

Nov. 10, 1970

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3,538,653

HYDRUALIC CONSTRUCTION SYSTEM

Filed Dec. 30, 1968

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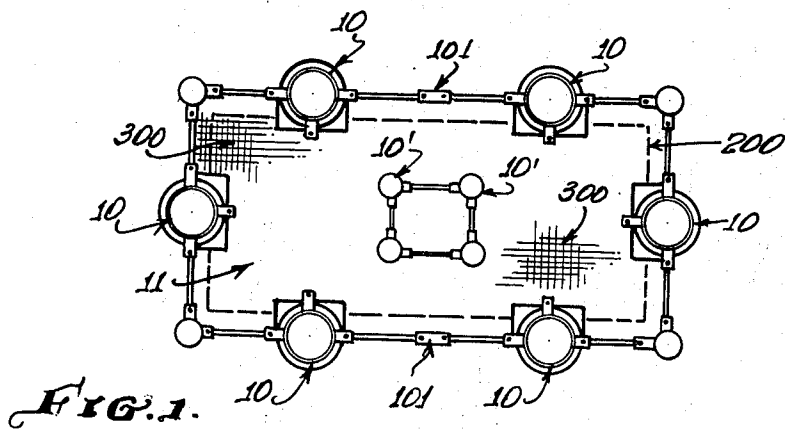


FIG. 5.

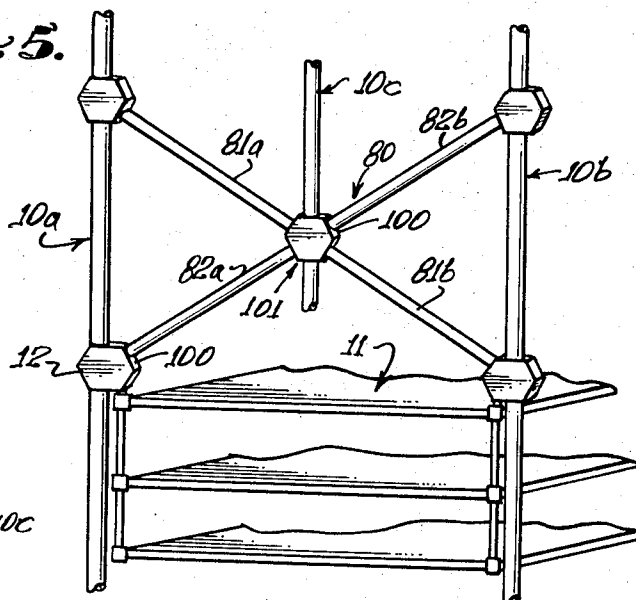
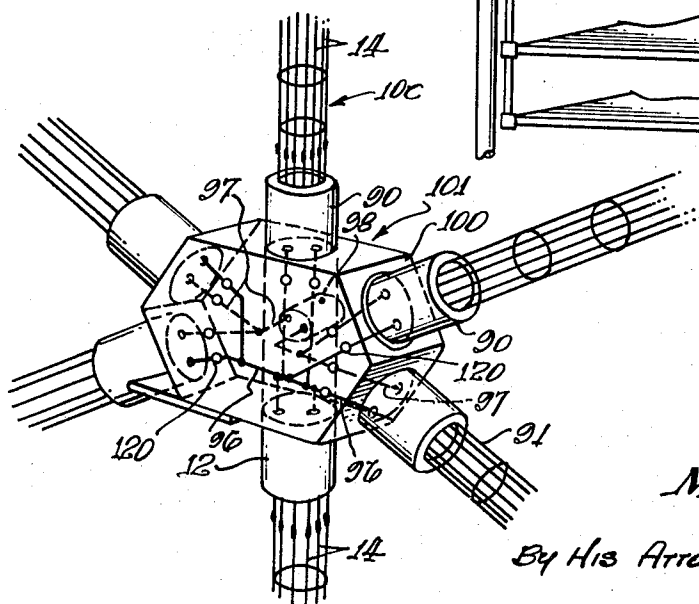


FIG. 6.



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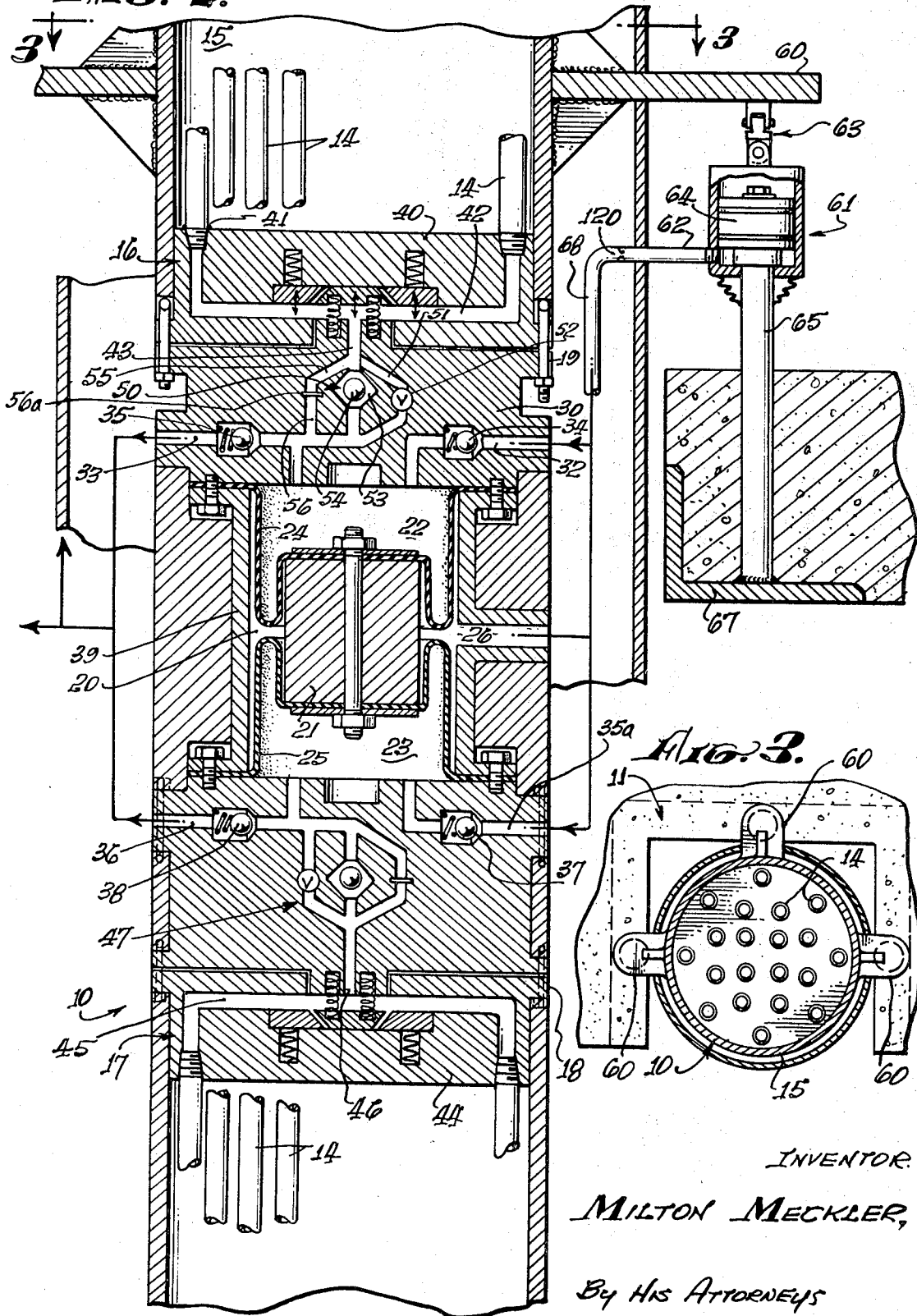
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HYDRUALIC CONSTRUCTION SYSTEM

