then $S = s \times (\text{No. of teeth})$.
 But $\text{No. of teeth} = \frac{\text{circum.}}{t}$,
 $\therefore S = \text{circum.} \times \frac{s}{t}$,

and $\frac{s}{t}$ is the coefficient of sliding, denoted by r in the preceding investigation.

It may be urged that if more than one pair of teeth are simultaneously engaged (as, indeed, is usually the case), the amount of sliding will be greater than this. Which is true; but the pressure being subdivided, the friction of each tooth will then be less. It may not be absolutely exact in all cases to assume, as we have done, that these two things will balance each other; but it is our conviction that the error will be so small as to be practically unimportant; and at any rate the comparison between the various trains, which it was our main object to make, is not affected by it.

It must not be inferred that the trains shown in Figs. 28 and 29 are of limited utility by reason of the great amount of friction that attends their action. Their compactness, consequent lightness, and simplicity render them peculiarly eligible for some purposes, more particularly in hoisting machines; and in this special application the very existence of this friction is rather an advantage than a drawback, since the weight cannot run down if the power be relaxed or the engine fails; contingencies which with other arrangements of mechanism have caused serious accidents.

A DELTA METAL YACHT.

It is well known that vessels built of thin steel will rust through rapidly if not kept constantly painted. This is found to be the case to a remarkable extent in such vessels when navigating the rivers draining the interior of the African continent, the waters of which possess the power of corroding and eating through steel plates very rapidly. A steam launch called the Delta has therefore been built entirely of this metal by Messrs. Yarrow & Co., of Poplar. The length of the launch overall is 36 feet, with a breadth of beam of 5 feet 6 inches, and a depth of gunwale to keel of three feet, the vessel being capable of seating conveniently twenty-five persons. Delta metal, which is an alloy of copper, zinc, and iron, having been proved by repeated experiments to be equal in strength, ductility, and toughness to mild steel, the

A DELTA METAL YACHT.

plates and angle pieces are of the same thickness they would be if steel were used, viz., $\frac{3}{8}$ of an inch. The stem, keel, and stern post are of forged Delta metal, and scarfed together, as is usually done. The angle frames are of the same material, and are placed longitudinally instead of transversely, by which arrangement greater longitudinal strength is obtained. The screw propeller is cast in Delta metal, and is four-bladed, 2 feet 4 inches in diameter, and with 3 feet pitch. The engine is of the usual direct-acting inverted type, and of sufficient power to give a speed of from eight to nine miles an hour. The application of the Delta Metal to the present purpose is of interest just now, when attention is being directed to the development of the African continent.

THE CONSTRUCTION OF FRAME BUILDINGS.*

By CLARENCE O. AREY, C.E.

I HAD intended when I selected the above title for my paper to take up the different classes of frame buildings, but after starting upon my subject I saw that, if I confined myself to the construction of the balloon framed dwelling, I should cover ground enough for one paper. I shall therefore take up the different points in which, according to my ideas, such buildings as constructed in this locality are faulty, and bring forward the qualifications necessary in order to have such a building properly constructed.

The two main requirements to secure this are: First, that there shall be as little settlement in the building as possible, and that whatever settlement there is shall be the same in amount in all parts of the building; second, that the frame shall be perfectly stiff against both dead weight and wind pressure.

In starting, it must, of course, be taken as one of the conditions that our foundation is solid, that the pieces that carry weight in the cellar bring as much weight upon their footings per square foot as the outside walls have upon their base per square foot.

Also we must consider that the tops of piers carrying the same line of girdles are level, so that they do not require to be completed by putting different thicknesses of plank on them in order to correct their inaccuracies of level.

The old-fashioned braced frame, if properly constructed, fills both the conditions of settlement and stiffness, were it not that there is so much settlement in all parts.

