CARPENTRY MADE EASY;

OR,

The Science and Art of Framing,

ON A NEW AND IMPROVED SYSTEM.

WITH SPECIFIC INSTRUCTIONS FOR

BUILDING BALLOON FRAMES, BARN FRAMES, MILL FRAMES, WAREHOUSES, CHURCH SPIRES, ETC.

COMPRISING ALSO

A SYSTEM OF BRIDGE BUILDING;

WITH

BILLS, ESTIMATES OF COST, AND VALUABLE TABLES.

ILLUSTRATED BY

Thirty-eight Plates and near Two Hundred Figures.

BY WILLIAM E. BELL,
ARCHITECT AND PRACTICAL BUILDER.

PHILADELPHIA:
JAMES CHALLEN & SON,
No. 25 SOUTH SIXTH STREET.
J. B. LIPPINCOTT & CO.—LINDSAY & BLAKISTON......NEW YORK: SHELDON, BLAKEMAN & CO......BOSTON: PHILLIPS, SAMPSON & CO.
CINCINNATI: RICKEY, MALLORY & CO......CHICAGO: S. C. GRIGGS & CO.
1859.

STEREOTYPED BY GEORGE CHARLES,
No. 607 Sansom Street, Philadelphia.

PREFACE.

The Author takes great pleasure in acknowledging the eminent services rendered him in the literary and scientific portions of this work, by E. N. Jencks, A. M., Professor of Mathematics and Natural Sciences; and the Public cannot fail to appreciate the value of his labors in these departments.

The inception of the work, its original designs, and the entire system, are mine. Whatever is found in it purely literary and scientific, I cheerfully attribute to his assistance. And believing that the work will supply a pressing want, and will be useful both to those who are devoted to the Mechanic Arts and to Amateurs who have felt the necessity of a faithful guide in house-building and other structures, especially in new settlements, I can confidently commend it tc them as supplying this deficiency.

WILLIAM E. BELL.

Ottawa, Ill., Jan. 1st, 1858.

CONTENTS.

PART I.—Geometry.

PART II.—Carpentry.

PART III.—BRIDGE BUILDING.

PART IV.—EXPLANATION OF THE TABLES.

INTRODUCTORY CHAPTER.

SUMMARY VIEW.

The Science and the Art of Framing.

No apology is offered for introducing to the Public a work on the Science and Art of Framing. By the *Science of Framing* is meant the *certain knowledge* of it, founded on mathematical principles, and for which the master of it can assign intelligent reasons, which he knows to be correct; while the *Art of Framing* is the system of rules serving to facilitate the *practice* of it, but the *reasons* for which the workman may or may not understand. That Carpentry has its rules of Science as well as its rules of Art, no intelligent mechanic can doubt. The rules of the Art are taught by the master-workman at the bench; or, more commonly, insensibly acquired by habit and imitation. But by whom have the rules of the *Science* been laid down, and where have its principles been intelligibly demonstrated?

Something New.

It is believed that this is the very first attempt ever made to bring the Science of Carpentry, properly so called, within the scope of practical mechanics.

Deficiencies of Former Works on Carpentry.

Whatever has formerly been published on this subject, that can, with any degree of propriety, be classed under the head of Science, has been only available by professional Architects and Designers, being written in technical language and mathematical signs, accompanied by no adequate definitions or explanations; and are as perfectly unintelligible to working-men of ordinary education as Chinese or Choctaw. On the other hand, the numerous works upon the Art of Carpentry, designed and published for the use of working-men, are sadly deficient in details and practical rules. They seem to take it for granted that the student is already familiar with his business; they furnish him with drafts and plans to work from; they tell him authoritatively that such or such an angle is the proper bevel for such a part of the frame; but they neither tell him *why* it is so, nor inform him *how* to begin and go on systematically with framing and erecting a building. These works are, in fine, chiefly valuable for their plates; and even these it is not always possible to work from with confidence and accuracy, because no man can work with confidence and accuracy in the dark: and he certainly is in the dark who does not understand the reasons on which his rules are founded.

The Author's Experience.

These facts and reflections have been impressing themselves upon the mind of the Author of this work for twenty years past, while he has been serving the Public as a practical carpenter. During much of this time it has been his fortune to have large jobs on hand, employing many journeymen mechanics, who claimed to understand their trade, and demanded full wages. But it has been one of the most serious and oppressive of his cares, that these journeymen knew so little of their business.

Few Good Carpenters.

They had, by habit, acquired the use of tools, and could perform a job of work after it had been laid out for them; but not more than one man in ten could himself lay out a frame readily and correctly.

Why Apprentices do not Learn.

Now, it is not commonly because apprentices are unwilling to learn, or incapable of learning, that this is so, but it is because they have not the adequate instruction to enable them to become master-workmen. Their masters are very naturally desirous to appropriate their services to their own best advantage; and that is often apparently gained by keeping the apprentice constantly at one branch of his business, in which he soon becomes a good hand, and is taught but little else; and when his time is his own, and he comes to set up business for himself, then he is made to feel his deficiencies. Should he have assistants and apprentices in his turn, he would be unable to give them proper instruction, even were he well disposed to do so—for he can teach them nothing more than what he knows himself.

In this condition, the young mechanic applies to books to assist him to conquer the mysteries of his Art; but he has not been able hitherto to find a work adapted to his wants. He anxiously turns the pages of ponderous quarto and folio volumes; he is convinced of the prodigious learning of the authors, but he is not instructed by them. On the one hand, their practical directions and rules are too meagre; and, on the other hand, their mathematical reasoning is too technical to yield our young working-man any real benefit or satisfaction. May not these faults be remedied? Is it not possible for instruction to be given, which shall be at once simple and practical in detail, and comprehensible and demonstrative in mathematical reasoning?

Design of this Work.

An attempt has been made, in this little work, to answer these questions affirmatively; and thus to supply a positive want, and to occupy a new field in the literature of Architecture. Its design is to give plain and practical rules for attaining a rapid proficiency in the Art of Carpentry; and also to prove the correctness of these rules by mathematical science.

Importance of Geometry to Carpenters.

No certain and satisfactory knowledge of framing can be gained without a previous acquaintance with the primary elements of Arithmetic and Geometry. It is presumed that a sufficient knowledge of Arithmetic is possessed by most mechanics in this country; but Geometry is not so commonly understood. It is not taught in our District Schools, and is looked upon as beyond the capacity of common minds. But this is a mistake. To mechanical minds, at least, the elements of Plane Geometry are so easily taught, that they seem to them to be almost self-evident at the first careful perusal; and mechanics have deprived themselves of much pleasure, as well as profit, in not having made themselves masters of this science.

Geometry in this Work.

Part I. is therefore devoted to so much of the Science of Geometry as is essential to the complete demonstration and thorough understanding of the Science and Art of Carpentry; and it is recommended to all mechanics into whose hands this volume may fall, to give their days and nights to a careful study of this part of the work. It is true that our rules and instructions in Carpentry are so plain and minute, that they are available to those who do not care to study Geometry at all; but the principles on which those rules are founded, and consequently the *reasons why the rules are as they are,* cannot, from their very nature, be made plain and intelligible to any one except by a course of geometrical reasoning.

New Rules of Carpentry.

Part II. comprises the main body of the work, and is devoted particularly to the framing of buildings. The rules for obtaining the bevels of rafters, joists, braces, &c., as explained in this part of the work, it is believed, have never been published before. That such bevels could be so found has been known, for several years past, among master-builders; and, to a limited extent, has by that means been made public; but this feature of the work will, no doubt, be new and useful to some mechanics who have followed the business for years, and will be especially useful to apprentices and young journeymen who have not yet completed their mechanical education.

They are Proved and Explained.

These rules have been here demonstrated by a new and rigid course of geometrical reasoning; so that their correctness is placed beyond doubt. The demonstrations are often given in foot-notes and in smaller print, so as not to interrupt the descriptive portion of the work, nor appall those who are not mechanically learned, by an imposing display of scientific signs and technical terms. In fact, it has been made a leading object, in the preparation of this work, to convey correct mechanical and scientific principles in simple language, stripped as much as possible of all technicalities, and adapted to the comprehension of plain working-men.

Bridge Building.

Part III. comprises a brief practical treatise on the framing and construction of Bridges, with bills of timber and iron given in detail, by the use of which intelligent carpenters can construct almost any kind of a bridge. This part of the work does not, however, make any special claims to new discoveries, or to much originality; nor is it intended to supercede the use of those works specially devoted to Bridge Building; but it is believed it will be found more practically convenient and simple than some others of more imposing bulk and of higher price.

Valuable Tables.

Part IV. contains a valuable collection of Tables, showing the Lengths of Rafters, Hip Rafters, Braces, &c., and also the weights of iron, the strength of timber, &c., &c., which will be found of the greatest convenience, not only to common mechanics but to professional designers, architects, and bridge builders. Some of these tables have been compiled from reliable sources; but the most important of them have been calculated and constructed, at a considerable amount of expense and labor, expressly for this work.

Plates and Illustrations.

Nor has any expense been spared in the preparation of the plates and illustrations, which are "*got up*" in the highest style of the art; and it is hoped, and confidently expected, that the work, as a whole, will prove to be satisfactory and remunerative equally to the Public and to their

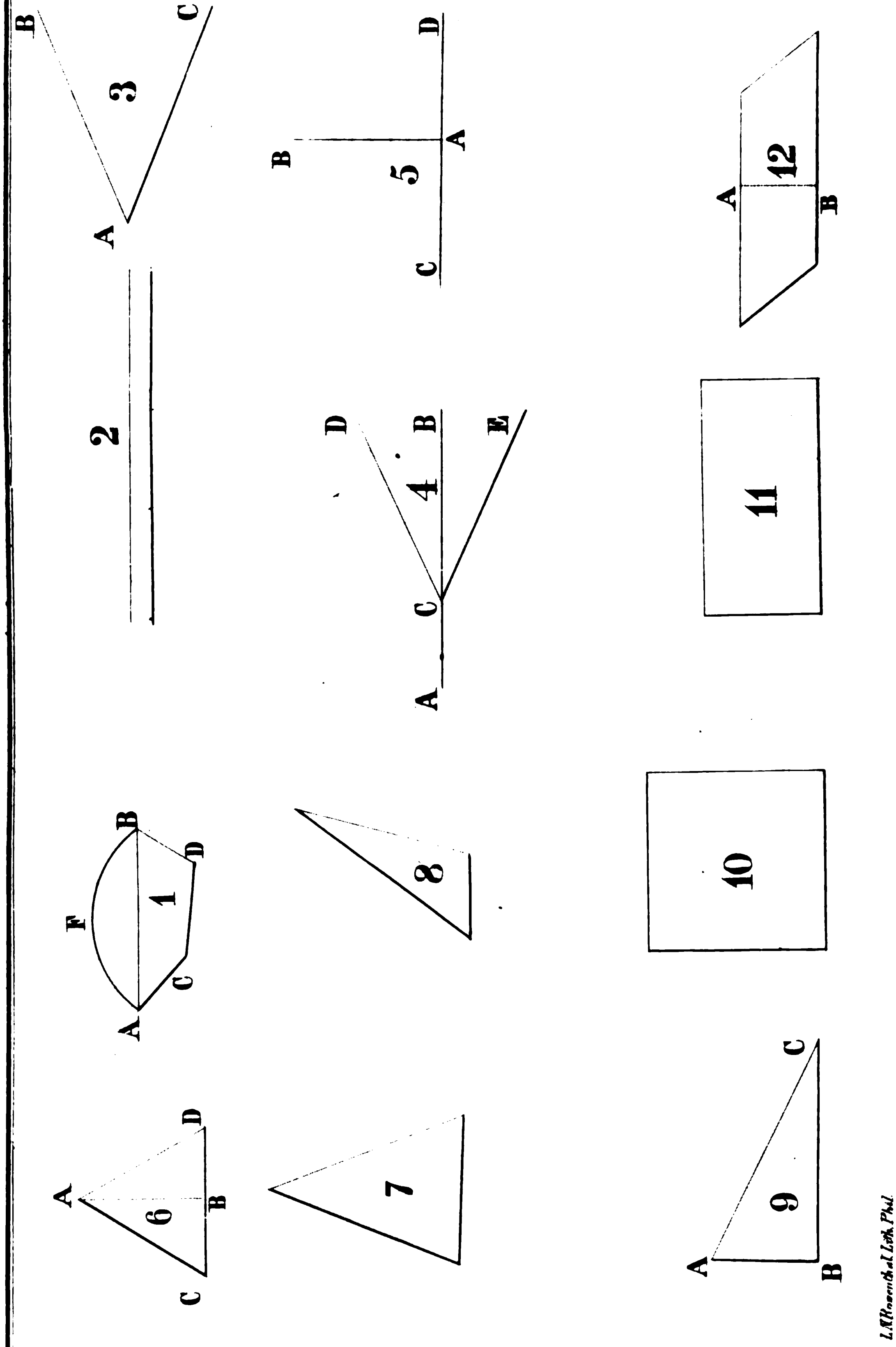
Humble and obedient servant,

THE AUTHOR.

Ottawa, Ill.

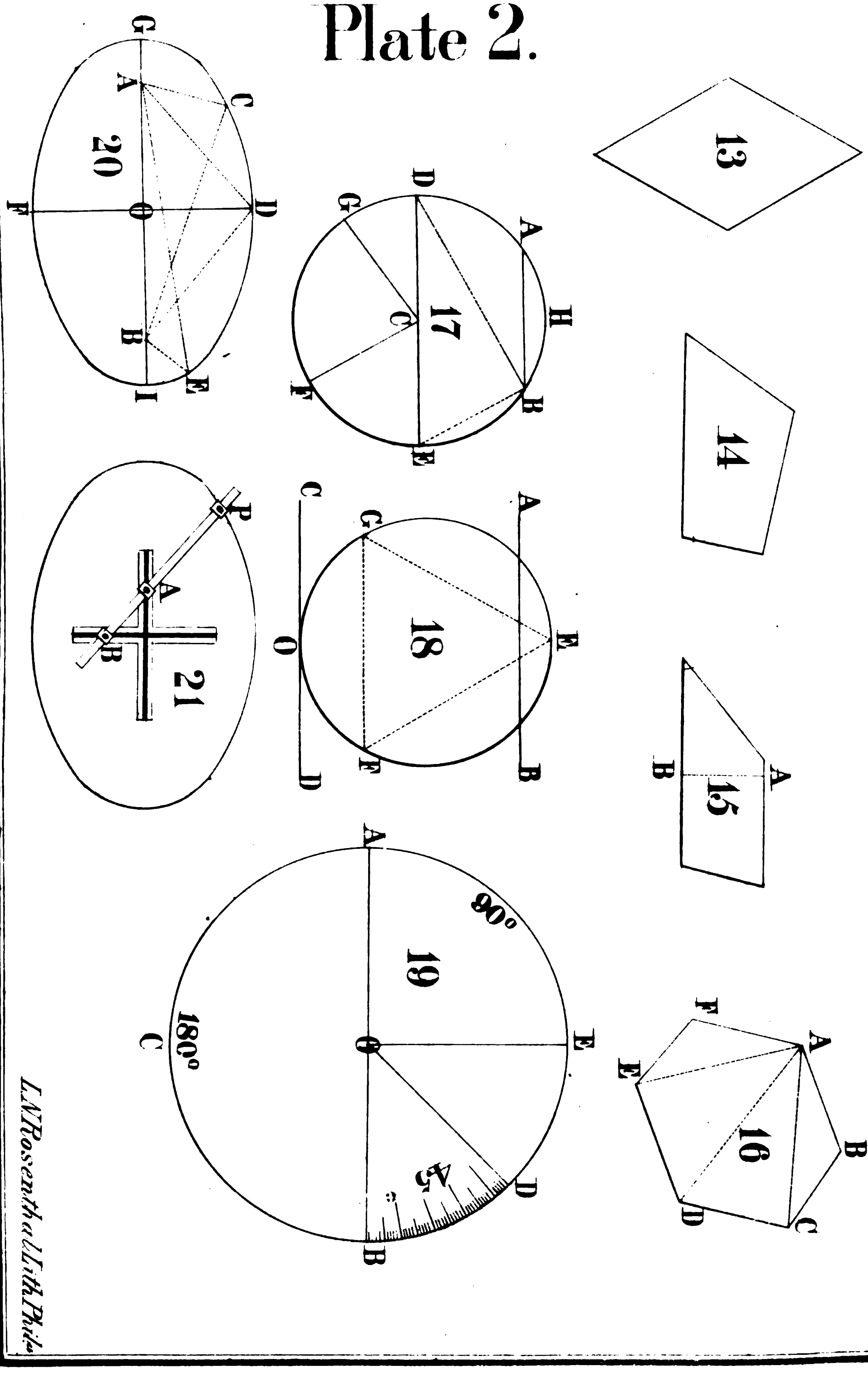
PART I.

Plate 1.



L.N.Rosenthal Lith. Phil.

Plate 2.



GEOMETRY.

PLATES I. AND II.

Definitions.

1. *Mathematics* is the science of quantity.

2. *Quantity* is any thing which can be measured, increased or diminished.

3. *The fundamental Branches* of Mathematics are Arithmetic and Geometry.*

4. *Arithmetic* is the science of numbers.

5. *Geometry* is the science of magnitude.

6. *Magnitude* has three dimensions: length, breadth, and thickness.

7. A *line* has length without thickness. The extremities of a line are called *points*. A point has no magnitude, but position only.

8. A *straight line* is the shortest distance between two points.

9. A *curved line* is one which changes its direction at every point. It is neither straight nor composed of straight lines.

Thus in Fig. 1, AB is a straight line. ACDB is a *broken* line, or one composed of straight lines; and AFB is a curved line.

10. The single term *line* is often used in the sense of *straight line;* and the single term *curve*, of *curved line*.

11. Two lines are *parallel* when they are everywhere equally distant. Fig. 2.

12. A *surface* has length and breadth without height or thickness.

13. A *plane* is a surface, in which, if any two of its points be joined by a straight line, that line will lie wholly on the surface.

14. A *solid*, or *body*, is that which combines the three dimensions of magnitude, having length, breadth, and thickness.

15. When two straight lines meet each other, the inclination or opening

---

* Algebra is a branch of Mathematics, but can scarcely be regarded as equally fundamental with Arithmetic and Geometry.

between them is called an *angle;* and this angle is said to be greater or less as the lines are more or less opened or inclined.

The *vertex* of an angle is the point where its sides meet. Thus, in Fig. 3, A is the vertex, and AB and AC are the *sides.*

Angles occupy surfaces; they are therefore quantities; and like all other quantities are susceptible of addition, subtraction, multiplication, and division. Thus, in Fig. 4, the angle DCE is the sum of the two angles DCB and BCE. And the angle DCB is the difference of the two angles BCE and DCE.

An angle is designated by the letter at the vertex, when there is but one angle there, as the angle A in Fig. 3; or otherwise by the three letters BAC or CAB, the letter at the vertex being always placed in the middle.

16. When a line, AB, stands on another line, CD, Fig. 5, so as not to incline either way, AB is said to be *perpendicular* to CD, and the angle on each side of the perpendicular is called a *right angle.*

17. Every angle less than a right angle is called an *acute angle,* as DCB, in Fig. 4; and every angle greater than a right angle, as ACD, is called an *obtuse angle.*

18. A *polygon* is a portion of a plane terminated on all sides by straight lines.

19. An *equilateral* polygon has all its sides equal, and an *equiangular* polygon has all its angles equal.

20. A *regular* polygon is one which is both equilateral and equiangular.

21. The polygon of three sides is called a *triangle;* that of four sides, a *quadrilateral;* one of five sides, a *pentagon;* one of six, a *hexagon;* one of seven, a *heptagon;* one of eight, an *octagon;* one of nine, a *nonagon;* one of ten, a *decagon;* one of twelve, a *dodecagon;* one of fifteen, a *pentedecagon;* and so on, according to the numerals of the Greek language.

22. An *equilateral triangle* has its three sides equal: Fig. 6. An *isosceles triangle* has two of its sides equal. A *scalene triangle* has all its sides unequal. Figs. 7 and 8.

23. A *right-angled triangle* contains one right angle. The side opposite the right angle is called the *hypotenuse.* Fig. 9: AC, opposite the right angle B, is the hypotenuse.

24. Quadrilaterals are designated according to their figures, as follows:

The *square* has its sides all equal, and its angles all right angles. Fig. 10.

The *rectangle,* or oblong square, Fig. 11, has all its angles right angles and its opposite sides equal and parallel.

The *parallelogram,* Fig. 12, has its opposite sides equal and parallel. Every rectangle is a parallelogram, but every parallelogram is not a rectangle.

The *rhombus,* or *lozenge,* has its sides all equal without having its angles right angles. Fig. 13.

The *trapezium* has none of its sides parallel. Fig. 14.

The *trapezoid* has two of its sides parallel. Fig. 15.

25. The *base* of any polygon is the side on which it is supposed to stand.

26. The *altitude of a triangle* is the perpendicular let fall upon the base from the vertex of the angle opposite the base. Thus, in Fig. 6, AB is the altitude of the triangle ACD.

27. The *altitude of a parallelogram*, or of a trapezoid, is the perpendicular which measures the distance between two parallel sides taken as bases. Thus, in Fig. 12, AB is the altitude of the parallelogram CD.

28. A *diagonal* is a line within a polygon, which joins the vertices of two angles not adjacent to each other. Thus, in Fig. 16, AC, AD, and AE are diagonals.

29. The *area* of a polygon is the measure of its surface.

30. *Equivalent polygons* are those which contain equal areas.

31. *Equal polygons* are those which coincide with each other in all their parts. (Ax. 13.)

32. *Similar polygons* have the angles of the one equal to the angles of the other, each to each, and the sides about the equal angles proportional.

33. *Homologous sides* and *homologous angles* are those which have like positions in similar polygons.

34. The *circumference* of a circle is a curved *line*, every point of which is equally distant from a point within, called the *centre*.

35. The *circle* is the *surface* bounded by the circumference.

36. A *radius* of a circle is a straight line drawn from the centre to the circumference. (The term *radius* is a Latin word, the plural of which is *radii*. Thus, we say one radius and two radii.) In the same circle all radii are equal; all diameters are also equal, and each diameter is double the radius.

37. A *diameter* of a circle is a straight line drawn through the centre, and terminated on both sides by the circumference. In Fig. 17, CD, CG, and CF are radii, and DE is a diameter.

38. An *arc* is a portion of the circumference; as AHB in Fig. 17.

39. A *chord* is the straight line which connects the two extremities of an arc. AB, Fig. 17.

40. A *segment* is a portion of a circle included between an arc and its chord; as segment AHB, Fig. 17.

41. A *sector* is a portion of the circle included between two radii; as sector CGF, Fig. 17.

42. An *inscribed angle* is one formed by the intersection of two chords upon the circumference. ABD and BDE are inscribed angles.

43. An *inscribed polygon* is one which, like EFG in Fig. 18, has all its angles in the circumference. The circle is then said to circumscribe such a figure. In Fig. 17, the triangle CGF is *not* an inscribed triangle, since all the angles do not lie in the circumference; but, in the same Fig., DBE *is* an inscribed triangle.

44. A *secant* is a line which intersects the circumference in two points, and lies partly within and partly without the circle. AB is a secant in Fig. 17.

45. A *tangent* is a straight line touching the circumference in one point only. CD is a tangent—O is the point of contact.

46. The circumference of every circle is measured by being supposed to be divided into 360 equal parts, called *degrees;* each degree contains 60 *minutes*, and each minute 60 *seconds*. Degrees, minutes, and seconds, are designated respectively by these characters, °, ′, ″; thus, 45° 15′ 30″ is read 45 degrees, 15 minutes, and 30 seconds.

47. *Arcs are measured* by the number of degrees which they contain. Thus, in Fig. 19, the arc AE, which contains 90 degrees, is called a *quadrant*, or the quarter of a circumference, because 90° is one quarter of 360°; and the arc ACB, which contains 180°, is a semicircumference.

48. *Every angle is also measured by degrees;* these degrees being reckoned on an arc included between its sides, described from the vertex of the angle as a centre. Thus, in Fig. 19, the right angle AOE contains 90°; and the angle BOD, which is one half a right angle, is called an angle of 45 degrees, which is the number it contains.

49. An *ellipse* is a curved line drawn around two points within, called *foci** (A, B, Fig. 20), in such a manner that if, from any point, C, of the curve, two lines be drawn, one to each focus, the sum of these two lines, AC and BC, shall be equal to the sum of two other lines drawn to the foci from any other point of the curve; as DA and DB, or EA and EB.

50. The *centre of an ellipse* is the middle point of the line joining the two foci. O in Fig. 20.

51. The *diameter of an ellipse* is any straight line passing through the centre, and terminated on both sides by the curve.

52. The *conjugate axis* of an ellipse is its longest diameter, or that one which passes through the two foci; as GI.

53. The *transverse axis* of an ellipse is its shortest diameter, or that one which is perpendicular to the conjugate axis; as DF.

Note. There are several methods employed *to describe an ellipse*, but the one which is at once the most correct and practicable is by means of the instrument called the *Trammel*, represented in Fig. 21. It consists of two grooved rules, mitered together in the middle, so that each arm is perfectly perpendicular to the two adjacent arms, and a rod with a movable pencil at P, and two movable pins, one at A and the other at B.

The distance from B to P equals half the conjugate axis.

The distance from A to P equals half the transverse axis.

The distance from A to B equals half the distance of either focus from the centre.

---

* The term *focus* is a Latin word, of which the plural is foci; thus, we say one *focus* and two *foci*.

Explanation of Mathematical Symbols.

In order to facilitate mathematical calculations, it has long been customary among civilized nations not only to employ figures to represent numbers, but also to employ certain other signs or symbols to represent such operations, in the combinations of numbers and quantities, as are of most frequent occurrence; and, by mutual consent, these symbols have come to be generally known and employed for this purpose.

1. The sign of *addition* is written thus $+$, and is read *plus;* for example, $2+3$ is read two plus three, and signifies two added to three.

2. The sign of *subtraction* is written thus $-$, and is read *minus;** for example, $3-2$ is read three minus two, and signifies three less two.

3. The sign of *multiplication* is written thus $\times$, and is read *multiplied by;* thus, 3×2 is read three multiplied by two.

4. The sign of *division* is written thus $\div$, and is read *divided by;* thus, $12\div3$ signifies 12 divided by 3. Division is more commonly indicated, however, by writing the divisor under the dividend, with a line between them, in the form of a fraction; thus, $\frac{12}{3}$ signifies, as before, 12 divided by three.

5. The sign of *equality* is written thus $=$, and is read *equals,* or *is equal to;* for example, $2+3=5$ is read thus, two plus three equals five.

6. The letters of the alphabet, A, B, C, &c., are used as *representatives* of quantities, the exact dimensions of which may either be known or unknown. We can let A, for example, stand for a given line, a given angle, a given square, or a given solid. Lines are most commonly represented by the two letters placed at their extremities; and angles by their three letters, the letter at the vertex being always placed in the middle.

7. A number placed before a quantity is called a *co-efficient;* thus, 5AB is read five AB, or five times AB, or AB multiplied by five: the sign of multiplication being understood but not written.

8. A number placed at the right, and a little above a quantity, is called an *exponent,* and indicates how many times a quantity is taken as a factor; thus, 5^2 is read *five square;* it is equal to 5×5, and signifies that five is to be multiplied by five, which equals 25; also, 5^3 is read *five cube;* it is equal to $5\times5\times5$, and signifies that five is to be multiplied by five, and that product by five, which equals 125.

9. This sign $\sqrt{}$ is used to show that a *root is to be extracted.* A small figure is placed in the bosom of the sign, called the *index of the root;* thus, $\sqrt[2]{}$ is the sign of the square root, and $\sqrt[3]{}$ is the sign of the cube root, &c. When no index is written, that of the square root is understood; thus, $\sqrt{4}$ represents the square root of 4.

---

* *Plus* and *minus* are Latin words, the former meaning *more,* and the latter *less;* these words, like the signs, are in common use in all civilized countries.

Definitions of Mathematical Terms.

1. An *axiom* is a self-evident truth.

2. A *theorem* is a statement which requires a demonstration, by reasoning from such truths as are either self-evident or previously demonstrated.

3. A *problem* is a query to be answered, or an operation to be performed.

4. The term *proposition* may be applied either to axioms, theorems, or problems.

5. A *corollary* is a necessary inference drawn from one or more preceding propositions.

6. A *scholium* is an explanatory remark on one or more preceding propositions.

7. An *hypothesis* is a supposition employed either in the statement or the demonstration of a proposition.

8. The term *ratio* is employed to denote the quotient arising from dividing one number or quantity by another: for example, the ratio of 3 to 12 is 12 divided by 3; or; $\frac{12}{3}$ or 4. The ratio can always be expressed in the form of a fraction, whether the divisor is contained in the dividend an exact number of times or not; thus the ratio of 2 to 1 is $\frac{1}{2}$, the ratio of 5 to 6 is $\frac{6}{5}$; and so also the ratio of A to B is $\frac{B}{A}$, and the ratio of x to y is $\frac{y}{x}$.

9. *Proportion* is an equality of ratios or an *equality of quotients* Thus when the quotient arising from dividing one quantity by another is equal to the quotient arising from dividing a third quantity by a fourth, then the four quantities are said to be in proportion to each other. For example, the quotient of 4 divided by 2 equals the quotient of 10 divided by 5; or $\frac{4}{2}=\frac{10}{5}$; then these four numbers 2, 5, 4 and 10 are in proportion.

Proportion is usually indicated by writing the four quantities thus: 2 : 4 : : 5 : 10, and is read 2 is to 4 as 5 is to 10; that is, 2 is just such a part of 4 as 5 is of 10; for 2 is half of 4, and 5 is half of 10. So also if $\frac{B}{A}=\frac{D}{C}$, then we have the proportion A : B : : C : D.

10. The four quantities of a proportion are called its *terms*. The first and last are called the *extremes*, and the two middle ones the *means* of a proportion. The first and third terms are called the *antecedents*, and the second and fourth terms are called the *consequents* of a proportion.

Axioms.

1. A whole quantity is greater than any of its parts.
2. A whole quantity is equal to the sum of all its parts.
3 When equals are added to equals, their sums are equal.
4. When equals are added to unequals, their sums are unequal.
5. When equals are subtracted from equals, their remainders are equal.

6. When equals are subtracted from unequals, their remainders are unequal.

7. When equals are multiplied by equals, their products are equal.

8. When equals are divided by equals, their quotients are equal.

9. When two quantities have, each, the same proportion to a third quantity they are equal to each other.

10. All right angles are equal.

11. When a straight line is perpendicular to one of two parallels it is perpendicular to the other also.

12. Only one straight line can be drawn from one point to another.

13. Two magnitudes are equal, when, on being applied to each other, they coincide throughout their whole extent.

Proposition I. Theorem.

If four quantities are in proportion, the product of the two means will equal the product of the two extremes.

	Numerically.	Generally.
Let	$2:4::5:10$;	$A:B::C:D$;
then will	$4\times5=2\times10$.	$B\times C=A\times D$.

For, since the given quantities are in proportion, their ratios are equal. (Def. of Terms, 9.)

And we have, $\frac{4}{2}=\frac{10}{5}$. $\frac{B}{A}=\frac{D}{C}$.

Multiply both quantities by the divisor of the first ratio, and the quantities will still be equal (Ax. 7); we shall then have,

$$2\times\frac{4}{2}=2\times\frac{10}{5}; \qquad A\times\frac{B}{A}=A\times\frac{D}{C};$$

or, $$4=2\times\frac{10}{5}. \qquad B=A\times\frac{D}{C}.$$

Again, multiply both quantities by the divisor of the second ratio, and the desired result is obtained; namely,

$$4\times5=2\times10. \qquad B\times C=A\times D.$$

Proposition II. Theorem.

When the product of two quantities equals the product of two other quantities, then two of them are the means, and the other two the extremes of a proportion.

	Numerically.	Generally.
Let	$4\times5=2\times10$;	$B\times C=A\times D$;
then will	$2:4::5:10$;	$A:B::C:D$;

for, divide both the given quantities by one of the factors of the first quantity, which will not alter their equality (Ax. 8), and we have,

$$4=\frac{2\times10}{5}; \qquad B=\frac{A\times D}{C};$$

again, divide both quantities by one of the factors of the second quantity, and we have,

$$\frac{4}{2}=\frac{10}{5}. \qquad \frac{B}{A}=\frac{D}{C}.$$

Here we have an equality of ratios, and, by Def. 9, the four quantities are in proportion; hence,

2 : 4 : : 5 : 10. A : B : : C : D.

Scholium. Quantities are said to be in proportion by *inversion*, when the proportion is read backward;

thus, 4 : 2 : : 10 : 5; B : A : : D : C;
or, 10 : 5 : : 4 : 2. D : C : : B : A.

Quantities are said to be in proportion by *alternation*, when they are read alternately;

thus, 2 : 5 : : 4 : 10; A : C : : B : D;
or, 4 : 10 : : 2 : 5. B : D : : A : C.

Quantities are said to be in proportion by *composition*, when the sum of the antecedents or consequents is compared with either antecedent or consequent.

thus, 2+5 : 5 : : 4+10 : 10; A+B : B : : C+D : D;
or, 2+5 : 2 : : 4+10 : 4. A+B : A : : C+D : C.

Proposition III. Theorem.

When four quantities are in proportion, they will also be in proportion by alternation.

	Numerically.	Generally.
Let	2 : 4 : : 5 : 10,	A : B : : C : D,
then will	2 : 5 : : 4 : 10;	A : C : : B : D;
for, by Prop. I.,	2×10=5×4;	A×D=C×B;
and, by Prop. II.,	2 : 5 : : 4 : 10.	A : C : : B : D.

Proposition IV. Theorem.

When four quantities are in proportion, they will also be in proportion by inversion.

	Numerically.	Generally.
Let	2 : 4 : : 5 : 10,	A : B : : C : D,
then will	10 : 5 : : 4 : 2;	D : C : : B : A;
for, by Prop. I.,	10×2=5×4;	D×A=C×B;
and, by Prop. II.,	10 : 5 : : 4 : 2.	D : C : : B : A.

Proposition V. Theorem.

When there are four proportional quantities, and four other proportional quantities, having the antecedents the same in both, the consequents will be proportional.

	Numerically.	Generally.
Let	2 : 4 : : 5 : 10, and	A : B : : C : D,
and	2 : 6 : : 5 : 15;	A : X : : C : Y;
then will	4 : 10 : : 6 : 15,	B : D : : X : Y.

Take the first proportion by alternation:

2 : 5 : : 4 : 10; A : C : : B : D;

hence, from equality of ratios (Def.),

$$\frac{5}{2}=\frac{10}{4}. \qquad \frac{C}{A}=\frac{D}{B}.$$

Take the second proportion by alternation:

2 : 5 : : 6 : 15, A : C : : X : Y;

and, by equality of ratios, we have,

$$\frac{5}{2}=\frac{15}{6}; \qquad \frac{C}{A}=\frac{Y}{X};$$

hence,

$$\frac{10}{4}=\frac{15}{6}; \qquad \frac{D}{B}=\frac{Y}{X};$$

and from this equality of ratios there results (by Def.),

4 : 10 : : 6 : 15. B : D : : X : Y

Corollary. When there are two sets of proportional quantities, having an antecedent and a consequent of the first equal to an antecedent and a consequent of the second, the remaining quantities are proportional.

Proposition VI. Theorem.

When four quantities are in proportion, they are also in proportion by composition.

	Numerically.	Generally.
Let	2 : 4 : : 5 : 10,	A : B : : C : D,
then will	2+4 : 2 : : 5+10 : 5.	A+B : A : : C+D : C.

The first proportion gives (Prop. I.),

$$2\times10=4\times5. \qquad A\times D=B\times C.$$

Add to each of these equal quantities the product of the two antecedents, and we have,

$$2\times10+2\times5=4\times5+2\times5; \qquad A\times D+A\times C=B\times C+A\times C;$$

or, the same simplified,

$$2\times10+5=5\times4+2; \qquad A\times D+C=C\times B+A;$$

hence, by Prop. II.,

2+4 : 2 : : 5+10 : 5. A+B : A : : C+D : C.

Proposition VII. Theorem.

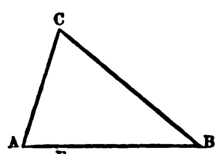
If any two quantities be each multiplied by some other quantity, their products will have the same ratio as the quantities themselves.

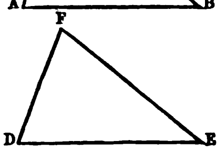
	Numerically.	Generally.
Let	2 and 4	A and B
	be any two numbers;	be any two quantities;
multiply each by	5;	S;
then	$2\times5:4\times5::2:4$;	$A\times S:B\times S::A:B$;
for,	$(2\times5)\times4=(4\times5)\times2$,	$(A\times S)\times B=(B\times S)\times A$,
since the quantities are identical;		
hence, by Prop. II.,	$2\times5:4\times5::2:4$.	$A\times S:B\times S::A:B$.

Proposition VIII. Theorem.

When two triangles have two sides and the included angle of the one equal to two sides and the included angle of the other, each to each, the two triangles are equal.

In the triangles ABC and DEF, let AB=DE, AC=DF, and the angle A= angle D; the triangles themselves will then be equal. For, apply the side AB to the equal side DE, so that the point A will fall upon D, and the point B upon E; then since angle A= angle D, the side AC will also fall upon its equal side DF, and the point C upon the point F; therefore the third side, CB, will fall upon the third side FE, and the two triangles will coincide throughout their whole extent, and be therefore equal. (Ax. 13.)





Proposition IX. Theorem.

When two triangles have two angles and the included side of the one, equal to two angles and the included side of the other, each to each, the two triangles are equal.

In the triangles ABC and DEF, let the angle A= angle D, C = F, and the included side AC = DF; then are the triangles also equal.

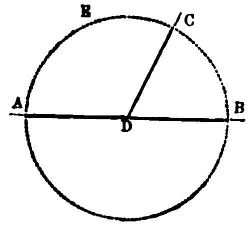
For, apply the side AC to its equal side DF, placing the point A upon the point D, and the point C upon F; then, since the angle A= angle D, the side AB will take the direction of DE, and the point B will fall somewhere upon the line DE; also, since the angle C=angle F, the side CB will take the direction of FE, and the point B will fall somewhere upon the line FE; and since the point B must fall upon both the lines DE and FE, it must fall upon E, the only point of coincidence; hence the two triangles coincide throughout their whole extent, and are therefore equal. (Ax. 13.)

Corollary. Every triangle has six parts, namely: three sides and three angles; and whenever two triangles are equal to each other, each of the six parts of the one are always equal to the corresponding six parts of the other, side to side, and angle to angle. It is to be observed, also, that the equal angles are always opposite to the equal sides, and the equal sides opposite the equal angles.

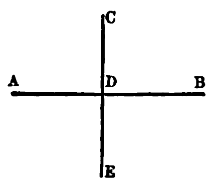
Proposition X. Theorem.

When a straight line meets another straight line, the sum of the two adjacent angles are equal to two right angles.

Let CD meet AB at D, then is the sum of the two angles ADC and CDB equal to two right angles.



From the point D as a centre, describe the circumference of a circle, then will the line AB coincide with its diameter, since it passes through the centre. (Def.) Angles are measured by the arcs intercepted by their sides (Def.); and since the sides of the angle ADC intercept a portion of the semicircumference, AEB, and the sides of the angle CDB intercept the remaining portion, then, both together intercept a semicircumference, or 180 degrees; but two right angles intercept 180 degrees (Def.); therefore the sum of the two angles ADC and CDB=two right angles.

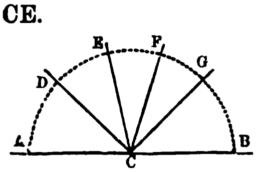


Cor. 1. When one of the given angles is a right angle, the other is a right angle also.

Cor. 2. When one line is perpendicular to another, then is the second line also perpendicular to the first.

Let CE be perpendicular to AB, then is AB perpendicular to CE.

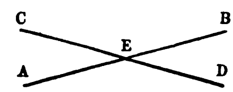
For, since CE is perpendicular to AB, both the angles ADC and CDB are right angles. Again, since AD is a straight line meeting another straight line CE at D, then the sum of ADC+ADE=two right angles; but ADC is a right angle; therefore must ADE be a right angle also. Hence AD, or AB, is perpendicular to CE.



Cor. 3. When any number of angles have their vertices at the same point, and lie on the same side of a straight line, their sum is equal to two right angles, for they all together intercept an arc of 180°

Proposition XI. Theorem.

The opposite or vertical angles, formed by the intersection of two straight lines, are equal.



Let AB and CD be two straight lines, intersecting each other at E, then will AEC=BED.

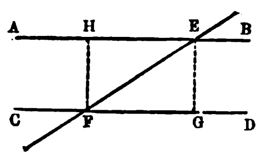
For the sum of AEC+CEB = two right angles (Prop. X.); and, for a similar reason, the sum of CEB+BED= two right angles.

Take away from each sum the common angle CEB, and there remains AEC=BED.

In a similar manner it may be proved that CEB=AED.

Proposition XII. Theorem.

If two parallel straight lines meet a third line, the sum of the two interior angles, on the same side of the line met, will be equal to two right angles.

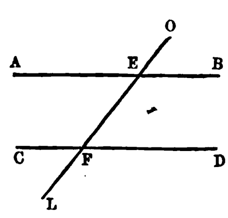


Let the two parallel lines AB and CD meet the line EF; then will BEF+EFG=two right angles.

Through E draw EG, perpendicular to CD, and through F draw FH, parallel with EG. Then, since parallels are everywhere equally distant, (Def. 10), we have EH=GF, and also EG=HF; and since AB is perpendicular to EG, it is also perpendicular to HF, (Ax. 11,) and the angles H and G are both right angles; therefore, the two triangles, EHF and FGE, are equal, (Prop. VIII.) And, since the angles opposite the equal sides are equal, (Prop. IX. *Cor.*), angle FEH= angle EFG.

But the sum of the angles BEF+FEH is equal to two right angles. (Prop. X.) Substitute for FEH its equal EFG, and we have BEF+EFG= two right angles.

Scholium. Where two parallel straight lines meet a third line, the angles thus formed take particular names, as follows:



Interior angles on the same side are those which lie within the parallels, and on the same side of the secant line. Thus BEF and EFD are interior angles on the same side; and so also are the angles AEF and EFC.

Alternate angles lie within the parallels, and on opposite sides of the secant line, but not adjacent to each other. AEF and EFD are alternate angles; also, BEF and EFC.

Alternate exterior angles lie without the parallels, and on opposite sides of the secant line. OEB and CFL are alternate exterior angles, and so also are AEO and LFD.

Opposite exterior and interior angles lie on the same side of the secant line, the one without and the other within the parallels, but not adjacent; thus OEB and EFD are opposite exterior and interior angles; so also are BEF and DFL.

Cor. 1. If a straight line meet two parallel lines, the alternate angles will be equal. For the sum BEF+EFD= two right angles; also, (by Prop. X), BEF+AEF= two right angles; take away from each the angle BEF, and there remains EFD=AEF.

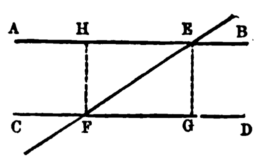
Cor. 2. If a straight line meet two parallel lines, the opposite exterior and interior angles will be equal. For the sum BEF+EFD= two right angles; also, (by Prop. I.), BEF+OEB= two right angles; taking from each the angle BEF, and there remains EFD=OEB.

Cor. 3. Hence of the eight angles formed by a line cutting two parallel lines obliquely, the four acute angles are equal to each other, and so also are the four obtuse angles.

Proposition XIII. Theorem.

If two straight lines meet a third line, making the sum of the interior angles on the same side equal to two right angles, the two lines will be parallel.

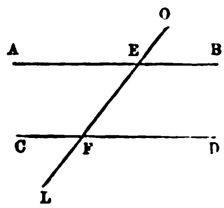
Let the two lines AB, CD, meet the third line EF, so as to make the angles BEF+EFG equal to two right angles; then will AB and CD be parallel, or everywhere equally distant.



Through E draw EG perpendicular to CD, and through F draw FH parallel with EG, then the two angles FEB+FEH= two right angles, (by Prop. X.); also, the angles FEB+EFG= two right angles, by hypothesis; take away from each the angle FEB, and there remains the angle FEH= angle EFG. Again, since HF and EG are parallel by construction, the alternate angles EFH and GEF are equal, (by last Prop., *Cor.* 1); hence, the two triangles EFH and EFG are equal, (Prop. IX.), having two angles and the included side of the one equal to two angles and the included side of the other; and HF, opposite the angle FEH, is equal to EG, opposite to its equal angle EFG. (Prop. IX., *Cor.*) But HF and EG measure the distance of the line CD from the line AB, at the points H and E respectively. The same demonstration may be applied to any other two points of the line AB; hence the lines AB and CD are everywhere equally distant, and therefore parallel.

Cor. 1. If two straight lines are perpendicular to a third line, they are parallel to each other; for the two interior angles on the same side are, in that case, both right angles.

Cor. 2. If a straight line meet two other straight lines, so as to make the alternate angles equal to each other, the two lines will be parallel.

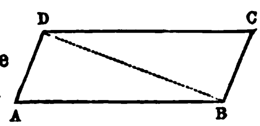


Let OL meet AB and CD, so as to make AEL= EFD; add to each the angle BEF; we shall then have AEL+BEF=EFD+BEF; but AEL+BEF= two right angles (Prop. VIII.); hence, EFD+BEF= two right angles: therefore, AB and CD are parallel.

Cor. 3. If a straight line, OL, meet two other straight lines, AB and CD, so as to make the exterior angle, OEB, equal to the interior and opposite angle, EFD, the two lines will be parallel: for, to each add the angle BEF; we shall then have OEB+BEF=EFD+BEF: but OEB+BEF are equal to two right angles; therefore, EFD+BEF is equal to two right angles; and AB and CD are parallel.