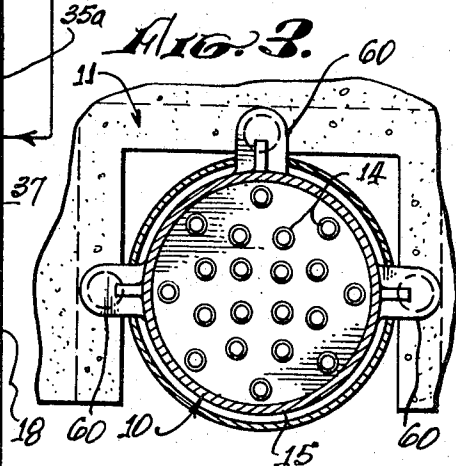
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FIG. 2.



416.3.



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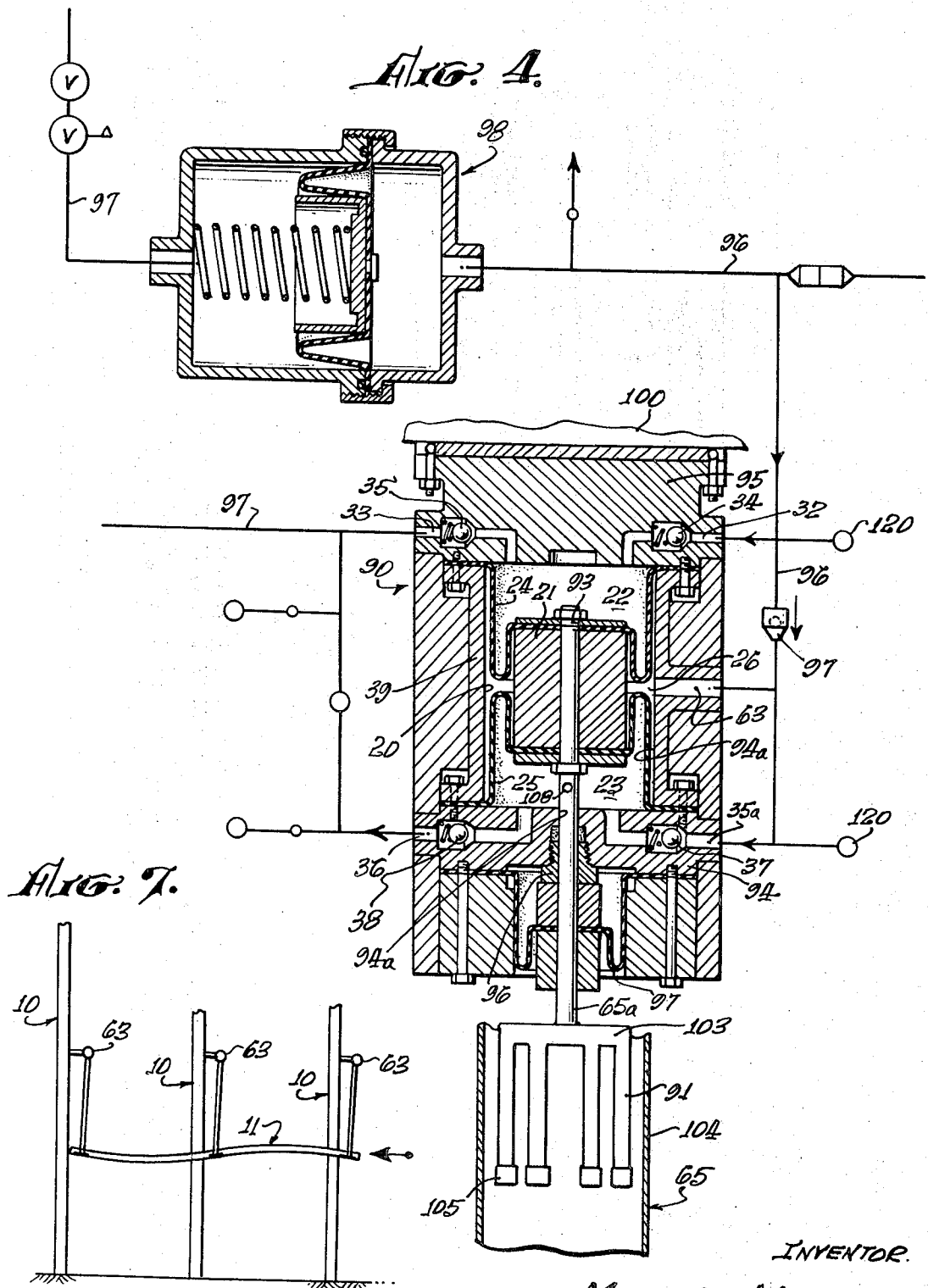
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HYDRAULIC CONSTRUCTION SYSTEM