Although the majority of the architects in the East have gone back to the braced frame after a trial of the balloon, I do not think that they can accomplish the same results with the degree of economy that the balloon frame gives. The balloon frame is still capable of many improvements, its weakest point being in the ribbon which carries the joists of the upper floors. It has also the disadvantage of having a greater amount of vertical timber than is necessary to carry the weight it receives, in order that the studs may be the proper distance apart for lathing. In order to compensate this, we use studs of a size that hardly gives a wall of sufficient thickness for proper window boxes.

I have been developing a modification of the balloon frame which I propose to bring into use in my own work, and which, I think, will overcome these difficulties; but my purpose this evening is to discuss the balloon frame as it is, so that this will not properly form part of my subject.

In discussing the framing the sheathing will be left out of consideration entirely, as being a factor that adds to the strength of the building; for if we depend on the sheathing to carry weight, we at once get the question of settlement from the shrinkage of horizontal timber so complicated that it would be impossible to tell the amount of shrinkage timber that we have at any one point of the building, while if the frame is so constructed as to fulfill the condition of settlement the sheathing will then come in place to give the building warmth and general, not entire, stiffness against the wind.

The necessity of equality of settlement is indicated by Fig. 1.

The figure represents a door opening in a cross partition that rests upon joists. If the joists settle more at one end than at the other, the floor settles as indicated by the dotted lines, and the door opening loses its rectangular form, while the door, being hung at right angles with the door jamb, will not shut. This point is quite clearly explained in Clark's Building Superintendence.

To properly discuss the conditions of stiffness and equality of settlement, it will be better to take the building in its different parts and consider what is necessary in order that each part may fill the requirements.

Sills, Girders, and Plates.—I consider the sill built of plates, and so common in this locality, to be thoroughly bad. In the first place, in a sill or beam built of more than one horizontal thickness there is a loss of strength in exact proportion to the number of thicknesses employed. That

of building, on account of bringing in too much shrinkage timber.

In this connection I will mention a case where I made some alterations in an almost new dwelling on Willson Avenue. I found that the girders in the cellar were made of three pieces of 2 inches $\times$ 10 inches on edge. In a span of some 8 or 9 feet the middle joist was spliced about 3 feet from one of the piers; the splice being simply one joist ending and another commencing, leaving really only a double joist to form the girder.

Second, as we cannot get absolutely dry timber in the market, several thicknesses of timber nailed together without

Fig. 1.

any air spaces between them have a decided tendency to dry rot. If these girders were keyed apart, leaving an air space between each division, after the manner of the chords of a Howe truss, they would be in all respects equal, if not superior, to a solid timber.

Having considered sills and girders with regard to strength, there still remains the consideration of equal shrinkage throughout the building. It will be assumed that all of the timber is of sufficient strength to avoid appreciable deflection. I suppose that it is understood that timber shrinks across its grain, but not lengthwise of its grain to any appreciable extent. By the term shrinkage timber, which I shall frequently use, I mean the timber which lies horizon-

Fig. 2.

tally in a building, and which carries joists, floors, or partitions upon it. Let us take a building in which the inside partitions, which carry joists, are carried by girders upon piers, and all studs that carry joists go through between the joists at their foot and rest upon the sill, girder, or plate below.

If the sills and girders are of unequal depth, the first floor may be made to have equal settlement by sizing the joists of this floor unequal amounts at the two ends—that is, if we have a 6 $\times$ 6 inch sill and 8 $\times$ 10 inch girder on edge, on account of having 4 inches more timber vertically, we require, in order that the floor may settle equally, 4 inches less of the joists resting on the girder than on the sill, as in

Fig. 3.

Fig. 2; thus giving us 14 inches of shrinkage timber at each end.

But with this arrangement the trouble comes in a balloon frame when we reach the third or attic floor. For the second floor we need at least a 4-inch plate on the top of the first floor studs that rest upon the girder; this, with the case already taken, will give us 14 inches of shrinkage timber without the second floor joist timber. If we set this plate into the joists 4 inches, the joists being 2 $\times$ 10 inches, we

is, if a beam of two horizontal thicknesses, you have exactly one-half the strength of the same amount of timber in one thickness. In a sill of three thicknesses you have only one-third the strength of a timber of the same dimensions in one thickness. To prove this we have simply to fill Rankin's formula for beams.

$$B. M. = n f b h^2.$$

$B. M.$ is an abbreviation for bending moment.

n being a constant depending on the section of the beam.

f being a constant depending on the material used.

b and h being the breadth and height.

