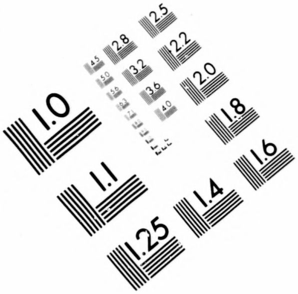

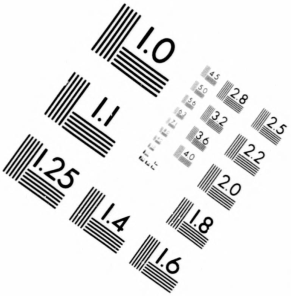

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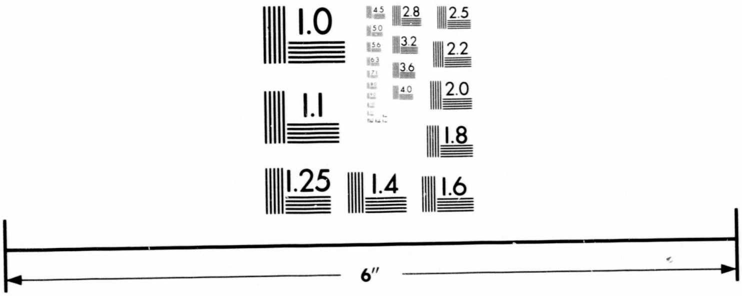

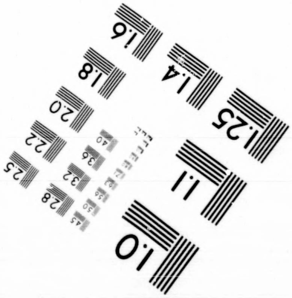

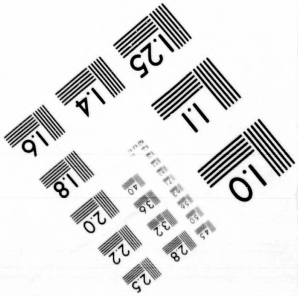

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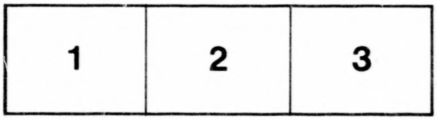

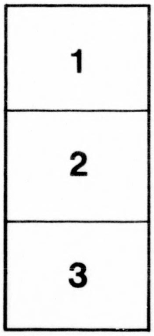

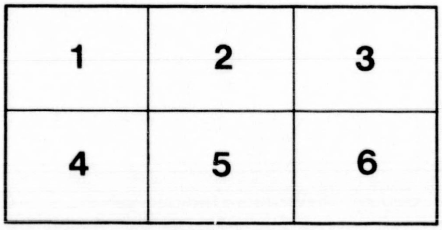

On the bearing and resisting strength of structures and that of their component parts and materials.

Read before the Province of Quebec Association of Architects at their annual meeting — October 2 1895 — at the Chateau Frontenac — Quebec.

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A PAPER READ BEFORE THE
Province of Quebec Association of Architects

At their annual meeting, October 2, 1895, at the Frontenac Hotel, Quebec.

On the bearing and resisting strength of structures and of that of their component parts and materials.

Many failures have (of late years) occurred of various buildings or of portions thereof; due to faulty, hasty or unmatured construction ; and hardly a day passes but what the news-papers chronicle some catastrophe, some collapse of a building just finished, or even before it is finished ; as evidently incapable of supporting its own weight ; let alone that of the living or dead weight or both which it should have been made strong enough to bear. Such failures have occurred, in Canadian as well as in United States and European cities, and in most cases with the loss of one or more lives.

Much more attention should also be bestowed on the erection of temporay stages or platforms in cases of reviews, races, athletic and other performances ; but with this, which is of secondary importance, and where sufficient solidity of construction can be arrived at without subjecting the structure to abstruse calculations, or to any thing more than giving it due consideration, we do not intend al.

The engineering of architecture must be more closely attended to by architects, as the engineer will take the matter out of the architect's hands; and that would be a slur to the profession which should and must be avoided. Not that engineering structures in this respect are always scathless; for there are also many cases on record of the failure of a bridge, a subaqueous tunnel or other such structure; but these are comparatively few and far between, while architectural mishaps are of far more frequent occurrence.

Our friend Mortimer, publisher of the Canadian Architect and Builder, rehearses the fact at page 112 of his "Hand Book" that the ultimate strength of a wall or pier built of good hard burnt bricks in good lime mortar, as given by Kidder of Boston, is 1500 lbs. to the square inch, say 216,000 lbs or 108 tons to the square foot,—while the use of Portland cement with the best hard burned bricks, increase the resistance to 2500 lbs. the inch or 180 tons the foot—though previous competent authorities have given results from 30 to 50 per cent less than these. Assuming therefore the known weights of mortar and cement brick work per cubic foot, it would require a wall or pier to be from 1600 to 2700 feet high to crush the bottom bricks; and since such extreme cases have not and can never occur in practice, and that walls do fall notwithstanding, which do not even reach to one tenth of the height; it is evident that not only must the mere crushing elements be made factors of, but other important data of length, breadth, height and thickness, and these are the considerations which apparently, from seldom or ever entering a builder's mind or that of a would-be architect, lead to the repeated accidents and fatalities of every day occurrence in some part or other of the civilized world.

