To Professor Farrar

with the respects of Benj. Peirce

INTRODUCTION

TO THE

MECHANICAL PRINCIPLES

OF

CARPENTRY.

IN TWO PARTS;

PART I. STRENGTH AND STIFFNESS OF TIMBER.
PART II. STATICS APPLIED TO CONSTRUCTIONS OF TIMBER.

BY BENJAMIN HALE,
PRINCIPAL OF GARDINER LYCEUM.

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TO

ROBERT HALLOWELL GARDINER, Esq.

OF OAKLANDS, GARDINER,

THIS VOLUME IS INSCRIBED

IN TESTIMONY OF RESPECT

FOR HIS ENLIGHTENED AND LIBERAL EFFORTS

IN PROMOTING

THE APPLICATION OF SCIENCE TO THE USEFUL ARTS;

BY HIS MUCH OBLIGED FRIEND

AND HUMBLE SERVANT

THE AUTHOR.

Errata. After the manuscript was prepared for the press some additions were made, which occasioned several errors in the reference to articles in the first part of the work. The most common reference is to the Tables in Articles 15, 16, 17 and 18, which are referred to as 13, 14, 15, and 16 Articles. A few other errors have been noticed; as the following.

Page 30, 3d line, for 8 read 9.
" " 11th " for 6010.2 read 15025.5.
" 37, 15th " for LENGTH read DEPTH,
" 48, 3d " in Art. 71, for .003 read .033

Note. The *cuts* in this book were made by Mr. L. T. Jackson, of Brunswick, Maine, of *brass rule*, according to a method recently invented by him. These are the first specimens which have appeared in any publication, and this note is inserted in justice to the author of an invention, which will probably be of considerable importance.

PREFACE.

When the Trustees of the Gardiner Lyceum had determined, a year or two since, to add to the regular classes, admitted annually, several *winter classes* to continue for a few months, for the benefit of those young men, whose circumstances would not permit them to devote any considerable time to study; it devolved upon the Author of the following pages to mark out, for each of these classes, a course of study, which would be appropriate and not too extensive for the time allotted to them.

It was while fixing upon a course for the *winter class in Carpentry and Civil Architecture*, that the design of publishing this book suggested itself to him. He could find "books of lines" sufficient; was at no loss for exemplars of the orders; could easily provide for instruction in practical geometry and drawing; but knew of no book which appeared to him suited to instruct young men, who had made no advances in mathematics, beyond arithmetic and the simplest elements of practical geometry, in Carpentry, as "a branch of mechanical science."

"The many volumes," as Dr. Robison justly observes, "called Complete Instructers, Manuals, Jewells, &c. take a humbler flight, and content themselves with instructing the mere workman, and sometimes give the master builder a few approved forms of roofs and other framings, with the rules for drawing them on paper, and from thence forming working draughts, which must guide the saw and the chisel of the workman. Hardly any of them offer any thing that can be called a *principle*, applicable to many particular cases, with rules for their adaptation."

Dr. Robison's own excellent articles, *Carpentry*, *Strength of Materials*, *Roofs*, &c. first published in the supplement to the Encyclopædia Brittannica, and afterwards in the first volume of his System of Mechanical Philosophy, have done much to supply the deficiency, of which he speaks in the passage just quoted, and which, in other places, he censures more explicitly and severely.

Since the publication of Dr. Robison's articles, Mr. Tredgold has published, in London, his "Elementary Principles of Carpentry," which has justly been characterized as a work of great practical utility.

It may be thought, that Mr. Tredgold's work might supersede the necessity of the one now offered to the public. To the Author it appeared otherwise. Mr. Tredgold's work is replete with the sound and judicious observations of a man, in whom practical knowledge is united with science; but it is not well constructed for elementary instruction. It frequently supposes the reader to be acquainted with the higher mathematics and mechanics, and a considerable part of it is taken up with the subject of Bridges, which adds to the expense of the work, and is not, to most carpenters, a matter of immediate interest.