A beam of any number of horizontal thicknesses, unless properly keyed and bolted together, must be considered as so many separate beams of the thickness of each, so that in getting the comparative strength of a beam of one thickness, and a beam of several thicknesses with the same total dimensions, we must fill the formula for the first case with h representing the total depth of the beam, and for the other with h representing one thickness of the beam, and multiply the result by the number of thicknesses.

All the factors excepting h remain constant.

For a beam of two thicknesses h being the depth of the beam of one thickness, h would become $\frac{1}{2}h$ and squared $\frac{1}{4}h^2$; doubling for each part of the beam it becomes $\frac{1}{2}h^2$. In the same manner for three thicknesses the h^2 for one thickness becomes $\frac{1}{3}h^2$. Substituting n for the number of divisions, we obtain for n thicknesses $\frac{1}{n}$ th of the strength for one thickness.

I have perhaps been unnecessarily explicit on this point, but my excuse is that it is a fact so commonly misunderstood outside of the engineering profession.

During the summer of 1881 I noticed in a large dwelling going up on the Chamberlin Allotment in this city, that the sills were made of two pieces of 2 inches $\times$ 6 inches, spiked together.

Examining them over one of the cellar window openings, I found a deflection of fully $\frac{1}{4}$ inch in a span of about 3 feet 0 inches. By this we see how such a sill will settle over an opening; and also if the foundation settles for a short distance in any part of the building, how this class of sill will settle with it.

For different reasons from the ones I have against built sills, I object to girders built out of joists on edge and spiked together.

First, you cannot make a good splice and have it entirely upon a bearing. Bolsters are not allowable in this class

* A paper recently read before the Civil Engineers' Club of Cleveland.

shall have 20 inches of shrinkage timber at this inner end of the joists. At the outer end we have 6 inches from the sill; the ribbon will probably set into the joists so as to leave 9 inches shrinkage timber in them. This makes 15 inches. To make up the 20 inches we need a 5-inch ribbon. The shrinkage of the ribbon not being exactly certain on account of its nailing, it would be better to use a 6-inch one.

Under the inside ends of the third floor or attic joists, if there are 4-inch plates at the top of the second floor studding, we have, adding this to the 14 inches below, 18 inches of shrinkage timber.

Under the outside ends we have, adding the 4 inches of the plate to the 6 inches of sill, 10 inches of shrinkage timber.

This would require us to cut 8 inches further into the inner ends of the attic joists than the outer, which is impracticable. Now let us start with the sills and girders of the same depth, and see how it simplifies the matter. (This case illustrated by Fig. 3.) I do this in practice by using 6×6 inch sill and a 6×10 inch or a 6×12 inch girder laid flat; the distance between the piers being proportioned to the weight.

If the first-floor joists are sized out so as to leave the same amount at each end, they will settle evenly as the timber dries. If a 4-inch plate is used on the top of the interior carrying partitions under the second floor, and a 6-inch ribbon (considered as equivalent to 5 inch) is used in the outside studding under the same floor, and is set into the joists 1 inch, we have 20 inches of shrinkage timber at each end of the joists for the sizes given in Fig. 3. I object to a 2-inch plate on the top of the studding that carries the second floor joists as being too light for a span of 16 inches to carry both the second-floor joists and the second-floor studding resting directly upon it. If this plate only carried one set of joists and not the partition above it, it would be sufficient. If under the attic joists a 4-inch plate is used on the outside wall and a 2-inch plate at the top of the inside partition, and this latter is set into the joists above it 2 inches, we have 18 inches of shrinkage timber from the foundation to the top of the attic joists at each end of them. In practice if the attic have no finish whatever, I generally use a 4-inch plate on the top of the interior bearing partitions, just under the attic joists. If it is desirable to raise the roof so as to have some height in the attic at the eaves, by setting a 6-inch ribbon into the studding and letting it into the attic joists 1 inch, the same as is done under the second floor, we still keep both ends of our joists resting on an equivalent amount of shrinkage timber.