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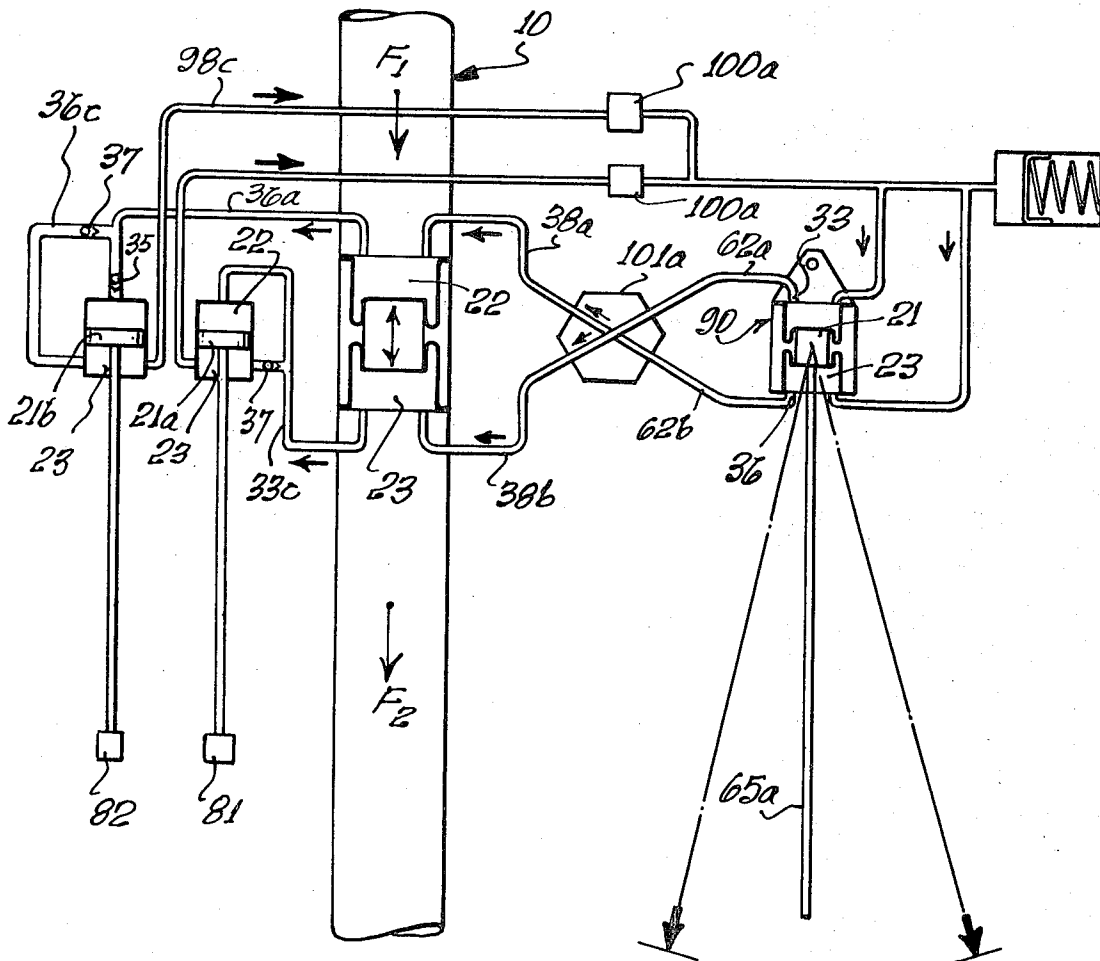
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HYDRUALIC CONSTRUCTION SYSTEM

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Fig. 8.



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HYDRAULIC CONSTRUCTION SYSTEM

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16 Claims

ABSTRACT OF THE DISCLOSURE

A building system for high rise construction which lends itself to 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 present 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 act also as vertical bars in composite concrete columns or as secondary support (tension) or cross brace members. The tubular primary columns in accordance with the present invention of the building are tubular hollow members which are placed in tension through circumferential stress by means of the hydraulic system of the present invention. The secondary tubular 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 column end conditions of the slender tubular columns.

BACKGROUND OF THE INVENTION

The building industry has become more and more conscious of the need for modular or prefabricated construction, due to the increase in cost of materials and labor. To the present, however, in high rise construction the use of modules to a large extent is limited primarily to the use of curtain wall construction, ceiling grids, modular partitions, etc. The use of curtain wall construction and modular ceiling construction has shown the design possibilities of modules and the need of coordinated components in any process of assembly. The adaptability of many functional interrelated building products to a concept of assembly by modular parts with the result in economy in time and labor have indicated a necessity for further modular construction in the building industry. There is, of course, factory assembly and mass production of components to be used in construction but the actual prefabrication of the parts for rapid erection at the building site consistent with current site assembly methods has not as yet progressed to a significant point in terms of materially reducing the cost or rate of assembly of high rise buildings.

A primary consideration in high rise building construction particularly is the necessity for designing structures to

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resist large lateral forces especially those exerted by wind and earthquakes. The necessity of standardized earthquake design has been brought into sharp focus in recent years by events such as the Good Friday earthquake in Anchorage, Alaska, and more recently in Missouri and Pennsylvania. Earthquake forces upon the structure result from erratic vibratory motion of the ground upon which the structure is supported. The ground vibrates both vertically and horizontally, but it has been customary to neglect in building design vertical components of such movement since most conventionally designed structures by virtue of their excess strength to load properties have considerable excess strength in the vertical direction which is further exaggerated through the application of standard safety factor requirements. For most of the requirements vital to earthquake resistant design of all types of buildings is the necessity of tying the critical elements of the building, i.e., columns, floors, walls, etc., together so that it acts as a fully unitized structure when undergoing severe lateral thrusts with the capability for self-damping. Generally this requirement is not stated in detail by the various building codes but must of necessity be left to the judgment of the responsible engineers. The present practice is to use actual design coefficients since they constitute the basic justification for designing with earthquake coefficients of 2½% to 13% G. The walls, however, must be substantially anchored to the rest of the structure to resist a force of 2% G.

A large number of uneconomical operations and waste of structural material 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 value 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 but also because of any increase in moment due to an increase in moment arm by lateral deflection between the ends of the column. A column with equal and opposite moments at the ends is bowed in 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. 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 compression and/or tension forces could be translated to act along material planes exhibiting superior volume to weight or volume to stress ratios.

SUMMARY OF THE INVENTION

The present invention is an hydraulic core structural construction for buildings which maximizes the benefits of unitized design by translating a sizeable proportion

of axially applied compression or tension forces into circumferential tension forces acting in the plane of the high strength skin of the primary and secondary members interacting hydraulically to meet maximum coincident loading conditions. 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. The secondary members supporting the floor can also be tubular members with fluid under pressure created by the weight of the floors such that the pressure in the secondary tubular elements (developed by weight of floors) 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 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.

In slender composite concrete columns having the hydraulic tubular columns positioned therein a large portion of the total load is carried by the hydraulic tubular members which are mechanically coupled into a composite continuous column.

By means of the present invention greater free span areas are possible in a building since the floor can be prestressed with fluid, or steel and erected by lift-slab or poured-in-place techniques. The present invention makes feasible the ability to utilize space frame construction of roof and ceiling areas of all intermediate floors and the adaptability of the overall building construction to modularity and prefabrication.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. 2 is a cross-sectional view of a single structural column including a liquid translator section in accordance with the present invention in a structure together with two floor support connections to the column;

FIG. 3 is a sectional view taken along line 3—3 of FIG. 2;

FIG. 4 is a presently preferred embodiment of the apparatus for translating hydraulic forces to secondary members or providing cross-bracing members within a structure;

FIG. 5 is a view of cross-bracing in accordance with the present invention applied between two columns;

FIG. 6 is a partial schematic view of the apparatus as shown in FIG. 4 interconnected and with forces applied;

FIG. 7 is a schematic diagram showing forces upon the structure, and

FIG. 8 is a schematic representation of the apparatus of the present invention illustrative of the flow of fluid in an X-brace embodiment.

