United States Patent [19]

Meckler

[11] **3,796,017**

[45] **Mar. 12, 1974**

[54] **HYDRAULIC STRUCTURAL APPARATUS**

[76] Inventor: **Milton Meckler,** 16348 Tupper, Sepulveda, Calif. 91343

[22] Filed: **Apr. 24, 1972**

[21] Appl. No.: **247,134**

[52] **U.S. Cl.** **52/292,** 52/1, 52/167
[51] **Int. Cl.** **E04b 1/36,** E04b 1/98, E04b 9/00
[58] **Field of Search** 52/1, 292, 2, 167

[56] **References Cited**

UNITED STATES PATENTS

3,538,653 11/1970 Meckler 52/1

Primary Examiner—John E. Murtagh
Attorney, Agent, or Firm—Spensley, Horn & Lubitz

[57] **ABSTRACT**

An improved building system for structural uses which employs high strength tubular elements to reduce the size, weight and extent of the structure required. The present invention utilizes tubular structural members with hollow cores filled with suitable hydraulic fluid and arranged to translate and distribute a sizeable portion of otherwise axial and lateral loads into an axial pre-stress in the thin walled tubular members which are arranged as steel columns or acts also as vertical bars in composite concrete columns or as secondary support (tension) or cross brace members. The primary columns of the building are tubular hollow members which are placed in tension through circumferential stress by means of a hydraulic system. The secondary floor support members suspended from the primary column support one or more floors by hydraulic means. Pressure equilibrium of the fluid within the column is achieved between the tubular primary and secondary support elements of the building. Other structural elements such as cross-bracing, are coupled to the hydraulic system and are used to restrain the column end conditions of the slender tubular columns. The present invention provides an improved means for constructing pressurized columns by utilizing an energized column with circulating fluid under pressure. Means are also provided in the present invention for eliminating the problem of fluid leakage within the hydraulic support members. The building system of the present invention also provides means for improving cable rod and long span structures for low rise buildings absorbing lateral and vertical shocks and displacements at the base of the support columns of conventional and hydraulic structures due to earthquakes.

3 Claims, 18 Drawing Figures

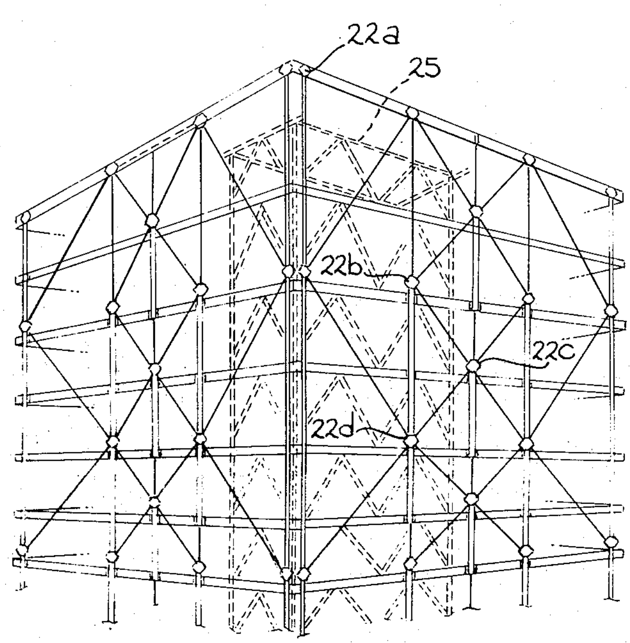


Fig. 1

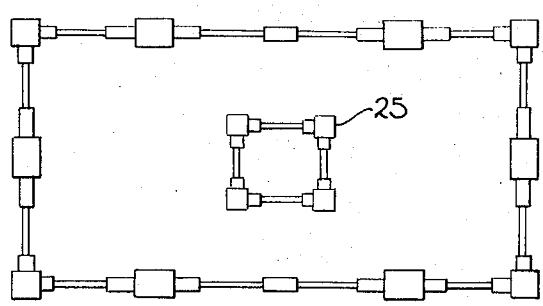


Fig. 5

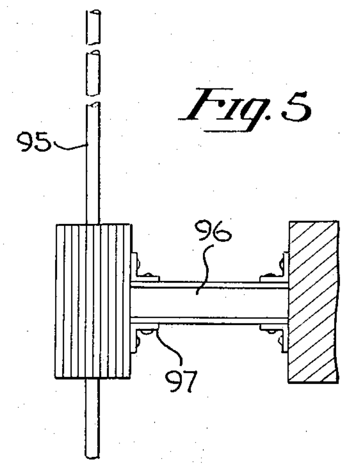
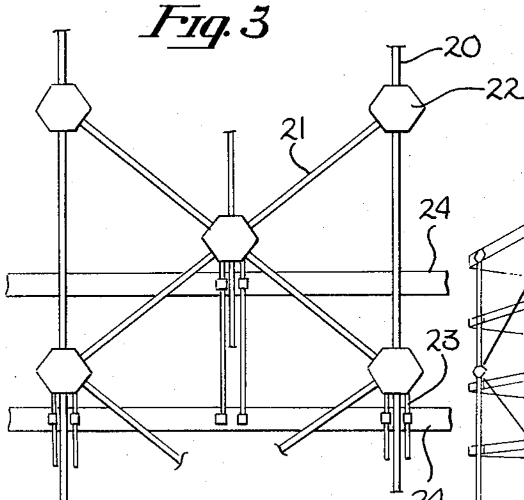


Fig. 3



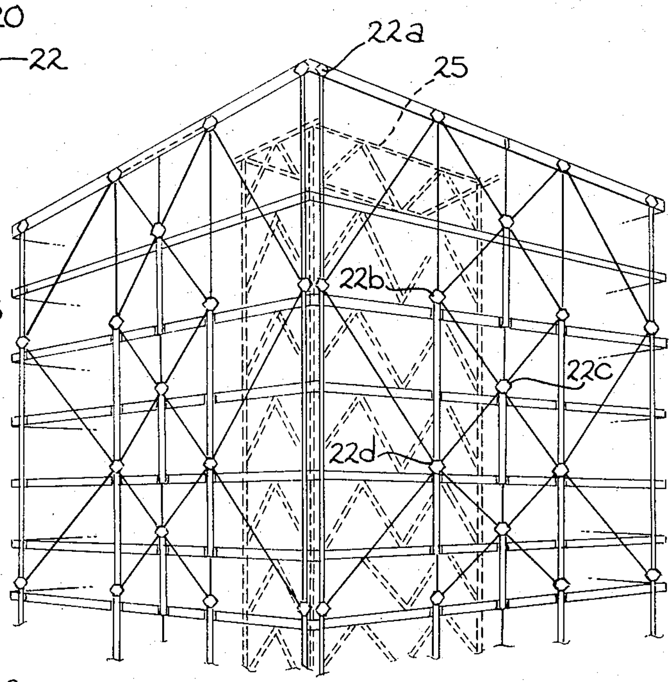
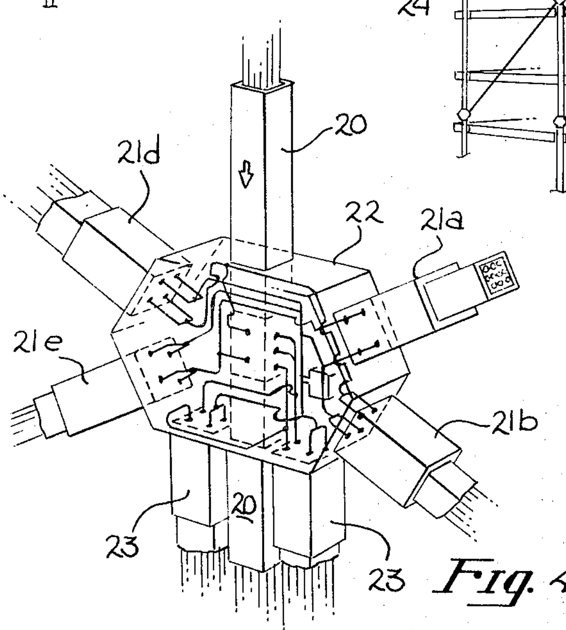