There came under my attention during the past summer a frame dwelling in which there were 6 inches more horizontal timber at the inner ends of the first-floor joists than at the outer ends, 10 inches more in the second-floor, and 26 inches more in the attic floor. I have heard the owner since complain that the plaster cracked in all the angles, of course; as by settlement the shape of the cross walls changes from rectangles to acute and obtuse angled parallelograms, the junction between these cross walls and the supporting walls must be severed, as plaster has no element of elasticity.

In this connection it may be well to mention that cracking of plastering is more generally the fault of the carpenter than the plasterer. Splintering, which is hardly the correct name for it, is generally caused by unslaked lime, or by work done in winter under artificial heat, under which conditions good work can never be obtained.

Framing Over Openings.—For openings not over 3 feet 0 inches in width I find that doubled 2-inch plates set into the studding on each side of the opening have sufficient strength. This setting in, although neglected by the carpenters unless carefully watched, is absolutely essential; otherwise we put in a timber amply strong, and hold this timber by a few nails which have nothing like the necessary strength.

Over openings wider than this I think it is best to truss. Although a joist set into the studding on edge is strong enough, unless it is absolutely dry it complicates our problem of shrinkage. In trussing it is necessary to see that the truss is a truss, and not a semblance of one held in place by a few nails.

It is wonderful what an amount of ignorance is displayed in the construction of simple trusses. Heavy timber is put in with no duty to perform whatever. Struts are used where there should be ties. Timbers of size only sufficient to withstand a direct thrust or pull are put under heavy bending moment. We hardly see all of these conditions in the little trusses of which I am speaking, but there are plenty of them built that might as well be left out as far as any purpose being accomplished by them is concerned. Perhaps the simplest form of a good truss for such places is that

shown in Fig. 4. The pieces *a a a* are set in after the truss is built for the purpose of lathing.

If the truss is very flat in proportion to its height, the doubled studding on each side of the opening will not be sufficient to withstand the horizontal thrust, and the struts will either need to be set into the tie B, or the two or three studs on each side of those forming the opening will want to be blocked together at the level of the tie B.

Stiffening the Walls of the Building against Wind Pressure.—This is a precaution to which generally very little attention is paid in balloon frames. This end may be accomplished in several ways, as follows: By setting into the studding diagonal 1-inch dressed boards at the angles of the building, and nailing to every stud which the diagonal crosses; by running a row of zigzag bridging all around the building between the studding; by bricking up a short distance between the studding. This fixes the lower ends of the studs solid, and makes them all act as beams fixed at one

end.—By covering the walls with narrow matched sheathing. Covering the wall with common sheathing is not an entire precaution against displacement by wind pressure, because by a very slight giving way of the wood against the side of the nails each board may have a parallel motion in the same manner that a parallel ruler acts. The matched sheathing, to be efficient, must be nailed on both edges, and not simply blind-nailed like flooring. In this case the matching and the fact that the narrowness of the boards makes less leverage between each pair of nails produce the superiority for this purpose over common sheathing. I do not consider that even the matched sheathing is as good a means of resisting wind pressure as the first few mentioned.

The Order of Progress.—It is customary with some contractors to space the studding equally distant all around the building, then to sheathe, and after this to cut out the openings wherever they may come. I have never seen a case of this in which the framing around openings was not a mere pretense, the framing studding being merely tacked into place against the sheathing, the studding that was originally set up carrying the weight against all openings to the studding. Sometimes the openings are not even framed till the roof is raised, then if the opening is wide and the roof is heavy, the wall-plate, being unsupported during the cutting out, settles out of level, where it permanently remains. It is my custom now to specify that the building shall not be sheathed till all openings have been framed, and that the roof shall not be raised till the building has been sheathed.

