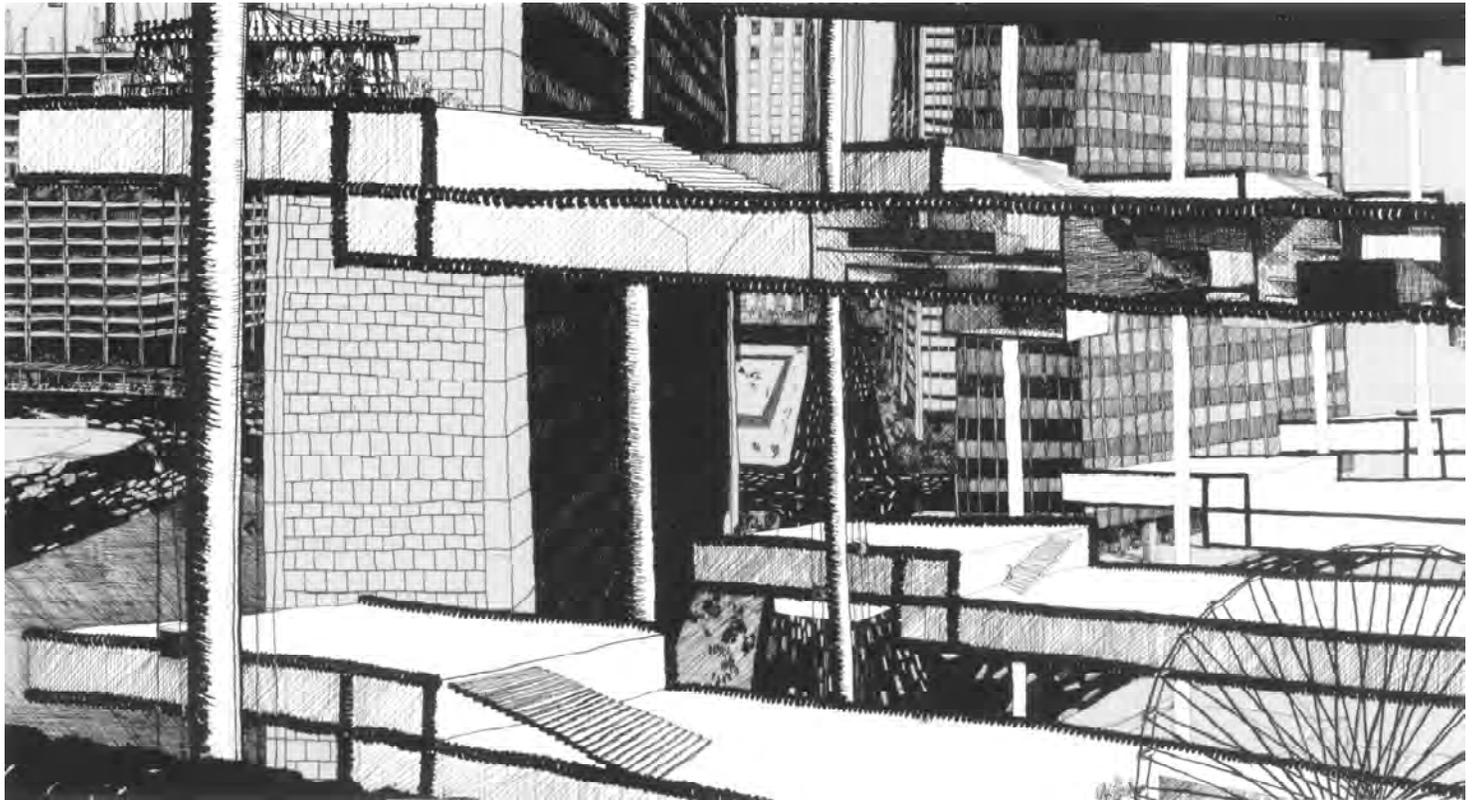


Architecture and 'Zero-stress'sm structures

A simple system using water-filled tubes lends itself to industrialized building and to greater spatial benefits and safety.

By John Mclean, RA



A building's weight is tremendous. Often the heaviest parts do nothing structurally. If the ratio could be reversed, structural efficiency would be greatly improved. A large building weight is indicative not only of massiveness but of redundant construction. Many types of exterior enclosures or "skins" are as strong as the structure supporting them, and may weigh more. Claddings should be tapped structurally.