Fig. 2



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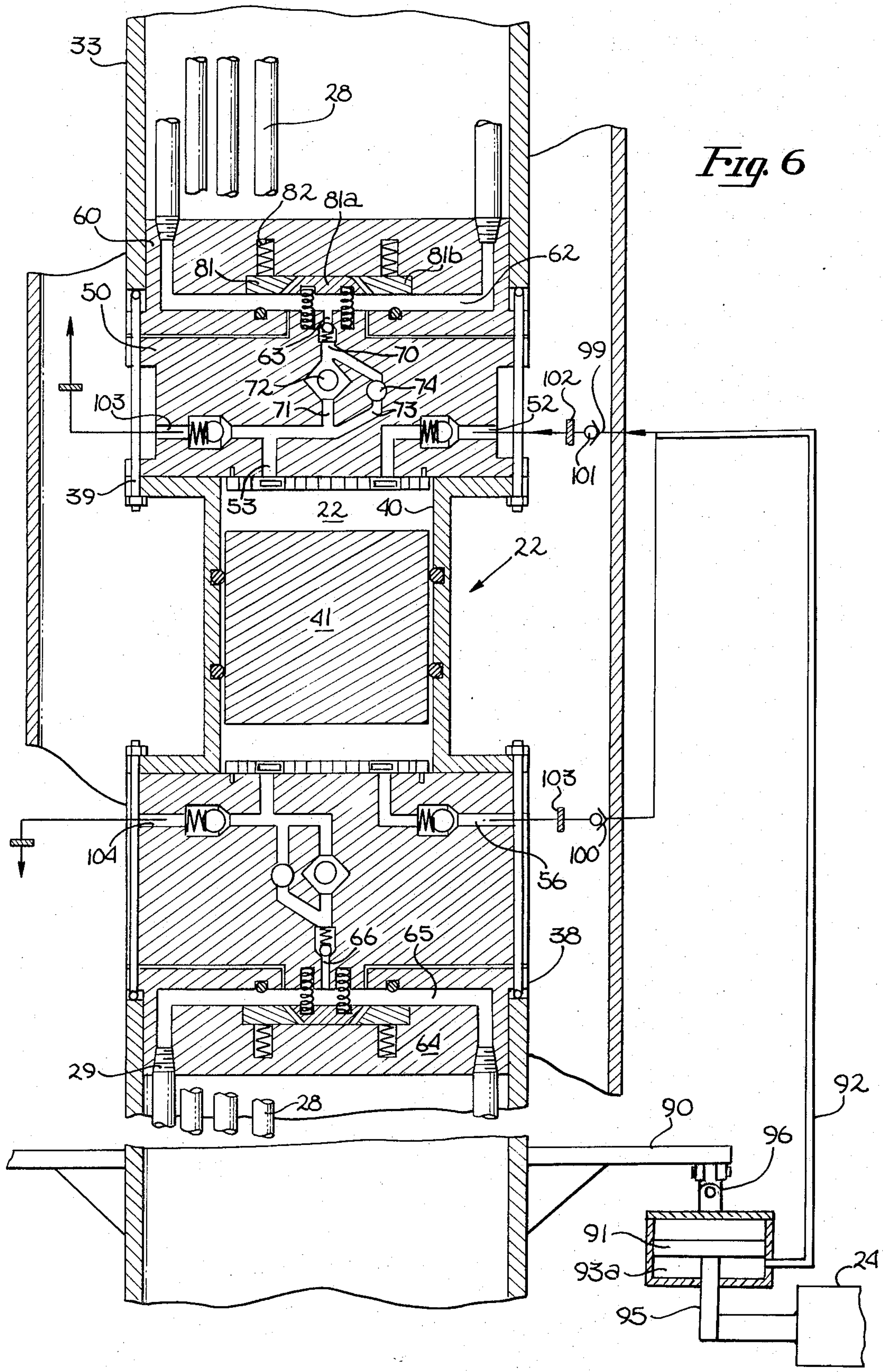
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Fig. 6

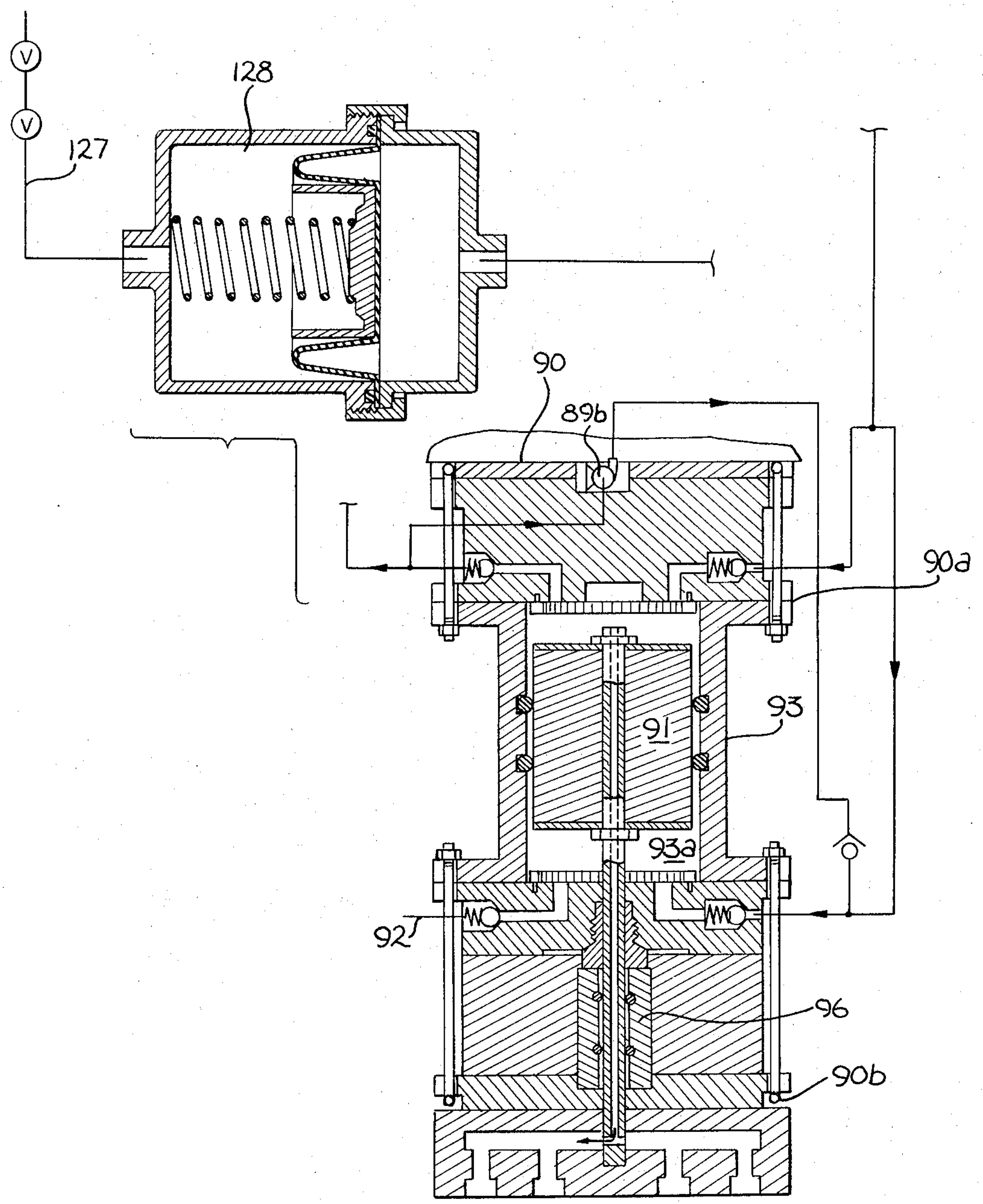

Fig. 7

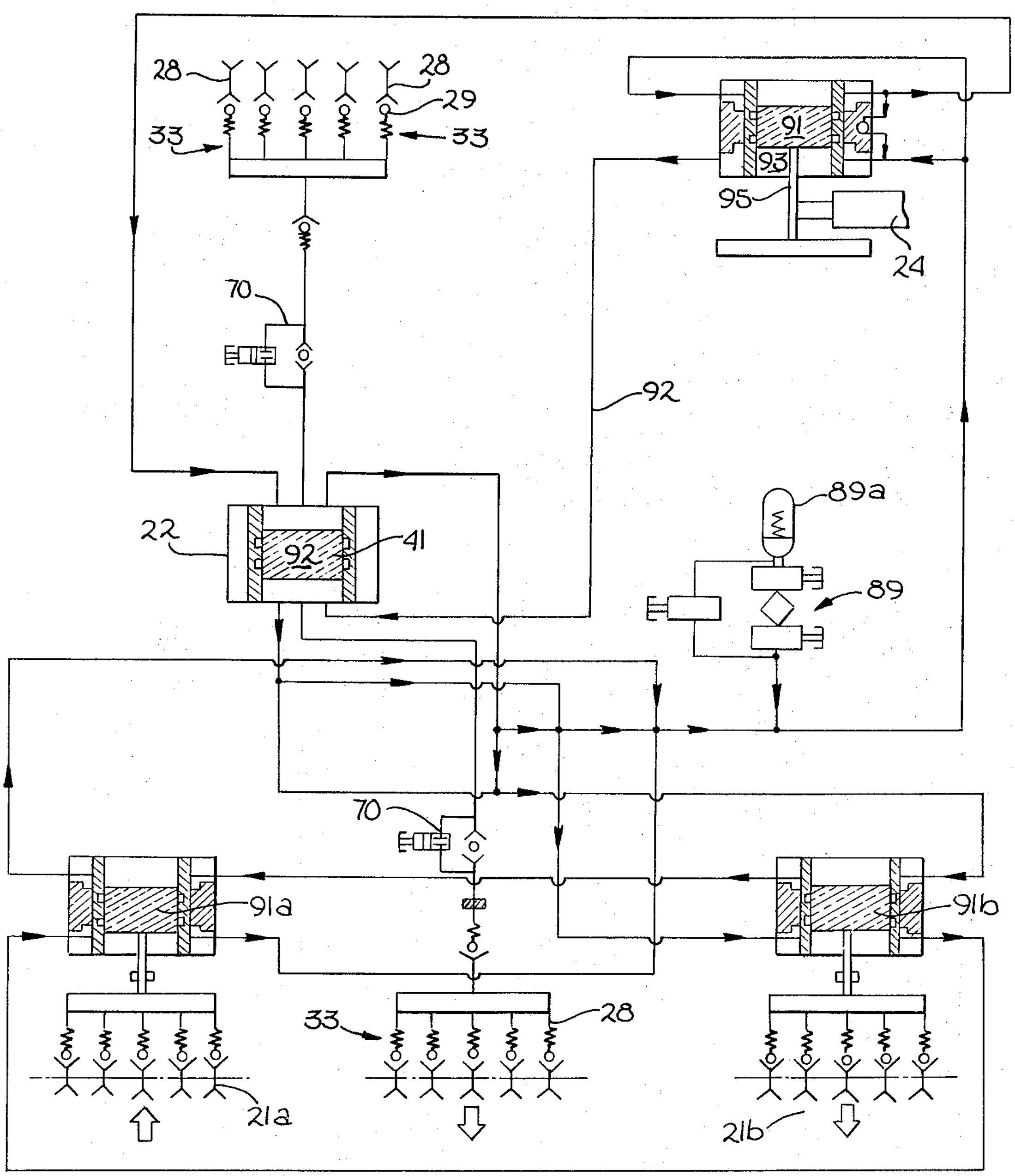
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Fig. 8