Now, this knowledge is at hand and to be found at page 109 of the "Canadian Contractor's Handbook" which gives the proper thickness of brick walls for dewelling houses up to 100 ft. in height; though of course there are other considerations to be dealt with, such as the supporting, staying or stiffening ministry of the successive tiers of joists or beams, whether of wood or iron, which enter into the structural arrangements of the building; important among which is the necessity that beams which would be otherwise of too lengthy a span and therefore liable to dangerous oscillation and destructive leverage on the walls, be supported at intermediate points by other walls and piers restorative of the necessary stiffness to insure stability.

When however a structure becomes very high and heavy, as with the present tall buildings like the Philadelphia City Hall, the New-York World (22 story) printing establishment, the American Surety building (307 ft. high above the sidewalk and may be 20 to 30 ft. below that level), the Manhattan and others in New-York and Chicago, and a beginning in that way in Montreal and others cities; it then behoves the architect charged with designing the structure to take crushing weights into consideration, and especially when the buildings are designed to be fire proof and that, to that end, the floors are beamed with iron joists, brick or terra cotta archings or vaultings between and concrete haunch or spandril filling with tile or cement floors to boot; and which including weight of superincumbent partitions walls and colums of the floor or story next above or resting on and supported by the columns next below, and with 90 lbs. live and dead weight additional for persons, furniture and fittings of all kinds, may be taken at 300 lbs. per foot sup. of floor space.

To this end, I have thought that on retiring from the presidency of the Association of Architects of the Province of Quebec, it might not be amiss for me to tabulate, as I have done herein-below ; and for the ordinary spans or inter-columniations of 10 x 10 ft. centres, 10 x 20 ft. centres and 20 x 20 ft. centres, or for floor spaces of 100, 200 & 400 ft. area respectively ; and for each and every successive story of a building up to 20 stories high, which I have done : the sectional area in square inches of steel built-columns to support the weights, the thickness of their component plates, the weights in tons to be supported and in the three last vertical columns of the table the corresponding prices at a uniform rate of 5 cents to the pound — while if 6, 7 or 8 or 10 cents to the pound or even more or less are to be allowed, as fluctuating with the market value of the metal to be put in place at any time ; then can the whole, the total cost be added to or deducted from by a known percentage of 20 for one cent additional, 40 % for 2 cents, 50 % for 2½, 60 % for 3 and 100 % for 5 and so on ; for in addition to the possible price of iron or steel being greater or less, there is also to be estimated the average cost of first raising the weights to the average height of the structure which, should the stories average 12 ft., in height, would be 120 ft. for a 20 story building, 60 ft. for a 10 story building and so on of other average heights.

To simplify, and speed me in the computation of the table—I have assumed one unique type of section or build of the supporting column of 12″ x 12″ from out to out with central web, the whole put together with valley, or angle or flange iron, riveted together as shown in diagram in the margin or herein below; but, as with this form and size of section, the plates for a 20 story structure reach to two inches in tickness or more, it is evident how by increasing the size of column to two ft. square instead of one, or four ft. bearing area (2′ x 2′) the plates would thus be reduced to ½ an inch in thickness instead of 2″ or to a thickness of one inch, by doubling the bearing area of column or making it 1.′42 x 1.′42=2.0164 square feet, or simply 1.′4 x 1.′4.=1.96 square feet which is near enough for all practical purposes, when the factor of safety as in this case is already on the safe side.

Or again, instead of the posts or columns being exactly square, it might suit better to double the dimension one way, leaving the other as it is: for instance 1′ x 2′ or 12″ x 24″ for inch plates instead of 2″, or for ½″ plates 1′.6″ (18 inches) x 2′.8″ (32 inches) or any other form of section to suit, as round or oval, etc.

The tabular statement does not give weight of column; but taking item No. I, the sectional area in square inches is given as 10 sqr. inch. and the thickness of plates at 0.1″ (one tenth of an inch). Now, how this is arrived at, will be immediately seen on refering to the diagram; for, as evident, there are four plates each 12″ wide, one web plate 6 inches, and 8 valleys of 3″ x 3″ or each 6″ in developed breadth, together 102 or say 100 inches in total horizontal girth. Now 100″ x 0.1″=10″ or 5/6 of a square ft. of inch thick iron per lineal ft of column. Again, wrot. iron being 480 bls. to the cubic foot, gives 40 bls. to the square foot of inch thick plate, or for 5/6 of a square foot 33⅓ lbs. per lineal ft. of column; and this into 14 the assumed height or length of column gives 467 lbs. or with rivets say 480 lbs. which at 5 cts. the pound give the figures $24.00 in the corresponding column opposite item No. I of table.

Or it may be plainer or easier to say that 102 inches total horizontal girth of plate and valley iron in the section, gives (dividing by 12) 8½ superficial ft. of iron or steel plate 1/10″ thick, and as iron 0.1″ thick=4 lbs., therefore does the 8½ ft. give as before 34 lbs. or neglecting the 2 odd inches (more than allowed for in not deducting the twice computed angles of the valley irons) 33 1/3 pounds.

Now this unit of weight and cost of column opposite item I for a 20′ x 20′ space or 400 ft. area, which at 300 lbs. a foot of floor surface gives the 60 tons in the sixth column, must of course be half of itself when the supported area is only 10′ x 20′, and ½ of this last or ¼ of itself, where the supported area is only 10 x 10 or 100 sup. ft., and so is also the thickness of iron reduced to 0.05" and to 0.025" respectively and the corresponding prices in the two last columns to $12.00 and $6.00 respectively.