If the industrialization of building aims to make construction more affordable, then it means, in addition to mass production methods, the further development of lighter and stronger structures, new materials technology and the integration of building components. Useful materials must be evaluated for their architectural potential. Ways of using glass and plastic materials structurally should be found. Conventional construction materials should be made able to perform at a higher level.

The zero-stresssm structural system, a design research project proposed here, is intended to reduce the cost of building. The reductions would come from the system's high structural strength and efficiency, and its receptiveness for integrating building components into the structural system itself.

A zero-stresssm structure is light. A zero compressive state maximizes the strength of the material used, so that the structure can be considerably less massive.

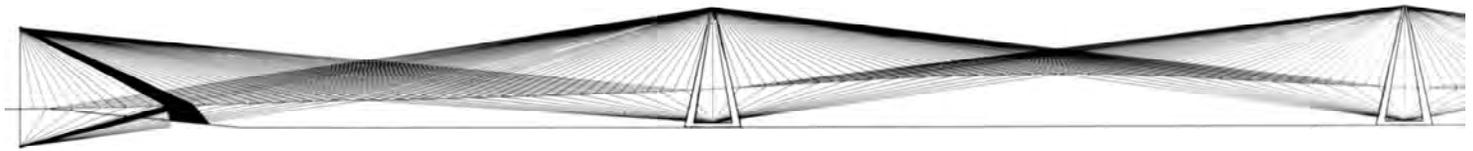
Zero-stressingsm extends architectural and spatial concepts. Unlike many structural systems, zero-stresssm is not based on a special geometric configuration and is therefore widely applicable. The design proposals illustrated are spatially tensile and vibrant.

Zero-stressingsm may allow us to use materials such as plastics and reinforced or structural glass for structural purposes. Plastic materials have been developed with strength—but not stiffness—approaching that of steel. Consequently, plastic columns and beams have had extremely limited uses. Nevertheless, the structural possibilities of plastics, glass, steel, nickel-stainless steel and reinforced concrete are tremendously extended by zero-stressingsm. A possible spin-off of the zero-stress technologysm is the further strengthening of materials such as steel. We increase the strength of glass fourfold by tempering it. In a similar manner, by highly pressurizing molten steel and allowing it to cool in a columnar form, there may result a column with greatly extended strength.

Some of the design potentials of zero-stressingsm can be seen in the illustrated concepts. One is the continuous tension bridge of multiple three-mile spans with zero-compression support towers. The second is the Horizontal Skyscrapersm. The system can also be applied to smaller projects such as a single-family house.

Horizontal Skyscrapersm

The principles of zero-stressingsm lend themselves to such applications as this urban housing complex. This horizontal skyscrapersm is a series of spanning units, each containing about five duplex or triplex residences. This fragmented skyscraper horizontally contrasts with the vertical monolithic office towers. The housing spans (or bridges) are zero-stressed beams or trusses. Each is built on the ground, and then zero-stressedsm and jacked into position, where it is supported on a zero-stresssm column system.