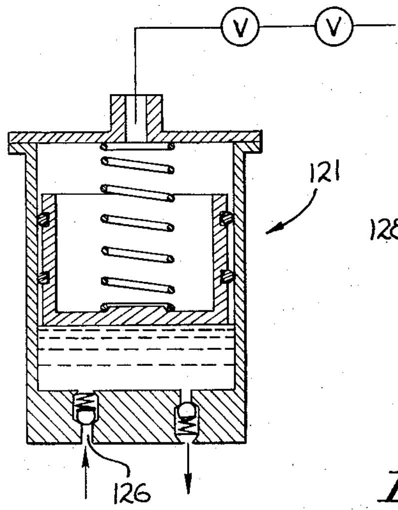


Fig. 10

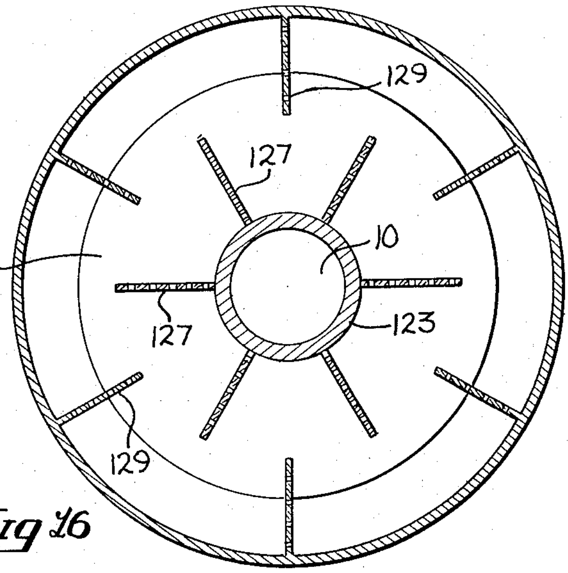


Fig. 16

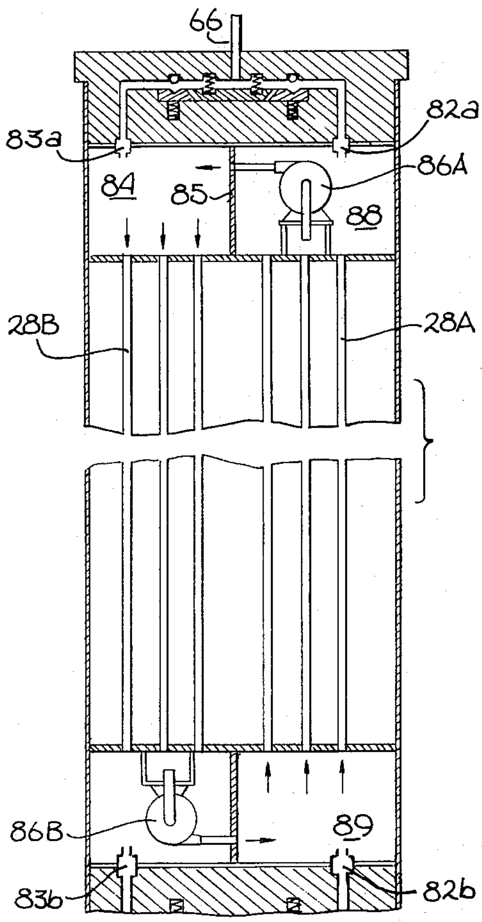


Fig. 9

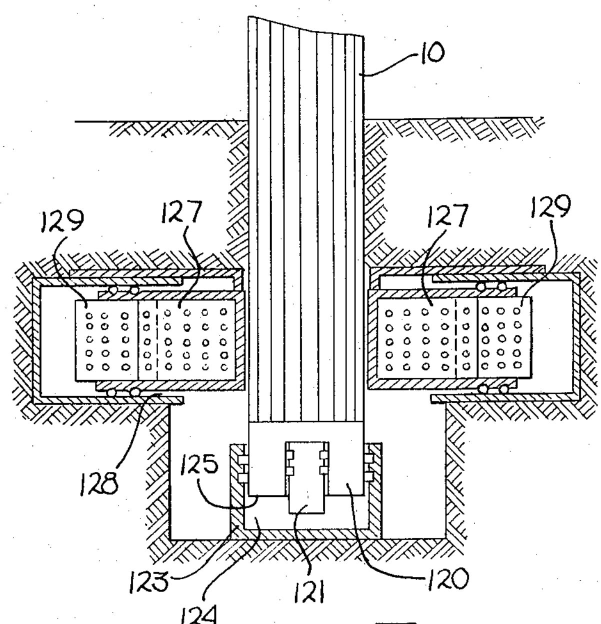


Fig. 17

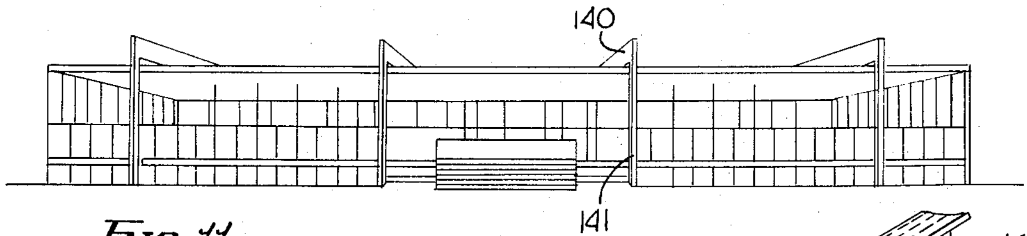


Fig. 11

Fig. 12

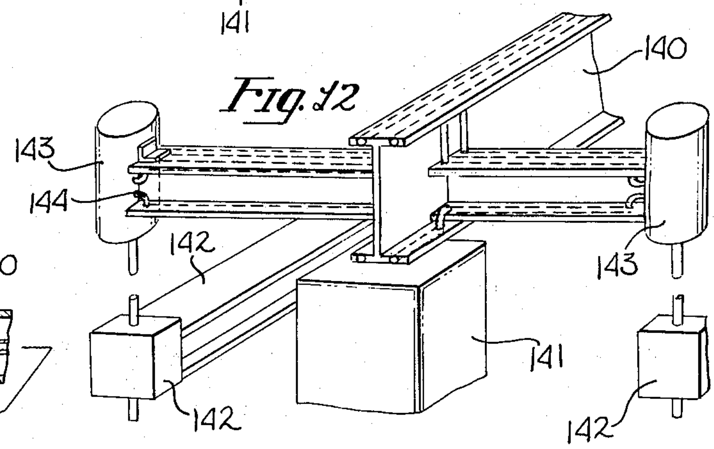
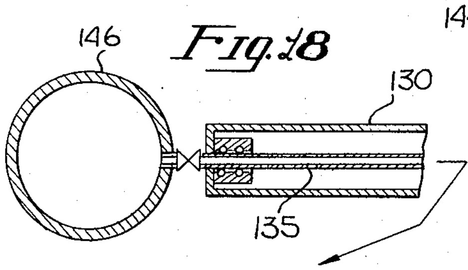


Fig. 18



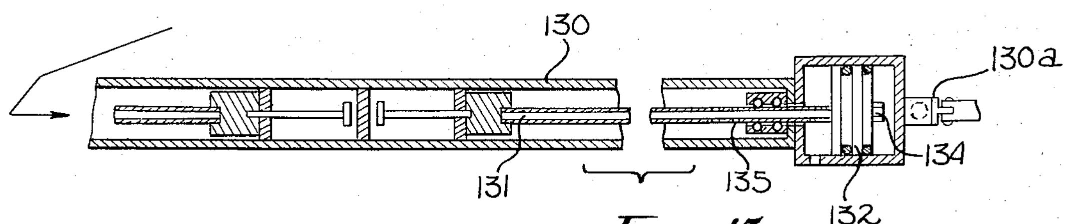


Fig. 15

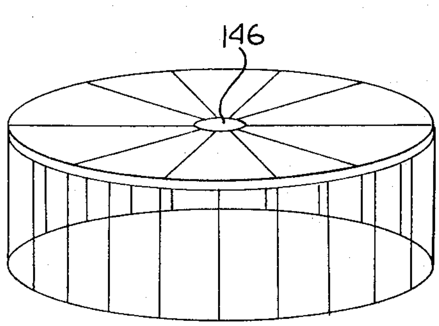


Fig. 13

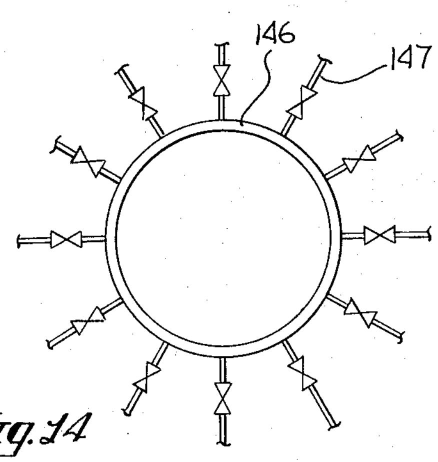


Fig. 14

HYDRAULIC STRUCTURAL APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is generally related to the field of construction systems and, more particularly, to those construction systems utilizing hydraulic members.