Again, as herein before stated, as to how to increase the area of bearing surface of column to reduce thickness of plates to inch or half inch ; so in a converse manner, may the 12" x 12" columns of the upper floors be reduced to half their size or to 6" x 6" and the plates in column 4 of table made 0.4" thick instead of 0.1" ; or to 6" x 12", and the plates increased to 0.1" for column 7 of table instead of 0.05" ; and to 0.05" instead of 0.025" for column 10 of table.

It will likely be evident or at any rate there can be no harm in remarking that in computing by this table for a building of any number of stories the process must be from above downwards, and can not be from below upwards except in the case the table is made to suit to wit : a building 20 stories high ; for the upper story supporting only the roof will remain invariable and if the total height of structure were, for instance, only nine stories, then would item No 9 represent the data for the first tier or story above street level with Nos. 10 and 11 for basement and subbasement.

I herewith also give a table for a corresponding building with brick piers instead of iron, where the cost of brick work in cement at as high as $20.00 per mil (taking its crushing strength at 180 tons the square foot with a factor of safety of 6, or assuming the square foot of pier as capable only of supporting 30 tons) just comes to half the corresponding prices of iron or steel at 5 cts. a pound or would be a quarter of the cost thereof if at 10 cts. the pound. Such piers as those given of a sectional area of only one square ft. opposite item N° 1 of table, column N° 7, and of ½ a square ft on same line of column N° 10 (the latter especially not being possible in practice) it would of course be necessary with such weights to bear, to have a piece of steel or iron or corresponding strength, or as indicated at columns 7 and 10 of table N° I ; and it might moreover be prudent to do the same with the smaller or more delicate piers of items N^{os} 2 and 3, or if not, to continue up these piers of undiminished size from items N^{os} 3 or 4 or even 5 according to circumstances; as, though theoretically capable of bearing the weight, such light brick structures would be dangerous of overthrowal by a comparatively slight side thrust.

On the other hand, as seen by the table the corresponding sizes for the lower floors or stories become so great, that they would be altogether inadmissible on account of the space thereby lost to useful purposes; and the object of this second table is rather to show the inadmissibility altogether of brick work in the premises; as, even though the cost of structure might be thereby reduced, it would be false economy to lose so much useful space, to say nothing of the very awkward appearance of such a structure, and again with most companies requiring such structures and with no want of funds to provide them, cost is generally a very secondary consideration, each insurance or other company or trust or syndicate striving to outvie its neighbours in magnificence and cost of structure. And this emulation exists even among individuals as I am proof to, when on one of my visits to New-York on inspection of an ordinary sized 25 ft. brown-stone front dwelling house on fourth avenue, which with its marble stairs and skirtings, etc., had cost its proprietor $100,000; the propietor of the neigboring lot with an old fashioned brick house thereon, seriously asked his architect if he could not build him one which would cost more money, to which of course, the architect immediately assented. We don't have such chances as that in poor old Quebec, where we are on the contrary always met with the demand to do things for half their value.

The construction of these high buildings is rendered possible only by the use of steel frame or skeleton work. The older type of buildings, whether of stone, brick or iron, depended for its strength upon its walls. The modern tall office building has a steel frame. This carries merely the whole weight, and the walls, solid and massive as they may appear, do not support the structure, but simply fill the interstices. It is startling to think of the entire superstructure of a 20 story building resting only on some 30 or 40 columns; yet, without this modern developement, without the use of steel, the walls would have to be so tick at the lower stories that there would be no room left for offices. The steel represents the osseous structure of the animal, while the enveloping masonry surrounding the same exemplifies the flesh or meat, which saves the skeleton from the extremes of temperature and thus from the exertion of contractive and expansive forces which might otherwise jeopardize the structure.

It becomes important also if not imperitive as a factor in the computation of the necessary bearing areas of the foundations supporting structures of the kind, to consider as data for comparison, what weights, are permissible to the square foot of underlying piles or piers, or of the natural soil when of a nature to subserve the purpose ; some of the columns bearing weights varying between 600 and 1,300 tons in the American Surety building already alluded to.

The inequality of the weights borne by a square ft. of the foundations of the buildings mentioned in table III, may appear striking at first sight ; but they are due to the weights being distributed over greater or lesser areas of the supporting soil. For instance, in table I, item No. 21, we have 1,260 tons supported by a steel column a foot square, while in the Am. Surety bdg. some of the columns are loaded to 1,280 tons ; but these are about two ft. square or of an area of 4 ft. which at once reduces the pressure per sup. foot to 320 tons ; and if the foundation piers bearing these and transmitting their weight to the solid rock below were only 10 ft. square or 100 ft. area, the weight per ft. reduces to a little less than 13 tons; while if the pier be made 14 ft. square, its area is doubled and the 13 tons reduced to 6½ or 6 as setforth in table ; and as stated last year by the writer in his paper on the foundations of heavy structures, the question is not so much the number of tons which one ft. of bearing surface is loaded with, as that (not to prevent settlement which is inevitable, but to render it equal throughout) the bearing surfaces of foundations be equally loaded ; the whole front of the new Joliette church having to be rebuilt at a cost of some $10,000 because while the side walls bear with only 2 tons weight or pressure on their footings, the tower and front wall bearing on their footings with a pressure of 4 tons or double the weight ; the tower, when I saw it three years ago had torn itself and the portal away from the aisle walls and sank to a depth of more than 11 inches below the latter, completely dislocating and destroying this portion of the structure and requiring its entire demolition and reconstruction.