Proposition XIV. Theorem.

In every parallelogram, the opposite angles are equal.



Let ABCD be a parallelogram; then will A=C, and B=D.

Draw the diagonal BD; then will the triangle ADB=the triangle CBD: for the angles ABD and BDC are alternate angles and equal (Prop. XII., *Cor.* 1), and the adjacent sides, AB=DC, and BD is common; hence, the triangles are equal (Prop. VIII.); therefore the angles A and C, opposite the common side BD, are equal. (Prop. IX., *Cor.*) In a similar manner it may be proved that the angles B and D are equal.

Cor. 1. The diagonal of a parallelogram divides it into two equal triangles.

Cor. 2. When two triangles have the three sides of the one equal to the three sides of the other, the angles opposite the equal sides are also equal, and the triangles themselves are equal.

Cor. 3. Two parallels, included between two other parallels, are equal.

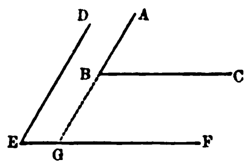
Cor. 4. If the opposite sides of a quadrilateral are equal, each to each, the equal sides will also be parallel, and the figure will be a parallelogram; for, having drawn the diagonal BD, the triangles ABD and BDC are equal; and the angle ADB, opposite AB, is equal to the angle DBC, opposite DC. But the two angles, ADB and DBC are alternate angles; therefore, AD is parallel with BC. (Prop. XIII., *Cor.* 2.) ABD and BDC are also equal alternate angles; therefore, AB is parallel with DC, and the figure is a parallelogram.

Proposition XV. Theorem.

When two angles have their sides parallel, and lying in the same direction, they are equal.

Let ABC and DEF be two angles, having the side AB, in one, parallel to DE, in the other, and BC parallel to EF, and lying in the same direction; then will the two given angles be equal.

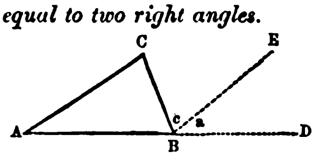
For, produce the side AB till it intersects EF at G, then ABC=BGF, for they are opposite interior and exterior angles (Prop., XII. Cor. 2); also, DEF and BGF are equal for a similar reason: therefore, ABC and DEF, being each equal to BGF, are equal to each other. (Ax. 9.)



Proposition XVI. Theorem.

The sum of the three angles of any triangle is equal to two right angles.

Let ABC be any triangle. Produce the base AB to any convenient distance, as D, and draw BE parallel with AC; then will the three angles having their vertices at B be equal to the three angles of the given triangle, for the angle B, or ABC, is common; the angle c=C, for they are alternate angles; and the angle a=A, for they are opposite exterior and interior angles. But the sum of the three angles at B are equal to two right angles (Prop. X., *Cor.* 3); hence the sum of the three angles of the given triangle, A+B+C, is equal to two right angles.



Cor. 1. The exterior angle, CBD, of any triangle formed by producing the base, is equal to the sum of the two opposite interior angles of the triangle.

Cor. 2. When the sum of two angles of any triangle is known, the third angle is found by subtracting that sum from two right angles or 180°.

Cor. 3. When two angles of one triangle are respectively equal to two angles of another triangle, their third angles are also equal, and the triangles are equiangular.

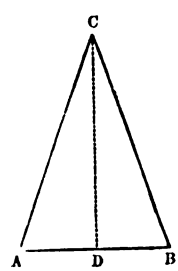
Cor. 4. It is impossible for any triangle to have more than one right angle, for if it could have two right angles, the third angle would be nothing. Still less can any triangle have more than one obtuse angle.

Cor. 5. In every right-angled triangle, the sum of the two acute angles is equal to one right angle.

Proposition XVII. Theorem.

In every isosceles triangle, the angles opposite the equal sides are equal.

In the triangle ABC let AC=BC; then will angle A= angle B. Draw the line CD so as to bisect the angle C, that is, so as to divide it into two equal parts; then are the two triangles ACD and BCD equal by Prop. VIII., having the two angles at C and the two adjacent sides equal. Hence, angle A= B. (Prop. IX., *Cor.*)

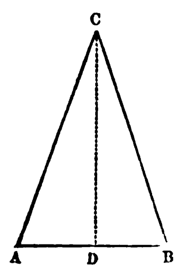


Cor. 1. Every equilateral triangle is also equiangular.

Cor. 2. The equality of the triangles ADC, and BDC, proves that the line which bisects the vertical angle of an isosceles triangle is perpendicular to the base at its middle point, for the two angles at D are each right angles. (Prop. X.)

Proposition XVIII. Theorem.

When two angles of a triangle are equal, the sides opposite them are also equal, and the triangle is isosceles.

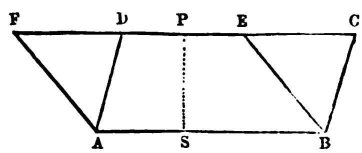


Let the angle A=B, then will the sides AC and BC be equal also.

Draw CD so as to bisect the angle C, then will the two triangles be equiangular (Prop. XVI., *Cor.* 3); and the side CD being common, the two triangles are equal (Prop. IX.); and the side AC, opposite the angle B, is equal to the side BC, opposite the equal angle A.

Proposition XIX. Theorem.

Parallelograms having equal bases and equal altitudes, contain equal areas, or are equivalent.



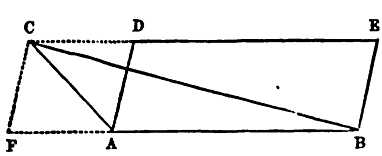
Let the two parallelograms, ABCD and ABEF, have the same base, AB, and the same altitude PS; then they will be equivalent.

In the triangles BCE and ADF, the sides BC and AD are equal, being opposite sides of the same parallelogram; and AF=BE for a similar reason; the included angle A is equal to the included angle B, since their sides are parallel and lie in the same direction (Prop. XV.); hence the two triangles are equal. (Prop. VIII.)

Now, from the whole quadrilateral figure ABCF, take away the triangle BCE, and there remains the parallelogram ABEF; from the same quadrilateral take away the equal triangle ADF, and there remains the parallelogram ABCD, which is therefore equivalent to ABEF.

Proposition XX. Theorem.

Every triangle contains half the area of a parallelogram of equal base and equal altitude.



Let ABC be any triangle, and ADBE be a parallelogram having the same base and altitude; then will the triangle contain half the area of the parallelogram.

Connect C and D, and complete the parallelogram ADCF. The triangle BCF is half the parallelogram FE, (Prop. XIV., *Cor.* 1); and the triangle ACF is half the parallelogram FD. If from the parallelogram FE we take the parallelogram FD, then the parallelogram AE will remain; and if from the triangle BCF, half the parallelogram FE, we take the triangle ACF, half the parallelogram FD, there will remain the triangle ABC, equal to one half the parallelogram AE.

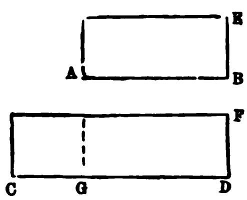
Cor. 1. The demonstrations in this and the preceding propositions, are equally applicable to rectangles, since every rectangle is also a parallelogram; therefore, every rectangle is equivalent to a parallelogram of the same base and altitude.

Also, every triangle is equivalent to half a rectangle of the same base and altitude.

Cor. 2. Triangles are equivalent to each other, when they have equal bases and equal altitudes; each being half an equivalent parallelogram.

Proposition XXI. Theorem.

Two rectangles having the same altitude are proportioned to each other as their bases.



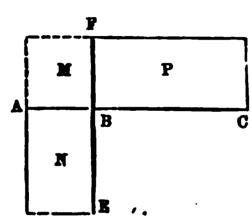
Let the two rectangles AE and CF have equal altitudes, then will their surfaces be proportional to the length of their bases.

For, since their altitudes are the same, and their angles are all right angles, they may be so applied to each other that the whole surface of the shorter rectangle shall perfectly coincide with an equal surface of the longer one; and this coincidence will be perfect as far as there is a coincidence of their bases, and no further; hence,

AE : CF : : AB : CD.

Proposition XXII. Theorem.

Rectangles are proportioned to each other as the products of their bases multiplied by their altitudes.



Let P be any rectangle, having BC for its base, and BF for its altitude; and let N be any other rectangle, having AB for its base, and BE for its altitude; then,

P : N : : BC×BF : AB×BE.

For, place the two rectangles P and N, so that the base AB will be the prolongation of the base BC, and complete the rectangle M; then, the two rectangles P and M, having the same altitude BF, will be proportioned to each other as their bases, CB and AB. (Prop. XXI.) And, for the same reason, the two rectangles N and M, having the same altitude AB, will be to each other as their bases BE and BF; hence, we have the two proportions:

P : M : : BC : AB; and

M : N : : BF : BE.

Combining these two proportions, by multiplying the corresponding terms together, we have

$$P \times M : N \times M :: BC \times BF : AB \times BE.$$

But the quantity M, since it is common to both antecedent and consequent, can be omitted; and the remaining quantities will still be proportional. (Prop. VII.) Hence,

$$P : N :: BC \times BF : AB \times BE.$$

Cor. 1. Hence the area or surface of any rectangle is measured by the product of its base multiplied by its altitude; and if its base be BC, and its altitude BF, its area or measure is $BC \times BF$.

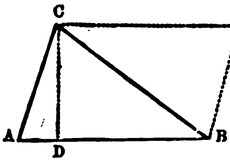
Cor. 2. Since the sides of every square are all equal, and since all squares are rectangles, the area of any square is expressed by the product of a side multiplied by itself: so if its side is AB, its area is AB^2.

Cor. 3. Since every rectangle is a parallelogram, and since all parallelograms of the same base and altitude are equivalent, (Prop. XIX.), therefore the area of any parallelogram is the product of its base by its altitude.

Cor. 4. Parallelograms of the same base are proportioned to each other as their altitudes, and those of the same altitude as their bases; and, in all cases, they are proportioned to each other, as the products of their bases by their altitudes.

Proposition XXIII. Theorem.

The area of any triangle is measured by the product of its base multiplied by half its altitude.



Let ABC be any triangle, of which AB is the base, and CD the altitude. This triangle is half the parallelogram AE, (Prop. XIV., *Cor.*); but the parallelogram is measured by its base, AB, multiplied by its altitude, DC; therefore the triangle is measured by the base multiplied by half the altitude.

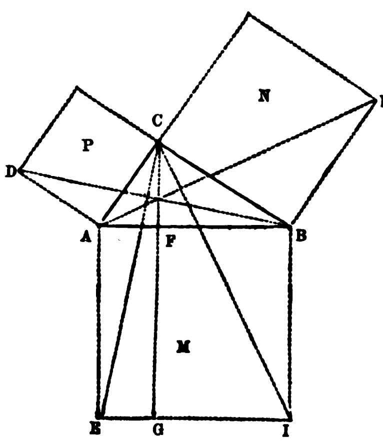
Cor. Triangles of the same altitude are proportioned to each other as their bases, and those of the same bases are to each other as their altitudes; and, in any case, they are proportioned to each other as the products of their bases by their altitudes.

Proposition XXIV. Theorem.

In every right-angled triangle, the square of the hypotenuse is equal to the sum of the squares of the other two sides.

Let ABC be a triangle, having the angle C a right angle; then will $AB^2 = AC^2 + CB^2$.

Complete the squares of the three sides of the given triangle, and let M represent the square described on AB, or AB^2; let N represent the square described on CB, or CB^2; and let P represent the square described on AC, or AC^2. Draw the diagonals DB, CE, CI, and AH, and from C let fall CG perpendicular to AB.



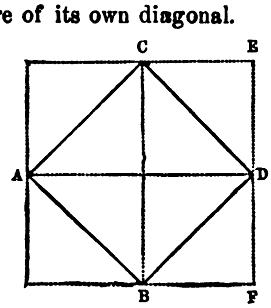
In the two triangles DAB and CAE, AC=AD, each being a side of the square P; and AB=AE, each being a side of the square M; the included angle DAB is made up of the right angle DAC and the angle CAB; the included angle CAE, in the other triangle, is made up of the same angle CAB, and the right angle BAE; hence, the angles CAE and DAB are equal, and the triangles themselves are equal (Prop. VIII.), each having two sides and an included angle equal.

The triangle DAB is equivalent to half the square P, for it has the same base AD, and the same altitude AC; also, the triangle CAE is equivalent to half the rectangle FAGE, for it has the same base AE, and the same altitude AF; hence, the rectangle FAGE is equivalent to the square P. Again, the two triangles ABH and CBI are equal, having also two sides and the included angle of the one equal to two sides and the included angle of the other; and AHB is half of the square N, and CBI is half of the rectangle FBIG: therefore, the square N is equivalent to the rectangle FBIG.

But the two rectangles FAGE and FBIG make up the square M; hence, M=P+N, or $AB^2=AC^2+CB^2$.

Cor. 1. In every right-angled triangle, the square of one side is equivalent to the square of the hypotenuse less the square of the other side. For example, in the triangle above, $AC^2=AB^2-BC^2$; also, $BC^2=AB^2-AC^2$.

Cor. 2. Every square is equal to half the square of its own diagonal.



Let AD and BC be the diagonals of the square ABCD; through the points A and D draw straight lines equal and parallel with BC; and through the points B and C draw lines equal and parallel with AD; the figure thus formed will be the square of the diagonal CB, or of its equal EF: but this figure contains eight equal triangles, of which the given square contains but four; hence,

$$CB^2 : AB^2 :: 2 : 1.$$

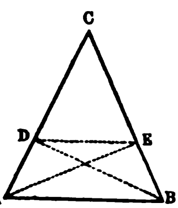
and, on extracting the square root of each of the terms of this proportion, we have,

$$CB : AB :: \sqrt{2} : 1;$$

or, the diagonal of a square is proportioned to its side, as the square root of two is to one.

Proposition XXV. Theorem.

In any triangle, a line drawn parallel to the base divides the other two sides proportionally.



Let ABC be any triangle, and let DE be parallel with the base AB. Draw AE and BD. The two triangles ADE and CDE, having the same altitude DE, are in proportion to each other as their bases AD and CD (Prop. XXIII., *Cor.*); also, the two triangles BED and CED, having the same altitude ED, are to each other as their bases BE and CE; hence the two proportions:

$$ADE : CDE :: AD : CD;$$
$$BED : CDE :: BE : CE.$$

The two triangles ADE and BED are equivalent, having the same base, AB, and the same altitude, since the line DE is parallel with BC; hence, the two proportions above having an antecedent and a consequent of one equivalent to an antecedent and a consequent of the other, the remaining terms are proportional (Prop. V., *Cor.*); hence,

$$AD : CD :: BE : EC;$$

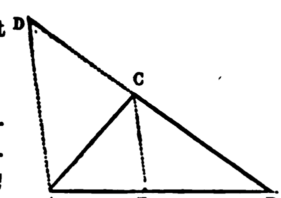
and, by composition, $AD+CD : CD :: BE+EC : EC;$

or, $AC : CD :: BC : CE;$

and, by alternation, $CD : CE :: AD : BE.$

Proposition XXVI. Theorem.

In any triangle, the line which bisects the vertical angle, when produced to the base, divides the base into two parts, which are proportional to the adjacent sides.



Let ABC be any triangle, and let CE bisect the vertical angle C; then will

$$BE : BC :: EA : AC.$$

The angles ACE and BCE are equal by hypothesis; draw AD parallel with CE, and produce it until it intersects the prolongation of BC at D; then will angle D= angle BCE; for they are opposite exterior and interior angles. Also, the angle DAC=ACE, since they are alternate angles; hence, those two angles D and A, in the triangle CAD, equal each other, and the triangle is isosceles. (Prop. XVIII.)

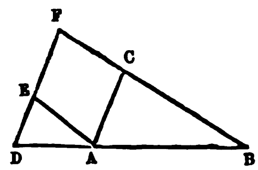
In the triangle BAD, since EC is parallel with the base AD, it divides the other two sides proportionally (Prop. XXV.), and we have

BE : BC : : EA : CD ;

but we have proved the triangle CAD to be isosceles; hence, AC=CD. Substitute, therefore, in the last proportion, AC for its equal CD, and we have, BE : BC : : EA : AC.

Proposition XXVII. Theorem.

All equiangular triangles are similar, and have their homologous sides proportional.



Let ABC and DEA be two triangles, having the angles, C=E, D=CAB, and B=DAE, then will their homologous sides be proportional, and we shall have

BA : AD : : BC : AE ; and

DA : AB : : DE : AC.

Place the two triangles so that the side AD shall be the prolongation of the homologous side AB, and produce DE until it intersects the prolongation of BC at F.

Then since the angles EDA and CAB are equal, the lines FD and CA are parallel, for the angles are opposite exterior and interior angles (Prop. XIII. *Cor.*); and since the angles DAE and ABC are equal, the lines BF and AE are parallel, for those angles are opposite exterior and interior angles also; the figure ACEF is therefore a parallelogram, and has its opposite sides equal.

In the triangle BDF, AC being parallel with the base DF, the other two sides are divided proportionally (Prop. XXV.);

and we have

BA : AD : : BC : CF. But AE=CF ; hence,

BA : AD : : BC : AE.

In the same manner it may be proved that,

DA : AB : : DE : AC.

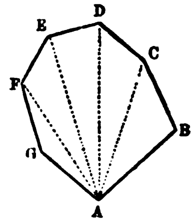
Scholium. It is to be observed, that the homologous or proportional sides are opposite to the equal angles.

Cor. Two triangles are similar, and have their homologous sides proportional, when two angles of the one are respectively equal to two angles of the other; for in that case the third angles must also be equal (Prop. XVI. *Cor.*), and the triangles be equiangular.

Proposition XXVIII. Theorem.

In every convex polygon, the sum of the interior angles is equal to two right angles, multiplied by the number of sides of the given polygon, less two.

Let ABCDEF be any convex polygon, and let diagonals be drawn from



any one angle, A, to each of the other angles not adjacent to A; these diagonals will divide the polygon into as many triangles, less two, as the polygon has sides, whatever the number of the sides may be.

The sum of the angles of every triangle being equal to two right angles (Prop. XVI.), therefore the sum of all the angles of the given polygon will be equal to twice as many right angles as there are triangles thus formed within it; so that, in order to ascertain the entire measure of the angles in any polygon, we have only to multiply two right angles by the number of its sides less two.

Cor. Since $2\times2=4$, the simplest mode of estimating the measure of the angles of any polygon, is to multiply the entire number of its sides by two right angles, and subtract four from the product.

A *quadrilateral* contains four right angles, since $4\times2=8$, and $8-4=4$.

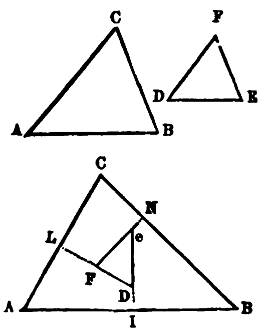
A *pentagon* contains six right angles, since $5\times2=10$, and $10-4=6$.

A *hexagon* contains eight right angles. since $6\times2=12$, and $12-4=8$.

A *heptagon* contains ten right angles, since $7\times2=14$, and $14-4=10$.

Proposition XXIX. Theorem.

When two triangles have the three sides of the one, respectively parallel or perpendicular to the three sides of the other, the two triangles are similar.



In the two triangles ABC and DEF,

First. Let the sides be respectively parallel; namely, let AB be parallel with DE, BC with EF, and AC with DF; then the angles are respectively equal; namely, A=D, B=E, and C=F, since their sides are respectively parallel and lying in the same direction. (Prop. XV.) Hence, their homologous sides are proportional, and they are similar. (Prop. XXVII.)

Secondly. Let the sides of the one be respectively perpendicular to the sides of the other; namely, ED perpendicular to AB, FE to BC, and DF to AC; then they will still be equiangular and similar.

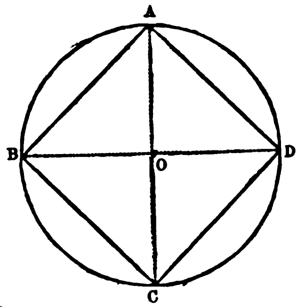
In the quadrilateral LADI, the sum of the four interior angles is equal to four right angles (Prop. XXVIII., *Cor.*); but the angles L and I are each right angles, since DL is given perpendicular to AC, and ED to AB; therefore, the sum of the two angles A and LDI is equal to two right angles; but the sum of the angles LDI and LDE equals two right angles (Prop. X.); take away the common angle LDI from each sum, and there remains, A= LDE.

For similar reasons, B=DEF, and C=EFD; hence, the two triangles, being equiangular, have their homologous sides proportional, and are similar. (Prop. XXVII.)

Scholium. The homologous sides are those which are perpendicular or parallel with each other, since they are also those which lie opposite the equal angles.

Proposition XXX. Problem.

To inscribe a square within a given circle.



Let ABCD be the circumference of any circle, and let two diameters, AC and BD, be drawn, intersecting each other at right angles; connect the ends of these diameters by the chords AB, BC, CD, and DA, then will these chords be equal and at right angles with each other, and thus form a perfect, inscribed square.

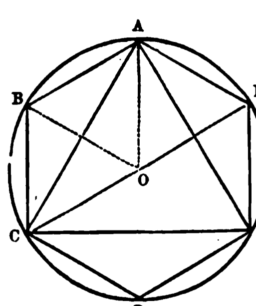
For, AO, BO, DO, and CO are all radii of the same circle, and therefore equal (Def.); the four angles at O are right angles by construction; hence, the four triangles AOB, BOC, COD, and DOA, are equal (Prop. VIII.), and the chords opposite the equal angles at O are also equal. (Prop. IX., *Cor.*)

Again, the angles BAD, ADC, DCB, and CBA are all equal, because they are each composed of two equal angles; and, since their sum equals four right angles (Prop. XXVIII., *Cor.*), each one is a right angle, and the figure ABCD, having four equal sides and four right angles, is a square.

Cor. The arcs embraced within the sides of the equal angles at O, and intercepted by the equal chords, are all equal, since each one is the fourth part of a circumference, or 90°; hence, in the same circle, or in equal circles, equal chords intercept equal arcs, and equal arcs are intercepted by equal chords.

Proposition XXXI. Problem.

To inscribe a regular hexagon and an equilateral triangle within a given circle.

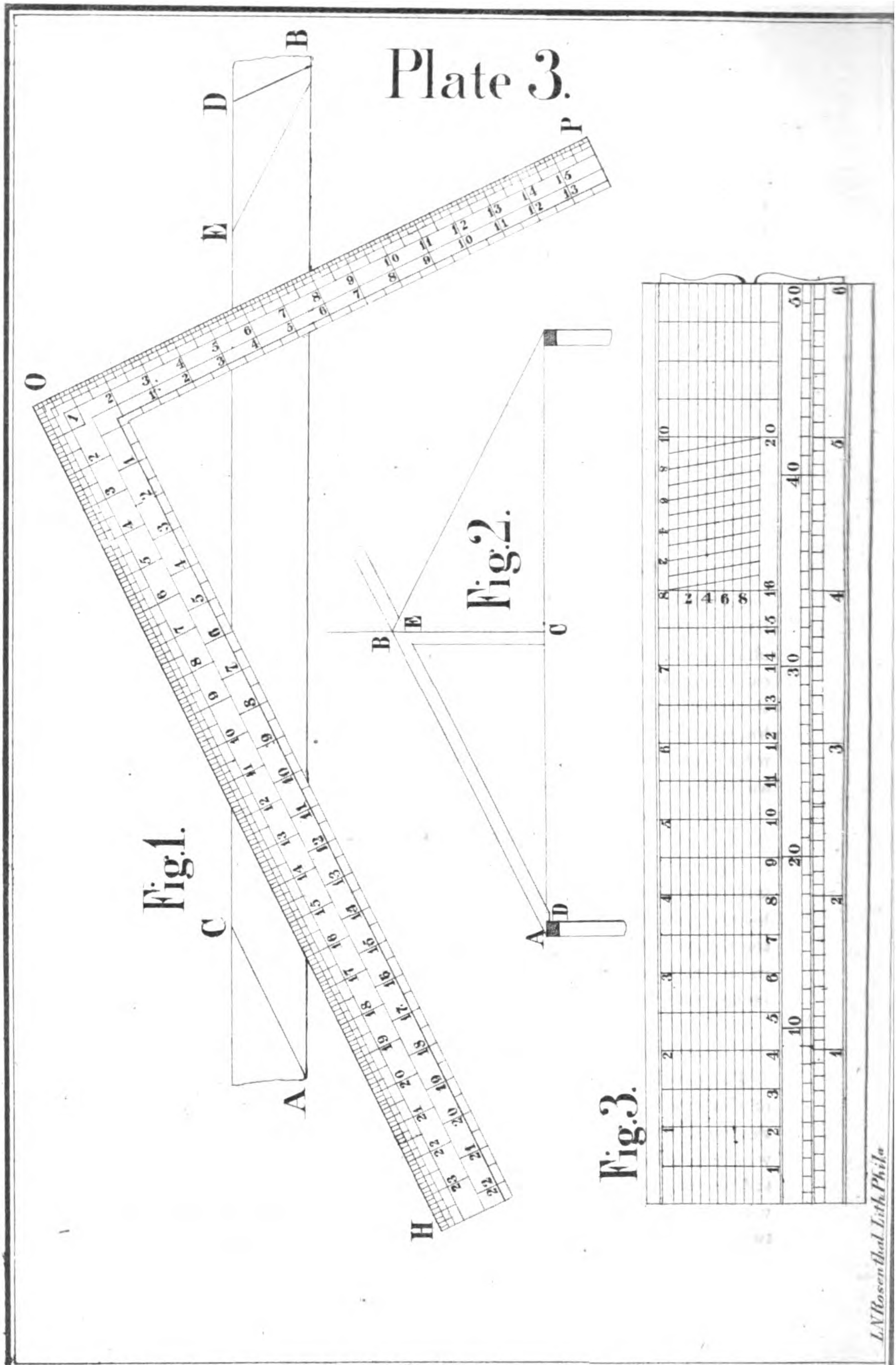


Let ABCDEF be the circumference of any circle. Draw the radii AO and BO, in such a manner that the chord AB, which connects their extremities, shall be equal to the radius itself. This chord will be one side of the regular, inscribed hexagon. For, the triangle ABO, being equilateral, is also equiangular (Prop. XVII., *Cor.*); and the sum of its three angles, being equal to two right angles (Prop. XVI.), each one of its angles is equal to two thirds of a right angle, or 60°, which is one sixth of a circumference; hence, the sides of the angle AOB intercept one sixth of the circumference: therefore, the chord AB, applied six times to the circumference, will exactly reach around it, and form a regular hexagon; for the angles of this hexagon will also be equal, since each one is made up of two equal angles, namely, BAO+OAF and ABO+OBC, &c.

After having inscribed the regular hexagon, join the vertices of the alternate angles of the hexagon, and the figure thus formed will be an equilateral triangle; for its sides are chords which intercept equal arcs, and are therefore equal.

PART II.

Plate 3.



CARPENTRY.

PLATE 3.

THE USE OF THE SQUARE IN OBTAINING BEVELS.

ALTHOUGH the square is one of the first instruments placed in the hands of the practical carpenter, yet there are many experienced mechanics who have never learned all the important uses to which it can be applied. And it is claimed as one of the principal merits of this work, that it teaches the manner of obtaining the bevels of rafters, braces, upper joists, gable-end studding, &c., in the most simple and most accurate manner possible, by the use of the square and scratch-awl alone, without drafts or plans.

The Square Described.

The *common square* is represented in Plate 3, Fig. 1, drawn to the scale of one fourth its size. The point O is called the corner or the heel of the square, the part OH is called the blade, and the part OP the tongue. The blade is 24 inches long; the tongue varies in length in different squares. We commence at the heel to number the inches each way.

Pitch of the Roof.

The bevels of rafters, joists, &c., must, of course, vary with the pitch of the roof. If the roof is designed to have a quarter pitch, which is the most common inclination for a shingle roof, the peak of the roof will be a quarter of the width of the building higher than the top of the plates. Although this is called, among builders, a quarter pitch, yet it would be more simple to call it a half pitch when the roof has two sides, which is most commonly the case, for the true inclination of each its side is 6 inches rise to every foot in width; and in like manner, a third pitch is, in reality, a two thirds inclination to each side of the roof, for it has 8 inches rise to every foot in width.

Bevels of Rafters.

Let AB, in Fig. 1, represent a rafter which is required to be beveled to a quarter pitch. First measure the exact length required, upon the edge AB, (which will be the upper edge of the rafter when it assumes its proper place in the frame,) and let the extreme points A and B be marked. Then place the blade of the square upon the point A at the 12 inch mark, and let the tongue rest upon the edge of the rafter at the 6 inch mark; hold the square firmly in this position, and draw the line AC along the blade: this line will be the lower end bevel. Take the square to the other end of the rafter, and place the 6 inch mark on the tongue upon the point B, still having the blade at the 12 inch mark, and while in this position draw the line DB along the tongue: this line will be the upper end bevel required.

Proceed in a similar manner to mark the bevels for any other pitch, placing the 12 inch mark on the blade upon the point A, and that mark on the tongue which corresponds with the rise of the roof to the foot, on the point B; then the blade of the square will show the lower end bevel, and the tongue the upper end bevel. Thus, if the roof has a pitch of five inches to the foot, let the square be placed at 12 and 5; if the roof has 8 inches rise to the foot, place it at 12 and 8, &c.

The reason of this rule can be explained in few words. In Fig. 2, let C represent the middle point of the line which is drawn from the top of one plate to the top of the other; let AB represent a rafter; and EC the longest gable-end stud, having its longest edge EC directly under the peak of the roof B. The lower end bevel of the rafter rests upon the upper surface of the plate, which is horizontal or level, while its upper end bevel is perpendicular, resting against the upper end of the opposite rafter; so that the upper and lower end bevels of every rafter are always at right angles with each other, whatever the pitch of the roof may be. The tongue of a square is also always at right angles with the blade; and a square can be conceived as having its heel at the point C, its blade resting upon the line AC, and its tongue standing perpendicularly along the line CB. Now let the distance from A to C be supposed to be 1 foot, or 12 inches; then, if the roof is designed to rise 6 inches to the foot, the point B will be 6 inches from C; if it rises 8 inches to the foot, the point B will be 8 inches from

C, &c.; and in all cases the line AC will be one bevel, and the line BC the other.

Bevels of Upper Joists and Gable End Studding.

The bevel of the upper joists is always the same as the lower end bevel of the rafters, and the bevel of the gable end studding is the same as the upper end bevel of the rafters, whatever the pitch of the roof may be. For, in respect to the upper joists, it is to be observed that their lower surfaces rest upon the plates, and their ends are to be beveled to fit the line AB, (Fig. 2), hence the angle BAD, the bevel of the rafter, is identical with that of the end of the joist. The bevel of the end studding is designed to fit it to the lower surface of the rafter; hence the angle DEC is the proper bevel. But DEC=ABC, since they are opposite exterior and interior angles. (Part I. Prop. XII., *Cor.*)

Bevels of Braces.

Proceed in a similar manner to obtain the bevels of braces. When the foot and the head of the brace are to be equally distant from the intersection of the two timbers required to be braced, and when the angle of their intersection is a right angle, then the brace is said to be framed on a *regular run*, and the bevels will be the same at both ends of it, and will always be at an angle of 45°, which is half a right angle, or the eighth part of a circle; and this bevel is obtained from the square by taking 12 on the blade and 12 on the tongue, or any other identical number, the *rise* being equal to the *run.**

But when the foot and the head of the brace are to be at unequal distances from the intersection of the timbers, the brace is said to be framed on an *irregular run*, and the bevel at one end will be different from that of the other. One rule, however, will answer in all cases. First find the length of the brace from the extreme point of one shoulder to the extreme point of the other, and mark those points as A and B. Then place the blade of the square upon the point A at such a distance from the heel as corresponds with the run of the brace, while the tongue crosses the edge of the brace at that distance from the heel which corresponds with the rise of the brace, and then the blade of the square will show one bevel, and the tongue the other.

For example, a brace is required to be properly beveled for an ir-

* For the explanation of those terms, *rise*, *run*, &c., see the Introduction to the Tables. Part IV.

regular run of 4 by 5 feet. Having found the *length* of the brace (by Table No. 4, or otherwise), and fixed the extreme points of the shoulders, then lay on the square at the 4 and the 5 inch marks, and describe the bevels along the blade and tongue respectively, as in finding the bevels of rafters.

Fig. 3 represents a small ivory rule, drawn full size. It is introduced here for the purpose of showing the manner of taking the measure of hundredths of an inch. It will be perceived that one of the inch spaces of the rule is divided into ten parts, by lines running down diagonally across ten other horizontal lines. Each of the intersections of these lines measures the hundredth part of an inch; the first line measuring tenths, the second twentieths, &c.

Plate 1.

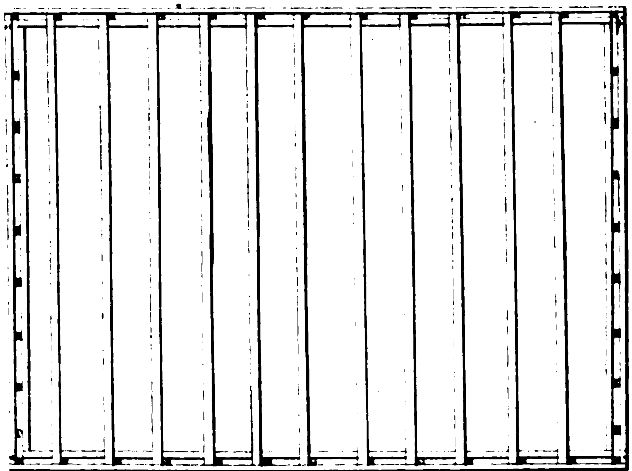


Fig. 1.

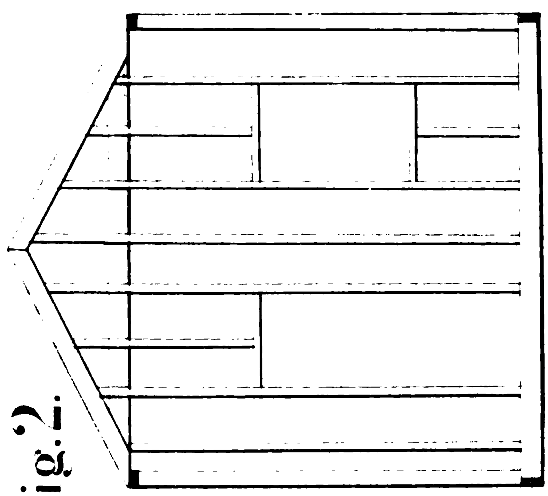


Fig. 2.

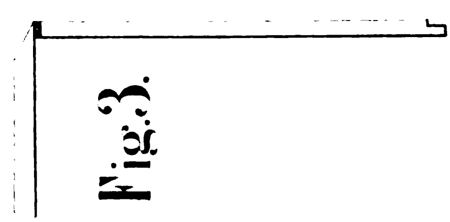


Fig. 3.

L.N. Rosenthal Lith. Phil.

PLATE 4.

Balloon Frames.

As Balloon Frames are the simplest of all, they are the first to claim our attention.

The Sills.

Where square timber can conveniently be furnished for sills, it is best to have it; but small buildings can be very well constructed without square sills, even when resting upon blocks only, by using a double set of common joists, with a 2 inch space between them, for the tenons of the studding.

Such a frame, of one story in height, 16 feet long, and 12 feet wide, is represented in Plate 4. For this building, joists which are 2 inches thick and 6 inches wide, will answer. First, for the sills, cut two joists 16 feet long, and two others, 11 feet 8 inches long. Spike them together at the ends in the form of an oblong square, 16 by 12 feet, making the outside rim of the sill.

The Studs.

Next, frame 13 studs for one side of the building; the two corner studs should be 4 inches square, the others 2 by 4. Cut out a 2 inch relish, six inches from the foot of each stud, on the face side, leaving a tenon on the inside of 6 inches long and 2 inches square, as represented in Fig. 3. Then cut off the other end of the studs at 10 feet from the shoulder.

The Plates.

A plate of 2 by 4 stuff, 16 feet long, is now to be nailed flat upon the upper ends of the studs, commencing at the front corner, and taking care to fix them 14 inches apart, or 16 inches from centre to centre. The last space will often be more or less than 14 inches; but it is better to have the odd space all at one end, for the convenience of the plasterers in lathing.

Raising and Plumbing the Frame.

This side of the frame is now ready to be raised. After having prepared the other side in the same manner, that can also be raised.

and the tenons spiked firmly to the inside of the sills. The corners should then be plumbed and securely braced.

The side sills should now be completed by cutting two joists, one for each side, each 15 feet 8 inches long, and framing them for the support of the floor joists by cutting notches into their upper edges 2 inches wide and 2½ inches deep; cutting the first notch 16 inches from the front end, and the next one just 14 inches from that, and so on to the last. After these inside sill-pieces are thus prepared, they should be spiked to their places upon the inside of the tenons of the studs.

The Floor Joists.

The floor joists are to be cut off 11 feet 8 inches long, and their lower corners notched off 2½ inches deep; then they should be fixed in their places in the sills, and also spiked to the studs. By this arrangement the joists are left one inch higher than the sills for the purpose of having the door-sill level with the flooring; the door-sill being 2 inches, and the flooring 1 inch thick

Upper Joists.

The next thing is to frame the upper joists, the rafters and the gable end studs; beveling the ends of each, so as to correspond with the pitch of the roof. The bevel is easily found by the use of the square, as is explained in Plate 3. The upper joists are equal in length to the width of the building. They should be nailed firmly upon the top of the plates, the first one being placed 4 inches from the end of the plate, to leave room for the end studding. The second one should be 14 inches from the first, and the others at the same distance from each other, or 16 inches from centre to centre.

The Rafters.

The exact length of the rafters is found by the use of Table No. 1., Part IV. Look at the left-hand column for the width of the building, and at the top for the rise of the rafter; where those two columns meet in the table, the length of the rafter is found in feet, inches, and hundredths of an inch. In this case, the width of the building is 12 feet, and the rise of the rafter is 6 inches to the foot, or a quarter pitch; therefore the length of the rafter, as given in the table, is (6 : 8.49) 6 feet 8 inches and $\frac{49}{100}$ of an inch. The rule for obtaining these lengths is of perfect accuracy, and is explained in the introduction to the Tables, in such a manner that every carpenter can calculate these lengths for himself, from the primary elements, if he chooses. The size of these rafters is 2 by 4.

Gable-End Studs.

The length of the gable-end studding may be found by first calculating the length of the longest one, which stands under the very peak, and then obtaining the lengths of the others from this; or, by first calculating the length of the shortest one next to the corner of the building, and then obtaining the lengths of the others from this.

The length of the middle stud is found by adding to the length of the side studding, the rise of the roof and the thickness of the plate; and deducting from that sum the thickness of the rafter, measured on the upper end bevel. For example, in this building, the length of the side studding from shoulder to shoulder is 10 feet, the rise of the roof is 3 feet, and the thickness of the plate is 2 inches. These all added are 13 feet 2 inches, from which deduct 4.47 inches, or 4½ inches, the thickness of the rafter measured on the upper end bevel, and the result is 12 feet 10½ inches, the length of the middle stud. The next stud, if placed 16 inches from this one, from centre to centre, is 8 inches shorter, since the rise of the roof is 6 inches to 12, or 8 inches to 16. The next one is 8 inches shorter still, and the others in proportion.

If it should be thought preferable to commence by first calculating the length of the shortest one, it can be done. For example, in this building the distance of the inside of the first stud from the outside of the building is 20 inches, the rise of the rafter in running 20 inches back is 10 inches, to which add 2 inches, thickness of the plate, and 10 feet for the length of the side studding, and the sum is 11 feet; from this deduct the thickness of the rafter, at the upper end bevel, 4½ inches, and the result is 10 feet 7½ inches, the length of the shortest stud. The length of the next one is found by adding the rise of the roof in running the distance, that is, if they are 16 inches apart from centre to centre, the difference between them is 8 inches; and so in any other pitch, in the proportion of the *rise* to the *run*.

The end studding having been properly beveled and cut off to the exact lengths required, they can be raised singly and spiked to the sills at the bottom and nailed at the top to the end rafters, and also to the upper joists where they intersect them. After the end studs are all fixed in their positions, the end sills can finally be completed by spiking a joist 11 feet in length to the inside of the studding at each end of the frame,

PLATE 5.

Plate 5 is designed to represent a balloon frame of a building a story and a half high, 16 by 26 feet on the ground, with 12 feet studding. Two end elevations are given, in order to exhibit different styles of roofs. Fig. 2 being a plain roof, of a quarter pitch; and Fig. 3 a Gothic roof, the rafters rising 14 inches to the foot.

Framing the Sills.

Solid timber, 8 inches square, being furnished for the sills of this building, the first business is to frame these. The carpenter will seldom have timber furnished to his hand which is perfectly square throughout its length; by carelessness in hewing, or by the process of seasoning after being hewed, it will most commonly have become irregular and winding.

Work Sides.

Having first selected the two best adjoining sides, one for the upper side and the other for the front, called *work sides*, they should *be taken ont of wind* in the following manner.

To take Timber out of Wind.

Plane off a spot on one of the work sides, a few inches from one end, and draw a pencil line square across it; then place the blade of a square upon this line, allowing the tongue to hang down as a plummet, to keep the blade on its edge. Leave the square in this position, and go to the other end of the sill, and place another square upon it, in the same manner; then sight across the two squares, and see if they are level or parallel with each other. If not, make them so, by cutting off the spots under the squares till they become so; then make the other work side square with this one, at these two spots, and draw a pencil mark square across both sides: these marks are called *plumb spots.*

On the upper side of the timber, strike a chalk-line, from one end to the other, at two inches from the front edge; this will be the front line for mortices for studs. On this line measure the length of the

Plate 5.

Fig. 1.

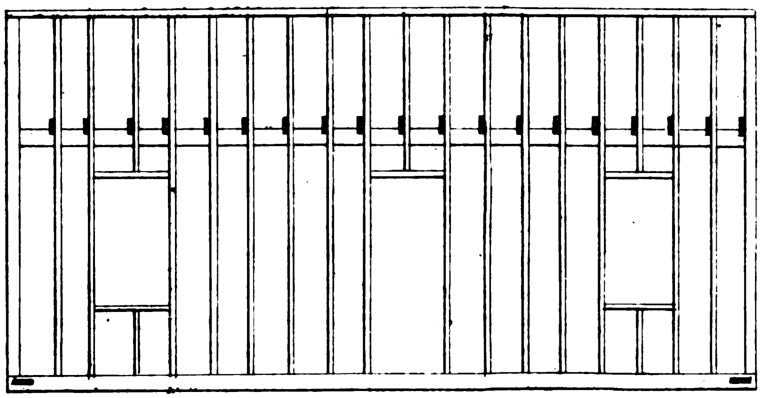


Fig 3.

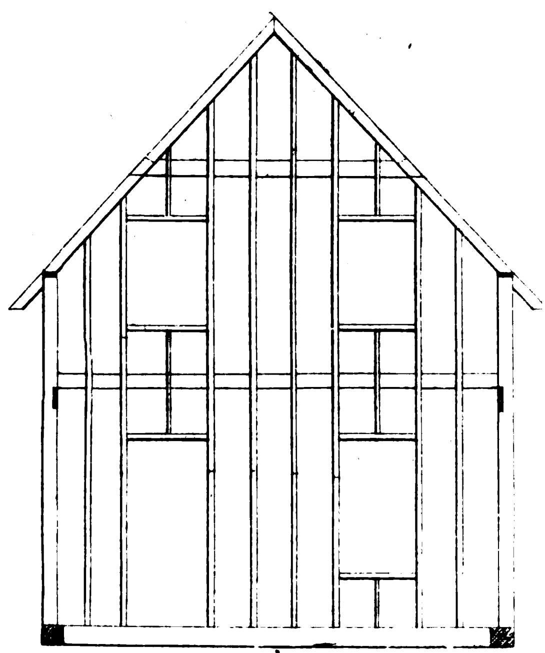
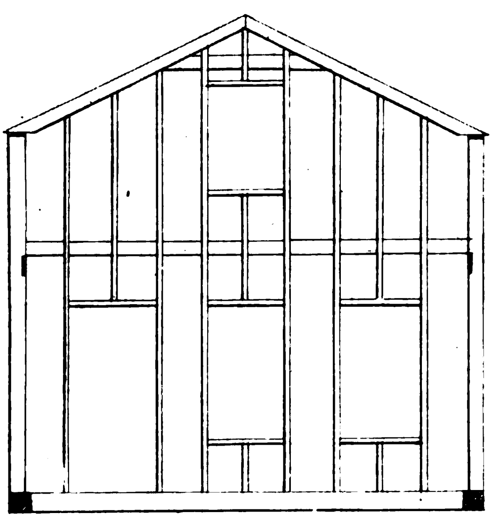


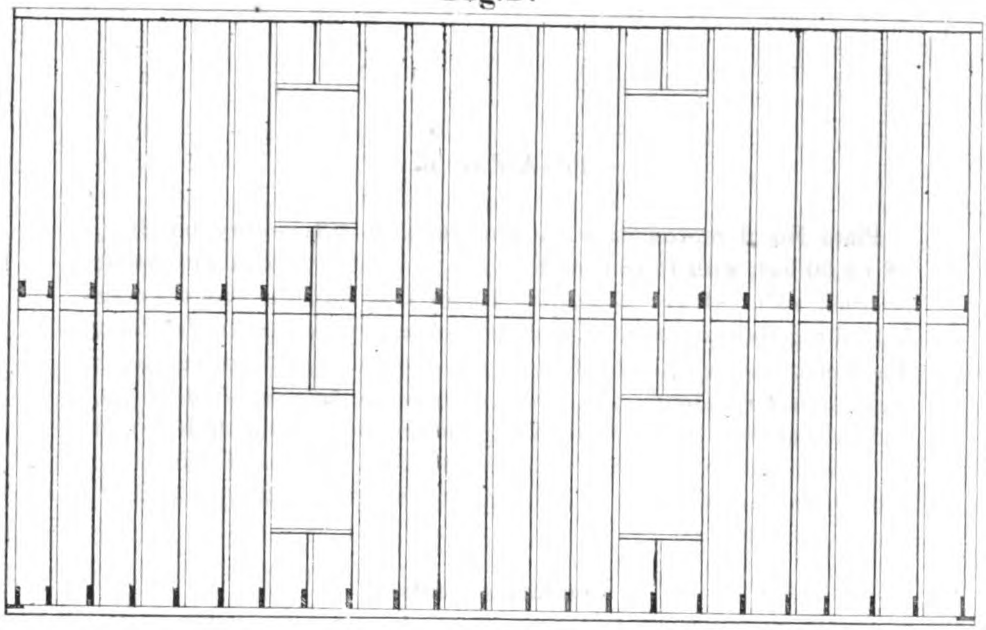
Fig. 2.