2. Prior Art

Conventional column and beam framing systems disclosed by the prior art which utilize solid steel or concrete members result in a significant loss of available material strength when compression forces are considered. The result often is a total structure which occupies more volume and is heavier than necessary provided most of the compressive force could be transferred into the wall of an equivalent tubular column, creating an axial pre-stress in the wall which acts in a direction opposite to the normally applied axial column force and operates to relax all or a significant percentage of the axial compressive stress.

A large number of uneconomical operations and waste of structural materials results in building construction today due to the traditional treatment of structural members acting either in compression or tension depending upon the resolution of the interacting forces. For example, concrete, a traditional building material, is noted for compressive stress but under tension has limited value unless steel reinforcing is added. Similarly, structural steel members have excellent values under tension, but particularly in column support, members have low values in compression such that care must be taken in the selection of slenderness ratio and section modulus when columns are subjected to compressive loading. The carrying capacity of a long steel or composite steel and concrete column or secondary support member is not only affected by possible buckling (stability problems) but also because of any increase in moment due to an increase in moment arm due to building drift. A column with equal and opposite moments at the ends is bowed in a single curvature while a column with equal moments at the ends is bowed in double curvature. Also, restrained columns in frames undergoing lateral loading are bent in double curvature. As stated, a conventional column and beam framing system with either steel or concrete construction material results in some loss of available material strength when the respective compression or tension forces are imposed on the various interconnected members. The result is a total structure which occupies more volume and is heavier than would be required if the normal compression forces could be neutralized by pressure forces operating in the opposite direction axially, to neutralize their effect and permit a greater load carrying capability for a given structure.

The present invention substantially solves those problems left unresolved by the systems disclosed by the prior art. Fluid filled columns and cross-braces are placed on the exterior of the structure, arranged in shear walls or placed within the exterior skin, depending upon the desired architectural effect. Structural strength is maximized in the various columns, floor supports, cross-brace members, etc., by means of a multiplicity of tubular elements filled with fluid, e.g., inhibited glycol-water solution. The fluid operates to redistribute a high proportion of axial and lateral load among the various structural members joined together, while providing a natural pre-stress effect. This, in turn, premits higher loading than current practice will allow in comparable solid members of the same length. Tubular elements are used to construct the primary columns and the secondary floor supports which rest on floating pistons and carry a grouping of several floors.

SUMMARY OF INVENTION

The present invention is an improvement in a hydraulic core construction for structures as shown and described in U.S. Letters Pat. No. 3,538,653.

The present invention as well as the invention described in U.S. Letters Pat. No. 3,538,653 also by Milton Meckler issued Nov. 10, 1970 describes a building system concept together with design principles and mechanisms wherein the live and static loads of a building are utilized to provide fluid under pressure which is then used within the system to pre-stress, strengthen and otherwise redistribute the load forces of the building to other forces of the structure for overall structural efficiency, stability and safety. By means of the present invention, fluid pressure is supplied at various points in the structural system and the flow volume pressure and level of that fluid under pressure at any given point in the structural frame is made to depend upon the time varying live and static loads upon the building as reacted by the various hydraulic devices and tubular elements of the structure in accordance with the present invention. The live forces are those generated by wind, seismic forces, equipment, occupants, furniture, and the like, whereas the static forces are the architectural loadings upon the building. The Meckler prior patent describes such a concept. The present invention includes mechanical improvements to such a system as well as new combinations of elements which are useful in such an overall system. In most structural frames for buildings the weight of the columns and walls is generally negligible compared to the weight of the floors. In accordance with the over-all concept of the present invention as well as the concept described in U.S. Pat. No. 3,538,653 the weight of the floors is utilized to generate fluid under pressure by supporting the floors from a closed volume of fluid whereby any increase in the floor loading or deflection of the lateral bracing system is transposed to additional pressure or flow by mechanical means in the closed volume of fluid.

In accordance with the present invention, support columns are compensated in accordance with the load which they are to bear by providing tubular members within or as a part of those columns, which tubular members are pre-stressed by being interconnected as fluid passages to receive the differences in fluid pressure resulting from the static loadings and live loadings of the building. Thus, in accordance with the present invention different pressures are maintained at different joints by mechanical means at different points in the various transducer elements by means of an independent accumulator circuit or the like, whereby a balance of forces commensurate with the loads imposed upon the building or its deflection is achieved. Upon reaching the foundation through the columns of the building, the foundations and the ground must react the net axial load comprising the cummulative live and dead loads of the building less any axial pre-stress made to act in opposite directions in accordance with the present invention. Also in accordance with the present invention means are provided at the foot of the column for allowing both lateral and vertical movements of the earth in response to seismic shocks without transposing such vertical or lateral movement of the columns. Thus, in an earthquake the foundation may move through a considerable series of both vertical and lateral movements without causing any movement or damage to the building. The present invention also includes mechanical improvements to the pressure translators previously described in U. S. Pat. No. 3,538,653.

Cross and horizontal brace members of the system of the present invention assist in transposing and redistributing various horizontal and vertical forces acting upon the structure and all surfaces attached to it. By suspending the floors from the basic structural frame through closed volumes of liquid the system is further pressurized when additional stiffening of the columns to reduce deflection is necessary. The pressure is equalized in a given column through the fluid system of the present invention.

In accordance with the present invention an improved foundation support means is provided for the vertical support columns of the structure which allow lateral and vertical ground displacement in the event of earthquakes, without displacement of the columns at their base. The present invention maximizes the benefits of unitized design by translating an axially applied compressive load into circumferential tensile stress, thereby providing a pre-stress which permits high axial loading.

Tubular members filled, under pressure with liquid, can resist considerably higher forces than conventional solid members. The increased capacity is due to the prestressing type effect of the pressurized tubular members, and also to the increased resistance to buckling of the columns and other compression members. Furthermore, by coupling the vertical load carrying members with the secondary and bracing tubular members, pressure equalization within the tubular network has a tendency to assist in resisting lateral forces due to wind and/or earthquake.

Construction in accordance with the present invention utilizes tubular steel columns either as the primary vertical support members of the structure as in the case of an all steel column or a large portion of load in a composite column. Such columns are filled with liquid and secondary support or brace members are joined to the primary column by means which place the fluid within the column in compression to thereby place the tubular column members in tension through circumferential stress. The secondary support members, i.e., those members supporting the floors of the building from the primary column members or those acting as diagonal or horizontal brace members as hereinafter described, are thus supported, by or subjected to the pressure of the fluid in the tubular members. This pressure force is reacted partially by placing the primary column tubular sections in compression with the balance of force reacting in the plane of tubular skin as circumferential stress with by Poisson Ratio results in an axial pre-stress due to foreshortening of tubular structure along its axis. The secondary members supporting the floor can also be tubular members with fluid under pressure creating by the weight of the floors and associated walls and other loads supported by it such that the pressure in the secondary tubular elements (developed by weight of floors and walls, etc., permits a large component of axial tension stress to shift to a circumferential mode, thereby increasing its ability to handle greater axial stress values due to resolution of stress forces in skin of tubular elements of secondary support members. Similarly, liquid under pressure can be transmitted to and contained within bracing members which are thereby increased in strength and resistance to bowing to resist lateral forces between columns, for example. In this way the forces acting upon the columnar supports of the structure do not exert compressive and buckling forces upon the columns comparable to conventional framing methods using solid members, for example, but do rather obtain a sizeable proportion of their support by the circumferential stress in the columnar tubular members by reason of the pressure upon the liquid contained in the manifolded individual tubular elements comprising the column. The present invention provides means for connecting such secondary floor supports and brace members to said liquid filled primary columns such that the above described circumferential stress loading is obtained. The action of the hydraulic pressure within tubular elements also acts to resist the bowing effects under all loading conditions and can be harnessed to resist frame deflections upon upper building floors due to wind and earthquake forces.

In accordance with the present invention energized columns can be utilized as the structural columns in order to achieve a substantial saving of weight and structural material. Thus, in accordance with one embodiment of the present invention the structural columns are designed as thin-walled tubular columns containing circulating fluid of such velocity and direction under pressure to pressurize the energized columns to a level which assures that the net axial stress in the tube walls will not become compressive upon the application of load or can be utilized to improve the heat transfer performance over thermal siphon fire protection systems of the type known to the art since the system of the present invention permits forced convection fire protection.

The present invention also provides additional structural improvements over the prior art systems.