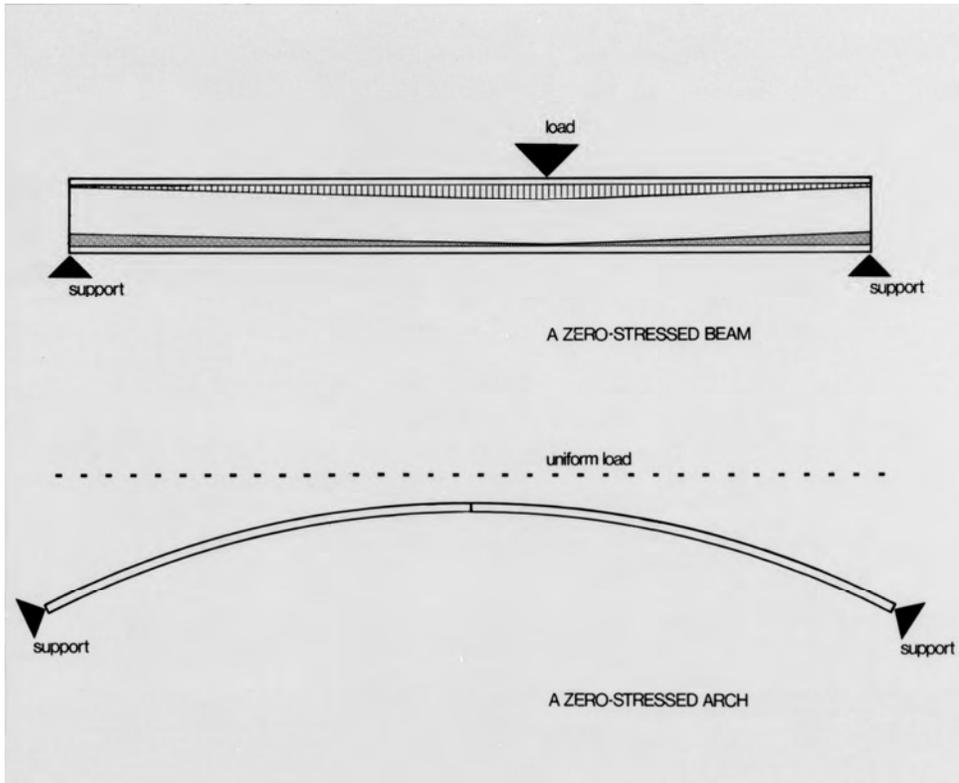


Above

Each span of this continuous-tension bridge is three miles long. It is supported by zero-compression towers and fluid-filled stays.

Left

Upper drawing shows the internal configuration of the elements needed to oppose bending stresses under the one-point load. At the top is a double cone shaped fluid column. A double cone shaped tension member is at the bottom. Lower drawing shows two arching fluid columns joined at the top. The arch can be either the sealed or piston type column.



How zero-stressingsm works

The backbone of the zero-stresssm system is the fluid column, a sealed, internally pressurized light-weight tube that forms a non-compressed column. Because its walls are far thinner than those of a comparably strong conventional column, it uses less material and is therefore more affordable to build. (Another kind of fluid column, incorporating a piston, will be discussed later.)

Pressurizing the fluid causes the ends of the unloaded column to stretch apart, yielding zero compression across the tube's cross-section. When a load is applied, the fluid transmits it uniformly throughout the tube, inducing tensile bursting forces in the tube's wall. It is this conversion of the compressive force into a tensile force that gives the fluid column its efficiency.

This means that buckling due to compressive force doesn't occur. Increasing its length doesn't diminish a fluid column's strength or efficiency, the cause of buckling in compressively loaded columns. (See graph.)

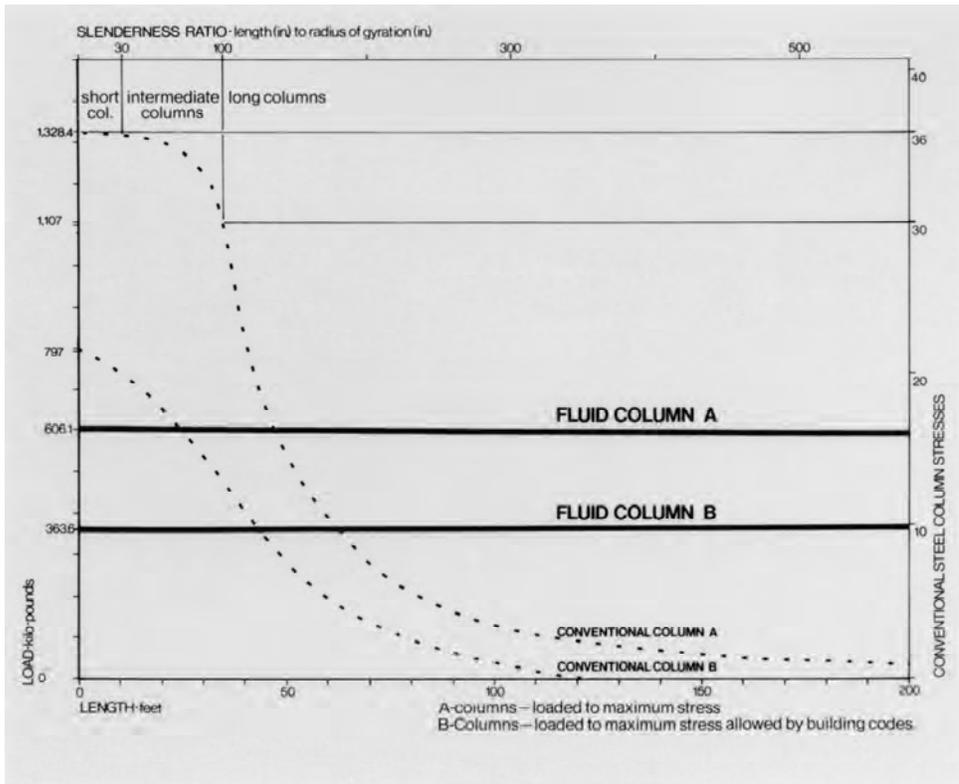
That's a basic description of how zero-stresssm works. To more fully understand the subtle features of the system requires a more complex and somewhat technical description. The methods of design engineering used in applying zero-stressingsm are

stress-skin analysis, pressure-vessel design, prestress and post-tension design, pneumatic system design and tent and shell structure analysis.