Referring now to the drawings, there is shown in FIG. 1 for purposes of clarity and description, a floor plan of an illustrative building employing the construction of the present invention. A schematic illustration of three columns of the building under lateral load conditions is shown in FIG. 7. In the plan view of FIG. 1, six primary vertically extending peripheral support columns 10 are shown with interior columns 10' around a building core opening. These columns will support the floor slabs of the building, one of which floor slabs shown in FIG. 1 is identified as 11. 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 is a composite steel column consisting of a plurality of individual tubular members of predetermined wall thickness as described hereinafter.

As will become more apparent hereinafter, the tubular hydraulic columns of the present invention 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 can be connected with structural shapes such as I-beams, H-beams and the like, such that they support a portion of the loading of the columns. The tubular members can also be combined into a composite column such as 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 concrete column, such column being designated generally by the reference numeral 10. In this embodiment a concrete column containing a plurality of tubular hydraulic column members is shown for purposes of illustration and description. A section of such column 10 is shown in FIGS. 2 and 3. In a high rise building in which the present invention has particular utility the number of tubular column elements designated as 14 would vary along the height of the building. Thus, a larger number of such elements can 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 portions of the column where the highest loads are encountered a large number of tubular elements are employed to carry a large proportion of the load while at the upper locations along the column 10 less tubular elements are employed due to the decreased loading. The columns are supported in conventional manner upon a building foundation and the overall height of such columns is dependent, of course, upon the height of the building under construction. Each of the composite columns 10 contains and is bonded or otherwise connected to a plurality of tubular columns 14. The tubular column elements are in turn filled with a liquid such as glycol-water solutions containing aqueous emulsions of soluble oil acting as rust inhibitors, and is sealed in a manner described hereinafter. Each floor slab 11 is supported at its proper height in the building by the primary columns 10 through the liquid under pressure. In conventional construction the slabs would be affixed by means of tied supporting members such as horizontally extending beams connected to the vertically extending columns by rivets, welding, or the like. Such connection would then place the column in compression and exert the buckling load upon the column. Either the compression or buckling load are the design criteria for a column 10 in normal building construction. In accordance

with the present invention, however, as shown in FIG. 2, the floor slabs are connected to the vertical column 10 by means of a hydraulic pressure translator designated generally as 12. By means of such hydraulic pressure translator the floor slabs are supported by axial tension in the secondary support members and by liquid pressure transmitted as circumferential stress to the skin of the secondary and primary members. The vertically extending primary fluid columns 14 in turn furnish a portion of the support strength of the support column 10. 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 strength in tension is sufficient to help support the fluid pressure exerted upon it as outward or circumferential pressure in the individual tubular members. Excessive circumferential pressure is avoided by use of orifices placed in interconnecting hydraulic lines which act to prevent too much force from being applied to any one member as well as serving to uniformly distribute forces to reacting members proportional to their load bearing capacities. In the secondary members from which the floor load is supported in tension such axial tensile load on the secondary members is transposed to a lesser tensile stress in the skin due to the composite force on the member created by the axial load and the outward circumferential load imposed by the pressure of the liquid supporting the floor load. Thus, in accordance with the present invention each support column 10 in the structure includes a structural column 15, such as the concrete column of circular cross-section shown in FIGS. 2 and 3, a plurality of tubular column elements 14 which form part of the column 10 by being bonded or otherwise connected to the structural column 15, and a plurality of pressure translators interposed at predetermined positions within the column at spacings determined to maintain particular floor slab positions. In the illustrative embodiment, for example, the plurality of tubular elements 14 and pressure translators 12 are prefabricated and ready for on-site assembly to form the columns as well as other structural elements such as framing and diagonal or horizontal bracing which is to be subjected to loading. The secondary members, e.g., floor supports, or horizontal bracing, are also prefabricated. The tubular elements are formed in convenient lengths and coupled to adjoining lengths by conventional means such as reinforcing ties or as a tube sheet 16 (FIG. 3). The tube sheets or equivalent means of tying together the vertical hydraulic elements when occurring between pressure translators are perforated or otherwise provide for the passage of concrete during subsequent pouring or slip forming operations. As construction of the building progresses each bundle of tubular elements is coupled to a tube sheet or a pressure translator, as described hereinafter, after which the concrete column is formed and bonded to the tubular elements by pouring, slip-forming or other well known means. In the illustrative embodiment the tubular elements are thus contained within and bonded to the concrete column to form with the pressure translators 12 the composite support columns 10. Referring now to FIGS. 2 and 5, the presently preferred column hydraulic pressure translator 12 is shown as applied to a single column within the building structure as shown in FIG. 1. In the embodiment of FIG. 1 no liquid under pressure is transmitted to the interior of the secondary member 65 as in the embodiment of FIG. 4 described below.

In FIGS. 2 and 3 the hydraulic translator is shown connected between two sections 17 and 17a of the vertically extending column 10. The hydraulic translator is so constructed and arranged relative to the column that it is inserted therein at a given location as required to provide uniform floor spacing. Thus, as shown in FIG. 2 the hydraulic translator 12 is coupled by conventional means,

such as flanges 18 and 19 to the two sections 17 and 17a so as to make a continuous vertically extending structural column. In the illustrative embodiment the hydraulic translator is shown in section in FIG. 2. The hydraulic translator in this embodiment has a housing of circular or rectangular cross-sectional exterior coextensive to that of the column sections 17 and 17a. The exterior dimensions of the column are uniform throughout their length, the difference in load carrying capacity of the column 10 being provided by an increased number of tubular elements 14 at the lower portions of the column. As will become apparent hereinafter it is the purpose of the hydraulic translator to translate fluid pressure (by means of fluid transfer) created by the support of the floor slab and/or lateral thrusts to the interior of the liquid column elements 14 which are in turn affixed to the structural column 15 such that the fluid columns 14 and the structural columns 15 in combination provide the support column 10 of the building. In the embodiment of FIG. 2 the fluid translator includes a cylinder 20 which is hydraulically sealed and within which there is a free floating piston 21. The free floating piston 21 has two active liquid sides designated as 22 and 23 which are separated and isolated by rolling diaphragms 24 and 25 affixed to opposite ends of the piston. The piston and diaphragms thus divide the cylinder 20 into three liquid spaces, these being the liquid spaces 22 and 23 at opposite ends of the piston and a third space 26 intermediate thereof between the rolling diaphragms 24 and 25. In the hydraulic translator there is provided above the piston section an upper manifold 30. The manifold 30 defines a liquid inlet passage 32 in communication with the liquid side 22 of the piston 21 and an outlet liquid passage 33 also in communication with the liquid side 22 of the piston 21 and an outlet liquid passage 33 also in communication with the liquid side 22 of the piston. In the liquid inlet passage 32 there is positioned an inlet check valve 34 and similarly in the liquid outlet passage 33 there is positioned an outlet check valve 35. The check valves are of the conventional type to allow the flow of liquid inwardly in the inlet passage and outwardly in the outlet passage only. Similarly there is provided at the lower end of the hydraulic translator a lower manifold 31 which defines a liquid inlet passage 35a and a liquid outlet passage 36. An inlet check valve 37 is positioned in the liquid inlet passage 35a and an outlet check valve 38 is positioned in the liquid outlet passage 36. The manifolds 30 and 31 provide the upper and lower closures respectively of the liquid cylinder 20, and are formed as independent parts connected by means of suitable seals and gaskets to the cylinder housing 39. The manifolds may be machined by means well known to the art to allow the insertion and removal of the check valves and to provide the assembly of the various components, although such separation and machining aspects of the apparatus are not shown.