Thus, the present invention permits minimum use of structural members permitting larger clear span floor areas by taking advantage of high strength tubular elements to reduce the size and extent of the structure required. The invention accomplishes this maximized structural strength in all steel columns or in composite columns by utilizing tubular structural members with hollow cores filled with suitable hydraulic fluid and arranged to translate and distribute a sizeable proportion of otherwise normal tension and compression forces into circumferential and longitudinal stresses in the thin walled tubular members which are arranged as steel columns or also act as vertical bars in composite concrete columns or as secondary support (tension) or cross brace members.

When comparing the potential weight and cost savings of a long pressurized tube with a conventional short solid structural column (of type normally found in multirise buildings), it can be shown that pressurization leads to roughly one-third savings in the weight of the building shell and a potential cost savings therefor of one-third. Furthermore, when using a glycol-water solution as the pressurization medium, the further advantage of fire protection by thermal siphon is gained.

A weight savings will always result provided that the ratio of the pressure level to the fluid density is always greater than the ratio of uniaxial yield strength to the material density of the solid column and, the tensile strength of the material is approximately two times its compressive strength (or greater).

In short, prestressed columns favor low values of structural index. Thus, longer column lengths become more economical than solid column members which favor high structual indexes. For the case of the pressurized tube, the potential wieght savings can be shown to be appreciable. The weight of the pressurized column varies directly with the applied load and the column length, but is surprisingly independent of the modulus of elasticity. For this reason, almost any gas tight material can be used, although materials of higher modulus of elasticity may provide more compact members.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objectives and advantages thereof will be better understood from the following description considered in connection with the accompanying drawing in which a presently preferred embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description only, and is not intended as a definition of the limits of the invention. In the drawings:

FIG. **1** is a plan view of a building in accordance with the present invention;

FIG. **2** is a view in perspective showing the core and exterior framing of the building of FIG. **1**;

FIG. **3** is a partial view of a building frame shown partly in schematic illustrating a typical cross brace and floor arrangement in accordance with the present invention;

FIG. **4** is a partially schematic view in perspective of a typical column cross brace connection;

FIG. **5** is a partial view showing a typical floor support connection;

FIG. **6** is a cross-sectional view of a single structural column including a liquid translator section in accordance with the present invention in the structure together with two floor support connections to the column;

FIG. **7** is a view in section of a presently preferred embodiment of the apparatus for translating hydraulic forces from the secondary members to cross bracing members within a structure;

FIG. **8** is a schematic hydraulic diagram of a system in accordance with the present invention;

FIG. **9** is an illustrative view of a column utilizing circulating fluid under pressure generated in accordance with the present invention to provide a steady flow of high velocity fluid to achieve a pre-stress level approaching the column load;

FIG. **10** is a detailed view of an embodiment of an accumulator utilized in connection with the column support members as shown in FIGS. **16** and **17**;

FIG. **11** is a view in elevation of a composite building in accordance with the present invention in which a combination of structural members in accordance with the present invention are utilized with conventional structural elements;

FIG. **12** is a view in perspective of the composite construction of the primary and secondary supports of the composite construction of FIG. **11**;

FIG. **13** is a schematic view of an alternative building construction in accordance with the present invention;

FIG. **14** is a partially schematic view of the interior circular ring support member of the building illustrated in FIG. **13**;

FIG. **15** is a sectional view of a tubular member such as used in the building of FIG. **13** which is prestressed in accordance with the present invention;

FIG. **16** is a sectional view showing prestressing member of FIG. **15** as it is utilized to pressurize the compressions ring of the building of FIG. **13**;

FIG. **17** is a view in elevation of a column foundation in accordance with the present invention for absorbing vertical and lateral displacement at the base of the column of the type which are encountered during earthquakes; and

FIG. **18** is a view of ring and cable connection of FIG. **14.**

Various features of the present invention are applicable to all building structures but the overall system concepts are most applicable to buildings upon which floor loadings are imposed. Accordingly, the present invention will be described in connection with the various types of buildings, it being understood, however, that the present invention is equally applicable to structures such as bridges.

Referring now to the drawings there is shown in FIG. **1** for purposes of illustration, a plan view of an illustrative building employing the construction of the present invention and in FIG. **2** there is shown a view in perspective of the building of FIG. **1.** In FIG. **3** there is shown three vertical columns and one cross-brace section typical of connections used throughout the building structure. In FIG. **3** the three vertical columns **20** are connected through hydraulic translators **22.** In FIG. **4** a single translator with primary column supports, cross-bracing and secondary floor support members is shown to illustrate the hydraulic flow and forces through a typical cross-brace translator. In FIG. **3** two floors **24** are illustrated as being supported by this typical bracing section. The static and live forces of the structure result primarily from the floor loadings with some additional forces generated by lateral loads such as wind forces on the building. Thus, under the loading conditions shown in FIG. **4** the vertical primary column **20** is normally in compression throughout its length extending to the foundation supports for the building. The axial prestress induced by means of the present invention can, however, result in no stress in tension or compression. The secondary supports **23** have the floors **24** attached to them as described hereinafter, and are thus always in tension. The cross-braces **21** will be in tension or compression dependent upon the direction and extent of lateral forces. In FIG. **4**, cross-braces **21*a*** and **21*c*** are shown in compression while **21*b*** and **21*d*** are in tension.

Referring to FIG. **2** in the illustrative building hydraulic joints identified as **22*a*** furnish support for the floors only. Hydraulic joints identified as **22*b*** support the floors when interconnected with joint **22*d*** whereas joints such as **22*c*** support two floors and function as a cross-brace. The support furnished and interrelationship of the joints is dependent upon the structure but various types of joints are shown in the structure in

FIG. 2. In the illustrative structure of FIG. 2 the joints identified as A support four floors; joints B and D are interconnected to support four floors; and joint C supports two floors while furnishing cross-bracing. Each of the joints 22*a* through 22*d* includes a hydraulic translator shown as typical in FIG. 6. In the structure as shown in FIGS. 1 and 2 a center core 25 of hydraulic construction in accordance with the present invention is also utilized. The hydraulic construction of the core frame is comparable to that described in connection with the skeletal or exterior frame and will not be separately described in detail. By utilizing such a core construction the core and exterior frame are joined by prestressed floors to increase interior volume and eliminate the need for additional columns or other structural vertical members in the spaces between the core and the exterior frame.

In FIG. 6 for purposes of illustration one floor is shown supported from the column which includes the translator 22. The floor is supported on a trapped volume of liquid to supply pressure to the system through the hydraulic translator. In FIGS. 1 through 6 the vertical columns 20 will support the floor slabs of the building, one of which floor slabs is shown in FIG. 6 and identified as 24. The slabs are supported from the columns but without lateral loading to the columns as set out in detail hereinafter. Each of the vertically extending columns in the illustrative embodiment of the present invention as shown in FIG. 6 is a pressurized column. An embodiment utilizing energized columns consisting of a plurality of individual tubular members is shown in FIG. 9. Energized columns are known to the art and briefly stated are ones in which a circulating fluid is utilized to prestress a column. Thus, to preclude local buckling the steady flow of fluid is used to achieve a prestress level equal to the load on the column. In the present invention, energized tubes known as the closed tube type are utilized, one of which is shown partially schematically in FIG. 9 and described more fully hereinafter. For purposes of describing the energized column, however, it can be seen by reference to FIG. 9 that the column contains a series of tubular members 28 spaced circumferentially within the column. The fluid flow is divided such that fluid under pressure from the translator is pumped downwardly through one-half of the tubes and upwardly through the other half. In such energized columns the fluid velocity is such as to produce an axial pre-force of the magnitude equal to the column load. In the unloaded condition both the horizontal and vertical members resist an axial force equal to one-half the column force while in the fluid circulating condition only the horizontal axial force is exerted upon the column. By selection of the proper velocity within the tubular cross section the loading can be equalized. The energized column can be thought of as comprising n closed tube elemental columns, each supporting the axial load divided by n. Due to fluid momentum of equal quantities of flow passing a given transverse section of column at any time, as the fluid velocity approaches infinity, for example the fluid weight approaches zero, thus the weight of the column and fluid together are less than that of a statically pressurized fluid filled column. In addition, the forces on the fluid produce a radial outward force (r). The circular column can be constructed with any radius desired by selecting n and the wall thickness of the closed tubular elements. By increasing the radius r, greater buckling resistance can be obtained. In summary, the centrifugal force developed by the moving fluid creates a tensile prestress in the walls of the tubular elements whose value can be increased by increasing fluid velocity without increasing the weight of the system, thus permitting greater structural advantages than columns without fluid flow.

As will become more apparent hereinafter, the tubular hydraulic columns of the present invention forming either pressurized columns or energized columns can be employed in many ways in combination with conventional structural columns. Such tubular members can be combined into all steel columns by being coupled within tubular structural columns or they can be connected with structural shapes such as I-beams, H-beams and the like. The tubular members forming the columns could also be combined into a composite column which is a concrete column or a tubular steel column filled with cement or other material. For purposes of illustration the tubular members are shown and described as components of a composite steel column, such columns being designated generally by the reference numeral 20.

