. In this embodiment, the powerhouse **710** comprises different types of modular blocks. In some embodiments, such as the one shown in FIG. 7, the power generation system, comprises an intake support structure **722**, a power generator support structure **724**, and a draft support structure **726**.

[0162] In some example embodiments, the intake support structure **722** may be configured to support at least one intake tube, the intake tube at least partially defining a flow path. In some example embodiments, the intake support structure **722** may be at least partially constructed of precast segments.

[0163] In some example embodiments, the power generator support structure **724** may be configured to support weight of a power generator in an arrangement operably disposed within the flow path. In some example embodiments, the power generator support structure **724** may be at least partially constructed of precast segments.

[0164] In some example embodiments, the draft support structure **726** may be configured to support at least one draft tube, the draft tube at least partially defining the flow path. In some example embodiments, the draft support structure **726** may be at least partially constructed of precast segments. In some example embodiments, the precast segments may be positioned above the at least one draft tube. In some example embodiments, such as the one shown in FIG. 7, the precast segments of the draft support structure function as thrust blocks to control thrust from the draft tube.

[0165] In some example embodiments, at least one of the precast segments of the power generator support structure **724** includes a form that defines an internal cavity. In some example embodiments, at least one of the precast segments of the intake support structure **724** includes a form that defines an internal cavity. In some example embodiments, at least one of the precast segments of the draft support structure **724** includes a form that defines an internal cavity.

[0166] In some example embodiments, one or more precast segments of the intake support structure may be positioned above the at least one draft tube. In some example embodiments, one or more precast segments of the power generator support structure may be positioned above the at least one draft tube.

[0167] In some example embodiments, at least two of the intake support structure **722**, the power generator support structure **724**, and the draft support structure **726** are removably coupled.

[0168] In some example embodiments, for example the one shown in FIG. 7, one or more prestressed beams may be coupled to one or more elements of the powerhouse. In some example embodiments, one or more of the prestressed beams may be oriented vertically. In some example embodiments, one or more of the prestressed beams may be oriented horizontally.

[0169] In some example embodiments, the powerhouse may include one or more cranes. For example, if the powerhouse includes multiple houses, there may be a crane associated with each house. In some embodiments, there may be more than one crane at a house of the powerhouse. In some embodiments, a house of the powerhouse may not include a crane. In some example embodiments there may be at least one crane associated with the intake support structure. In some example embodiments there may be at least one crane associated with the power generator support structure. In some example embodiments there may be at least one crane associated with the draft support structure.

[0170] In some example embodiments, a powerhouse may include one or more flow control gates. In some example embodiments, one or more flow control gates may be positioned in a fluid conduit.

[0171] FIG. 8A shows a top view of an example embodiment of a modular block **815**. In various embodiments, such as the embodiment shown in FIG. 8A, the modular block **815** comprises a square shape. In alternative embodiments, the modular block may comprise a different shape, including, but not limited to rectangle, circle, trapezoid, any such suitable polygon, or combinations thereof.

[0172] FIG. 8B shows a bottom view of the example embodiment of a modular block of FIG. 8A.

[0173] FIG. 8C shows a bottom view of the example embodiment of a modular block of FIG. 8A. In various embodiments, such as the one shown in FIG. 8A, the modular block **815** defines a cavity **816** configured to receive a filling material. Example filling materials may include, but are not limited to: concrete, cement, ecomaterials, volcanic ash, glass, portions of brick, rubble, ground auto tires, steel fibers, fiber mesh, carbon fiber, flowable fill, or portions of solar panels.

[0174] In various embodiments, such as the embodiment shown in FIG. 8C, the modular block **815** defines a cavity **816** with a square shape. In alternative embodiments, the modular block may define a cavity with a different shape, including, but not limited to rectangle, circle, trapezoid, any such suitable polygon, or combinations thereof. In alternative embodiments, the cavity may comprise a different volume.

[0175] In alternative embodiments, the cavity may be divided into different sections.

[0176] In various embodiments, such as the one shown in FIGS. 8A-8C, the modular block **815** defines at least one aperture **817**. In the embodiment shown in FIGS. 8A-8C the modular block **815** comprises one aperture **817**. In alternative embodiments, a modular block may comprise a different number of apertures.

[0177] In various embodiments, such as the one shown in FIGS. 8A-8C, the aperture has a circular shape. In alternative embodiments, the modular block may define an aperture with a different shape, including, but not limited to rectangle, square, trapezoid, any such suitable polygon, or combinations thereof.

[0178] In various embodiments, such as the one shown in FIGS. 8A-8C, the aperture 817 is centrally located in the cavity 816 of the modular block 815. In alternative embodiments, at least one aperture may be located at a different location.

[0179] In various embodiments, the modular block may comprise one or more curing chambers. In various embodiments, one or more of the curing chambers may comprise characteristics identical or similar to those characteristics described in connection with any other figure.

[0180] In various embodiments, such as the one shown FIGS. 8A-8C, the modular block 815 comprises one or more attachment mechanisms constructed and arranged to allow the modular block to couple to other modular blocks or structures. The embodiment shown in FIGS. 8A-8C shows different attachment mechanisms including dowels, elongated members, and/or vertical linkages. The modular block attachment mechanism may comprise one or more elongated members. At least one of the elongated members may be configured to couple one modular block to a neighboring modular block. For example, as shown in FIGS. 8A-8C, one or more elongated members may pass through the aperture 817 of the modular block 815 and be arranged in a bent configuration. Some elongated members may be used to secure other elongated members in place. The elongated members may comprise any suitable material, including, but not limited to metal, plastic, or combinations thereof. Different modular blocks may comprise different numbers of elongated members. The modular block may also be configured to include one or more lift points. In some example embodiments, one or more modular blocks may be coupled using one or more expandable linkages.

[0181] FIG. 9A is a perspective view of an example embodiment of three modular blocks 915 in a stacked configuration. In various embodiments, such as the one shown in FIG. 9A, one or more modular blocks may be stacked, with at least one of the blocks coupled to a neighboring block. In this embodiment, elongated members from a modular block are coupled to elongated members of the neighboring modular block. In various embodiments, the elongated members of a modular block may be indirectly coupled to the elongated members of a neighboring modular block. In various embodiments, the elongated members may be arranged such that when a filling material is inserted into the cavity of a modular block, it will submerge one or more of the elongated members.

[0182] In some instances, filling material may be poured through an aperture of one modular block to fill a lower modular block. In various embodiments, a modular block at the top of a stack of modular blocks is capped.

[0183] FIG. 9B is a side view of the example embodiment of FIG. 9A.

[0184] FIGS. 10A-10B are perspective views of an example embodiment of three modular block in a stacked configuration and shows example levels to which the cavity of each modular block may be filled. The level to which the cavities may be filled may be similar (or approximately the same) or the levels may be different for different blocks. In some instances, one or more of the blocks that are coupled may not include a cavity.

[0185] FIG. 11 shows an example embodiment of two stacks of modular blocks 1115a-1115f, the two stacks being

coupled together laterally. In different configurations a different number of modular blocks may be coupled vertically and/or horizontally.

[0186] In various embodiments, one or more modular blocks may be configured to individually serve as a capacitor. In various embodiments, one or more modular blocks may be coupled to collectively serve as a capacitor.

[0187] In various embodiments, one or more of the modular blocks may be coupled using at least one dowel, at least one bolt, at least one keyway, at least one re-rod, or at least one port. In various embodiments, one or more of the modular blocks may be coupled using at least one expandable linkage, at least one automatic linkage (that locks itself), at least one prestressed cable (vertical configuration, horizontal configuration, or other configuration), at least one linkage port, or any other mechanism suitable for connecting items.

[0188] In various example embodiments, spaces between neighboring precast segments may be filled with concrete, grout, liners, or water stopping agents. In various example embodiments, spaces between precast segments and other elements (for example, fluid conduits) may be filled with concrete, grout, liners, or water stopping agents. In various example embodiments, spaces within precast forms may be filled with concrete, grout, liners, or water stopping agents. In various example embodiments, spaces between any elements associated with a powerhouse or dam may be filled with concrete, grout, liners, or water stopping agents.

[0189] In various example embodiments, one or more nanotech coatings may be applied to seals or filler materials between neighboring precast segments. In various example embodiments, one or more nanotech coatings may be applied to seals or filler materials between precast segments and other elements (for example, fluid conduits). In various example embodiments, one or more nanotech coatings may be applied to seals or filler materials between spaces or filler material within precast forms. In various example embodiments, one or more nanotech coatings may be applied to seals or filler materials associated with a powerhouse or dam.

[0190] FIG. 12 shows an example embodiment of four stacks of modular blocks 1215 with precast concrete infill blocks 1214. In some example embodiments a precast segment includes a precast form and a precast infill block 1214. The precast form may be sized and shaped to accept one or more precast infill blocks 1214. In some example embodiments, the tolerances (i.e., spaces) inside the modular blocks 1215 may be filled with fine processed stone, rubber grindings, or any such similar or suitable material, for example other materials described herein.