Positioned above the upper manifold 30 and connected thereto by suitable flanges or other mechanical coupling means 19, is an upper header 40 to which the liquid column elements 14 are connected. The liquid columns 14 are as described hereinbefore tubular elements and are connected into the header by suitable threads, mechanical joints, or by welding as shown at 41, for example. A liquid header passage 42 is provided in the header in communication with each of the fluid columns 14, the plurality of which is shown in FIG. 3 as being contained within the concrete support column 15. The liquid header 40 is in turn in fluid communication by means of a liquid passage 43 with the liquid outlet passage 33 and the fluid header passage 43 is through a system of two-way check valves to prevent any leakage as described more fully hereinafter. Similarly, a lower header 44 is connected at the lower end of the liquid translator by means of flanges 18. The construction of the lower header is comparable to that of the upper header in that a liquid header passage 45 is in fluid communication through liquid passage 46 with the liquid outlet passage

from the hydraulic translator through a system of two way check valves as described hereinafter. The liquid columns 14 are again affixed into the header. Positioned between the liquid outlet passage 33 from the pressure translator and the header passage 43 is a two-way check valve assembly 50 through which fluid is conducted from the liquid side 22 of the piston to the header 42 or vice versa and thus to the fluid columns 14.

The passage 50 is defined by three liquid branches, the first branch being a fill branch 51 with a fill valve 52 positioned therein. The second passage 53 has a neutral check valve 54 positioned therein. The third branch is a secondary orifice branch 55 having a by-pass orifice 56 therein and a slow acting check valve 56a in series and not shown separately. Thus, liquid is communicated from the liquid volume 22 under pressure to the header 40 and thus to the liquid columns 14 by opening the fill valve 52. After the columns have been filled with liquid the fill valve 52 is closed and a drop in pressure in the liquid columns within the structural column will cause a pressure drop across the orifice 56 which in turn closes the short stroke check valve 54 and upon action of residual pressure check valve 56a in series with orifice 56 then closes to prevent further flow of liquid to the column.

As shown in FIG. 2 there is attached to the support column a bracket 60 for supporting the load of the floor slab 11 by means of liquid cylinders 61 attached to the bracket means 60. In order to obtain flexibility of the structure and to avoid the imposition of any lateral loads to develop a moment load on element 60, while shifting load to the floor slab connections, the secondary supports 65 are pin or pivotally connected to permit full 180 degree rotation at a convenient point, as by means of a universal type joint 63. The cylinder 61 can be affixed to the bracket or to the column by any suitable mechanical means and it is preferable that a plurality of brackets be affixed at diametrically opposed points on the column for concentricity of load. The cylinder is connected by means of a liquid conduit 62 passing through force distributing orifice 120 to the liquid inlets 32 and 35a of the hydraulic translator as well as the liquid inlet 26 to the cylinder 20 in the liquid space between the floating bellows 24 and 25. A piston 64 is positioned within the cylinder 61 with a piston rod 65 extending from the piston outwardly from the lower end of the cylinder 61. In order to prevent leakage of liquid from the cylinder the piston rod 65 is sealed by means such as a bearing seal or bellows seal 66 which allows vertical movement of the piston rod while preventing leakage of liquid from the cylinder. The pressure of the liquid within the cylinder 61 is thus transmitted through flow of hydraulic fluid through the liquid line 62 to a manifold 68 which is in turn connected to the three liquid inlets to the hydraulic translator. Thus, the pressure of the liquid in the cylinder 61 is transmitted to the three liquid spaces within the cylinder 20, i.e., the liquid space 22 above the piston 21, the space 23 below the piston 21 and the intermediate space 26. A floor slab 11 is then connected to the piston rod 65 and is supported thereby. The floor slab is connected to and supported by the secondary support member 65 by means well known to the art such as the embedment of a structural steel plate or collar 67 in the concrete slab to react lateral thrusts and react floor load to secondary floor support member 65. The collar surrounds the column 10 and absorbs the shear, lateral, and tension forces between the secondary support member 65 and the slab 11. Other means of attachment of a floor slab to support member 65 can also be utilized. For heavily loaded floor slabs a pressurized element or plurality thereof can be utilized in lieu of the piston rod 65 as discussed in connection with the embodiment of FIG. 4 in which embodiment the secondary support member is a tubular hollow column rather than a solid piston rod 65. Thus, in the embodiment of FIGS. 2 and 3 the floor slab 11 is supported by the piston rod 65 which is in tension, the piston 64 and the

body of liquid under pressure within the cylinder 61. The liquid within the cylinder 61 is thus placed under high pressure by the load of the floor slab through the piston and this pressure is transmitted through the inlet passageways to the liquid translator to in turn be passed to the fluid columns 14 by way of the liquid passages 43 and 46 from the upper and lower liquid sides of free floating piston. The liquid also being contained in an intermediate space between the two ends of the piston provides a pressure balance of the system by means of controlled area relationship such that the fluid columns 14 above and below the hydraulic translator are in pressure balance. Additional liquid under pressure is available through the liquid outlet passages 33 and 36 for pressurizing auxiliary structural members as described more fully hereinafter. In connection, however, with the fluid columns 14 it may be seen that when the condition previously described has been achieved, such that the columns 14 attached to the support column 10 are pressurized, an increase in structural strength of the composite column 10 is achieved. By means of the present invention as described above, the floor slab 11 is now supported elastically through steel plates bonded to secondary support members 65 which members are in turn supported from the columns. The columns are in turn reinforced to a composite increased strength with a high degree of elasticity throughout the structural columns and floor load structure. For example, the use of the tubular hydraulic core system as described above utilizing two or more tubular structures arranged to form a composite structural column 10 as shown in FIG. 2 to resist an applied load can be shown to maximize the inherent strength of the structural column or other compressive member in terms of pounds of axial force applied per pound of structural steel. As described above, it can be seen that the structure in accordance with the present invention requires less non-usable building volume; enhances the physical integration of functional building services and allows for modular construction. For example, it can be shown that independent of structural column length an additional applied load (axial or other) can be supported by the configuration of FIG. 2 and that such a composite structural system will, in fact, have a load carrying capacity of