In highrise buildings and other structures to which the present invention is particularly applicable, the strength required in the vertical columns will vary depending upon the height and loading of the building. A larger number of tubular support elements within, or forming the primary columns, will be utilized at the high loading portions of the column to thereby maintain the overall diameter of the column constant. That is, at the lower portion of the columns where the highest loads are encountered a larger number of tubular elements are employed to carry a larger proportion of the load while at the upper locations along the column less tubular elements are employed due to the decreased loading. In accordance with the present invention, the columns are supported at their base by means of the hydraulic foundation support shown particularly in FIGS. 16 and 17 and described hereinafter. The fluid pressure throughout the system is substantially uniform under static loads except for the relatively minor increase downwardly due to the static head of the fluid. When the pressure imbalance tends to occur within the system due to transient loading, such as lateral wind loads, increased live loads on the floor or earthquake loading, the entire overall pressure of the system tends to increase and mechanical redistribution of fluid results as will become more apparent hereinafter.

When desirable for structural reasons or economy the pressure within various portions of the columns and transducers can be varied or staged. One means would be the introduction of multiple stacked circuits in accordance with the present invention or by variation of pressures through areas utilized to generate the pressures.

The system of the present invention is energized by being filled with a liquid such as a glycol-water solution containing emulsions of soluble oil which act as rust inhibitors. Suitable sealing at all relatively moving surfaces is provided as will become more apparent hereinafter.

Referring now to FIGS. 5 and 6, each floor slab 24 is supported at its proper height in the building by the primary columns 20 through liquid under pressure. In conventional construction the slabs are fixed to the columns by means of tied supporting members such as horizontally extending beams connected to the vertically extending columns. Such connection places the column in compression and exerts a buckling load upon the column. Either the compression or buckling load are the design criteria for a column in accordance with normal building construction. By means of the present invention, however, as shown particularly in FIG. 6 the floor slabs are connected to the vertical column 20 by means of the hydraulic pressure translator designated generally as 22. By means of such hydraulic pressure translator the floor slabs are supported by axial tension in the secondary support members 23 and by liquid pressure transmitted throughout the system. The vertically extending fluid columns furnish a portion of the support strength of the support column 20. Thus, the load of the floor slab and that imposed from lateral thrusts upon the individual tubular members of the column is partially translated into a compressive force upon the fluid within the primary columnar members and secondary columnar and horizontal or diagonal bracing (in tension or compression) members such that their circumferential loading in tension is increased.

Positioned above the upper manifold 50 is an upper header 60 connected to the manifold by suitable bolted flanges or other mechanical coupling means 39. The liquid column elements 28 are connected to the header as in FIG. 6 for a pressurized column and as in FIG. 9 for an energized column. The liquid columns 28 are tubular elements which are connected into the header, preferably by quick connect and disconnect mechanisms which include a check valve 29, as shown schematically in FIG. 16. It is the purpose and function of the header assembly in general to conduct fluid under pressure to that portion of the system at which it is required. Thus, in the embodiment shown a liquid-header passage 62 is provided in the header in communication with each of the fluid columns 28, the plurality of which is contained within the support column 33 which may be concrete, steel or a combination of both. The liquid header 60 is, in turn, in fluid communication by means of a liquid passage 63 with the liquid outlet passage 53 through a system of two-way check valves to prevent any leakage as described more fully hereinafter. Similarly, a lower header 64 is connected at the lower end of the liquid translator by means of flanges 38. The construction of the lower header is comparable to the upper header, in that a liquid header passage 65 is in fluid communication through liquid passage 66 with the liquid outlet passage from the hydraulic translator through a system of two-way check valves. The liquid columns 28 are again affixed into the header. Positioned between the liquid outlet passage 53 from the pressure translator and the header passage 63 is a two-way check valve assembly through which fluid is conducted from the liquid side 22 of the piston to the header 62, and thus to the fluid columns 28 or vice versa, depending upon the circumstances.

The passage 70 is defined by two liquid branches, the first branch being a fill branch 73, with a fill valve 74 positioned therein; the second passage 71 has a neutral check valve 72 positioned therein. Thus, liquid is communicated from the liquid column 92 under pressure to the header 50 and thus to the liquid columns 28 by opening the fluid valve 74; after the columns have been filled with liquid, the fill valve 74 is closed, and a drop in pressure in the liquid columns will cause a pressure drop which in turn closes the short stroke check valve 72. A spring loaded plate 81 is placed in the header 50 to close the fluid path 62 in the event of a pressure drop in either the fluid columns 28 or the translator. For this purpose the plate 81 is in two spring loaded sections; the first section 81*a* is spring loaded normally away from the fluid passage 63 and is maintained in the open position by the pressure of the fluid from the fluid outlet passage 63. If the pressure in the outlet 63 drops the plate 81a closes the passage 63 to maintain the pressure in the tubular columns 28. Conversely if the pressure in the tubular columns fails, as by a rupture or the like the portion 81*b* of the plate is urged closed by the springs 82 and prevents further flow of liquid to the columns 28.

By conducting the liquid under pressure induced by the loading on the floor slab through the inlet passages 52 and 56 to opposite sides of the free floating piston 41 a pressure balance above and below the piston in the liquid spaces 42 and 43 is achieved. The pressure of that liquid is then transmitted as previously described through the pressure outlet openings 63 and 66 into the tubular column elements 28 to thereby pressurize each of those elements equally. Additional liquid under pressure is availale through the liquid outlet passages 103 and 104 for pressurizing those auxiliary structural members such as cross braces. The liquid columns 28 forming part of the support column 20 are thus pressurized and an increase in structural strength of the composite column can be achieved.

If additional liquid is required within the system, due to an adverse loading condition or because of leakage, the pressure balance within the liquid translator will be disturbed and the piston 91 as shown in FIGS. 6 and 7 will move toward its upper or lower extremity of travel. If it reaches either extremity an automatic switch is positioned on the top and bottom surface of the piston and is triggered when the piston touches either of these travel extremities. When the switch is actuated, a built-in pump 89*b* is started and additional liquid is drawn to or from the common accumulator circuit to the respective chamber as shown, particularly for chamber 93, in FIG. 8.

In an alternative embodiment of the present invention, the floating piston 41 of the translator 22 can be omitted. One of the improvements of this invention over U.S. Pat. No. 3,538,653 is the elimination of the rolling diaphragm seals and the need to predetermine the direction of building movement to modulate the flows to the various interconnected members. By revised circuiting of the present invention a hydraulic structure which is adaptable to all force modes (combinations of secondary floor support, cross brace movements, etc.) is possible with the use of directional valves and/or pumps.

Furthermore, the piston shown in the primary column can be eliminated if desired. The latter piston serves to minimize shock loading effects resulting from pressure rise by a quick stop of the flow of any of its circuits and/or quick pressure drop. Decompression shock can prove as destructive as compression shock, particularly in large bore cylinders of the type illustrated. The design of the piston size, weight, and geometry are determined by the magnitude of pressure difference anticipated, its duration, the anticipated time span between the minimum and maximum pressure levels, and the area affected by the shock. The rings at either end act as cushions that provide positive, gradual deceleration and are tapered to eliminate shock upon entrance of free floating piston. It should be appreciated that an accumulator, discharging rapidly in response to building movements, often tends to amplify shock conditions by its inherent time lag.

Where shock conditions permit elimination of free floating pistons, a simplified, primary column design is utilized.

Referring now to FIG. **9** there is shown the embodiment of the primary column when an energized column is utilized rather than a pressurized column as shown in FIG. **6** and previously described. Thus, referring to FIG. **9** the manifold section **50** and the header section are comparable to, or the same as, those previously described. The header, however, in the energized column embodiment has only two fluid outlets at each end shown as **82** and **83** in FIG. **9**, whereas in the embodiment of FIG. **6** a fluid outlet from the header is provided for each tubular fluid column. A submersible pump **86** is positioned in the fluid chamber to one side of the partition wall. The pump is so constructed and arranged within the liquid volume that it has a suction side at one side of the partition wall and a liquid outlet at the other side of the partition wall. Thus, as shown in the figure, the pump is placed in one-half of the liquid chamber and pumps through a port into the other half of the liquid chamber. The tubular column elements **28** are then connected as shown in FIG. **9** to be in fluid communication with the upper liquid chamber **88** and the lower liquid chamber **89**. As shown in FIG. **9** the tubular elements **28** are arranged within the steel column or within a combination of steel and concrete. As shown in FIG. **9** the pump **86A** then draws liquid upwardly through the liquid columns **28A** at one side of the primary support column and discharges the liquid into the other half of the liquid reservoir **88** such that it flows downwardly through the fluid columns **28B** conversely, the liquid pump **86B** has its suction side on the upwardly flowing columns such that a closed circuit of high velocity liquid under pressure is maintained through the tubular columns **28**. Although two pumps are shown, one is sufficient to maintain the fluid flow. By utilizing two pumps if one fails circulation can be maintained by the single remaining pump, thus improving reliability.