One would think at first sight ; that is, the popular idea may be and is, that a solid structure or one of solid masonry like the pyramids, is that which with the same height and weight of material, bears heaviest on its foundations ; but such is by no means the case, the greatest pressure being generally borne by the piers of a domed church or other structure ; each pier being loaded, in addition to its own weight and portion of dome bearing directly on it, with one quarter of such portions of the vaulted or arched structure as correspond to the archways or openings of the aisle and transept, and which as in the case of St. Peter of Rome must be close upon 35 tons to every square ft. of the supporting pier.

Nor is there any thing extraordinary even in this figure, as I beleive some of the so called chapter houses of churches in England, support weights even in excess of this, where one half the weight of the domed or stone groined vaulted ceiling is borne by a single marble column of only a few inches in diam. at the centre of the structure. Another example of heavy weights borne by a small base is, where a 100 ton gun for instance or ponderous piece of machinery supported by the jib or boom of a derrick, is thus transferred to and supported by the derrick mast or upright post, which if say of a 14 inches square piece of timber, giving a sectional area of only 2 ft. or less, loads the bearer with a weight of 50 tons together with the additional weigth of the derrick itself; representative also, the derrick post or mast, of a column in any building and the boom or jib with its suspended weight, of the 100,200 or 400 ft. area of supported flooring with column at 10'-10' centre, 10'-20' or 20'-20' distance apart, or (at 300 lbs the ft.), 15, 30 and 60 tons respectively.

Now even 60 tons or 160 to a square foot of a solid stone pier, not monolithic, but made up of monolithic or large and closely fitting cut stones, is in no way excessive, since good cement brick work will bear 180 tons; while good ordinary cement stone masonry will bear twice that weight or 360 tons and up to twice that figure or even more; for the experiments made on a brick pier for instance, are so made on one of only a foot square, and those on piers of masonry have also been made on comparatively small based areas, where there was no lateral support or resistance round about to prevent the giving away by lateral failure.

Again the strength of piers of stone masonry may be made to approximate almost indefinitly to that of the stone itself, as given in the ensuing table IV where crushing pressures are recorded of, as much as 1200 tons and over to the square ft. or rather, equivalent thereto and which would be much greater if it were possible, which it practically is not, to test a foot of stone in the same manner instead of only a small cube of an inch or an inch and a half square and then reduced to inch; for the small cube, as would also be the case with a larger one, must necessarily fail first at the angles or corners and along the edges; while if the same weight or pressure were applied to an equal area at the centre of a 12 inch stone or more; it is evident it would produce no effect, the tendency to crush and crack being counteracted by the lateral support given to the central portion by the strength and resistance of the outlying margin of the material experimented on.

And not only would the crushing weight of masonry approximate to that of the solid stone, as determind by experiments upon the tiny cubes thus treated; but, there can be no doubt of it, go far beyond such data and indefinitely so; for even if the nucleus of the earth be fluid, and the crust only 40 miles in tickness as geologists pretend, and if the crust be stone and even if no heavier than granite, then would we have on each square foot of the inner rim or area of base thereof, more than 200,000 cubic feet of stone and at 160 bls. to the foot, a crushing pressure of 16,000 tons; but which, were it ten times greater, a hundred or a thousand times, could never crush the stone, supported on all sides as is every foot of the crust or solid component masonry thereof, by the equally resisting power of every other foot hemming it in on all sides and preventing the possibility of its ceding or giving away to any other force than the disrupting seismic action of the interior.

I must, gentlemen, insist again, as I did in my last years' paper on foundations in deep and unreliable soils, on the necessity of a consideration, not of absolute, but of comparative stresses to secure uniformity or prevent inequality of sttlement—that being the all important desideratum.

The very term "the engineering portion of architecture" or rather the necessity for such a term is a slur on the profession, an insult so to say to any architect who pretends he knows his business; for if we are to call in the superior scientific acquisitions of the engineer in dealing with the foundations, then, a fortiori, shall we have to do so in dealing with the stresses much more difficult of calculation of a domed structure for instance; and surely it never shall be said that the architect has come down from the high pedestal on which, long before the days of engineering science, stood and stand to this day the Bramante's and the Michael Angelo's, the Perrault's and the Mansards', the Jones (Inigo) and the Wren's. Well may we hide our heads, if ever that should come to passs; for, without the aid of the engineer, we architests can do as they do and thus make themselves appear more scientific than they really are. Can *we* not also call in the aid of mathematics, and direct a professor or expert at that science, to calculate a stress of any kind whether of direct weight, lateral pressure or resistance to overthrowal by a cyclonic wind or hurricane.

If the profession would have that standing which it had of yore and still lays claim to in other countries, I must tell you and I do so squarely — we must hear of no more such failures as those at Nicolet, St. Basile, Joliet, Cornwall and elsewhere, nor should there be any more roof failures whether from rain saturated snow or due to faulty construction. Montreal must not in respect to falling buildings emulate New York, where such accidents are the order of the day, which are to the disgrace of the profession.

But though or while giving you a table for calculating the component weights, and strengths and costs of a building up to 20 stories in height, I hope none of you will ever be called on to design such an ungainly, unaesthetic piece of construction, and at any rate that you will set your face against any thing of the kind elsewhere than in but a purely manufacturing or suburban district and not where its presence would mar the landscape and architectural effect of surrounding common sense structures; and I here transcribe a most pertinent article from the "London Surveyor." It reads as follows :

" A *propos* of a monstrous "sky-scraper" apartment house recently erected at Washington, the American *Architectural Record* has a deservedly-severe article on "Architectural Aberrations," and puts forward the plea that city authorities should be allowed to veto plans for new buildings, not only if they sin against sanitary laws, but if they outrage the canons of art. As it pertinently remarks, "There is a patent absurdity in taking thought and spending vast sums of money for the purpose of making a harmonious city and then permitting any promiscuous private person who can get possession of a piece of ground, and raise money enough, to put a building on it, to nullify all your dispositions and vulgarise your town." There is much in the protest, and though we do not suffer so badly as our cousins do from the *piled-up monuments of bad taste and cupidity*, still even London suffers from the tall-house mania, not to mention other hideous forms of architectural aberrations. Edinburgh, too, will note the timely protest with interest. But the task of acting as censor would be full of difficulties where mutable taste rather than positive science would have to be the guide."

To this I would add that there should be no foolish rivalry in such matters, as it is as easy for one architect to outdo another in hight as for a naval arct. to beat the record in point of length and strength or for an artillerist to design a target that will resist a shot, a shot to pierce it, another target to resist the latter and again another shot to hole it and so on, without end; but though there may be a reason for this when a nation wishes to retain its prestige over its neighboor; and though engineers are forced into long and still longer spans for bridges due to the widths and depths of rivers to be traversed and to conditions imposed by the authorities, as in the 1,700 feet twin spans over the Firth of Forth in Scotland, the Brooklyn suspension bridge and now the 3,200 feet span structure about to be thrown over the Hudson between New York and Jersey City; no similar necessity exists for structures of the Eiffel tower type, which all Paris is clamorous to have demolished, though it certainly is not an outrage to artistic taste and merit in any way approaching the superposed box-like piles which are now in a fair way to disgrace our neighbors in the eyes of European nations.

Gentlemen, let us also be severe in architecture, to the extent at least of not allowing it to assume, as it is bidding fair to do in Ottawa, the phase of what may be called " bed post architecture " ; and in truth though there are hundreds of otherwise very pretty villas and cottages in the new Capital, quite a number of their verandas and entrance porches are rendered hurtful to the eye of good taste, by being supported on bed posts, for they certainly can not be called columns; and to cap the climax, in some of the twin dwelling houses or where there are two doors side by side, with a veranda or portico in common, the separation between the doors is for all you can imagine, of the exact shape of a partition between two horse stalls.

Type of steel-built-column on which calculations of stresses, weights and prices are based, for computation of data in table I.

Scale $\frac{1}{4}$ inch to one inch.

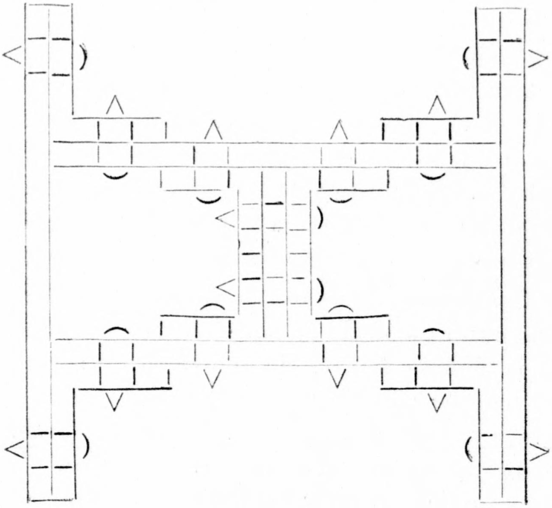

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TABLE of steel thicknesses and sectional areas, box built columns to support fire proof or iron, brick and concrete floorings in buildings from 1 to 20 stories high. Weight per sup. or square foot of roofing and flooring, partition walls, etc., 300 lbs. including 90 lbs. live load. Factor of safety = 5 or 1/5 of crushing load.

No. of Item for reference	No. of stories counting up-wards.	No. of stories counting down-wards.	Columns at 20' – 20' centres. Area supported 400 sqr. ft.			Columns at 10' – 20' centres. Area supported 200 sqr. ft.			Columns at 10' – 10' centres. Area supported 100 sqr. ft.			At 14 ft. long in position & at 5 cts per lb.		
			Thicks. of plates.	Sectional area.	Weight supported in tons.	Thicks. of plates.	Sectional area.	Weight supported in tons.	Thicks. of plates.	Sectional area.	Weight supported in tons.	Cost of each column at 5 cts lb. 20' – 20'	Cost of each column at 5 cts lb. 10' – 20'	Cost of each column at 5 cts lb. 10' – 10'
			Inches.	Sqr. Inch.		Inches.	Sqr. Inch.		Inches.	Sqr. Inch.		$	$	$
1	Roof	Roof	0.1	10	60	0.05	5	30	0.025	2.5	15	24	12	6
2	20	1	0.2	20	120	0.10	10	60	0.050	5.0	30	48	24	12
3	19	2	0.3	30	180	0.15	15	90	0.075	7.5	45	72	36	18
4	18	3	0.4	40	240	0.20	20	120	0.100	10.0	60	96	48	24
5	17	4	0.5	50	300	0.25	25	150	0.125	12.5	75	120	60	30
6	16	5	0.6	60	360	0.30	30	180	0.150	15.0	90	144	72	36
7	15	6	0.7	70	420	0.35	35	210	0.175	17.5	105	168	84	42
8	14	7	0.8	80	480	0.40	40	240	0.200	20.0	120	192	96	48
9	13	8	0.9	90	540	0.45	45	270	0.225	22.5	135	216	108	54
10	12	9	1.0	100	600	0.50	50	300	0.250	25.0	150	240	120	60
11	11	10	1.1	110	660	0.55	55	330	0.275	27.5	165	264	132	66
12	10	11	1.2	120	720	0.60	60	360	0.300	30.0	180	288	144	72
13	9	12	1.3	130	780	0.65	65	390	0.325	32.5	195	312	156	78
14	8	13	1.4	140	840	0.70	70	420	0.350	35.0	210	336	168	84
15	7	14	1.5	150	900	0.75	75	450	0.375	37.5	225	360	180	90
16	6	15	1.6	160	960	0.80	80	480	0.400	40.0	240	384	192	96
17	5	16	1.7	170	1020	0.85	85	510	0.425	42.5	255	408	204	102
18	4	17	1.8	180	1080	0.90	90	540	0.450	45.0	270	432	216	108
19	3	18	1.9	190	1140	0.95	95	570	0.475	47.5	285	456	228	114
20	2	19	2.0	200	1200	1.00	100	600	0.500	50.0	300	480	240	120
21	1	20	2.1	210	1260	1.05	105	630	0.525	52.5	315	504	252	226

II

COMPARATIVE TABLE of sizes or sectional areas of brick piers to support fire proof or iron, brick and concrete floorings in buildings from 1 to 20 stories high Weight per sup. ft. of roofing, flooring, partition walls, etc. 300 lbs. including 90 lbs. live load.

No. of Item for reference	No. of stories counting up-wards.	No. of stories counting down-wards.	Piers at 20' – 20' centres. Area supported 400 sqr. ft.			Piers at 20' – 10' centres. Area supported 200 sqr. ft.			Piers at 10' – 10' centres. Area supported 100 sqr. ft.			Piers calculated at 14 ft. high, 20 bricks per ft. cube		
			Area of pier in Ft. – In.	Size of pier square.	Weight supported in tons.	Area of pier in Ft. – In.	Size of pier square.	Weight supported in tons.	Area of pier in Ft. – In.	Size of pier square.	Weight supported in tons.	Cost of each pier 20' – 20' at $20.00 mil.	Cost of each pier 10' – 20' at $20.00.	Cost of each pier 10' – 10' at $20.00.
	Roof	Roof	' "	' "								$	$	$
1			2.0	1.41	6	1	1.00	30	½	0.70	15	12	6	3
2	20	1	4.0	2.00	120	2	1.41	60	1	1.00	30	24	12	6
3	19	2	6.0	2.45	180	3	1.73	90	1½	1.29	45	36	18	9
4	18	3	8.0	2.83	240	4	2.00	120	2	1.41	60	48	24	12
5	17	4	10.0	3.16	300	5	2.24	150	2½	1.58	75	60	30	15
6	16	5	12.0	3.46	360	6	2.45	180	3	1.72	90	72	36	18
7	15	6	14.0	3.74	420	7	2.65	210	3½	1.87	105	84	42	21
8	14	7	16.0	4.00	480	8	2.83	240	4	2.00	120	96	48	24
9	13	8	18.0	4.24	540	9	3.00	270	4½	2.12	135	108	54	27
10	12	9	20.0	4.47	600	10	3.16	300	5	2.24	150	120	60	30
11	11	10	22.0	4.69	660	11	3.32	330	5½	2.35	165	132	66	33
12	10	11	24.0	4.90	720	12	3.46	360	6	2.45	180	144	72	36
13	9	12	26.0	5.10	780	13	3.60	390	6½	2.55	195	156	78	39
14	8	13	28.0	5.29	840	14	3.74	420	7	2.65	210	168	84	42
15	7	14	30.0	5.47	900	15	3.82	450	7½	2.74	225	180	90	45
16	6	15	32.0	5.65	960	16	4.00	480	8	2.83	240	192	96	48
17	5	16	34.0	5.83	1020	17	4.12	510	8½	2.92	255	204	102	51
18	4	17	36.0	6.00	1080	18	4.24	540	9	3.00	270	216	108	54
19	3	18	38.0	6.16	1140	19	4.36	570	9½	3.08	285	228	114	57
20	2	19	40.0	6.32	1200	20	4.47	600	10	3.16	300	240	120	60
21	1	20	42.0	6.48	1260	21	4.58	630	10½	3.24	315	252	126	63

ick piers to
gs from 1 to
walls, etc

rs calculated at
14 ft. high, 20
cks per ft. cube

at $20.00 mil.	Cost of each pier 10' - 20' at $20.00.	Cost of each pier 10' - 10' at $20.00.
$	$	$
12	6	3
24	12	6
36	18	9
48	24	12
60	30	15
72	36	18
84	42	21
96	48	24
08	54	27
20	60	30
32	66	33
44	72	36
56	78	39
68	84	42
80	90	45
92	96	48
04	102	51
16	108	54
28	114	57
40	120	60
52	126	63

III

Weights per square or superficial foot borne by piers and foundations of certain buildings, bridges and others structures.