[0191] In the example embodiment shown in FIG. 12, precast infill blocks 1214 are defined by a rectangular shape. In alternative embodiments, one or more of the precast infill blocks may be defined by a different shape.

[0192] In the example embodiment shown in FIG. 12, two precast infill blocks 1214 are positioned in a modular block 1215. In alternative embodiments, a different number of precast infill blocks may be positioned in a modular block 1215.

[0193] In the example embodiment shown in FIG. 12, two precast infill blocks 1214 are oriented next to each other. Alternatively or additionally, in some example embodiments precast infill blocks 1214 may be stacked on each other.

[0194] In some example embodiments, one or more of the precast infill blocks are fixedly coupled to a precast segment. In alternative embodiments, one or more of the precast infill blocks may not be fixedly coupled to a precast segment.

[0195] FIG. 13 shows example dimensions for an example embodiment of a modular block. In alternative embodiments, the dimensions may be different. In some embodiments, a modular block may be about 18 feet by 18 feet. In some embodiments, the modular block may be about 4 feet thick. In some embodiments a cavity of a modular block may be about 15 feet by 15 feet. In some embodiments, a cavity of the modular block may be about 3 feet deep. In some embodiments, a keyway may be at a lower surface of the block and have dimensions of about 12 feet by 12 feet. In some embodiments, a modular block and/or keyway may have dimensions that are different than those shown in FIG. 13.

[0196] FIG. 14 shows an example embodiment of a rectangular modular block 1415. In this embodiment the rectangular modular block 1415 comprises a rectangular cavity 1416. In alternative embodiments, the cavity may be a different shape.

[0197] In various embodiments, such as the one shown in FIG. 14, the rectangular modular block 1415 may comprise one or more attachment loops 1418 configured to allow for coupling to other structures or coupling to fillable material. In the embodiment shown in FIG. 14, the modular block 1415 comprises attachment loops 1418 both in the cavity and outside the cavity. In alternative embodiments, the modular block may comprise attachment loops in a different configuration. In alternative embodiments, the modular block 1415 may comprise attachment loops only outside the cavity. In alternative embodiments, the modular block 1415 may comprise attachment loops only inside the cavity. In alternative embodiments, the modular block 1415 may not comprise attachment loops.

[0198] A modular block may comprise different curing compartments. In the embodiment shown in FIG. 14, the modular block 1415 comprises five curing compartments 1419a-1419e. In alternative embodiments, the modular block 1415 may comprise a different number of curing compartments. In the embodiment shown in FIG. 14, the curing compartments 1419 are arranged such that they extend along a shorter dimension of the modular block 1415. In alternative embodiments, the curing compartments 1419 extend along the longer dimension of the modular block 1415. In alternative embodiments, the curing compartments 1419 extend along a diagonal dimension of the modular block 1415. In alternative embodiments, the curing compartments 1419 extend along a different dimension of the modular block 1415. In various embodiments, the rectangular modular block 1415 may comprise at least one aperture.

[0199] FIG. 15A shows a perspective of an example embodiment of a working platform 1581 coupled to rock anchors 1582.

[0200] FIG. 15B shows a close-up view of the working platform 1581 of FIG. 15A. In some example embodiments, such we the one shown in FIG. 15B, the working platform 1581 comprises pleats and/or grooves configured to couple with segments of a powerhouse or dam. In alternative embodiments the working platform may not comprise pleats and/or grooves.

[0201] In some embodiments, such we the one shown in FIG. 15B, the working platform 1581 is coupled to connectors (for example, bolts) to couple with segments of a powerhouse or dam. In alternative embodiments, the working platform may not be coupled to connectors.

[0202] FIG. 16A shows a perspective view of an example embodiment of a working platform 1681 coupled to multiple rock anchors 1682. In the example embodiment shown in FIG. 16A a cutoff wall 1683 is coupled to a lower surface of the working platform 1681.

[0203] FIG. 16B shows a perspective view of an example embodiment of a working platform 1681 coupled to multiple cleats 1674, rock anchors 1682, and diffusers 1642. In the example embodiment shown in FIG. 16B the diffusers are coupled to a downstream side of the working platform 1681. In alternative embodiments, the working platform may not be coupled to cleats. In alternative embodiments, the working platform may not be coupled to rock anchors. In alternative embodiments, the working platform may be coupled to diffusers at the upstream side of the working platform. In alternative embodiments, the working platform may not be coupled to diffusers.

[0204] FIG. 17 shows an example embodiment of an earthquake prevention system 1780. Any of the structures described herein such as an impoundment structure, tank, or powerhouse may comprise an earthquake prevention system 1780. In various embodiments, the earthquake prevention system 1780 may comprise at least one platform 1781 coupled to a lower surface of a powerhouse 1710 (or other structure such as an impoundment structure or tank). In various embodiments, such as the one shown in FIG. 17 the platform is coupled to multiple blocks or precast segments. In various embodiments the platform is coupled to modular blocks. The earthquake prevention system 1780 may comprise one or more precast components. In various embodiments, one or more components of the earthquake prevention system 1780 are constructed with precast components.

[0205] In various embodiments, the earthquake prevention system 1780 may comprise at least one cleat 1774. In various embodiments, the earthquake prevention system may comprise at least one cleat 1774 coupled to at least one of the at least one platform 1781. In alternative embodiments, the platform may be coupled to a different number of cleats. In various embodiments, processed stone is positioned around the cleats. In various embodiments, the earthquake prevention system 1780 is configured such that water can be injected around at least one of the cleats.

[0206] In various embodiments, the earthquake prevention system may comprise at least one subsurface structure 1785 coupled to the platform. In various embodiments, the earthquake prevention system or stabilization system 1780 may comprise at least one subsurface structure 1785 coupled to the platform using at least one corresponding cable 1786. In the embodiment shown in FIG. 17, the earthquake prevention system 1780 includes three subsurface structures 1785a-1785c. In alternative embodiments, the earthquake prevention system 1780 may include a different number of subsurface structures.

[0207] In the embodiment shown in FIG. 17, at least two of the subsurface structures 1785 are coupled to a platform 1781 with a cable 1786. In alternative embodiments, a different configuration of cables may be used.

[0208] In various embodiments, at least one of the at least one platform comprises at least two segments. In various

embodiments, the at least two segments are coupled using rubberized interconnections. In various embodiments, the at least two segments are coupled using keyway linkages.

[0209] In various embodiments, the earthquake prevention system may comprise a first platform and a second platform, the second platform being larger than the first platform.

[0210] In various embodiments, the earthquake prevention system may comprise one or more snubbers. Snubbers may comprise insulators that reduce vibrations and allow for little movement.

[0211] FIG. 18 shows an example embodiment of a powerhouse **1810** configured to be at a cavernous subterranean location underground. In some example embodiments, a powerhouse may be positioned 400 feet underground. In some example embodiments, a powerhouse may be positioned 2000 feet underground. In alternative embodiments, the powerhouse may be a different depth underground. In some example embodiments, an upper impoundment structure may be positioned 400 feet above sea level. In alternative embodiments, an upper impoundment structure may be positioned at a different height.

[0212] In some example embodiments, the powerhouse is composed of precast segments. In some example embodiments, the powerhouse is composed of poured concrete. A flow path may extend from the cavernous powerhouse to one or more impoundment structures. The flow path may be composed of precast segments and/or poured concrete.

[0213] FIG. 19 shows an example embodiment of a powerhouse **1910** configured to be at a cavernous subterranean location underground.

[0214] FIG. 20 shows an example embodiment of a powerhouse **2010** configured to be at a cavernous subterranean location underground.

[0215] FIG. 21 shows an example embodiment of a precast powerhouse **2110** configured to be at a cavernous subterranean location underground.

[0216] FIG. 22 shows an example embodiment of a precast powerhouse **2210** in an excavated cavern. In some example embodiments, such as the one shown in FIG. 22, an access tunnel **2278** may facilitate access to the powerhouse. In some example embodiments, such as the one shown in FIG. 22, a hole **2276** above the powerhouse may facilitate access to the powerhouse. In some example embodiments, the hole is part of a channel to the powerhouse. In some example embodiments, a man-made structure (e.g., tube) may fit inside the channel to facilitate access to the powerhouse.

[0217] FIG. 23 shows example embodiments of modular blocks for mass and powerhouse galleries.

[0218] FIGS. 24A-D show an example embodiment of a water storage tunnel **2484**. In various embodiments, a tunnel may be constructed with precast components **2415**. A tunnel may be constructed (FIG. 24A) to allow for underground transmission lines. FIG. 24A illustrates use of a tunnel boring machine that employs circular cutting to excavate earth to form a tunnel and use of a conveyor belt to move soil to a soil deposit area. In various embodiments, underground tunnels may comprise rails to transport material. In various embodiments, underground tunnels may be accessible via one or more access points at a surface. In various embodiments, one or more or the one or more access points may be covered using rubberized manhole covers. FIG. 24B shows that a tunnel wall is strengthened with precast modules after the tunnel boring machine of FIG. 24A has completed its

work. FIGS. 24C and 24D shows top and side views, respectively, of a precast segment that has rock bolts that extend from the precast segment to a solid underground formation, such as bedrock, to secure the precast segment in place. FIG. 24D shows a completed structure defining the tunnel **2484** used, for example, to water flow.

[0219] Fluid may be pumped from a lower position to a higher position using a local power source. In various embodiments, the local power source may be solar, geothermal, nuclear, wind, gasoline, biomass, or any other suitable power source.

[0220] FIG. 25 shows an example embodiment of a seismic relief fluid conduit system **2590**. In various embodiments, such as the one shown in FIG. 25, the seismic relief fluid conduit system **2590** may comprise a base holder **2592**, a fluid conduit **2520**, and fill material. The base holder **2592** may comprise an inner diameter greater than the outer diameter of a fluid conduit **2520**. In various embodiments, the base holder **2592** may be configured to surround at least a portion of the fluid conduit **2520**. In some example embodiments, the base holder **2592** surrounds a portion of the fluid conduit **2520** along the direction of extension of the fluid conduit **2520**. In various embodiments, the base holder **2592** surrounds all of the fluid conduit **2520**. In various embodiments, the base holder **2592** surrounds a portion of each cross-section of the fluid conduit **2520**.

[0221] The seismic relief fluid conduit system **2590** may comprise fill material positioned between the inner diameter of the base holder **2592** and the outer diameter of the fluid conduit **2520**. The fillable material could be any material suitable for absorbing seismic waves. In various embodiments, the fillable material may comprise soft earth material, for example, soil, rocks, etc.

[0222] In the embodiment shown in FIG. 25, the base holder **2492** has a circular cross-section. In alternative embodiments, the cross-section of the base holder **2492** may have a different shape. In various embodiments, the base holder **2492** may be constructed using one or more precast segments.

[0223] FIGS. 26A-26B show example configurations for pulling fluid to an upper

[0224] impoundment structure. In various embodiments, pump storage system comprises a vacuum house **2693**. In various embodiments, the vacuum house **2693** comprises at least fan **2694** (see FIG. 26A) configured to provide suction to pull fluid to the upper impoundment structure. The speed of at least one of the at least one fan **2694** may be adjusted to adjust the fluid flow speed. In various embodiments, the vacuum house **2693** may be positioned at a height that is different than the height shown in FIG. 26B.

[0225] FIG. 27 shows an example of an assembly of an example embodiment of an impoundment structure **2701**. The impoundment structure could be an upper impoundment structure, a lower impoundment structure, or an intermediate height impoundment structure. In some example embodiments, assembly includes securing a position of a working platform. In some example embodiments, assembly includes securing one or more precast segments to the working platform using one or more connectors. In some example embodiments, a precast segment is secured to a working platform using one or more bolts. In some example embodiments, one or more precast segments are secured together using any suitable means, including means described herein. In some example embodiments, one or more precast infill

blocks are secured to a precast form using any suitable means, including means described herein.

[0226] FIG. 28 shows an example of an assembly of an example embodiment of an impoundment structure 2801. The impoundment structure could be an upper impoundment structure, a lower impoundment structure, or an intermediate height impoundment structure.

[0227] FIG. 29 shows an example embodiment of an impoundment structure 2901 comprising energy dissipation elements (also referred to as diffusers). The impoundment structure could be an upper impoundment structure, a lower impoundment structure, or an intermediate height impoundment structure.

[0228] In various embodiments, such as the one shown in FIG. 29, the impoundment structure 2901 may comprise at least one diffuser 2942 configured to reduce the velocity and/or redirect the flow of fluid in the impoundment structure. In the embodiment shown in FIG. 29, the impoundment structure 2901 comprises four triangular shaped diffusers 2942a-2942d arranged in a row. In alternative embodiments, there may be a different number of diffusers. In alternative embodiments, one or more of the diffusers may be shaped differently. In alternative embodiments, one or more of the diffusers may be arranged in a different position and/or orientation. In various embodiments, one or more of the diffusers may comprise precast material or neoprene.

[0229] In various embodiments, such as the one shown in FIG. 29, the impoundment structure 2901 may comprise at least one rudder 2944 configured to redirect the flow of fluid. In various embodiments, one or more of the Rudders may be hydraulic rudders. In the embodiment shown in FIG. 29, the impoundment structure 2901 comprises six triangular shaped rudders arranged in a row. In alternative embodiments, there may be a different number of rudders. In alternative embodiments, one or more of the rudders may be shaped differently. In alternative embodiments, one or more of the rudders may be arranged in a different position and/or orientation. One or more of the rudders may be controlled independent of the others. In some instances, one or more of the rudders may adjust their position/orientation based on flow conditions. In some instances, one or more of the rudders may adjust their position/orientation based on operator control input. In some instances, one or more of the rudders may adjust their position/orientation based on predetermined configuration settings. In various embodiments, one or more of the rudders may rotate every hour to change water pressure on the walls of the impoundment structure.

[0230] In various embodiments, such as the one shown in FIG. 29, the impoundment structure 2901 may comprise a modular water deflector 2946 configured to redirect the flow of fluid. The embodiment shown in FIG. 29 comprises one modular water deflector 2946. Alternative embodiments may comprise a different number of modular water deflectors. In alternative embodiments, the modular water deflector may be positioned and/or arranged and/or shaped differently. In alternative embodiments, the modular water deflector may comprise a different radius of curvature. In various embodiments, the modular water deflector may comprise a first radius of curvature on one side and a second, different, radius of curvature on a second side. In various embodiments, the modular water deflector may comprise the same radius of curvature on each side.

[0231] In various embodiments, the impoundment structure may comprise a solar heating system. In various

embodiments, an impoundment structure with one or more of the characteristics described in connection with FIG. 29 may be constructed using precast segments.

[0232] FIG. 30 shows an example embodiment of an impoundment structure or tank 3001 comprising energy dissipation elements. The impoundment structure or tank could be an upper impoundment structure or tank, a lower impoundment structure or tank, or an intermediate height impoundment structure or tank.

[0233] In various embodiments, such as the one shown in FIG. 30, the impoundment

[0234] structure or tank 3001 comprises at least one flow control rudder and/or gate 3044 configured to direct the flow of fluid. The rudders and/or gates may be automated in view of conditions or may be directly controlled by an operator. The rudders and/or gates may be different shapes, sizes, or orientations. The rudders and/or gates may be arranged differently than the arrangement shown in FIG. 30.

[0235] In various embodiments, impoundment structure or tank may comprise a protective inner shock and cushion system 3048. In various embodiments, the shock and cushion system may comprise a baffle wall.

[0236] FIG. 31 shows an embodiment of an impoundment structure or tank 3101 comprising energy dissipation elements. The impoundment structure or tank could be an upper impoundment structure or tank, a lower impoundment structure or tank, or an intermediate height impoundment structure or tank. In various embodiments, such as the one shown in FIG. 31, the impoundment structure or tank 3101 comprises at least one flow control gate 3149 configured to direct the flow of fluid. The gates may be automated in view of conditions or may be directly controlled by an operator. The gates may be different shapes, sizes, or orientations. The gates may be arranged differently than the arrangement shown in FIG. 31. In various embodiments, such as the one shown in FIG. 31, the gates 3149 may be arranged in a circular pattern at different radial positions relative to the center of the impoundment structure inner cavity. In various embodiments, the gates 3149 comprise different access points for water flowing at one radial distance to flow into a channel at a different radial distance. In various embodiments, control of these gates access points may or may not be automated. In various embodiments, the impoundment structure may comprise one or more features described herein.

[0237] In various embodiments, impoundment structure or tank may comprise a protective inner shock and cushion system. In various embodiments, the shock and cushion system may comprise a baffle wall.

[0238] FIG. 32 shows an embodiment of an impoundment structure 3201 comprising energy dissipation elements. The impoundment structure could be an upper impoundment structure, a lower impoundment structure, or an intermediate height impoundment structure.

[0239] As shown in FIG. 32, at least a portion of the impoundment structure 3201 may comprise an inner wall 3251 defining at least one aperture 3254. Fluid flowing in the impoundment structure may pass through at least one of the at least one aperture. A portion of the fluid is configured to flow between the inner wall 3251 and an outer wall 3252 of the impoundment structure 3201. The fluid flowing along the perimeter of the impoundment structure between the inner wall 3251 and the outer wall 3252 may reduce the pressure of fluid flow at an inner surface of the outer wall 3252.

[0240] In various embodiments, such as the one shown in FIG. 32, the impoundment structure 1701 comprises multiple supports 1754 positioned between the inner surface of the outer wall 3252 and the inner wall 3251. The supports 3254 each comprise at least one aperture 3255 constructed and arranged to allow fluid flow between the inner surface of the outer wall 3252 and the inner wall 3251.

[0241] In various embodiments, such as the one shown in FIG. 32, the apertures of the inner wall are circular. In alternative embodiments, at least one of the at least one aperture may comprise a different shape.

[0242] In various embodiments, such as the one shown in FIG. 32, the apertures of the inner wall are the same size. In alternative embodiments, at least one of the at least one aperture may comprise a different size.

[0243] In various embodiments, such as the one shown in FIG. 32, the apertures of the supports are circular. In alternative embodiments, at least one of the apertures of at least one of the supports may comprise a different shape.

[0244] In various embodiments, such as the one shown in FIG. 32, the apertures of the supports are the same size. In alternative embodiments, at least one of the apertures of at least one supports may comprise a different size.

[0245] In various embodiments, each support may comprise more than one aperture. In various embodiments, each support may comprise more than one aperture, each aperture being at a different height.

[0246] In various embodiments, the inner wall is configured to flex in response to water pressure.

[0247] In various embodiments, the impoundment structure may comprise multiple walls comprising the characteristics described in connection with the inner wall of FIG. 32. In such embodiments, water may flow between each one of the multiple walls to reduce the pressure of water flow along an outward direction (relative to the center of the impoundment structure). In various embodiments at least one of the walls of the impoundment structure may be configured to rotate.

[0248] FIG. 33 shows an embodiment of an impoundment structure or tank 3301 comprising energy dissipation elements. The impoundment structure or tank could be an upper impoundment structure or tank, a lower impoundment structure or tank, or an intermediate height impoundment structure or tank.

[0249] In various embodiments, the impoundment or tank may comprise one or more baffle walls 3303 configured to reduce the water pressure at an outer wall. The embodiment shown in FIG. 33, the impoundment structure 3301 comprises two baffle walls 3303a, 3303b. Alternative embodiments may comprise a different number of baffle walls. In alternative embodiments, the configuration of the baffle walls may be different, for example, rather than curving toward a front end of the impoundment structure (relative to the fluid conduits), the baffle walls may be curved in a different direction. Alternatively, one or more of the baffle walls may not be curved. At least one of the baffle walls may be configured to flex.

[0250] In various embodiments, at least one of the at least one baffle wall may comprise one or more protrusions 3356. In various embodiments, at least one of the protrusions may define port holes. In the embodiment shown in FIG. 33, the protrusions are at both sides of each baffle wall. In alternative embodiments, the protrusions may be on only one side of the baffle wall.

[0251] In various embodiments, such as the one shown in FIG. 33, the impoundment structure or tank 3301 may comprise rudders 3344 as previously described. In various embodiments, the impoundment structure 3301 may comprise at least one swing guide 3345 with at least one of the rudders 3344.

[0252] In various embodiments, such as the one shown in FIG. 33, the impoundment structure may comprise baffled walls near the outer wall, as previously described.

[0253] FIG. 34 shows an embodiment of an impoundment structure 3401 comprising a sensor system configured to monitor conditions in the impoundment structure 3401. In various embodiments, one or more sensors 3458 are arranged on a track 3459 and travel to various positions near the edge of the impoundment structure 3401 to monitor water flow and/or damage to walls of the impoundment structure 3401. In alternative embodiments, the sensors may not be on a track. In various embodiments, one or more sensors may monitor turbine activity. Such sensors may operate automatically based on predetermined configurations or may operate based on user control in real-time.

[0254] FIG. 35A shows an example embodiment of tube gates 3562 at fluid conduits 3520. The tube gates 3562 may be configured to redirect flow of fluid and/or reduce the velocity of the fluid. The fluid gates may be automated or controlled by an operator. The fluid gates may be configured to direct the fluid flow evenly or not evenly. The fluid gates may be automated based on characteristics of fluid flow.

[0255] In the embodiment shown in FIG. 35A, the fluid gates 3562 are on each fluid conduit 3520. In alternative embodiments, the fluid gates may not be on each fluid conduit.

[0256] In the embodiment shown in FIG. 35A, the fluid gates 3562 are arranged in an orthogonal pattern aligned with a vertical and horizontal orientation. In alternative embodiments, the fluid gates may be arranged orthogonally, but at an angle relative to vertical and horizontal axes. In alternative embodiments, the fluid gates may not be arranged in an orthogonal pattern. In alternative embodiments, at least a portion of at least one gate may be curved. The fluid gates may be configured to rotate about their elongated axis. The fluid gates may be configured to translate in a plane orthogonal to the direction of fluid flow. The fluid gates may be configured to reduce or eliminate fluid flow into the impoundment structure or tank.

[0257] FIG. 36 shows an example embodiment of an environmental protective system 3670. In some embodiments the environmental protective system 3670 comprises multiple barriers 3672 at a natural water impoundment location (e.g., a river, lake, ocean). In alternative embodiments, the environmental protective system may comprise a different number of barriers. In alternative embodiments, the size, shape, and/or arrangement of the barriers may be different.

[0258] Example Embodiment 1: A power generation system, comprising: an impoundment structure at least partially defined by a plurality of precast segments, at least one of the precast segments including a precast form and at least one precast infill block.

[0259] Example Embodiment 2: The power generation system of Example Embodiment 1 or any other Example Embodiment, wherein the impoundment structure defines an intake or egress configured to receive or output fluid with a fluid supply via a flow path.

[0260] Example Embodiment 3: The power generation system of any one of Example Embodiments 1-2 or any other Example Embodiment, further comprising a power generation module configured to pump fluid from the fluid supply and into the impoundment structure via the flow path.

[0261] Example Embodiment 4: The power generation system of any one of Example Embodiments 1-3 or any other Example Embodiment, further comprising a power conversion module configured to convert kinetic energy of fluid released from the impoundment structure and travelling through the flow path into electric energy.

[0262] Example Embodiment 5: The power generation system of any one of Example Embodiments 1-4 or any other Example Embodiment, wherein the power conversion module includes: an intake support structure configured to support at least one intake tube, the intake tube at least partially defining a flow path, the intake support structure being at least partially constructed of precast segments; a power generator support structure configured to support weight of a power generator in an arrangement operably disposed within the flow path, the power generator support structure being at least partially constructed of precast segments; and a draft support structure configured to support at least one draft tube, the at least one draft tube at least partially defining the flow path, the draft support structure being at least partially constructed of precast segments positioned above the at least one draft tube.

[0263] Example Embodiment 6: The power generation system of any one of Example Embodiments 1-5 or any other Example Embodiment, further comprising a flow path structure coupled to the impoundment structure, the flow path structure at least partially defining the flow path, the flow path structure including at least one precast segment.

[0264] Example Embodiment 7: The power generation system of any one of Example Embodiments 1-6 or any other Example Embodiment, wherein the precast infill block is fixedly coupled to the precast segment.

[0265] Example Embodiment 8: A power generation system, comprising: an impoundment structure, including: a containment wall defining at least a portion of a boundary of a containment volume, the containment volume configured to store a volume of fluid; and at least one inner wall positioned within the containment volume and offset from the containment wall, the at least one inner wall defining at least one aperture.

[0266] Example Embodiment 9: The power generation system of Example Embodiment 8 or any other Example Embodiment, wherein the impoundment structure includes at least one precast segment, the at least one precast segment including a precast form and at least one precast infill block.

[0267] Example Embodiment 10: The power generation system of any one of Example Embodiments 8-9 or any other Example Embodiment, further comprising one or more supports coupling the containment wall with the inner wall.

[0268] Example Embodiment 11: The power generation system of any one of Example Embodiments 8-10 or any other Example Embodiment, wherein one or more of the one or more supports defines at least one aperture configured to allow fluid to pass therethrough.

[0269] Example Embodiment 12: The power generation system of any one of Example Embodiments 8-11 or any other Example Embodiment, further comprising at least one energy dissipation element disposed within the impoundment structure, the at least one energy dissipation element

being configured to redirect the flow of the pumped fluid entering the impoundment structure.

[0270] Example Embodiment 13: The power generation system of any one of Example Embodiments 8-12 or any other Example Embodiment, wherein the at least one energy dissipation element disposed within the impoundment structure causes the flow of the pumped fluid to be redirected to be in a circulating direction between inner wall and outer wall.

[0271] Example Embodiment 14: The power generation system of any one of Example Embodiments 8-13 or any other Example Embodiment, wherein the containment wall or the at least one inner wall is at least partially defined by a plurality of precast segments.

[0272] Example Embodiment 15: The power generation system of any one of Example Embodiments 8-14 or any other Example Embodiment, wherein at least a subset of the plurality of precast segments are interconnected via complementary coupling elements.

[0273] Example Embodiment 16: A power generation system, comprising: a powerhouse, the powerhouse comprising: (1) an intake support structure configured to support at least one intake tube, the intake tube at least partially defining a flow path, the intake support structure being at least partially constructed of precast segments; (2) a power generator support structure configured to support weight of a power generator in an arrangement operably disposed within the flow path, the power generator support structure being at least partially constructed of precast segments; and (3) a draft support structure configured to support at least one draft tube, the at least one draft tube at least partially defining the flow path, the draft support structure being at least partially constructed of precast segments positioned above the at least one draft tube.

[0274] Example Embodiment 17: The power generation system of Example Embodiment 16 or any other Example Embodiment, wherein at least one of the precast segments includes a precast form and at least one precast infill block.

[0275] Example Embodiment 18: The power generation system of any one of Example Embodiments 16-17 or any other Example Embodiment, further comprising: a stabilization system, the stabilization system including: at least one support structure configured to be positioned below a lower surface of the powerhouse; and an attachment mechanism configured to couple the at least one support structure with the powerhouse.

[0276] Example Embodiment 19: A power generation system, comprising: a water intake structure configured to intake fluid and configured for fluid communication with a powerhouse via a flow path, the water intake structure being at least partially constructed of precast segments.

[0277] Example Embodiment 20: The power generation system of Example Embodiment 19 or any other Example Embodiment, further comprising a flow path structure configured to facilitate fluid communication between the water intake structure and the powerhouse, a first end of the flow path structure being coupled to the water intake structure and a second end of the flow path structure being coupled to the powerhouse.

[0278] Example Embodiment 21: The power generation system of any one of Example Embodiments 19-20 or any other Example Embodiment, wherein the water intake structure comprises one or more layers, each layer including one or more precast segment.

[0279] Example Embodiment 22: The power generation system of any one of Example Embodiments 19-21 or any other Example Embodiment, wherein each layer comprises at least one protrusion.

[0280] Example Embodiment 23: The power generation system of any one of Example Embodiments 19-22 or any other Example Embodiment, wherein at least one of the precast segments includes a precast form and a precast infill block.

[0281] Further details and example embodiments are now described, with particular focus on an alternative embodiment of the fluid intake structure, a transition region at the fluid flow conduit and fluid intake tube and/or draft tube at the powerhouse, and a flow path within the powerhouse. The example embodiments also address features that support a fluid flow path between, for example, an upper impoundment (e.g., water containment) structure and lower impoundment structure, and enable excess pressure within a fluid flow path or enable access to the fluid flow path. To set a context of the further details and example embodiments described hereinbelow in reference to FIGS. 37A-45B, a high-level description of a hydropower pumped storage power generation system with the foregoing features is presented first, and specifics in reference to each figure is presented in turn thereafter.

[0282] As described above in reference to FIGS. 1A-36, according to an example embodiment, a power generation system that forms a pumped storage system may include a powerhouse. The powerhouse may include an intake support structure, a power generator, and a draft support structure. The intake support structure may be configured to support at least one fluid intake tube ("intake tube"), the intake tube at least partially defining a flow path that is arranged to direct fluid into an intake port of the power generator. The draft support structure may be configured to support at least one fluid draft tube ("draft tube") that is arranged to accept fluid from a draft port of the power generator. The intake support structure and draft support structure may be at least partially constructed of precast segments of any form described hereinabove or equivalents thereof.

[0283] It should be understood that fluid flow may be from an upper fluid supply or upper reservoir to a lower fluid supply or lower reservoir, or flow in an opposite direction through use of turbine(s) in the powerhouse that may be capable of operating in both power generating mode and fluid pump mode. Accordingly, the terms "intake" and "draft" may be reversed herein depending on the direction of fluid flow. It should also be understood that the hydropower generation system may be an open system with natural, unbounded fluid supplies (e.g., rivers) at each end of the fluid conduit; closed system with a man-made or natural impoundment structures at each end of the fluid conduit; or combination of open and closed system, such as with an impoundment structure serving as the upper fluid supply and river, ocean, canal or other natural body of water serving as the lower fluid supply.

[0284] In an example embodiment, there is an elevation change between a given fluid intake tube to a corresponding fluid draft tube changes within a vertical change region of the powerhouse. The elevation change may be zero (i.e., flat) or a differential of several feet, several tens of feet, or several hundreds of feet, with at least one turbine being disposed

within the elevation change region of the flowpath between the given fluid intake tube and corresponding fluid draft tube.

[0285] In some embodiments, such as in the case of a closed system having an upper fluid impoundment structure and a lower fluid impoundment structure, which may be natural or man-made structure(s), above-or below-ground flow paths may be at least partially defined by precast segments coupled together with fluid-tight seals. Liners within the fluid flow path may span many lengths of precast segments and may be coupled to or integrated with the precast segments in various manners depending on a composition of a given liner and the precast segment(s) to which the given liner is coupled.

[0286] In an example embodiment, the intake and draft tubes may be coupled to respective liners with watertight seals through a direct mechanical connection with corresponding precast segment(s), mechanical element(s) used for such coupling, or a compound used at an interface between adjacent ones of the liners, precast segments, and mechanical elements. It should be understood that the term "coupled" or the like covers any of these or other embodiments. For example, a liner may be coupled to precast segment(s) at an interior surface, exterior surface, or integrally coupled (e.g., "sandwiched") at an edge or multiple edges within a volume of precast segment(s) between the interior and exterior surfaces.

[0287] The liners are typically fluid impermeable and may be coated with hydrophobic material(s) or compound(s) to reduce friction between the fluid flowing within the flowpath to ensure fluid flow is smooth, thereby reducing wear of the liner and reducing turbulence within the flowpath. A low level of turbulence may yield a correspondingly low level of cavitation experienced by a respective turbine. It is generally understood that a low cavitation level within a turbine yields a higher efficiency and longer lifespan of the turbine. Cavitation may be sensed with proper sensing equipment of, for example, sound, vibration, anomalies in produced current or voltage waveforms, or other detectable metric created by a turbine experiencing cavitation. A processor that determines that cavitation is occurring may cause an element or subsystem with the hydropower pumped storage system to reduce a rate of fluid flow to or through the turbine(s) experiencing cavitation. Examples of elements or subsystems include fluid intake structure control gates, turbine input port control gates, turbine draft port control gates, or other structural elements or subsystems that may be employed and explicitly or implicitly described herein or known in the art.

[0288] Additional details and example embodiments are presented hereinbelow and in corresponding drawings being filed herewith.

[0289] FIGS. 37A-37C are diagrams of an alternative embodiment of an intake modular precast structure 3730 relative to the intake modular precast structure of FIGS. 1A-3C. In this alternative embodiment, the intake module 3730 includes a roof 3738a, support columns 3738b, and control gates 3738c. Within a boundary of the intake module 3730 is an opening to a channel 3735, the diameter of which is defined by a ground layer or liner 3787 that, in this embodiment, is positioned above a support base platform 3781. The channel 3735 may be referred to herein as a fluid flow path or water flow path.

[0290] The support base platform 3781 composes a portion of a support base 3732, the other portion of which being formed by a support base column 3733, which provides support for the support base platform 3781. The support base 3733 may further define the channel 3735 with seamless continuity. The support base column 3733, in this embodiment, is formed of many modular blocks 3715, such as modular blocks formed as described hereinabove, which may also be used to form other features of the support base 3732.

[0291] The intake module 3730 may be positioned at least partially above a surface of water, or at least partially below a ground surface of a natural or man-made body of water (not shown).

[0292] FIGS. 37B and 37C are a sectional view and side view of the intake module 3730, respectively.

[0293] It should be understood that the particular design of the intake module 3730 may be any size and shape that is capable of performing functions described herein. For example, in FIG. 37A, control gates 3738c open and close in a horizontal sliding manner. This means that when a reduction in flow of fluid is desired by a pumped storage operator or by a processor or controller configured to operate the hydropower pumped storage system in an automated manner, at least one control gate 3738c slides toward or into a closed position, meaning the at least one control gate 3738c spans a partial or full distance between adjacent support columns 3738b. Alternatively, the at least one control gate 3738c may open and close in a vertical manner between the ground layer or liner 3787 and the roof 378a. Opening or closing control gates 3738c may be performed through any actuation means, such as hydraulic, pneumatic, electromagnetic, or simple mechanical lever arm, to name a few.

[0294] FIG. 38 is a diagram of aspects of a powerhouse 3810 that includes a portion of the fluid conduit 3820, including intake tube(s) 3860a and draft tube(s) 3860b, that spans between an upper fluid supply (not shown) and lower fluid supply (not shown) via the powerhouse 3810. Portions of an intake tube 3860a or draft tube 3860b following a split may be referred to herein as a “subtube.”

[0295] The powerhouse 3810 includes power generating elements, such as turbines 3812, between the intake tube(s) 3860a and draft tube(s) 3860b. The turbines 3812 in this embodiment are arranged vertically within respective vertical change regions 3811. The vertical change regions 3811 may have a vertical drop in which fluid (not shown) within the fluid conduit 3820 experiences a change in elevation of zero (i.e., flat) or several feet, several tens of feet, or several hundreds of feet. The change in elevation causes the turbines 3812 to convert more kinetic energy of the descending fluid into rotational energy, and hence electrical power, than were the vertical elevation change not provided.

[0296] It should be understood that in a case in which the turbines 3812 are arranged horizontally such that a vertical elevation does not occur at the turbines 3812, a reduced production of electrical power is achieved for the same volume of fluid passing through the turbines 3812 relative to the vertical arrangement.

[0297] As mentioned above, in the example embodiment of FIG. 38, the fluid conduit 3820 is illustrated as splitting from a single path into two paths at the intake tube 3860a and draft tube 3860b, with the multiple paths defined by “subtubes,” but it should be understood that alternative

embodiments may split the fluid conduit 3820 into more than two paths and include a corresponding number of turbines 3812 within respective vertical change regions 3811 at the powerhouse 3810.