As shown in FIGS. **5** and **6**, there is attached to the primary support column a bracket **90** for supporting the load of the floor slab **24** by means of a transducer assembly including a piston supported by a contained volume of liquid and transmitting the loading on the floors as the source of hydraulic pressure within the structure. A cylinder **93** containing a closed volume of liquid is in turn affixed to the bracket **90** or to the column by any suitable mechanical means and it is preferable that a plurality of brackets be affixed at the diametrically opposed points on the column for concentricity of load. Between the cylinder and the translator assembly, the cylinder is connected by means of a liquid conduit **92** to the liquid inlets **52** and **56** of the hydraulic translator. A piston **91** is positioned within the cylinder with a piston rod **95** extending from the piston outwardly from the upper end of the cylinder **93**. The cylinder is sealed by suitable means which allow vertical movement of the piston rod while preventing leakage of liquid from the cylinder. In the presently preferred embodiment a double metallic o-ring seal **96** is utilized. The cylinder is filled with liquid and the pressure conduit **92** is connected in communication with the portion of the cylinder above the piston. Thus, a load imposed on the cylinder housing is transmitted to the liquid above the piston to increase the pressure thereof and that liquid pressure is transmitted through the liquid conduit **92**. A floor slab **24** is connected to the cylinder housing through any suitable mechanical means, one example of which is shown in FIG. **5**. The transducer assembly thus, for example, extends from the interface at **90***a* to the interface at **90***b*. In FIG. **5**, an embodiment particularly adapted to space frame construction is shown in which the slab **24** is attached to an angle iron **96** which is in turn connected to a bracket **97** mounted upon the cylinder housing **93**. In the embodiment illustrated in FIGS. **5, 6** and **2** the floor slab **24** is supported by the piston rod **95** which is in tension. The piston rod **95** is connected to piston **91** which is supported by the body of liquid under pressure within the cylinder **93**. The liquid within the cylinder **93** is thus placed under high pressure by the load of the floor slab through the piston and this pressure is transmitted through the liquid conduit **92** to the liquid inlet ports **52** and **56** of the pressure translator **22**. In the branches which lead from the liquid conduit **92** to the liquid inlet ports, i.e., branches **99** and **100** in FIG. **6**, there are positioned appropriate check valves **101** which allow flow of liquid only in the direction into the pressure translator. There is also positioned in the branch lines orifice assemblies **102** which allow the insertion of orifices of different openings to thereby vary the pressure of liquid into the particular pressure translator. That is as previously described, the system of the present invention is adaptable to an overall liquid balanced construction of a building or other structure. In high-rise buildings of magnitude over six stories, for example, the pressure in support columns can be increased at the lower portions of the columns where the compressive force is greatest. This allows the use of less expensive tubular materials at the upper portions where less strength is required. At various discontinuities different circuits and transducers generating different pressures can be utilized. In FIG. **7** there is shown an alternative embodiment of the present invention in which the secondary supports from which the floor slabs **24** are hung are also pressurized for increased strength. In the embodiment of FIG. **7** the piston rod **95** extends downwardly from the piston **91** such that the piston **91** rests upon the cushion of liquid under pressure in chamber **93***a*. The liquid under pressure is not only transmitted to the column elements **28** through the translator **22** by way of pressure conduit **92** but also into columns **28***c* forming the secondary support from which the floor slab **24** is suspended. Additional fluid pressurization or return of internal leakage can be returned by pump to the system through line **127** to accumulator **128**.

Not only can columnar or transducer pressurization be varied but hydraulic building or structure section can be combined with non-hydraulic conventional building systems for esthetic or economic reasons.

Referring now to FIGS. **2, 3** and **4**, there is shown a building constructed in accordance with the present invention which provides a liquid filled bracing system and in particular a type of construction utilizing the liquid supported floor suspension system. In the building shown schematically in FIG. **2** a core structure is formed utilizing the elements of the present invention and an exterior or outer frame is also formed using the hydraulic translators of the present invention as floor supports as interconnecting elements between the floors and the support column and as cross-bracing elements. One such composite framing element is shown particularly in FIG. 3.

Referring to FIG. 2, structural strength is maximized in the various columns, floor supports, cross-brace members, etc., by means of a multiplicity of tubular elements filled with fluid, i.e., inhibited glycol-water solution. The fluid operates to redistribute a high proportion of axial and lateral load among the various structural members joined together, while providing a natural prestress effect. This, in turn, permits higher loading than current practice will allow in comparable solid members of the same length. Tubular elements are used to construct the primary columns and the secondary floor or crossbrace supports which are maintained by floating pistons and carry a grouping of several floors as shown.

In FIG. 2 there is shown an idealized square building with center core and skeletal structural frame joined by means of a prestressed floor to eliminate interior columns. Fluid filled columns, cross-braces, etc., in actual practice may be placed on the exterior as shown, arranged in shear walls or placed within the exterior skin, depending upon the desired architectural effect.

Diagonal bracing placed on the exterior frame creates vertical trusses and gives the building a high torsional stiffness, improved resistance to earthquake, etc. Slender tension members hung from every point of intersection of the diagonal bracing support the load of one or more floors. The load then travels down to exterior (or interior) columns with lateral and axial forces partially reacted by fluid. The tension member concept in addition to its participation in the over-all truss, affords an opportunity to eliminate about one-half the number of columns that might otherwise be required using traditional methods.

The present invention provides an improved means for the design of tall structures that economically resist wind and earthquake forces. Earthquake forces which act upon the structure result from erratic vibratory motion of the ground upon which the structure is supported. Additionally, however, on very tall structures such as those above forty stories in height the wind forces approach the order of magnitude of seismic forces. The present invention has the capacity to absorb and redistribute such impact loads to dampen prevailing frequencies. Thus, in conjunction with the previously described construction of the present invention for specifically damping transient loads a damping bar is connected between each floor slab **24** and the adjacent primary column with a joint on either end similar to **96,** FIG. **6.** A viscous energy absorber is provided in each damping rod. The energy absorber comprises a closed liquid filled cylinder affixed to one position of the damping rod and a perforated piston affixed to the other portion of the rod. The piston is longitudinally movable within the cylinder. The perforations through the piston allow the piston to move within the fluid but in a damped manner. Thus the rod can be lengthened or shortened but the rate at which either occurs is governed by the number and size of the perforations through the piston through which the fluid must flow when the piston moves within the cylinder.

A building in accordance with the present invention if assumed to be a linear model could be expressed as:

$\{F\} = [m]\{\ddot{x}\} + [c]\{\dot{x}\} + [k]\{x\} - [S]\{x\}$

where $[M]$, $[C]$, $[K]$, and $[S]$ represent respectively the mass, damping, stiffness and stability matrix and $\{x\}$, $\{\ddot{x}\}$, $\{\dot{x}\}$, and $\{F\}$, represent respectively the acceleration, velocity, displacement, and forcing function of the structure. The forcing function can be thought of as the characteristic energy input from earthquake or wind, etc. which sets the basic structure in motion. By proper selection of the hydraulic factors that establish the damping and stiffness matrix, the acceleration $\{\ddot{x}\}$ and displacement $\{x\}$ of the overall structure can be critically damped for the probable range of earthquake energy levels which principally occur in frequencies ranging from approximately 0.1 to 10 cycles per second, corresponding respectively to the natural periods of a short (one story) building to a tall (100 story) building, etc.

The hydraulic building structure is soft (rather than stiff). However, the stiffness matrix $[K]$ is relatively high by virtue of the separated columinar frame, cross-bracing, etc. Since the value of the damping matrix at any limit $[C]$ can be increased upon excitation by the various mechanisms previously described (since it can be shown that $[C] = [C]_1 + [C]_2x^2$ the structure can be programmed to approach high values of critical damping for the predetermined natural frequency of the structure.

Pressurized fluid within the tubular structures illustrated, not only operates to provide favorable damping characteristics as earlier described, but also inertial forces, as described by the term $[S]\{x\}$.

The ratio of $[k]\{x\}/[S]\{x\}$ represents the ratio between the critical buckling load and the axial load used to generate the stability matrix $[S]$. By means of careful selection of fluid axial prestress levels, maintained within the tubular elements, the natural frequency of the basic structure can be favorably modified so that the resultant displacement of the structure $\{x\}$ can be minimized for a given level of $\{F\}$ and the stability matrix $[S]$ is significantly improved over comparable solid membered structures.

Referring now to FIG. **8** in order to clarify the liquid flow through a typical portion of a building constructed in accordance with the present invention a flow diagram of the hydraulics of the system is shown. The floor actuated piston **91** is shown schematically and induces a pressure on the liquid contained in the chamber **93***a* of cylinder **93** as previously described which pressure is then transmitted through the pressure conduit **92** to the chambers above and below the floating piston **41** of the translator **22.** The translator shown as **22** is one of the type contained in a column which in turn transmits liquid under pressure to the tubular elements **28** contained within a support column. Typical cross-bracing or horizontal actuators are shown as **22***c* and **22***d* in FIG. **8** consistently with their location in the structure as shown in FIG. **2.** The direction of liquid or pressure flow in the diagram is shown by the arrows in the various conduits. Thus, the pressure in the system is induced by the slab **24** at the piston **91** the load initiating pressure translator being shown as the embodiment in which the load supporting piston rod **95.** The fluid under pressure is transmitted from the load initiating cylinder through check valve **100** and **101** and through the variable orifices **102** and **103** through the inlets ports of the pressure translator **22**. The orifices **102** and **103** are sized to admit the desired amount of pressure to the chambers above and below the floating piston **41** which pressure is determined by the location of the translator in the over-all system. The pressure is then transmitted from the translator **22** into the tubular elements **28** again through suitable valving as at **70** to pressurize the tubular elements **28** which form part of the primary support column **33**. The check valve shown as **29** are check valves which allow a field connected-disconnected construction for the primary column. One cross-brace translator with a cross-brace **21***a* in compression and one translator with a cross-brace **21***b* in tension are shown for purposes of illustration. An accumulator **89***a* with a filter **89***c* is also shown. Thus, it can be seen that the weight of the floor slab on piston **91** (also shown in FIG. **6**) causes pressure in the liquid beneath the piston **91** to be transmitted to the underside of the floating piston **41** in the translator **22**. By means of the floating piston the pressure is equalized on the upper side of the piston **41** and the resultant high pressure is transmitted to the column member **28** above and below the translator in the primary support columns. Similarly since cross-brace member **21***b* is in tension high-pressure is generated at the underside of the piston **91***b* of that cross-brace transducer while in the cross-brace transducer **21***b* high pressure is generated at the upper side of the piston **91***b* since that member is in compression. The resultant high pressure is transmitted to the low pressure side of the respective piston, as well as to the pressurized support members **21***a* and **21***b* of the cross-braces. By means of the hydraulic circuitry and transducer pumps all pressurized support members are at balanced high pressure induced by the various force bearing members of the structure.