To Mr. Tredgold's work, however, the Author is greatly indebted, as will be manifest, from the perpetual reference to it, as well as from several chapters, which are taken from it, with little alteration. He has also made free use of the above mentioned articles of Dr. Robison, and of the "Essay on the Strength of timber," by Prof. Barlow, of the Royal Military

Academy, at Woolwich. These books have been his principal resources. The article "Carpentry," in the Edinburg Encyclopœdia, and a Memoir of M. Dupin, in the 10th vol. of the Journal of the French Polytechnic School, have furnished some contributions, and other works are occasionally referred to.

The plan of this Introduction is, to give, in the first place, some knowledge of the *Strength and Stiffness of Timber*, as the foundation, both of the science and art of Carpentry. In this part of the work, the principles are deduced directly from a comparison of *well conducted* experiments; a method, which, while it is the most satisfactory to practical men, and the only intelligible one to those, who are not skilled in mathematics, is also the most safe. This part is followed by an elementary view of those doctrines of the *statical equilibrium*, which are particularly applicable to *constructions*, and which shew the strength of timber, as it depends upon *position*, and in this part of the book the Author has taken occasion to introduce most of the simple *mechanical powers*. The principles of equilibrium are next applied to the constructions of *Roofs*, *Domes*, and *Partitions*, and the book ends with an excellent chapter from Tredgold, on *scarfing*, *joints*, and *straps*.

It was contemplated originally, to add a chapter on the nature and properties of timber, but this is rendered in a great measure unnecessary by the reprinting of Mr. Tredgold's chapter on this subject in a valuable publication,* which we presume to be extensively circulated among mechanics.

Numerous practical questions are introduced to be solved by the student. Those in the *second part* are to be solved by the *scale and compasses*. More accurate solutions may indeed be obtained by calculation; but the scale and compasses, skilfully used, will give results sufficiently accurate, for practical purposes, and solutions by *construction* have the advantage of being conformed to the practice of carpenters, and of getting the student into the habit of drawing with accuracy.

This work is not offered to the public as a complete system of carpentry. It is designed only to furnish a familiar introduction to a most important part of it, which has been hitherto very much neglected; and if it should be in any measure the means of convincing carpenters of the true dignity of their art, and giving them a taste for acquiring a scientific knowledge of it; the Author will think he has done no unacceptable service to the public.

With regard to the execution of the work, the Author hopes to be judged with some indulgence: for it was undertaken from a conviction that something of the kind was wanting; and has been pursued from its commencement, without leisure, and with frequent interruptions. If however he deserves censure, he is too well persuaded of the importance of just criticism, to refuse to submit to it.

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* *The Franklin Journal, published at Philadelphia.*

CONTENTS.

PART I.

PART II.

INTRODUCTION TO CARPENTRY.

PART I.

STRENGTH AND STIFFNESS OF TIMBER.

1. "To know the resistance, which a piece of timber offers to any force tending to change its form, is one of the most important species of knowledge that a carpenter has to acquire; and to be able to judge of the degree of resistance from observation only, even in common cases, requires nothing less than the practice of a life devoted wholly to carpentry."*

The knowledge, usually acquired by carpenters from their experience, although extremely valuable, is little more than "a feeling of fitness" or unfitness, and cannot be communicated. The young carpenter, therefore, if he would not be ignorant of the strength and stiffness of timber, the very qualities upon which the excellence of his constructions must continually depend, must study the laws which govern them, as they are deduced from actual experiments.

2. The principal strains, to which timber is exposed, are the following: viz.

i. When the force, producing the strain, tends to pull the piece asunder in the direction of its length. The strength of timber to resist this strain is called its *direct cohesion.*

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* *Tredgold. Elem. Prin. of Carp. p. 22.*

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ii. When the force tends to break the beam across. This is called a *cross* or *transverse strain.*

iii. When the force tends to *compress* the body in the direction of its length, as in the case of a column.

iv. A piece may be crushed across, as when a pin or tenon fails. Resistance to this kind of strain is called by some writers *lateral resistance;* by others, *resistance to detrusion.*

v. The strain upon a piece of timber may tend to *twist it,* as in the case of mill shafts.

CHAPTER I.

Of the direct cohesion of timber.