L. N. Rosenthal's Lith. Phil.a

Plate 6.

Fig. 1.



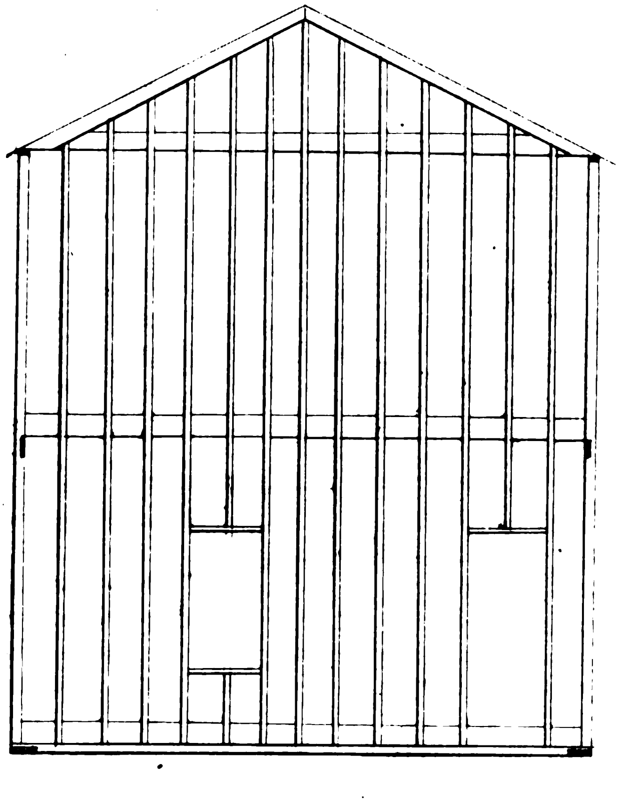


Fig. 2.

L. N. Rosenthal's Lith. Phil^a.

sills, and square the ends by it. If the stick is *very irregular*, it should be *counter-hewed*, and the two work sides made square and straight.

Spacing for Windows and Doors.

Next, lay out spaces for windows and doors, leaving a space for the doorway 2½ or 3 inches more than the width of the door; and leave spaces, 7 inches more than the width of the glass, for the windows.

Mortices for the Studs.

Then lay out the mortices for the studding, spacing them as described in Plate 4. The studding on each side of the doors and windows should be 4 inches square, as well as those at the corners of the building. The rest of the studding may be 2×4. The mortices need to be a little more than 2 inches deep, and the tenons 2 inches long.

The lower joists for this building should be 2×8, and 10 inches shorter than the width of the building. They should be placed 16 inches apart, from centre to centre, as already described.

The Gains,

As they are called, for receiving the ends of the joists, should be cut out of the side sills, 4 inches deep and 2 inches square, and 5 inches from the front or outside of the sill. Having framed the sills for the studding and joists, they should next be framed for each other. Make mortices in the ends of the side sills, 2½ inches from the upper surface and 2 inches from the end, 2 inches wide and 5½ inches long. The inside of the sills should be faced off, along the mortice, to within 7½ inches of the work side, in front. The length of the side sills should be the same, of course, as that of the building; but the end sills should be measured from shoulder to shoulder, 15 inches less than the width of the building. Make the tenons of these to correspond with the mortices of those which have just been described.

The Draw Bores.

The draw bores should be 1 inch in diameter, and 1½ inches from the face of the mortice. The draw bore through the tenon should be $\frac{3}{16}$ of an inch nearer the shoulder than that through the mortice, in order to draw the work snugly together.

A Draw Pin.

The proper way to make a *draw pin* for an inch bore is, first, to make it an inch square; then cut off the corners, making it eight-square, then taper it to a point, the taper extending one third the length of the pin. The pin should be about 2 inches longer than the thickness of the timber.

The sills having thus been framed, they can be brought to their places and pinned together, and then the lower joists laid down.

To Support the Upper Joists.

This building being a story and a half high, the upper joists are laid upon a piece of inch board, from 4 to 6 inches wide, which is let into the studs, as seen in the Plate. The bevels and lengths of the rafters are found as already described.

In Fig. 3 the rafters are represented as projecting beyond the plate; this projection may be 3 feet, or more, according to each one's fancy; but whatever it may be, it must be added to the length of the rafter as given in the table; where it is calculated from the upper and outer corner of the plate. The *bevel* will be the same, whatever the additional length may be, as if the rafter did not project at all. In this case, the rafter should be cut out to about one half its width, where it intersects the plate, and must be spiked securely to the plate. The two bevels, at the intersection, will be the same as the upper and lower end bevels, and will make a right angle with each other where they meet at this place.

The *collar beams* can be spiked to the rafters, or they can be dovetailed into them. Both methods are represented in the plate.

PLATE 6.

Plate No. 6 represents a balloon frame of a two-story building, 18 by 30 feet, with 18 feet studding, to be erected upon a good stone or brick wall. Heavy joists, 3 by 10, are used for sills, with the ends halved together, and fastened with spikes, as represented in the Plate. The lower joists should be 2 by 9 inches, of full length, equal to the width of the building. The lower corners are notched off 3 inches, and they are spiked to the studding. The mortices for the studs should be 1½ inches deep, the studding being 2 by 4. The middle joists are 2 by 9, and arranged as in Plate 5; and the upper, 2 by 7, and arranged as in Plate 4.

Crowning of Joists.

It will almost always happen that one edge of a joist will have become somewhat rounded out, and the other edge rounded in, by the process of seasoning; and it is of much importance, especially in long joists of 18 feet or more, to be careful, in placing the joists in a building, to place the rounding or crowning side up.

Bridging of Joists.

Joists 12 feet long, or over, should also be *bridged* in one or more places, by nailing short pieces of board, 2 or 3 inches wide, in the form of a brace, from the lower edge of one joist to the upper edge of the next one; and then another piece, from the lower edge of this one to the upper edge of the first one; and so on, throughout the whole length of the building: having two braces crossing each other between each joist, beveling the ends so as exactly to fit, which would add very much to the strength of the floor.

Lining or Sheeting Balloon Frames.

After an experience of fifteen years in constructing and repairing balloon-framed buildings, I have found it best to line the frame on the *inside* for three reasons:

FIRST—*the work is more durable.* For, when a frame is lined on the outside, (the common way,) it is very difficult to weather-board it sufficiently tight, to prevent the rain beating in between the siding and the lining, and thus rotting both, since there is so little opportunity there for the moisture to dry out.

SECOND—*the lining is stiffer and warmer.* For, in that case, the lath being but half an inch from the lining-boards,* the mortar is pressed in between every board, making it almost air-tight.

THIRD—*the wall itself is made more solid.* For the mortar being pressed against the lining-boards, is forced both ways, both up and down, forming more perfect clinchers.

*** When a building is thus lined on the inside, it is best to lath it in the following manner. Single strips of lath are first nailed perpendicularly, sixteen inches apart, upon the lining-boards, and to these the laths for the wall are nailed as usual.**

Plate 7.

Fig. 1.

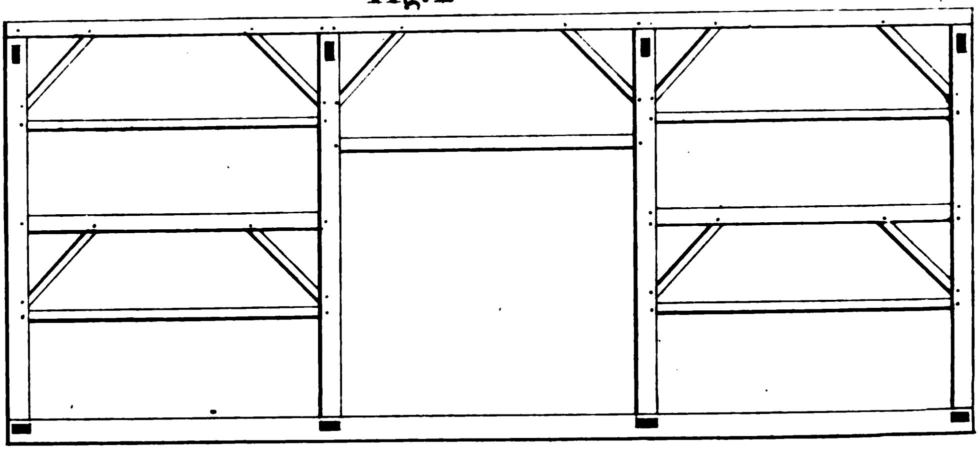


Fig. 2.

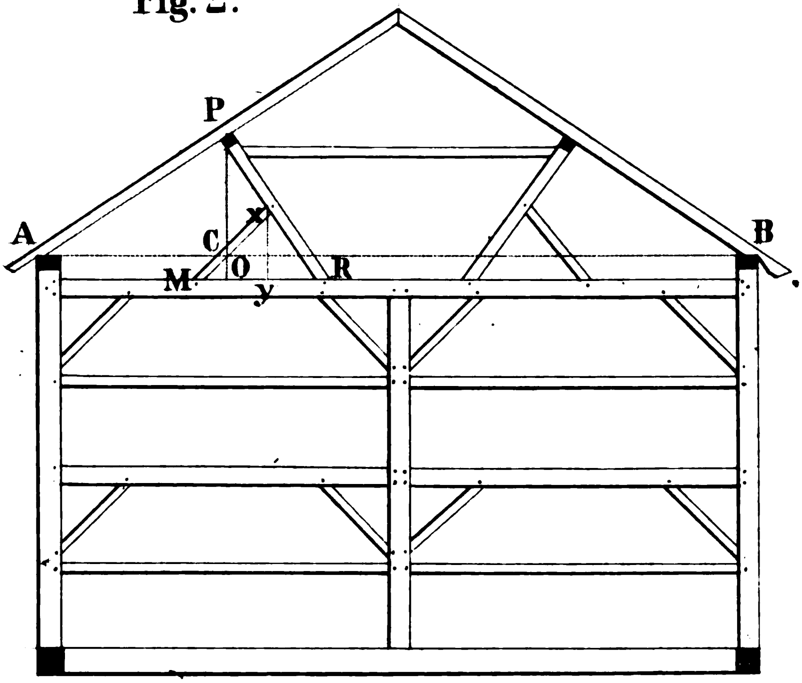


PLATE 7.

BARN FRAMES.

Plate 7 represents the frame of a barn 30 by 40 feet, and 16 feet high between shoulders.

The sills are 12 inches square;

Posts and large girders, 10 inches square;

Plates and girders over main doors, 8 by 10;

Purlin plates, 6 by 6;

Purlin posts and small girders, 6 by 8;

Braces, 4 by 4; and rafters, 2 by 6.

First proceed to take the timber out of wind, as directed under Plate 5. Frame the sills together as represented in the Plate, the four short sills being framed into the two long ones, having taken care to select the best of the short sills for the ends.

Size of Mortices.

The mortices for the end sills should be 3 by 9 inches, with a relish of 2½ or 3 inches on the outside. The mortices for the middle sills may be 3 by 11 inches. The mortices for the corner posts should be 3 by 7 inches, and for the middle posts, 3 by 9 inches; all the mortices in the sills being 3 inches from the work sides. The general rule for draw bores and draw pins may be stated as follows:—The size of the draw bore should be equal to half the thickness of the tenon, when the tenon is not more than 3 inches thick; but it never need be more than 1½ inches in size, even though the tenon may be more than 3 inches thick. In wide mortices, it is customary to have the tenons secured with two, and sometimes three pins, as represented in the Plate. Let one draw bore be 2 inches from one side of the mortice, and the other 2 inches from the other side, and each one 2 inches from the face of the mortice.

In the tenons, let the draw bores be 2 inches from each side, and about one fourth of an inch, in large tenons, nearer the shoulder than the draw bores of the mortices. Great care should be observed to have the draw bores perfectly plumb; and workmen should be cautioned against making a *push bore*, as it is called, when not plumb.

The posts need not be pinned at the bottom, and the manner of pinning the other tenons is represented in the Plate.

Braces.

The braces are framed on a regular 3 feet run; that is, the brace mortice in the girder is 3 feet from the shoulder of the girder, and the brace mortice in the post is 3 feet below the girder mortice. *Always remember* that the measure for braces and brace mortices is computed to the furthest end, or *toe of the brace*, and the furthest end of the mortice. The mortices for 4 inch braces need to be 5¾ inches long, so that the end of the mortice in the post, next the girder, will be 2 feet 6¼ inches from the girder, and the end furthest from it will be 3 feet. The bevel of braces on a regular run is always at an angle of 45°, and is the same at both ends of the brace.

Pitch of the Roof.

In this building the roof is designed to have a third pitch; that is, the peak of the roof would be one third the width of the building higher than the top of the plates, provided the rafters were closely fitted to the plates at their outer surfaces, as in Plates Nos. 3, 4, and 6; but it is common in barns, and sometimes in other buildings, as has been already illustrated in Plate 5, Fig. 3, to let the rafters down only half their width upon the plates, allowing them to project beyond the plate, so that in this case the peak of the roof is 10 feet 3 inches above the plates, the pitch being still a third pitch, or 8 inches rise to a foot run. In order to give strength to the mortices for the upper end girders, these girders are framed into the corner post several inches below the shoulders of the post, say 4 inches; the thickness of the plates being 8 inches, it will be perceived that the dotted line, AB, drawn from the outer and upper corner of one plate to the outer and upper corner of the other, is just 1 foot higher than the upper surface of the girder; and that the peak of the roof is 11 feet 3 inches above this girder. The length and bevels of the rafters can be found as already described in Plate 3 and Table 1.

Purlins.

The purlin plates should always be placed under the middle of the rafters; and the purlin posts, being always framed square with the purlin plates, the bevel at the foot of these posts will always be the same as the upper end bevel of the rafters;* also, the bevel at each end of the gable-end girder will be the same, since—the two girders being parallel, and the purlin post intersecting them—the *alternate angles* are equal. (Prop. XII., *Cor.*, p. 29.) The length of the gable-end girder will be equal to half the width of the building, less 18 inches; 6 inches being allowed for half the thickness of the purlin posts, and 6 inches more at each end for bringing it down below the shoulders of the posts.

Length of the Purlin Posts.

In order to obtain the length of the purlin posts, let the learner pay particular attention to the following explanation of Fig. 2. Let the point P represent the middle point of the rafter, and let the dotted line PO be drawn square with AB; then will AC be the $\frac{1}{2}$ of AB, or $7\frac{1}{2}$ feet, and PC, half the rise of the roof, will be 5 feet, and PO 6 feet. The purlin post being square with the rafter, and PO being square with AB, we can assume that PR would be the rafter of another roof of the same pitch as this one, provided PO were half its width, and OR its rise; and then, since we know the length of PO, the length of PR could also be found by the rafter table (No. 1, Part IV.), as follows:—Width of building, 12 feet; rise of rafter, $\frac{1}{3}$ of 12, or 4 feet; hence, length of rafter, or PR, equals 7 feet $2\frac{52}{100}$ inches; from this deduct half the width of the rafter and the thickness of the purlin plate, or 9 inches, and we have, 6 feet $5\frac{52}{100}$ inches as the length of the purlin post, from the shoulder at the top to the middle of the shoulder at the foot.† This demonstration determines also the place of the purlin post mortice in the girder; for AC being $7\frac{1}{2}$ feet, and OR being 4 feet, by adding these together, we find the point R, the

* This fact is capable of a geometrical demonstration; for the triangle POR is similar to the triangle ACP; the side PR in one, being perpendicular to the side AP in the other, the side PO being also perpendicular to AC, and the side RO perpendicular to PC. (Part I., Prop. XXIX.) Hence, the angles opposite the perpendicular sides are equal; and we have angle APC, which is the same as the upper end bevel of the rafter—being parallel with it—equal to PRC, the angle formed by the purlin post and the girder at their intersection at R.

† The following geometrical demonstration of the above proposition is subjoined. In the two similar triangles ACP and POR, the sides about the equal angles are proportional (Def. 81); and we have, CP : AC : : OR : OP; but CP is $\frac{2}{3}$ of AC; consequently, OR is $\frac{2}{3}$ of OP. But OP equals 6 feet; hence, OR equals 4 feet. Again, the triangle POR being right-angled at O, then $PO^2+OR^2=PR^2$. $4^2=16$, and $6^2=36$; $36+16=52$, and $\sqrt{52}$ ft. = 7 ft. 2.52 in., as above.

middle of the mortice, to be 11½ feet from the outside of the building; and the length of the mortice being 7½ inches, the distance of the end of the mortice, next the centre of the building, is 11 feet 9¾ inches from the outside of the building.

Purlin Post Brace.

The brace of the purlin post must next be framed, and also the mortices for it, one in the purlin post and the other in the girder. The length of the brace and the lower end bevel of it will be the same as in a regular 3 feet run; and the upper end bevel would also be the same, provided the purlin post were to stand perpendicular to the girder; but, being square with the rafter, it departs further and further from a perpendicular, as the rafter approaches nearer and nearer toward a perpendicular; and the upper end bevel of the brace varies accordingly, approaching nearer and nearer to a right angle as the bevel at the foot of the post, or, what is the same thing, the upper end bevel of the rafter departs further and further from a right angle. Hence, *the bevel at the top of this brace is a* COMPOUND BEVEL, *found by adding the lower end bevel of the brace to the upper end bevel of the rafter.** (See Plate 8.)

Purlin Post Brace Mortices.

In framing the mortices for the purlin post braces, it is to be observed, also, that if the purlin post were perpendicular to the girder, the mortices would each of them be 3 feet from the heel of the post; but as the post always stands back, so the distance will always be more than 3 feet from the heel of the post; and the sharper the pitch of the roof, the greater this distance will be. Hence the true distance on the girder for the purlin post brace mortice is found by adding to 3 feet the rise of the roof in running 3 feet; which, in this pitch of 8 inches to the foot, is 2 feet more, making 5 feet, the true distance of the furthest end of the mortice from the heel of the purlin post.

The place in the purlin post for the mortice for the upper end of the brace may be found from the rafter table, by assuming that Rx

---

* This proposition is capable of demonstration, thus: The angle PxM equals the sum of the angles MRx and xMR, since PxM is the exterior angle of the triangle MRx, formed by producing the base Rx in the direction RxP. (See Prop. XVI., *Cor.*) But the angle PxM is the upper end bevel of the purlin post brace; therefore, it is equal to the sum of the two bevels, one at the foot of the brace and the other at the foot of the post, as above.

would be the rafter of another roof of the same pitch as this one, if xy were half the width, and yR the rise. For then, since xy equals 3 feet, we should have width of building equal 6 feet, rise of rafter, one third pitch, gives yR equal 2 feet; and hence xR would equal 3 feet 7.26 inches, the true distance of the upper end of the mortice from the heel of the purlin post.*

---

* The same proposition is demonstrated by Geometry, as follows: xy being parallel with PO, the two triangles RPO and Rxy are similar, (Geom., Prop. XXIX), hence the sides opposite the equal angles are proportional, and we have Rx : RP : : xy : PO. But we have already found PO to equal 6 feet, and xy equal to 3 feet, and RP equal to 7 feet 2.52 inches. Hence,

6 : 3 : : 7 ft. 2.52 in. : 3 ft. 7.26 in. Answer as above.

PLATE 8.

UPPER END BEVEL OF PURLIN POST BRACES.

Plate 8 is designed to illustrate the manner of finding the upper end bevel of purlin post braces, to which reference is made from the preceding Plate.

In Fig. 1, let AB represent the extreme length of the brace from toe to toe, the bevel at the foot having been already cut at the proper angle of 45 degrees. Draw BC at the top of the brace, at the same bevel; then set a bevel square to the bevel of the upper end of the rafter, and add that bevel to BC, by placing the handle of the square upon BC and drawing BD on the tongue. This is the bevel required.

Fig. 2 shows another method of obtaining the same bevel. Let the line AB represent the bevel at the foot of the brace, drawn at an angle of 45 degrees. Draw BD at right angles with AB, and draw BC perpendicular to AD, making two right-angled triangles. Then divide the base of the inner one of these triangles into 12 equal parts, for the rise of the roof. Then place the bevel square upon the bevel AB, at B, and set it to the figure on the line CD, which corresponds with the pitch of the roof. This will set the square to the bevel required for the top of the brace. In this figure the bevel is not marked upon the brace, but the square is properly set for a pitch of 8 inches to the foot, or a one third pitch. The square can now be placed upon the top of the brace, and the bevel marked.

Plate 8.

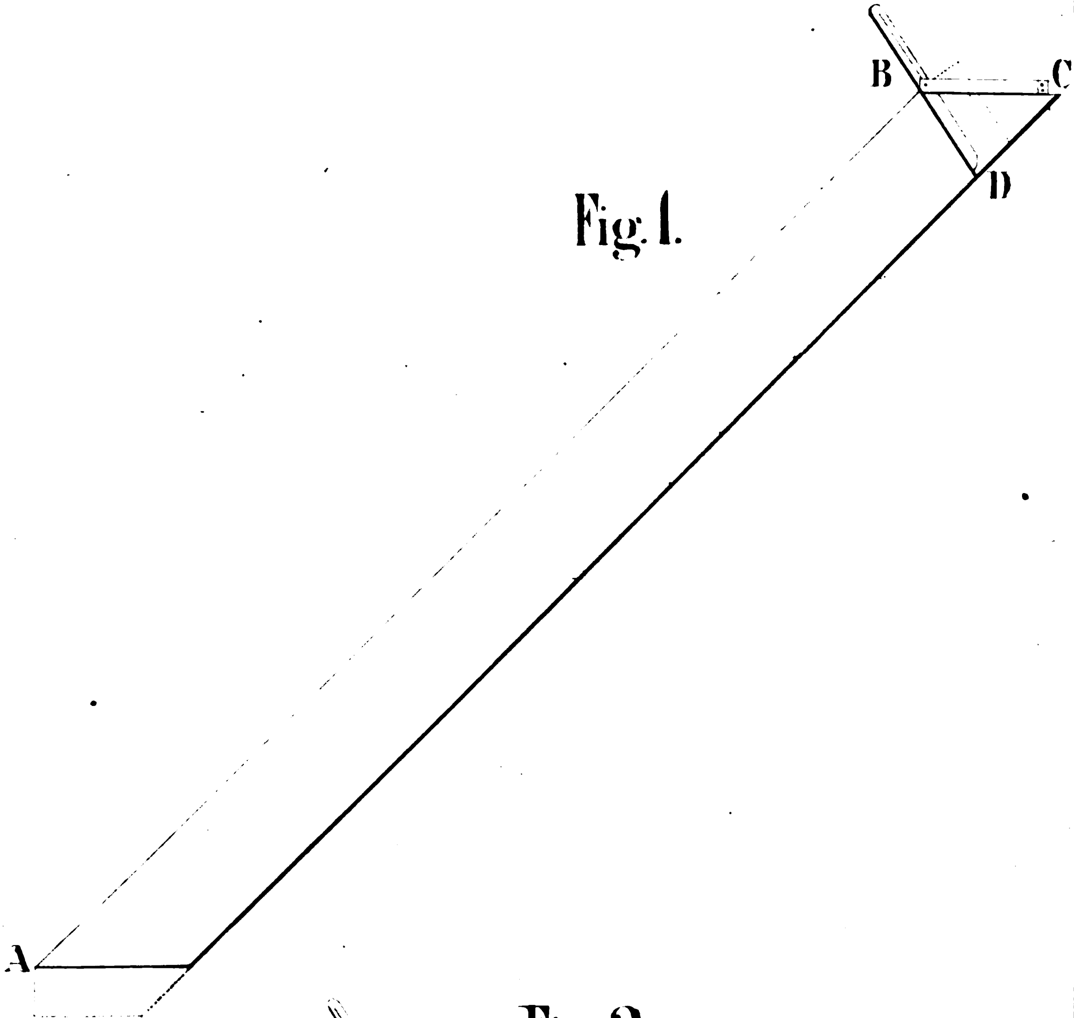
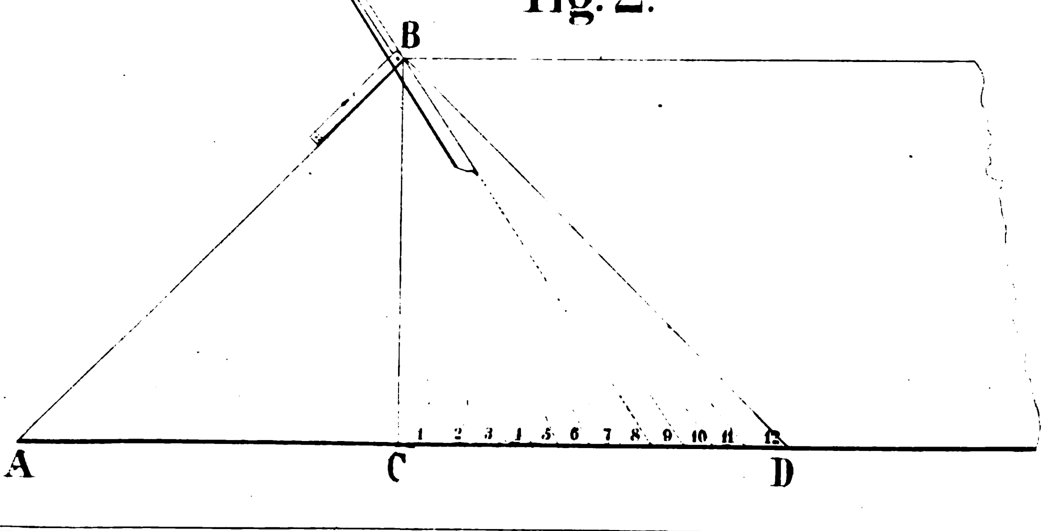


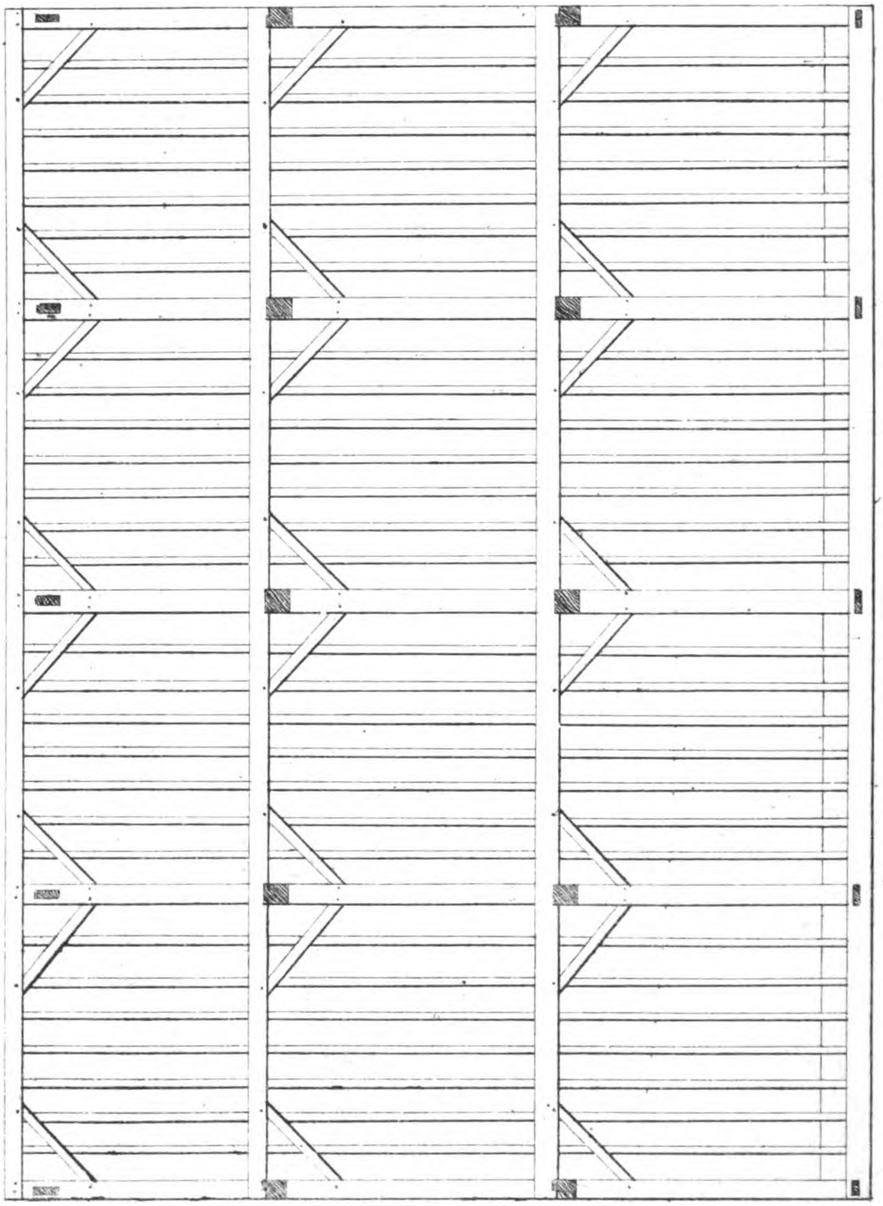
Fig. 1.

Fig. 2.



L. N. Rosenthal. Lith. Phil.

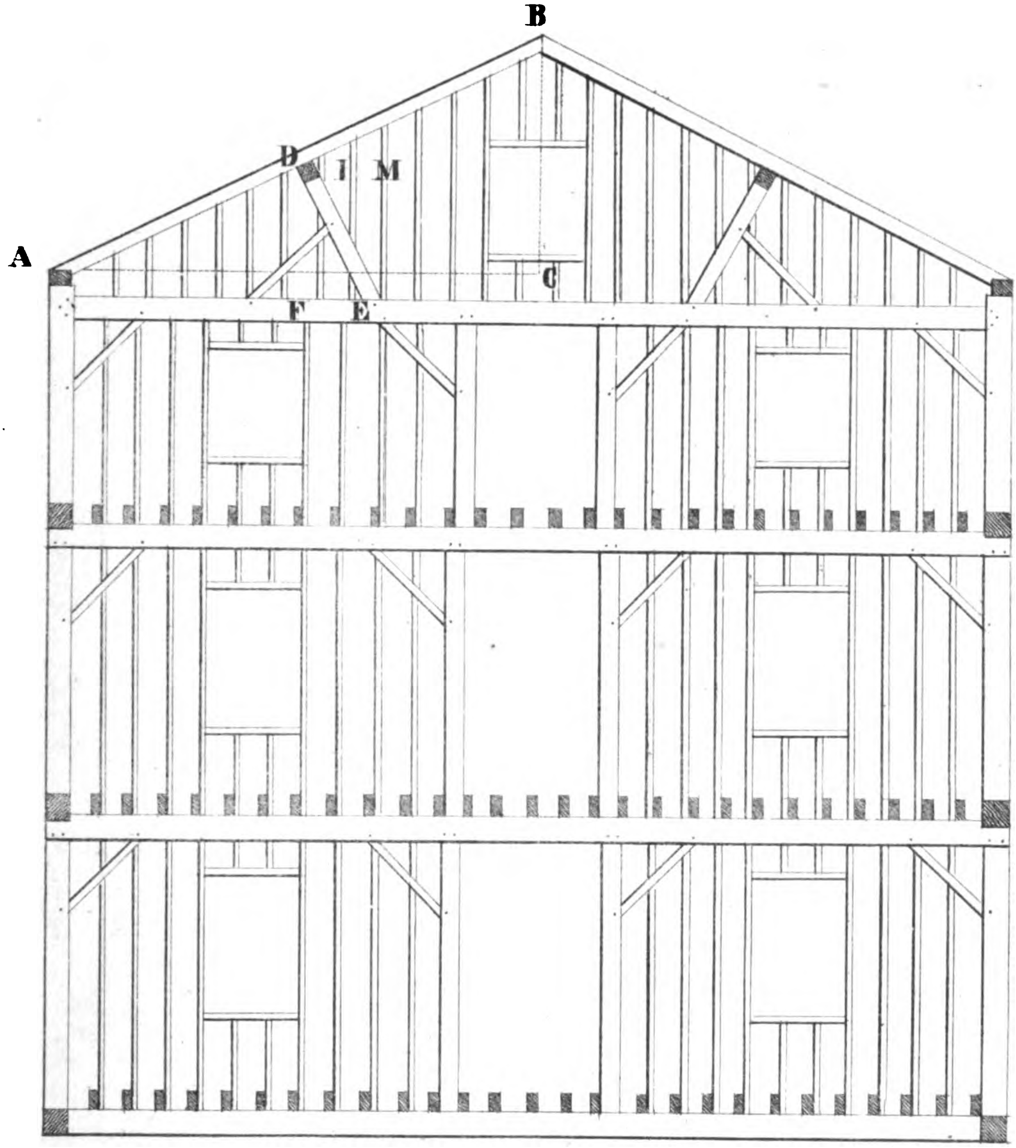
Plate 9.



Scale 8 feet to the Inch

L. N. Rosenthal's Lith. Phil.a

Plate - 10.



L.N. Rosenthal Lith. Phil.

PLATES 9 & 10.

Plates 9 and 10 exhibit the side and end elevations of a building designed for a warehouse, or mill.

Length of building, 50 feet;
Width of building, 40 feet;
Height of building from the foundation to the top of plates, 36 feet;
Main timbers, 12 inches square;
Door posts, 10 by 12;
Purlin posts, 8 by 10;
Plates and purlin plates, 8 by 8;
Braces, 4 by 6;
Lower joists, 3 by 12;
Upper joists, 3 by 10;
Studding, 2 by 8;
Rafters, 2 by 6.

The posts are framed in sections, one story at a time, on account of the difficulty in procuring long timbers, also for facility in raising the building; for, by this means, each story can be raised separately. It has also been proved by experience, that when the timbers are locked together as represented in the Plate, this mode of building is equally strong as to have the posts in one length. The ends of the joists are sized to a uniform width, and placed upon the timbers, *the crowning side up;* the studs are morticed into the timbers as usual. The roof is framed to a quarter pitch, and the braces to a regular 3 feet run. Plate 3 describes the manner of obtaining the bevels of the rafters and gable-end studding. Plates 7 and 8 show the manner of obtaining the bevels of the purlin posts and braces. Plate 4 gives the method of finding the length of the gable-end studding.

Cripple Studs.

The length of the *cripple studs,* which are to be nailed to the braces, depends upon the run of the braces. The braces in this building, being on a regular run, are all set at an angle of 45 degrees, so the bevel of the cripple studs will be the same; and the rise of the brace being equal to the run, the length of each cripple stud will be equal to the height of the post from the sill to the toe of the brace, added to the distance of the stud from the post. In this building, the height of the brace from the sill to the toe of the brace in the first story, is 8 feet, and the inside of the first stud being 16 inches from the inside of the post, the length of the first cripple stud will be 16 inches longer than the height of the post from the sill to the toe of the brace, or 9 feet, 4 inches; and the length of the next cripple stud will be 16 inches more, or 10 feet 8 inches.

It now remains to determine the bevels and the lengths of those cripple-studs in the gable end, which are to come against the purlin posts. Having already (Plate 7) found the bevel at the foot of the purlin post equal to the *upper* end bevel of the *rafters*, it will follow that the bevel of the cripple studs upon the purlin post is equal to the *lower* end bevel of the *rafters*.* The length of the cripple studs standing between the rafter and the purlin posts depends both upon the rise of the roof and the rise of the purlin post; but the purlin post being set square with the rafter, its *rise* is always the same as the *run* of the rafter, and its *run* is the same as the *rise* of the rafter.

Hence, for finding the length of a cripple stud, standing in any building between the rafter and the purlin post, at a certain horizontal distance from the top of the purlin plate, we have the following Rule: *Add the* RISE *of the roof in* RUNNING *the given distance to the* RUN *of the roof in* RISING *the given distance; the sum will give the length of the cripple stud.*

For example, in this plate, suppose the cripple stud *I* to be 18 inches from the top of the purlin plate, horizontal distance, then the rise of the roof on a quarter pitch in running 18 inches would be 9 inches, and the run of the roof in rising 18 inches would be 36 inches; so that the length of *I* is 45 inches. The stud marked *M* being 16 inches from *I*, the additional rise is 8 inches, and the additional run is 32 inches, so that *M* is 40 inches longer than *I*.

Note on Bevels.—The bevels in a frame of this kind are only four in number:—

1. The bevel of the upper end of the rafter.
2. The bevel of the foot of a rafter.
3. The bevel of the braces, &c—equal to 45 degrees.
4. The bevel of the upper end of the purlin post brace, always equal to the sum of the first and third. Balloon frames have but two bevels—the first and second above mentioned.

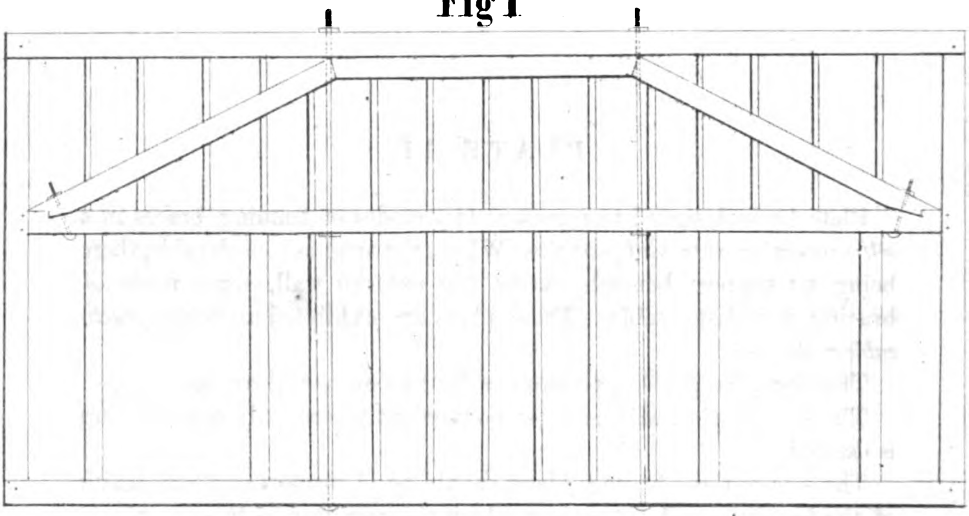
---

* Demonstrated as follows. The triangle ABC is similar to the triangle DEF, since the sides of the one are perpendicular to the sides of the other; consequently the angles opposite the perpendicular sides are equal. (Geom., Prop. 29.)

The side FE, in one triangle, is perpendicular to the side BC in the other; hence, the angle A = angle D. The angle A is the lower bevel of the rafters, and the angle D is the bevel of the cripple stud on the purlin post.

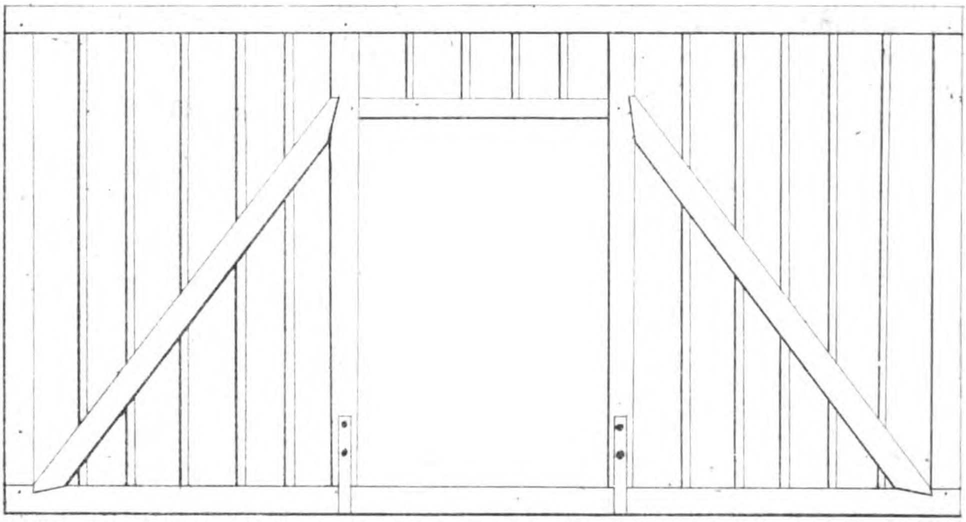
Plate II.

Fig I



Scale 6 feet to 1 inch.

Fig 2.



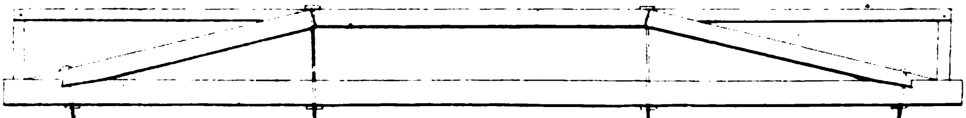


Fig 3.

L. N. Rosenthal's Lith. Phil'a.

PLATE 11.

Plate 11 is designed to represent two modes of framing braces in a *self-supporting* or *trussed partition.* Where the span is considerable, there being no support beneath except the exterior wall, some mode of bracing is indispensable. These plans are exhibited as being *practicable and secure.*

The first plan gives opportunities for two or even three openings.

The second plan will be most convenient where only one opening is desired.

The size of these brace timbers should be in proportion to the width of the building, and the weight which the partition is to sustain. If they are ten or twelve inches square, they will safely sustain a brick wall built upon the partition.

Fig. 3 is designed to show the proper mode of trussing a beam over a barn floor, or in front of a church gallery, or any other situation where it is inconvenient to support it by posts.

PLATE 12.

SCARFING.

This Plate exhibits several designs for scarfing or splicing timber. The length of the splice should be about four times the thickness of the timber; and when the joint is beveling, it will be found the best and most expeditious way, first, to prepare an exact pattern of boards, and then to frame the timbers by the pattern: by this means a perfect joint can be made.

Straps and Bolts.

Fig. 4 is spliced by strapping pieces of plank upon the upper and lower sides of the joint, and securing them with bolts of $\frac{3}{4}$ inch or 1 inch in diameter, according to the size of the timber.

Figs. 5, 7, and 8, have iron straps bolted in a similar manner.

Fig. 9 exhibits a strong mode of splicing timbers where they are doubled throughout their whole length, for a very long span, such as roofs in churches.

Those styles which are numbered 1, 2, 7, and 5, are recommended as being the best in proportion to the cost.

Plate 12.

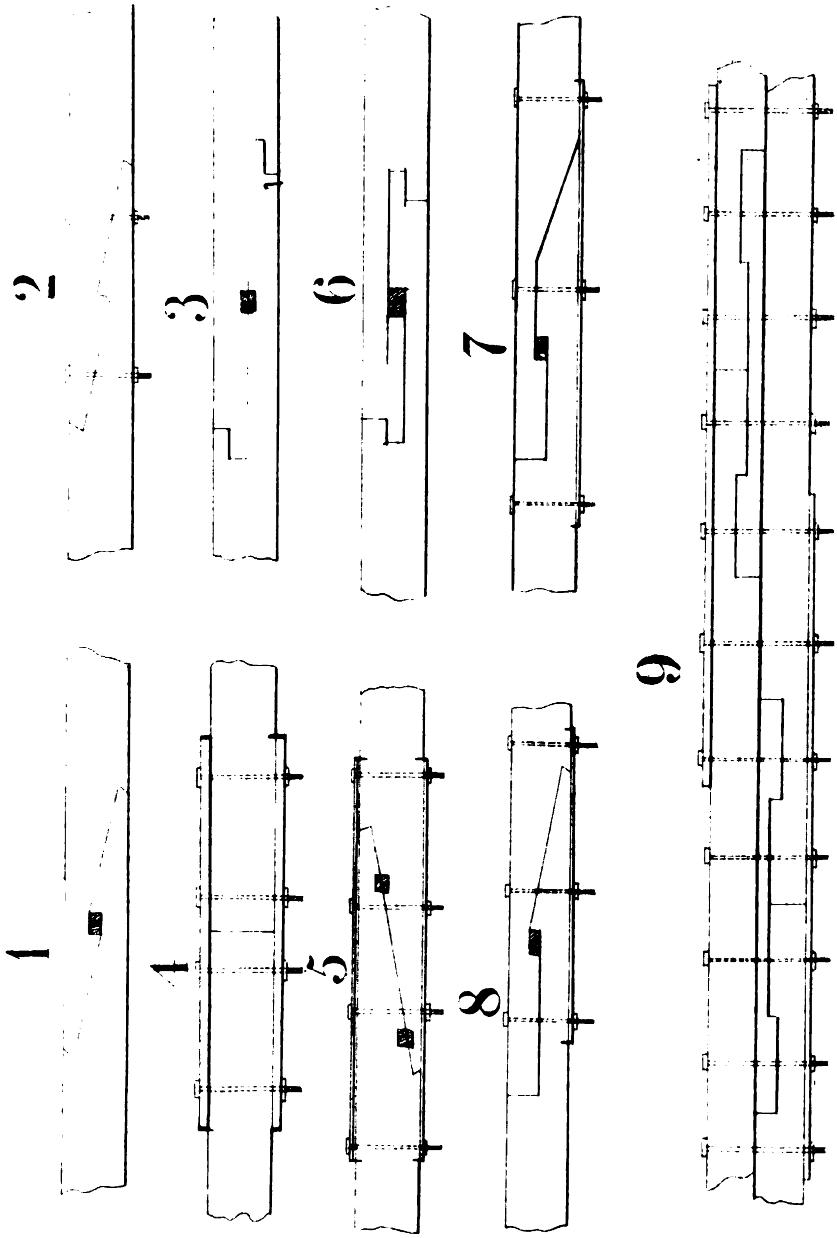


Plate 13.