For example, the fluid column's cross section also takes bending stresses larger than the conventional, withstanding lateral forces that can cause buckling. (See graph.) Bending is a combination of compressive and tensile stresses acting on a cross section. Designing the fluid column with *entasis*, or a swelling, according to the maximum deflection profile minimizes bending stresses or eliminates the compressive stresses that can develop along the bent column's length from the fluid pressure.

The maximum strength of a fluid column is about one-half of the same tube loaded in tension to a stress equal to that of the column's bursting stress. Therefore the fluid column is most efficient as a long column compared with conventional columns. The accompanying graph and tables bear that out.

Compressing a substance with ever increasing force means it must be bulky to stay straight. The extra mass needed in the compressed state—above the amount required in tension—is used to keep the structure in its original geometry. Add to the problem of massing the effects of the structure's size and we see that the scale (independent of the



The longer a conventional column is, the lighter the load it can support. This isn't true of fluid columns.

weight it is to support) will increase structural massiveness disproportionally from its smaller version. The conclusion we draw is that structural obesity is tied directly into the nature of forces, particularly compressive, and how they are transmitted through the material. In contrast, a tension member yields the highest ratio of load supported to the structure's own weight.

Which fluid to use?

The selection of a fluid can be critical in the fluid column. Gases are compressible and hydraulic fluids are almost incompressible. Air and water are plentiful and essentially "free." Certain soil materials can behave as fluids and can be considered for use in the system. For the purpose of this article, water is the understood fluid, but the zero-stresssm structural system isn't limited to it.

Since the fluid column is in fact a large container of fluid, it can include its own fire protection. Regarding a steel-water fluid column, the larger the fluid's volume the greater the fire insulation. It is therefore safe to leave the steel exposed. In addition, since the pressure is high, the freezing point of water is lowered—possibly avoiding the need for an anti-freeze additive—and the boiling point is

raised, increasing the fireproof potential. The technical considerations involved in the selection of a particular fluid are beyond the scope of this article.

The piston type fluid column's chief use is to control thermal expansion. Since it employs two materials that have two rates of expansion, by proportioning the volume of the fluid against the circumference of the tube an increase in temperature may result in the column's lowering, remaining the same or rising. Controlling the effect of temperature advantageously makes the piston fluid column an ideal choice for the towers of a suspension or tension bridge to take up the expansion of the cables holding the deck in place. The continuous tension bridge has fluid column towers.

The container forming the fluid column-towers hangs from the top of the fluid, with the piston at the base of the support tower. Consequently, the container's hanging dead weight induces a straightening action along its length. Any compressive stresses, for example those caused by the friction of the piston against the column's inner wall surface, will not travel up the length of the column-tower. The dead weight in this case counteracts any induced compressive stresses. The piston fluid col-

umn is intended for very large structures where control of thermal expansion is required.

The fluid column is the instrument for zero stressing horizontally spanning structures. Just as the limiting factor for a conventional column is unsupported length, the unsupported length of a beam dictates how much loading it can hold up. The top portion of a beam (supported at its ends) acts as a column resisting compression. The lower portion is in tension.

A zero-stresssm beam has a fluid column in its upper side. The longitudinally inserted column negates compressive stresses caused by bending with equal tensile ones in the compressive section of a beam. The column in the loaded beam is compressively zero-stressedsm. Coupled with the fluid column is a tension member in the beam's lower portion to negate tensile stresses. With the induced upward bending stresses, the beam, when loaded, will have zero-bending stresses. The extent to which bending is zero-stressedsm is entirely dependent on the profile of the fluid column and tension member. The proper profile will reflect loading and therefore produce zero bending at any point along the beam's length.