Before any lathing is commenced it is necessary to see that all angles have been made solid, and in making an angle solid it is necessary that the end studs of the partitions that form the angle shall be against each other. This is so that each room may be lathed by itself and have no lath running through from one room to another. When the laths run through in this manner the two angle partitions have no connection with each other, and any jar in one of them will not affect the other, so they spring apart and crack the plastering down the angle. Where a frame partition joins a chimney there is only one way of preventing a crack, and that is by furring all around the chimney with wood, and this I should not recommend unless the chimneys have 8-inch outside walls.

Sheathing and Siding.—Sheathing a building on the outside is altogether preferable to sheathing it on the inside. When a building is sheathed on the inside the spaces between the floor joists are generally left open, letting the cold air pass in, and making cold floors; also the clapboards on the outside, being only $\frac{1}{2}$ inch thick in their thickest place, have a tendency to spring in different curves between the studding, thus opening a space for the inlet of cold air. Sheathing on the inside has the disadvantage of having no grip on the angles of the building; and any building paper used in this case loses half of its efficiency by having nothing to hold it flat in place and keep its lapped joints tight together.

On the other hand, if the building is sheathed on the outside the sheathing runs up continuously, gripping the angles and covering the ends of all joists. It keeps the clapboards close against each other, and packs the building paper tight between the clapboards and sheathing. In comparing these two methods of work, I have spoken of the building as if clapboards were the only covering. I consider it the only good covering to the outside of a frame building excepting shingles. Drop-siding either leaves large spaces to hold water, if the casings are laid on top of it, or it splinters on the end from the lack of an air space behind it if it is butted against the casing. Clapboards from being thinner at one end than at another, and from their lapping each other, leave a triangular air space between every two consecutive ones and the sheathing, which greatly enhances their durability.

In general, air spaces between consecutive pieces of timber in a frame building are essential to its durability.

Roofs.—These have both dead weight and wind pressure to resist. I shall leave out of consideration roofs covering large spans, requiring frame trusses, and take up only the ordinary roof and such trussing as may be put together with spikes acting as rivets or pins. My idea of the ordinary roof is that the hips, valleys, ridges, and wall rafters should form a frame, not necessarily strong enough to carry the whole roof, but strong enough to act as a decided stiffener to the whole. The common rafters in this case act almost entirely as filling. The valley rafters are almost always made too light, the fact not being taken into consideration that they have to carry the weight that is on all the rafters that butt against them.

Where the rafters are 2×6 inches, a doubled 2×8 inches is necessary for the valley rafters. Hips and ridges should never be less than 2 inches thick, and deep enough to receive the diagonal dimensions of the rafters. If these are less than 2 inches thick, we do not have straight but wavy ridge and hip lines. In one of the first buildings that I erected in this city, which was built by the day, I had specified the ridges 2 inches thick. As the building went on the owner wished to economize as much as possible, and a 1-inch ridge was put in. This building happened to have an exceptionally long ridge and a good place to illustrate the weak point of a 1-inch ridge-pole.

When the attic floor was laid, I took the owner into the attic at one end of the ridge and had him sight along it. The straightness of the ridge averaged all right. It was as much out on one side as it was on the other; it was like Mark Twain's watch, which was all right at 12 o'clock at noon every day, but the rest of the time he could not tell whether it was slow or fast. The workmen employed on this building were experienced and careful men.

The attic of a dwelling may just as well and cheaply be made clear and unobstructed between its outside walls as to be all cluttered up with posts supporting angles of the roof. If the roof is properly framed it does not need this, even if it has a deck. If in each case where two valley rafters come together one of them is run through to the ridge or deck plate, if no spliced timber is used, and if the roof is properly braced against the wind, the most complicated roof can be made to stand without intermediate supports. Of course each case will want special study. When supports are put in the roof is framed to rest on them, so that they cannot be removed, and if ever it becomes desirable to divide the attic into rooms they are always just in the wrong place. If the attic is ever furnished off as a dancing hall, the posts are terrible in the way.