The coil conditions of the building site in areas prone to earthquake can materially effect the degree of damage to a building structure subjected to vertical, horizontal, torsional, and/or rocking oscillations. Of principal concern in lurching, soil amplification, and soil interaction is the response of the structure through its footings and foundation that can be traced to characteristic soil properties, i.e., density, damping shearing modulus, poissons ratio, geometry of layers, etc., responding to incident surface, shear and/or P wave velocities, emanating from the exciting mechanism. It has been shown that all modes of vibration of a rigid circular footing, resting on an elastic medium, can be represented by an equilibrium equation similar to a damped single degree of freedom system, except for the fact that the equivalent damping and spring factors are functions of the frequency of vibration. The reaction of a rigid structure on flexible soil differs substantially from a flexible structure on rigid soil. Although the magnitude of such reactions can be estimated from analysis of core specimens and that subsequent analysis of soil mechanisms of the site, limitations of duplicating soil conditions at various points in the subsurface soil structure in the laboratory make accurate prediction of forces, developed by soil reaction on the base of the footing, somewhat questionable. To avoid the uncertainties of response to a potentially wide range of the translational modes of vibrations we have developed an hydraulic footing, capable of physical isolation of foundations responding simultaneously to the six degrees of freedom possible for the motion of a rigid body, namely translation in the three coordinate axis and rotation about each of the axes, including coupled motion, exhibited principally as rocking and sliding.

Isolation of structures and foundations from ground motions has been attempted in the past, using trenches and sheet wall barriers that fully surround the source of vibration. Yet, such methods are of limited value when dealing with earthquake generated shear waves, impinging normally to ground surfaces below foundations. The configuration shown acts as a vibration transducer with inherent damping and energy absorbing features which operate to minimize effects upon fluid filled or conventional structures placed as shown upon it.

Referring now to FIGS. **16** and **17** there is shown a hydraulic foundation support in accordance with the present invention which allows both vertical and lateral movement of the earth at the foundation for the primary columns of the structure without vertical or lateral displacement of the column. Thus, the columns and the building or other structures are isolated from the adverse effects of earth movement due to earthquakes. In the embodiment shown the primary column **10** terminates in a piston **120** which includes an accumulator **121**, shown particularly in FIG. **10**, to allow the flow of liquid to and from the accumulator depending upon the exterior pressure of the liquid which is contained within a chamber defined between the piston and an open ended cylinder **123**. Thus, as shown in FIGS. **17** and **10**, a quantity of liquid **124** is entrapped beneath the lower surface **125** of the piston upon which the primary column rests. Suitable pressure filled metallic o-rings or equivalent seals are contained within the inner wall of the cylinder in sealing contact with the outer surface of the piston such that the liquid within the cylinder **123** is entrapped and furnished with the vertical support for the piston **120** and thus for the primary column **10**. If earth movements or other severe shocks cause a relative force upwardly upon the foundation the cylinder **123** tries to move up along the piston **120** and thus places the liquid into greater pressure at which time the valves **126** in the accumulator **121** open and allow the liquid to flow into the accumulator in order that the cylinder can move upwardly relative to the column without a resulting movement of the column. Similarly the primary column is laterally moveable relative to the foundation. In the embodiment shown a series of radially extending plates **127** are affixed to the primary column **10** and are contained within a fluid filled annulus **128** which forms a portion of the foundation support. Suitable means are provided for capturing the fluid within the annulus as by pressure filled o-rings shown in FIG. **17**. The foundation annulus has a series of inwardly extended radial plates **129** which overlap in radius the column plates as shown in FIG. **16**. The radial plates affixed to both the column and to the foundation are perforated. Thus, if the column tries to move laterally, it is damped by disapation of energy resulting from the fluid flowing through the openings in the various plates via tortuous path, etc., and the foundation can move without causing a similar movement of the column. An accumulator such as shown in FIG. **10** can also be used by being mounted in combination with the primary supports of the structures described to allow compensation for sudden compression or decompression shocks in the hydraulic system.

One of the principal features of the subject invention is the dynamic seals, located in the various components, which in addition to containing pressure, are designed to withstand relative motion without dragging, wearing, galling, or welding, when subjected to ground motion or wind excitation. Such seals are well known in the art and comprise metallic o-ring, labyrinth, metal lip, and two stage seals or combinations of the above, as appropriate.

In the case of the secondary floor support and cross-brace seals that operate to house a shaft which must pass into, or out of, an area of pressurized fluid, the axial mechanical seal is composed of materials that lap each other in a very fine fit, providing a very small axial laminar path. By control of the quality of fit at these critical system points the flow is reduced to a level at which the fluid surface tension can complete the seal and there is no leakage. Wear is reduced by balancing of the pressure induced sealing forces.

For seals joining the various internal members, a drain at, or between, seals can connect to a system return line (not shown) which can be returned to the nearest adjacent accumulator by means of a single acting or reciprocating intensifier (not shown) that boosts the low pressure leakage oil to higher pressure by adding input horsepower to the circuit by taking advantage of the principle of ratio of areas. For example, a single acting intensifier has two different cylinder bores with matching pistons mounted on a common shaft. Low pressure internal drainage (return fluid) flows to the large cylinder end and acts on the large piston area. The resulting force is transmitted by the smaller piston to the fluid in the smaller chamber, thereby providing sufficient pressure multiplication to overcome the accumulator level setting in the same ratio as the piston area, etc. Volumetric pump output is intermittent and determined by the smaller piston diameter and stroke which is carefully matched to overcome design leakage rates of internal seals, etc.

Referring now to FIGS. **11** and **12**, there is shown a specific building structure also in accordance with the present invention in which all of the floors of the structure are hung from overhead support members **140** without the necessity of interior columns. The overhead members are supported by vertical columns **141** and all of the load bearing structure **142** is hung from the overhead support **140** by means of a piston supported by a volume of liquid, as previously described, such that the load is transposed to pressure in the liquid within cylinders **143**. The pressure of the liquid is then transmitted to conduits **144** only one of which is shown to thereby pressurize and increase the strength of the support members **140**. The column **141** can be conventional construction or can be of hydraulic construction with a transducer section at the upper end to thereby transpose the load of the support member **140** to liquid pressure which is transmitted to pressurize sections of the column **141**.

Similarly in FIGS. **13** and **14** there is shown a structure in which a support annulus **146** is pressurized by the transmission of liquid pressure through radially extending support members **147** the pressure in the liquid again being obtained by suspending the building loads from a closed volume of liquid as previously described. In FIGS. **15** and **18** pressurized liquid is generated by the roof and bearing member loads being transmitted to the piston **132** to allow transmission of liquid pressure through the conduit opening **134** and through apertures **135** to thereby prestress the skin **130**. This prestressing by load induced pressure is applicable to many other structures such as catenarys for bridges and the like.

I claim:

1. A structure comprising:

support columns extending upwardly from column foundations;

a piston at the lower end of each of said support columns;

load bearing members connected to and supported by said support columns;

said column foundations comprising means at the lower end of said piston supporting said column on a volume of liquid;

means in combination with said piston to allow passage of liquid past said piston if said column support is displaced vertically;

means laterally supporting said column in said body of liquid; and

means in combination with said lateral support means to allow passage of liquid if said lateral support is displaced horizontally.

2. The apparatus as defined in claim **1** in which said piston support includes a pressure loaded accumulator;

said piston being supported within a cylinder upon a body of liquid; and

said accumulator being so constructed and arranged as to allow passage of liquid into and from said cylinder if said cylinder is vertically displaced.

3. The apparatus as defined in claim **2** wherein said lateral support includes a series of circumferentially spaced vanes affixed to said column;

said vanes being positioned within a closed liquid filled annulus;

said vanes including means to allow movement of said vanes within said annulus if said foundation is laterally displaced.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,796,017 Dated April 24, 1972

Inventor(s) Milton Meckler

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Drawings:

Figure 4, the reference numeral "21e" should read -- 21c --. Figure 6, the reference numeral "96" should be deleted. Figure 8, the reference numeral "89" should read -- 89c --; Figure 8, the reference numeral "93" should read -- 93a --. Column 3, line 59, "with" should read -- which --; line 64, "creating" should read -- created --. Column 5, line 11, "wieght" should read -- weight --. Column 9, line 32, "FIG. 16" should read -- FIG. 8 --. Column 10, line 24, "availale" should read -- available --. Column 14, line 6, the order of the symbols should be -- $\{\dot{x}\}$, $\{\acute{x}\}$, $\{x\}$ --; Column 15, line 27, the reference numeral "21b" should read -- 21a --; line 28, the reference numeral "91b" should read -- 91a --; line 37, "coil" should read -- soil --.

Signed and sealed this 5th day of November 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents