Lectures

ON

Building Construction

BY

Captain John Stephen Sewell
Corps of Engineers, United States Army

DELIVERED AT THE
United States Engineer School of Application
April 9, 10, and 11, 1903

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LECTURES ON BUILDING CONSTRUCTION

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The fundamental principles underlying the art of building are the same as those governing all forms of construction. To one well versed in the principles of engineering they can present nothing new, except in their particular mode of application. So much has been written and printed on the art of building that it might seem superfluous, at this time, to add another word. Yet, up to the present, the design and erection of buildings has been a matter of tradition, precedent, and rule of thumb; but modern requirements are such that it has been necessary to call in the engineer to the assistance of the architect; as this is a thing of recent development, it is possible that the application of engineering criteria may not only indicate the way to safe and successful development of features not founded on precedent, but even disclose room for improvements in the most time-honored rules of practice. Architecture is a matter of tradition and precedent; engineering is one of principles, to be well ascertained and established, and then logically but fearlessly applied, whether along old lines or not.

The art of building has never been fully discussed from the engineer's standpoint, and it is not proposed herein to attempt such discussion, but there are a number of points resulting from practical experience which will be touched upon with a view to supplementing the course in Building Construction at the Engineer School.

Every military engineer should be master of construction in all its forms. Probably the first really difficult structures erected by man had their origin in military requirements; so, military engineering may fairly claim to be the father of all construction.

Coming to buildings proper, there was not a great amount of structural design in the architecture of India, Babylonia, Egypt, or Greece. With the free use and great development of the arch and dome by the Romans, the structural aspect of buildings became more interesting; and with the development of the Gothic and related styles of architecture there appeared structural skill of a high order; to produce the wonderful effects seen in the old cathedrals, the material was often called upon to do its utmost limit of work and there was an accurate adjustment of opposing forces which must always command our admiration. Yet the design was such that the forces had always to be counterbalanced in a very indirect and costly way. Only the religious enthusiasm of the Middle Ages and a fine artistic sense, combined with the modern engineer's skill, without his sense of economy, could have produced such a type of building. The modern architect seems often to have inherited the artistic sense of his medieval predecessor—but not always his skill as a structural designer.

With buildings of the simpler and cheaper type, the engineer has not often much to do; yet they present many interesting points in construction, though not requiring any great amount of mathematics in their design.

On the subject of frame buildings, little can be added to Part II of Kidder's Building Construction and Superintendence. Some points brought out by him, however, may well be emphasized. In the matter of the frame, the method shown in Figure 19, page 50, could hardly be improved; considering cost and efficiency together, it is probably the best that can be done. The importance of having at all points the same amount of timber capable of shrinking in a vertical direction can not be overestimated. The lengthwise shrinkage of timber, while by no means inappreciable, is not enough to cause cracks in plaster or to spoil the fit of doors and windows. But its crosswise shrinkage is a very different matter. If one end of a partition is supported on 6 inches more of shrinkable timber than the other, cracks will surely appear in time, and the fit of doors will be noticeably impaired. Where inequalities in the amount of shrinkable timber are inevitable, it would be well, in the case of those members whose shrinkage will cause trouble, to buy kiln-dried lumber, if obtainable in suitable sizes, and give it a priming coat of paint before exposing it to the weather in the unfinished building. Even this will not entirely cure the trouble, but it will greatly lessen it. Thoroughly aired seasoned lumber would be better, but it can not always be obtained. Kiln drying is of doubtful utility in large pieces; if thoroughly done, it is likely to cause serious checking; if not thoroughly done, the shrinkage is not taken out, and ordinary lumber might as well be used. The expense of kiln drying large pieces would also be prohibitive in most cases. A certain amount of shrinkage and a few cracks in a frame building are probably inevitable.

The method shown by Kidder for the support of an interior partition, in Figure 62, page 80, is one of the few mistakes in his Part II. Partitions weigh a good deal themselves, and often support floors above. To depend on the holding power of a lag screw under a direct pull is not safe; besides, it seriously weakens the joists at the most vital point.

In many cases, where shrinkage and settlement are feared, an interior partition might be built as a truss, so as to carry itself, from end to end, and thus be independent of the floor joists beneath it; but probably the end supports, in a frame building, would be as liable to settlement as the joists. A reasonable amount of care and money expended upon fire and vermin stops is a good investment. The underside of girts and partition caps might well be covered with tin, where they are exposed between the studs. This will prevent fire from attacking these members until the temperature has become quite high; it will also entirely prevent vermin from weakening them by gnawing. A rat will easily gnaw through a piece 4 by 4 inches, if he can get at the wood.

In addition to the tin underneath, it is well to use brick nogging above, so as to prevent the horizontal passage of fire and vermin from one room to another between the floor and ceiling.

The roof, even of a frame building, is much better covered with slate or tin than shingles, so far as mere utility is concerned. Sparks from chimneys and neighboring conflagrations are much less liable to set the house on fire, and slate, at any rate, will last much longer than shingles. On the other hand, shingles can be used to obtain effects that are very attractive, and in isolated houses the fire risk is not a fatal objection to their use. Economy often compels it.

A slate or tile roof, because of its permanence, is worthy of copper flashing; but a shingle or tin roof should be flashed with tin. The best grades of I C plates should be used for this purpose. In any case, the flashing must be done with the utmost care; rain and snow are thorough inspectors; if there is a defect in the flashing they will surely discover it and announce the fact in the form of ruined ceilings and falling plaster. Gutters also must be well designed and carefully built. In latitudes where there is much real winter, the best forms of gutter are those shown in Figures 129 and 142, Kidder's, Part II. In these forms the freezing of the gutter can never cause water to back up under the roofing and appear inside of the house.

Chimneys in frame houses must always be so constructed that relative shrinkage or settlement between them and the house can not strain either structure or impair the flashing. No part of the brickwork should project over or have a bearing on any part of the timber construction. The chimney should be a separate and self-contained structure, including the fireplaces, but not the hearths, from the ground up.

When buildings have brick walls, timber floors, and timber partitions, a certain inequality of shrinkage is generally inevitable. Partition caps and girders are bound to shrink; so are floor joists. The brick walls will shrink if they are laid up in lime mortar, but the amount of shrinkage varies in different cases and can not be predetermined. If the walls are laid in cement mortar, as they should be in all Government buildings of any importance at all, the shrinkage of the masonry will be negligible. Assuming that the walls will not shrink appreciably, the problem is presented of preventing shrinkage elsewhere from throwing floors out of level, spoiling the fit of doors and producing unsightly cracks. One method is to make all partitions that are continuous from the foundation up of brick; but this is often impossible because of expense. Even if this is done, there will be other partitions that must be supported by the floors; the only sure remedy, in this case, is to use a steel beam to carry the partition. In the case of the partitions that are continuous from the foundations up, serious shrinkage can be prevented by building them of brick to the first floor, and of studding above, provided the studs start from the bricks in the first story and are supported always on the partition caps above. If these caps are of timber there will be a little shrinkage, but they might be made of two steel angles forming a sort of inverted channel, and secured to the tops of the studs, in each case; the upper studs could be secured to the caps by lugs or clips. All shrinkage that would do any harm could be eliminated by supporting all partitions and the ends of all floor joists on a system of steel girders and beams supported in turn by the brick walls.

If any of the methods mentioned above are applied with thoroughness, the cost of the building will be materially increased. In the case of any building small enough to justify the use of studded partitions at all, the same result could be attained, at a cost slightly greater yet, by making the floors of reinforced concrete and omitting wooden joists altogether. This would make the building practically fireproof, and in all cases where it is likely to be permanent, even if it is only a set of quarters, this construction should be adopted if sufficient funds are available. Where the walls are of brick, the conditions are favorable for trussed partitions, transferring their load to their ends. If firepoof floors and steel beams are both out of the question, much can be accomplished by trussing the partitions, even if some of the end supports are timber struts, since the endwise shrinkage is of small importance. If well-seasoned timber girders happen to be available in sufficient numbers, they can be used for the support of partitions and floor joists and will greatly lessen shrinkage cracks. In any case, every reasonable precaution should be taken to prevent or lessen these cracks; while not dangerous to the structure, they are unsightly and are a refuge for vermin. If a brick house is not furred on the inside, the angle between a brick wall and a studded partition should be lathed with wire cloth or expanded metal, or cracks will surely appear.

Fire and vermin stops are just as important in a brick house as a wooden one. The most effective form is a fireproof monolithic floor, stretching unbroken from wall to wall. But much can be done by treating studded partitions in the manner suggested for frame houses; and if the walls are furred on the inside the brickwork should be corbeled out as far as the finished plaster surface, from a point one course below the joists to a point one course above them. In all cases, hot-air flues in studded partitions should be made of bright tin or galvanized iron and kept at least 1 inch away from neighboring studs and joists, which should be covered with tin where the flue passes near them. The lathing over the flue should be of wire cloth or expanded metal.

The roof of a brick building should always be of tile or slate, if possible. If, however, the roof has a very flat slope, and in any case if money is not abundant, some form of sheet metal is more suitable and is very generally employed.

The metals available for roofing are tin plates, copper, zinc, and lead. Copper and tin are the only ones that are commonly employed in this country. Zinc is said to be used a good deal in Belgium, and many European nations have used lead quite extensively. It is doubtful whether there are any mechanics in the United States thoroughly competent to work in either zinc or lead.

Copper, besides being very expensive, has a very high coefficient of expansion and contraction, and invariably gives trouble. It requires attention all the time on this account. No matter how much allowance is made for expansion and contraction, it appears sooner or later where not expected, and is a continual source of leaks. However, if the necessity for frequent inspection and small repairs is accepted, a copper roof is very durable and permanent, and is not by any means to be condemned, if there is money to pay for it. Copper is probably the ideal material for flashing. As it is used for this purpose in small pieces, usually not soldered together, temperature changes are not a source of trouble. Copper for roofing and flashing should be hot rolled, so as to be soft, and should weigh not less than 16 ounces per square foot. For important work, where expansion stresses can be well provided for, it would better weigh 20 ounces per square foot. Where copper is used for gutters and spouts it should be cold rolled and weigh not less than 16 ounces per square foot; 20 ounces is again preferable, if expansion troubles can be obviated. Copper is sometimes pressed into shapes resembling roofing tiles, and when used in this way is very durable and gives no trouble from temperature changes. It should be cold pressed so as to be as stiff as possible.

Tin roofing plates consist of sheets of black iron, dipped in a molten mixture of lead and tin. The best plates are made by a process known as the hand-dipped palm oil process, or, sometimes, as the "old method." The plates are pickled, thoroughly cleansed and annealed, dipped in an oil expressed from the seeds of a certain variety of African palm, and then dipped in the mixture of lead and tin. The best grades are not submitted to any further process, except sorting and packing. Inferior grades, after dipping, are run through rolls, which reduce the coating to a minimum thickness. Great skill is required in dipping to secure uniform distribution of the coating; when this is accomplished, and the plates are not subsequently rolled, the thickness of the coating and therefore the durability of the plate are a maximum. In some plates of an inferior grade, acid is used instead of palm oil, to secure adhesion between the plates and the coating. The use of acid, and the rolling of the plates after dipping, are devices for lessening their cost, and, in this case at least, their efficiency. The only really cheap tin plate is the best, when ultimate economy is in view.

Tin plates come in two weights, known as I C and I X. The difference in weight is in the iron, and not in the coating. I C is the lighter weight and is usually used for roofing; I X is heavier and is used for flashing, for gutters, and for spouts. Tin plates also come in two sizes, 14 by 20 inches and 20 by 28 inches. For roofing, the smaller size is more expensive to lay, but is also preferable, because it provides more thoroughly for expansion. All good tin plates are stamped with the name of the brand and the maker. A box contains 112 sheets; it should weigh 120 pounds if of 14 by 20 inch, and 240 pounds if of 20 by 28 inch plates. The total weight of coating in a box of the best 14 by 20 inch plates is about 20 pounds, of which 6 pounds are tin and 14 pounds are lead. It would probably be possible to get as much as 30 pounds of coating on a box of 14 by 20 inch plates, but the process would be very slow and more expensive than it is worth. Plates coated with tin and lead are known as terne plates; if coated with tin alone they are called bright plates; the leading manufacturers claim that bright plates are not as durable in a damp climate as terne plates, and probably the claim is well founded. After the plates are coated they have to be carefully sorted, as there are always some defective ones. These may carry the full weight of coating, but have it unevenly distributed, in which case they are not as good as if they had less coating uniformly distributed. The defective plates resulting from the manufacture of any brand of high-grade terne plates are known as the "wasters" of that brand.

In the matter of using the plates, a standing seam roof is preferable, if the pitch is steep enough. Painting on the underside before laying, and on the outer surface after laying, should not be neglected. The statement often made that the roof should be allowed to show slight signs of rust before painting on the outer surface had its origin in ignorance, if in nothing worse. One good coat on the underside is usually considered sufficient; but two would be better. No waterproof paper or felt should ever be used under a tin roof, as this would promote condensation and rusting out of the metal from the underside. Acid should never be used as a soldering flux, whether for tin or copper. Copper should always be tinned where it has to be soldered; this is necessary to produce the requisite adhesion between the copper and the solder. The tinning need be done, of course, only over the small surfaces to which the solder must be actually applied, and is often done at the site of the work by the mechanics themselves. All soldered joints in copper work must be made very heavy with solder; even then they will almost inevitably open, sooner or later.

Waterproof felt is much used both by itself and in connection with other materials for the weather finish of roofs. Used by itself, laid a slight lap and fastened with nails and tin washers, it is very suitable for temporary buildings, sheds, workshops, etc., and is very cheap. It may be swabbed where it laps with a waterproof cement, which will add to its efficiency and prevent rain from driving up under the lower edges. Laid in several thicknesses, with heavy swabbing coats between the layers, it forms a very durable and satisfactory roof finish. It can be further covered with gravel or tile, laid in waterproof cement or mastic, and in the case of the tiles, with all vertical joints grouted with Portland cement. A roof finish like this, where appearance is not important, is good enough for any building. It is practicable only on comparatively flat roofs, though the tile can be used on slopes as steep as $\frac{1}{10}$. The best and most durable felt is made entirely of wool, and saturated with some refined asphalt which will not rot in contact with water, nor dry out in the sun. Trinidad asphalt is not suitable for this purpose. Of asphalts available in this country, Alcatraz and Bermudez are the best. They should be softened with enough residual oil from the distillation of petroleum to give them the necessary fluidity, but no more. An asphaltic cement for use with this felt is made of the same material as the saturating compound; if it is to be applied hot, it is made quite stiff. But by mixing the compound with naphtha or benzine, it can be made fluid enough to apply cold; the evaporation of the solvent leaves a thin uniform coat of the compound, which will preserve its flexibility and waterproof qualities for a long time, if not subjected to mechanical injury.

Tarred felt, and swabbing coats of coal tar, are more commonly used than asphalt felts and cements. But coal tar is so devitalized by the extraction of the components useful for the manufacture of aniline dyes, perfumes, flavoring extracts, etc., that the part of it that finds its way into the market in tar papers and felts lasts but a short time; moreover, tar felts and papers nearly always contain much vegetable fiber, which is not nearly so durable as wool. Asphalt felts and cements cost only a little more, and should always be used.

There is a felt in the market, known as Paroid, manufactured by F. W. Bird & Son, of East Walpole, Mass., which the makers claim is a pure wool felt, saturated with Alcatrez asphalt. If this is true, it is as good a felt as can be made. There are several brands that are saturated with Trinidad asphalt, but they are hardly better than good tarred felts. The makers of the Paroid roofing felt, not only saturate the felt with their asphaltic compound, but also coat it on both sides with their liquid cement, which they sell under the name of Parine cement liquid. They further roll a dusting of powdered soapstone into both surfaces, to prevent the felt from being sticky.

In addition to copper and tin, corrugated iron, both black and galvanized, is often used for roofs; but it is not cheap—it is ugly, and possesses no advantages except for permanent shops where it is desired to fasten the weathering of the roof directly to the steel framework, without fire protection of any kind.

In the use of all sheet metal roofs, great care must be taken to prevent the wind from taking off the metal covering. Corrugated iron must be very firmly fastened down, for it is not practicable to keep the wind from under it. Copper and tin roofs must be turned down at the eaves and closely tacked along the edges, or, in some cases, soldered to the gutter, to prevent the wind from getting under it. Otherwise, a violent storm will roll it up, pulling the nails as it goes, and end by stripping the entire roof covering off, in an astonishingly short time.

Of the various forms of roof covering described, copper and the tiles laid on an asphalt base are really too expensive for non-fireproof buildings; of the others, a simple felt, of single thickness, without a swabbing coat, is the cheapest. In a general way, shingles come next, then tin, and then slate or roofing tiles. The latter, when used in highly ornamental forms, may be very expensive, but are often used in non-fireproof buildings of a high class for architectural effects.

So far, only those points have been touched upon which pertain peculiarly to such buildings as ordinary dwellings, whether of wood or brick. Many other matters, such as paint, plumbing, heating, hardware, dampproofing, quality of finish, lighting, etc., are of importance, but must be discussed in connection with fireproof work, and can then be best discussed for all classes of buildings. Before leaving the subject of non-fireproof buildings, however, a few points should be brought out relative to mill construction, or, as it is sometimes called, slow-burning construction. This is quite sufficiently well described in current literature, and complete general specifications for its design can always be obtained by simply addressing a request to Mr. Edward Atkinson, of Boston, Mass., who was largely instrumental in introducing it, and has a missionary's zeal in disseminating information in regard to it. This construction has for its most essential points the use of none but large timbers and the avoidance of all cellular or hollow construction, such as studded partitions, covered with either plaster or matched boarding. It necessarily involves the use of iron or steel post caps, joist hangers, etc. A great variety of these devices can be had in stock, guaranteed by their makers to be safe under specified loads. The main point is that these guarantees are usually worthless. Every engineer who adopts mill construction must use them, but he should carefully calculate their strength against shearing and bending at every point, for many current designs are produced by mere rule of thumb and are fatally weak at some point. Another thing about mill construction is that it is not slow burning at all; it might be very properly called slow igniting, for that would be a truthful description. Large timbers are slow to ignite, and with every nook and corner open to view, there is much less probability of a fire starting and getting beyond control before discovery; combined with a thorough automatic sprinkler installation, a mill construction building is comparatively safe from destruction by fire. But once a fire gets a fair start in it, it is doomed to certain and speedy destruction. There are long lists of such catastrophes, such as the destruction of the Capital Traction Company's power house at Fourteenth and E streets, in this city, some years ago. It usually takes from thirty minutes to an hour for the complete destruction of a four to six story building occupying an entire block. One reason probably is that no available timber but long leaf pine can be secured in sufficiently large sizes at a reasonable price. Once fairly started, it burns with almost explosive violence, and nothing can save it. The people who live in the long leaf pine belt never use this timber in their stoves, if they can help it, because it burns so furiously it soon destroys the stoves, besides making a proper control of the temperature, whether for cooking or heating, quite out of the question.

One point that should never be neglected in any brick building, with timber floors, is the cutting of the wall ends of girders and joists on a bevel, to prevent throwing the wall by the breaking of the joist or girder when burned through in a fire. Anchors in such cases should be fastened near the bottom of the beam, preferably with one large bolt, just inside the wall line. Then, when the beam falls, even if it hangs by the anchor, it can freely revolve downwards without bringing any leverage on the walls. Where the load of a joist or girder does not require bearing plates or templates to distribute the pressure, the course immediately under the beam should be a header course, otherwise severe shocks and vibrations might cause the bricks to loosen and slip out of the wall. Major Abbot observed, after the Charleston earthquake, that this was a very vital point. Where the ends of the joists rested on header courses, they invariably remained in place, but very often, where the joists rested on a stretcher course, the bricks slipped out and allowed the floors to drop.

There are some advantages in corbeling out a shelf to receive the ends of joists, provided the corbeling is not objectionable on artistic grounds, and is well done. It should project about 1 inch to a course, be made entirely of headers, and be only wide enough to give the requisite bearing. On the whole, however, in a well-built wall, it is better to let the girders and joists project into the wall, leaving a small space on the sides and top for ventilation. This insures greater unity of the structure, and applies the load nearer to the center of the wall. If heavy loads call for templates or bearing plates, it is better to put them entirely within the wall, at least 2 inches back from the face, to avoid concentrated pressure at the inner edge. It is also well, in such cases, to support the end of the beam on a small plate in the center of the bearing plate or template, to prevent deflection in the beam from disturbing the distribution of pressure. It is to be observed that the usual method of reducing the thickness of the wall as the upper stories are reached, by dropping off half a brick at a time on the inside, has a beneficial effect in counteracting the eccentricity of the floor loads; corbeling always increases this eccentricity, and that alone should condemn it, where very heavy loads must be carried. It seems entirely possible, and even probable, that advances in fireproof construction will, before long, displace mill construction in all important factory buildings. While this is a consummation much to be desired, mill construction has played an important role, and will always be looked upon as a long step in advance, taken at a time when there was urgent need of it.

FIREPROOF BUILDINGS

It is in buildings so large and important that carrying the weights is a serious matter, and fireproof construction is considered necessary, that the civil engineer first becomes indispensable. Many of the improvements in design, and execution introduced by him in such structures, are applicable also to the smaller, non-fireproof buildings and if applied would produce much better results than those commonly attained, without increase of cost. Where such points are brought out, their application to less important buildings will be indicated.

The first question in any building is the plan. This is manifestly determined by the uses to which the building is to be put, and the space within which it must be confined. It must be so arranged as to be fit for its purpose, yet not inconsistent with a suitably artistic treatment of the elevations. Right here is where the architect, engineer, and owner often clash. Architects lay great stress upon the plan, and are very jealous of their jurisdiction over it. This is quite natural, for a poor plan may make good architectural treatment impossible; yet, the architect is apt to lay undue stress upon the artistic, and to overlook, neglect, or deliberately sacrifice convenience and utility. The engineer and owner are apt to consider the latter points first, and not to give due consideration to the former.

As an example of what the architect will do, if unrestrained, one of the most prominent architects of Washington, in making plans for a hospital building recently, located the dumb waiter 40 feet from the kitchen, and stopped it off at the third floor, although there was a ward on the fourth floor, designed for thirty or forty patients. How they were to be fed, and the directness of the service to all the floors, were not considered at all. The fact remains, however, that in the majority of cases, the architect should make the plan; but he should be compelled to change it, if necessary, until it not only satisfies the artistic requirements, but the utilitarian ones as well. There is always some solution reasonably good, from all points of view, and if the engineer has any control at all, he should see to it that this solution is finally worked out. Making floor plans for buildings is not a simple matter—not even for a small dwelling. It should receive the most careful consideration from all concerned, if the highest efficiency is to be attained.

The floor plans having been fixed, the architect will soon have the elevations, in skeleton form, at least, for these must be considered, along with the plans, before the latter can really be fixed. With the plans and preliminary elevations, the engineer is ready to begin, in some detail, his own peculiar work. The floors and interior partitions always, and the exterior walls generally, in a modern building, will be carried by the framework, which is usually of steel. The first task is to locate the columns. This has to be done with a view to the interior subdivision and finish, as a matter of course. Next must be considered the system of girders and beams by which the floor loads are carried and finally concentrated at the columns. Then the loads imposed on the columns at each floor must be calculated. They should be divided into live and dead. The former comprises the entire superimposed floor load, and the latter the weight of construction. The dead load can not always be calculated accurately until two or three preliminary designs have been made, since the design itself determines part of the dead load. It is possible to assume quite closely what the dead load will be, however, for a given class of building, and usually one preliminary design and one corrected one, will be sufficient. Having the column loads, the foundations can be designed. If the external walls are not carried on the framework, they will still start from the same foundations as the wall columns and thus their weight must be carried at the bottom just the same as if it were part of the column load proper. Where a building is of moderate height and has heavy walls, no steel columns need be used; the ends of girders and beams would be borne by the walls, and thus the floor loads would go from the outer bearings of girders and beams to the exterior foundations through the walls themselves. But the foundation problem would not be essentially different from that presented by a building with steel wall columns, carrying either the floors alone or both the floors and the walls.

In designing the foundations, the first requisite is a knowledge of the nature of the strata upon which they are to rest. Certain and definite knowledge upon this point is difficult and often expensive to obtain. If some engineer or physicist could devise a reasonably simple system whereby from physical analysis of a soil its power to carry loads could be predicted within 100 per cent., he would earn the gratitude of all future generations of engineers. It is not in the least likely that this will ever be accomplished.

There are various ways of securing information as to the strata underlying a proposed structure. Borings are the most obvious, as well as the quickest and cheapest of all methods yielding results of any value. But even borings are very deceptive; they often miss the vital and controlling feature of the whole situation, even when very close together. Actual excavations or test pits carried to sub-grade, or deeper, are better than borings, and more expensive. Only the excavation of the foundation trenches or pits themselves will disclose the whole truth, and even they often fail to reveal it all. When the structure is of any importance, the excavation should be carried to sub-grade, over the entire area probably required for foundations, then borings and occasional pits should be carried still deeper, and full-sized tests of the bearing power should be made, if possible.

The object of the foundation is to so distribute the weight of the building and its contents to strata in position that there will either be no settlement at all, or, if there must be settlement, that it shall be uniform. If there is any hope of limiting the settlement to zero or to a negligible quantity, it should be done, even at a considerable expense. A poor superstructure will stand a long time on a good foundation; but no sort of superstructure can stand intact on a poor foundation. Therefore, it is better to make the foundation good, even if it has to be done by skinning down what goes on top of it.

Of the various materials likely to be met in constructing foundations, solid rock, gravel, hard pan (i. e., a consolidated mixture of clay, sand, and gravel), beds of bowlders, and reasonably coarse clean sand need never give any anxiety, provided there is nothing soft beneath them. They will all carry loads of from three to fifty tons per square foot with perfect safety. A load of from three to six tons per square foot will always result in footings of a reasonable size, so there is no need of extravagant designs. Of the materials named, sand is the only one that calls for much investigation; yet it would be well always to build an experimental pier like the probable footings, and load it if possible, until settlement begins. Such tests should last for several days, at least, as the yielding of some soils is very gradual, but, unfortunately, none the less certain.

It is generally assumed, no doubt correctly, that when pressure is applied to a certain area of the top surface of a given stratum, it spreads laterally as it is transmitted downwards, so that the successive areas which feel its effects become constantly larger. The angle of spread for a given material can not be certainly determined. It will be seriously modified if adjacent areas at the surface are also loaded; let it be denoted by θ, and be measured from vertical planes through the edges of loaded area at the surface; let it be considered positive when it is really an angle of spread. It is possible that θ may be reduced to 0 or perhaps even to a negative value, by reason of adjacent surface loads. In the latter case, it is almost certain that the bearing power would be exceeded, and there would be settlement over the entire surface of all structures, both old and new. Sometimes the strata near the surface are able to bear the superimposed loads, and even though there are weaker strata below, θ may have such a value that the pressure is distributed over a sufficient area of the softer lower strata, to enable them also to carry it. This is true for an isolated structure. If other adjoining structures are erected afterwards, the area of the softer strata available for carrying the first structure will be diminished, and settlement of both old and new works may follow. In the case of a mortar battery built by Major Abbot at Charleston, the overlying stratum was sand, and it was about 10 feet thick. It bore on small areas, unit pressures at least as great as those due to the battery, without a sign of settlement. But when the larger area occupied by the battery was loaded, settlement followed to the extent of 2 feet and some inches. The necessary precautions for securing uniform settlement were observed, however, and the structure reached its final level without serious cracks or damage. To illustrate the principle involved, suppose that θ has such a value in a given case that the pressure has spread 2 feet all around when it reaches the soft lower stratum. Suppose a test load on the surface is applied to an area 1 foot square. It will spread over an area at the lower stratum bounded by a figure consisting approximately of a square 5 feet on a side, with its corners cut off by quadrants tangent to the sides, having a radius of 2 feet, and centers located on the diagonals of the square. This area will be about 21 square feet. Now suppose that the area at the surface is 10 feet square. The area below, even if the corners are not rounded off, will be only 14 by 14, or 196 square feet—not twice as much as the surface area, whereas in the other case, it was twenty-one times as much. The conditions illustrated here may occur on city blocks, as the city becomes more closely built, and new structures are erected in juxtaposition to existing ones. If the softer lower strata are compressible, settlement of both old and new works may follow. On the other hand, if the soft strata are saturated with water, they will be incompressible. Settlement will then be impossible, unless the material can escape laterally or both laterally and vertically. If the whole of a large area is loaded, both of these things may be prevented, and the load will be carried on the same principle as the pressure on the piston of a hydraulic jack. The condition is one of unstable equilibrium, however, and is not by any means desirable. Strata that are soft and filled with water, act partly like liquids and partly like solids. If they are loaded vertically, and can not yield laterally, they may bulge up around the loaded area, causing settlement of the latter. This can be prevented by properly loading the areas likely to bulge up; but just what load per square foot will be required and how much of the adjacent area must be loaded would be difficult to determine in any case, and must be largely a matter of judgment and experience.

In testing soils, it should be remembered that when only a small area at the surface is tested, the pier or post used for applying the load will often have a sort of punching effect and begin to settle under unit loads which would be perfectly safe over large areas. Sand, with water in it, will slip out from under a test pier or post, and the test load will work downwards when it does not amount to 10 per cent. of what the sand would carry under an actual structure. It is evident from all that has been said that the results of tests on the bearing power of soils must be used with judgment. The very same results might follow from a given method of testing in soils of widely varying bearing power.

It is useless to add in this paper anything on the ordinary methods of increasing the bearing power of a compressible soil. They are all thoroughly described in current literature. It might be useful to say, however, that when tests show manifest compression of the surface strata, under loads approximating those desired to be used in practice, it is better to adopt some mode of treatment at once. The same is true of unyielding strata overlying soft ones, unless the thickness of the former is sufficient to guarantee the load against breaking through.

If it is decided to use wooden piles, they must be cut off below the water line, to insure permanence. If this is inconvenient or expensive, concrete piles may be used, which do not depend upon the condition of the soil for their durability. Great progress is being made in the use of concrete piles or piers put down like piles. All the student officers should observe and make notes of the method now in use at the site of the officers' quarters for the Engineer School, as it is a very simple and economical one—scarcely more expensive than wooden piles. The conditions here are as follows: A fill of from 10 to 14 feet of argillaceous material, settling seriously under loads of from 500 to 1,000 pounds per square foot; a firm stratum of sand below the fill, of unknown depth, but certainly good for the loads likely to be brought upon it by the officers' quarters. If wooden piles were used, they would surely decay, for the fill is sometimes wet and sometimes dry. Nothing would be gained by driving them and cutting them off at the level of the water line, for this would carry the excavation to the firm sand, which can carry the load without piles. If the excavation were carried to the sand, it would be quite expensive, and would necessitate a very large mass of concrete to bring the foundations up to the basement floor levels. By the use of concrete piles, the weight can be transferred to the sand at much less expense, and there is no doubt as to the durability of the piles. In this case, the piles clearly act as columns, deriving some lateral support from the surrounding earth, but transmitting their loads by direct compression, nevertheless. It often happens, however, that a pile driven fairly deep in very soft material will carry a heavy load, without reaching a firm bearing at all. A group of piles, in such material, will often carry a load that would sink out of sight if distributed directly over the area occupied by the piles. Just why this occurs is a little obscure; it is not certain that it could always be duplicated. In a case of this sort on the river front of New York, as nearly as the writer can remember, as it was related to him verbally, an average of one pile to a certain number of square feet, driven in the mud, but not to a firm bearing, had been carrying a certain load per pile for a long time. It was decided to increase the size and weight of the superstructure, and to provide for it, more piles were driven between the old ones, but when the new and heavier load was applied, the entire piled area settled quite seriously.

Apparently the piles distribute the load by skin friction throughout a certain volume of the materials. It will stand, when reinforced in this way, a certain amount of stress without deformation, but beyond this it is not possible to go. Some very remarkable statements as to the bearing power of piles when driven in what seemed almost liquid mud can be found in Patton's Foundations. There is some law here, quite obscure and unknown at present, which would be very valuable if fully disclosed. Possibly the piles tie together a large volume of the soft material, compelling it to act as a unit, giving it strength against deformation, and at the same time making available a sort of buoyancy that it must have in its semi-liquid surroundings. At any rate, piles that have been settled into place under the mere weight of the ram, have, after a few days, borne loads ten or twelve times as great as the ram, without further settlement. This seems almost incredible, but is apparently true. It would hardly be safe practice to count on it, however, without tests in each individual case.

As a rule, the most suitable material for foundations is concrete. This material, when tested to destruction under compression, generally fails by shearing along planes making an angle of about 30° with the direction of the applied force. Holes punched through slabs of concrete generally increase in size as they pass through, at about the same rate. It is well to spread concrete foundations at the same rate, as by this means all tensile stresses will be avoided. This leads to rather heavy foundations, but it is certainly safe practice, and none too good for important buildings. It should be remembered that, regardless of unit pressures, every wall should have a footing appreciably wider than itself to insure stability.

In commercial office buildings, where settlement is expected, it is customary to proportion the footings under different parts of the buildings according to the dead load alone. But in important Government buildings the foundations should first be made secure against settlement, if possible, and then proportioned everywhere for the total load. The live load will not be as likely to produce settlement as a dead load of the same amount. If settlement is inevitable, a grillage over the entire site stiff enough to resist distortion under the varying concentrated loads of columns and piers is the best solution, but it is very expensive. The next best plan is to find out what the average actual total load will be, and proportion for this. Where the live load is considerable and subject to much variation, it would be very hard to hit upon any method that would insure uniform settlement, short of preventing settlement altogether.

If steel beam grillages are necessary to spread the pressure under columns and walls over a sufficient area, they should be kept above the ground water level if possible, and very carefully and thoroughly bedded in Portland cement concrete to avoid corrosion. The best plan is to avoid the use of beams altogether, if possible.

Within recent years foundations carried to the solid rock by means of pneumatic caissons have been used in some important buildings. In several cases in New York, where it was desired to have several stories of cellars below the water line, the entire site has been surrounded with rectangular caissons, separated from each other by guiding angles, forming a pocket between the caissons. The caissons were filled with concrete, and the pockets were rammed full of clay puddle; the bottom of the excavation was pumped out, floored with concrete, and a layer of waterproofing, and then enough more concrete to resist the upward pressure of the water. In this way immense volumes of storage space have been made available at depths of 20 or 30 feet below the water line.

One troublesome class of operations often encountered in foundation work is the underpinning of existing structures. In Kidder's Building Construction, Part I, and in other works, many methods are shown for temporarily supporting the old structures while the new work is going in under them; but the most interesting and difficult part of the whole operation is getting the temporary supports in without allowing the old work to settle or collapse. On this point very little is to be found in current literature. It is necessary to put in the temporary supports so that they will not interfere with the new work nor be disturbed by it. This often involves an excavation close up to the old structure and extending some distance below it. The trouble is to avoid settlement of the old work while this is going on. In material not full of water, the excavation can be safely accomplished by means of cases, similar to those used in military mining, but modified according to circumstances. If the excavation seems too dangerous, piles may be driven at the points where the ends of needles are to be supported; if it will not do to drive them with an ordinary ram, they can be screwed in or sunk with a water jet. There is a patented method of supporting an old wall during underpinning which consists in cutting slots in it, setting up in them piles made of iron pipe, and forcing the latter down with jacks working between the tops of the piles and the masonry above. This operation is continued until it is evident that the piles are able to carry the load without further settlement. The space between the tops of the piles and the masonry can be filled up with iron blocks, or otherwise, and the old foundation taken out. The piles would be built into the new foundation. The writer can not refer to work actually done by this method, nor give any figures of cost. But it seems plausible where the conditions are otherwise difficult and the work important. The cost would probably be considerable. Where a wall is supported by inclined shores, these should cut into it at points not far from girders and floor beams, so as to get the benefit of their lateral support. If it is supported on needles, it is sometimes necessary to excavate both inside and outside to get support for the needles from the level of the new foundation. Sometimes, by using a long needle and allowing the inner end to rest on the basement floor or the earth inside for some distance back from the wall, inside excavations can be avoided.

Sometimes it is necessary, not only to hold a vertical weight, but also to hold a bank from caving. In such cases great care is required, but no general rule can be laid down. In all cases of underpinning, the engineer must consider not only what his temporary supports shall be, but how he will get them in place, which is the larger half of the work.

All foundations should be finished with a dampproof course, to prevent moisture from rising in the walls. The best materials for waterproofing and dampproofing are asphalted wool felts and certain asphalts, which do not rot in the presence of water. Neuchatel and Seyssel Rock Asphalt mastics, Alcatraz or Bermudez asphalts are all reliable, when properly applied. Where the tops of foundations are covered with dampproofing, it must be made so it will not squeeze out under the pressure. Rock asphalt mastic can be mixed with fine gravel and made waterproof, yet hard enough, when applied in very thin layers, to withstand heavy crushing loads. On vertical surfaces and in the body of concrete floors, it is better to use the felts and swabbing coats of asphaltic cement, either hot or cold; the mastic might crack in such places, as it is quite stiff when cold.

Having settled the question of foundations, the steelwork is in order. The columns should always rest on bases of built-up steel or of cast steel or iron. If of cast-iron, no part should be less than 1 inch thick; an inch and a half would be a better minimum. Such a base should never be shallow, and should not be too economically designed. It should consist essentially of top and bottom bases, connected by ribs running in both directions across the plates. The sides of the base should slope at angles of about 60° with the horizontal—certainly not less than 45°. A base built up of steel can be allowed to have some transverse strain, but must be so stiff it can not suffer appreciable distortion. Building up an efficient steel column base is not so simple as it looks, and it should receive the careful attention of the engineer in charge of the work in every case. Like post caps and joist hangers, a built-up column base must be carefully designed in all of its parts, to resist all possible local strains.

With the columns, the question of structural steel proper is reached. It is customary to use, as the maximum fiber stress on structural steel in buildings, 16,000 pounds per square inch. In the case of the columns, this is the constant that is put into the column formulæ, and, of course, the actual direct stress per square inch is considerably less, because of the allowance for buckling. If the column is properly fireproofed, however, it will be stiff enough, without any allowance for buckling. It is better, in such a case, to design it in simple compression—i. e., divide the total load in pounds by 16,000, and take the result as the area of cross section of the column in square inches. What is considered proper fireproofing will be described later. In cases where buckling must be considered, the parabolic formula given in Johnson's Modern Framed Structures, or Gordon's formula, should be used. The straight line formula is reliable within certain limits, but it gives loads much too great beyond these limits. In considering various forms of column, it should be remembered that often the entire load is directly applied to only a part of the column, and must be distributed throughout the section by whatever means have been adopted for tying the parts of the section together. A good test of a column design is to consider whether, if used as a girder, in any position, it would have sufficient strength in the web members to develop the strength of the flanges; unless it has, it is not an ideal design. It is not necessary to have it absolutely ideal, and in most cases in ordinary practice it is not. There should be a fairly close approximation to ideal conditions, however—and judged by this criterion there are a number of column sections—notably, one made up of angles connected at intervals by short batten or tie plates—which are wholly bad, and should never be used, unless they can be entirely bedded in a mass of concrete.

An ideal column section considered merely from its capacity to resist compression and the tendency to buckle under compression, is a hollow circular cylinder; but such a column would be difficult to splice and it would be very difficult to attach beam and girder brackets to its sides. Every practicable column section is a compromise between the extremes of ideal resistance to compression and buckling under a centrally applied load on the one hand, and of facility and ease of designing and applying practicable connections, on the other. Columns made up of channels, with lattice bars or cover plates, according to the load, and columns of I section built of plates and angles, or of an I beam and two channels, or other equivalent shapes, are among the best.

Eccentric loading must be provided for, in every case. The best way to provide for it is to eliminate it, even at some expense, and at the sacrifice of ideal conditions in other respects. In the case of a latticed channel column, which is one of the best types, if there is a load on only one side of it, a seat for the girder or beam can be built in between the channels, so as to apply the load on the axis. Z-bar columns, or columns of I section, can usually be set so that unbalanced loads can be applied directly to the webs, thus largely eliminating eccentricity. If a column is loaded symmetrically, even though the loads are all applied at a distance from its axis, it is quite safe to consider the total load as centrally applied. In this case, if, in the use of the building, the live load should be in place on one side, but not on the other, there will be an eccentric load, causing transverse stress in the column; but the metal put in to carry the remaining live load, will usually take care of this bending safely enough, although the stresses may run up to 24,000 or 25,000 pounds per square inch. Great care should be exercised in connecting heavy girders of long span to the columns that carry them.

It will not do to make rigid connections in such cases, for the normal deflection of the girder under its load will introduce strains in the column beyond all reasonable limits. If the span of the girder exceeds ten times its depth, or if it is greater than 15 feet, the equation of the curve of mean fiber—or, at any rate, its first differential coefficient, should be deduced. From this the inclination of the curve of mean fiber at the points of support can be determined. Compute the moment of inertia of the column section, and find from the differential equations of the curve of mean fiber, what uniform bending moment would cause the curve of mean fiber to take an inclination at the ends at right angles to that of the girder. From this the fiber stress produced by the bending can be determined. This method is only approximate; it treats the columns as a beam resting on two points of support, and subjected to a uniform bending moment. As a matter of fact, the column is generally continuous past several girder connections, and if these connections are rigid, both columns and girders are partially fixed at the reaction points. However, the approximation will always be on the side of safety, and if it indicates dangerous stresses in the column from the deflection of the girder, the connection should be so designed as to leave the girder free to deflect, without sliding off. This will generally result in a bracket riveted to the column, for the ends of the girder to rest upon. It should be bolted to the bracket, to prevent all danger of sliding off.

The columns, in fireproof buildings, are generally made continuous from bottom to top. If the increments of load at successive floors are very great, it will be cheaper to splice the columns at every floor; but this does not often happen, and columns are generally made two or three stories high. A column of any of the ordinary types can be made and kept reasonably straight and true in lengths up to 40 feet. It is better to reduce the number of splices as much as possible, even if the column weighs a little more, and rather high stresses have to be accepted in its lower part. It is not practicable to splice columns in buildings with full splices, as in the case of compression members of bridges. There are two reasons for this: one is that the splices would be very awkward to design and execute, and the other is that they are very expensive. When the function of the splice plates and angles is reduced to merely holding the columns in line, it is necessary that the column ends should be very accurately faced off. Just how serious a matter this is may be seen from a discussion by the writer in Engineering News, December 25, 1902, page 544. It is sufficient here to say that to realize the full factor of safety at the column splices requires a grade of workmanship not always easy to obtain. This is another reason for making as few splices as possible. Where a splice is to be made, the maximum economy of metal would place it just at the point where the full section of the lower column is first required. This would be at the bottom of floor girders; further consideration would point to a location at the middle of the depth of the floor girders, so that the ends of the columns would be in a pocket formed by girders and beams, and thus secure a certain reinforcement for the splice. But practical experience demands that the entire splice be above the tops of girders and beams. This makes it possible to complete a floor of beams and girders without waiting for the tier of columns above. When the upper columns come, they can be placed and the splices riveted up without the use of hanging scaffolds, which is in itself a point of enough importance to more than counterbalance any saving in metal effected by placing the splice lower down. The column bearing can be more readily inspected, and the work on the splice, being more accessible, will be better done. If a floor of beams and girders is not complete without the upper tier of columns, a multitude of details of other work will be delayed thereby, and this again is in itself a sufficient reason for locating the splice as herein recommended.

In specifications for columns, it would be well to require that the ends be faced off true to within 1 per cent., as this is entirely practicable; to require all rivet holes in splices to be reamed with all parts assembled together, or else drilled to a steel template; all holes for connections to be reamed with all parts assembled, or else drilled to steel template. These requirements, of course, are in addition to the standard ones as to rivet spacing, quality of steel, etc. The inspector at the mill should be required to pay especial attention to these points. If they are properly attended to, the columns can be designed for a minimum stress of 20,000 pounds per square inch, and yet be safer than current practice, based on 16,000 pounds. The execution in the field must also be closely watched by competent inspectors. It is well for the engineer in charge himself to look pretty closely after field rivets and bolts and column bearings. The writer has always done this, and has found it quite necessary.

In the upper stories of buildings, the ordinary splices will be practically full splices, because of light column loads. In such cases, if the splice rivets are properly put in, it is a matter of minor importance for the columns themselves to bear accurately.

In all construction work, however, it should be borne in mind that execution is often of more importance than design. Good execution will often save a poor design, but no excellence in design can make a structure proof against the evils of poor workmanship. Yet here again the young engineer must remember that there is a practical limit; no work can be done with theoretical accuracy, and it often costs enormously to make a very close approximation. The end in view should be the required factor of safety, attained beyond all doubt, but at the least total expense in dollars and cents. It requires judgment to determine the economical limit between mere labor and mere material; but it can be said in a general way that current practice in building construction is lavish of material and parsimonious in labor and supervision. Better results could be achieved for less money, by sacrificing part of the material and increasing the standard of workmanship, within reasonable limits.

Next to the columns, the girders are the most vital members of a steel frame. Little can be added to the chapter on the plate girder in Johnson's Modern Framed Structures. A plate girder for a building should always be designed without stiffeners if possible. Stiffeners form pockets between the flanges, which make the placing of the floor beams very difficult and expensive and add to the pound price of the girder. All things considered, it is usually cheaper to put more metal in the web plate and do away with the stiffeners except at the ends; here they should never be omitted. All rivet holes in a plate girder should be punched small and then reamed out with all parts assembled. Of course, holes drilled from the solid to a steel template would be ideal; and punched holes are too ragged and match too poorly to be tolerated in first-class work. But the drilling from the solid is too expensive in the present state of the art, and the method recommended is probably as good for all practical purposes. Every rivet in a plate girder is supposed to do full duty, so that both the holes and the rivets themselves should be carefully watched. It is in points of this kind that the inspector at the mill should prove his worth; he should never relieve the contractors from responsibility for correct dimensions and fit of various pieces, and, if necessary, should check up no dimensions at all, but devote his whole time to the quality of the work.

If rolled beams conform to the usual standard specifications, nothing further will be required. Wherever possible, they should transmit their loads to girders and columns through single heavy angle brackets without stiffeners beneath, as this avoids introducing tensile stress in the rivets due to deflection of the beam and the concentration of the load on the outer edge of the bracket. The idea is that the outstanding leg of the angle will bend and accommodate itself to the deflection of the beam and thus throw the load close in to the web, where it will produce only shearing stresses in the rivets.

It is in the details and connections that the structural designer has the best opportunity to show his skill. These make up quite a percentage of the total weight; they almost never fall below 10 per cent., and often go as high as 20. Cases arise more frequently in buildings than in other structural work, where many heavy connections have to be crowded into a small space. These often demand a great deal of care and ingenuity for their proper solution.

There are other points affecting the economy of the design in a steel-frame building, however. If columns and girders can be so placed that a girder comes over a partition, it will often be possible to give it the full economical depth; whereas, in another location, the architect might object to so great a projection below the ceiling, and the girder would have to be made shallow, regardless of economy.

Long spans for beams and girders should always be avoided as far as possible. It is much cheaper to put in more columns, which carry their loads by direct stress, than to use long span deep girders. The span of girder should not exceed 20 feet, unless longer spans are imperatively demanded. If a bay of the floor system is wider in one direction than the other, and the depth of the girders is not seriously limited, it will usually be more economical to run the girders the long way, and the floor beams the short way.

In making the steel plans for a large building, the columns should first be marked by a system of cöordinates, so that the mark of the column would indicate its location. The different stories or tiers would be indicated by prefixing the number of the story or tier to the mark of the column. Thus if a corner of the building be assumed as an origin of coördinates, the rows of columns in one direction could be lettered, and in the other numbered, beginning in each case at the origin—the corner column here being 1-A. The girders can conveniently be designated by the number of the floor and the marks of the columns they connect, while floor beams can receive the number of the floor, the mark of the bay, and their serial number in the bay. By this means, the location of every piece can be determined at once by its marks. The make-up of columns can be conveniently indicated by taking a large sheet and ruling it in parallel vertical columns. Each of these should receive a column mark, and be divided into a number of equal lengths, representing the stories. The make-up of the columns, the location and general character of splices, and levels at which main girders are connected, can all be written and otherwise indicated in the spaces thus laid out. It only remains then to make drawings illustrating typical details and supplement them by proper specifications.

For the girders, it is best to make a complete drawing for each type, though small variations, covering many slightly different girders, can be indicated on a single type drawing. For floor beams, it is sufficient to indicate their size and weight on the beam plans, and to illustrate their connections by drawings. The beam plan should show column centers by means of crosses or circles, and centers of girders or beams by straight lines. The mark, size, weight, etc., of each girder or beam should be indicated on this plan.

In writing specifications, it should always be provided, in case of a very large building, that the erector must provide a storage place apart from the building, where the steel can be delivered and sorted, and then brought to the building in the order in which it is needed for erection. The reason for this is that it is never economical for the mills to turn the material out in this order; there may be girders in all the floors exactly alike; there are sure to be beams that are uniform for all stories; the mills will usually run out all pieces of a kind together. If they were allowed to be delivered at the building, the erection of the lower tiers would soon be stopped by the congestion of materials intended for the upper ones.

Better prices will usually be obtained if the specifications provide for partial payments on steel delivered at the building, but not fully erected and accepted. To prevent the contractor from taking undue advantage of this, steel delivered at the storage yard and not needed for immediate erection should not be allowed at the building, nor paid for, until it is brought in, in due course.

To protect the steel from corrosion during transporation and erection, it should receive a coat of paint or linseed oil before shipment. The best results would be attained by thorough cleansing of the steel in an acid bath or by the sand blast, or both, and the immediate application of the paint to fresh and pertectly clean surfaces. All trace of acid and of the lubricating oil smeared on during handling and manufacturing should be cleaned off before painting. As a matter of fact, no shop is equipped for treating structural steel in so elaborate a way. It ought to be done, nevertheless, for bridges and viaducts, but it is not necessary for buildings, if proper precautions are observed. If the durability of the steel in a building really depended on the paint, the average life of a steel-frame building would hardly exceed twenty-five years. In practice, however, all the steel members are more or less thoroughly covered with Portland cement masonry, and this is the real protection. If it is carried to its logical conclusion, so as to secure complete covering and perfect contact throughout, the life of the steel will be indefinite; this will be true, even if the steel is red with rust when built in, provided scales have not begun to form. It may stop the corrosion and suspend it indefinitely, even in the latter case. For a discussion of the writer's views on this subject, reference is made to an article published in Engineering News of October 23, 1902, under the title of "Columns for Buildings." It is sufficient here to say that the corrosion of steel or iron requires the simultaneous presence of an acid, moisture, and oxygen. A limited amount of acid, with an indefinite supply of moisture and oxygen, will ultimately corrode a large amount of steel. Portland cement in contact with steel protects it, because it is alkaline and has a stronger affinity for acids than iron has; it therefore neutralizes any acid before it can attack the steel. Under the conditions existing in buildings, there is enough Portland cement around the steel, if the latter is completely imbedded, to neutralize all the acid that is likely to be absorbed by the covering for hundreds of years. If, however, the masonry is built around the steel, leaving hollow spaces, and if it cracks or has unfilled joints, allowing circulation of the air, the moisture and acid may reach the steel without being filtered through the masonry, and in that case, corrosion may proceed at a serious rate. For the best results, all the steel should be in close contact with Portland cement mortar over all parts of its surface.

Closely related to the protection of steel from corrosion is its protection from fire. The first iron that was used for columns and beams in buildings was introduced with the idea that it would be fireproof. This turned out to be an erroneous idea; but, in modern high buildings there is the additional reason for the use of iron or steel, that, up to the present, at any rate, no other material has been found strong enough to carry the heavy loads without cross-sections so large that the floor space in the lower stories would be seriously diminished. This consideration was what led to carrying the walls of a building as well as the floors on the steel frame. No wall being more than one story high, it was possible to make all of them of a minimum thickness, and reduce them to a mere curtain for keeping out the weather.

It is vitally important for a high building to be fireproof; all Government structures of any prominence should be fireproof. It is well then to inquire what a fireproof building is, and in what its fireproof character consists.

A building is entitled to be called fireproof only when it is able to stand an ordinary fierce conflagration without damage, except to paint, plaster, glass, and wooden floor finish, if there is any. This damage repaired, the building must be able to come through a second—indeed many, similar ordeals. Making a building fireproof will not make its contents incombustible, so that quite fierce fires may occur in fireproof buildings; but, although the damage to the contents may be 100 per cent., that to the buildings should not exceed 5 or 6 per cent., if it is really fireproof.

To be fireproof, a structure must be incombustible and infusible, and must retain its form and strength unimpaired at any temperature possible in a fire; temperatures in a conflagration rarely exceed 2,500° F., although wrought-iron has been known to melt in spots, which would indicate local temperatures as high as 3,000° F.

Steel and cast-iron are incombustible, but not fireproof. At comparatively low temperatures they lose their rigidity and are bent and twisted in every conceivable way. When this happens, the floors are destroyed, the contents of the building are precipitated to the ground, the expansion of the steel often throws the walls, and the wreck is worse than if the floors and columns had been entirely of timber.

The fireproof problem generally consists in devising a covering for steel and iron which will protect the steel from high temperatures, resist the fire itself, and have sufficient strength to resist ordinary wear and tear. This covering is nearly always some form of masonry.

Very few natural stones can resist high temperatures. Limestones and marbles are destroyed by driving off the CO_2; all stones crack and fly to pieces, except some rare forms of sandstone, when exposed to high temperatures. While stones are incombustible they are not fireproof.

The various forms of burned clay all have more or less power to resist heat. They have all been subjected to fairly high temperatures in burning, and they are all relatively poor conductors of heat, which is essential if the steel is to be prevented from attaining a high temperature. Dense, hard burned clay, however, when subjected to the sudden changes of temperature, is very liable to crack, although it does not fly to pieces as stone does. In the kiln it is subjected to very great changes of temperature, but they are very gradual. When used for fireproofing, clay products are generally known as terra cotta. By this name they will be called hereafter. The clay used for terra cotta fireproofing should be strong and tough, and should not melt at temperatures less than 3,000° F. It should be thoroughly burned, and should require a temperature of at least 2,300° to 2,500° F. to accomplish this. It is much more efficient both as a non-conductor and in resisting strains due to sudden changes of temperature if as large a proportion of sawdust as possible is mixed with it before burning. This produces what is known as porous terra cotta. If burned hard enough for the highest efficiency, it can not be cut with a saw and will not hold nails, as is often claimed for it. Even the softer grades commonly used can not be depended upon in this respect, the statements in the maker's catalogues to the contrary notwithstanding. Selected pieces can always be found of which it is true, but no large deliveries will contain a sufficient percentage of such pieces to be depended upon.

No fireproof material is superior to the best grades of porous terra cotta, when it is properly applied. In the form of the hollow blocks ordinarily found in the market, however, it is merely fire-resisting, not fireproof. These blocks have very thin webs; when exposed to the fire, they very quickly become heated through. They are backed by dead air spaces, and are joined at the corners of the blocks to other thin webs not exposed to the fire. The result is very serious strains due to unequal heating of the block as a whole, with comparatively sudden transition from the hot to the cold parts. This alone will cause the outer webs to crack and fall off in a hot fire, and the application of cold water from a fire hose brings this about at once. The hollow tiles were developed with a view to lightness, and with the idea that the dead air spaces would increase the protection from fire.

The latter is a fallacy; the effects of unequal distribution of heat were not foreseen and do not seem to be fully realized yet. Two fires in a store building, known as the Horne Store, in Pittsburg, in the years 1897 and 1900, illustrated this weakness of hollow tile very well. These fires will be found described in the Engineering Record of May 22, June 26, and July 17, 1897, and of April 14, 1900. Hollow tiles present two or more parallel webs of thin section, separated by dead air space, when in place. To expect those to successfully resist a fierce fire, is like holding a military position with a series of thin skirmish lines, the most advanced of which occupies the key to the whole position. When it is known beforehand what the exact location of the supreme trial of strength is to be, it follows that there should be concentrated the full strength of the defense. This is as true of fireproofing as of a battle. When the outer webs are broken off, the hollow blocks themselves are a total loss, even though they may still protect the steel with more or less success. What is true in this respect of porous terra cotta is doubly true of the dense variety.

To make hollow blocks really fireproof, the webs should be 2 inches thick. The material can not be successfully and economically burned in greater thickness than this, or it would be desirable to make it greater.

A better form of fireproofing would be 4 inches of brickwork, in which the bricks were made solid of porous terra cotta. But where flat ceilings are required, flat floor arches of hollow blocks, with webs 2 inches thick, can be safely used. They will not be found in stock, but must be made to order. The reason the thicker webs, or the solid bricks, are more successful in resisting fire is that there is a greater thickness of homogeneous material, and the change of temperature from hot to cold is gradual. The resulting strains do not exceed the strength of the material at any point. Of course, the thicker webs make heavier blocks, and this requires more steel to carry the dead load. Herein lies one reason for the continued use of blocks too light to be efficient for fireproofing. Another is the increased cost of the heavier blocks themselves.

Flat floor arches are almost always made with parallel joints, from motives of economy in manufacture; it reduces the number of separate patterns required and makes it easier to allow for accidental variations in the spacing of floor beams. While parallel joints seem all wrong, from a theoretical point of view, in practice they are all right. Flat side construction hollow tile arches almost invariably fail by shearing the webs of the blocks nearest the beams—i. e., in the skewbacks; so the joints are stronger than the blocks. End construction arches, with thin webs, are very difficult to set properly, because of the small area of end section available for receiving the mortar. In these blocks the joints may be the weakest part and should be carefully looked after. If webs were made 2 inches thick, this trouble would be largely obviated. Conditions would be still further improved by inserting thin continuous slabs in the joints, but this is never done, except to make up for accidental variations in the spacing of beams.

No matter what kind of floor arch is used, the lower flanges of the beams should be protected with at least 2 inches of fireproof material. The best method of doing this, probably, is with a heavy protecting skewback of the same material as the arches. Metal laths and plaster will not do; the fire will strip them off in ten or twelve minutes, and if the fire does not the water will. In the case of a protecting skewback, the design must be such that the pressure of the arch, under its load, will not tend to break off the protecting flange. This will have quite enough to do if it stays in place under the action of fire and water.

For the protection of girders, heavy shoes should be made in two pieces to fit over the lower flange; even at some extra expense, the thickness of the material in these shoes should be made at least 2¾ inches. The shoe should be filled with Portland cement mortar and squeezed into place; as soon as the cement is sufficiently set, the web covering should be built up on either side. The best form of this is 4 inches of porous terra cotta brickwork. It is somewhat heavy, of course, but when completed it possesses considerable transverse strength, and will transmit a part of its own weight to the columns. Instead of 4 inches of solid brickwork, the side covering might be built of hollow blocks with webs at least 2 inches thick; but the weight would be the same, and the solid brickwork is more efficient.

Columns should always be covered with 4 inches of solid brickwork and all interior spaces filled with Portland cement concrete. It has been repeatedly demonstrated that 4 inches of brickwork will protect steel in any ordinary conflagration, and if it is sufficiently tough and refractory itself it will be good for many fires, instead of only one. Porous terra cotta should be used because it is a poor conductor, and is able to take up contraction and expansion within itself without developing cracks. It should be hard burned to enable it to stand mechanical shocks, to which it is sure to be subjected in practice, and it should be highly refractory to prevent it from melting. It would be well to specify that porous terra cotta for fireproofing should be made of tough, refractory clay, with at least 20 per cent. of its volume of sawdust mixed with it before molding. That it should be burned almost to vitrification, and must be able to stand a temperature of at least 2,800° F. without melting or running. These specifications can be complied with at a small extra cost as compared with the materials commonly used. The extra cost should not exceed one-sixth. The result in the work will be better by 100 per cent. The same grade of materials should be used for floor arches, and for column and girder coverings. If flat ceilings are not required, a segmental arch of the solid porous terra cotta bricks, with heavy protecting skewbacks, can not be excelled. To secure a flat ceiling with these floor arches would require metal lathing to be stretched under them, at an extra cost of 5 or 6 cents per square foot of floor. The floor arches themselves ought not to cost more than 25 cents to 27 cents per square foot of floor. In considering the relative importance of different parts of the fireproofing, it should be remembered that the failure of a single floor arch or floor beam is a comparatively small matter; the failure of a girder is more serious, and that of a column is a catastrophe. Accordingly, the column protection should be the first, the girder covering next, and the floor system last, in power of resistance, if there is any difference. In current practice, this order is just reversed; in the forms recommended herein, it is realized. The column and girder coverings recommended will cost at least twice as much as those in common use, but the expenditure is fully justified by the results.

In the case of the columns, they will be so greatly stiffened by the covering and concrete filling that they can be safely designed without reference to buckling in simple compression. This will enable enough steel to be saved to more than pay for the extra cost of the covering, and the completed column will be both cheaper and better than those used in current practice, with their flimsy hollow tile covering.

Next to porous terra cotta, concrete is the best material for fireproof purposes. When made with Portland cement, it will withstand very high temperatures without material injury. The best concrete for resisting fire is made of Portland cement, sand, and the ash and clinker from steam boilers in large power plants. Domestic ashes and ashes from small plants are apt to contain a good deal of unburned coal, which always has sulphur in it; this is liable to corrode the steel. Where the coal is entirely burned, however, practically all of the sulphur goes off with the volatile products of combustion, and the ashes left behind will not corrode iron. Cinders, like locomotive cinders, which consist practically of bits of coke, are combustible and corrosive; they never give a good bond with cement, so they make a very weak concrete. They should never be used. There are cases on record where concrete made of them has been subjected to the heat of a fire, and has slowly burned up.

Concrete, made with broken stone, when subjected to heat, cracks and flakes off to some extent, just as the stone itself does. Gravel concrete stands heat better, and seems to give greater strength when reinforced with steel bars than stone under like conditions. Broken brick gives a concrete stronger than that obtainable from ashes and clinker, and probably stands fire just as well. Furnace slag is said to give a good fireproof concrete when broken and used in the same way as gravel or broken stone. There is likely to be some sulphur in furnace slag in a dangerous form, especially if the slag is finely divided. If slag is to be used, it would be well to screen out all crusher dust and wash the slag, so as to have all pieces clean and not smaller than a pea. Under these conditions, the sulphur is not likely to be very active. Portland cement clinker and neat Portland cement made into concrete, make a product that can not be excelled for fire-resisting properties. Many cement mills mold their kiln linings from such a mixture, and find it superior to the best fire bricks. This material, however, is not generally available for fireproof work. Portland cement is burned at temperatures probably as high as 3,500° to 4,000° F., so the clinker has passed through a more than ordinary severe test in the process of manufacture. The only weak point about Portland cement concrete is the fact that water has been added to it and taken up in the process of setting. This water can probably be driven off, in large part at least, by the application of heat. But it is possible that the cement is to some extent re-clinkered by this; if so, the concrete ought not to suffer serious diminution of strength. Practical tests show that, as a matter of fact, it does not; whether this is due to re-clinkering, is another question. A fierce fire will probably damage stone or gravel concrete, and possibly brick and cinder concretes, to a depth of about three-fourths of an inch, so that the damaged layer will either come off or have to be taken off. It would be well, in using concrete for fireproofing, to add about an inch extra thickness all around; then, in the event of a fire, the damaged concrete could be cleaned off and its place supplied by metal lath well fastened on and plastered with Portland cement mortar.

This would probably prevent the damage in a second fire from proceeding farther than that due to the first.

In using concrete for fire protection, the minimum thickness should be about the same as for terra cotta, and all column and girder coverings should have a skeleton of light metal shapes to hold them together and give them tensile strength.

Within recent years concrete, reinforced with steel bars, has been much used under transverse stress. It is used in flat slabs between I beams, instead of floor arches. In some cases, it is used as an arch proper, built on a wire lath center; but in this case it is considered as an arch, pure and simple. The metal is not counted on to furnish any part of its strength. But beams, girders, and columns are also built now of reinforced concrete with entire success. Frames of buildings have been built of it in Europe, similar to the steel frames used here, only on a smaller scale. It seems destined to play a most important part in the structural work of the future. It would not be surprising if it should ultimately drive out steel-frame construction altogether. Where it can be suitably used it probably yields, considering its cost, a greater return in the way of durability, strength, and fireproof qualities combined than any other form of construction. It is designed on the assumption that the concrete in the upper part of a beam, girder, or floor plate takes all the compressive stress, while the tensile stress in the lower part is taken entirely by the steel reinforcement, or partly by the steel and partly by the concrete. A great many formulæ have been worked out for the design of reinforced concrete beams under flexure. They are all based on the ordinary theory of flexure, modified to suit the circumstances and the individual views of the author. Probably as convenient a set of working formulæ as any can be found in the latest catalogue of the St. Louis Expanded Metal Company, which contains a discussion of the subject by Mr. A. L. Johnson, Member American Society of Civil Engineers. It is probable that his formulæ are as reliable as any others available at the present time. It should be stated, however, that the writer has not been able, so far, to verify equation 23, on page 58, and of course this applies to all the subsequent equations depending upon it. Only a very little time has been spent upon equation 23, and it is quite possible that it is correct. Another equation in this catalogue that seems to be wrong is No. 39, page 62. The writer thinks this should be $S = \frac{f\ c \cos\theta \sin\theta}{2}$.

A word might be said here as to the value of catalogues as sources of professional information. Along with the technical periodicals, and transactions of the Engineering Societies, they constitute the most valuable and indispensable part of an engineer's library. A treatise, setting forth the fundamental principles of any branch of engineering, is useful as the first step. But so far as the details of practice go, it is out of date before it is printed, and the engineer who wishes to be abreast of the times must derive his information from current literature and the practice of leading contractors and manufacturers. It should be remembered that, more and more, contracting work and industrial processes are passing into the control of trained engineers. These engineers supply the information that goes into the catalogues. They are generally honest men and state what they really think; they would not dare to make seriously inaccurate statements of a technical nature; they are in a better position than any other men to get accurate knowledge of the details of their specialties; and, as a matter of fact, on many branches of engineering, the catalogues of certain large concerns are the best and most reliable source of information. The fact that it is coupled with advertising matter should not be allowed to belittle the value of the information they contain.

Probably the best work on reinforced concrete is "Béton Armé," by M. Christophe. No thoroughly satisfactory work is printed in English, but a series of articles descriptive of the experiments of M. Considére on hooped concrete has been published in recent numbers of the Engineering Record, and should be read by every one interested in the design of reinforced concrete columns.

In addition to terra cotta and concrete, plaster of paris has been extensively used for fireproofing. But this substance rapidly deteriorates under fire and water, is mechanically frail, and should not be used, as a general thing, in important buildings. There are circumstances under which it is suitable, but there is not space to go into this subject here. The writer would have been glad, indeed, to go more extensively into the whole subject of fireproof construction, for in no other part of a building is there more need of an engineer's special training and in none is the lack of the engineer's work more glaringly apparent; but the limitations of time and space prevent a full discussion, and other points must be touched upon.

HEATING AND VENTILATION

Most modern buildings are heated, in some way, by either steam or hot water. If radiators are placed in the rooms to be heated, the system is called direct; if they are placed in the basement and used to heat air which is forced over them and through hot-air flues into the rooms, the system is called indirect. If the radiators are placed under windows, with provision for the admission of fresh air over their heated surfaces through openings under the window sills, the system is known as the direct-indirect. In any of these systems, either steam or hot water may be used. If a blower is used to insure the movement of air over indirect radiation, it is called a plenun system; if an exhaust fan is used it is a vacuum system. The latter is almost never used in indirect heating, however, as it is not as reliable as the other. All the necessary details and calculations for a steam-heating plant can be found in "Baldwin on Heating," and in a book on the same subject by Prof. R. C. Carpenter. "Hot Water Heating and Fitting" is the title of another work by Baldwin, which is a standard on the subject.

A steam-heating system consists of a boiler to evaporate the water, supply pipes for carrying the steam to the radiators, radiators for condensing and making available its latent heat, and return pipes for carrying the condensation back to the boiler. The supply and return pipes are sometimes combined in one set, giving a "one pipe" system. This is suitable only for small plants. In all such cases, the condensed water falls back through the rising steam, and the pipes must be made large enough to permit of this without interfering with the necessary supply of steam. In the case of steam heaters, a damper regulator, consisting of a diaphragm, weighted on one side, and subjected to the steam pressure on the other, can be very advantageously used for automatic regulation. As the steam pressure rises above a certain point, it raises the arm carrying the weight, and by means of a chain connection closes, or partly closes, the damper supplying air to the fire or regulating the draft. By shifting the weight the pressure in the system may be changed from day to day, according to the temperature. For small plants, this is a great convenience, and enables the plant to get along quite satisfactorily with only occasional attention. No other system of heating admits of automatic regulation in so simple and direct a way.

In tall buildings it is customary to take the main supply pipe direct to the top of the building, and then distribute downwards. This gives much more positive results, and may be said now to be the general practice. Ordinarily, where low pressure steam is used, some sort of air valve is put on the radiators to enable them to expel the air; otherwise the radiators will remain cold, as the steam will be unable to fill them. Air valves generally act by the unequal expansion of two metals. Many of them are quite reliable, if properly placed on the radiators.

In large installations, however, it is often the case that a vacuum pump is placed on the returns. This speedily empties the entire system of air, and increases the effective pressure of the steam by creating a vacuum in front of it. The supply pipes can be made much smaller than where the steam and condensation are expected to circulate under gravity and low pressure alone. Up to the present, no book on the subject has treated this phase of the subject with thoroughness, and information concerning it can be obtained only through the current publications, and from people controlling certain patents in reference to it. Steam has the advantage in climates subject to sudden changes, that heat can be obtained quickly, and gotten rid of quickly, since the weight of water required to fill the system with steam is comparatively small.

A hot-water plant includes a heater, supply and return mains, radiators, and expansion tank at the highest point of the entire system. All the pipes, radiators, tanks, heaters, etc., are filled with water. This entire volume has to be heated before its effects are felt in the rooms, and must cool off again before the rooms will cool. It gives a very equable and satisfactory temperature, but is more suitable for rigorous climates than comparatively mild ones. Great care is required in laying out a hot-water plant to insure efficient circulation.

In a general way, indirect hot water is the most expensive system, indirect steam next, then direct hot water, and finally direct steam.

Open fires and hot-air furnaces are still often used in private houses. Both are satisfactory under certain conditions, but neither can be recommended for general application.

PLUMBING

The object of the plumbing in a house or building is to supply water and gas at the necessary points, and to carry off all liquid and solid waste, into the sewers or other systems of disposal. Piping a house for gas and water is comparatively simple. The other matters are more complicated. The various fixtures connected with the drains comprise water closets, baths, lavatories, kitchen and pantry sinks, urinals, laundry tubs, and slop sinks. These must all be connected by suitable pipes with the drains and sewers. The drains in the house are known, in a general way, as soil pipes. All sewers are filled with offensive gases; it has been very generally believed that these gases were a source of disease; while this danger is probably exaggerated, sewer gas is a most unpleasant constituent of the air in a dwelling house. Even the soil pipe in a house becomes foul enough to be a source of disagreeable odors; drains leading from wash basins, baths, sinks, and tubs, become coated with a slimy, ill-smelling deposit on the inside. An ideal system of plumbing provides for cutting off the house from all these sources of bad odors, just as near the various fixtures as possible. The means used is always a trap in the drain itself, so arranged as to provide a water seal between the house and the drains. All parts of the waste pipe between the traps and the house should be accessible for inspection and cleaning. It is also found necessary to provide for a free circulation of air through the soil pipes to secure the best results, and to prevent a discharge of water from a fixture above, from syphoning off the water in a trap below, thus leaving the house open to the drains. As the house is usually warmer than the ground, especially in the winter, there is nearly always an inward draft, tending to draw air from sewers into the house.

Two prints* are attached hereto, showing two ways of piping a house. In one, a connection is made from the sewer side of every trap to the open air, above all fixtures, with the idea of securing circulation and a supply of air to restore the pressure when a discharge passes through the adjacent soil pipe, thus preventing the water seal in the trap from breaking. In the other, these "back-air vents," as they are called, are omitted, but the ends of all wastes are carried to the open air above all fixtures. This is just as good and somewhat simpler than the other plan, although it takes more pipe. This latter system provides for an exceedingly thorough circulation in all the drain pipes. There are some persons who object to the fresh-air inlet in front of the house, as it sometimes emits foul odors from the house drains. But, on the whole, it seems better to retain it, as the amount of fouling in the house pipes is not very great, and the draft will generally be in at the fresh-air inlet and out through the pipe at the top of the house. If any opening is made on the sewer side of the house trap, it must always be carried above the roof. All traps should have means of getting at them to clean them out without breaking the drains. This is indicated by the letters C. O. on the drawings. All clean-out openings must be stopped gas tight and water tight with a plug, and opened up only when the trap needs at-

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*Not printed.

tention. For soil pipe, cast-iron and steel are used. Cast-iron soil pipe comes in lengths of 5 feet, with hubs and spigots for calking. There are two weights, standard and extra heavy; the latter should always be used. The pipes should be dipped, hot, into melted asphalt or coal tar, so as to give them a thorough coating, both inside and out. Fittings for cast-iron soil pipe should all be of the long turn or sanitary kind, to reduce friction and prevent deposits. Steel pipe, for waste purposes, should be extra heavy, and used with the special recessed drainage fittings to be found in the catalogues of the best makers. These recessed fittings have shoulders inside against which the pipe abuts. The shoulder is of the same thickness as the pipe and insures a continuous smooth surface on the inside. Where steel pipe and screwed fittings are used, flanged joints should be introduced at convenient points, so that if repairs or changes necessitate breaking the line of pipe, it can be done with a minimum of damage and expense. Steel drainage pipes are sometimes galvanized; this is good for the outside of the pipe, but of doubtful value on the inside; decomposing animal matter gives rise to acids, and if the inside of the pipe is galvanized there will be galvanic action, which will be quite deleterious, and hasten the destruction of the pipe. There is no reason why steel drainage pipes should not be dipped in hot asphalt; the result would be better.

After the question of pipes is settled, there remains the fixtures and traps. The ideal plumbing fixture is made of vitreous ware, practically like porcelain. It has a hard surface glaze, but is vitreous all the way through, so that if the glaze is cracked, it will not absorb any unclean fluids. It is free of crazing—i. e., cracking of the glaze, and is made as nearly as possible in one piece, without joints or other places where dirt can collect. There are only two concerns in the United States making thoroughly first-class plumbing material. One of these is the J. L. Mott Iron Works, and the other is the Meyers-Sniffen Co., both of New York. There are a number of large jobbing houses that handle plumbing materials and fixtures, but they handle many grades besides the best. The Mott Works make some cheaper goods for which there is a demand, but they can be trusted not to sell them for anything except what they are. The jobbers may be perfectly reliable in matters of this kind, but some of them are not. It is understood the Meyers-Sniffen Co. does not handle any of the cheaper grades of plumbing materials at all.

Some fixtures, such as bath tubs, very heavy water closets, slop sinks, pantry sinks, etc., have to be made so thick that they can not be made of the vitreous ware, which can be burned only in thin pieces. The heavier sections are made with a fire clay body and a hard glaze. The maker should guarantee them against crazing, and the fire clay body should be almost vitrified.

The only way to test the quality of porcelain fixtures is to break them across and test them for strength and absorption. Vitreous ware, or, as the Mott catalogues call it, vitro-adamant, should be absolutely non-absorbent all the way through. The fire clay wares will absorb a certain amount of water; but they should be burned so hard that if hydrostatic pressure be introduced into the pores, the ware will not crumble to pieces under less than 1,500 pounds per square inch, or more. It is possible to form a very fair idea of the degree to which fire clay has been burned by simply testing its hardness. The same is true, to a limited extent, of the vitreous ware.

Any plumbing fixture, in addition to being made of thoroughly sanitary, non-absorbent material, must be of a proper shape and size. This can best be illustrated by considering the case of the water closet. This fixture, in its early form, consisted of a porcelain or porcelain lined bowl, with a movable pan for a bottom. When the closet was used, a handle was pulled, which dumped the pan, flushed the bowl, and filled the pan again with water. The pan was dumped into a sort of hopper which communicated with the soil pipe through a trap. The sides of the hopper formed a large inaccessible surface, which soon became very foul. An improvement in this consisted in the use of a bowl emptying into a trap through an opening closed by a plunger valve. The bowl had a flushing rim and could be kept fairly clean, but there was much fouling space around the plunger. Then came a porcelain bowl or hopper, with a flushing rim, supplied from a tank. This was the first really successful solution; but the surface of water presented for the reception of excrement was small, and the sides of the bowl became soiled and required much attention. An attempt to remedy this led to the form known as the washout closet, which was really a step backwards. Then the hopper and trap were combined in one piece of porcelain, and efforts made to enlarge the water surface. It was found impracticable to make this form flush properly with a large water surface; moreover, it would not flush successfully with a very deep seal in the trap. Not over an inch seal was used at first. By dint of much experimenting, forms of the simple combined hopper and trap have been developed which present a reasonably large water surface, have a seal of nearly 2 inches, and flush very successfully. For use in public places these are to-day the most desirable forms. But a modification, known as the syphon jet closet, is better for private houses. In this form a part of the flush is directed through a jet arm, which discharges at the bottom of the trap upwards and towards the soil pipe. This enables a very large body of water to be maintained in the bowl, with a very deep seal—as much as 3 inches, in some cases. The jet moves the entire volume of water along together. As soon as it begins to pass through the outlet a vacuum is created, and the contents of the bowl are ejected by syphonic action with a rush. The bowl then refills from the flush. The outlets of all syphonic closets have a rather tortuous form; this is to retard the water enough to form a partial vacuum in the outlet itself. It has been found possible in the case of a wash-down closet—which is another name for the combined hopper and trap—to secure some syphonic action by enlarging the outlet and then contracting it again, and also by making it more or less tortuous. This has made a deeper seal possible, which is a matter of great importance.

The limits of time and space prevent further discussion of plumbing fixtures and many other points that require attention in buildings, but it is hoped that the fragmentary notes contained herein may prove of some value and smooth out a few of the difficulties that present themselves to a young engineer engaged for the first time in the erection of a building.