Comparison of round tube column as conventional and fluid column

Conventional column

length	40.0	60.0	80.0	100.0	120.0	140.0	160.0	180.0	200.0
load	824.0	366.0	206.0	132.0	91.5	67.4	51.5	41.7	33.0
compressive stress	22.4	9.93	5.59	3.57	2.48	1.82	1.39	1.1	0.89
tube weight	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0
weight supported	821.5	362.25	201.0	125.75	84.0	58.65	41.5	30.45	20.9

Fluid column

Tube wall thickness changes in order to support the same load as the above conventional column.

load	824.0	366.0	206.0	132.0	91.5	67.4	51.5	41.7	33.0
length	40.0	60.0	80.0	100.0	120.0	140.0	160.0	180.0	200.0
pressure of water	0.017	0.026	0.035	0.043	0.052	0.061	0.060	0.078	0.086
pressure of load	9.1	4.04	2.28	1.46	0.99	0.744	0.569	0.460	0.365
total bursting pressure	9.12	4.07	2.31	1.50	1.04	0.805	0.638	0.538	0.451
bursting stress	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
wall thickness	1.36	0.61	0.35	0.23	0.16	0.12	0.095	0.080	0.067

Fluid column

Tube wall thickness is the same as the conventional column. In addition, this table shows the effect of water's weight and the tube's weight on the weight supported.

length	1.0	200.0	220.0	240.0	260.0	280.0	300.0	400.0	1000.0
bursting stress	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
total bursting pressure	6.697	6.697	6.697	6.697	6.697	6.697	6.697	6.697	6.697
pressure of water	0.0	0.087	0.096	0.104	0.113	0.122	0.130	0.174	0.434
load pressure	6.697	6.611	6.601	6.593	6.584	6.575	6.567	6.523	6.263
load	606.1	598.2	597.5	596.7	595.8	595.0	594.2	590.5	566.8
tube weight	0.01	25.0	27.5	30.0	32.5	35.0	37.5	50.0	125.0
weight supported	606.1	573.2	570.0	566.7	563.3	560.0	556.7	540.5	441.8

The simplest structure to zero-stresssm is the truss. Since it is a triangulation of tension and compression members, replacing the compressive ones with fluid columns makes the entire assembly one of tension and zero-stresssm members.

Conceptually, the zero-stresssm fluid structure means a structure that benefits from the composite nature of the containing material and the fluid material, such as water. Keeping that in mind, the zero-stresssm fluid structure is a natural seismic shock absorber that instantly broadcasts the shock as a small stress.

Conclusion

Zero-stressingsm horizontally spanning structures is important because it achieves control of deflection. This is especially important for long spans, where large deflections occur, without reaching maximum bending stresses or strength. It further allows for the elimination or lessening of the number of lateral supports related to the beam's upper portion resisting compression. The increased strength is from the conversion of bending stresses into a composition of tensile and bursting stresses.

Structural safety, as in the case of the tremendous heat developed in the September 11th act of terrorism, is maximized in tall or large structures using fluid-filled / zero-stressedsm members and components. The large amount of water in each structural member is a natural coolant or fire pro-

tection for the steel. In the case of stainless steel, the safety advantage is even greater.

The fluid filled structure is an efficient structure that resists seismic shock.

Although I have attempted to explain the structural behavior of the zero-stresssm structural system by presenting ideas and principles of design, the mathematics of the system is a smorgasbord of structural design techniques. Water-filled floor slabs and stairwell partitions made of stainless steel would afford the greatest protection in the event of a major fire or catastrophe.

Zero-stress' value is its simplicity and relation to industrialized building systems. The tie between the two is that each shares and serves the other's purposes. Both are intended to reduce building costs, increase safety, provide quality products and realize profits for the entrepreneur. ■