Says professor Butler, as given by Mortimer at page 104–5 of his " Hand book."

	Per square foot.	
" The load on the monalithic piers supporting the large churches in Europe does not exceed (Early builders using much more massive masonry, proportionally to the load to be carried than at present).....	30	tons.
" The Toff bridge in France.............	21	"
" Former bridge at same place said to have failed at.....	64	"
" Rennie subjected good 4 ft. rubble piers to	22	"
" Granite piers Saltask bridge England...	9	"
" Brooklyn bridge piers............. ...	29	"
" St. Louis bridge piers before completion.	38	"
" The same after completion......	19	"
" Niagara suspension bridge limestone towers failed under..................	36	"
" Maximum pressure on rubble masonry and cement mortar of some of the large masonry dams...	14	"
" Proposed Quaker bridge dam — 270 ft. high......	17	"

The following are from the writer and others :

	Per square foot.
At centre of the Cheops pyramid say.....	40 tons.
Piers of the dome at St. Peters (the great thickness of these piers say 20 to 30 renders the confined centre as resisting, so to say, as solid rock.) say about....	35 “
Weight on foot side walls Joliette church.	2 “
Weight under tower (causing failure by sinking or settlement).....	4 “
Strasbourg Cathedral tower say..........	40 “
Washington Monument 555 feet high.....	45 “
Tower of Babel or of Belus 650 ft. high say	52 “
Central piers Britannia bridge...........	33 “
“ Manhattan Life ” building 353 ft. high..	15 “
The “ Equitable ” bdg. and Union Trust built with wide footings load the foundations, it is said, only to.............	3 “
Proposed Hudson river bridge 3,200' ft, span piers................	26 “
The Stock Exchange Chicago is said to load the foundation soil at	4 “
Allowed by New York City regulations...	15 “
Load per foot square of foundation brick piers of Am. Surety bdg. say........	6 “
The authors design for the proposed London Eiffel tower (see fig. 5, page 18 of the 68 designs sent in, printed and published for “ The Tower Company limited,” by “ Industries ” 358 Strand	

	Per square foot.
London, under title of "The Great Tower for London. Height of tower 1,600 ft., diam. at base 280 ft., total weight 14,303 tons, 20' wide offset balconies at every 200 ft. of total height, greatest weight on lower column at centre...........................	117 tons.
Average weight on the 312 first tier columns...........	46 "
Total weight distributed by inverts or footings over the 61,600 ft. area, less than	$\frac{1}{4}$ "
Weight at centre distributed by inverts or footings over the 100 ft. sup of bearing to each column at centre of tower....	$1\frac{1}{6}$ "
Brunel (Paris), design for proposed London Eiffel tower, 500 ft. square, 2,296 ft. high, of granite, weight 196,902 tons, weight per foot square supported by bottom piers......	160 "
Weight per square ft. distributed over soil area of 250,000, say................	$\frac{4}{5}$ "

TABLE IV.

CRUSHING TESTS OF BUILDING STONE.

For many years the resistance to crushing force shown by a building stone has been considered high evidence of its homogeneousness and durability.

The following table gives the resistance to crushing per square inch, shown by various stones, granites and marbles, and is compiled from General Q. A. Gillmore's report to the Chief of Engineers, United States Army; from Haswell's Engineers Pocket Book; from "Stones for Building and Decoration," by Dr. George P. Merrill, of the Department of Geology Smithsonian Institution, and from tests made by Mr. Ira H. Woolson, C. E., at the request of the Professor of Geology of Columbia College School of Mines, on the Emery testing machine belonging to the College. Where tests have been made on a number of specimens, the highest result is given.

Paving brick should stand 10,000.00 to inch crushing force and absorb not over 2 to 3% water.

CRUSHING WEIGHT PER SQUARE.

		Inch in lbs.	Foot in tons.
Aberdeen, Scotland, Granite	Haswell,	10760	774.7
Albion, New York, Sandstone	Gillmore,	13500	972.0
Altamount, California, Sandstone	Merrill,	1149	82.7
Arbroath, England, Sandstone	Haswell,	7850	460.2
Aquia Creek, — Sandstone	Haswell,	5340	389.5
Bardstown, Kentucky, Limestone	Gillmore,	16250	1170.0
Bay of Fundy, Canada, Granite	Gillmore,	12020	865.5
Bedford, Indiana, Oolitic, Limestone	Merrill,	10125	729.0
Belleville, New Jersey, Sandstone	Gillmore,	11700	842.4
Berea, Ohio, Sandstone	Gillmore,	10250	738.0
Billingsville, Missouri, Limestone	Gillmore,	7250	522.0
Caen, France, Limestone	Gillmore,	3650	262.8
City Point, Maine, Granite	Gillmore,	15093	1086.7
Cleveland, Ohio, Sandstone	Gillmore,	7910	569.5
Connecticut, Freestone	Haswell,	3319	238.9
Cornish, Wales, Granite	Haswell,	6339	456.4

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h bs.	Foot in tons.
60	774.7
00	972.0
49	82.7
50	460.2
40	389.5
50	1170.0
20	865.5
25	729.0
00	842.4
50	738.0
0	522.0
0	262.8
3	1086.7
0	569.5
9	238.9
9	456.4