3. By the *direct cohesion* of timber, we mean its strength to resist fracture, when drawn in the direction of its length. The direct cohesion is ascertained by suspending vertically a stick of known dimensions, by the upper end, and hanging weights to the lower, until it breaks. It is a strain of this kind, to which king-posts, and all tie-beams are exposed.

4. The experiments, which have been made upon the direct cohesion of timber are not numerous, probably on account of the great care, which is necessary in performing them, the great weights which are required to break even small pieces, and the consequent necessity of well constructed apparatus. The experiments, which have been principally relied upon, are those of Musschenbroeck, Emerson, and Anderson, and to these may be added Professor Barlow, of Woolwich. Musschenbroeck and Barlow have given us minute descriptions of their apparatus, and of the manner of conducting their experiments.* Emerson has given us only the results of his experiments, and those perhaps not without being modified by his calculations. Of Dr. Anderson's experiments the Edinburgh Encyclopedia observes, they are probably faithfully related.

* *Musschenbroeck's Introductio ad Philosophiam Naturalum,* §MCXXVII, *Leyden,* 1762; *and Barlow's Essay on the Strength and Stress of Timber, London,* 1817.

5. In constructing the following table, the authorities of Barlow and Musschenbroeck are preferred; and where they differ Barlow is followed. This preference is given to Barlow, because of the care he took to ascertain very exactly the dimensions of his pieces, and because they were somewhat larger than those of Musschenbroeck. These circumstances are of great importance. A slight error in the measure of small pieces (those of Musschenbroeck were only one fifth of an inch square) may produce a very considerable error in the result, because the error may bear a very considerable proportion to the whole dimensions of the piece.

Table of the direct cohesion of different kinds of wood.

Woods.	*Specific Gravity.*	*Cohesion of square inch in lbs.*	*Mean cohesion of sq. in. in lbs.*	*Remarks.*	*Authority.*
Fir	532	11180			
do.	600	12857	12203	This *mean* was derived from 12 experiments.	Barlow
do.	611	11736			
Ash	594	17850			
do.	600	16947	17077	*Mean* derived from six experiments.	do.
do.	611	16886			
Beech	694	11437			
do.	700	11338	11467	*Mean* from 3 experim'ts.	do.
do.	712	11626			
Oak	770	9198	10389	*Mean* from 6 exp'ts. The piece of sp. gr. 770 was fine & dry old Eng. oak.	do.
do.	920	11580			
Teak	860		15090	*Mean* of 3 exp'ts.	do.
Box	960	19964	19891	*Mean* of 3 do.	do.
do.	1024	20348			
Pear	646		9822	*Mean* of 3 do.	do.
Mahogany	637		8041	*Mean* of 3 do.	do.
Locust			20100		Musschen.
Orange			15500		do.
Alder			13900		do.
do.			4290		Emerson
do.			5094		Anderson
Elm			13200		Musschen.
do.			6070		Emerson
do.			4455		Anderson
Willow			12500		Musschen.
do.			4290		Emerson
Walnut			8130		Musschen.
Pitch Pine			7650		do.
Poplar			5500		do.
Cedar			4880		do.
Norway Pine			7287		Rondelet*
Larch			10220		do.

* *Quoted by Mr. Tredgold, Elementary Principles of Carpentry.*

6. The above table exhibits, in the fourth column, the cohesion of timber, measured by the weight in pounds, which is necessary to tear asunder pieces of an inch square. It is generally assumed, that the *direct cohesion* of timber, since it depends upon the cohesion of its particles, must be in proportion to the number of them. But the number of the particles is as the area of the section, and therefore, the *direct cohesion of a stick of timber must be as the area of the section.* We have then an easy rule for ascertaining, by the help of the preceding table, the weight which would be sufficient to overcome this direct cohesion. *Multiply the number placed against the name of the timber in the fourth column of the table, by the number of square inches contained in the area of the section of the piece, and the product will be the answer in pounds.*

Note. The number of square inches in the area of the section of any piece of timber is found by multiplying together the breadth and depth of the piece.

Examples.

i. Required the direct cohesion of an oak joist, whose dimensions are 3 inches by four.

10389
12 equal to 3 multiplied by 4, or area of section.

124668 equal to answer.

ii. The same of a joist of ash, 6 inches by 7. Ans. 717234 lbs.
iii. The same of a joist of fir, 4 inches by 6. Ans. 292872 lbs.
iv. The same of a joist of pine, 7 inches by 10.
v. The same of a joist of beech, 6 inches square.

7. In practice it would not be safe to load a piece with more than half the weight, which, according to the above rule, is sufficient to break it. The reason is obvious. The very action of the weight, in some measure, weakens the timber. There are, also, imperceptible defects in large sticks, which are always avoided in those small pieces, upon which experiments are performed; and a very considerable allowance should be made in comparing the most perfect specimens with pieces which *may* be unsound. A slight change in the position of a stick may (as we shall hereafter shew) greatly increase the strain. These reasons well considered,

it will be perceived to be *unsafe to trust a beam to support more than half the weight necessary to break it.*

vi. What would be the greatest load proper for a joist of ash, whose dimensions are 6 inches by 7? Ans. 358617.

vii. What for a stick of walnut two inches square?

viii. What should be the dimensions of a stick of oak to support a load of 500000 lbs.

```
10389)500000(48 nearly.
      41556
      -----
       84440
       83112
       -----
        1328
```

48 will be the area of section of a stick, which would just break with a weight of 500000 lbs. To obtain the size of a stick, which would carry such a load with safety, we must double this area, and shall obtain 96. 96 being the area of the section, any two numbers, which are factors of 96, as 8 and 12, may be the dimensions, and will be an answer to the question. Ans. 8 and 12.

Note. This process is only the reverse of that required in the former examples.

ix. What should be the dimensions of a stick of fir, to support 42600 lbs.?

x. What the dimensions of a stick of ash to support the same?

xi. Answer the same questions, upon the supposition, that each stick is to be square.

8. When the breaking weights of the table are compared with each other, they manifestly express the *relative cohesion* of the different kinds of wood. It will be easy therefore to answer such questions as the following.

xii. If the direct cohesion of a stick of beech is equal to 600000 lbs. what will be the direct cohesion of a stick of larch of the same size?

xiii. If a tie of Norway pine is to be substituted for a tie of oak 6 inches square; what must be its size in square?

xiv. What must be the size in square of a stick of box to sustain the same load as a stick of oak 2 inches square?

xv. What the size of a stick of pear to replace a stick of fir 3 inches by 5 ?

9. Some experiments have been made by Mr. Tredgold,* on oak, poplar and larch, to ascertain their lateral cohesion, *i. e.* their strength, when drawn in a direction perpendicular to the direction of their fibres. The results are shewn in the following table.

Table of lateral cohesion of square inch in pounds.

Oak,	2316
Poplar,	1782
Larch, from 870 to 1700,—mean	1325

It is here seen at a glance, what indeed common experience teaches us, that wood is much weaker across the grain, than in the direction of it. Hence a stick, the grain of which is twisted and irregular, will support less, by its direct cohesion, than another, whose grain is straight. For in the former case, a weight, acting in the direction of the length of the stick, will tend to separate some of the fibres laterally. In the experiments of Mr. Barlow, it was observed, that some of the pieces twisted by the action of the weight, probably in consequence of a spiral direction of the fibres. In all such cases the pieces broke with less weight, than was required by those of straighter grain.

10. The opinion of Mr. Nimmo,† is apparently in contradiction to the above statement. He says, "It is highly probable, that the cohesion of timber, especially that of which the fibres are *much intertwisted*, such as oak, increases in the thicker pieces, in a ratio, which is greater than that of the area of the section. Such fibrous bodies, by being drawn in length, are strongly compressed together, and those weaker fibres are more firmly retained, which, by breaking at their finest part, might otherwise tear out. This is indeed the way, in which such bodies fail, viz. by the fibres sliding out from among each other, and not by an absolute snap. In this respect, therefore, timber may be compared to cordage; and then we have several examples of the truth of this principle, Duhamel mentions that a 6 thread rope bore 631 lbs., but that thicker cords bore more in proportion. We have arranged the result below."

* *Elementary principles of Carpentry, p. 29.*

† *Edinburgh Encyclopedia, Art. Carpentry.*

Number of threads.	*Weight borne in lbs.*	*Weight, which is as the area of the section.*	*Excess of fact above theory.*	*Ratio of excess.*
6	631	631		
9	1014	956	68	1.072
12	1564	1262	302	1.238
18	2148	1893	255	1.135

11. Wood, whose fibres are *very much intertwisted*, may have greater direct cohesion; but when they are simply twisted, or irregular in their direction, they cannot be compared with the fibres of a rope, and will be found, as in the experiments of Mr. Barlow, to impair the cohesion of timber in which they are found.

With regard to the cohesion increasing faster than the area of the section, the reference to ropes does not seem sufficient to confirm the opinion. The fibres of ropes are doubtless "strongly compressed together," when the ropes are in a state of tension; but this will not be the case with wood, the fibres of which have the common degree of straightness. And if timber with twisted fibres, derives any additional strength from this circumstance, it is safest, as Mr. Nimmo himself observes, to disregard it.

CHAPTER II.

Of the transverse strength of rectangular beams.

12. By the *transverse strength* of beams, is meant their strength to resist fracture, when they are placed horizontally upon supports at their extremities, and loaded with weights suspended from some point between.

The simplest case is when the weight is suspended from the middle of the beam. The case, also, in which the ends of the beams are merely *laid upon their supports*, must be distinguished from that in which the ends are *firmly fixed*. In this chapter, the ends of the beams are supposed to be merely *supported*, and the weight to be suspended from the *middle*, between the points of support.

13. In relation to the subject of this chapter, we are well furnished with experiments by Professor Barlow, and others. Prof.

Barlow's experiments were performed on fir and oak battens, carefully selected, and well seasoned. The battens were placed horizontally on firm supports, at proper distances asunder, and the scale, in which the weights were placed, was suspended from the centre of the batten between the supports. In order to observe the *deflection* of the battens, a fine silk line was stretched across from one support to the other, and kept extended by weights hung at the ends. Graduated scales being attached to the battens, the degrees on the scales, cut by the silk line, shewed the *deflection.* In some of the following experiments, the *lengthening* is introduced, viz. the lengthening of the under side of the batten, when it is bent by the weight. This was measured by a silk line fixed to one end of the batten, and extended along its lower surface to the other end, where it fell over the support, and was loaded with a small weight. An index attached to the weight, pointed out the lengthening on a graduated scale fixed to the side of the support. For a more particular description of the apparatus used by Mr. Barlow, the reader is referred to his Essay.

14. The results of Prof. Barlow's experiments are arranged in the first and second of the following tables, which were taken from his Essay. The *first* column contains the number of the experiments. The *three following*, the dimensions of the battens. The *fifth,* their deflections. The *sixth,* their specific gravity. The *seventh,* the weight in pounds necessary to break them. The *eighth,* the weight, which would be necessary to break the battens, if they were of the specific gravity 600; calculated upon the supposition, that the strength of timber is as its specific gravity. The relation between the strength and the specific gravity of timber, will be examined in its place. The *ninth* column contains the *mean* weight required to break battens of the dimensions, to which they correspond in the table; deduced from the preceding column, by dividing the *sum* of the weights by the *number* of them.

In the latter division of Table I. a different arrangement of the columns is introduced, which in general is sufficiently explained by the table itself. In the column of *successive deflections,* are given the deflections shewn by a succession of graduated scales, placed at equal distances, from one end to the middle. Where only one deflection is given, it is always that which is indicated by the scale at the middle of the batten.

15. **Table I.** *Experiments on Fir battens, supported at each end.*

By Prof. Barlow.

	No. of exp'ts.	Length in inches.	Depth in inches.	Breadth in inches.	Deflection in inches.	Specific gravity.	Weight in pounds.	Weight reduced to sp. gr. 600.	Mean weight, sp. gr. 600.
	1					504	360	428	
	2					533	388	436	
	3					564	418	444	439
A	4	15	1	1		646	453	421	
	5					588	453	462	
	6					600	441	441	
	7					552	318	346	
	8					647	364	338	
	9					724	436	371	342
B	10	18	1	1		719	404	337	
	11					648	353	327	
	12					672	376	336	
	13				1.25		270		
	14				1.25		262		265
	15				1.25		262		
C	16	24	1	1		560	261	279	
	17					560	283	303	288
	18					540	256	284	
	19				1.80		242		
D	20	30	1	1	1.80		234		237
	21				1.80		235		
	22				1.85	577	229	237	
	23				3.12	505	162	192	
	24				3.00	505	148	160	196
E	25	36	1	1	2.2	553	181	196	
	26				3.2	553	181	196	
	27				2.2	558	181	196	
	28					646	420	390	
	29					646	424	393	
	30					646	441	409	416
F	31	24	1.5	.75	.70	746	557	448	
	32				.70	709	501	424	
	83				.70	734	531	434	
	34				1.12	733	412	337	
G	35	30	1.5	.75	1.12	733	411	336	336
	36					646	360	334	
	37				.625	613	1190	1164	
H	38	24	2	1		563	1000	1166	1119
	39					600	1128	1128	
	40					586	882	903	
I	41	30	2	1		581	871	901	900
	42				1.08	571	852	895	
	43				1.		600		
	44				1.12		622		
	45				1.12		680		600
	46				1.12		595		
K	47	36	2	1	1.52		552		
	48				1.50		560		
	49				1.12	606	722	715	
	50				1.12	606	752	744	745
	51				1.12	564	730	776	

Table of experiments on Fir battens, supported at each end.
By Prof. Barlow.
[*Continued.*]

	No. of exp'ts.	Length in inches.	Depth in inches.	Breadth in inches.	Specific Gravity.	Weight in pounds.	Successive deflections.				M. wt. sp. gr. 600.
L	52	44	2	2	630	441	.175		.266	.300	1255
						848	.350		.566	.660	
						1054	.450		.700	.900	
						1166	.530		.900	1.025	
						1211	.600		1.000	1.150	
						1226	650		1.100	1.300	
						1288	.900		1.570	1.950	
						1317				2.350	
	53	44	2	2		421	.175		.275	.350	
						848	.366		.633	.763	
						1054				2.000	
M	54	48	2	2	601	421	.150	.250	.330	.360	1116
						711	.270	.470	.600	.660	
						920	.400	.600	.900	1.020	
						1020	.530	.900	1.230	1.400	
						1125				2.300	
	55	48	2	2	601	1110	*Same deflections.*				
	56	72	2	2	563	221	.350		.600	.750	
						421	.700		1.200	1.450	
						521	.900		1.550	1.870	
						621	1.300		2.300	2.800	
N						682				4.300	744
	57	72	2	2	600	221	.300		.530	.650	
						421	.600		1.030	1.200	
						521	.760		1.330	1.500	
						521	1.000		1.700	2.000	
						760				3.500	

The lengthening of the under side was observed in the two last experiments, and was as follows.

No. 56, with the weight of	221 lbs. the lengthening was	.062 inches.
	421	.125
	521	.150
	621	.187
	682	.200
No. 57,	221	.075
	421	.162
	521	.187
	621	.225
	760	.350

16. TABLE II. *Of experiments on* OAK *battens, supported at each end.*

BY PROF. BARLOW.

	No. of Experiments.	Length in inches.	Depth in inches.	Breadth in inches.	Deflection.	Specific Gravity.	Weight in pounds.	Weight reduced to sp. gr. 600.	Mean reduced weight.
	1					767	323	337	
a	2	18	1	1		768	353	368	358
	3					768	339	368	
	4					764	266	278	
b	5	24	1	1		774	251	260	269
	6					774	260	268	
	7					777	196	202	
c	8	30	1	1		777	196	202	202
	9					777	196	202	
	10				2.95		158		
d	11	36	1	1	4.20		190		180*
	12						176		
	13				1.1	768	387	403	
e	14	24	1½	¾	1.1	784	408	416	408
	15				1.1	777	395	406	
	16				1.5	777	316	325	
f	17	30	1½	¾	1.5	784	327	333	326
	18				1.5	768	300	311	
	19				1.4	777	721	742	
g	20	30	2	1	1.4	777	736	758	753
	21				1.4	777	736	758	
	22					764	598	626	
h	23	36	2	1		764	607	635	634
	24					764	612	641	

* Found by assuming 777 as the specific gravity of the pieces, their actual specific gravity not having been taken.