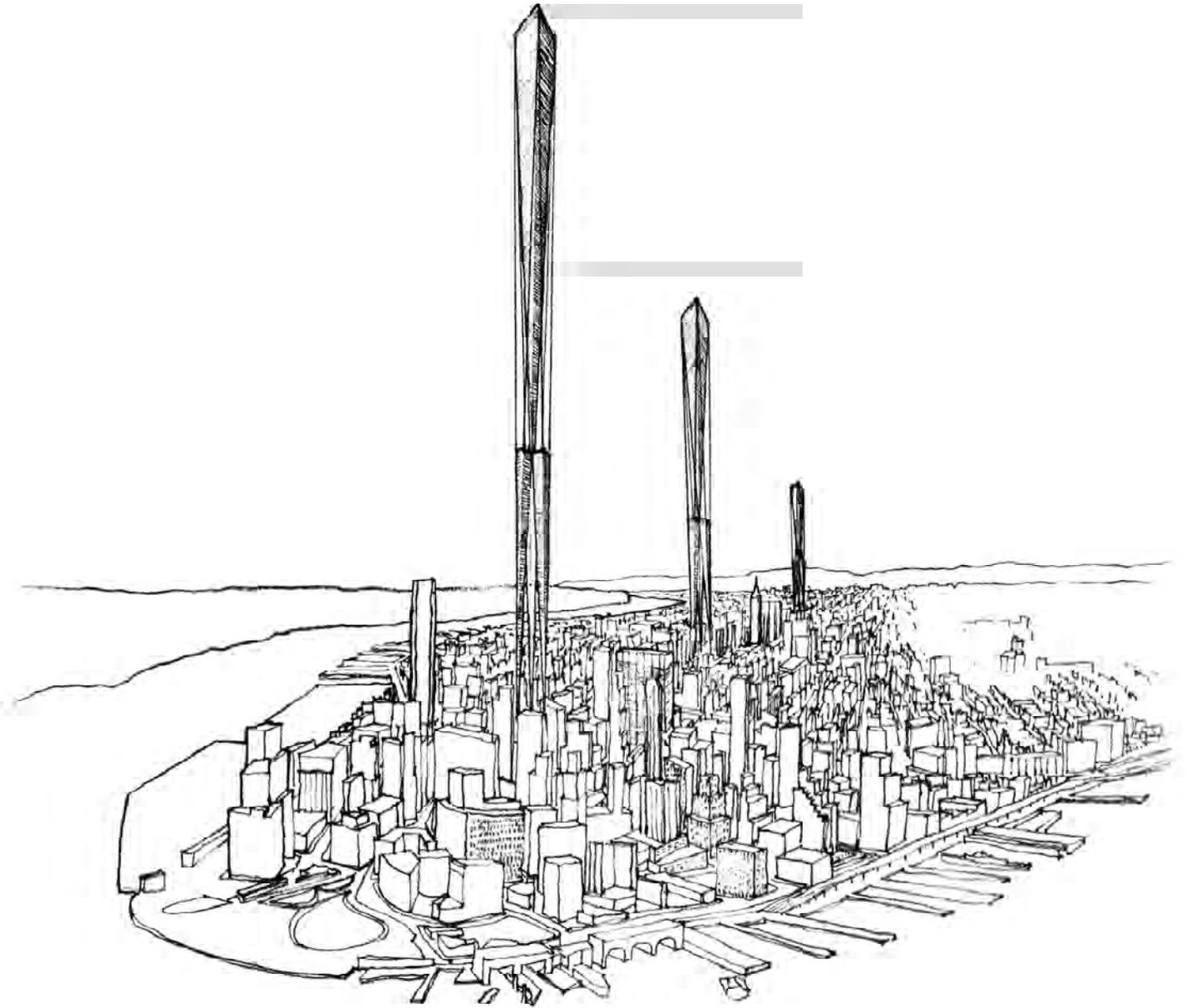
Notes

The dimensional units used for lengths are feet; for load or weight, kilo-pounds; for stresses and pressures, kilo-pounds per square inch; and for thickness, inches.

The properties of the steel tube are: inside and outside diameters, 10.75 and 12.75 inches, with a 1 inch wall thickness; 36.9 square inch cross-sectional area of steel with a hollow area of 90.5 square inches; the moment of inertia is 641.7 quadric inches; the radius of gyration is 4.17 inches; tube weight is 0.12549 kilo-pounds per foot of length.

Steel's elastic limit stress is 30 kilo-pounds per square inch, and the yield point stress is 36 kilo-pounds per square inch.

The term load means the total amount of kilo-pounds the column can withstand at an allowable stress. In the case of the conventional column, the load is the sum of the supported weight plus one-half of the column's own weight. For the fluid column, the calculation is different. The tube's weight, since it hangs from the top of the pressurized fluid, is added to the weight supported to yield the total load



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Mile-high skyscrapers

Very tall buildings are unique environments that relieve the demand on ground surfaces while increasing the stresses on the surface and the infrastructure. The practicality of tall structures is not a structural one but rather a spatial one and a matter of public policy. The tops are well suited for telecommunications, entertainment and tourism, and the lower levels for human activities. The notion of the Horizontal Skyscrapersm fragments the building mass and provides access to light, air and visual vistas.