[0298] Gate(s) (not shown) may be employed at the splits to cause fluid flow to be directed to fewer than all subtubes to turbines, such as during periods of maintenance of a turbine or in an event of lower fluid availability so as to maintain increased fluid flow through a fewer number of turbines.

[0299] It should also be understood that, depending on the application, the fluid conduit 3820, including the intake tube 3860a or draft tube 3860b, may be reinforced cementitious material with or without liners (not shown) or may be steel, composite material, or other material(s) such that force of water or other fluid within the intake tube 3860a or draft tube 3860b is constrained without risk of loss of integrity of any component of the fluid conduit 3820. Combinations of materials may be employed to form any component within the hydropower pumped storage system.

[0300] As described hereinabove, the turbines 3812 may be used in this embodiment to generate electrical power based on flow of water from an upper fluid supply (not shown) to a lower fluid supply (not shown), or the turbines 3812 may be operated in a reverse direction to pump water or other fluid from the lower fluid supply to the upper fluid supply. Typically, a powerhouse operator may choose to generate power during peak power periods within a neighborhood or geographical region and pump fluid from the lower fluid supply to the upper fluid supply during off-peak power periods.

[0301] FIGS. 39A through 39H are diagrams that illustrate example embodiments of transition regions 3927a and 3927b at which a precast fluid conduit 3920 interfaces with an intake tube 3960a or draft tube 3960b that form a portion of a fluid conduit 3920 in a proximal location of a powerhouse (not shown).

[0302] Referring to top views FIGS. 39A and 39B, alternative transition region embodiments 3927a and 3927b are shown in which transition collars 3925 are over a steel liner 3929 (FIG. 39A) or the transition collars 3925 are inside the steel liner 3929 (FIG. 39B), respectively.

[0303] In FIG. 39A, the precast transition collars 3925 are illustrated as multiple adjacent precast segments. In an example embodiment, the precast transition collars 3925 form a series of rings, with a watertight seal between adjacent collars, to retain fluid flowing within the fluid conduit 3920 in the transition region 3927a and into the intake tube 3960a. The precast transition collars 3925, in this embodiment, encircle a portion of the steel liner 3929 that forms the intake tube 3960a such that fluid flows smoothly into or out of the intake tube 3960a. Expandable waterstop 3921 is disposed between the steel liner 3929 and the precast transition collars 3925 to ensure fluid pressure does not cause a leak within the transition region 3927a.

[0304] Adjacent segments that form the intake tube 3960a, in this embodiment, may be coupled together by way of corresponding adjacent complementary flanges 3919a and 3919b, with expandable waterstop material 3921 therebetween. The complementary flanges are held tightly together by way of an assembly of bolts, fasteners, rivets, welding, or other mechanism(s) to secure the adjacent complementary flanges 3919a, 3919b together.

[0305] In at least one embodiment, to ensure correct assembly, at least one of the complementary flanges enables use of a guide dowel (not shown) or off-centered bolt (not shown), and wherein the other complementary flange further enables the use through having a complementary feature to accept the guide dowel or off-centered bolt. It should be understood that such techniques may be employed to ensure proper assembly between the complementary flanges or anywhere adjacent elements are to be in coupled arrangement throughout the pumped storage system.

[0306] The embodiment of FIGS. 39A, 39B also include precast or cast-in-place support structures 3913 to maintain the intake tube 3960a (or draft tube 3960b) in a stable, low vibration position to maintain structural integrity of the intake tube 3960a (or draft tube 3960b).

[0307] The fluid conduit support structure 3913 may also serve as a thrust block that resists displacement of the intake tube 3960a (or draft tube 3960b) that would otherwise be caused by fluid flowing within a water tunnel 3984 defined by the intake tube 3960a (or draft tube 3960b) as the fluid flows away from the powerhouse (not shown). Because water or other fluid has tremendous force when flowing in large volumes, such as would be the case in a pumped storage system, the support structures 3913 are designed to address downward, upward, left, or right forces to maintain the integrity of individual elements and interfaces between or among elements illustrated in the embodiments of FIGS. 39A and 39B.

[0308] Precast segments (not shown) defining a portion of the fluid conduit 3920 taper in diameter as the fluid conduit 3920 approaches the transition collars 3925. The precast segment (not shown) that is closest to the transition collar 3925 assembly, and the transition collar 3925 that is farthest from the intake tube 3960a, are mechanically coupled together (not shown) in any manner described herein or otherwise such that a fluid leak does not occur therebetween.

[0309] FIGS. 39C and 39D are side views of the embodiments of FIGS. 39A and 39B.

[0310] FIGS. 39E and 39F are sectional views of the embodiments corresponding to FIGS. 39A and 39B. In the sectional view, a sleeve 3923, made of steel or other strength-enhancing material, may be positioned at locations of angular changes within the intake tube 3960a, but the sleeve 3923 may extend any distance within the intake tube 3960a. The steel liner sleeve 3923 may be soldered or coupled to the steel liner 3929 in any other manner that maintains integrity and reinforces strength at diameter-changing locations within intake tube 3960a, and similarly within the draft tube 3960b, optionally at non-diameter-changing locations.

[0311] It should be understood that the transition collars 3925 may be precast cement and, in some applications, assembled by a tunnel boring machine (TBM) or other system that is used to create a tunnel that defines the fluid conduit 3920. Another example technique that may be used to create a tunnel and precast segments or transition collars strengthening the tunnel and creating a fluid conduit 3920 may be a “drill blast and shoot” system, with a subset of the precast segments being an assembly of precast transition collars 3925 to couple to a structure defining an intake tube 3960a or draft tube 3960b.

[0312] FIGS. 39G and 39H are example embodiments of a draft tube 3960b having similar alternative assembly embodiments as FIGS. 39A and 39B. In FIGS. 39G and

39H, there is a similar transition region 3927a and 3927b, respectively, in which transition collars 3925 are over a steel liner 3929 (FIG. 39G) or under the steel liner (FIG. 39H). The fluid conduit support structure 3913, or multiple ones of same, similarly serve as thrust blocks to maintain stability of the draft tube 3960b, especially as water or fluid traverses from left to right within the draft tube 3960b because the powerhouse (not shown) typically has water outflow under tremendous pressure when converting energy of fluid flow to electricity via power generating elements (not shown).

[0313] FIGS. 40A-40C are diagrams of the transition region 4027a that illustrate details of an embodiment of an assembly. In particular, FIGS. 40A-40C include precast transition collars 4025 coupled together and include waterstop 4021 therebetween. Waterstop 4021 is also positioned between a continuous steel (or other material) liner 4029 that forms a portion of the intake tube and draft tube, and also includes a sleeve 4023 that may be soldered or otherwise coupled to the steel liner 4029 in a manner that maintains laminar fluid flow within the intake tube or draft tube at those intersections. The liner sleeve 4023 may be disposed at transition regions within the intake tube or draft tube to provide extra strength, such as at locations of diameter changes, toward maintaining integrity of the intake tube or draft tube.

[0314] The steel panel sections of the intake tube include flanges 4019a and 4019b, which, when coupled together, interconnect adjacent steel segments. The flanges, in this embodiment, include assemblies of linkages 4028 to couple the flanges 4019a, 4019b together. Waterstop 4021 is illustrated as being disposed between adjacent segments of the intake tube to prevent water from leaking between the adjacent segments or between a segment and other adjacent element(s), such as a precast liner transition collar 4025.

[0315] FIGS. 40D-40F illustrate an embodiment in which precast transition collars 4025 are located inside a steel liner 4029. This embodiment depicted in FIGS. 40D-40F illustrates a transition of a between the precast transition collars 4025 and steel liner 4029 in the form of a precast collar interface segment 4088 and corresponding wedge 4089 such that low turbulence of flowing fluid is caused by a transition from the collars 4025 to the sleeve 4023 or liner 4029.

[0316] Although not shown, remote sensors 4058 may be placed at joints within the transition region or elsewhere within the fluid conduit to detect indications of possible aging, wearing, leaking, or other loss of integrity indications that may occur. Examples of sensors 4058 that may be employed include vibration sensors, stress sensors, moisture sensors, or acoustic sensors. The sensors may communicate with a process or located locally or in a cloud server, for example, via communication path(s) that are wired, optical, wireless, or other communication medium. A sensor electronic system may convert transducer signals into meaningful information that can be used to give notice to an operator or electronic process control system or the like of the power generation system that preventative maintenance, maintenance, or other remedial action may be required at a given location within the transition region or elsewhere within the hydropower generator system.

[0317] FIGS. 41A-41B are isometric views consistent with the embodiment of FIG. 39A, with elements in FIGS. 41A-41B corresponding to elements with like reference numbers in FIG. 39A.

[0318] FIGS. 41C-41D are isometric views consistent with the embodiment of FIG. 39B with elements in FIGS. 41C-41D corresponding to elements with like reference numbers in FIG. 39B.