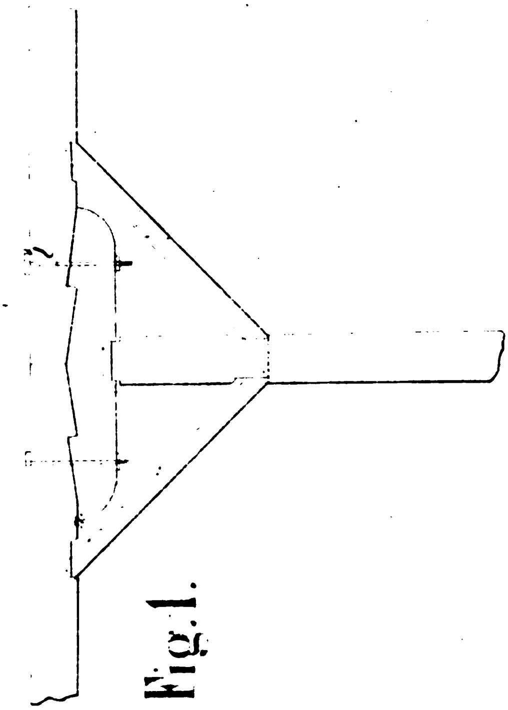


Fig. 1.

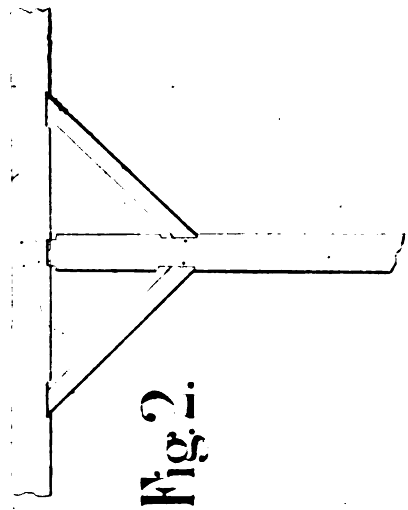


Fig. 2.

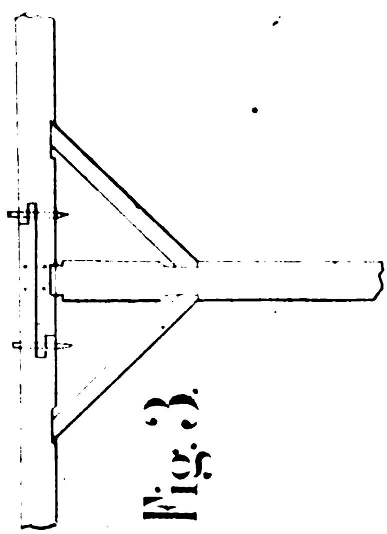


Fig. 3.

PLATE 13.

Scarfing, whenever it is practicable, should be made directly over a post, when a simple and inexpensive style, such as is exhibited in Plate 13, will be found sufficiently strong. Indeed, it is hardly possible to find a stronger mode of scarfing than that illustrated in Fig. 1; and yet, being supported by the post, the design is more simple than most of those represented in Plate 12.

In this design, the head of the post is framed into a bolster, which ought to be fully equal in size to the timber which it is required to support; in heavy frames it should be about 6 feet long, the braces being framed on a 4 feet run. The bolster is secured to the timber with inch bolts, as represented in the figure.

Fig. 1 also illustrates the proper mode of framing braces; the dotted lines show the form of the tenons, and the notchings in the post and the girder represent the facing of the mortices. These are usually notched-in half an inch at least, in order to give all possible support to the toe of the brace; and the measurement, for the length and the run of the braces, must be from the furthest point of the face of the mortice, inside of the notch, and not from the outside of the rough timber.

The shoulder of the post is also notched or *sized* into the bolster an inch, and the bolster is locked into the girder 2 inches; and, if the timber is 12 inches square, the shoulder of the post is 10 inches lower than it would be without any bolster; and the carpenter must, of course, make his brace mortices in the post, accordingly, 10 inches nearer the shoulder than usual.

Figs. 2 and 3 are designed to represent a less expensive mode of scarfing on posts. In these plans the tenons extend quite through, and are double-pinned to both timbers, as represented in the plate. This mode is sufficiently strong for scarfing plates and purlin plates.

PLATE 14.

FLOORS IN A BRICK BUILDING.

Plate 12, Fig. 1, exhibits the ground plan of one room, 18 feet wide. The joists are 2 by 10, 18 feet long.

Trimmer Joists.

Those marked A, B, and C, at each side of the fire-place, are called *trimmer joists;* they are 4 by 10; or they may be made by spiking two common joists together, as represented in the plate.

A course of *bridging* is represented at D, as described in Plate 6.

Fig. 2 and Fig. 5 exhibit the method of framing the tenons of the common joists.

Fig. 3 shows the mode of framing together the trimmer joists at the corners of the hearth

Fig. 4 shows the beveled ends of the joists where they are set into the brick wall. They are beveled in the manner represented, that the springing of the joists may not endanger the wall; and, in case of fire, the joists may burn and fall out without destroying the wall.

Plate 14.

Fig. 1.

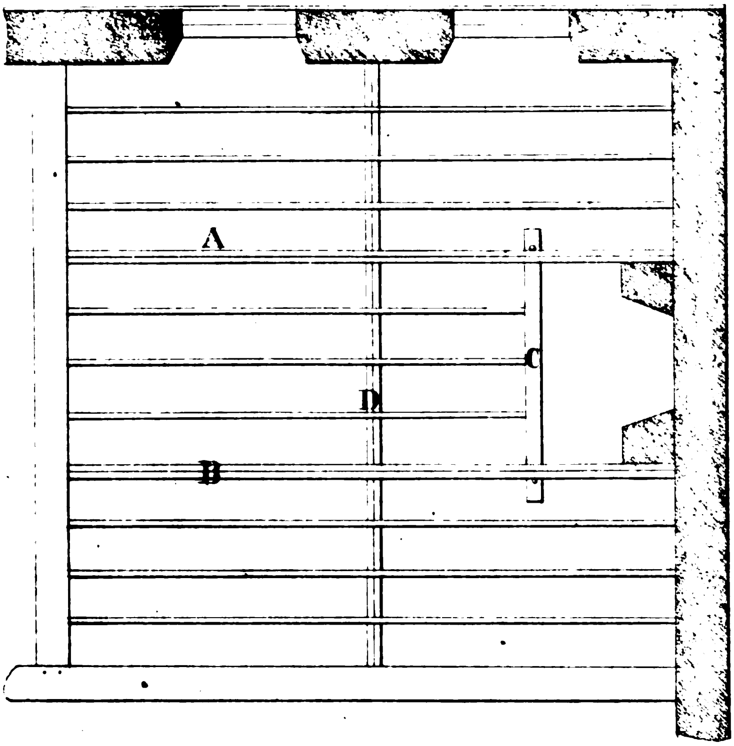


Fig. 3.

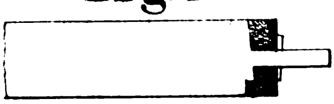


Fig. 2.

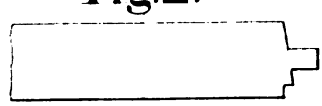


Fig. 4.

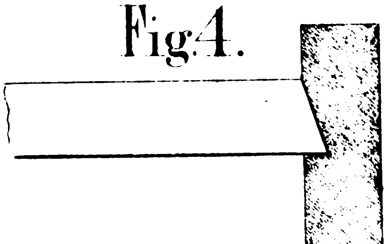
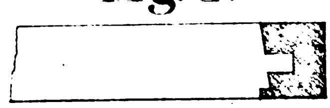
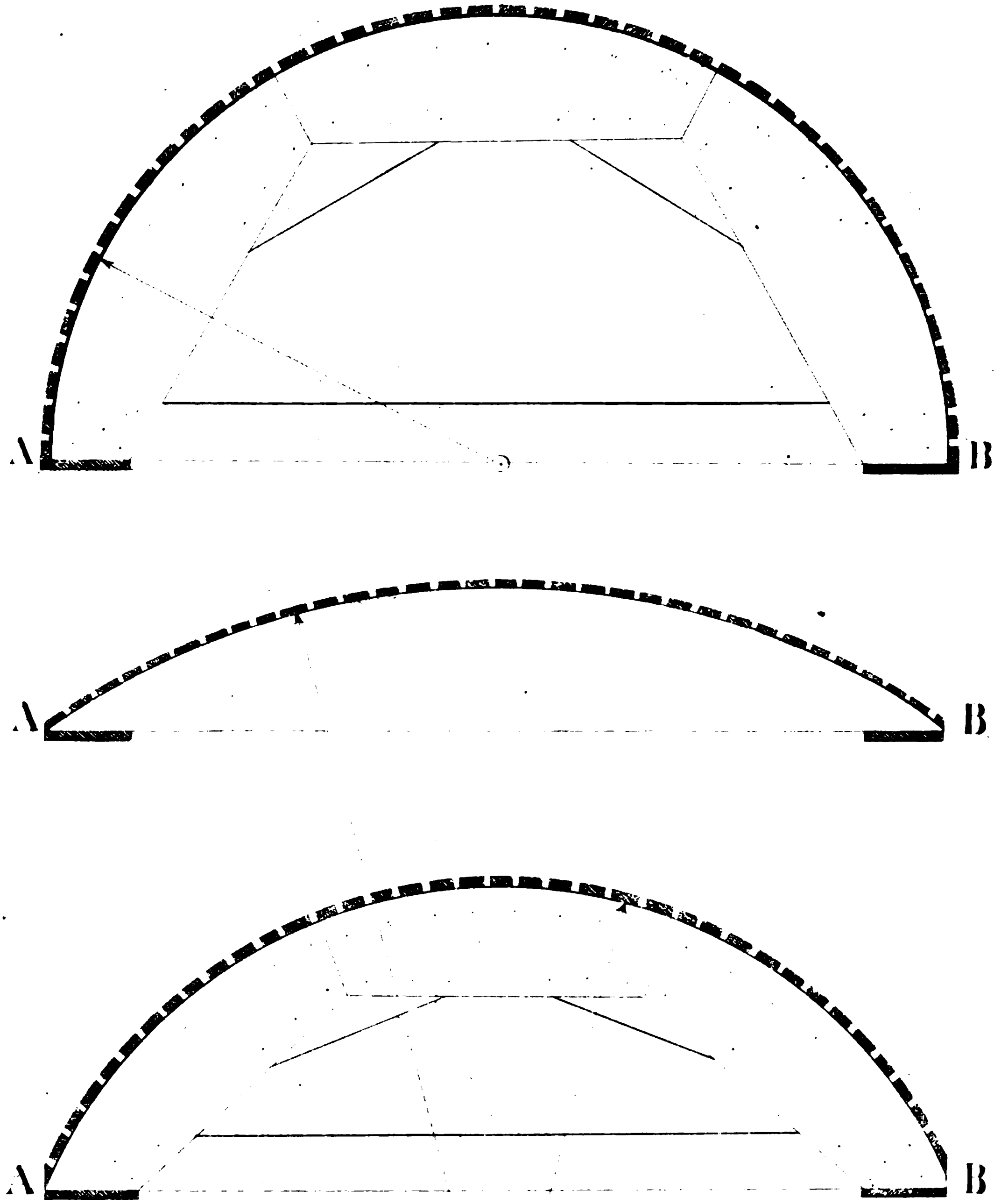


Fig. 5.



L. N. Rosenthal. Lith. Phil.

Plate 15.



L. N. Rosenthal Lith. Phil.

PLATE 15.

CIRCULAR CENTRES.

Plate 15 exhibits several designs, more or less convex, for the construction of centres, which are skeletons used by stone and brick masons to build an arch upon, but which are to be taken away when the arch is sprung and the mortar set.

First, draw the line AB upon a floor, two inches less than the width of the skeleton required, and take OA as a radius, and describe the semi-circumference. Inch boards are then to be fitted to this curved line, and their ends beveled to fit each other, as represented in the Plate. The bevel is determined by simply drawing a straight line from any point of the curve to the central point O. Other boards are then to be nailed over the joints, on the inside of these; and the long brace AB nailed at each end at the bottom.

Having prepared the other end of the skeleton in the same manner, strips of boards, an inch thick, two inches wide, and of a length equal to the thickness of the wall, are nailed upon their convex edges, as represented.

Should the arch have more than 12 feet span, it would be proper to use thicker boards; but for any thing less than 12 feet, inch boards are amply sufficient.

PLATE 16.

ELLIPTICAL CENTRES.

This Plate illustrates the manner of constructing elliptical centres. The elliptical curve is described most accurately by means of a *trammel,* the construction and use of which are explained in Plate 2, page 20.

In order to describe the curve for these centres, take AB equal to the span of the arch, less 2 inches, and set the trammel so that the intersection of the arms will fall upon O, the middle point of AB. Then set the pin B, so that PB will equal the height of the arch less 1 inch; and set the pin C so that PC will equal AO.

Plate 16.

Fig. 1.

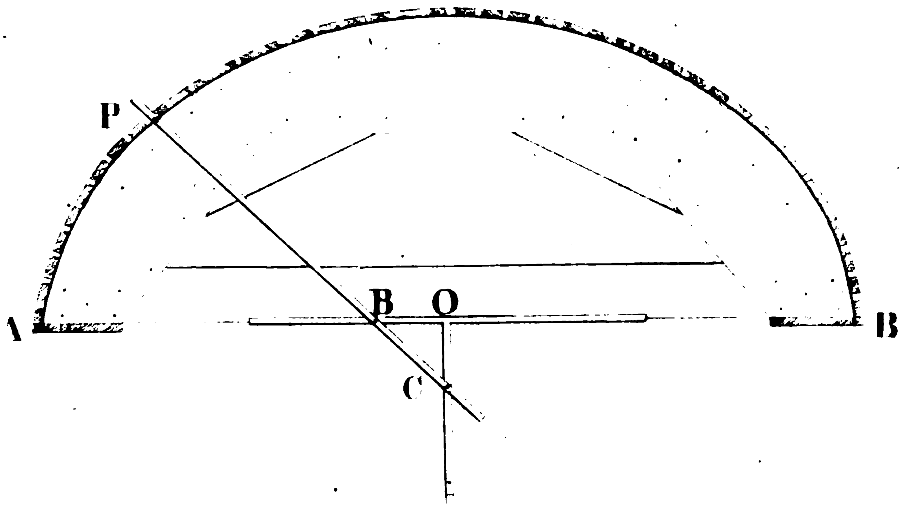
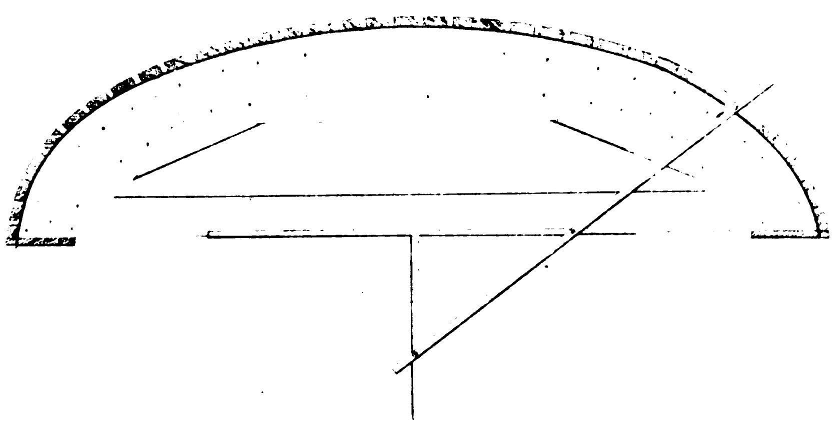


Fig. 2.



L. N. Rosenthal's Lith. Phil^a.

Plate 17.

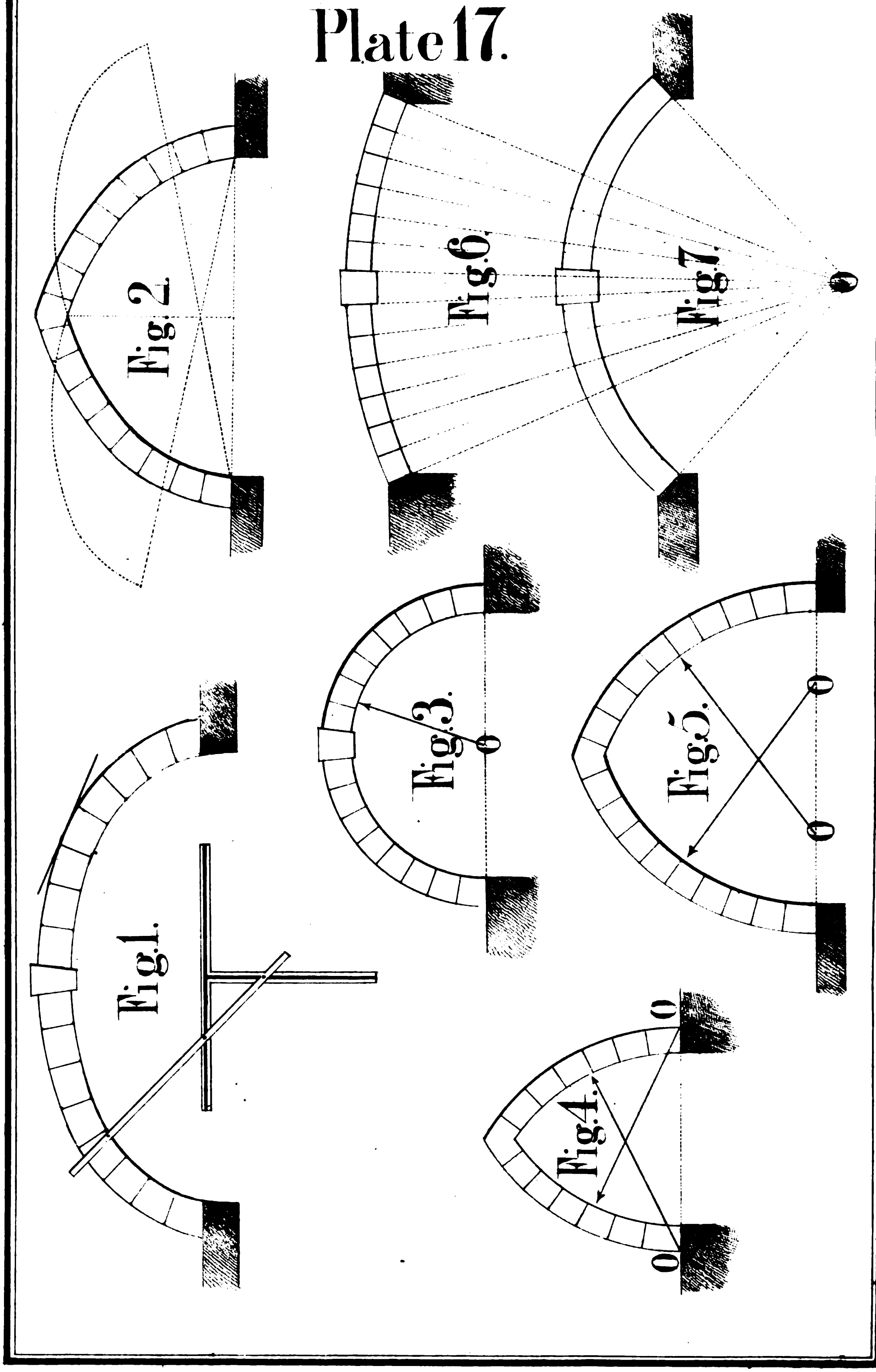


PLATE 17.

ARCHES.

It is also the business of the carpenter to prepare patterns for stone-cutters, by which they are to cut their stones to fit arches of any desired form. This Plate exhibits seven different styles of arches, with the most accurate and convenient modes of drawing them, and of dividing them into proper sections or patterns for the arch-stones.

Fig. 1 represents an elliptical arch, drawn by means of a trammel, as has been already described. The arch is divided into blocks of proper form and size, by first dividing the curve into any desired number of equal spaces; then, wherever a joint is required, first draw a tangent to the curve at that point, and then a line perpendicular to this tangent will divide the arch properly.

Fig. 2 exhibits the Tudor arch, drawn in two rampant semi-elliptical curves, as represented in the Plate. The same rule is to be observed as before for finding the joints of this arch, and for dividing it correctly into proper patterns.

Fig. 3 is a semicircular arch. This is most easily and correctly jointed by drawing a radius from the centre O to any point of the curve where a joint is desired.

Fig. 4 is a Gothic arch, described by two equal radii from the points O, O, as centres, and jointed from the same points.

Fig. 5 is so similar to the last, as to require no further description.

Figs. 6 and 7 exhibit two depressed segmental arches of the same span, but representing different degrees of curvature, one being drawn with a longer radius than the other, and both jointed by radii drawn from the common centre O.

PLATE 18.

HIP ROOFS.

Plate 18, Fig. 1, exhibits the plan of a hip roof in a building 50 feet long and 40 feet wide, the rise of the roof being 5 inches to the foot. AB, CD, and EF, are the upper girders, which are trussed for supporting the roof, with short principal rafters and straining beams, as represented in the Plate at CD.

GH, IH, KL, and ML, are the hip rafters, and HL the ridge pole. The purlin plates are placed upon the principal rafters, and the straining beams are framed on a level with the purlin plates, so that the end ones may answer the double purpose of straining beams and purlin plates also.

The lengths* and bevels of the common rafters, in the middle of the building, the upper ends of which rest against the ridge pole, are found as usual in common roofs. (Table No. 1.)

Hip Rafters.

The *length* of the hip rafters is given in the Hip Rafter Table, (No. 2, p. 119) where the rule for obtaining it is fully explained.

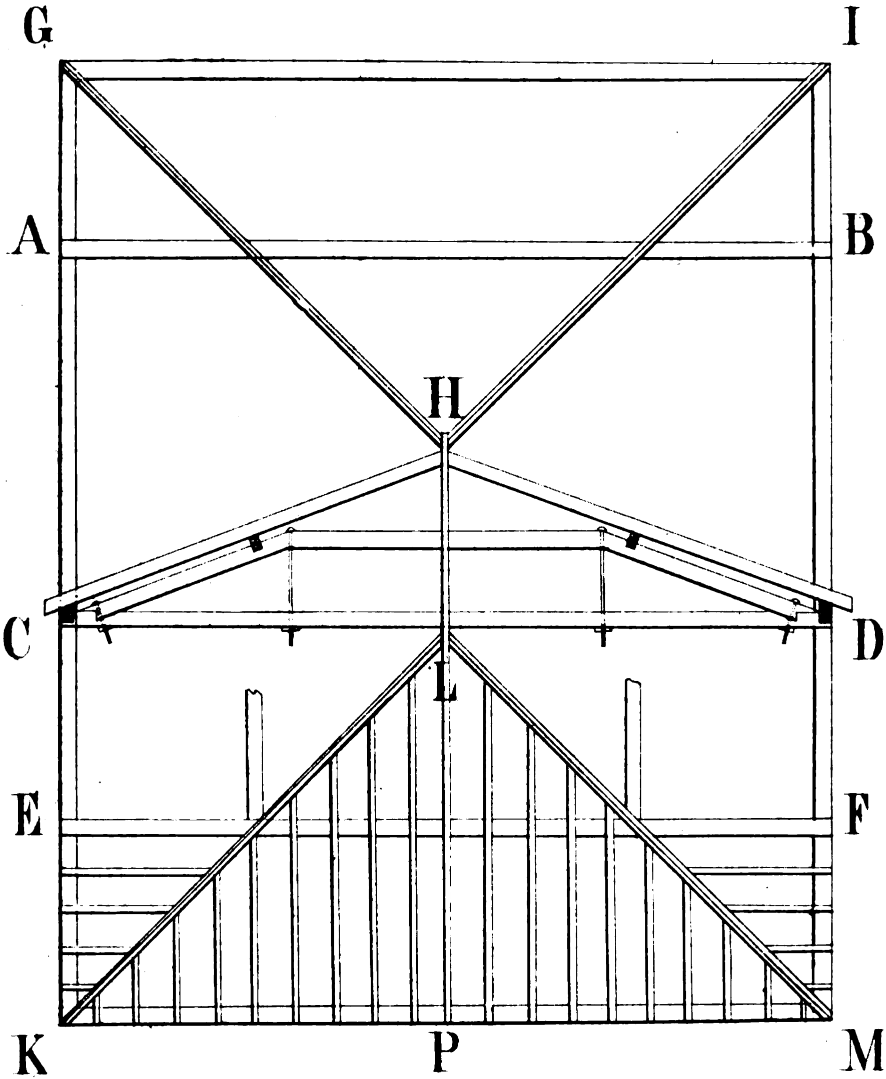
In addition to the two bevels common to all rafters, namely, the upper end bevel and the lower end bevel, hip rafters have two other bevels, which are the *side bevel*, as it is called, being the angle which the two hip rafters make with each other at their intersection, and the *backing*, which is the angle made by the intersection of the side roof with the end roof.

Side Bevel of the Hip Rafters.

It is evident that if there were no pitch to the roof, this bevel would be 45 degrees, since the two hip rafters would be perfectly square with each other; but as soon as the roof begins to rise, the hip rafters are no longer square with each other, but begin to approach a parallel,

* Throughout this work, the length of rafters is computed from the upper and outer corners of the plates to the very peak of the roof, without allowances for the projection of the rafters or the thickness of the ridge poles. In case the building has a ridge pole, therefore, it will be necessary to deduct one half the thickness of it from the length as given, measuring for this deduction square from the down bevel, and not lengthwise of the rafter.

Plate 18.



L. N. Rosenthal Lith. Phil.

till, in a very steep roof, as that of a tower or steeple, they are nearer parallel than square with each other. The side bevel, therefore, is always greater than 45 degrees, and is obtained from the square by taking the length of the hip rafter on the blade, and its run on the tongue; the blade then shows the side bevel of the hip rafter required.

Down Bevel of the Hip Rafters.

The upper end bevel is commonly called, in hip rafters, the *down bevel*. It is always square with the lower end bevel, the one being the complement of the other. This bevel varies with the pitch of the roof; for the pitch of the hip rafter always has the same proportion to the pitch of the common rafter, that the *run* of the common rafter has to the *run* of the hip rafter, or that the side of a square has to its diagonal; for, if we let O represent the foot of the perpendicular let fall from L upon the middle of the girder, CD, then ODPM is a square, of which OD, the run of a common rafter, is the side, and OM, the run of the hip rafter, is the diagonal. Now, it is a well-known principle in mathematics, that *the side of any square is proportioned to its diagonal, as* ONE *is to the* SQUARE ROOT OF TWO, (Prop. XXIV., *Cor.*); or, as 1 is to 1.4142; or, as 12 inches are to 17 inches *nearly*. When the common rafter, therefore, has 5 inches rise to 12 inches run, the hip rafter of the same roof has 5 inches rise to 17 inches run; and when the common rafter has 6 inches rise to 12 inches run, the hip rafter has 6 inches rise to 17 inches run; &c.

From these demonstrations we derive the following Rule for finding the down bevel and the lower end bevel of the hip rafters. *Take 17 inches on the blade of the square for the run, and the rise of the roof to the foot on the tongue.* The tongue will give the down bevel, or upper end bevel, and the blade the lower end bevel.

Backing of the Hip Rafters.

This is found on the square by taking the length of the hip rafter on the blade, and the rise of the roof on the tongue; the bevel of the tongue will be the backing required. For illustration, in this building the length of the hip rafters, as given in the Table, equals 29½ feet *nearly*, and the rise of the roof is 8½ feet. Take proportional parts of each on the square, and the tongue will give the backing; that is, place the square upon a strait edge, with the blade at the 14¾ inch mark, and the tongue at the 4¼ inch mark, and draw a scratch along the tongue; then set a bevel square to the angle which this scratch makes with the straight edge, and it is the backing required.

Lengths and Bevels of the Jack Rafters.

Since the pitch of the jack rafters is the same as that of the common rafters, the longest jack rafter, the upper end of which rests against the end of the ridge pole, is of the same length as the common rafters, as given in the Common Rafter Table, less half the thickness of the hip rafters at their side bevel on the ridge pole. The difference in length between the longest jack rafter and the next one, or between any two adjacent ones, is equal to their distance apart, added to the *gain* of the rafter in running that distance.

For example, in this building, the width being 40 feet, the *run* of the jack rafter is 20 feet, or 240 inches; and its *length*, on a pitch of 5 inches rise to the foot, is 260 inches; therefore, its *gain* is 20 inches in running 20 feet, or an inch to a foot. The jack rafters being 2 feet apart, the difference in length between any two adjacent ones is, therefore, 2 feet 2 inches.

Or, the length of the shorter jack rafters may be obtained from that of the longest one, by dividing the length of the longest one by the number of spaces between the longest one and the corner of the building; the quotient will be the length of the shortest one, and it will be also the difference between any two adjacent ones.

The *down bevel* and the *lower end bevel* are the same as the upper and lower end bevels of the common rafters.

The *side bevel* of the jack rafters is always more than 45°, for a similar reason as that given in the description of the side bevel of the hip rafters; and, since all the jack rafters have the same pitch as the common rafters, we have the following

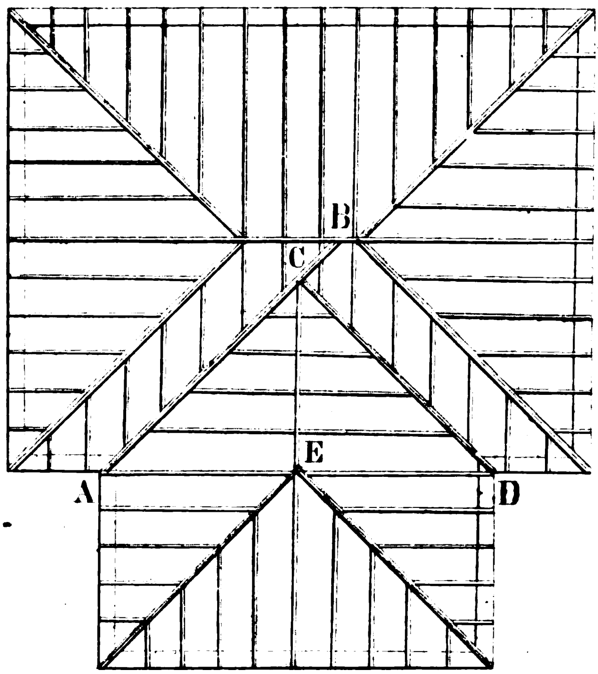
Rule for obtaining the side bevel of the jack rafters.—Take the length of a common rafter on the blade of a square, and its run on the tongue—or proportional parts of each. The bevel on the blade is the side bevel of all the jack rafters in the frame.

Or, take the length of the longest jack rafter on the blade, and half the width of the building on the tongue, or proportional parts of each, and the bevel on the blade will be the required side bevel.

Remark.—In a hip roof which is perfectly square, the hip rafters need have no side bevel; for two of them can be cut of full length, and set up, opposite each other first, with their down bevels resting full against each other like common rafters; the other two hip rafters can then be set against these, having been cut off half their thickness shorter than the full length.

Plate 19.

Fig 1.



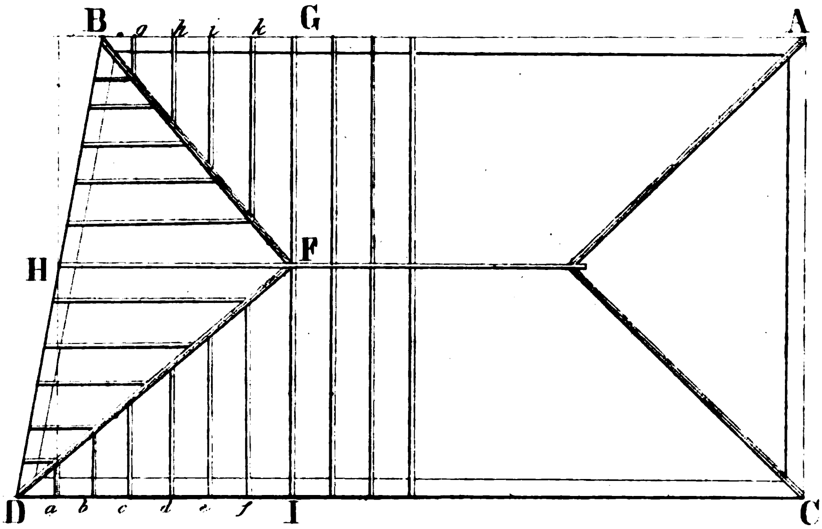


Fig 2.

Scale 10 Feet to the Inch.

L. N. Rosenthal's Lith. Phil.ª

PLATE 19.

HIPS AND VALLEYS.

Plate 19, Fig. 1, represents the hip roof of a building consisting of a main portion and a wing, the walls of the wing being of the same height as those of the main building. The main building being 24 by 30 feet, and the wing 10 by 20 feet, the roof of the wing being of the same pitch, will not rise as high as that of the other part.

The timbers AB and CD at the intersection of these roofs are called *valley rafters.* The upper end of the first one, AB, is extended to the ridge pole of the main building; the other valley rafter is supported by the first one, by being spiked to it at their intersection at C. From that point of intersection, a ridge pole extends to the intersection of the end hip rafters at E. This ridge pole is equal in length to the whole width of the wing; the valley rafter and hip rafter on each side being parallel with each other.

The lengths and bevels of the various rafters are found as explained in the preceding Plate.

TRAPEZOIDAL HIP ROOFS.

Fig. 2 exhibits the plan of a hip roof for a building constructed in the form of an irregular square, or trapezoid; the side CD being 4 feet longer than the side AB, the width 24 feet and the rise 5 inches to the foot.

The length and bevels of the common rafters and of the hip rafters on the square end of the frame are obtained in the same manner as described, in the regular hip roof. The lengths and bevels of the two hip rafters BF and DF on the beveled end of the frame are unlike each other, and unlike those on the square end, one being longer and the other shorter than those. As such buildings are comparatively rare, it has not been deemed necessary to encumber this work with a table for such rafters, but the facts and principles applicable to such frames are here stated.

Lengths of the Irregular Hip Rafters.

If this end of the building were square, then BG and DI would each of them be equal to half the width of the building, or 12 feet;

but since one side of the building is 4 feet shorter than the other side, the short side is 2 feet less than 12, and the long side 2 feet more than 12; or BG equals 10 feet, and DI equals 14 feet.

The length of the common rafters GF and IF is found by the table to equal 13 feet; and the two triangles GFB and IFD being right-angled, we are now furnished with the means of finding the lengths of the two hip rafters BF and DF, by the use of that familiar principle in mathematics, that *in every right-angled triangle the square of the hypotenuse is equal to the sum of the squares of the other two sides.* (Part I., Prop. XXIV.) For in the right-angled triangle GFB, we have the side GB equal to 10 feet, which we reduce to inches, to secure greater accuracy in calculation. GB then equals 120 inches, and GF, a common rafter, equals 13 feet or 156 inches. The square of 120 is 14,400, and the square of 156 is 24,336; the sum of these squares is 38,736, which is the same as the square of the hypotenuse BF; and by extracting the square root of 38,736 inches, we have 195 inches and 81 hundredths of an inch, or 16 feet 4.81 inches, as the length of the hip rafter BF.

The length of DF is found in a similar manner from the triangle IFD, DI being 14 feet or 168 inches, the square of which is 28,224, to which add the square of IF, equal to that of GF, found above to be 24,336. The sum of these squares is 52,560 inches, of which the square root is 229.25 inches, or 19 feet 1.25 inches, the true length of the longest hip rafter.

Bevels of the Irregular Hip Rafters.

The *down bevel* and the *lower end bevel* of these irregular hip rafters, like those of all other rafters, are square with each other: and are found together on the square by taking the *run* on the blade and the *rise* on the tongue; the tongue will give the down bevel, and the blade the lower end bevel.

Note.—Take the square of BG, and the square of DI, respectively; add to each the square of half the width of the building; extract the square root of each of these sums, and they will give the *runs* of BF and DF, respectively.

Thus, the square of BG, 10 feet, or 120 inches, is 14,400 inches; the square of DI, 14 feet, or 168 inches, is 28,224 inches; and the square of half the width of the building, 12 feet, or 144 inches, is 20,736 inches; this added to 14,400 is 35,136 inches, the square root of which is 187.44 inches, or 15 feet 7.44 inches, which is the *run* of BF.

Again, 20,736 added to 28,224 equals 48,960, the square root of which is 221.26 inches, or 18 feet 5.26 inches, the *run* of DF.

The *side bevel* of irregular hip rafters is obtained by adding together the distance from the foot of the hip rafter to the foot of the first common rafter, and the gain of the hip rafter; then take this sum on the tongue of a square, and half the width of the building on the blade; and the tongue will give the side bevel required.

Backing of Hip Rafters on Trapezoidal and other Irregular Roofs.

As the oblique angles of trapezoidal and other irregular buildings are liable to many variations, so the backing of the hip rafters must also vary on different roofs. The simplest and most practical manner of finding these backings, when thus irregular, is to take a small square block, and bevel one end of it to the same bevel as the lower end of the hip rafter in question. Then place this beveled end upon the plates, just as the hip rafter is to be placed, at the oblique corner of the building, and draw a pencil line on the under side of the block, along the upper and outer edges of the plates, till they meet at the corner; these lines will be the bevel of the backing required. And then the block can be worked off to the lines, and a bevel square set to the angle thus formed, by which the hip rafter itself can then be beveled.

Length of the Jack Rafters.

First. Of those on the long side of the building, between D and I. In the triangle DFI, the jack rafter *f*, being parallel with the base FI, has the same proportion to FI that D*f* has to DI (Geom., Props. XXV. & XXVII.); and in order to find the length of the jack rafters coming between I and D, we have only to divide IF by the number of rafters required from IF to the corner inclusively, and the quotient will be the difference between any two of them, and will equal also the length of the shortest one. Since it is 14 feet from I to the corner of the building, and the rafters are 2 feet apart, it will require 7 rafters, including IF. We therefore divide IF, 13 feet, by 7, and have 1 foot $10\frac{2}{7}$ inches for the difference between IF and *f*, and also between *f* and *e*; or, what is equally true, we can take this number, 1 foot $10\frac{2}{7}$ inches, as the length of *a*; double this, or 3 feet $8\frac{4}{7}$ inches, for the length of *b*; three times this number, or 5 feet $6\frac{6}{7}$ inches, for the length of *c*; 7 feet $5\frac{1}{7}$ inches, the length of *d*; 9 feet $3\frac{3}{7}$ inches, the length of *e*; 11 feet $1\frac{5}{7}$ inches, the length of *f*; and 13 feet the length of IF: proving the calculation to be correct. It will be most convenient in practice to cut the longest ones first, that the short pieces of stuff may be worked in to better advantage.

Second. In the same manner obtain the difference between GF and *k*, on the other side of the building, by dividing GF, 13 feet, by 5, the number of rafters required in GB; 13 feet divided by 5 equals 2 feet $7\frac{1}{5}$ inches; this is at once the length of *g* and the difference between any two adjacent rafters between B and G.

Third. Of those on the end of the building. Divide the length of HF by 6, which is the number of rafters required between HF and each corner of the building, including HF. HF equals the length of a common rafter, less 2 inches—the bevel of the hip rafters —or 12 feet 10 inches, which, divided by 6, equals 2 feet $1\frac{2}{3}$ inches, the length of each of the short rafters on the end, and also the difference between HF and the jack rafters on each side of HF.

Side Bevels of the Jack Rafters on the Sides of the Frame.

It is evident that, if the roof were horizontal, this bevel would be found on the square, by taking half the width of the building on the blade, and the distance from the corner of the building to the foot of the first common rafter on the tongue; but when the roof begins to pitch, this bevel will be too short; and the relation of the pitch of the roof to the length of the common rafter is such, that the side bevel of the jack rafters is obtained with perfect accuracy, by taking *the length of the common rafter on the blade, and the distance from D to I and from B to G, respectively, on the tongue*—the blade will give the side bevels required.

The *down bevels* and lower end bevels of these jack rafters on the sides of the frame are the same as those of the common rafters, since they have the same pitch that the common rafters have.

Side Bevels of the Jack Rafters on the Slant End of the Frame.

For a similar reason assigned above, *add to BG the gain of a common rafter in running the length of GB. Then take this sum on the blade of a square, and half the width of the building on the tongue,* and it will give the side bevel of the end rafters which are nearest BG. In like manner, add to DI the gain of a common rafter in running the length of DI. Take this sum on the blade, and half the width of the building on the tongue, and it will give the bevel required of those rafters nearest DI.

For illustration, BG equals 10 feet; as the common rafters are 13 feet long, in running 12 feet, they gain an inch in running a foot. So, in running 10 feet, a rafter would gain 10 inches. We therefore take a certain proportional part of 10 feet 10 inches on the blade of a square, say 10¾ inches, and the same proportional of half the width of the building, say 12 inches, on the tongue; the bevel of the blade is the side bevel for all those jack rafters on the end of the frame which are nearest GB, or which rest against BF.

So, also, DI equals 14 feet, to which add 14 inches; hence, take 15⅙ inches on the blade, and 12 inches on the tongue; the bevel on the blade will be the side bevels of those jack rafters on the end of the frame nearest DI, which rest against the hip rafter DF.

Down Bevel of the Jack Rafters on the Beveled End of the Frame.

In order to obtain these bevels and the corresponding lower end bevels with perfect accuracy, it is necessary to obtain them for each rafter separately, for there are no two of them which have the same pitch. In order to ascertain with ease what this pitch and the corresponding bevels are, it is necessary to suppose all these end rafters to be produced beyond where they now rest on the hip rafters, and all to rest upon a common ridge pole PR, which is drawn through the point F, and extends on a level with F directly over the points G and I. These rafters would then have each one the same pitch they now have, since we have not supposed their *direction* changed, but their *length* only. Now, however, the rise is 5 feet for each one, and their run can easily be computed from the length of BG; for the run of the one nearest B is 4 inches more than BG, or 10 feet 4 inches; that of the next one, 4 inches more, or 10 feet 8 inches; &c.

Now, in order to obtain the down bevel and the lower end bevel of any rafter, we take the run on the blade of a square, and the rise on the tongue.

The measurements of these bevels are therefore as follows:

5 inches on the tongue for each of them, and 10⅓ inches, 10⅔ inches, 11 inches, 11⅓ inches, 11⅔ inches, 12 inches, 12⅓ inches, 12⅔ inches, 13 inches, 13⅓ inches, 13⅔ inches, respectively, on the blade.

PLATE 20.

OCTAGONAL AND HEXAGONAL ROOFS.

Plate 20, Fig. 1, is designed to exhibit the proper mode of framing the roof of a building, the ground plan of which is a *regular octagon.* This style of building having become quite common, a Rafter Table (No. 3) has been prepared, which will be found very useful and convenient, as it gives at one view the precise lengths of the longest hip rafters and the longest jack rafters. In the introduction or explanation of the table, full instruction and demonstrations are given for enabling the intelligent mechanic to test these calculations, or to extend and apply them to roofs of other dimensions.

Length of the Hip Rafters.

The length given in the Table is that of the first pair, and is calculated from the outer and upper corner of the plates, at their intersection with each other, to the very central point or apex of the roof.

One of the first pair having been cut off of the above length and of the proper down bevel, the length of the second pair is obtained from this one, by taking off from this one half its thickness, measured back square from the down bevel; and the length of the third and fourth pairs, by taking off in like manner two thirds its thickness, or more accurately, $\frac{17}{24}$ of its thickness, since 17 is half the diagonal of a square, the side of which is 24. (See Prop. XXIV., *Cor.*)

Bevels of the Hip Rafters.

The *down bevel,* and lower end bevel, are found as usual, that is, by the run of the rafter and its rise, on the square. (The *run of the hip rafter* is half the diagonal width of the building. See Explanation of Octagonal Hip Roof Table.)

The first and second pairs of hip rafters have no *side bevel,* since, in raising the frame, the first pair, HI, have their ends resting against each other, as in common rafters. The second pair, AP, are next raised at right angles with the first, and their ends resting square against the first. The third and fourth pairs have their side bevels

Plate 20

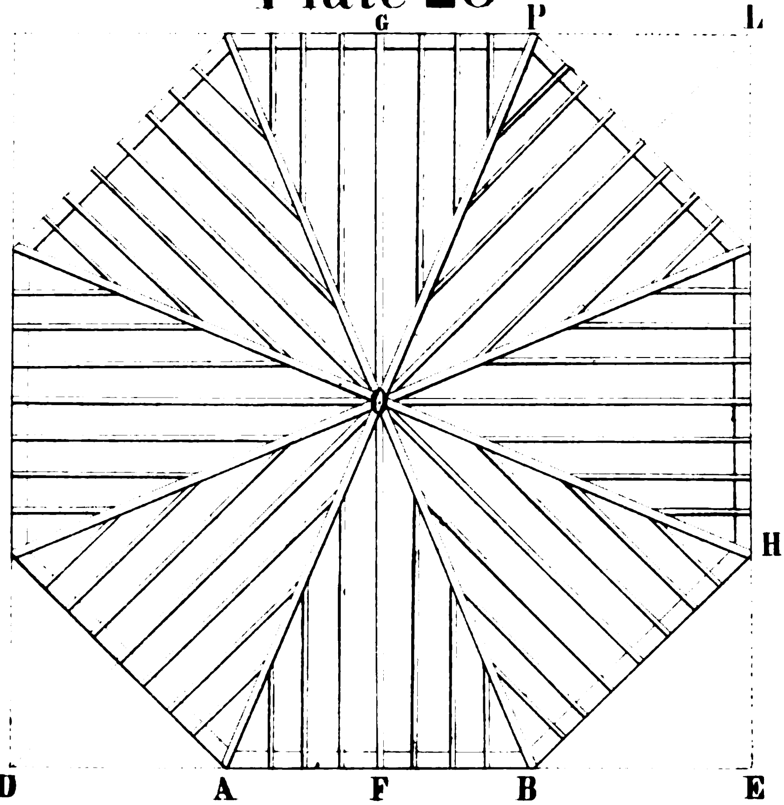


Fig. 1.

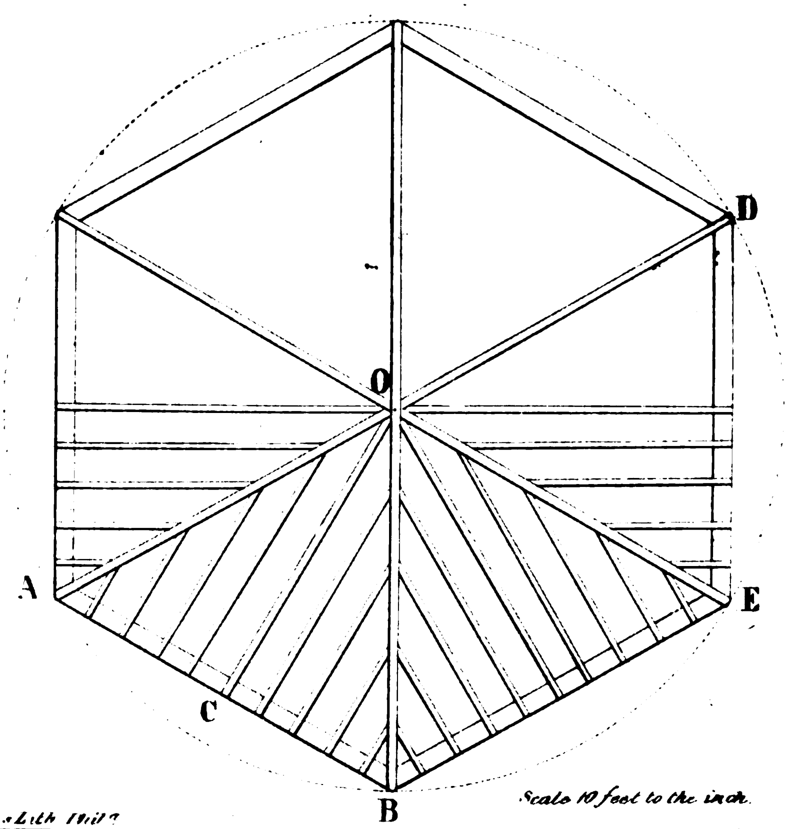


Fig. 2.

L. N. Rosenthal's Lith. Phil.a

Scale 10 feet to the inch.

cut on both sides of the upper end; and that bevel is found by taking the length of the rafter and its run on the square.

The *backing* of the *hip rafter* is obtained on the square by taking $\frac{5}{12}$ of its *rise* on the tongue, and its *length* on the blade.

Length of the Jack Rafters.

The length of the middle jack rafters is given in the Table. Having found this, in order to obtain the length of the shortest one, proceed as directed in the article on trapezoidal hip roofs; that is, divide the length of the longest one by the number of rafters required between that and the corner inclusively—the quotient will be the length of the shortest one, and also the difference between any two adjacent ones.

THE BEVELS OF THE JACK RAFTERS are obtained on the same principle as those in common hip roofs.

The *down bevel* is found on the square by taking the length and the run of the middle jack rafter; and the *side bevel* by taking the length of this rafter and half the side of the building.

Fig. 2 represents the roof of a building, the ground plan of which is a *regular hexagon.*

Width of the Building.

In every regular hexagon the *side* is equal to the radius of the circumscribed circle; and the *diagonal width* is equal to the diameter of the circumscribed circle, or twice the side. If we let O′ represent the foot of the perpendicular let fall from O, then AB and BE are each equal to AO′ and BO′, and AD is equal to twice AB.*

Half the *square width of the building* is found by subtracting from the square of the side, the square of half the side, and extracting the square root of the difference: since, in the right-angled triangle CO′B, $CO'^2 = BO'^2 - CB^2$. The side of this building being supposed to be 20 feet, we have the square of 20=400, and the square of $\frac{20}{2}=100$; their difference is 300 feet, the square root of which is 17.35 feet, or 17 feet 4.2 inches, which is half the width of the building, or the run of the middle jack rafter

The Length of the Rafter

Must be computed as explained in the Introduction to the Rafter

* See Geom., Prop. XXXI.

Table; that is, to say, every rafter is the hypotenuse of a right-angled triangle, of which its *run* and its *rise* are the other two sides. The square of the length is therefore equal to the sum of the squares of the run and the rise.

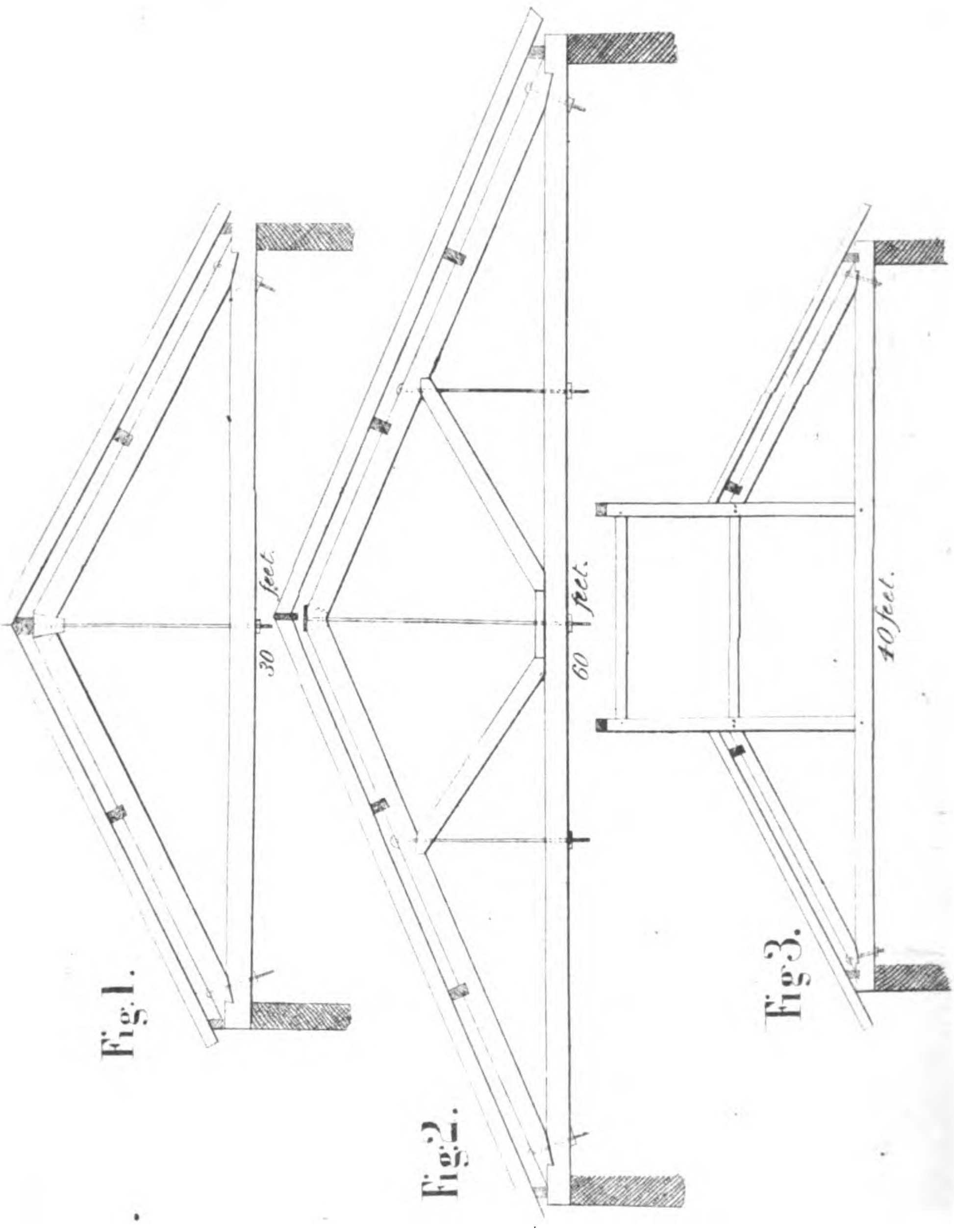
In this Fig. the roof is supposed to rise 3 inches to the foot. The whole rise is therefore one fourth the run of the middle jack rafter, or one eighth the square width of the building, or 4 feet 4.05 inches, the square of which is 2,709.2025 inches. The run of the hip rafter we have already proved to be equal to the side of the building, or 20 feet=240 inches, the square of which is 57,600 inches. The square root of the sum of the above two numbers is 245.56 inches, or 20 feet 5.56 inches, which is the length of the hip rafter.

In a similar manner the length of the *middle jack rafters* is found to be 17 feet 10.26 inches. The length of the shortest jack rafters is obtained in the same manner as in hip roofs generally.

The *bevels of the hip jack rafters* are obtained by the same rule as in octagonal roofs.

The *backing of the hip rafters* is found on the square by taking $\frac{7}{12}$ of its rise on the tongue, and its length on the blade.

Plate 21.



L. N. Rosenthal's Lith. Phil^a

PLATE 21.

ROOFS OF BRICK AND STONE BUILDINGS.

Plate 21, Fig. 1, exhibits a simple and excellent mode of framing a roof of a moderate span of from 25 to 35 feet, designed for a stone or brick building. The iron bolts, by which the feet of the principal rafters are secured to the tie-beam, are ¾ of an inch in diameter, and the supporting rod in the middle is 1 inch in diameter. The block between the upper ends of the principal rafters, is beveled to suit the pitch of the roof, while the ends of the principal rafters are square. The block should be of hard wood, and placed with its grain running in the same direction as that of the rafters, to avoid shrinkage.

By means of the supporting rods, any proper degree of camber or crowning can be given to the tie-beam.

The bolts and rods in this and the following figures are left rough in the Plates, to show them more distinctly; but if the rooms beneath are to be ceiled or plastered, the heads of the bolts should be countersunk into the beam, and the nuts screwed upon the upper ends.

Fig. 2 represents another style of roof, with two braces and two additional rods to each bent, and also a 2 inch block of hard wood about 2 feet long, placed between the feet of the braces. The grain of this block should also run parallel with the beam.

Length and Bevels of the Braces.

Suppose the distance of the upper end of the brace mortice in the principal rafter from the heel of that rafter to be five ninths of the whole length of that rafter, then the perpendicular let fall from the heel of the brace to the tie-beam will be five ninths of the rise of the rafter—and this we will call the *rise of the brace;* then also the distance from the foot of this perpendicular to the toe of the foot of the brace, will be four ninths of one half the length of the tie-beam less 2 feet—one foot for the setting back of the principal rafter, and one foot for half the block at the foot of the brace: this is the *run of the brace;* then the sum of the squares of the rise and the run will give the square of the length of the brace, the square root of which will be that length from the lower toe to the upper heel.

The Span of this Roof

May be from 50 to 65 feet. The middle rod should be 1¼ inches, the others ¾ of an inch.

Dimensions of Timbers for Figs. 1 & 2.

For both frames—Rafters, 2 by 6; plates and purlin plates, 6 by 8.

For each bent in Fig. 1—Tie-beams, 8 by 10; principal rafters, 7 by 9.

For each bent in Fig. 2—Tie-beams, 10 by 12; principal rafters, 7 by 10; braces, 6 by 7.

The bents in each frame may be from 10 to 14 feet apart.

Fig. 3 represents a simple mode of framing a roof for a shop or foundry, where it is required to have a ventilator.

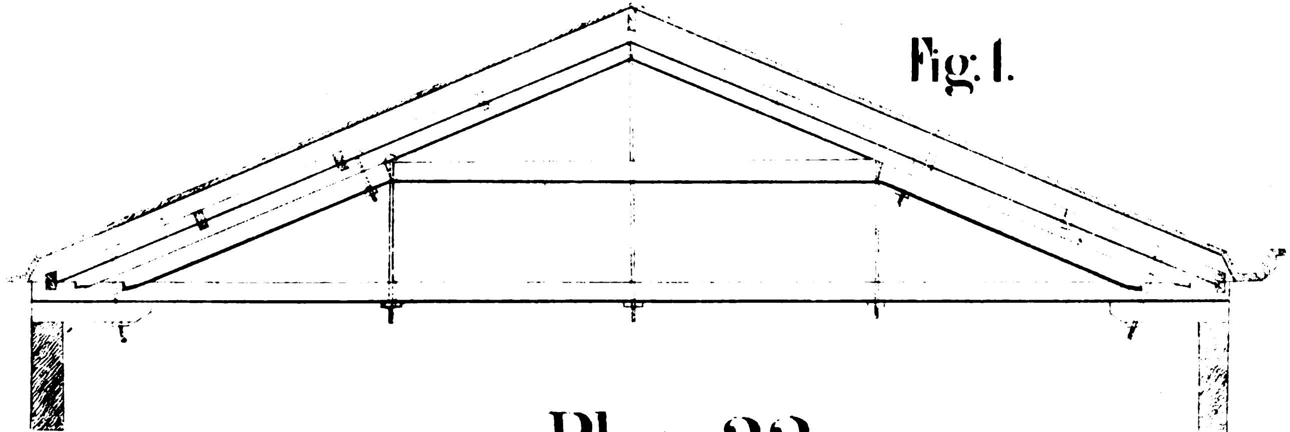


Fig. 1.

Plate 22.

Scale = 8 feet to the inch

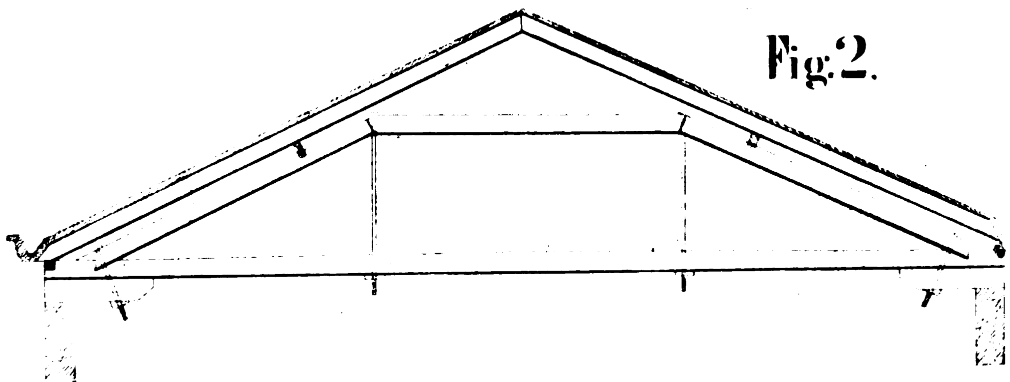


Fig. 2.

L. N. Rosenthal Lith. Phil.

PLATE 22.

Fig. 1 represents a bent of a very strong roof, designed for machine shops and other buildings, where it is necessary for great weights or heavy machinery to be supported by them. The Author of this work has superintended the construction of roofs of this kind upon the machine shops for the Railroad Works at Peoria, Ill., and at Davenport, Iowa, where they have proved sufficiently strong to sustain locomotive engines weighing more than twenty tons, when hoisted from the ground, and suspended by chains from the roof for repairs.

The width of the building represented in Fig. 1 is 50 feet; the principal rafter is set back a foot from the end of the tie-beam, to give room for the wall plate; the rise of the roof is 5 inches to the foot. In framing roofs of this kind, the supporting rods should be furnished before commencing the frame: for then the length of the short principal rafters and that of the straining beam, can be regulated or proportioned according to the length of the rods. It is best, however, for the middle rod to be twice the length of the short ones, reckoning from the upper surface of the beam to the upper surface of the principal rafters, and allowing 1 foot more to each rod for the thickness of the beam, and the nut and washer. For example, the middle rod is 11 feet long, and the short ones 6 feet each; which, after allowing 1 foot, as above mentioned, makes the length of the long one, above the work side of the beam, twice that of the short ones.

The length of the rod above the beam is the rise of the rafter, and the distance from the centre of the rod to the foot of the rafter is the run of the rafter; the length of the rafter can therefore be found from the Common Rafter Table.

Length of the Straining Beam.

Add the run of the short principal rafter to the lower end bevel of the long one; subtract this sum from the run of the long principal, and the difference will be half the length of the straining beam.

The *bolsters* under the ends of the tie beams are of the same thickness as that, and about 5 feet long.

Fig. 2 is in every respect similar to Fig. 1, with the exception of the long principal rafters and the middle supporting rod being omitted. This roof is suitable for blacksmith shops and foundries, as it is also capable of sustaining great weights, and may be very convenient for the safe storing of unwrought iron bars upon the beams.

PLATE 23.

This plate exhibits sections of three roofs, of different dimensions, but similar to each other in style. This style is ancient, and, no doubt, has been proved of sufficient strength; but it is not recommended for convenience or economy, except where labor is cheap, timber plentiful, and iron scarce.

In Fig. 1, the post in the middle is called the *king post*, and the other two *queen posts*. The tie beam is secured to their feet by iron straps; and braces extend in pairs from the posts to the principal rafters, as represented in the Plate. The heads of the posts are beveled to correspond with the pitch of the roof, and the ends of the principal rafters are left square.

The manner of scarfing the tie beam is represented immediately below.

Fig. 2 is very similar in design to Fig. 1, in the preceding Plate, the principal difference consisting in having king and queen posts instead of supporting rods.

Fig. 3 shows the ridge pole supported by braces from the ends of the straining beam. The king post is, therefore, omitted; and the space between the queen posts may be appropriated for an attic chamber. The queen posts are let into the tie-beam an inch or more, to prevent displacement by the lateral pressure of the braces.

Plate 23

Fig 1.

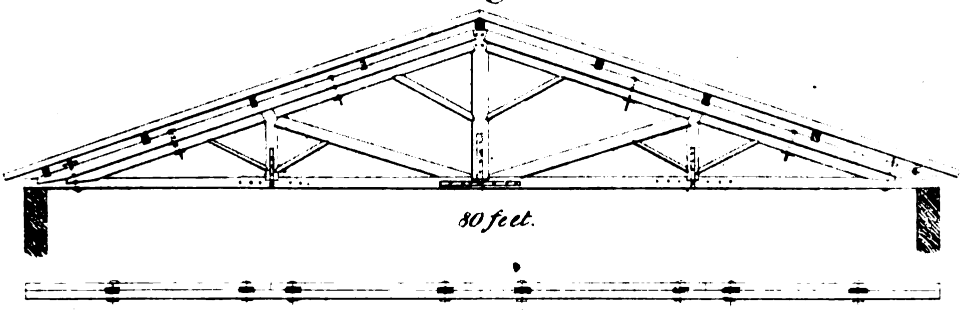


Fig. 2.

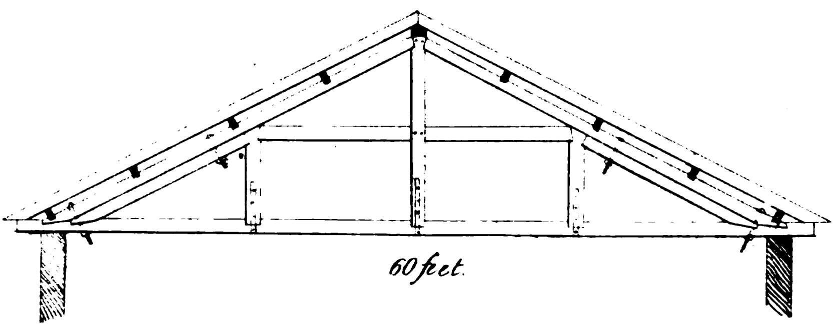
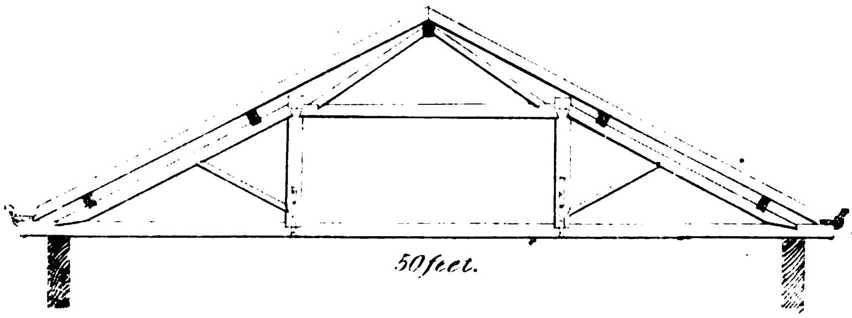


Fig. 3.



L. N. Rosenthal's Lith Phil.a

Plate 24.

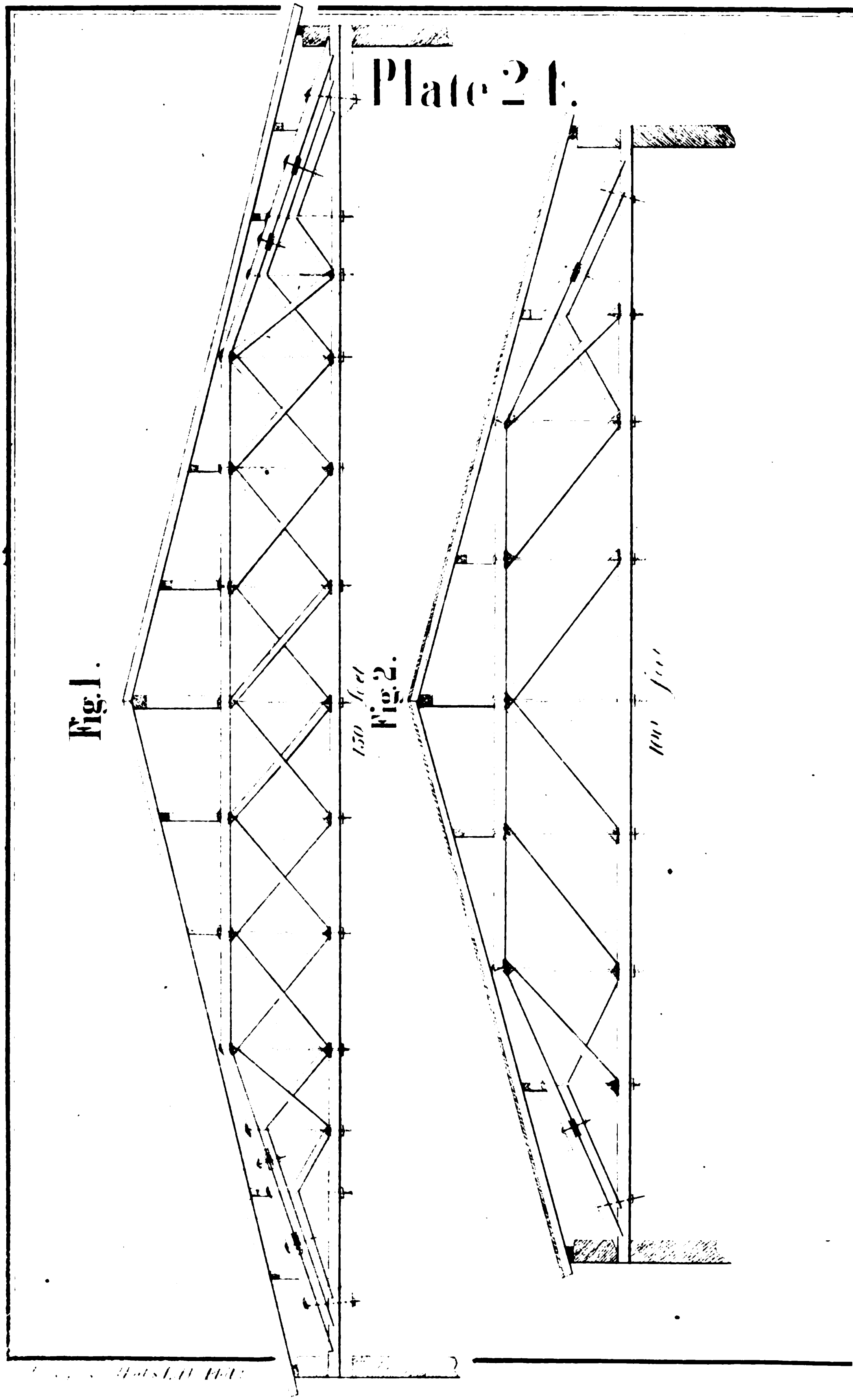


PLATE 24.

Plate 24 exhibits several designs for roofs in a new and improved style, particularly adapted to those of a great span, as they may be safely extended to a very considerable width, with less increase of weight, and less proportionate expense, than any of the older styles. The principle on which they are constructed is essentially the same as that of the Howe Bridge. The braces are square at the ends, the hard wood blocks between them being beveled and placed as described in the foregoing Plates. Each truss of this frame supports a purlin post and plate, as represented.

These roofs are easily made nearly flat, and thereby adapted to metallic covering, by carrying the walls above the tie beams to any desired height, without altering the pitch of the principal rafters, which ought to have a rise of at least 4 inches to the foot, to give a sufficient brace to the upper chord or straining beam.

Fig. 1 is represented with counter-braces; and

Fig. 2 without them. The counter-braces do not add any thing to the mere support of the roof, and are entirely unnecessary in frames of churches, or other public buildings, where there is no jar; but they may very properly be used in mill frames, or other buildings designed for heavy machinery.

PLATE 25.

This Plate exhibits two plans for roofs of the same style as the last, but of simpler construction, and designed for a shorter span.

In Fig. 2 the middle truss is omitted, to afford room for an attic chamber.

Plate 25

Fig 1.

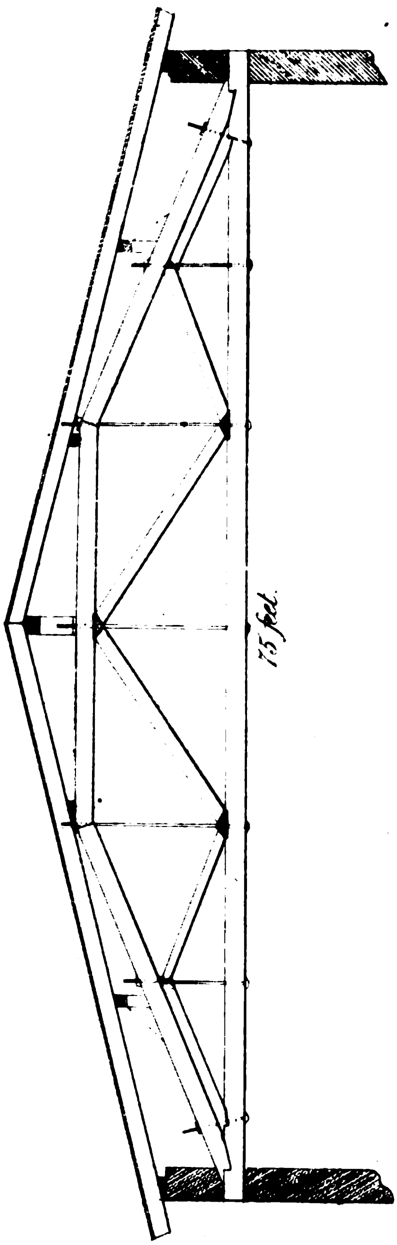
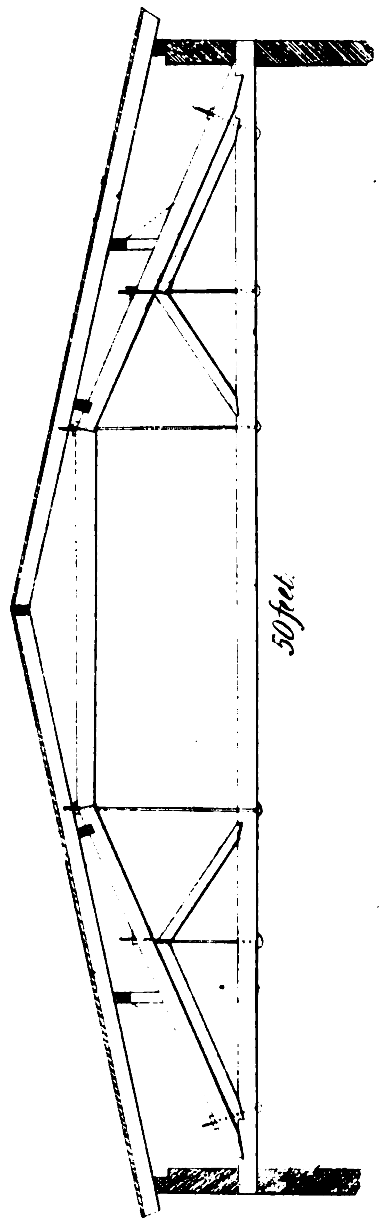


Fig 2.



L. N. Rosenthal's Lith Phila.

Plate 26.

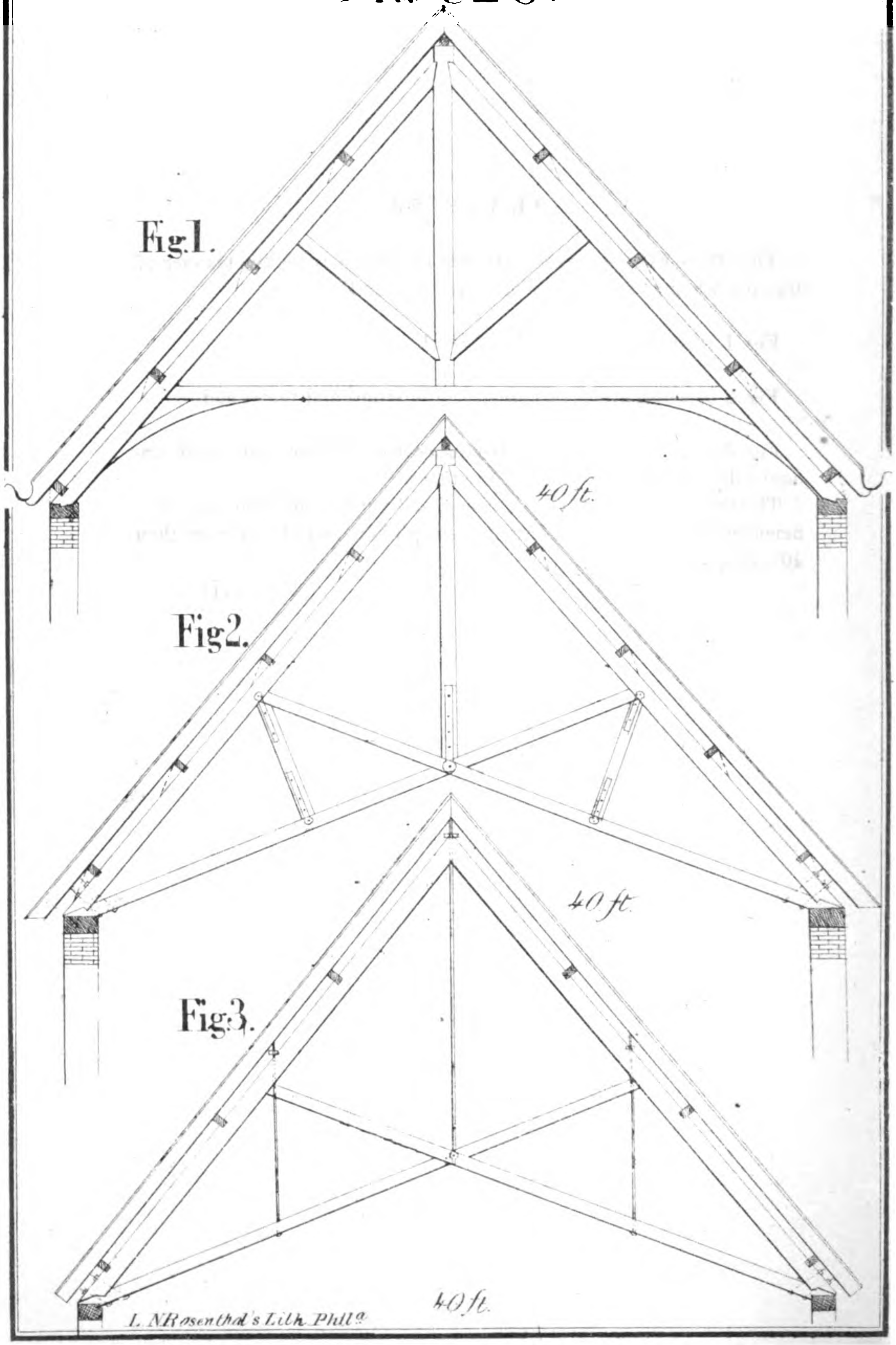


PLATE 26.

This Plate exhibits several designs of Gothic roofs, the manner of framing which is sufficiently indicated by the Plate.

Fig. 1 is constructed entirely of wood.

Fig. 2 of wood, strengthened with iron straps and bolts; and

Fig. 3 with still less wood, but supported by iron rods; and, undoubtedly, the strongest roof of the three.

The first is, however, a neat, cheap, and very simple plan, and sufficiently strong for a roof having a steep pitch, and of not more than 40 feet span.

PLATE 27.

Plate 27 represents two designs for church roofs, with arched or vaulted naves.

In Fig. 1 the arch is formed of 2 inch planks, from 6 to 8 inches wide, after being wrought into the proper curve. These planks are doubled, so as to break joints, and firmly spiked together. Lighter arches, of similar construction, are sprung, at a distance of 16 inches apart, between the bents, for supporting the lathing.

In Fig. 2 the arch is formed of 3 inch planks, 10 to 12 inches wide, and made in three sections, and spiked to the braces, as represented.

Note.—**The foregoing designs for roofs have been selected from more than a hundred drafts in the Author's possession, and are believed to be the best selection ever offered to the public eye. The number could have been increased with ease to an indefinite extent; but it has been deemed necessary to insert those only which are at once excellent and practicable, and which combine the latest improvements.**

Plate 27.

Fig. 1.

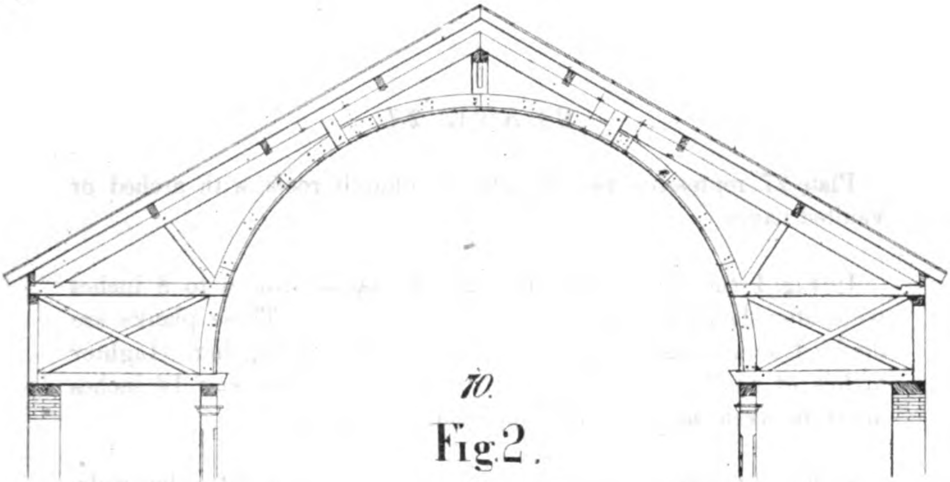
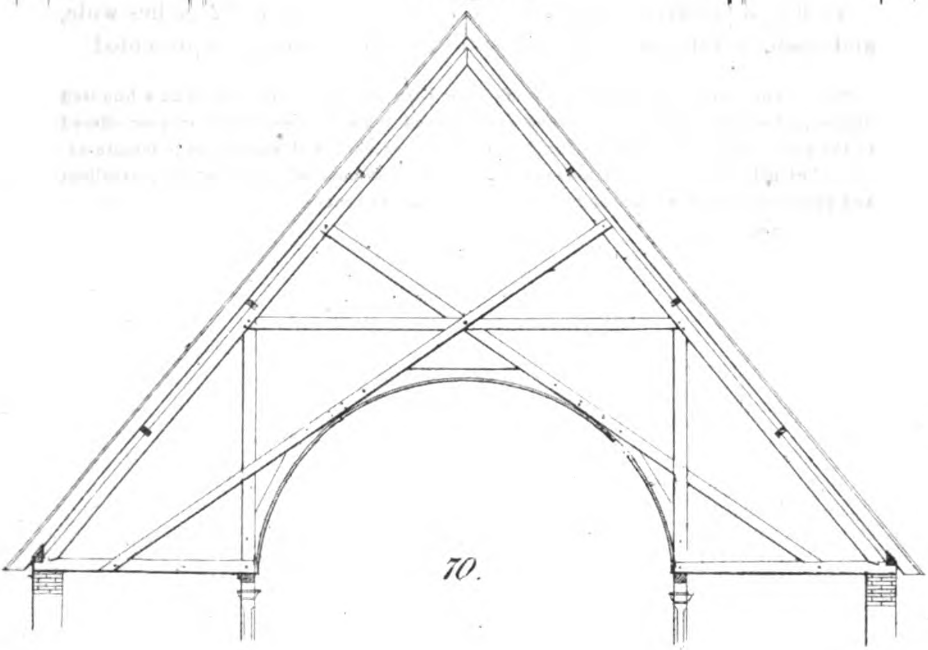
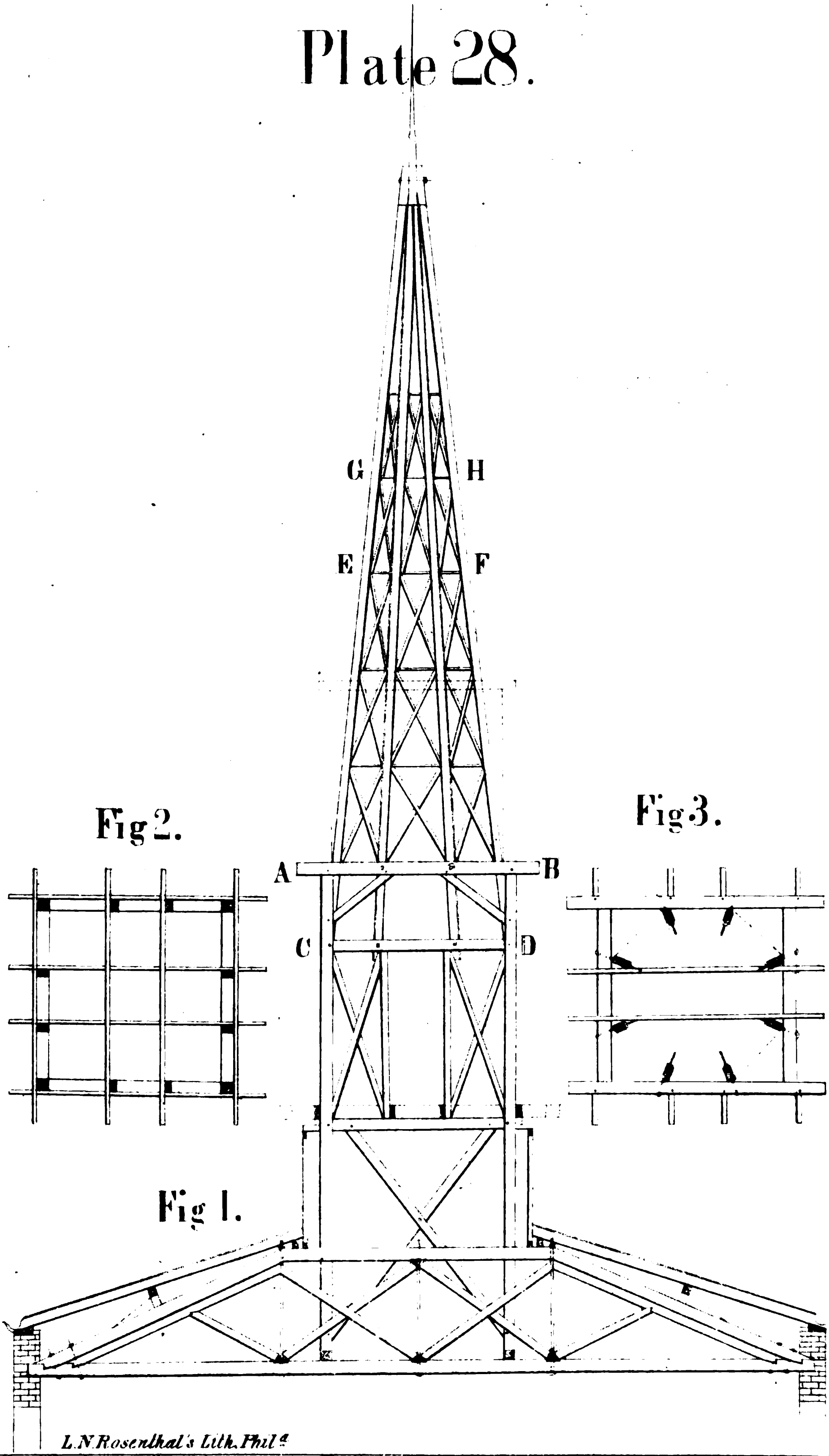


Fig. 2.



L. N. Rosenthal's Lith. Phil.a

Plate 28.



L. N. Rosenthal's Lith. Phil^a

PLATE 28.

Plate 28 exhibits the frame-work of a church spire, 85 feet high above the tie beam, or cross timber of the roof. This is framed square as far as the top of the second section, above which it is octagonal. It will be found most convenient to frame and raise the square portion first; then to frame the octagonal portion, or spire proper, before raising it: in the first place letting the feet of the 8 hip rafters of the spire, each of which is 48 feet long, rest upon the tie beam and joists of the main building. The top of the spire can, in that situation, be conveniently finished and painted, after which it may be raised half way to its place, when the lower portion can be finished as far down as the top of the third section. The spire should then be raised and bolted to its place, by bolts at the top of the second section at AB, and also at the feet of the hip rafters at CD. The third section can then be built around the base of the spire proper; or the spire can be finished, as such, to the top of the second section, dispensing with the third, just as the taste or ability of the parties shall determine.

Fig. 2 presents a horizontal view of the top of the first section.

Fig. 3 is a horizontal view of the top of the second section, after the spire is bolted to its place.

The lateral braces in the spire are halved together, at their intersection with each other, and beveled and spiked to the hip rafters at the ends. These braces may be dispensed with on a low spire.

A conical finish can be given to the spire above the sections, by making the outside edges of the cross timbers circular.

The bevels of the hip rafters are obtained in the usual manner for octagonal roofs, as described in Plate 20

Note.—In most cases the *side* of an octagon is given as the basis of calculation in finding the width and other dimensions; but in spires like this, where the lower portion is square, we are required to find the side from a given width. The second section in this steeple, within which the octagonal spire is to be bolted, is supposed to be 12 feet square outside; and the posts being 8 inches square, the width of the octagon at the top of this section, as represented in Fig. 3, is 10 feet 8 inches, and its side is 4 feet 5.02 inches, as demonstrated in the explanation of the Table for Octagonal Roofs (No. 8).

The side of any other octagon may be found from this by proportion, since all regular octagons are similar figures, and their sides are to each other as their widths, and, conversely, their widths are to each other as their sides.—See Explanation of Table No. 8.

PLATE 29.

Plate 29 exhibits the plan of a large dome of 60 or 75 feet span, built upon a strong circular stone or brick wall. In constructing this roof, there are four bents framed, like the one exhibited in Fig. 1, all intersecting each other beneath the king post at the centre. The tie beams in the first and second bents are of full length, and halved together; those in the third and fourth bents are in half lengths, and mitred to the intersection of the first and second.

The King Post.

Has eight faces, and on each face two braces; one large brace from the top of the post to the end of the tie beam, and one small brace from the bottom of the post to the middle of the large brace. These four tie beams are supported by eight posts, extending from the top of the main wall to the ends of the beams, and each one braced as represented in the figure.

Two circular arches, constructed of planks, as described in Plate 27, are then sprung, one above and one below each bent, as represented in the figure. Between each of these four arches, three others are constructed, supported by short timbers, framed into the ties of the tie beam, as represented in Fig. 2.

Fig. 2 is a horizontal section of the dome, drawn through it at the main tie beam AB, which corresponds with AB, in Fig. 1.

Fig. 3 is a horizontal view of the apex of the dome, where all the 32 arches intersect each other, showing the mode of beveling them at their intersection.

Plate 29.

Fig. 2.

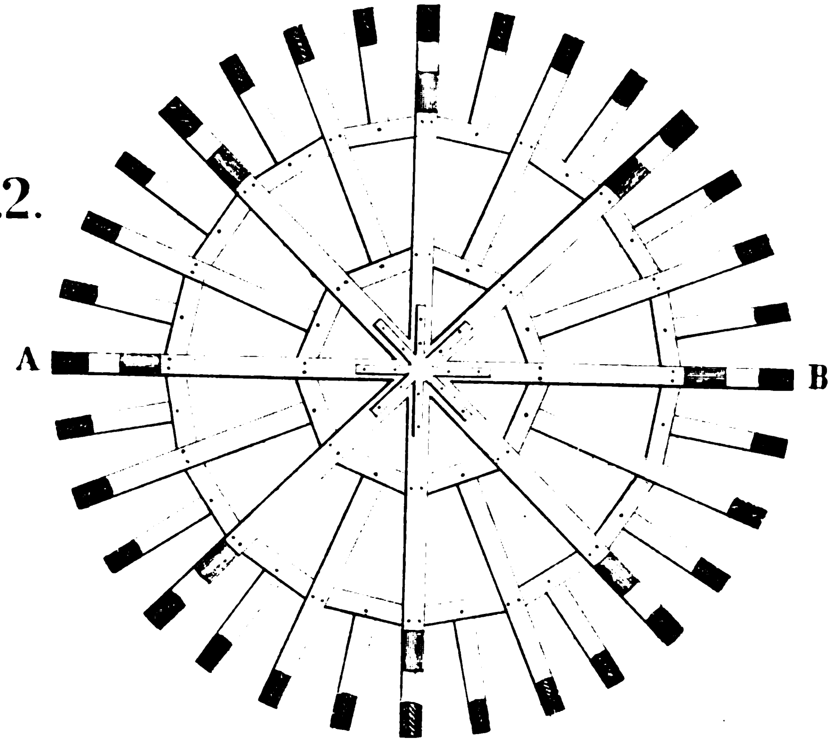


Fig. 1.

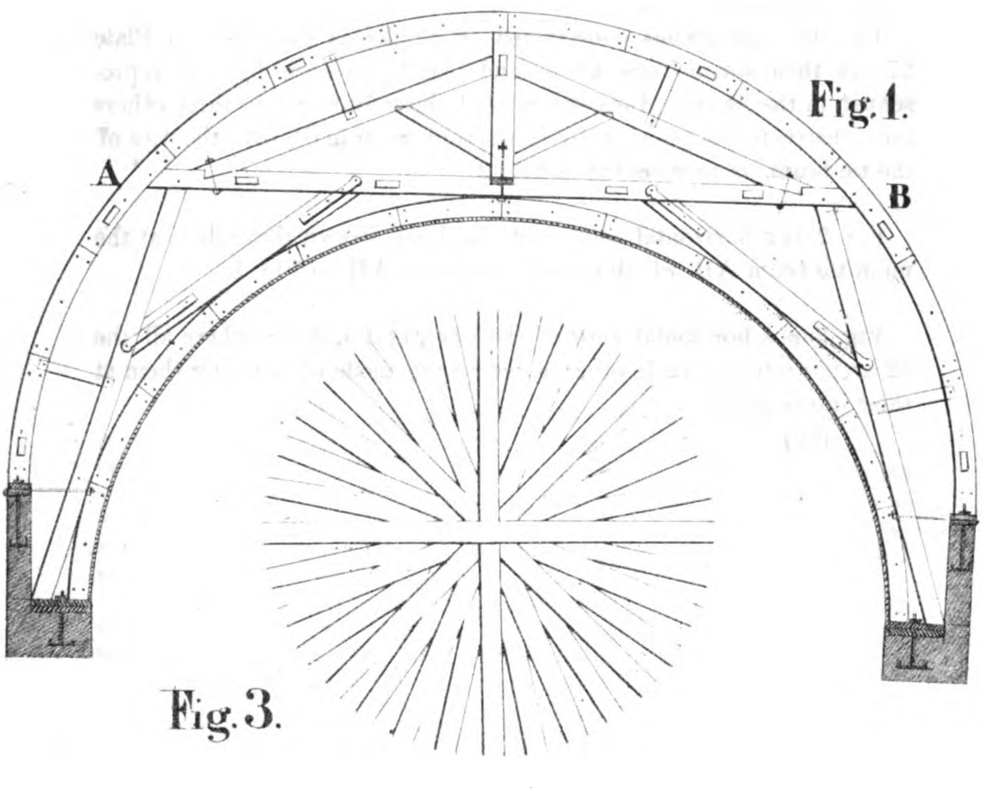
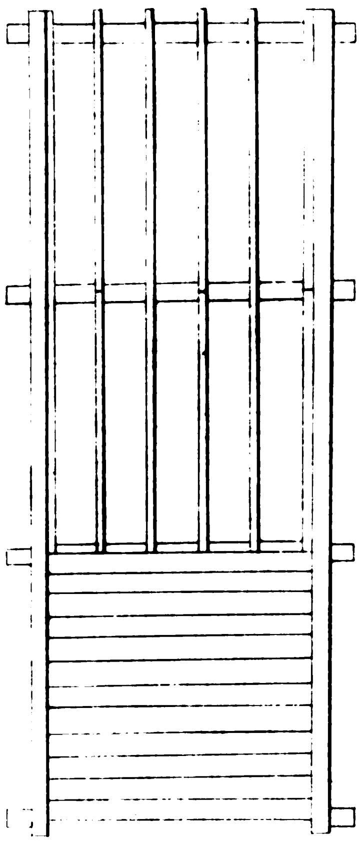


Fig. 3.

L. N. Rosenthal. Lith. Phil.

PART III.

Plate 30.



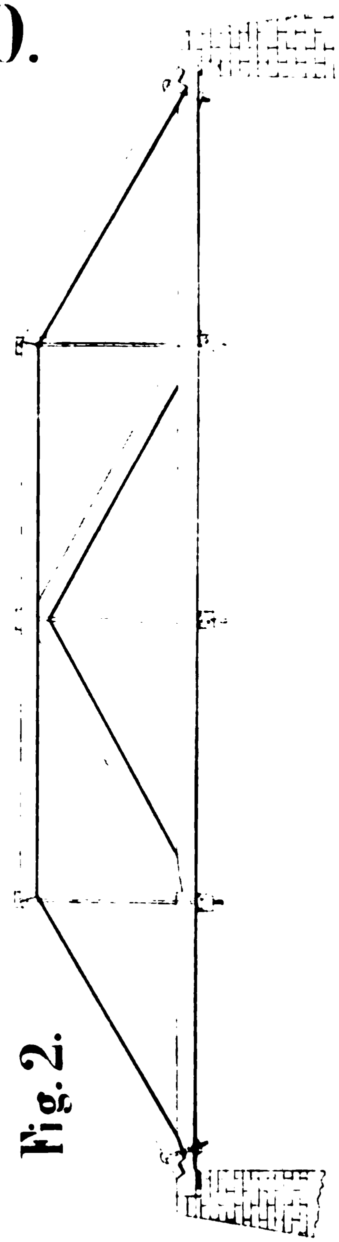
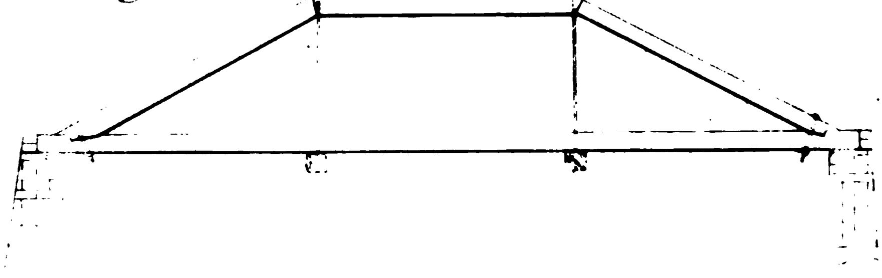


Fig. 2.

Fig. 1.



L.N. Rosenthal, Lith. Phil.

BRIDGE BUILDING.

PLATE 30.

STRAINING BEAM BRIDGES.

Plate 30, Fig. 1 represents a *straining beam bridge* of 30 feet span, designed for a common highway. The stringers or main timbers are 35 feet long, extending over each abutment to a distance of 2½ feet. The straining beam is equal in length to ⅓ of the span, or 10 feet. The supporting rods are 8 feet 2 inches long: 1 foot is allowed for the thickness of the stringer, 10 inches for the needle beam, and 4 inches nut head and washers; leaving 6 feet as the rise of the brace, or the distance of the top of the straining beam from the top of the stringer.

The *length of the brace* can therefore be found, as usual, by extracting the square root of the sum of the squares of the run and the rise.

Bevels.

The bevel at the foot of the brace is like that at the foot of a rafter, and is obtained in the same manner. The bevel at the upper end of the brace and the bevel of the straining beam are equal to each other, and are each equal to half that of a rafter of the same rise and run.

Fig. 2 exhibits the horizontal plan of the floor timbers, and the manner of laying both the joists and the planks.

A moderate degree of camber should be given to every bridge of this kind, by screwing up the supporting rods.

Bill of Timber.

2 Stringers,	12 by 12, in. 35	feet	long,	Board	measure	=840	feet.
4 Braces,	8 by 10, " 12	"	"	"	"	=160	"
2 Straining beams	8 by 10, " 10	"	"	"	"	=133	"
2 Wall plates,	10 by 12, " 16	"	"	"	"	=320	"
2 Needle beams,	8 by 10, " 18	"	"	"	"	=240	"
5 Joists,	3 by 10, " 12	"	"	"	"	=150	"

5 Joists,	2 by 10, 22 feet long, Board measure	=245	feet.
932 feet, 2-inch planks	" "	=932	"
Total timber, B. M.		3020	"

Bill of Iron.

4 Supporting rods, 1½ in. diameter, 8 ft. 2 in. long, each 34½ lbs.	=138	lbs.
8 Washers, 4 lbs. each; and 4 nuts 1 lb. each,	= 36	"
4 Bolts, 1 in. diameter 22 in. long, each 5½ lbs.	= 22	"
8 Washers, 1 lb. each, and 4 nuts ¾ lb. each,	= 11	"
40 lbs. spikes,	= 40	"
	247	"

Estimate of Cost.

3020 feet lumber,	@ $15	per M.	=$45.30
247 lbs. iron,	@ 7c.	" lb.	= 17.29
Workmanship,	@ $10	" M. Board measure.	= 30.20
Total cost,			$92.79

Fig. 2. In respect to this bridge, it is only necessary to say that it is constructed upon the same principle as the former; the difference being caused only by the increase of the span, and this difference being sufficiently represented by the Plate.

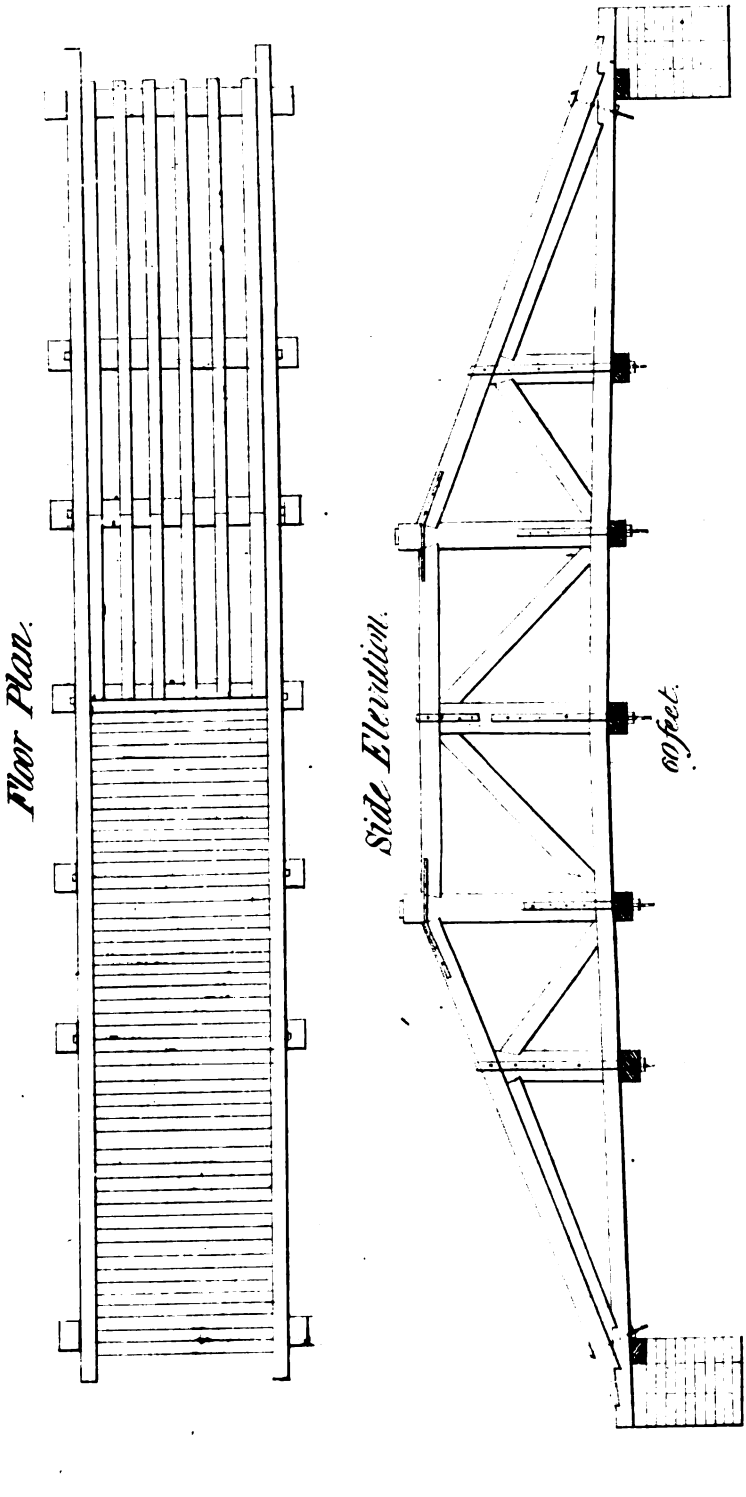
In raising the former of these bridges, no false work or temporary supports are needed, but for this one they may be.

Concerning the economy and durability of these bridges, it may be proper to observe that they are comparatively simple and cheap; and they are also sufficiently strong, so long as the supports maintain their vertical position. But this plan has two objections.

1. The absence of side braces induces a *leaning* or twisting of the braces, caused by their pressure toward each other; and when this *twisting*, or *torsion* as it is often called, has once commenced, it cannot well be remedied. It may, however, be guarded against, to a certain extent, by such a modification of the design as will allow of two supporting rods at each end of the needle beams—these rods being crossed; one passing inside of the stringer, and the other at some distance outside of it, toward the end of the needle beam.

2. The absence of counter braces exposes the bridge to injury from vibration; which is specially destructive to the stone-work of the abutments, the repeated jars being almost sure to break the mortar and loosen the stones. The use of a wall-plate serves in some degree to obviate this objection; and in case of the bridge being supported by trestles, it disappears.

Plate 31



T. N Rosenthal's Lith Phil.a

PLATE 31.

This bridge is more expensive and more durable than those before represented, as it is also less liable to the objections mentioned concerning them. The counter braces of this bridge are sufficient to prevent injurious effects from vibrations; and the size of the posts, or upright ties, when secured by straps of iron, as represented, will also prevent the torsion or twisting of the braces, to which the others are liable. The manner of framing this bridge is sufficiently indicated by the Plate; and the lengths and bevels of the braces are obtained as usual.

Bill of Timber.

2 String pieces,	12 by 12 in.	65	feet long	1560	feet.
2 Straining beams,	12 by 12 "	18	" "	432	"
4 Long braces,	12 by 12 "	26	" "	1248	"
4 Short end braces,	10 by 12 "	15	" "	600	"
4 Middle braces,	10 by 12 "	10	" "	400	"
4 Counter braces,	10 by 12 "	9	" "	360	"
4 Long posts,	12 by 12 "	10	" "	480	"
2 Middle posts,	12 by 12 "	9	" "	216	"
4 Short posts,	12 by 12 "	6	" "	288	"
2 Wall plates,	6 by 12 "	18	" "	216	"
5 Needle beams,	10 by 10 "	20	" "	833	"
12 Joists,	3 by 10 "	24	" "	720	"
6 Joists,	3 by 10 "	18	" "	270	"
2000 feet, B. M., of floor plank,		16	" "	2000	"
				9623	"

PLATE 32.

This Plate presents a view of a bridge offered as an improvement of the Howe Bridge, of a moderate span, by shortening the upper chord, and bracing the ends of it in the same manner as in a straining beam bridge. In the Howe Bridge, the upper chord is of the same length as the lower one, and the braces and counter braces are placed in a uniform manner throughout the entire length. In the plan represented in this Plate, by reducing the length of the upper chord to the limit of a single piece of timber, it is proposed to secure, at least, an equal degree of strength to the ordinary Howe Bridge, and at the same time to effect economy in both material and labor.

The ends of the braces are left square, and the proper bevels are made upon the angle blocks, which are of hard wood or of cast iron, and are let into the chords to the depth of 1 inch or more.

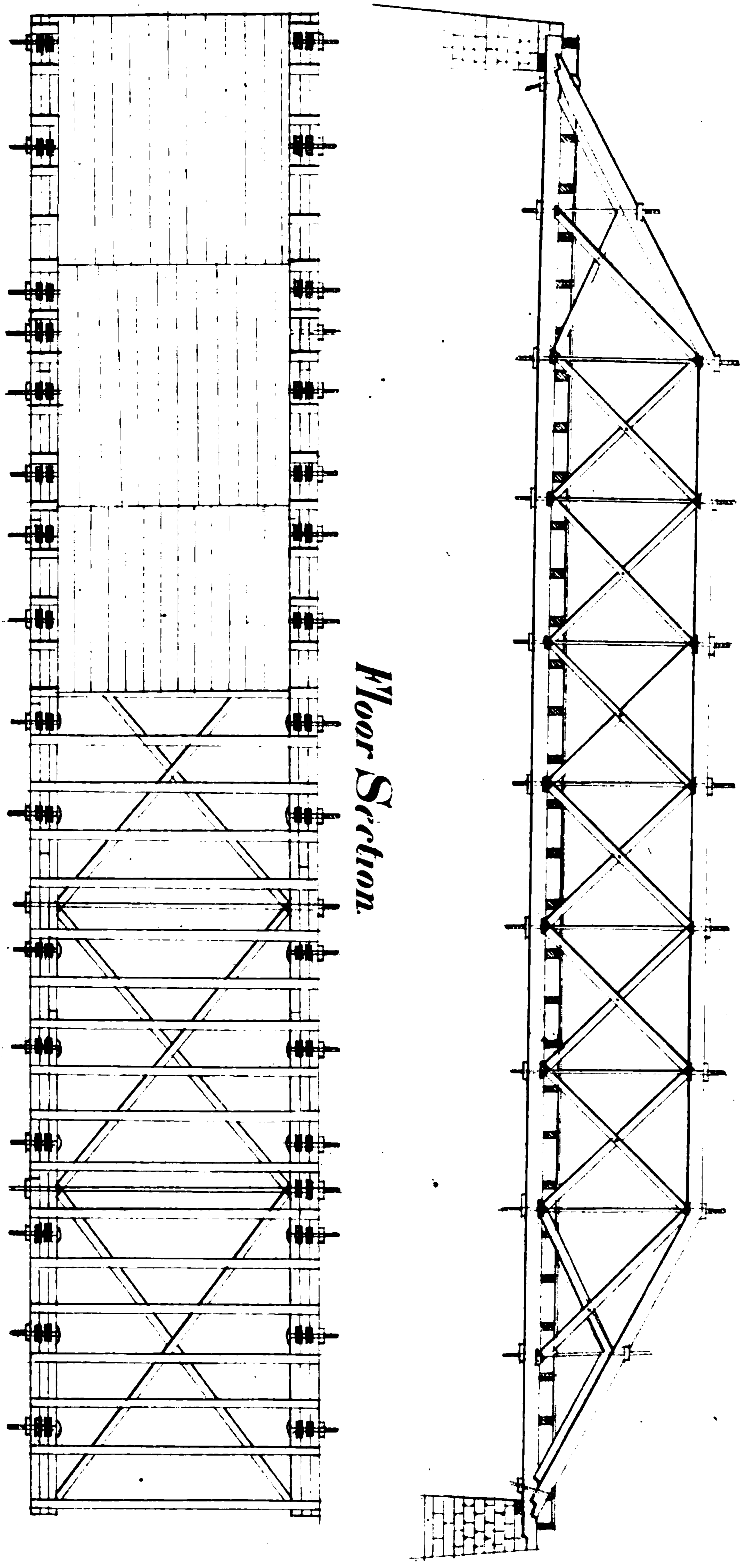
The main braces all lean inward toward the centre of the span, and are double, passing one outside and one inside of the counter braces, which are single, leaning in the opposite direction from the centre toward the ends, each brace passing between each pair of main braces, and are all three bolted together at their intersection.

The lower chords in each truss, or each side, are three in number, and bolted together in the most firm manner possible. Hard wood keys, 2 inches thick, 6 inches wide, and 12 inches long, are inserted on each side of every joint, and at certain intervals even where there are no joints. These keys are let into the chords only about three fourths of an inch on each side, leaving a half inch space between the chords for the free circulation of air.

Bill of Timber.

2 Upper chord pieces,	10 by 14	in. 54	feet	long	=1260	feet.
4 Long end braces,	10 by 14	" 22	"	"	=1027	"
4 Short " "	6 by 6	" 12	"	"	= 144	"
4 Short end counter braces,	4 by 6	" 12	"	"	= 96	"
32 Middle main braces,	5 by 7	" 13	"	"	=1212	"
12 Counter braces,	4 by 7	" 13	"	"	= 364	"
6 Lower chord pieces,	6 by 12	" 31	"	"	=1116	"
4 " " "	6 by 12	" 40	"	"	= 960	"

Plate 32.



4 Lower chord pieces,	6 by 12 in.	30	feet	long	= 720	feet.
4 " " "	12 by 2 "	23	"	"	= 552	"
2 Wall plates,	8 by 12 "	20	"	"	= 320	"
32 Joists,	4 by 12 "	18	"	"	=2304	"
10 Lateral braces,	4 by 6 "	24	"	"	= 480	"
3000 feet, B. M., floor plank,					3000	"

Bill of Iron

4 Middle support. rods,	1	in. diam.,	12 ft. 2 in.	long,	32 lbs.	= 128 lbs.
8 Next to middle "	1¼	"	12 " 2 "	"	51 "	= 408 "
16 End rods,	1½	"	12 " 2 "	"	73 "	=1168 "
8 Short end rods,	1½	"	6 " 1 "	"	36½ "	= 292 "
4 Long cross rods,	1	"	18 " 3 "	"	48⅝ "	= 194 "
4 End bolts,	1	"	2 " 0 "	"	5¼ "	= 21 "
24 Lower chord bolts,	1	"	22 "	"	5 "	= 120 "
16 Brace bolts,	¾	"	16 "	"	2 "	= 32 "
72 Nuts for supporting rods,					2 "	= 144 "
18 Plates " " "	¾ in. thick,		4 w., 14 long,		12 "	= 216 "
18 " " " "	"		4 w., 19 long,		16 "	= 288 "
96 Washers,					1 "	= 96 "
48 Nuts for small bolts,					1 "	= 48 "

Note.—The cost of labor in constructing this bridge is estimated at $11.00 per thousand, B. M., of the timber required.

PLATE 33.

TRESTLE BRIDGES.

This Plate exhibits the design of a bridge supported from below; and, for a moderate span, it is one in which the important elements of simplicity, strength, and durability, are well combined.

The plan of this bridge is so simple, as to require little further explanation than the inspection of the Plate. It will be perceived that the bearings are 10 feet apart, and that the braces are framed to correspond. The cross timbers are extended out several feet on each side, to give room for bracing the hand-rail.

This bridge is supported by trestles; and the Plate represents the manner of framing the end ones and the middle one. It is of the utmost importance that the embankments behind the end trestles are perfectly solid, as on their firmness depends the whole strength of the bridge.

Bill of Timber for One Span.

4 String pieces,	12 by 12 in.,	28 feet long,	=1344	feet.
2 Straining beams,	12 by 16 "	30 " "	= 960	"
4 Long braces,	10 by 10 "	24 " "	= 800	"
4 Short braces,	10 by 10 "	14 " "	= 467	"
6 Cross timbers,	6 by 12 "	24 " "	= 864	"
12 Hand-rail posts,	6 by 6 "	4½ " "	= 162	"
104 feet (lineal) hand railing,	6 by 6 "		= 312	"
12 Hand-rail braces,	3 by 4 "	4½ " "	= 54	"
12 Joists,	3 by 10 "	20 " "	= 600	"
6 "	3 by 10 "	11 " "	= 165	"
1660 feet, B. M., floor plank,			=1660	"
Total			7388	"

Bill of Timber for the Two End Trestles.

4 Posts,	12 by 12 in.,	13 feet long,	= 624	feet.
8 Studs,	6 by 12 "	13 " "	= 624	"
4 "	6 by 12 "	8 " "	= 192	"

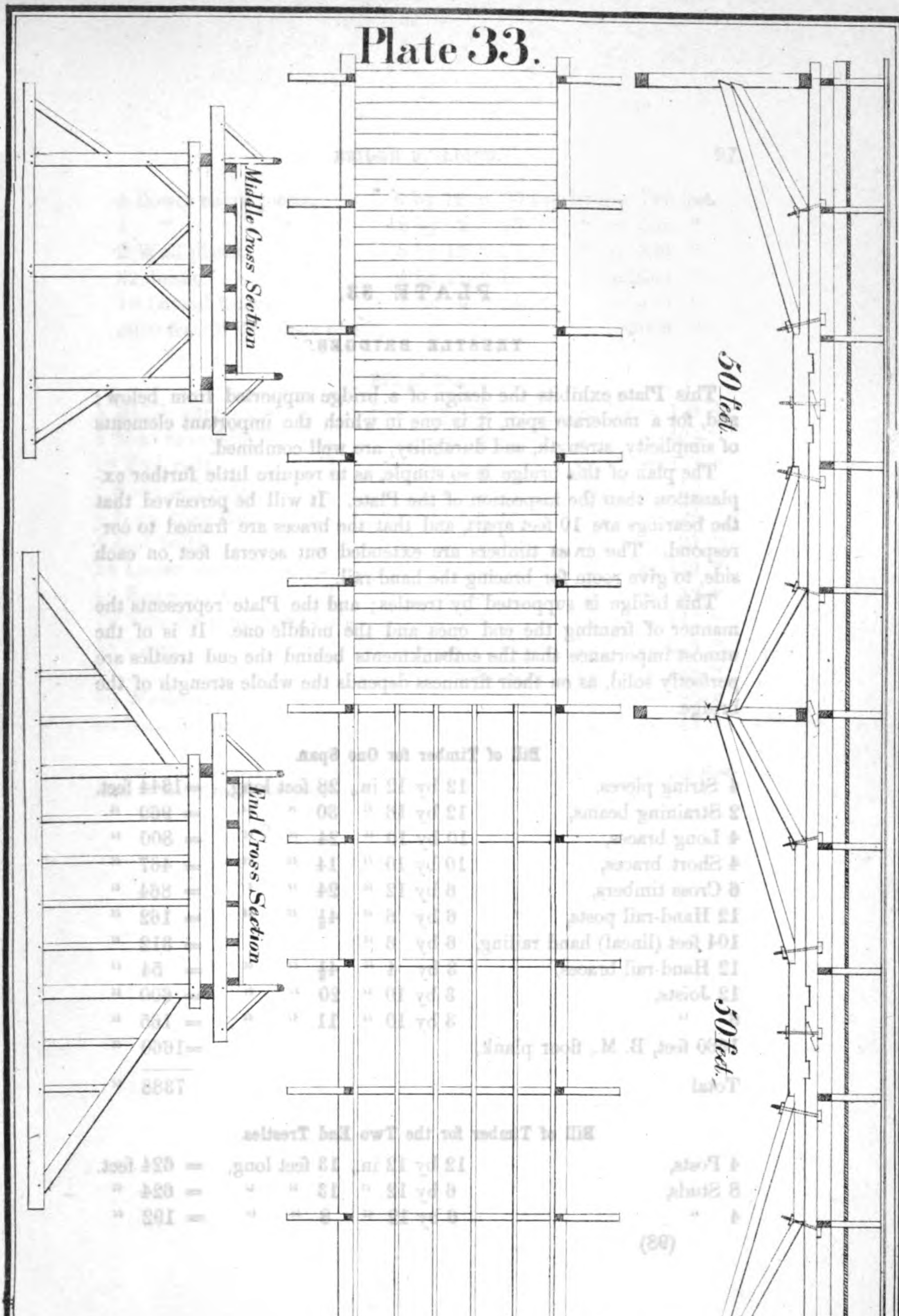


Plate 33.
Middle Cross Section
End Cross Section
50 feet.
50 feet.
J. N. Rosenthal Lith. Phil.a

4 Studs,	6 by 12 in.,	6 feet long,	= 144	feet.
2 Mud sills,	12 by 12 "	52 " "	=1248	"
2 Caps,	12 by 12 "	20 " "	= 480	"
1000 ft., 2 in. hard wood plank for supporting embankm't,			=1000	"
			4312	"

Bill of Timber for Middle Trestle.

3 Posts,	12 by 12 in.,	13 feet long, B.M.,	= 468	feet.
1 Mud sill,	12 by 12 "	30 " " "	= 360	"
1 Cap,	12 by 12 "	20 " " "	= 240	"
4 Post head braces,	4 by 4 "	5½ " " "	= 30	"
2 " foot braces,	8 by 8 "	8 " " "	= 90	"
			1188	"
For the two end trestles,			4312	"
Total of the three trestles, Board measure,			5500	"

PLATES 34 & 35.

Plates 34 and 35 represent a strong trestle bridge, such as is often used for rail-roads in crossing small streams and ravines, where the banks are high, and where there is little danger from ice. The Author of this work has constructed bridges of this kind at Spring Creek, Bureau Co., and at Nettle Creek, Grundy Co., on the Chicago and Rock Island Rail-road; and one on the plank road, between Peru and La Salle, in La Salle Co., Ill.—the last with posts, 51 feet high.

In *framing the trestles*, the posts are framed into the sills and caps as usual; but the braces are bolted upon the outside with inch bolts. The outside lower braces of the trestles, marked in the plan C, C, have 1 foot run to 2 feet rise; the posts of the trestles at A are set in such a manner as to act as braces, having 1 foot run to 4 feet rise. The *horizontal lateral braces* are also laid and bolted between the longitudinal timbers and cross timbers, without being framed into them. The lower longitudinal timbers are let into the posts to the depth of 2 inches, and lapped across the posts, one on one side, and the other on the other side, where they are bolted to the posts and to each other.

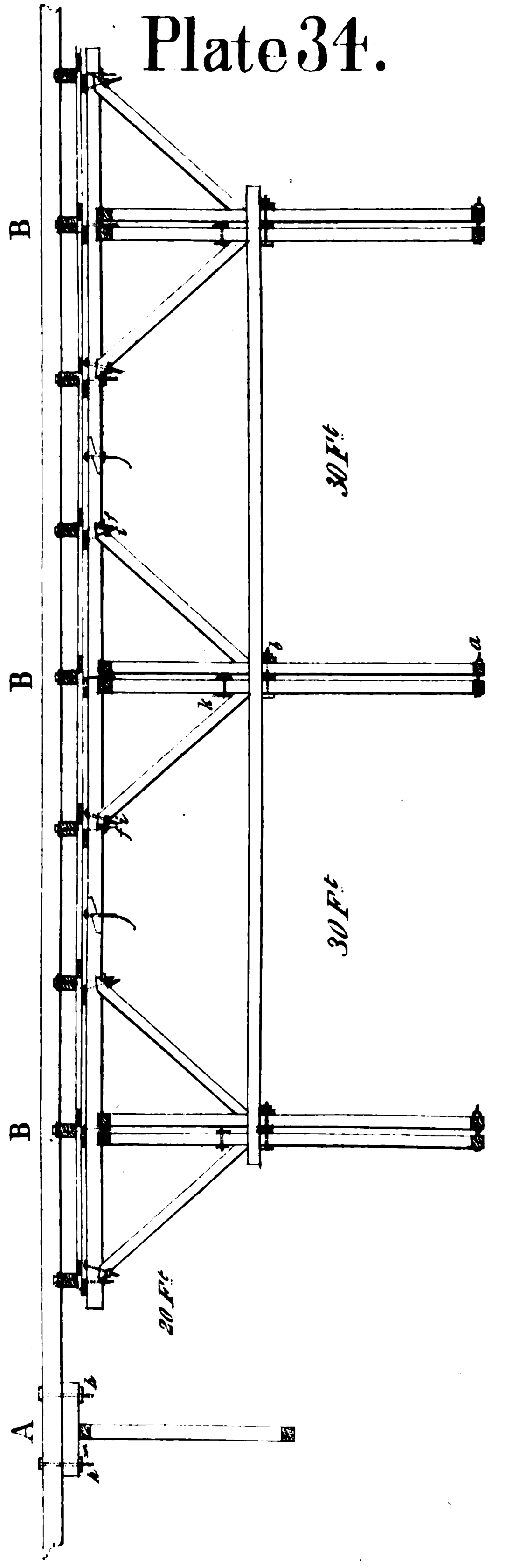
The *bearings are ten feet apart*, and each bearing is supported either by a post or a brace; these braces are framed to a 10 feet rise and a 9 feet run, and the upper ends are bolted to the longitudinal timbers, as represented in the Plate.

A *bill of timber and iron*, which is here subjoined, will assist the mechanic in framing a bridge of this kind more than any extended description could do. (The small letters in the Plate refer to the bolts.)

Bill of Timber.

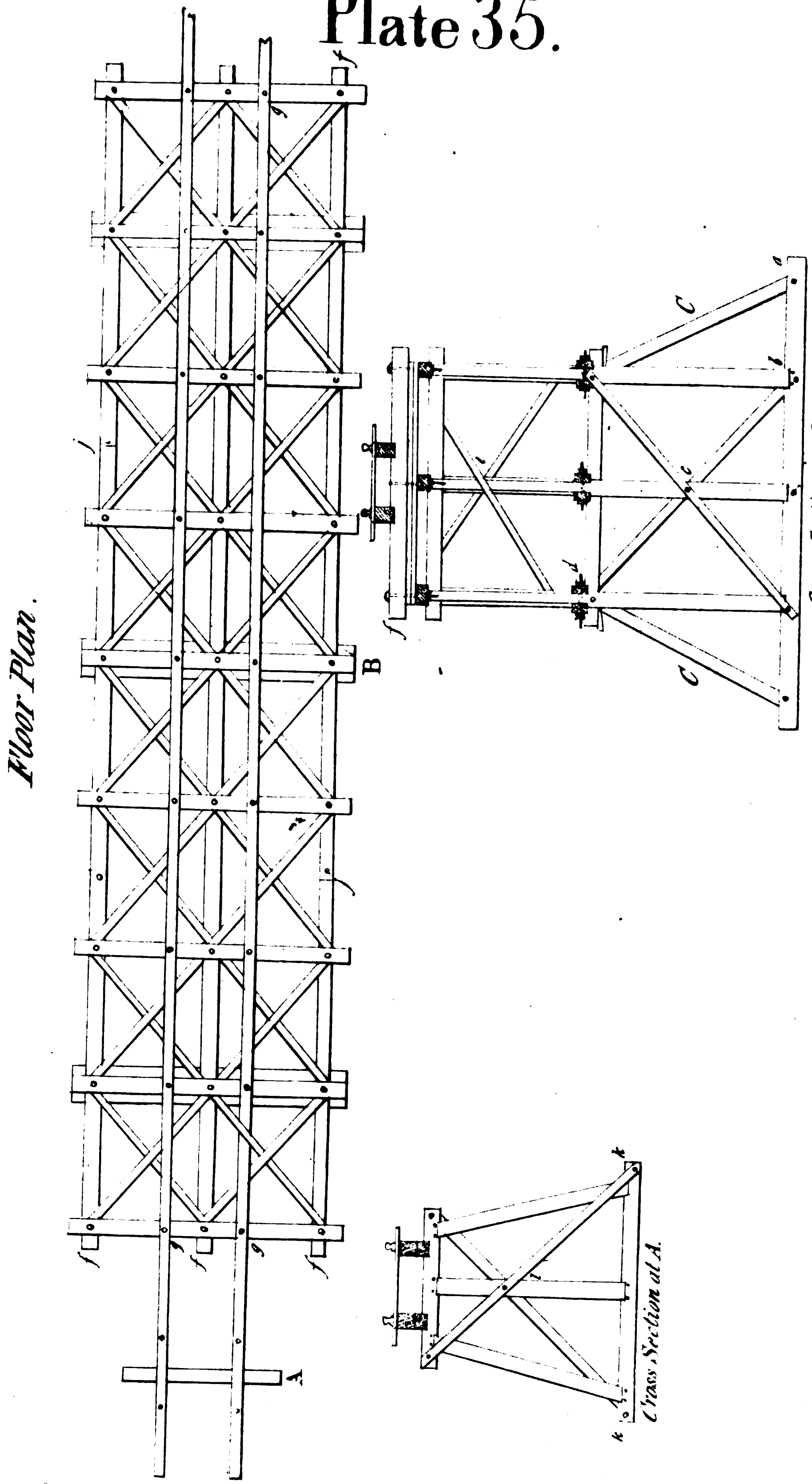
6 Sills,	12 by 12 in.,	33	feet	long,	B. M.,	=2376	feet.
1 Sill,	12 by 12 "	18	"	"	"	= 216	"
1 "	12 by 12 "	16	"	"	"	= 192	"
18 Posts,	12 by 12 "	25	"	"	"	=5400	"
3 "	12 by 12 "	12	"	"	"	= 432	"
3 "	12 by 12 "	10	"	"	"	= 360	"
6 Caps,	12 by 12 "	19	"	"	"	=1368	"
2 "	12 by 12 "	11	"	"	"	= 264	"
3 Lower cross timbers,	6 by 12 "	19	"	"	"	= 342	"

Plate 34.



L. V. Rosenthal's Lith. Phil.a

Plate 35.



L. N. Rosenthal's Lith Phil^a

6 Lower longitudinal timbers,	6 by 12 in.,	35 feet long,	=1260	feet.
18 Braces,	8 by 10 "	14 " "	=1680	"
6 "	8 by 10 "	15 " "	= 600	"
6 String pieces,	9 by 12 "	27 " "	=1458	"
3 " "	9 by 12 "	32 " "	= 864	"
9 Cross timbers,	10 by 12 "	19 " "	=1710	"
16 Lateral braces,	4 by 8 "	27 " "	=1152	"
8 Rail stringers,	12 by 14 "	30 " "	=3360	"
4 Bolsters,	12 by 12 "	6 " "	= 288	"
6 Cross braces,	4 by 8 "	14 " "	= 224	"
6 " "	4 by 8 "	19 " "	= 304	"
2 " "	4 by 8 "	16 " "	= 85	"
2 " "	4 by 8 "	18 " "	= 96	"
Total, Board measure,			24,031	"

Bill of Iron.

6 Bolts (letter *a*),	32 in. long,	1 in. diam.,	= 42½	lbs.
12 " (" *b*),	36 "	" "	= 95½	"
12 " (" *c*),	18 "	" "	= 24	"
18 " (" *d*),	22 "	" "	= 87½	"
3 " (" *e*),	22 "	" "	= 15	"
27 " (" *f*),	31 "	" "	=185	"
18 " (" *g*),	26 "	" "	=103½	"
8 " (" *h*),	28 "	" "	= 50	"
294 Heads, nuts, and washers, @ 1 lb. each,			=294	"
18 Bolts (letter *i*),	20 in. long,	¾ in. diam.,	= 45	"
6 " (" *j*),	11 "	" "	= 8¼	"
20 " (" *k*),	18 "	" "	= 45	"
2 " (" *l*),	22 "	" "	= 5¼	"
138 Bolt-heads, nuts, and washers, @ ¾ lb. each,			=103	"
Total of iron,			1100½	"

PLATE 36.

ARCHED TRUSS BRIDGES.

This Plate represents a design of a Burr Bridge without counter braces, but combined with an *arch beam.* This mode of construction is designed either for railroad bridges, or for common road bridges of a great span. If wanted for a common road, and the span be not more than 150 feet, the arch beam may be safely dispensed with; and in that case, counter braces should be introduced; but if the bridge be designed for a railroad, the arch beam should never be omitted.

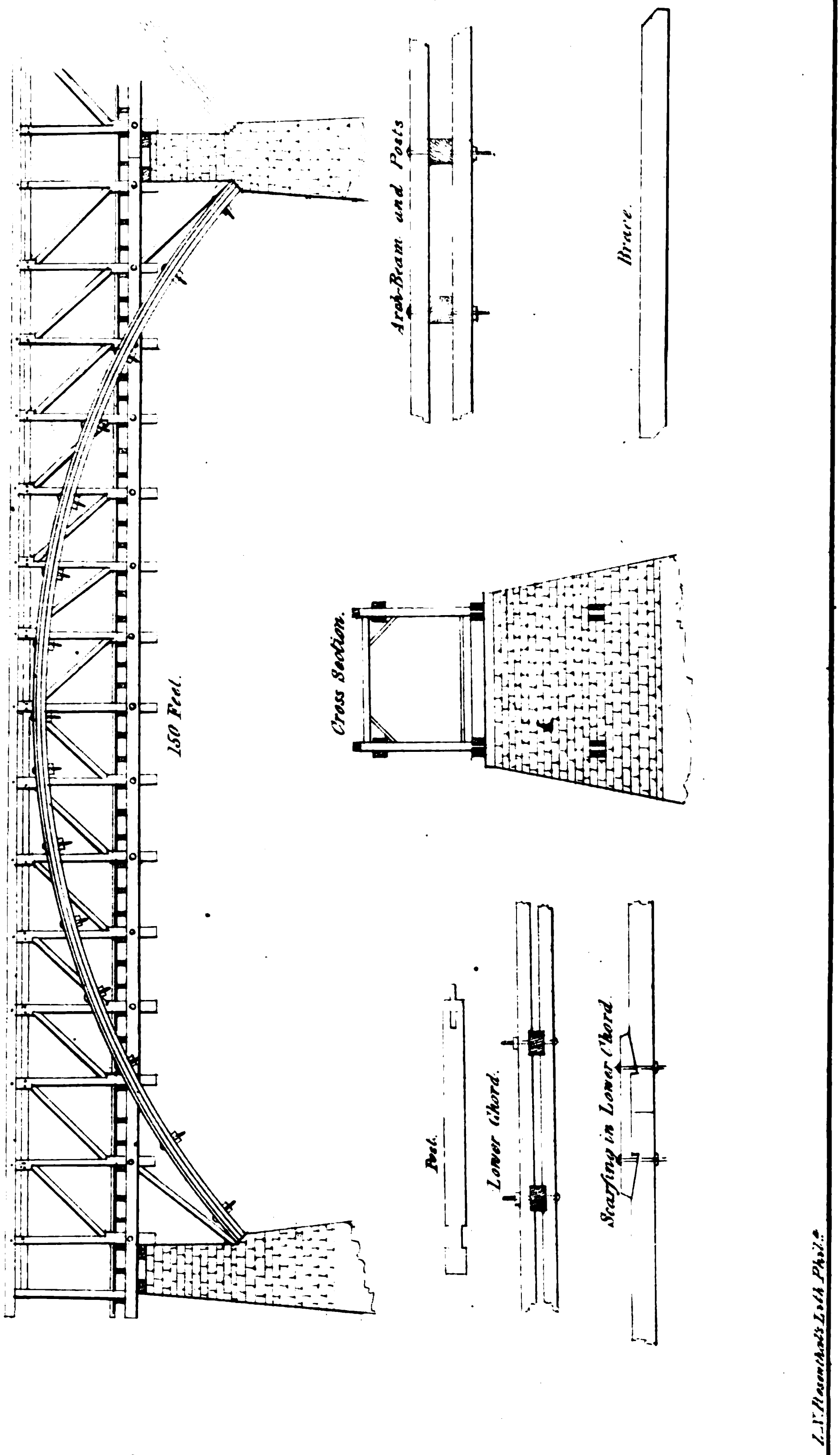
The panels of bridges of this kind ought never to be as great in extension as in height between chords; or, in other words, the rise of the braces should always be greater than their run; and practically, it is expensive and inconvenient to extend the panels more than 12 or 14 feet. In all bridges of this kind, the greatest strain upon the braces is at the end of the span; and it will be most proper to use the best and largest pieces of timber for the end braces, and those of inferior quality, if such must be used somewhere, should be placed in the middle.

The posts should be sized down at the lower end, where they pass through the lower chord, to about 6 inches in thickness; the chord pieces should also be cut out to the depth of 1 inch on each side of the post, and both locked into the post in the firmest possible manner, in order to resist the thrust of the brace. The post should also be boxed into the upper chord not less than 1 inch.

In scarfing the lower chord pieces, they must be so arranged that only one splice be made at the same place; and if the bolts which pass through the scarfing extend also through both lower chord pieces, (the short piece inserted to lock the joint being of just sufficient thickness to fill the space between the two chord pieces), it would be still better than that plan represented in the Plate.

It will be found necessary, in a bridge of this kind, to make the main braces at least 1½ inches longer than the exact calculation would require, in order to produce the necessary camber, and to guard against the settling of the centre of the span below the general level, which will be likely to happen if not guarded against, from the com-

Plate 36.


150 Feet.
Arch-Beam and Posts
Brace.
Cross Section.
Post.
Lower Chord.
Scarfing in Lower Chord.
L. N. Rosenthal's Lith Phila.

pression and shrinkage of the timber, and which would materially weaken the bridge; and whatever camber the bridge is designed to have, must be given to it on its first erection, before the false works are removed, since the camber cannot afterward be increased as it can be in most of the bridges represented on the preceding Plates, where supporting rods, in those plans, occupy the place of the posts in this.

For floor plan, see Plate 37.

Bill of Timber for One Span.

2 Wall plates,	10 by 12 in.,	22 feet long,	B. M.=	440 feet.
8 Lower chord pieces,	7 by 14 "	34 " "	" =	2286 "
8 " " "	7 by 14 "	43 " "	" =	2809 "
4 Upper " "	11 by 11 "	36 " "	" =	1452 "
4 " " "	11 by 11 "	44 " "	" =	1774 "
46 Floor beams,	4 by 12 "	20 " "	" =	3680 "
60 Arch pieces,	7 by 10 "	33 " "	" =	11550 "
12 Queen posts,	11 by 15 "	19 " "	" =	3135 "
8 " "	11 by 14 "	19 " "	" =	1950 "
8 " "	11 by 13 "	19 " "	" =	1811 "
2 Centre posts,	11 by 16 "	19 " "	" =	557 "
4 Arch braces,	12 by 14 "	18 " "	" =	1008 "
28 Panel girths,	6 by 8 "	11 " "	" =	1232 "
12 Scarfing blocks,	6 by 14 "	5 " "	" =	420 "
16 Tie beams,	10 by 10 "	19 " "	" =	2533 "
32 Knee braces,	4 by 6 "	6 " "	" =	384 "
18 Lateral braces,	4 by 8 "	24 " "	" =	1152 "
7000 feet 3 inch floor plank,		14 " "	" =	7000 "

Bill of Iron.

9 Cross rods,	1 in. diam.	19 feet 3 inches long	=460 lbs.
22 Arch bolts,	1 "	2 " 9 " "	=160 "
24 Splice bolts,	1 "	1 foot 8 " "	=106 "
30 Post bolts,	1 "	1 " 8 " "	=132 "
60 Arch bolts,	⅞ "	2 feet 0 " "	=179 "
Head, nut, and washer to each bolt, 1 lb. each,			345 "

PLATE 37.

This Plate represents an ordinary Howe Bridge, with the addition of two arch beams to each truss. The arch beams are combined with the truss by supporting rods, extending downward between each panel from the upper surface of the arch and through the angle block to the lower surface of the lower chords. As another modification of the Howe Bridge has been already described in Plate 32, and as the arrangement of the arch beams in this design is similar to that represented in Plate 36, it will only be necessary, in this place, to add a bill of timber and iron, which, with the inspection of the various figures of the Plate, will be sufficient to enable any practical carpenter to understand the construction of this bridge.

Bill of Timber for One Span.

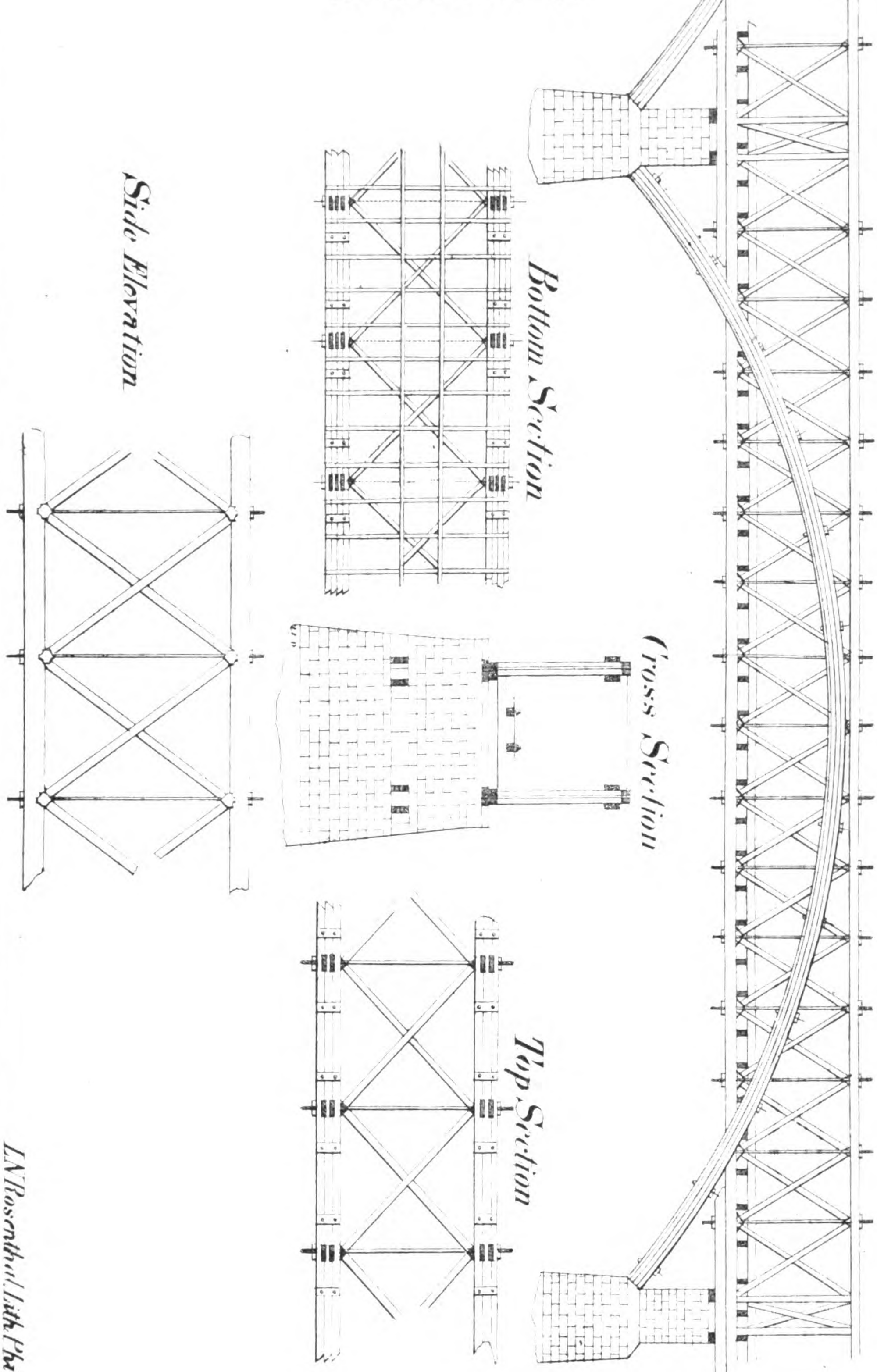
2 Wall plates,	10 by 12 in.,	20 feet	long,	B. M.	=	400	feet.
4 Bolsters,	10 by 12 "	22 "	"	"	=	880	"
8 Pier braces,	7 by 7 "	18 "	"	"	=	588	"
16 Lower chords,	5 by 12 "	45 "	"	"	=	3600	"
16 " "	5 by 12 "	41 "	"	"	=	3280	"
12 Upper "	6 by 10 "	45 "	"	"	=	2700	"
12 " "	6 by 10 "	41 "	"	"	=	2460	"
64 Main braces,	6 by 8 "	19 "	"	"	=	4864	"
32 Counter "	6 by 7 "	19 "	"	"	=	2128	"
80 Arch pieces,	7 by 10 "	36 "	"	"	=	16800	"
34 Cross floor timbers,	7 by 14 "	19 "	"	"	=	5276	"
32 Lateral braces,	4 by 8 "	24 "	"	"	=	2048	"
8 Rail stringers,	7 by 14 "	45 "	"	"	=	2940	"
"	7 by 14 "	41 "	"	"	=	2679	"

Bill of Iron for One Span.

Castings.

30 Lower chord angle blocks,	80 lbs. each,	=2400	lbs
30 Upper " " "	75 "	=2250	"
8 Half angle blocks,	50 "	= 400	"
44 Arch rod washers,	3 "	= 132	"
282 Washers,	1 "	= 282	"

Plate 37.



L.N. Rosenthal Lith Phila

Wrought Iron.

8 End supporting rods,	1½ in. diam.,	19½ feet long,	= 930 lbs.
16 " " "	1½ "	18½ " "	=1775 "
24 " " "	1¼ "	18½ " "	=1865 "
12 Middle "	1⅛ "	18½ " "	= 755 "
8 Arch " "	1¼ "	6½ " "	= 218 "
8 " " "	1¼ "	10¾ " "	= 361 "
8 " " "	1⅜ "	13½ " "	= 540 "
8 " " "	1⅜ "	15 " "	= 600 "
8 " " "	1⅜ "	16 " "	= 640 "
4 " " "	1⅜ "	17 " "	= 320 "
9 Top cross rods,	1 "	19 " "	= 460 "
9 Bottom cross rods,	1 "	19½ " "	= 470 "
64 Upper chord bolts,	¾ "	21 in "	= 168 "
64 Lower " "	¾ "	23 " "	= 183 "
52 Arch beam bolts,	¾ "	30 " "	= 195 "
28 " cross bolts,	¾ "	40 " "	= 140 "
32 Main brace bolts,	¾ "	20 " "	= 80 "
32 Rail stringer bolts,	¾ "	16 " "	= 64 "
208 Large nuts and heads,	3 lbs. each		= 624 "
540 Small " "	1 lb. "		= 540 "
22 Bottom gibs, 4 holes,	40 lbs. "		= 880 "
8 " " 2 holes,	31 " "		= 320 "
30 Top " 2 "	5 " "		= 750 "

Estimate of Cost.

The entire cost of a bridge of this kind in the State of Illinois is about $25 per lineal foot

PLATE 38.

This bridge is similar, in its general principles of construction, to the one represented in Plate 37; but is quite different in its minor details, being much heavier and stronger, as well as more expensive. The main differences are these: Counter braces are employed in this bridge, which are omitted in the other; this has two sets of posts and main braces, and but one arch beam to each truss, while the other bridge has two arch beams and one set of posts and braces; the chord pieces in this bridge, instead of being placed side by side, with their edges vertical, with an open space between them for the circulation of air, are placed one upon the other, with their edges horizontal, and their surfaces in close contact.

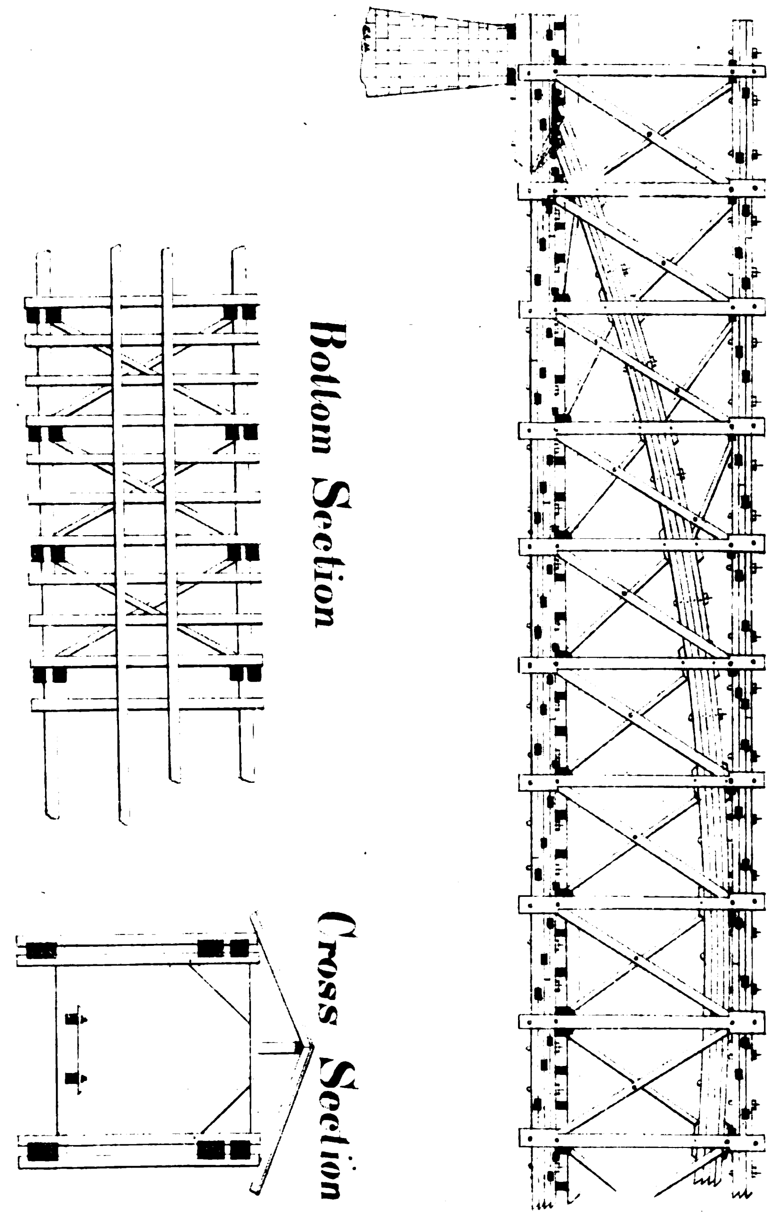
The upper chord is in three sections, and the lower chord and the arch beam are each in four sections; each chord piece and arch piece being 6 inches deep and 12 inches wide; making the combined upper chord 12 by 18 inches, and the combined lower chord and arch beam each 12 by 24 inches.

The foot of the arch beam rests upon a cast iron shoe, secured by iron straps to each of the lower chord pieces; each shoe having four flanges, and each flange beveled to fit the square end of each section of the arch beam.

There is one set of counter braces to each truss, each counter brace passing between each pair of main braces, to which it is bolted at their intersection. The foot of each counter brace rests upon an angle block fixed upon the lower chord, at the foot of each pair of posts, and the upper end of each counter brace rests against the arch beam at its intersection with the next pair of posts. A key is inserted, however, between the upper end of each counter brace and the arch beam, by means of which the whole structure can be kept tight, and the relative strain upon the arch beam and the chords can, to some extent, be regulated and proportioned. Each pair of posts is bolted together with four bolts—one above, and one below each chord.

Bridges of this style are in extensive use on the New York and Erie Rail-road, where they have been proved to be of great strength and stability.

Plate 38.



L. N. Rosenthal Lith. Phil^a

GENERAL PRINCIPLES OF BRIDGE BUILDING.

In concluding this Part of the work, it is proper to bring together into one place the most important principles and most useful hints to practical builders, which we have been able to gather, either from the study of other works,* or from the lessons of our own experience.

Size of Timber and Iron required to enable a Bridge of a given Span to sustain a given Load.

The most proper way of ascertaining the resisting powers of timber and iron is by actual experiment; and it has been found by such experiment, that the greatest safe strain for sound timber is about 1,000 lbs. per square inch, measured on the square end of the timber, the strain being one of either extension or compression, but applied in the direction of the grain of the wood. It has also been ascertained by experiment, that the greatest safe *tensile strain*, as it is technically called, that is the lifting or supporting strain, of large wrought iron rods, is 10,000 lbs. per square inch. Small wire or nail rods, manufactured with more care, and of the best materials, can, undoubtedly, sustain a much greater weight than this.

In proportioning the different parts of a bridge, however, it is customary and expedient to allow a considerable excess of strength in favor of stability. The deterioration of timber, caused by age, must be taken into the account; for after a wooden bridge has been in use for some years, it becomes much weaker than when first erected.

The weight of the bridge itself must also be considered in determining the load which it is able to sustain, and this weight it is considered safe to assume at 35 lbs. to the cubic foot of timber employed. If the quantity of timber in a given bridge is equal to 30 cubic feet to every foot in length, as is asserted by Haupt to be the case with the average of the Howe Bridges on the Pennsylvania Rail-road, then the weight of the structure would be 1050 lbs. per lineal foot, or a

---

* Many of these remarks are condensed and simplified from the work on "Bridge Construction," by Herman Haupt, A. M.—D. Appleton & Co., New York, a work more especially designed for the use of engineers than for practical builders, yet one which we commend to all persons interested in this part of Carpentry.

little more than half a ton per foot for the weight of the timber, exclusive of the iron.

The greatest load that can be brought upon a rail-road bridge, with a single track, is when several locomotive engines of the first class, weighing about one ton per foot in length, are attached together. So that the greatest strain upon such a bridge, including both its own weight and the weight of the load, is a little more than a ton and a half per foot. What, then, must be the dimensions of the timber to resist this strain?

The Strain upon the Chords.

When a beam is supported at the ends and loaded in the middle until it breaks, it is observed that the fibres in the lower portion of the fracture are broken by being extended or pulled violently apart, and that those on the upper portion are broken by being compressed or jammed violently together. In theory, this compression is said to be equal to the expansion; that is, that it will require an equal force to tear the fibres apart as to break them by forcing them together, and the neutral axis in the beam, or the line where there is neither sufficient expansion nor compression to break the fibres of the timber, is said to be in the middle of the beam. But it is doubtful whether facts will warrant this conclusion. Common observation would lead most persons to the opinion that timber has a greater power to resist compression than it has to resist expansion, and to this opinion we are ourselves inclined; but for the present purposes it will be sufficiently accurate to be governed by the theory usually adopted by engineers, as stated.

The power of a bridge to sustain a load, and to resist the various strains upon it, may be compared to that of the beam supported at the ends—the strain on the upper chord being one of compression, and that on the lower chord one of extension; and the strain on both being greatest in the middle of the span, and diminishing toward the ends. When the beam is laid over several supports, its strength for a given interval is much greater than when simply supported at the ends. The same principle is applicable to bridges; and when several spans occur in succession, it is of great advantage to continue the upper and lower chords across the piers.

The greatest strain on the upper chord being in the middle of the span, is equal to that force which, being applied horizontally, would sustain one half the span with its load were the other half to be removed. In order to ascertain this force, multiply half the span and its load by one fourth its length, and divide that product by its height, measured from centre to centre of the upper and lower chords.

For example, if the length of a span be 160 feet, and the height of the truss be 16 feet from centre to centre of upper and lower chords, and the weight of the loaded bridge be 1½ tons to the lineal foot, the greatest strain upon the upper chord would be expressed by the product of 120 tons multiplied by 40, and the product divided by 16; which gives 300 tons, or 600,000 lbs. as the result. The reason of multiplying the weight of half the loaded span by 40 is, because 40 feet is the middle of the half-span, or its centre of gravity; and the reason for dividing its product by 16 is, because that is the width of the truss; and the wider the truss, the greater leverage there is, and the less strain, for the same reason that a thick beam is stronger than a flat one, as there is less strain on the upper and lower surfaces of the thick beam from the same weight than in a flat one. Then, as each square inch is able to resist 1000 lbs., there must be 600 square inches in the end section of the upper chords, in order to enable them to sustain the weight required, or 300 inches in the upper chord of each truss. If, therefore, each chord is 12 inches deep, it must be 25 inches wide; hence, three chord pieces, 12 by 8⅓ inches, will contain the requisite material.

The strain on the lower chord is at least equal to that on the upper one; but the timbers being in several pieces, and the strain being one of extension, the joints are opened, and the whole strength of the timber is not available; while in the upper chord the strain is one of compression, and the joints being pressed together, causes no loss to the resisting force of the timber. There must, therefore, be at least one additional line of timbers in the lower chord; and each piece should be sufficiently long to extend through four panels, so that there can be three whole timbers and a joint in each panel.

From the same data, similar calculations can easily be made for estimating the strain and fixing the dimensions of the other timbers.

PART IV

EXPLANATION OF THE TABLES.

Definitions of Terms and Phrases used in this Explanation. and in other Places in this Work.

The LENGTH *of a rafter* is understood to be measured from the extreme point of the foot to the extreme point of its upper end.* But in these Tables no allowances are made for the projection of rafters beyond the plate, or for ridge poles; so that the *length of common rafters is understood to be the distance from the upper and outer corner of the plate to the very peak of the roof.*

The RUN *of a rafter* is the horizontal distance from the extreme point of the foot to a perpendicular let fall from the upper end. *In common roofs, the run of the rafters is half the width of the building.*

The RISE *of a rafter* is the perpendicular distance from the upper end of the rafter to the level of the foot.

The GAIN *of a rafter* is the difference between its *run* and its *length.* For example, a rafter whose run is 12 feet, and whose length is 13 feet, has 1 foot gain.

The learner will easily perceive that the length of any rafter is the hypotenuse of a right-angled triangle, of which its run and its rise are the other two sides. The length is therefore ascertained with perfect accuracy by adding the square of the run to the square of the rise, and extracting the square root of their sum. (See Part I., Prop. XXIV.)

Example 1. The length of a common rafter is required in a building 24 feet wide, the roof of which is desired to have a pitch of 5 inches to the foot. The *run* is therefore 12 feet, the square of which

---

* Except in *hip rafters*, the length of which is always to be measured on the *backing*, or along the middle line of the upper surface; for when the side bevel is all cut on one side of the upper end, as it sometimes is, then the point of the rafter will extend half its thickness beyond its estimated length, as given in the table, &c.

is the product of 12 multiplied by 12, or 144 feet. The *rise* is 12 times 5 inches, or 60 inches, or 5 feet, the square of which is 25 feet; which, added to 144, makes 169 feet, of which we extract the square root *thus:* (the rule for which may be found in any common-school arithmetic) and find it to be 13 feet, the exact length of the rafter required.

```
  1)169(13
    1
   --
 23)69
    69
    --
    00
```

But in most cases the result is obtained in the form of a fraction; and it will be found convenient to reduce the *run* and the *rise* to inches, in the first place, and then the root is obtained in inches and decimals of an inch, which can be carried out to any degree of accuracy required. In these Tables they are carried to hundredths of an inch.

Example 2. Required the length of a rafter for the building described in Plate 4 of this work. Width of building, 12 feet; rise of rafter, 6 inches to the foot.

The *run* of the rafter is 6 feet, or 72 in., of which the square is 5184
" *rise* " " " 3 " or 36 " " " " " 1296

and their *sum* is 6480

of which we proceed to extract the square root *thus:* and find it to be 80 inches and 49 hundredths of an inch; or, 6 feet 8 inches and $\frac{49}{100}$, as given in the Table, which is the exact length of the required rafter.

```
      8)6480(80.49
        64
        ------
   1604)8000
        6416
        ------
  16089)158400
        144801
        ------
         13599
```

TABLE I.

The use of this Table is to furnish the practical carpenter with the precise lengths of common rafters for buildings of all sizes, and for roofs of every pitch. The Table is carried out to buildings of 60 feet in width; but should the length of rafters for a wider building be required, it will be necessary to add such numbers together in the left-hand column as will make their sum equal to the width of the building, and then the sum of the lengths of the rafters given in the Table opposite these numbers, thus added together, will be the true length of the rafters required.

For example, suppose it were required to find the length of rafters for a building 84 feet wide, 6 inches rise. We find the length of a rafter of half that width, of the same pitch, to be 23 ft. 5.74 in., and double this number would be the length of the rafter required, or 46 ft. 11.48 in.

Example 2. Required the length of the rafters for a building 102 feet wide, 5 inches rise. We perceive that 50 and 52 added together will make 102. The lengths of these two dimensions for this pitch, as given in the Table, are 27 ft. 1 in., and 28 ft. 2 in., the sum of which is 55 ft. 3 in., the length of the rafters required.

TABLE I.

Length of Rafters in Feet, Inches, and Hundredths of an Inch. Rise of Rafter to the Foot in Inches.

Width of Building in Feet.	Run of Rafter.	1 inch Rise.	2 inch Rise.	3 inch Rise.	4 inch Rise.	5 inch Rise.	6 inch Rise.	7 inch Rise.	8 inch Rise.	9 inch Rise.
4	2	2 : 0.08	2 : 0.33	2 : 0.73	2 : 1.29	2 : 2.00	2 : 2.83	2 : 3.78	2 : 4.84	2 : 6
5	2 : 6	2 : 6.10	2 : 6.41	2 : 6.92	2 : 7.62	2 : 8.50	2 : 9.54	2 : 10.73	3 : 0.05	3 : 1.50
6	3	3 : 0.12	3 : 0.49	3 : 1.10	3 : 1.94	3 : 3	3 : 4.24	3 : 5.67	3 : 7.26	3 : 9
7	3 : 6	3 : 6.14	3 : 6.57	3 : 7.30	3 : 8.27	3 : 9.50	3 : 10.95	4 : 0.62	4 : 2.47	4 : 4.50
8	4	4 : 0.16	4 : 0.66	4 : 1.47	4 : 2.59	4 : 4	4 : 5.66	4 : 7.56	4 : 9.68	5 :
9	4 : 6	4 : 6.18	4 : 6.74	4 : 7.66	4 : 8.92	4 : 10.50	5 : 0.36	5 : 2.51	5 : 4.89	5 : 7.50
10	5	5 : 0.20	5 : 0.82	5 : 1.84	5 : 3.24	5 : 5	5 : 7.08	5 : 9.45	6 : 0.10	6 : 3
11	5 : 6	5 : 6.22	5 : 6.91	5 : 8.03	5 : 9.57	5 : 11.50	6 : 1.78	6 : 4.41	6 : 7.31	6 : 10.50
12	6	6 : 0.25	6 : 0.99	6 : 2.21	6 : 3.89	6 : 6	6 : 8.49	6 : 11.34	7 : 2.52	7 : 6
14	7	7 : 0.29	7 : 1.15	7 : 2.58	7 : 4.54	7 : 7	7 : 9.91	8 : 1.23	8 : 5.94	8 : 9
16	8	8 : 0.33	8 : 1.32	8 : 2.95	8 : 5.19	8 : 8	8 : 11.32	9 : 3.12	9 : 7.36	10 :
18	9	9 : 0.36	9 : 1.48	9 : 3.32	9 : 5.84	9 : 9	10 : 0.74	10 : 5.03	10 : 9.79	11 : 3
20	10	10 : 0.40	10 : 1.64	10 : 3.69	10 : 6.49	10 : 10	11 : 2.16	11 : 6.92	12 : 0.22	12 : 6
22	11	11 : 0.44	11 : 1.81	11 : 4.06	11 : 7.14	11 : 11	12 : 3.58	12 : 8.81	13 : 2.64	13 : 9
24	12	12 : 0.49	12 : 1.98	12 : 4.43	12 : 7.79	13 :	13 : 4.99	13 : 10.70	14 : 5.06	15 :
26	13	13 : 0.53	13 : 2.15	13 : 4.80	13 : 8.44	14 : 1	14 : 6.41	15 : 0.59	15 : 7.48	16 : 3
28	14	14 : 0.57	14 : 2.31	14 : 5.17	14 : 9.09	15 : 2	15 : 7.82	16 : 2.48	16 : 9.90	17 : 6
30	15	15 : 0.62	15 : 2.48	15 : 5.54	15 : 9.73	16 : 3	16 : 9.24	17 : 4.38	18 : 0.32	18 : 9
32	16	16 : 0.66	16 : 2.64	16 : 5.91	16 : 10.38	17 : 4	17 : 10.65	18 : 6.27	19 : 2.74	20 :
34	17	17 : 0.70	17 : 2.80	17 : 6.28	17 : 11.03	18 : 5	19 : 0.07	19 : 8.16	20 : 5.16	21 : 3
36	18	18 : 0.73	18 : 2.96	18 : 6.65	18 : 11.68	19 : 6	20 : 1.48	20 : 10.06	21 : 7.58	22 : 6
38	19	19 : 0 78	19 : 3.12	19 : 7.02	20 : 0.33	20 : 7	21 : 2.90	21 : 11.95	23 : 10	23 : 9
40	20	20 : 0.81	20 : 3.28	20 : 7.39	21 : 0.98	21 : 8	22 : 4.32	23 : 1.85	24 : 0.43	25 :
42	21	21 : 0.85	21 : 3.45	21 : 7.76	22 : 1.63	22 : 9	23 : 5.74	24 : 3.74	25 : 2.85	26 : 3
44	22	22 : 0.89	22 : 3.62	22 : 8.12	23 : 2.28	23 : 10	24 : 7.16	25 : 5.64	26 : 5.27	27 : 6
46	23	23 : 0.93	23 : 3.79	23 : 8.49	24 : 2.93	24 : 11	25 : 8.58	26 : 7.53	27 : 7.69	28 : 9
48	24	24 : 0.97	24 : 3.96	24 : 8.86	25 : 3.57	26 :	26 : 10	27 : 9.42	28 : 10.12	30 :
50	25	25 : 1.01	25 : 4.13	25 : 9.23	26 : 4.22	27 : 1	27 : 11.41	28 : 11.31	30 : 0.54	31 : 3
52	26	26 : 1.06	26 : 4.30	26 : 9.60	27 : 4.87	28 : 2	29 : 0.83	30 : 1.20	31 : 2.96	32 : 6
54	27	27 : 1.10	27 : 4.46	27 : 9.97	28 : 5.52	29 : 3	30 : 2.24	31 : 3.09	32 : 5.39	33 : 9
56	28	28 : 1.14	28 : 4.63	28 : 10.34	29 : 6.17	30 : 4	31 : 3.66	32 : 4.98	33 : 7.81	35 :
58	29	29 : 1.18	29 : 4.79	29 : 10.71	30 : 6.82	31 : 5	32 : 5.08	33 : 6.87	34 : 10.24	36 : 3
60	30	30 : 1.23	30 : 4.96	30 : 11.08	31 : 7.47	32 : 6	33 : 6.49	34 : 8.76	36 : 0.66	37 : 6

TABLE I.—*Continued.*

Length of Rafters in Feet, Inches, and Hundredths of an Inch. Rise of Rafter to the Foot in Inches.

Width of Building in Feet.	Run of Rafter.	10 inch Rise.	11 inch Rise.	12 inch Rise.	13 inch Rise.	14 inch Rise.	15 inch Rise.	16 inch Rise.	17 inch Rise.	18 inch Rise.
4	2	2: 7.24	2: 8.55	2: 9.94	2 : 11.38	2: 0.87	3 : 2.41	3: 4	3: 5.61	3: 7.26
5	2 : 6	3: 3.05	3: 4.69	3: 6.42	3: 8.22	3 : 10.09	4 : 0.02	4: 2	4: 4.02	4: 6.08
6	3	3 : 10.86	4: 0.83	4: 2.91	4: 5.07	4: 7.31	4 : 9.62	5:	5: 2.42	5: 4.89
7	3 : 6	4: 6.67	4: 8.97	4 : 11.39	5: 1.92	5: 4.53	5 : 7.23	5 : 10	6: 0.82	6: 3.71
8	4	5: 2.48	5: 5.11	5: 7.88	5 : 10.76	6: 1.75	6 : 4.83	6: 8	6 : 11.23	7: 2.53
9	4 : 6	5 : 10.29	6: 1.25	6: 4.36	6: 7.61	6 : 10.97	7 : 2.44	7: 6	7: 9.63	8: 1.34
10	5	6: 6.10	6: 9.39	7: 0.85	7: 4.45	7: 8.19	8 : 0.04	8: 4	8: 8.04	9: 0.16
11	5 : 6	7: 1.91	7: 5.53	7: 9.33	8: 1.30	8: 5.41	8 : 9.65	9: 2	9: 6.44	9 : 10.98
12	6	7: 9.72	8: 1.67	8: 5.82	8 : 10.15	9: 2.63	9 : 7.25	10:	10: 4.84	10: 9.79
14	7	9: 1.34	9: 5.95	9 : 10.79	10: 3.84	10: 9.07	11 : 2.46	11: 8	12: 1.65	12: 7.43
16	8	10: 4.96	10 : 10.23	11: 3.76	11: 9.53	12: 3.51	12 : 9.67	13: 4	13 : 10.46	14: 5.06
18	9	11: 8.58	12: 2.51	12: 8.73	13: 3.22	13: 9.95	14 : 4.88	15:	15: 7.27	16: 2.69
20	10	13: 0.20	13: 6.79	14: 1.70	14: 8.91	15: 4.39	16 : 0.09	16: 8	17: 4.08	18: 0.33
22	11	14: 3.82	14 : 11.07	15: 6.67	16: 2.60	16 : 10.83	17 : 7.30	18: 4	19: 0.88	19: 9.96
24	12	15: 7.44	16: 3.34	16 : 11.64	17: 8.30	18: 5.27	19 : 2.51	20:	20: 9.69	21: 7.59
26	13	16 : 11.06	17: 7.62	18: 4.61	19: 1.99	19 : 11.71	20 : 9.72	21: 8	22: 6.50	23: 5.22
28	14	18: 2.68	18 : 11.90	19: 9.58	20: 7.67	21: 6.14	22 : 4.93	23: 4	24: 3.31	25: 2.86
30	15	19: 6.30	20: 4.18	21: 2.55	22: 1.37	23: 0.58	24 : 0.14	25:	26: 0.12	27: 0.49
32	16	20: 9.92	21: 8.46	22: 7.52	23: 7.07	24: 7.02	25 : 7.35	26: 8	27: 8.92	28 : 10.12
34	17	22: 1.54	23: 0.74	24: 0.49	25: 0.77	26: 1.46	27 : 2.56	28: 4	29: 5.73	30: 7.76
36	18	23: 5.16	24: 5.02	25: 5.47	26: 6.46	27: 7.90	28 : 9.77	30:	31: 2.55	32: 5.39
38	19	24: 8.78	25: 9.30	26 : 10.44	28: 0.15	29: 2.34	30 : 4.98	31: 8	32 : 11.36	34: 3.02
40	20	26: 0.40	27: 1.57	28: 3.41	29: 5.84	30: 8.70	32 : 0.19	33: 4	34: 8.17	36: 0.66
42	21	27: 4.02	28: 5.85	29: 8.38	30 : 11.53	32: 3.22	33 : 7.39	35:	36: 4.97	37 : 10.29
44	22	28: 7.64	29 : 10.13	31: 1.35	32: 5.22	33: 9.66	35 : 2.60	36: 8	38: 1.78	39: 7.92
46	23	29 : 11.26	31: 2.41	32: 6.32	33 : 10.92	35: 4.10	36 : 9.81	38: 4	39 : 10.59	41: 5.55
48	24	31: 2.88	32: 6.69	33 : 11.29	35: 4.61	36 : 10.54	38 : 5.02	40:	41: 7.40	43: 3.19
50	25	32: 6.50	33 : 10.97	35: 4.26	36 : 10.30	38: 4.98	40 : 0.23	41: 8	43: 4.21	45: 0.82
52	26	33 : 10.12	35: 3.25	36: 9.23	38: 3.99	39 : 11.42	41 : 7.44	43: 4	45: 1.01	46 : 10.45
54	27	35: 1.74	36: 7.53	38: 2.20	39: 9.68	41: 5.86	43 : 2.65	45:	46: 9.82	48: 8.09
56	28	36: 5.36	37 : 11.80	39: 7.17	41: 3.37	43: 0.30	44 : 9.86	46: 8	48: 6.63	50: 5.72
58	29	37: 8.98	39: 4.08	41: 0.14	42: 9.06	44: 6.74	46 : 5.07	48: 4	50: 3.44	52: 3.35
60	30	39: 0.60	40: 8.36	42: 5.11	44: 2.75	46: 1.18	48 : 0.28	50:	52: 0.25	54: 0.99

TABLE II.

Length of Hip Rafters.

If a roof were perfectly horizontal or flat, the hip rafters would each be equal to the diagonal of a square, having for its side half the width of the building; and the square root of twice the square of half the side, would, in that case, be the length of the hip rafter. This we call the RUN *of the hip rafter*. But if the roof has any pitch, the *length* of the rafter is greater than its *run*, and is always equal to the hypotenuse of a right-angled triangle, having the *run* for a base, and the *rise* for a perpendicular; and the length is found, as in common rafters, by adding the square of the run to the square of the rise, and extracting the square root of the sum.

Two calculations are necessary according to the above demonstration: First, for obtaining the *run;* and secondly, having found the run, from that to obtain the *length*.

First. Suppose the width of the building to be 40 feet, and the rise of the roof 5 inches to the foot, or 100 inches; then half the width of the building, 20 feet, is 240 inches. the square of which is 57,600. Double this number (for the two sides of the square) is 115,200 inches, of which the square root is $339\frac{41}{100}$ inches, or, 28 ft. $3\frac{41}{100}$ in., which is the *run of the hip rafter*.

Second. To obtain the *length*, which equals the hypotenuse of a right-angled triangle, of which the run is the base and the rise the perpendicular.

The *run* is 339.41 inches as obtained above,

The square of which is	115,200
The rise is 100 inches, of which the square is	10,000

The sum of these two squares is 125,200 inches, of which the square root is 353.83 inches, or 29 ft. 5.83 in., which is the true *length of the hip rafter*.

The process of obtaining the length is explained above according to the *long way*, and the most obvious and analytical way also, and one which every practical mechanic should make himself fully familiar with: but *practically*, the process may be shortened as follows:—

Add the square of the rise to twice the square of half the width, and the square root of the sum will be length of hip rafter required. Thus:—

The square of the rise (100 inches) is	10,000
Twice the square of half the width is	115,200
Their sum is	125,200

of which the square root is 353.83 in., or 29 ft. 5.83 in. as before; which is the true length of the hip rafter as measured on the backing. See note on p.113.

TABLE II.

Length of Hip Rafters in Feet, Inches, and Hundredths of an Inch.

Width of Building in feet.	Run of Rafter.	1 inch Rise.	2 inch Rise.	3 inch Rise.	4 inch Rise.	5 inch Rise.	6 inch Rise.	7 inch Rise.	8 inch Rise.
4	2: 9.94	2: 10	2: 10.17	2: 10.46	2: 10.87	2: 11.38	3:	3: 0.71	3: 1.52
5	3: 6.42	3: 6.50	3: 6.72	3: 7.08	3: 7.58	3: 8.22	3: 9	3: 9.89	3: 10.90
6	4: 2.91	4: 3	4: 3.26	4: 3.70	4: 4.30	4: 5.07	4: 6	4: 7.07	4: 8.28
7	4: 11.39	4: 11.50	4: 11.80	5: 0.31	5: 1.02	5: 1.92	5: 3	5: 4.25	5: 5.66
8	5: 7.88	5: 8	5: 8.35	5: 8.93	5: 9.74	5: 10.76	6:	6: 1.43	6: 3.04
9	6: 4.36	6: 4.50	6: 4.89	6: 5.55	6: 6.46	6: 7.61	6: 9	6: 10.60	7: 0.42
10	7: 0.85	7: 1	7: 1.44	7: 2.16	7: 3.17	7: 4.45	7: 6	7: 7.78	7: 9.80
11	7: 9.33	7: 9.50	7: 9.98	7: 10.78	7: 11.89	8: 1.30	8: 3	8: 4.96	8: 7.18
12	8: 5.82	8: 6	8: 6.52	8: 7.39	8: 8.61	8: 10.15	9:	9: 2.14	9: 4.56
14	9: 10.79	9: 11	9: 11.61	10: 0.63	10: 2.04	10: 3.84	10: 6	10: 8.50	10: 11.33
16	11: 3.76	11: 4	11: 4.70	11: 5.86	11: 7.48	11: 9.53	12:	12: 2.86	12: 6.09
18	12: 8.73	12: 9	12: 9.79	12: 11.09	13: 0.91	13: 3.22	13: 6	13: 9.21	14: 0.85
20	14: 1.70	14: 2	14: 2.88	14: 4.33	14: 6.35	14: 8.91	15:	15: 3.57	15: 7.61
22	15: 6.67	15: 7	15: 7.96	15: 9.57	15: 11.79	16: 2.60	16: 6	16: 9.93	17: 2.37
24	16: 11.64	17:	17: 1.05	17: 2.80	17: 5.22	17: 8.30	18:	18: 4.29	18: 9.34
26	18: 4.61	18: 5	18: 6.14	18: 8.03	18: 10.66	19: 1.99	19: 6	19: 10.64	20: 3.90
28	19: 9.58	19: 10	19: 11.23	20: 1.26	20: 4.09	20: 7.68	21:	21: 5	21: 10.66
30	21: 2.55	21: 3	21: 4.32	21: 6.50	21: 9.53	22: 1.37	22: 6	22: 11.36	23: 5.42
32	22: 7.52	22: 8	22: 9.40	22: 11.73	23: 2.96	23: 7.06	24:	24: 5.72	24: 11.18
34	24: 0.49	24: 1	24: 2.49	24: 4.97	24: 8.40	25: 0.76	25: 6	26: 0.07	26: 5.94
36	25: 5.46	25: 6	25: 7.58	25: 10.20	26: 1.83	26: 6.45	27:	27: 6.43	28: 0.70
38	26: 10.44	26: 11	27: 0.67	27: 3.43	27: 7.27	28: 0.14	28: 6	29: 0.79	29: 7.47
40	28: 3.41	28: 4	28: 5.76	28: 8.27	29: 0.71	29: 5.83	30:	30: 7.15	31: 2.23

TABLE III.

Hip and Jack Rafters on Octagonal Roofs.

The length of one side of an octagonal building being commonly given as the basis of calculation in framing, it will first be necessary from this basis, to determine with accuracy the width of the building from the middle of one side to the middle of the opposite side; and also the diagonal width, from one corner to the opposite corner.

The width FG (in Plate 20, Fig. 1) is obviously the same as one side of the circumscribed square DE; and DE is made up of three parts, namely, DA, AB, and BE, one of which parts, AB, is known—being a side of the given octagon. The other two parts are equal to each other, namely, DA=BE.* We have, therefore, to find the length of DA, to double it, and to add AB to it in order to ascertain the width of the building. The length of DA is found as follows:—

In the right-angled triangle CAD, the hypotenuse AC, being one of the sides of the given octagon, is known; and the square of this hypotenuse is equal to the sum of the squares of the other two sides DA and DC, or to double the square of DA.

For example, suppose the sides of the regular octagon be given equal to 16 feet, which, on reducing it to inches to insure greater accuracy, is 192 inches.

The square of 192 inches is 36,864 inches, one half which is 18,432 inches, which is the square of DA.

The square root of 18,432 inches is 135.76 inches, or 11 ft. 3.76 in., the length of DA.

Double this number (for DA×BE), and add 16 feet for the length of AB, and we have 38 ft. 7.52 in., *the width of the building.*

The *diagonal width* is obtained as follows:

Let O′ represent the point at the foot of the perpendicular let fall

* The equality of DA and BE may be demonstrated thus:—Suppose the figure divided into two parts by the line FG, and these two parts to be folded together, the line FG forming the fold; then the point A would fall upon the point B, the point C upon the point H, and the point D upon the point E; otherwise, the polygon is not a regular polygon, nor the circumscribed square a perfect square. In a similar manner, it may be demonstrated that the line AD is equal to DC, by supposing the figure to be folded upon the line DL.

from O, the apex of the roof, upon the plane or level of the plates CA, AB, &c.

Then, in the right-angled triangle O′FA, the sum of the squares of the two sides AF and FO′ will equal the square of the hypotenuse AO′

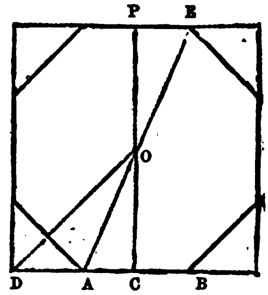
Having found above that FG=38 ft. 7.52 in., then FO′ will equal half this number, or 19 ft. 3.76 in., or 231.76 inches, the square of which is 53,712.6976 inches.

FA is half of the given side AB, and is 8 feet, or 96 inches, of which the square is 9,216 inches, which, being added to 53,712.6976 inches, is 62,928.6976 inches, the square root of which is 250.85 inches, or 20 ft. 10.85 in., the length of AO′, or half the diagonal width of the building. Double this number is 41 ft. 9.70 in., the length of AP, the *diagonal width required.*

Half the diagonal width is of course the run of the hip rafters, and half the square width is the run of the middle jack rafters; and, having ascertained these, the lengths of the rafters are calculated according to the rule given at the commencement of this general explanation of the Tables—by taking the square root of the sum of the squares of the *run* and the *rise* of any given rafter.

II. Width of Octagon given to find the Diagonal and the Side.

It sometimes happens, as in church spires for example, that the width of an octagon is given, from which the other dimensions must be found.



Let PC, the width of a regular octagon, be given, to find AB the side, and AE the diagonal.

Draw OD from the centre of the octagon to an angle of the circumscribed square. Then $OD^2 = CD^2 + OC^2$, or $2OC^2$, since OD is the hypotenuse of the triangle ODC, of which the other two sides OC and DC are equal to each other, and each one equals half the given width of the octagon. Then, since OA bisects the vertical angle of the triangle COD, it divides the base into two segments, which are proportional to the adjacent sides (Part I., Prop. XXVI.); and we have the following proportion:

$$DO : OC :: DA : AC;$$

and, by composition,

$$DO+OC : OC :: DA+AC : AC;$$

but AC is half the required side AB.

Having obtained, by the above formula, the length of AC, it will be easy to obtain that of OA, since $OA^2=OC^2+AC^2$.

Example. Suppose PC, the given width, equals 10 ft. 8 in., which is the width of the base of the church spire described in Plate 28. Reducing this number to inches, to insure greater accuracy, we have PC=128 inches. And OD would then equal the square root of the sum of the squares of OC and DC, each of which equals 64 inches. Double the square of 64 inches equals 8192 inches, the square root of which is 90.51 inches, which is the length of OD; then, by applying or substituting this value in the first proportion given above, we have

$$90.51 \text{ in.} : 64 \text{ in.} :: DA : AC;$$

and DA being yet unknown, we ascertain it by composition, thus:

$$90.51+64 : 64 :: DA+AC, \text{ or } DC : AC;$$

or, $$154.51 : 64 :: 64 : AC.$$

Multiplying the middle terms of this proportion together, and dividing the product by the first term, we have the value of the last term, or AC, equal to 26.51 inches. Double this, and we have AB, *the required side, equal to* 53.02 *inches, or* 4 ft. 5.02 in., and $OC^2+AC^2=AO^2$, or 702.78+4096=4798.78 inches, the square root of which is 69.27 inches, or 5 ft. 9.27 in.; and the whole of the *required diagonal* equals twice this number, or 11 ft. 6.54 in.

Note.—Since all regular octagons are similar figures, any two regular octagons of different dimensions will not only have their sides proportional, but their widths and their diagonal widths proportional also; and if we have the exact dimensions of all the parts of one octagon given, and any one part of the other octagon also given, then all its remaining parts can be found by proportion.

Example 1. Required the diagonal width of a regular octagon, the side of which is 12 feet.