$$1 + \frac{f_t}{2f_a}$$

times a hollow core value at the same $1/R$ ratio where f_t is the tensile strength of the individual tubular member, f_a is the compressive stress, l is the length of the column, and R is the radius thereof. Since f_t for a steel tubular member is usually greater than f_a for a finite slenderness ratio (l/R), the latter multiplier can represent an appreciable load factor. To illustrate, assume that a structural live and dead load of 940 kips is to be carried by a uniform floor slab on four columnar members and that four standard steel pipe columns twelve inches in diameter are initially selected resulting in an applied load of 235 kips per column. The weight of a standard 12-inch pipe column is 49.56 pounds per foot. It can be shown that such a column will perform adequately when the vertical column dimensions do not exceed 26 ft. Compare now an hydraulic core system in accordance with the present invention as previously described in which each column consists of four 4-inch standard steel pipe columns with the tube sheets 10 ft. on centers located within a common poured concrete sheath (of negligible structural value) to simulate an effective slenderness ratio of

$$(0.65 \times 10 \times 12 / 1.16)$$

or 67 versus the 12-inch hollow core, 12-inch column at a comparable slenderness ratio of $(26 \times 12 \div 4.38)$ or 65. Considering the single equivalent column consisting of four 4-inch standard steel tubular members joined as indicated in FIG. 1 to a cylindrical support column but

without fluid therein the combined system could handle a maximum applied load of 38×4 or 152 kips. However, this same system filled with a fluid of the type described previously and with a calculated $f_t = 17,000$ p.s.i. and $f_a = 15,140$ using recommended AISC formulas at $l/R = 67$ as calculated previously, would provide an actual available load for the system of

$$\frac{152 \times 1 + 17,000}{15,140}$$

or 235 kips. In a comparison of the two columnar systems it is found that while both have relatively comparable slenderness ratios namely, 67 vs. 65, the conventional system cannot exceed an unsupported length of 26 ft., or approximately two stories of nominal building height while the hydraulic core system of the present invention can be extended indefinitely for numerous floors if desired provided end conditions are constrained within allowable limits by diagonal or horizontal bracing as hereinafter described. By means of the present invention, an increase structural efficiency of approximately 40% in available load carrying capacity with structural columns using approximately 30% less cross-sectional area is possible.

Referring now particularly to FIGS. 4, 5 and 6 there is shown apparatus in accordance with the present invention for providing a liquid filled bracing system in addition to the liquid supported floor suspension system. Thus, referring particularly to FIG. 5 there is shown two columns of the structural outline of a building structure employing the structural columns 10 as previously described with suspended floors but with a diagonal or horizontal bracing structure 80 which includes a hydraulic translator for imposing a liquid under pressure into tubular elements in a manner comparable to that previously described in connection with the fluid columns 14. One of the key factors in improving the strength qualities of the hydraulic core system of the present invention comprises the use of multiple tubular elements such that the K factor approaches a theoretical factor of 0.5. The K factor being the ratio of effective column length to actual unbraced length. If sufficient axial load is applied to the columns in a frame structure dependent entirely upon the bending stiffness of the structure for stability and side sway, the effective length of columns may exceed their actual length. If, however, the frame is braced in such a way that lateral movement of the tips of the columns with respect to their base is prevented, the effective length is less than the actual length due to restraint provided by the horizontal or X-brace member. Thus, in FIGS. 5 and 6, the use of the present invention in an X-braced structure, is shown. The X-brace comprises crossed support members 81a-81b and 82a-82b extending between adjacent vertical columns 10. At the intersection of the cross-bracing members 81 and 82 there is provided an hydraulic translator in accordance with the present invention as shown schematically in FIG. 6 and in mechanical detail in FIG. 4. Additionally, the embodiment of FIGS. 4, 5 and 6 employs liquid pressurized tubular secondary elements 91 as components of the secondary support members 65 for heavily loaded floor slab construction. In the embodiment of FIGS. 4, 5 and 6 the apparatus as shown in FIG. 4 is utilized to connect and fluid couple the elements under load to the support column 10 and accordingly replaces the piston 61 of the embodiment of FIG. 2 with a translator 90 in this embodiment. Thus, referring to FIGS. 5 and 6, six load bearing members are shown at a common point of intersection at a structural joint module 101. Cross-bracing members 81a, 81b and 82a, 82b extend between support columns 10a and 10b and intersect at column 10c to form an X-brace structure. Column 10c is a support column as previously described and members 65 are secondary support members or floor support members. The secondary support member 65 affixed to column 10c is not shown in FIG. 5, but is shown in detail in FIG. 4. For the construction of the hydraulic translator

in the support column 10c a translator 12 as previously described is employed. A translator as shown in FIG. 4 and designated generally as 90 is employed to impart an hydraulic load into tubular members 91 contained within, or forming, the floor support members 65, and the X-bracing members 81a, 81b, 82a and 82b. The construction of the primary column elements 14 and support column 10c are as previously described.

Referring now particularly to FIG. 8, a schematic representation of the fluid flow and forces in cross-brace embodiment comparable to that shown in FIG. 6 and previously described is shown. The utility of the present invention in resisting lateral loads and thrusts can be better understood with reference to the schematic representation of FIG. 8. Thus, in response to an elongation load on the secondary support 65a and the action of a lateral thrust, the piston 21 is caused to drop and thereby increase the pressure in liquid space 23 of the hydraulic translator 90. Liquid outlets 38a and 38b being interconnected through the four-way valve 101a with the liquid conduits 62a and 62b in the equivalent embodiment. Flow-through 62b tends to try to reduce pressure in 23 of 90 and build pressure in liquid space 22 of the primary column 10. Liquid outlet 33 is connected to the cross-brace member (see FIG. 6) in tension and liquid outlet 36 to the corresponding cross-brace member in compression. Thus, with the cross-brace member 81 in tension, the tendency is to elongate and thus, reduce its internal fluid pressure; whereas, with the cross-brace member 82 in compression, the tendency is to foreshorten the member and to increase its internal fluid pressure. In response to the elongation load (tension) on the cross-brace member 81 fluid flows from chamber 23 of primary column 10 through conduit 33c, check valve 37 of cross-brace member 81 to chamber 23 of tension member 81. Simultaneously in response to the foreshortening load (compression) on cross-brace member 82, pressure buildup in chamber 23 of the translator for cross-brace 82 causes a flow of fluid from chamber 22 of primary column 10 to flow through conduit 36a to chamber 22 of the translator for member 82 and a release of fluid pressure in chamber 23 of the translator for cross-brace 82 by fluid flow through conduit 98c and its respective back pressure control valve 100a resulting in pressure equalization after fluid discharges into chamber 22 of secondary floor support pressure translator 90. In this way the flow path is completed back to the point of its origin (initial fluid displacement from lateral thrust). Four way valve 101a in the position shown interconnects 62b with 38a and 62a with 38b. If the resulting direction of forces were opposite, 101a would reverse the action to interconnect 62b with 38b and 62a with 38a and the reactions of cross-brace member 82 and 81 would also be transposed.