[0319] FIG. 42A is a side view of an example embodiment of a transition region 4227b that is located beneath the surface of the ground. In this environment, a tunnel boring machine (not shown) or other system may be employed to create a tunnel underground and deploy precast segments that support the tunnel with a watertight seal to form a fluid flow path. Precast transition collars 4225 are deposited close to a fluid intake tube 4260a to form a portion of a continuous fluid conduit 4220. The fluid intake tube 4260a may include a steel liner 4229 coupled to and surrounding a subset of the precast transition collars 4225. A set of rock anchors 4282 may be employed, and an embodiment includes rock anchors 4282 that project into and out of at least a subset of the precast transition collars 4225 and the steel liner 4229. The rock anchors 4282 may also be used to align the steel liner 4229 with the subset of precast transition collars 4225, as well as to couple firmly the intake tube 4260a to a natural structure, such as natural or man-made structure(s) beneath the ground of the transition region 4227b.

[0320] In the embodiment of FIG. 42A, the intake tube 4260a is coupled to fluid conduit support structure elements 4213, which may also have rock anchors 4282 projecting therefrom in all directions for stabilizing and minimizing vibration effects on the structures forming the fluid flow path 4420, where the vibration effects are typically caused by fluidic flow and related pressure or other forces.

[0321] Flanges 4288 may be formed between the fluid conduit support structures 4213 and the steel liner 4229, where in this embodiment, the flanges 4288 extend from a steel structure (not visible) that is disposed between the fluid conduit support structure 4213 and the steel liner 4229 that compose at least a portion of the fluid intake tube 4260a. Enabling the steel structure (not visible) to form the flanges 4288 is useful during the assembly process for a press-fit to form a water-tight seal between an intake tube 4260a component and the support structure 4213 to prevent fluidic leakage at that location. Expandable waterstop (not shown) may be employed between or among any of the elements described in reference to FIG. 42A.

[0322] Referring to the fluid conduit 4220, a tunnel boring machine or other tunnel boring system may excavate a tunnel and then apply precast segments (not shown) that form the fluid conduit 4220. The tunnel boring machine or other tunnel boring system may also deposit precast transition collars 4225 for coupling to the fluid intake tube 4260a. The same tunnel boring machine or other system may create an excavated area 4297 within unexcavated soil 4296, in which much of the fluid intake tube 4260a resides, with the fluid conduit support structure 4213 or multiple ones thereof, reside with rock anchors 4282 projecting into the unexcavated soil 4296 as part of the support mechanism for the fluid intake tubes 4260a.

[0323] FIG. 42B is a top view of the structural elements within the transition region 4227b, described in detail in reference to FIG. 42A.

[0324] FIG. 42C is a top view of the structure of FIG. 42B with the excavated area 4297 and unexcavated soil 4296 omitted for clarity.

[0325] FIG. 42D is another view of the embodiment of the transition region 4227b.

[0326] FIG. 42E is a sectional side view corresponding to FIGS. 42A-42D.

[0327] FIG. 42F is another sectional side view that illustrates an interface segment 4289a with interface segment wedge 4289b that help make a smooth and secure transition of the precast transition collars 4225 to the fluid intake tube 4260a. This view also shows the fluid conduit support structure 4213 with a flange 4288 extending therefrom that enables the steel liner 4229 to extend into the support structure 4213 with a watertight fit. It should be understood that expandable waterstop (not shown) may be positioned therein.

[0328] FIG. 42G is a sectional view at the transition region 4227b that includes a fluid conduit support structure 4213 with rock bolts 4282 extending therefrom to help maintain integrity of the water intake tube 4260b and components associated therewith.

[0329] FIGS. 43A-43C are diagrams of a powerhouse 4310 illustrating the flow tubes 4360a and draft tubes 4360b in context with other aspects of the powerhouse 4310.

[0330] Referring to FIGS. 43A and 43B, within the powerhouse 4310, there are three superstructures 4391a, b, c that are configured to support cranes (not shown) that may be used during installation and maintenance phases of the powerhouse 4310. An intake superstructure 4391a is positioned above the intake tubes 4360a; a draft tube superstructure 4391b is positioned above the draft tubes 4360b; and a turbine superstructure 4391c is positioned above the turbines (not shown) located within the power generator support structure 4324. As illustrated in previous drawings referenced herein, the intake tubes 4360a are mechanically coupled to an intake support structure 4322; the draft tubes 4360b are mechanically coupled to a draft tube support structure 4326; and the turbines are coupled to the power generator support structure 4324.

[0331] As mentioned in the prior paragraph, the superstructures 4391a and 4391b include cranes (not shown) coupled thereto to support installation, maintenance, and exchange activities of the intake tubes 4360a and draft tubes 4360b, respectively, or components thereof. Similarly, the power generator superstructure 4391c includes a crane (not shown) coupled thereto to enable power generating modules (e.g., turbines) 4312 to be installed and extracted from the power generator support structure 4324. The crane coupled to the power generator superstructure 4391c is arranged to deploy and extract a turbine vertically with respect to its operating position in the power generator support structure 4324 and translate the deploying or extracted turbine from or to, respectively, an exchange shaft 4395.

[0332] Above the turbine exchange shaft 4395 may be a permanent or temporarily positioned “deployment and extraction” crane (not shown) that is capable of deploying or extracting a turbine via the turbine exchange shaft 4395 toward or from, respectively, the power generator support structure 4324. In the case of deploying a turbine through the turbine exchange shaft 4395, following the lowering of a turbine, the crane coupled to the power generator superstructure 4391c translates the turbine from the turbine exchange shaft 4395 to its respective location in the power generator support structure 4324 for operational readiness within the powerhouse 4310.

[0333] FIG. 43C is a side view of the powerhouse 4310 of FIGS. 43A and 43B. FIG. 43C further illustrates an elevation change 4363, which is a minimum elevation change of fluid

that enters the powerhouse **4310** on its way from the intake tubes **4360a** to the draft tubes **4360b** as the water flows along the fluid conduit **4320** from an upper fluid supply (not shown) to a lower fluid supply (not shown).

[0334] The elevation change **4363** provides for additional kinetic energy of fluid to flow through the turbines that convert kinetic energy of flowing fluid into electrical power. It should be understood that the elevation change **4363** may alternatively be measured from an intake port of a turbine to a draft port of a turbine within the power generator support structure **4324**, or other relevant location.

[0335] FIG. 44 is a diagram similar to FIGS. 43A-43C that shows the elements of FIGS. 43A-43C with more visibility of the hydro turbines **4412**. In particular, a vertical drop of the fluid passing through the hydro turbines **4412** is more clearly shown. It should be understood that the form of the transition regions **4427a** or **4427b** having transition collars (not shown) over or inside the intake and/or draft tubes may be the same or different, but, in either case, are preferably configured to provide for a smooth, laminar flow to avoid producing turbulence. Laminar flow, hence a low level of turbulence, helps the hydro turbines **4412** from experiencing cavitation that may unnecessarily cause early maintenance needs.

[0336] FIGS. 45A and 45B are scene diagrams of a pumped storage system **4500** from a top view and section view, respectively. Referring to FIG. 45A, the pumped storage system **4500** includes an upper reservoir **4502a** defined by an upper impoundment structure **4501a** and a lower reservoir **4502b** defined by a lower impoundment structure **4501b**. A fluid intake structure **4530a** is located in the upper reservoir **4502a**, and a fluid draft structure **4530b** is located in the lower reservoir **4502b**. Depending on the flow of water direction, i.e., from the upper reservoir **4502a** to the lower reservoir **4502b**, or vice-versa, the terms "intake" and "draft" may be reversed, such that fluid draft structure **4530b** may become a fluid intake structure **4530b**, and so forth. Similarly, the fluid direction within the water tunnel **4520** may flow in either direction. The version of fluid intake structure **4530a** and draft **4530b** may be the same or similar to those of FIG. 3A or FIG. 37A, or combination thereof.

[0337] Similar to an embodiment described above in reference to FIGS. 39A and 39B, in FIGS. 45A and 45B, precast segments (not shown) defining a portion of the fluid conduit **4520** approaching a transition region **4527a** or **4527b** taper in diameter as the fluid conduit **4520** approaches transition collars **4525** coupled to an intake tube **4560a** or draft tube **4560b**. The precast segment (not shown) closest to the transition collar **4525** farthest from the intake tube **4525** are mechanically coupled together (not shown) in any manner described herein or otherwise such that fluid leak does not occur therebetween. Dowels, bolt linkages, and/or prestressed cables may be applied at a location at which the precast segment and transition collar **4525** are coupled together.

[0338] Continuing to refer to FIGS. 45A and 45B, at least one surge tunnel **4504** is fluidically coupled to the water tunnel **4520** to accept excess water within the water tunnel **4520** to relieve pressure should, for example, a turbine within the powerhouse **4510** be down for maintenance or there be any other cause of a disruption from a free flow of water therethrough. The surge tunnel **4504** may be sized, shaped, and oriented relative to the water tunnel **4520** to

accept a predetermined amount of water at a given maximum rate. Also, an auxiliary shaft **4506** may be provided from a surface level of the ground, such as a surface level of a mountain **4598**, into the water tunnel at various locations to enable humans and/or machines to be lowered into the water tunnel **4520**, such as by way of an elevator (not shown) or crane (not shown), to clear debris or perform other forms of maintenance. The auxiliary shaft **4506** may have a gentle slope with rail system (not shown) or have a 90-degree vertical angle with elevator (not shown).

[0339] It should be understood that various sensors (not shown) may be deployed along the water tunnel **4520** to monitor for leaks or other indications of condition(s) for which maintenance or an inspection may be required.

[0340] Continuing to refer to the embodiment of FIGS. 45A and 45B, as described above, there is a transition between a subset of precast segments (not shown) and smaller water pipes in (i) a transition region **4527a** where precast segments defining the water tunnel **4520** are coupled to the intake tubes **4560a** and (ii) a transition region **4527b** where precast segments defining the water tunnel **4520** are coupled to the draft tubes **4560b**. In this embodiment, the water tunnel **4520** resides beneath a mountain **4598**, and excavating soil **4596** is surrounding the water tunnel **4520**, powerhouse **4510**, surge tunnels **4504**, auxiliary shaft **4506**, and any other aspects of the pumped storage system **4500** between the upper impoundment **4501a** and lower impoundment **4501b**.

[0341] Referring specifically to the section view of FIG. 45B, a section view of the mountain **4598** is illustrated with the features described above in reference to FIG. 45A. The section view of FIG. 45B provides further understanding of a flow of water from the upper reservoir **4502a** to the lower reservoir **4502b** via the powerhouse **4510** as fluidically coupled by the fluid flow path **4520**. The section view of FIG. 45B further illustrates more clearly the relationship between the water tunnel **4520** and surge tunnel **4567**. A surge tunnel **4567** may also be provided between the lower reservoir **4502b** and the powerhouse **4510** and be fluidically coupled to the water tunnel **4520** to alleviate any local pressures. Additional auxiliary shafts **4568** may be provided at multiple locations along the water tunnel **4520**, and an auxiliary shaft **4568** may also be positioned directly above the powerhouse to enable turbines to be deployed or exchanged for maintenance or upgrade purposes.

[0342] The teachings of all patents, published applications, and references cited herein are incorporated by reference in their entirety.

[0343] The features and/or dimensions shown and/or described in this application are not necessarily to scale. Features and/or dimensions may be any size and/or any shape. Example dimensions may be provided herein. In alternative embodiments, one or more of the example dimensions may be different. In some embodiments, one or more characteristics described in connection with an embodiment described or shown herein may be used with any other embodiment described or shown herein.

[0344] While example embodiments have been particularly shown and described, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the embodiments encompassed by the appended claims.

What is claimed is:

1. A power generation system, comprising:
a powerhouse including a power generating module disposed therein;
an intake tube coupled to the power generating module at an intake port and a draft tube coupled to the power generating module at a draft port; and
a fluid conduit defining a fluid flow path and including at least one transition collar at a transition region between the fluid conduit and the intake tube, the draft tube, or both.
2. The power generation system of claim 1, wherein the fluid conduit is defined by at least one precast segment of cementitious material and at least one of the intake tube or draft tube is of non-cementitious material.
3. The power generation system of claim 1, wherein the at least one transition collar is a precast segment of cementitious material and at least one of the intake tube and draft tube are non-cementitious, and wherein waterstop material is disposed between the at least one transition collar and the intake tube, draft tube, or both.
4. The power generation system of claim 1, further comprising a structural material disposed between the at least one transition collar and the intake tube or draft tube in a coaxial arrangement, the structural material forming a flange external from the at least one transition collar or the intake tube or draft tube having the larger dimension.
5. The power generation system of claim 1, wherein at the transition region, at least one transition collar defines a circumference of the fluid conduit and the intake tube and the draft tube define respective circumferences, the at least one transition collar and intake tube and draft tube are coupled together in a coaxial arrangement, and wherein:
 - a) the circumference of the fluid conduit is larger than at least one of a circumference of the intake tube or the draft tube;
 - b) the circumference of the fluid conduit is smaller than at least one of a circumference of the intake tube or the draft tube; or
 - c) the precast segment at the interface region has a thickness of cementitious material and wherein the circumference of the intake tube or the draft tube is within an outer circumference and inner circumference of the precast segment.
6. The power generation system of claim 1, further comprising a liner sleeve coupled circumferentially to an interior or exterior of the fluid conduit at the interface region and extends at least a portion of at least one precast segment, the liner sleeve disposed between the at least one precast segment and a corresponding intake tube or draft tube; and further comprising waterstop material coupled to at least one of an inner surface or outer surface of the liner sleeve.
7. The power generation system of claim 1, wherein multiple segments compose at least one of the intake tube and draft tube and wherein adjacent segments are coupled together by complementary flanges, and wherein waterstop material is disposed between the complementary flanges.
8. The power generation system of claim 7, wherein at least one of the complementary flanges includes a guide dowel or off-centered bolt, and the other complementary flange include a complementary feature to accept the guide dowel or off-centered bolt.
9. The power generation system of claim 1, wherein the intake tube and draft tube are made of metal or other

material of sufficient strength to contain water pressure corresponding to a pressure of the fluid conduit filled with a fluid for a vertical distance between the powerhouse and a fluid intake structure at a respective fluid supply.

10. The power generation system of claim 1, further comprising at least one support segment coupled to at least one of the intake tube or the draft tube between the respective portion of the fluid conduit and the powerhouse, and wherein the at least one support segment is configured to secure the intake tube or the draft tube to a structural feature to support or resist displacement force on the intake tube or the draft tube caused by fluid flow therein.

11. The power generation system of claim 10, wherein the at least one support segment includes extenders that project outward from the at least one support segment and is configured to be coupled to at least one natural structural feature.

12. The power generation system of claim 1, wherein the intake tube and draft tube split into a corresponding number of subtubes to direct fluid to a corresponding number of power generating modules within the powerhouse.

13. The power generation system of claim 1, wherein multiple precast segments form the fluid conduit between an upper fluid supply and the powerhouse or a lower fluid supply and the powerhouse, and wherein an interior surface of the fluid conduit has a smoothness with a tolerance that controls creation of turbulence within the fluid conduit, and further wherein the fluid conduit is coupled at an interface region to the intake tube or the draft tube in a manner defining a substantially continuous surface internally in the fluid flow path.

14. The power generation system of claim 13, wherein the interior surface is coated with a hydrophobic compound.

15. The power generation system of claim 1, wherein the powerhouse is disposed beneath a surface of the ground.

16. The power generation system of claim 15, further comprising multiple precast segments that define a maintenance shaft extending from a surface of the earth location to the powerhouse to enable replacing of a power generating module.

17. The power generation system of claim 15, further comprising multiple precast segments that define an auxiliary shaft with an opening arranged to enable access to the fluid conduit.

18. The power generation system of claim 15, further comprising multiple precast segments that define a surge tunnel fluidically coupled to the fluid conduit and sized to relieve at least 5% of the pressure within the fluid conduit between a fluid supply and the powerhouse.

19. The power generation system of claim 1, wherein the power generating module is oriented in a vertical arrangement, the intake port and the draft port defining an elevation differential at least a height of the power generating module in the vertical arrangement.

20. The power generation system of claim 19, wherein the elevation differential has a distance of multiple feet, multiple tens of feet, or multiple hundreds of feet.

21. The power generation system of claim 1, wherein the power generating module includes multiple power generating modules configured to operate in parallel within the powerhouse.

22. The power generation system of claim 1, further comprising sensors arranged to sense an indication of a

reduction in integrity relative to a desired performance, the indication being at least one of vibration, stress, or moisture.

- 23.** A power generation system, comprising:
a powerhouse including a power generating module disposed therein;
an intake tube coupled to the power generating module at an intake port and a draft tube coupled to the power generating module at a draft port, the intake port elevated with respect to the draft port.
- 24.** The power generation system of claim **23**, further comprising:
a power generating module support structure; and
a power generating superstructure with at least one crane coupled thereto, the at least one crane having a capacity to deploy and extract the power generating module from the power generating module support structure.
- 25.** The power generation system of claim **24**, further comprising:
an intake tube support structure with corresponding superstructure;
a draft tube support structure with corresponding superstructure; and
at least one crane coupled to at least one of the intake tube superstructure and draft tube superstructure.
- 26.** The power generation system of claim **25**, wherein at least one of the power generating module support structure,

intake tube support structure, and draft tube support structure includes multiple precast segments coupled together.

27. The power generation system of claim **24**, further comprising a turbine exchange shaft structure defining a shaft of dimensions to enable a power generating module to be deployed and extracted therethrough.

28. The power generation system of claim **23**, further comprising at least one sensor configured to detect an operational parameter of the power generating module or at least one of the intake tube or draft tube.

29. The power generation system of claim **28**, further comprising a controller communicatively coupled to the at least one sensor, the controller further communicatively coupled to an operational element within the power generation system to cause the operational element to adjust a fluid flow associated with the intake tube, draft tube, or both.

30. A power generation system, comprising:
means for securing an intake tube of a powerhouse to a first section of a fluid conduit;
means for securing a draft tube of the powerhouse to a second section of the fluid conduit; and
means for converting fluid flow to electrical power within the powerhouse, said means for converting being deployed at a location fluidically between the intake tube and draft tube.

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