It is much easier to dodge two couples than it is to dodge two couples and a post at the same time. In the more complicated roofs without decks, the timbers run from so many different directions that they brace themselves against the wind. Take, however, a long, narrow building, or a building with a deck, and they need bracing against wind pressure.

In the case of a long building with the gables at the end, and where the roof starts above floor, there is nothing to

prevent the rafters moving transversely to the building and parallel to each other when the rafters are only tied by collar beams. Such a roof very much resembles the ordinary railroad bridge trusses in principle of lateral pressure. An equivalent to the diagonal bracing of the horizontal panels in these bridges is all that is needed here. This may be accomplished by dividing the building lengthwise into approximately square panels, then laying joists flat on the top of the collar beams, so as to form diagonals to these panels, and then spiking them to every collar beam. This construction may of course be varied for special cases.

In deck roofs our problem is very much that of the ordinary trapezoidal truss, which is perfectly stiff under dead weight, but liable to give under wind pressure. If we tie the angles of the trapezoid there is no chance for it to change its form, provided, of course, that our timbers are heavy enough not to be affected by what little bending moment is brought upon them by this operation. I have put up quite a number of roofs leaving a clear attic or barn loft, and by using the precautions mentioned, varied to suit each case, have found them perfectly stiff, making the building more convenient and appearing much better inside. Now that we are on the roof I think it is as good a place to stop as any, leaving you to get down as best you may.

RITTER'S PERSPECTOGRAPH.

The accompanying engraving (Fig. 2) represents an apparatus which is designed for quickly putting architectural drawings into perspective, and which is the invention of Mr. Hermann Ritter, who recently presented it before the Society of Architects and Engineers of Frankfurt-on-the-Main.

Say we wish to put into perspective a plane figure situated in the plane $r' r' S S'$ (Fig. 1). The eye of the spectator

FIG. 1.

is at H, $S S'$ is the trace of the plane of the perspective called the picture, $r' r'$ is the trace of a parallel plane passing through H, and H R is a perpendicular to $r' r'$. The points P and P' have K and K' for perspectives, and H R remains constant.

Let us refer to the figure of the instrument: A plan drawing is glued upon a board which will be taken for the plane of the lines of a horizontal course whose perspective is desired. The ruler, s , occupies the position of $S S'$ in the diagram shown in Fig. 1, and the same is the case with the ruler, $r' r'$, and the fixed point, R. The point H is fixed at a distance from R that corresponds to H R of the diagram. At the points of juncture, P, of two rulers that are capable of sliding and revolving upon the fixed points, H and R, there is fixed a pencil which follows the contours of the horizontal line to be put into perspective.

In a slot in the ruler, P R, at its intersection, F, with $s s'$, there moves a button which is fixed to a wooden slide movable in the axis of $s s'$ and carrying a joint, f , at its other extremity. The intersection, K, of P H and $s s'$ is connected in a like manner with a metallic rod, which is also in the axis, $s s'$, and carries at the other extremity the joint, k , of the parallelogram, $f c k c$. The movements of F, and con-

FIG. 2.—RITTER'S PERSPECTOGRAPH.

sequently those of f , therefore exactly follow those of the point, F, of the diagram. The variations of F K, corresponding to the ordinate, F K, of the perspective of the point, P, upon the diagram, will produce equivalent movements of k .

A second parallelogram, $f b a b$, whose sides, $f b$, are equal and perpendicular to the sides, $f c$, carries a fixed joint at a . The sides, $a b$, are prolonged to D by a distance equal to their length, and D carries the pencil which traces the perspective of P. As the two parallelograms, which are lozenges, are constantly equal, it will be seen that the ordinate, D f, will undergo variations equal to the movements of the points, k and K, with respect to F.

We have thus realized the condition that the foot, f , of the ordinate of the point, D, and the ordinate, D f, itself, both undergo exactly the same motion and the same variation in length as the point, F, and the ordinate, F K, of the diagram. D will therefore trace the perspective of the