In accordance with the present invention energy is absorbed in the fluid transfer of wind and/or earthquake forces and is dissipated as frictional heat in the various structural members through which the fluid set in motion flows by conduction to aid convection and radiation from their exposed surfaces to the surrounding environment.

In the proposed embodiment the right frame arrangement (X-brace) not only eliminates floor-to-floor column drift but also permits the entire embodiment to act as a cantilever beam. This is as opposed to a conventional high rise building consisting of a series of tiered floors cantilevered vertically from a foundation by framed structures consisting of vertical columns, beams and girders spanning between columns to support each floor level. In such structures additional material must be provided to add sufficient rigidity so that lateral deflections will not be sensed by occupants on upper floors nor will the accompanying elastic distortions cause damage to the exterior curtain wall, floor, or interior partitions and the like. In the system of the present invention significant material savings result since the X-brace members not only provide stiffness and enhance the live and dead load

carrying capability of the hydraulically joined frame, but redistribute forces through selective fluid transfers within the frame in proportion to the strength qualities of its interconnected members. Thus, as the fluid pressure starts to build in liquid space 22 of the hydraulic translator 90 the check valve 35 will open. With the cross-brace member in tension its piston 21 will move upwards upon the flow of fluid to tension member 81 through liquid conduit 36.

The pressure translator 90 employed for those elements to be pressurized other than the tubular elements of the support column 10, is comparable in most respects to the pressure translator previously described but is shown in detail in FIG. 4 of the drawing. Each of the pressure translators 90 is similarly constructed. In FIG. 6, for example, six such pressure translators are utilized. The primary distinction between the pressure translator 90 and the pressure translator 12 previously described lies in the fact that the translator 90 utilizes in conjunction with secondary members a means for conducting fluid under pressure directly from the piston to the secondary elements which are imposing a load on the system. Thus, referring to FIG. 4, the piston housing and cylinder arrangement are comparable to that of the translator 12 and may be prefabricated for use in either the translator 12 or the translator 90. That is, the cylinder 20 is again employed as is the piston 21, rolling diaphragms 24 and 25, and the cylinder housing 39. In the translator 90, however, a piston rod comparable to the element 65 previously described is directly connected to the piston 21 and is a tubular element. The tubular piston rod designated therefore as 65a is connected to the piston by suitable means such as threads 93 and extends axially of the cylinder 20 outwardly from the translator 90. A header 94 is affixed to the cylinder housing 39 and has extending there-through an axial bore 94a within which the tubular piston rod 65a is longitudinally movable. Since liquid under pressure is present in the liquid sides of the piston at 22 and 23 an efficient seal along the length of the piston rod 65a as it passes through the translator housing and particularly the header 94 is required. Suitable low friction sealing and bearing elements 96 are employed as a bearing for the piston rod to retain its axial alignment. Additionally, however, a suitable sealing bellows 97 which can move longitudinally with the piston rod while retaining the seal thereabout is also employed. The header 94 again includes a liquid inlet passage 35a with suitable check valve 37 and a liquid outlet passage 36 with an outlet check valve 38 as previously described in connection with the translator 12. An upper header 95 is attached to the cylinder housing and provides a liquid inlet 32 with an inlet check valve 34, and a liquid outlet 33 with a liquid check valve 35. An intermediate liquid inlet 63 is provided through the cylinder housing to the intermediate liquid space 26 between the diaphragms 24 and 25 to maintain a pressure balance between the liquid pressure sides 22 and 23 of the piston. Thus, conduits 96 with force equalizing orifices 120 connect the liquid inlets 32, 35a and 63 with suitable check valves such as shown at 37 to provide liquid inlet to the opposite sides 22 and 23 of the piston and the intermediate liquid volume therebetween. In the embodiment as shown at FIGS. 4 and 6 the liquid inlet conduit 96 is connected to an accumulator 98 which maintains uniform pressure of the liquid throughout the self contained interconnected system. Comparably, the liquid outlet conduits 99 are connected to the inlet side of the accumulator 98 such that a predetermined pressure balance of the liquid through a given hydraulic sub-system is assured. The pressure to the liquid is, of course, supplied by the tension load exerted upon the piston rod 65a by the secondary support member such as 65, 81a and 82b as shown in FIGS. 5 and 6. Thus, when a tensile load or a compressive load is applied to the secondary support element designated as 65 in FIG. 4, pressure is imposed upon the liquid in the cylinder and the element is

supported by the liquid in the tension side 23 of the piston or the compression side 22 thereof. Such pressure is translated through the liquid outlets 33 or 36 to the system conduits 99. The liquid under pressure is then available for additional support elements or for supply to the accumulator 98 in the system. The accumulator is of the type well known to the art for maintaining uniform liquid pressure throughout a hydraulic system. In FIG. 4 the translator 90 is shown connected to a structural stress plate 100. Referring now to FIGS. 4 and 6 the plate 100 would constitute the structural surfaces of the connecting module 101 of FIG. 6 or the support collars for a floor slab designated schematically as 100 in FIG. 4. The accumulator is shown as 98 in FIG. 6 and the various conduit lines with equalizing orifices 120 extending from the support column translator 12 and each of the secondary element translators 90 are also shown schematically to illustrate the manner in which all of the elements are connected for a predetermined design distribution of liquid pressure throughout the system. Thus, for example, in connection with the floor support member 65 shown in FIGS. 4 and 6, the support element in this embodiment again contains tubular elements 91 to be filled with liquid under pressure for the additional strengthening and load bearing capacity of the interconnected secondary support element or X-brace member, etc. Accordingly, in FIG. 4 the tubular piston rod 65a terminates in a header 103 from which a plurality of tubular elements 91 are extended. The tubular elements 91 are bonded to or sheathed by a column 104 and are distributed within the column. Suitable mechanical type fluid couplings such as dresser couplings 105 are provided at the end of each of the tubular elements 91 for connection to additional elements or for connection to floor support members. Thus, when the pressure translator 90 is employed for the support of a cross-brace such as 81a in FIG. 6, the coupling 105 will in turn be coupled to tubular element 91 which extends to the next juxtaposed translator. Thus, in FIGS. 4 and 5 if the pressure translator 90 is connected to the X-brace 81a, at the column 10c the elements 91 connected by means of couplings 105 extend upwardly to a comparable module designated as 106 and are connected thereto by means of another pressure translator 90. If the pressure translator 90 is used to support the floor slab as at 65 in FIG. 5 the elements 91 of FIG. 4 are coupled to support means which are in turn affixed to the collar of the floor slab as previously discussed in connection with the embodiment of FIG. 2. In the connecting lines various hydraulic orifices 120 of the type well known to the art are positioned as shown in FIG. 6 to assure pressure distribution between the various hydraulic components of the system and to prevent overstress in any line due to localized stresses. When the embodiment of FIG. 4 is utilized to support the floor slab the elements 91 are under tension but fluid under pressure is supplied to the interior of such tubular elements by means of a liquid orifice 108 in the piston rod within the liquid space 23 of the translator 90. The elements 91 thus have a tensile force exerted upon their skin axially but the fluid pressure within the element exerts a radially outward circumferential force such that the composite force upon the skin of the tubular element is transposed to a lesser tensile force in the skin due to the composite force of the member created by the combined axial load and the outward circumferential load.

