ON THE BEARING AND RESISTING STRENGTH OF STRUCTURES AND THAT OF THEIR COMPONENT PARTS AND MATERIALS.*

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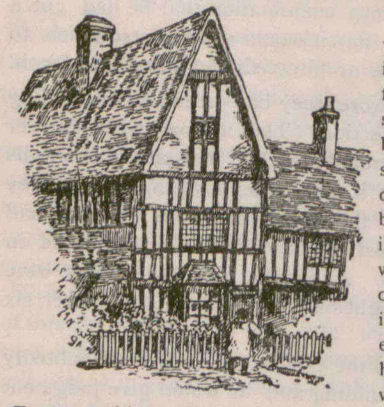

Many failures have, of late years, occurred of various buildings or of portions thereof, due to faulty, hasty or unmatured construction, and hardly a day passes but what the newspapers chronicle some catastrophe, some collapse of a building just finished, or even before it is finished, as evidently incapable 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 temporary 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 anything more than giving it due consideration, we do not intend to deal.

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 of good hard burnt bricks in good lime mortar, as given by Kidder, of Boston, is 1,500 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, increases the resistance to 2,500 lbs. to the inch, or 180 tons to 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 brickwork per cubic foot, it would require a wall or pier to be from 1,600 to 2,700 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 Hand-Book," which gives the proper thickness of brick walls for dwelling 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 Manhatten and others in New York and Chicago, and a beginning in that way in Montreal and other 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 partition walls and columns 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 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 intercommunications of 10x10 ft. centres, 10x12 ft. centres, and 20x20 ft. centres, or for floor spaces of 100, 200 and 400 ft. area respectively, and for each and every successive story of a building as 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 last three 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 ten 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"x12" 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 thickness or more, it is evident how by increasing the size of column to two feet square instead of one, or four feet 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 ft. x 2 ft., or 12 in. x 24 in. for inch plates instead of 2 in., or for ½ in. plates 1 ft. 6 in. (18 inches) x 2 ft. 8 in. (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 square inches and the thickness of plates at 0.1 in. (one-tenth of an inch). Now, how this is arrived at will be immediately seen on reference to the diagram, for, as evident, there are four plates each 12 in. wide, one web plate 6 inches, and 8 valleys of 3 in. x 3 in. or 6 in. in developed breadth, together 102 or say 100 inches in total horizontal girth. Now 100 in. x 0.1 in. = 10 in. or 5/6 of a square foot. of inch thick iron per lineal foot of column, Again, wrought iron being 480 lbs. to the cubic foot, gives 40 lbs. to the square foot of inch thick space, or for 5/6 of a square foot 33⅓ lbs. per lineal foot 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 cents 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 in. thick, and as iron 0.1 in. 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) 33⅓ pounds.

Now this unit of weight and cost of column opposite item I for a 20 ft. x 20 ft. 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 20 ft. x 10 ft., and ½ of this last or ¼ of itself, where the supported area is only 10x10 or 100 sup. feet, and so is also the thickness of iron reduced to 0.05 in. and to 0.025 in. 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 in. x 12 in. columns of the upper floors be reduced to half their size, or to 6 in. x 6 in., instead of 0.1 in., or to 6 in. x 12 in., and the plates increased to 0.1 in. for column 7 of table instead of 0.05 in., and to 0.05 in. instead of 0.025 in. 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 sub-basement.

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 to 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 cents a pound, or would be a quarter of the cost thereof if at 10 cents the pound. Such piers as those given of a sectional area of only one square foot opposite item No. 1 of table, column No. 7, and of ½ a square foot on the same line of column No. 10 (the latter especially not being possible in practice), it would of course be necessary with such weights to bear, to have made of steel or iron or corresponding strength, or as indicated at columns 7 and 10 of table No. I—and it might moreover be prudent to do the same with the smaller or more delicate piers of items Nos. 2 and 3, or if not, to continue up these piers of undiminished size from items Nos. 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 secondary consideration—each insurance or other company or trust or syndicate striving to outvie its neighbors 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 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 proprietor of the neighboring 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 on some 30 or 40 columns; yet, without this modern development, without the use of steel, the walls would have to be so thick 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 imperative, 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 foot 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 American Surety building some of the columns are loaded to 1,280 tons, but these

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