Let us compare this with another octagon, all the dimensions of which we know, or which we can find from the Table; say, an octagon of 16 feet side, the diagonal width of which, as given in the Table, is

41 ft. 9.7 in.; then, since all the parts of the one figure are proportional to the corresponding parts of the other, we shall have

side to side, as diagonal width to diagonal width;

or, 16 : 12 : : 41 9.7 to the answer =31 ft. 4.27 in.,

Thus:

We multiply the second and third terms together, and divide by the first:

```
     41 ft. 9.7 in.
     12
    ---
    492
      9.7
    -----
16)501.7(31.356 feet and decimals of a foot, which we reduce to
   48             feet and inches, thus:
   --
    21                          31.356
    16                              12
    --                          ------
     57                          4.27
     48
     --
      90
      80
     ---
     100
```

By multiplying the tenths of a foot by 12 to bring them to inches, and disregarding the third decimal figure, we have for a final answer 31 ft. $4\frac{27}{100}$ in. as the required answer; which is verified by the number as given in the Table.

Example 2. Required the *side* of a regular octagon, the square width of which is 30 feet. We compare this with the same octagon as before, and have

width to width as side to side;

or, 38 7.52 : 30 : : 16 : to the answer =12 feet 5.12 inches,

Thus:

as in this case the first term or divisor is a compound number, we reduce all the three given terms to inches, and have

38 ft. 7.52 in. =463.52 inches,

30 feet =360 inches,

16 feet =192 inches.

So that the proportion, in inches, is

463.52 : 360 : : 192 : answer = 12 ft. 5.12 in.

```
           360
          -----
          11520
          576
          -----
463.52)69120(149.119 in., or 12 ft. 5.12 in., Ans.
       46352
       ------
       227680
       185408
       ------
        422720
        417168
        ------
          55520
          46352
          -----
           91680
           46352
           ------
           453280
```

TABLE III.

OCTAGONAL ROOFS.—One side of the Octagon being given to find: 1. The Width of the Building. 2. Its Diagonal Width. 3. The Length of the Hip Rafters. 4. The Length of the Middle Jack Rafters, in Feet, Inches, and Hundredths of an Inch.

Rise of the Roof to the Foot on the Jack Rafters.

Length of One Side.	Width of Building.	Diagonal Width of Building.	1 inch Rise.		2 inch Rise.		3 inch Rise.		4 inch Rise.		5 inch Rise.		6 inch Rise.	
			Jack.	Hip.	Jack.	Hip.	Jack.	Hip.	Jack.	Hip.	Jack.	Hip.	Jack.	Hip.
6 ft.	14: 5.82	15: 8.14	7: 3.21	7: 10.35	7: 4.11	7: 11.18	7: 5.59	8: 0.55	7: 7.61	8: 2.43	7: 10.15	8: 4.79	8: 1.17	8: 7.62
7 "	16: 10.79	18: 3.49	8: 5.75	9: 2.07	8: 6.79	9: 3.04	8: 8.49	9: 4.63	8: 10.87	9: 6.83	9: 1.81	9: 9.59	9: 5.36	10: 0.89
8 "	19: 3.76	20: 10.85	9: 8.28	10: 5.80	9: 9.47	10: 6.90	9: 11.42	10: 8.72	10: 2.14	10: 11.24	10: 5.53	11: 2.38	10: 9.56	11: 6.16
9 "	21: 8.73	23: 6.20	10: 10.81	11: 9.53	11: 0.16	11: 10.76	11: 2.35	12: 0.81	11: 5.41	12: 3.64	11: 9.22	12: 7.18	12: 1.75	12: 11.43
10 "	24: 1.70	26: 1.56	12: 1.35	13: 1.25	12: 2.84	13: 2.62	12: 5.28	13: 4.90	12: 8.68	13: 8.05	13: 0.91	13: 11.98	13: 5.95	14: 4.70
11 "	26: 6.67	28: 8.92	13: 3.88	14: 4.98	13: 5.52	14: 6.68	13: 8.21	14: 9	13: 11.95	15: 0.45	14: 4.60	15: 4.78	14: 10.14	15: 9.97
12 "	28: 11.64	31: 4.27	14: 6.42	15: 8.70	14: 8.21	15: 10.35	14: 11.14	16: 1.09	15: 3.22	16: 4.86	15: 8.30	16: 9.58	16: 2.34	17: 3.21
14 "	33: 9.58	36: 6.98	16: 11.50	18: 4.15	17: 1.58	18: 6.07	17: 5	18: 9.27	17: 9.76	19: 1.67	18: 3.68	19: 7.17	18: 10.73	20: 1.78
16 "	38: 7.52	41: 9.70	19: 4.56	20: 11.60	19: 6.95	21: 1.80	19: 10.85	21: 5.45	20: 4.29	21: 10.48	20: 11.06	22: 4.77	21: 7.12	23: 0.32
18 "	43: 5.46	47: 0.42	21: 9.63	23: 7.05	22: 0.32	23: 9.52	22: 4.70	24: 1.63	22: 10.83	24: 7.29	23: 6.45	25: 2.37	24: 3.51	25: 10.86
20 "	48: 3.40	52: 3.12	24: 2.70	26: 2.50	24: 5.68	26: 5.25	24: 10.56	26: 9.81	25: 5.36	27: 4.10	26: 1.83	27: 11.96	26: 11.90	28: 9.40
22 "	53: 1.34	57: 5.83	26: 7.77	28: 9.95	26: 11.05	29: 0.97	27: 4.42	29: 6	27: 11.90	30: 0.91	28: 9.21	30: 9.56	29: 8.29	31: 7.94
24 "	57: 11.28	62: 8.55	29: 0.84	31: 5.40	29: 4.42	31: 8.70	29: 10.27	32: 2.17	30: 6.44	32: 9.72	31: 4.60	33: 7.16	32: 4.68	34: 6.48
26 "	62: 9.22	67: 11.26	31: 5.91	34: 0.85	31: 9.79	34: 4.42	32: 4.13	34: 10.35	33: 0.97	35: 6.53	33: 11.98	36: 4.75	35: 1.07	37: 5.02
28 "	67: 7.16	73: 1.97	33: 10.98	36: 8.30	34: 3.16	37: 0.15	34: 10	37: 6.53	35: 7.51	38: 3.34	36: 7.36	39: 2.35	37: 9.46	40: 3.56
30 "	72: 5.10	78: 4.68	36: 4.05	39: 3.75	36: 8.53	39: 7.87	37: 3.84	40: 2.72	38: 2.05	41: 0.14	39: 2.75	41: 11.75	40: 5.85	43: 2.10

TABLE IV.

The *length of braces*, like the length of rafters, must be determined by extracting the square root of the sum of the squares of the perpendicular and the horizontal runs.

This table embraces almost every length that can be required in framing buildings, and comprises those of both regular and irregular runs.

The exact length is here given to the hundredth part of an inch; but *practically* it will be found best to cut each brace from a sixteenth to an eighth of an inch longer than the exact rule requires, in order to compensate for compression and the shrinkage of the timber.

TABLE IV.

Length of Braces given in Feet, Inches, and Hundredths of an Inch.

Length of Run. Ft. In. Ft. In.	Length of Brace.	Length of Run. Ft. In. Ft. In.	Length of Brace.	Length of Run. Ft. In. Ft. In.	Length of Brace.
0 : 6 by 0 : 6	0 : 8.48	3 : 3 by 3 : 3	4 : 7.15	5 : 6 by 5 : 6	7 : 9.33
0 : 6 by 0 : 9	0 : 10.81	3 : 3 by 3 : 6	4 : 9.31	5 : 9 by 5 : 9	8 : 1.58
0 : 9 by 0 : 9	1 : 0.72	3 : 3 by 3 : 9	4 : 11.54	6 : 0 by 6 : 0	8 : 5.82
0 : 9 by 1 : 0	1 : 3	3 : 3 by 4 : 0	5 : 1.84	6 : 3 by 6 : 3	8 : 10.06
1 : 0 by 1 : 0	1 : 4.97	3 : 6 by 3 : 6	4 : 11.39	6 : 6 by 6 : 6	9 : 2.30
1 : 0 by 1 : 3	1 : 7.20	3 : 6 by 3 : 9	5 : 1.55	6 : 9 by 6 : 9	9 : 6.55
1 : 3 by 1 : 3	1 : 9.23	3 : 6 by 4 : 0	5 : 3.76	7 : 0 by 7 : 0	9 : 10.79
1 : 3 by 1 : 6	1 : 11.43	3 : 9 by 3 : 9	5 : 3.63	7 : 3 by 7 : 3	10 : 3.03
1 : 6 by 1 : 6	2 : 1.45	3 : 9 by 4 : 0	5 : 5.79	7 : 6 by 7 : 6	10 : 7.28
1 : 6 by 1 : 9	2 : 3.65	4 : 0 by 4 : 0	5 : 7.88	7 : 9 by 7 : 9	10 : 11.52
1 : 9 by 1 : 9	2 : 5.69	4 : 0 by 4 : 3	5 : 10.03	8 : 0 by 8 : 0	11 : 3.76
1 : 9 by 2 : 0	2 : 7.89	4 : 0 by 4 : 6	6 : 0.25	8 : 3 by 8 : 3	11 : 8
2 : 0 by 2 : 0	2 : 9.94	4 : 0 by 4 : 9	6 : 2.51	8 : 6 by 8 : 6	12 : 0.24
2 : 0 by 2 : 3	3 : 0.12	4 : 0 by 5 : 0	6 : 4.83	8 : 9 by 8 : 9	12 : 4.49
2 : 0 by 2 : 6	3 : 2.41	4 : 3 by 4 : 3	6 : 0.12	9 : 0 by 9 : 0	12 : 8.73
2 : 3 by 2 : 6	3 : 4.36	4 : 3 by 4 : 6	6 : 2.27	9 : 6 by 9 : 6	13 : 5.22
2 : 6 by 2 : 6	3 : 6.42	4 : 3 by 4 : 9	6 : 4.49	10 : 0 by 10 : 0	14 : 1.70
2 : 6 by 2 : 9	3 : 8.59	4 : 3 by 5 : 0	6 : 6.74	10 : 6 by 10 : 6	14 : 10.19
2 : 9 by 2 : 9	3 : 10.66	4 : 6 by 4 : 6	6 : 4.36	11 : 0 by 11 : 0	15 : 6.67
2 : 9 by 3 : 0	4 : 0.83	4 : 6 by 4 : 9	6 : 6.51	11 : 6 by 11 : 6	16 : 3.16
3 : 0 by 3 : 0	4 : 2.91	4 : 6 by 5 : 0	6 : 8.72	12 : 0 by 12 : 0	16 : 11.64
3 : 0 by 3 : 3	4 : 5.02	4 : 9 by 4 : 9	6 : 8.61	12 : 6 by 12 : 6	17 : 8.13
3 : 0 by 3 : 6	4 : 7.31	4 : 9 by 5 : 0	6 : 10.75	13 : 0 by 13 : 0	18 : 4.61
3 : 0 by 3 : 9	4 : 9.62	5 : 0 by 5 : 0	7 : 0.85	13 : 6 by 13 : 6	19 : 1.10
3 : 0 by 4 : 0	5 :	5 : 3 by 5 : 3	7 : 5.09	14 : 0 by 14 : 0	19 : 9.58

TABLE V.

Weight of Square Iron in Pounds and Ounces.

Size.	1 foot.	2 feet.	3 feet.	4 feet.	5 feet.	6 feet.	7 feet.	8 feet.	9 feet.
Inches.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.
½	0 : 13	1 : 11	2 : 8	2 : 6	4 : 3	5 : 2	5 : 15	6 : 13	7 : 10
⅝	1 : 5	2 : 10	4 : 0	5 : 5	6 : 10	7 : 9	9 : 5	10 : 10	12 : 0
¾	1 : 15	3 : 14	5 : 13	7 : 12	9 : 10	11 : 9	13 : 7	15 : 6	17 : 4
⅞	2 : 10	5 : 4	7 : 14	10 : 8	13 : 0	15 : 8	18 : 2	20 : 12	23 : 6
1	3 : 6	6 : 12	10 : 2	13 : 5	16 : 12	20 : 4	23 : 10	27 : 0	30 : 6
1⅛	4 : 5	8 : 10	12 : 15	17 : 3	21 : 8	25 : 12	30 : 0	34 : 5	38 : 9
1¼	5 : 5	10 : 10	15 : 15	21 : 2	26 : 7	31 : 12	37 : 0	42 : 4	47 : 8
1⅜	6 : 6	12 : 12	19 : 3	25 : 9	32 : 0	38 : 6	44 : 12	51 : 2	57 : 8
1½	7 : 10	15 : 4	22 : 12	30 : 6	38 : 0	45 : 10	53 : 4	60 : 14	68 : 7
1⅝	8 : 14	17 : 12	26 : 11	35 : 9	44 : 8	53 : 7	62 : 6	71 : 5	80 : 4
1¾	10 : 6	20 : 12	31 : 2	41 : 7	51 : 13	62 : 2	72 : 8	82 : 14	93 : 4
1⅞	11 : 14	23 : 12	35 : 10	47 : 8	59 : 6	71 : 5	83 : 3	95 : 2	107 : 0
2	13 : 8	27 : 0	40 : 10	54 : 2	67 : 10	81 : 2	94 : 10	102 : 03	121 : 11
2⅛	15 : 5	30 : 8	45 : 13	61 : 2	76 : 6	91 : 10	106 : 13	122 : 2	137 : 6
2¼	17 : 2	34 : 3	51 : 5	68 : 6	85 : 9	102 : 11	119 : 13	136 : 15	154 : 0
2⅜	19 : 1	38 : 2	57 : 3	76 : 4	95 : 5	114 : 6	133 : 7	152 : 8	171 : 9
2½	21 : 1	42 : 3	63 : 6	84 : 8	105 : 10	126 : 14	147 : 15	169 : 0	190 : 1
2⅝	23 : 5	46 : 10	69 : 15	93 : 3	116 : 8	139 : 13	163 : 1	186 : 5	209 : 10
2¾	25 : 10	51 : 02	76 : 12	102 : 3	127 : 13	153 : 6	178 : 15	204 : 8	230 : 0
2⅞	27 : 14	55 : 14	83 : 13	111 : 12	139 : 11	167 : 10	195 : 9	223 : 5	251 : 7
3	30 : 6	60 : 12	91 : 3	121 : 9	152 : 2	182 : 8	212 : 14	243 : 5	273 : 11
3⅛	33 : 0	66 : 0	99 : 0	132 : 0	165 : 1	198 : 1	231 : 1	264 : 2	297 : 2
3¼	35 : 11	71 : 6	107 : 2	142 : 13	178 : 8	214 : 3	249 : 15	285 : 10	321 : 5
3⅜	38 : 8	77 : 0	115 : 8	154 : 0	192 : 8	231 : 0	269 : 8	308 : 0	346 : 8
3½	41 : 6	82 : 12	124 : 3	167 : 9	207 : 0	248 : 6	289 : 12	331 : 3	372 : 10
3⅝	44 : 6	88 : 12	133 : 4	177 : 11	221 : 2	266 : 8	310 : 14	355 : 5	399 : 13
3¾	47 : 8	95 : 1	142 : 9	190 : 2	237 : 11	285 : 3	332 : 11	380 : 5	427 : 13
3⅞	50 : 13	101 : 8	152 : 5	203 : 0	253 : 13	304 : 8	355 : 5	406 : 0	456 : 13
4	54 : 2	108 : 3	162 : 4	216 : 5	270 : 6	324 : 8	376 : 10	432 : 11	486 : 13
4⅛	57 : 8	115 : 0	172 : 10	230 : 2	287 : 10	345 : 2	402 : 10	460 : 2	517 : 11
4¼	61 : 1	122 : 2	183 : 3	244 : 4	305 : 5	366 : 6	427 : 7	488 : 7	549 : 8
4⅜	64 : 11	129 : 6	194 : 2	258 : 13	323 : 8	388 : 3	452 : 14	517 : 10	582 : 5
4½	68 : 6	136 : 14	205 : 5	273 : 13	342 : 3	410 : 11	479 : 2	547 : 10	616 : 0
4⅝	72 : 5	144 : 10	216 : 15	289 : 3	361 : 8	433 : 13	506 : 2	578 : 7	450 : 11
4¾	76 : 5	152 : 8	228 : 12	305 : 1	381 : 5	457 : 9	533 : 13	610 : 1	686 : 6
4⅞	80 : 5	160 : 11	241 : 0	221 : 5	401 : 11	482 : 0	562 : 5	642 : 11	723 : 0
5	84 : 8	169 : 0	253 : 6	337 : 15	422 : 6	506 : 15	591 : 6	675 : 14	760 : 5

TABLE V.—*Continued.*

Weight of Square Iron in Pounds and Ounces.

Size.	10 feet.	11 feet.	12 feet.	13 feet.	14 feet.	15 feet.	16 feet.	17 feet.	18 feet.
Inches.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.
½	8 : 8	9 : 5	10 : 2	11 : 0	11 : 13	12 : 9	13 : 8	14 : 6	15 : 3
⅝	13 : 5	14 : 10	16 : 0	17 : 5	18 : 10	19 : 15	21 : 4	22 : 9	23 : 14
¾	19 : 0	20 : 15	22 : 13	24 : 12	26 : 10	28 : 8	30 : 6	32 : 4	34 : 02
⅞	26 : 0	28 : 8	31 : 2	33 : 12	36 : 6	38 : 14	41 : 8	44 : 2	46 : 12
1	33 : 12	37 : 3	40 : 10	44 : 0	47 : 6	50 : 12	54 : 2	57 : 8	60 : 14
1⅛	42 : 14	47 : 2	51 : 6	55 : 11	59 : 15	64 : 4	68 : 8	72 : 13	77 : 0
1¼	52 : 12	58 : 1	63 : 6	68 : 11	74 : 0	79 : 4	84 : 8	89 : 13	95 : 0
1⅜	63 : 14	70 : 4	76 : 10	83 : 0	89 : 7	95 : 14	102 : 2	108 : 9	115 : 0
1½	76 : 0	83 : 10	91 : 4	98 : 14	106 : 8	114 : 2	121 : 12	129 : 6	137 : 0
1⅝	89 : 4	98 : 3	107 : 2	116 : 1	125 : 0	133 : 15	142 : 14	151 : 13	160 : 11
1¾	103 : 10	114 : 0	124 : 5	134 : 11	145 : 0	155 : 5	165 : 11	176 : 0	186 : 6
1⅞	118 : 13	130 : 11	142 : 10	154 : 8	166 : 6	178 : 3	190 : 2	202 : 0	213 : 14
2	135 : 3	148 : 11	162 : 3	175 : 12	189 : 4	202 : 13	216 : 5	229 : 13	243 : 6
2⅛	152 : 10	167 : 14	183 : 3	198 : 7	213 : 11	229 : 0	244 : 5	259 : 9	274 : 14
2¼	171 : 2	188 : 3	205 : 5	222 : 8	239 : 10	256 : 11	273 : 13	290 : 15	308 : 0
2⅜	190 : 10	209 : 11	228 : 12	247 : 14	266 : 15	286 : 0	305 : 1	324 : 2	343 : 3
2½	211 : 3	232 : 5	253 : 7	274 : 9	295 : 12	316 : 14	337 : 15	359 : 0	380 : 3
2⅝	232 : 15	256 : 3	279 : 8	302 : 13	326 : 2	349 : 7	372 : 12	396 : 0	419 : 5
2¾	255 : 10	281 : 3	306 : 13	332 : 6	357 : 13	383 : 6	409 :	434 : 8	460 : 1
2⅞	279 : 6	307 : 5	335 : 4	363 : 3	391 : 1	419 : 0	447 : 0	475 : 0	502 : 14
3	304 : 2	334 : 9	365 : 0	395 : 6	425 : 13	456 : 3	486 : 10	517 : 1	547 : 8
3⅛	330 : 2	363 : 2	396 : 2	329 : 2	462 : 2	495 : 3	528 : 3	561 : 3	594 : 3
3¼	357 : 0	392 : 11	428 : 6	464 : 3	500 : 0	535 : 11	571 : 5	607 : 0	642 : 11
3⅜	385 : 0	423 : 8	462 : 0	500 : 8	539 : 0	577 : 8	616 : 0	654 : 9	693 : 1
3½	414 : 1	455 : 8	496 : 15	538 : 5	579 : 11	621 : 2	662 : 8	703 : 14	745 : 5
3⅝	444 : 3	488 : 9	533 : 0	577 : 6	621 : 15	666 : 5	710 : 11	755 : 2	799 : 8
3¾	475 : 5	522 : 14	570 : 6	617 : 15	665 : 8	713 : 0	760 : 8	808 : 1	855 : 10
3⅞	507 : 10	558 : 5	609 : 1	659 : 13	710 : 10	761 : 5	812 : 2	862 : 15	913 : 10
4	540 : 14	594 : 15	649 : 0	703 : 2	757 : 3	811 : 4	865 : 5	919 : 6	973 : 8
4⅛	575 : 3	632 : 11	690 : 3	747 : 11	805 : 3	862 : 12	920 : 5	977 : 13	1035 : 5
4¼	610 : 9	671 : 10	732 : 11	793 : 12	854 : 13	915 : 14	976 : 15	1037 : 15	1099 : 0
4⅜	646 : 0	711 : 11	776 : 6	841 : 2	905 : 13	970 : 8	1035 : 3	1099 : 14	1164 : 10
4½	684 : 8	752 : 15	821 : 6	889 : 13	958 : 5	1026 : 11	1095 : 3	1163 : 10	1232 : 2
4⅝	721 : 1	793 : 6	867 : 11	940 : 0	1012 : 5	1084 : 10	1156 : 15	1229 : 3	1301 : 8
4¾	762 : 10	838 : 15	915 : 3	991 : 7	1067 : 11	1144 : 0	1220 : 3	1296 : 8	1372 : 13
4⅞	803 : 5	883 : 11	964 : 0	1044 : 5	1124 : 11	1205 : 0	1285 : 5	1365 : 11	1446 : 0
5	844 : 13	929 : 5	1013 : 14	1098 : 3	1182 : 11	1267 : 3	1351 : 11	1436 : 3	1520 : 10

TABLE VI.

Weight of Flat Iron in Pounds and Ounces.

Thick.	Wide.	1 foot.	2 feet.	3 feet.	4 feet.	5 feet.	6 feet.	7 feet.	8 feet.	9 feet.	10 feet.
Inches.	Inches.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.
¼	1	0 : 13	1 : 11	2 : 8	3 : 6	4 : 2	5 : 0	5 : 14	6 : 13	7 : 10	8 : 8
	1¼	1 : 1	2 : 2	3 : 3	4 : 3	5 : 4	6 : 5	7 : 6	8 : 7	9 : 8	10 : 9
	1½	1 : 4	2 : 8	3 : 12	5 : 1	6 : 5	7 : 9	8 : 13	10 : 1	11 : 5	12 : 10
	1¾	1 : 8	3 : 0	4 : 7	5 : 14	7 : 6	8 : 14	10 : 6	11 : 13	13 : 5	14 : 13
	2	1 : 11	3 : 6	5 : 1	6 : 13	8 : 8	10 : 1	11 : 13	13 : 8	15 : 3	16 : 14
	2¼	1 : 14	3 : 12	5 : 11	7 : 10	9 : 8	11 : 6	13 : 4	15 : 3	17 : 1	19 : 0
	2½	2 : 1	4 : 3	6 : 5	8 : 7	10 : 9	12 : 11	14 : 13	16 : 14	19 : 0	21 : 1
	2¾	2 : 5	4 : 10	7 : 0	9 : 5	11 : 10	13 : 14	16 : 5	18 : 10	20 : 15	22 : 3
	3	2 : 8	5 : 1	7 : 10	10 : 1	12 : 11	15 : 3	17 : 11	20 : 5	22 : 13	25 : 5
	3¼	2 : 12	5 : 8	8 : 3	11 : 0	13 : 12	16 : 8	19 : 3	22 : 0	24 : 12	27 : 8
	3½	3 : 0	5 : 14	8 : 13	11 : 12	14 : 11	17 : 10	20 : 10	23 : 9	26 : 9	29 : 8
	3¾	3 : 3	6 : 5	9 : 8	12 : 11	15 : 13	19 : 0	22 : 3	25 : 6	28 : 8	31 : 11
	4	3 : 6	6 : 13	10 : 2	13 : 8	16 : 14	20 : 5	23 : 11	27 : 0	30 : 6	33 : 13
⅜	1	1 : 4	2 : 8	3 : 12	5 : 1	6 : 5	7 : 9	8 : 14	10 : 2	11 : 6	12 : 11
	1¼	1 : 10	3 : 4	4 : 13	6 : 5	7 : 14	9 : 8	11 : 1	12 : 11	14 : 5	15 : 13
	1½	1 : 14	3 : 12	5 : 11	7 : 10	9 : 8	11 : 6	13 : 5	15 : 2	17 : 1	19 : 0
	1¾	2 : 3	4 : 6	6 : 10	8 : 14	11 : 1	13 : 5	15 : 8	17 : 11	20 : 1	22 : 3
	2	2 : 8	5 : 1	7 : 9	10 : 1	12 : 9	15 : 2	17 : 11	20 : 5	22 : 11	25 : 6
	2¼	2 : 14	5 : 11	8 : 8	11 : 6	14 : 4	17 : 2	20 : 0	22 : 12	25 : 10	28 : 8
	2½	3 : 3	6 : 6	9 : 8	12 : 11	15 : 13	19 : 0	22 : 3	25 : 6	28 : 8	31 : 11
	2¾	3 : 8	7 : 0	10 : 8	13 : 15	17 : 7	20 : 14	24 : 7	27 : 15	31 : 7	34 : 15
	3	3 : 13	7 : 10	11 : 6	15 : 3	19 : 0	22 : 12	26 : 9	30 : 6	34 : 3	38 : 0
	3¼	4 : 2	8 : 4	12 : 6	16 : 8	20 : 10	24 : 12	28 : 14	33 : 0	37 : 2	41 : 4
	3½	4 : 7	8 : 14	13 : 5	17 : 12	22 : 3	26 : 10	31 : 0	35 : 7	39 : 15	44 : 6
	3¾	4 : 12	9 : 8	14 : 4	19 : 0	23 : 12	28 : 8	33 : 4	38 : 0	42 : 12	47 : 8
	4	5 : 1	10 : 2	15 : 3	20 : 4	25 : 5	30 : 6	35 : 8	40 : 9	45 : 10	50 : 11
½	1	1 : 11	3 : 6	5 : 1	6 : 13	8 : 8	10 : 2	11 : 13	13 : 8	15 : 3	16 : 14
	1¼	2 : 1	4 : 3	6 : 5	8 : 7	10 : 9	12 : 11	14 : 13	16 : 14	19 : 0	21 : 2
	1½	2 : 8	5 : 1	7 : 9	10 : 1	12 : 10	15 : 3	17 : 11	20 : 5	22 : 13	25 : 5
	1¾	3 : 0	5 : 15	8 : 14	11 : 13	14 : 12	17 : 11	20 : 10	23 : 10	26 : 9	29 : 9
	2	3 : 6	6 : 12	10 : 2	13 : 8	16 : 14	20 : 5	23 : 10	27 : 0	30 : 6	33 : 12
	2¼	3 : 13	7 : 10	11 : 7	15 : 3	19 : 0	22 : 13	26 : 10	30 : 7	34 : 4	38 : 0
	2½	4 : 3	8 : 6	12 : 10	16 : 14	21 : 2	25 : 5	26 : 9	33 : 14	38 : 2	42 : 4
	2¾	4 : 10	9 : 5	13 : 15	18 : 9	23 : 3	27 : 14	32 : 8	37 : 3	41 : 13	46 : 8
	3	5 : 1	10 : 2	15 : 3	20 : 4	25 : 5	30 : 6	35 : 8	40 : 9	45 : 10	50 : 11
	3¼	5 : 8	11 : 0	16 : 8	22 : 0	27 : 8	33 : 0	38 : 8	44 : 0	49 : 8	55 : 0
	3½	5 : 14	11 : 12	17 : 11	23 : 10	29 : 9	35 : 8	41 : 7	47 : 5	53 : 4	59 : 3

TABLE VI.—*Continued.*

Weight of Flat Iron in Pounds and Ounces.

Thick. Inches.	Wide. Inches.	1 foot. lbs. oz.	2 feet. lbs. oz.	3 feet. lbs. oz.	4 feet. lbs. oz.	5 feet. lbs. oz.	6 feet. lbs. oz.	7 feet. lbs. oz.	8 feet. lbs. oz.	9 feet. lbs. oz.	10 feet. lbs. oz.
½	3¾	6 : 5	12 : 11	19 : 0	25 : 5	31 : 11	38 : 0	44 : 6	50 : 11	57 : 0	63 : 5
	4	6 : 12	13 : 8	20 : 5	27 : 0	33 : 12	40 : 9	47 : 4	54 : 0	60 : 12	67 : 9
⅝	1	2 : 1	4 : 3	6 : 5	8 : 7	10 : 9	12 : 11	14 : 13	16 : 15	19 : 0	21 : 2
	1¼	2 : 10	5 : 5	7 : 15	10 : 9	13 : 3	15 : 13	18 : 8	21 : 2	23 : 12	26 : 6
	1½	3 : 3	6 : 6	9 : 8	12 : 11	15 : 13	19 : 0	22 : 3	25 : 6	28 : 8	31 : 11
	1¾	3 : 11	7 : 6	11 : 1	14 : 13	18 : 8	22 : 3	25 : 14	29 : 9	33 : 4	37 : 0
	2	4 : 3	8 : 6	12 : 10	16 : 14	21 : 1	25 : 5	29 : 9	33 : 12	38 : 0	42 : 3
	2¼	4 : 12	9 : 8	14 : 5	19 : 0	23 : 12	28 : 8	33 : 5	38 : 0	42 : 12	47 : 8
	2½	5 : 5	10 : 9	15 : 13	21 : 1	26 : 6	31 : 10	37 : 0	42 : 3	47 : 8	52 : 12
	2¾	5 : 13	11 : 10	17 : 6	23 : 3	29 : 0	34 : 13	40 : 11	46 : 8	52 : 5	58 : 2
	3	6 : 5	12 : 11	19 : 0	25 : 5	31 : 11	38 : 0	44 : 6	50 : 11	57 : 10	63 : 0
	3¼	6 : 14	13 : 12	20 : 9	27 : 8	34 : 5	41 : 3	48 : 1	55 : 0	61 : 12	68 : 10
	3½	7 : 6	14 : 12	22 : 3	29 : 9	37 : 0	44 : 6	51 : 13	59 : 3	66 : 8	73 : 14
	3¾	7 : 14	15 : 12	23 : 11	31 : 10	39 : 9	47 : 8	55 : 7	63 : 6	71 : 5	79 : 4
	4	8 : 7	16 : 14	25 : 5	33 : 12	42 : 3	50 : 10	59 : 1	67 : 9	76 : 0	84 : 8
¾	1	2 : 8	5 : 1	7 : 9	10 : 1	12 : 10	15 : 3	17 : 11	20 : 5	22 : 13	25 : 5
	1¼	3 : 3	6 : 6	9 : 8	12 : 10	15 : 13	19 : 0	22 : 3	25 : 6	28 : 8	31 : 11
	1½	3 : 12	7 : 9	11 : 6	15 : 3	19 : 0	22 : 12	26 : 9	30 : 6	34 : 3	38 : 0
	1¾	4 : 7	8 : 14	13 : 5	17 : 12	22 : 3	26 : 10	31 : 1	35 : 8	39 : 15	44 : 6
	2	5 : 1	10 : 2	15 : 3	20 : 4	25 : 5	30 : 6	35 : 8	40 : 9	45 : 10	50 : 11
	2¼	5 : 11	11 : 6	17 : 1	22 : 12	28 : 8	34 : 3	39 : 15	45 : 10	51 : 5	57 : 0
	2½	6 : 5	12 : 10	19 : 0	25 : 5	31 : 10	38 : 0	44 : 6	50 : 11	57 : 0	63 : 5
	2¾	7 : 0	14 : 0	21 : 0	28 : 0	35 : 0	42 : 0	49 : 0	56 : 0	63 : 0	69 : 0
	3	7 : 10	15 : 4	22 : 13	30 : 6	38 : 0	45 : 10	53 : 4	60 : 14	68 : 8	76 : 0
	3¼	8 : 4	16 : 8	24 : 12	33 : 0	41 : 4	49 : 7	57 : 12	66 : 0	74 : 3	82 : 7
	3½	8 : 14	17 : 12	26 : 10	35 : 8	44 : 6	53 : 4	62 : 6	71 : 0	79 : 14	88 : 12
	3¾	9 : 8	19 : 0	28 : 8	38 : 0	47 : 8	57 : 0	66 : 8	76 : 0	85 : 8	95 : 0
	4	10 : 2	20 : 4	30 : 6	40 : 9	50 : 11	60 : 14	70 : 15	81 : 1	91 : 3	101 : 6
1	1½	5 : 1	10 : 2	15 : 3	20 : 4	25 : 5	30 : 6	35 : 8	40 : 9	45 : 10	50 : 11
	2	6 : 12	13 : 8	20 : 4	27 : 0	33 : 12	40 : 9	47 : 5	54 : 0	60 : 12	67 : 9
	3	10 : 2	20 : 4	30 : 6	40 : 9	50 : 11	60 : 13	70 : 15	81 : 1	91 : 3	101 : 5
	4	13 : 8	27 : 0	40 : 9	54 : 1	67 : 9	81 : 1	94 : 9	108 : 1	121 : 10	135 : 2
	5	16 : 14	33 : 12	50 : 11	67 : 9	84 : 8	101 : 6	118 : 5	135 : 4	152 : 2	169 : 0
	6	20 : 5	40 : 10	60 : 15	81 : 2	101 : 6	121 : 11	141 : 14	162 : 3	182 : 8	202 : 12

TABLE VII.

Weight of Round Iron in Pounds and Ounces.

Size. Diameter in inches.	1 foot. lbs. oz.	2 feet. lbs. oz.	3 feet. lbs. oz.	4 feet. lbs. oz.	5 feet. lbs. oz.	6 feet. lbs. oz.	7 feet. lbs. oz.	8 feet. lbs. oz.	9 feet. lbs. oz.
½	0 : 11	1 : 5	2 : 0	2 : 11	3 : 5	4 : 0	4 : 11	5 : 5	6 : 0
⅝	1 : 0	2 : 1	3 : 2	4 : 3	5 : 4	6 : 5	7 : 5	8 : 6	9 : 7
¾	1 : 8	3 : 0	4 : 8	6 : 0	7 : 8	9 : 0	10 : 8	12 : 0	13 : 8
⅞	2 : 0	4 : 1	6 : 1	8 : 2	10 : 3	12 : 3	14 : 4	16 : 5	18 : 5
1	2 : 11	5 : 5	8 : 0	10 : 10	13 : 5	15 : 15	18 : 10	21 : 3	23 : 14
1⅛	3 : 6	6 : 12	10 : 2	13 : 7	16 : 13	20 : 3	23 : 8	26 : 14	30 : 4
1¼	4 : 3	8 : 6	12 : 8	16 : 11	20 : 14	25 : 0	29 : 3	33 : 6	37 : 8
1⅜	5 : 0	10 : 0	15 : 1	20 : 1	25 : 2	30 : 2	35 : 2	40 : 3	45 : 3
1½	6 : 0	11 : 15	17 : 15	23 : 14	29 : 14	35 : 13	41 : 12	47 : 12	53 : 11
1⅝	7 : 0	14 : 0	21 : 0	28 : 0	35 : 1	42 : 1	49 : 1	56 : 1	63 : 1
1¾	8 : 2	16 : 4	24 : 6	32 : 8	40 : 10	48 : 12	56 : 14	65 : 0	72 : 3
1⅞	9 : 5	18 : 11	28 :	37 : 5	46 : 11	56 : 0	65 : 5	74 : 11	84 : 0
2	10 : 10	21 : 4	31 : 14	42 : 8	53 : 2	63 : 12	74 : 5	84 : 14	95 : 8
2⅛	12 :	24 :	36 :	48 :	60 :	72 :	84 :	96 :	108 :
2¼	13 : 8	26 : 14	40 : 6	53 : 13	67 : 4	80 : 9	94 : 2	107 : 8	121 :
2⅜	15 :	30 :	45 :	60 :	75 :	89 : 15	104 : 13	119 : 13	134 : 13
2½	16 : 11	33 : 4	50 : 1	66 : 12	83 : 7	100 : 1	116 : 12	133 : 8	150 : 3
2⅝	18 : 13	37 : 10	54 : 6	73 : 3	92 : 10	112 : 8	131 : 4	150 : 0	168 : 12
2¾	20 : 1	40 : 3	60 : 5	80 : 6	100 : 7	120 : 8	140 : 9	160 : 10	180 : 11
2⅞	21 : 15	43 : 14	65 : 13	87 : 12	109 : 11	131 : 10	153 : 9	175 : 8	197 : 7
3	23 : 14	47 : 12	71 : 11	95 : 9	119 : 7	143 : 5	167 : 3	191 : 1	215 : 0
3⅛	25 : 14	51 : 13	77 : 12	103 : 11	129 : 10	155 : 9	181 : 8	207 : 7	233 : 6
3¼	28 : 0	56 : 1	84 : 2	112 : 3	140 : 3	168 : 4	196 : 5	224 : 5	253 : 6
3⅜	30 : 4	60 : 5	90 : 12	121 : 0	151 : 4	181 : 7	211 : 11	241 : 15	272 : 3
3½	32 : 8	65 : 0	97 : 8	130 : 0	162 : 9	195 : 1	127 : 9	260 : 1	292 : 9
3⅝	34 : 14	69 : 12	104 : 10	139 : 8	174 : 6	209 : 5	244 : 3	279 : 1	314 : 0
3¾	37 : 5	74 : 11	112 : 0	149 : 5	186 : 11	224 : 0	261 : 5	298 : 11	336 : 0
3⅞	39 : 14	79 : 12	119 : 10	159 : 8	199 : 5	239 : 3	279 : 0	318 : 14	358 : 12
4	42 : 8	84 : 15	127 : 6	169 : 14	213 : 5	254 : 13	297 : 4	339 : 12	382 : 4
4⅛	45 : 3	90 : 5	135 : 8	180 : 11	225 : 14	271 : 0	316 : 4	361 : 7	406 : 10
4¼	48 : 0	95 : 15	143 : 14	191 : 13	239 : 12	287 : 11	335 : 10	383 : 9	431 : 9
4⅜	50 : 12	101 : 11	152 : 7	203 : 5	254 : 1	304 : 15	355 : 11	406 : 8	457 : 5
4½	53 : 12	107 : 8	161 : 5	215 : 0	268 : 12	322 : 11	376 : 5	430 : 2	483 : 13
4⅝	56 : 12	113 : 10	170 : 6	227 : 3	283 : 15	340 : 11	397 : 8	454 : 5	511 : 2
4¾	60 : 0	119 : 14	179 : 12	239 : 10	299 : 8	359 : 6	419 : 5	479 : 2	539 : 1
4⅞	63 : 2	126 : 3	189 : 5	252 : 6	315 : 8	378 : 10	441 : 11	504 : 12	567 : 13
5	66 : 12	133 : 8	200 : 5	267 : 0	333 : 12	400 : 8	467 : 5	534 : 0	600 : 12

TABLE VII.—*Continued.*

Weight of Round Iron in Pounds and Ounces.

Size.	10 feet.	11 feet.	12 feet.	13 feet.	14 feet.	15 feet.	16 feet.	17 feet.	18 feet.
Diameter in inches.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.	lbs. oz.
½	6 : 11	7 : 5	8 : 0	8 : 11	9 : 5	10 : 0	10 : 11	11 : 5	11 : 14
⅝	10 : 7	11 : 8	12 : 8	13 : 9	14 : 10	15 : 10	16 : 11	17 : 12	18 : 13
¾	15 : 0	16 : 8	18 : 0	19 : 8	21 : 0	22 : 8	24 : 0	25 : 8	27 : 0
⅞	20 : 6	22 : 7	24 : 7	26 : 7	28 : 8	30 : 8	32 : 8	34 : 9	36 : 10
1	25 : 8	29 : 3	31 : 13	34 : 8	37 : 3	39 : 13	42 : 8	45 : 2	47 : 12
1⅛	33 : 9	37 : 0	40 : 5	43 : 11	47 : 0	50 : 6	53 : 12	57 : 2	60 : 8
1¼	41 : 11	45 : 14	50 : 1	54 : 4	58 : 6	62 : 9	66 : 12	70 : 14	75 : 1
1⅜	50 : 3	55 : 4	60 : 4	65 : 4	70 : 6	75 : 6	80 : 5	85 : 5	90 : 4
1½	59 : 11	65 : 11	71 : 10	77 : 10	83 : 9	89 : 9	95 : 10	101 : 8	107 : 8
1⅝	70 : 2	77 : 2	84 : 2	91 : 2	98 : 3	105 : 3	112 : 3	119 : 3	126 : 3
1¾	81 : 5	89 : 7	97 : 9	105 : 11	113 : 13	121 : 15	130 : 0	138 : 2	146 : 4
1⅞	93 : 5	102 : 11	112 : 0	121 : 5	130 : 11	140 : 0	149 : 5	158 : 11	168 : 0
2	106 : 2	116 : 12	127 : 6	138 : 0	148 : 10	159 : 4	169 : 14	180 : 8	192 : 2
2⅛	120 :	132 :	144 :	156 :	168 :	180 :	192 : 0	204 : 0	216 : 0
2¼	134 : 7	147 : 13	161 : 5	174 : 11	188 : 2	211 : 10	215 : 0	228 : 8	242 : 0
2⅜	149 : 12	164 : 12	179 : 12	194 : 11	209 : 11	224 : 11	239 : 10	254 : 10	269 : 10
2½	166 : 14	183 : 9	200 : 4	216 : 15	233 : 10	250 : 5	267 : 0	283 : 10	300 : 5
2⅝	187 : 8	206 : 4	225 : 0	243 : 12	262 : 8	281 : 4	299 : 11	318 : 12	337 : 8
2¾	200 : 12	220 : 13	240 : 15	261 : 1	281 : 1	301 : 2	321 : 3	341 : 5	361 : 6
2⅞	219 : 6	241 : 5	263 : 5	285 : 4	307 : 2	329 : 2	351 : 2	373 : 0	395 : 0
3	238 : 14	262 : 12	286 : 10	310 : 8	334 : 6	358 : 4	383 : 3	406 : 1	430 : 0
3⅛	259 : 5	285 : 4	311 : 3	337 : 1	363 : 0	388 : 14	414 : 12	440 : 11	466 : 10
3¼	280 : 7	308 : 7	336 : 8	364 : 8	392 : 9	320 : 10	448 : 10	476 : 11	504 : 11
3⅜	302 : 7	332 : 10	362 : 14	392 : 2	423 : 6	453 : 10	483 : 13	514 : 1	544 : 4
3½	325 : 2	357 : 10	390 : 2	422 : 10	455 : 3	487 : 10	520 : 3	552 : 12	585 : 5
3⅝	348 : 14	383 : 12	418 : 10	453 : 8	488 : 6	523 : 5	558 : 4	593 : 2	628 : 0
3¾	373 : 5	410 : 11	448 : 0	483 : 5	522 : 11	560 : 0	597 : 5	634 : 11	672 : 0
3⅞	398 : 10	438 : 8	478 : 6	518 : 4	558 : 2	598 : 0	637 : 13	677 : 11	717 : 9
4	424 : 10	467 : 2	509 : 9	552 : 1	594 : 8	637 : 0	676 : 6	621 : 14	764 : 6
4⅛	451 : 11	496 : 14	542 : 2	587 : 5	632 : 7	677 : 10	722 : 12	761 : 0	813 : 2
4¼	479 : 8	527 : 7	575 : 6	623 : 6	671 : 5	719 : 4	767 : 3	815 : 2	863 : 2
4⅜	508 : 3	559 : 0	609 : 13	660 : 10	711 : 6	762 : 4	813 : 0	863 : 15	914 : 11
4½	537 : 11	591 : 6	645 : 2	698 : 15	752 : 10	806 : 6	860 : 3	913 : 14	967 : 11
4⅝	567 : 15	624 : 11	681 : 8	738 : 3	795 : 0	851 : 13	908 : 10	965 : 6	1022 : 3
4¾	599 : 0	658 : 14	718 : 12	778 : 11	838 : 10	898 : 8	958 : 6	1018 : 5	1078 : 3
4⅞	630 : 15	694 : 0	757 : 2	820 : 3	883 : 5	946 : 6	1009 : 8	1072 : 10	1135 : 12
5	667 : 8	734 : 5	801 : 0	867 : 12	934 : 8	1001 : 5	1068 : 0	1134 : 12	1201 : 8

TABLE VIII.

This table exhibits at one view the weight and strength of various kinds of timber, as ascertained by actual experiments.

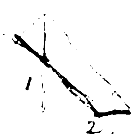
The estimates of the weight are made when the timber is well-seasoned and dry, but not kiln-dried.

There may appear to be a discrepancy between the strength of timber here given, and that found in the concluding remarks on Bridge Building; but it must be borne in mind that the calculations there made were on the greatest *safe* strain to which timber should be submitted for a long time without injury, or even impairing its elasticity, while the figures here given show the absolute strength, or the point of breakage.

TABLE VIII.

Weight and Strength of Timber.

Kind of Timber.	Weight compared with water—water being 1000.	No. of lbs. in a cubic foot.	No. of cubic feet in a ton.	Greatest tensile strength of a square inch in lbs.	Greatest safe strain upon a beam resting upon the ends, and loaded in the middle; per square inch in lbs.
White Oak, American	672	42	53	10200	800
English Oak	930	58	38	11800	875
Beech	850	42	45	12200	1000
Sycamore	600	38	59	9600	720
Chestnut	610	38	59	10650	650
Ash	845	52	43	14100	950
Elm	670	42	53	9700	700
Walnut	670	42	53	8800	675
Poplar	380	34	66	5900	380
Cedar	560	33	68	7400	400
White Spruce	550	34	66	10200	750
White Pine	590	37	60	12300	775
Yellow Pine	460	28	80	11800	770
Pitch Pine	660	41	54	9800	750
Fir	550	34	66	9500	675


1
2