		Inch in lbs.	Foot in tons.
Craigleith, Scotland, Sandstone	Gillmore,	12000	864.0
Dix Island, Maine, Granite	Gillmore,	15000	1080.0
Dorset, Vermont, Marble	Gillmore,	8670	624.2
Dorchester, New Brunswick, S. S	Gillmore,	9412	677.6
Dublin, Ireland, Granite	Haswell,	10450	737.4
Duluth, Minnesota, Granite	Gillmore,	19000	1368.0
Edinburg, Scotland, Sandstone	Merrill	12000	864.0
English Magnesian Limestone	Haswell	3130	225.3
English Anglesa Limestone	Haswell,	3600	259.2
Fairhaven, Vermont, Slate	Merrill,	12870	926.6
Fond du Lac, Wisconsin, Sandstone	Gillmore,	6250	450.0
Fox Island, Maine, Granite	Gillmore,	15062	1084.4
Glencoe, Colorado, Sandstone	Merrill,	12752	918.1
Glens Falls, New York, Limestone	Gillmore,	11475	826.2
Greenwich, Connecticut, Granite	Gillmore,	11700	842.4
Harbor Quarry, Maine, Granite	Gillmore,	16837	1212.3
Haverstraw, New York, Sandstone	Gillmore,	4350	313.2
Hummelstown, Pensylvania, S. S	Merrill,	13610	979.9
Huron Island, Michigan, Granite	Merrill,	20650	1486 8
Hurricane Island, Maine, Granite	Gillmore,	14937	1075.4
Italian Marble	Merrill,	12156	875.2
Joliet, Illinois, Limestone	Gillmore,	16900	1216.8
Jordan, Minnesota, Sandstone	Merrill,	3750	270.0
Kasota, Minnesota, Sandstone	Gillmore,	11675	840.6
Keene, New Hampshire, Granite	Merrill,	10375	747.0
Little Falls, New York, Sandstone	Gillmore,	9850	709.2
Long Meadow, Massachusetts, S. S	Merrill,	8812	634.4
Manitou, Colorado, Sandstone	Merrill,	13046	939.3
Marquette, Michigan, Limestone	Gillmore,	8050	579.6
Marquette, Michigan, Sandstone	Gillmore,	7450	536.4
Marblehead, Ohio, Limestone	Gillmore,	12600	907.2
Massillon, Ohio, Sandstone	Gillmore,	8750	630.0
Medina, New York, Sandstone	Gillmore,	17725	1276.2

		Inch in lbs.	Foot in tons.
Michigan Sandstone	Merrill,	6323	455.2
Middletown, Connecticut, Sandstone	Gillmore,	6950	500.2
Mount Raymond, California, Granite	Merrill,	5970	429.8
Monson, Massachusetts, Granite	Merrill,	15390	1108.0
New Gunnison, Colorado, Sandstone	Merrill,	9903	713.0
New Haven, Connecticut, Granite	Gillmore,	9750	702.0
New London, Connecticut, Granite	Merrill,	12500	900.0
Newry, England, Granite	Haswell,	12850	925.2
North Amherst, Ohio, Sandstone	Gillmore,	6650	478.8
North River, Limestone	Gillmore,	13425	966.6
Oswego, New York, Sandstone	Merrill,	6220	447.8
Patapsco, Maryland, Granite	Haswell,	5340	384.5
Port Deposit, Maryland, Granite	Gillmore,	19755	1422.3
Potsdam, New York, Sandstone from a Quarry of the Potsdam Red Sandstone Co., (Not crushed.)	**Woolson,**	**42804**	**3081.8**
Quincy, Massachusetts, Granite	Gillmore,	17750	1278.0
Quincy, Illinois, Marble	Gillmore,	9787	704.0
Rawlins, Wyoming, Sandstone	Merrill,	10833	779.9
Richmond, Virginia, Granite	Merril,	19104	1375.5
Rockport, Massachusetts, Granite	Gillmore,	19750	1422.0
Scotch Whinstone	Haswell,	8300	547.6
Seneca, Ohio, Sandstone	Gillmore,	10500	756.0
Stony Creek, Connecticut, Granite	Merrill,	16750	1206.0
Stockbridge, Massachusetts, Marble	Haswell,	10382	747.5
Taylor's Falls, Minnesota, Sandstone	Merrill,	5500	396.0
Tuckahoe, New York, Marble	Gillmore,	13594	978.7
Vermillion, Ohio, Sandstone	Gillmore,	8850	637.2
Vermont Marble	Merrill,	13400	964.8
Vinalhaven, Maine, Granite	Gillmore,	16750	1206.0
Warrensburg, Missouri, Sandstone	Gillmore,	5000	360.0
Westerly, Rhode Island, Granite	Gillmore,	17750	1278.0
Williamsville, New York, Limestone	Gillmore,	12375	891.0
Yorkshire, England, Sandstone	Haswell,	5710	411.1

Foot in tons.
455.2
500.2
429.8
1108.0
713.0
702.0
900.0
925.2
478.8
966.6
447.8
384.5
1422.3
3081.8
1278.0
704.0
779.9
1375.5
1422.0
547.6
756.0
1206.0
747.5
396.0
978.7
637.2
964.8
1206.0
360.0
1278.0
891.0
411.1