In the construction of a building employing apparatus of the present invention a system is erected rapidly upwardly from the foundation and is partially prefabricated by the manufacture and assembly of the pressure translators 12 and 90. The balance of the construction is accomplished on the site. As erection of the building progresses hydraulic fluid from a suitable portable pressurizing pump supplies fluid to the hydraulic actuator from the pressure translator 12 and the pressure translator 90 which have been fabricated and installed. When the var-

ious load bearing members are filled with fluid to a predetermined pressure, the next section of the various columns are erected and filled with fluid through quick disconnect mechanical couplings or the like. Thus, during the various erection stages the various support members installed are pressurized and modular construction continues until the complete fluid system has been installed and equalized. In this way the overall concept of the present invention permits rapid construction of high rise buildings by concurrent assembly operations, maximum use of available strength of materials by translation of compression to tension stresses in those elements whose primary strength is in tension. The resulting structure has a capacity of absorbing and withstanding intense shocks and forces greater than construction systems heretofore known to the art due to plasticity and self-damping characteristics of the system as shown schematically in FIG. 7 wherein deflection of the horizontal components under lateral load is shown.

Thus, the system of the present invention is particularly adapted to high-rise building construction and makes possible large floor slab areas between support columns. As shown in FIG. 1 the glass line 200 of the building can be positioned within the cross-bracing and secondary bracing members. The ability to post-tension the floor slabs over large uninterrupted areas is also made more feasible as shown schematically at 300 of FIG. 1. As pointed out hereinbefore the hydraulic core construction of the present invention particularly adapts the building to modular construction. The planning module can be defined by interfacing subfunction modules such as material modules, performance modules, structural modules, joint modules, fixture modules, and the like.

Additions and modifications to the system of the present invention will be apparent to those skilled in the art. An important feature of the present invention is that by reason of the hydraulic core construction and the greater floor spans available due to support by slender spaced apart columns and space-frame construction can be readily adapted for roofs and interior construction within the building. Additionally, such construction system makes feasible the use of both modular construction and erection with respect to the structural frame of the building described hereinbefore and interior components and structural elements within the building.

I claim:

1. A building structure comprising:

support columns extending upwardly from a building foundation;

load bearing members connected to and supported by said support columns, said load bearing members including floor support members connected to said floor slabs;

a liquid pressure translator connected into each of said support columns;

a cylinder containing liquid means for supporting said floor support member by the liquid in said cylinder whereby the load of said floor support member is transposed to pressure in said liquid;

said liquid pressure translator including means for transmitting said liquid under pressure into structural elements to be pressurized.

2. The apparatus as defined in claim 1 in which said floor support member is affixed to and supported by a piston within said cylinder, said piston being supported by liquid.

3. The apparatus as defined in claim 2 in which said liquid pressure translator forms a part of said support column primary tubular elements extending from said pressure translator longitudinally within and forming part of said column, said liquid translator including means for passing liquid under pressure within said cylinder to said primary tubular elements.

4. The apparatus as defined in claim 3 in which said

liquid pressure translator includes a liquid filled cavity in fluid communication with the liquid in said cylinder and in fluid communication with said primary tubular elements.

5. The apparatus as defined in claim 4 in which said liquid pressure translator comprises a housing forming a coextensive portion of each of said support columns, said housing defining a liquid sealed cavity, pressure balancing means dividing said cavity into first and second liquid containing cavities, liquid conduit connecting the liquid under pressure in said cylinder to both said first and second sides of said pressure balancing means.

6. The apparatus as defined in claim 5 which includes an orifice in said liquid conduit for damping any surge pressure in said system.

7. The apparatus as defined in claim 5 in which said first and second cavities of said pressure translator are connected by liquid conduits to the interior of said primary tubular elements.

8. The apparatus as defined in claim 7 in which said floor slab is supported from said piston by a secondary support member, said secondary support member having a plurality of secondary tubular elements forming a structural part thereof, means for conducting liquid under pressure from said cylinder to said secondary tubular elements.

9. The building structure as defined in claim 7 which includes additional load bearing members, said load bearing members including in their structure a plurality of third tubular members, a second pressure translator connected to said third tubular members for conducting the pressure in said first pressure translator to said third members and the load from said additional load bearing members through said second pressure translator to said first pressure translator.

10. The apparatus as defined in claim 9 in which an orifice is positioned in all interconnecting liquid conduits for damping pressure surges between said tubular members.

11. A building structure comprising:

a plurality of vertical support columns, tubular liquid filled members forming a structural part of said columns;

a plurality of floor slabs supported by said columns; means for supporting said floor slabs upon a plurality of bodies of liquid in pressure communication with said liquid in said columns.

12. A building structure comprising:

a plurality of support columns extending vertically from a building foundation;

a plurality of floor slabs;

said support columns each including a pressure translating means defining a liquid filled cylinder in said column and a plurality of primary tubular elements within and forming a support portion of said support column;

a secondary support member affixed to one of said floor slabs and extending vertically upwardly therefrom, a piston connected at the upper end of said secondary support member;

a second liquid filled cylinder connected to said pressure translator, said piston being confined within said cylinder and supported upon the liquid therein, means for communicating the pressure of said liquid within said second cylinder to said first cylinder;

means for transmitting said liquid pressure from said translator to said primary tubular element; and

means for balancing said pressure within said elements.

13. The building structure as defined in claim 12 which includes cross-bracing members extended between adjacent ones of said plurality of vertical support columns, said cross-bracing members having third liquid filled tubular members contained therein and forming a structural part thereof, a second pressure translator connected to said third tubular members for conducting the pressure in

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said first pressure translator to said third members and the load from said additional load bearing members through said second pressure translator to said first pressure translator.

14. The building structure as defined in claim 13 in which said pressure translators include means for equalizing liquid pressure in said pressure translators and in said first, second and third tubular elements.

15. The building structure as defined in claim 14 in which said floor slabs are of post-tensioned concrete.

16. The building structure as defined in claim 15 which also includes space frame construction of roof areas connecting said vertical support columns.

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