17. Table III.* *Belidor's experiments on Oak bars, in French inches and pounds.*

No. of exp'ts.	*Length in inches.*	*Depth in inches.*	*Breadth in inches.*	*Weight in pounds.*	*Mean weight.*	*Remarks.*
1	18	1	1	400 415 405	406	Supported at both ends
2	18	1	1	600 600 624	608	Ends firmly fixed.
3	18	1	2	810 795 812	805	Ends supported.
4	18	2	1	1570 1580 1590	1580	Ends supported.
5	36	1	1	185 195 180	187	Ends supported.
6	36	1	1	285 280 285	283	Ends supported.
7	36	2	2	1550 1620 1585	1585	Ends supported.
8	36	$2\frac{1}{3}$	$1\frac{2}{3}$	1665 1675 1640	1660	Ends supported.

Note. An English inch $= \frac{76}{81}$ of a French inch.
An English lb. av. $= \frac{100}{108}$ of a French lb.

18. The following table contains the results of Buffon's experiments. It is copied from Barlow's Essay. Prof. Barlow observes of these experiments, that "they are the most important of any that have yet been made, both as regards the number of them, and the size of the pieces: many of them having been from 20 to 28 feet in length, and from 4 to 8 inches square." *They were performed upon timber the next day after it was cut*, and the weights which were required to break them, were greater, than if they had been seasoned. "When the weights were laid briskly on, nearly sufficient to produce fracture, a very sensible smoke was observed to issue from the two ends, with a sharp hissing noise, which continued all the time the tree was bending or cracking."

* *Barlow's Essay.*

The juices, thus forced out, increased the resistance of the pieces to compression, and of course the strength.

The pieces upon which Buffon made his experiments were all square. The size in square is given in the second column.

TABLE IV. *Buffon's experiments on the transverse strength of square Oak beams.*

No. of exp'ts.	*Side of square in inches*	*Length in feet and inches.*		*Weight of the pieces in pounds.*	*Wt. which broke them, in pounds.*	*Deflection before cracking, in inches.*
1	4.28	7	6	64.50	5756	3.47
2		7	6	60.25	5676	4.82
3		8	6.8	73.17	4950	4.01
4		8	6.8	67.79	4842	5.00
5		9	7.7	83.85	4401	5.17
6		9	7.7	76.39	4250	5.89
7		10	8.5	90.37	3900	6.25
8		10	8,5	88.28	3884	6.96
9		12	10.3	107.60	3281	7.50
10		12	10.3	105.45	3174	7.50
11	5.35	7	6	101.14	12670	2.67
12		7	6	95.32	12133	2.67
13		8	6.8	111.91	10653	2.85
14		8	6.8	109.76	10411	3.12
15		9	7.7	126.97	9038	3.21
16		9	7.7	124.82	8958	3.51
17		9	7.7	123.75	8822	3.75
18		10	8.5	142.04	7774	3.39
19		10	8.5	139.91	7586	3.74
20		10	8.5	138.28	7639	4.28
21		12	10.3	167.87	6510	5.89
22		12	10.3	165.71	6563	6.16
23		15	0	191.54	5811	8.57
24		15	0	189.38	5595	8.83
25		17	1.7	224.90	4861	8.65
26		17	1.7	220.59	4600	8.74
27		19	3.4	249.65	4034	8.57
28		19	3.4	248.57	3948	8.74
29		21	5.1	284.12	3523	9.46
30		21	5.1	278.71	3416	10.71
31		25	8.6	333.59	2367	11.88
32		25	8.6	330.36	2286	12.05
33		30	0	391.69	1936	19.78
34		30	0	365.40	1882	23.57

Table, &c. continued.

35		7	6	138.27	20715	
36		7	6	129.66	20069	
37		8	6.8	160.33	16894	2.50
38		8	6.8	157.11	16517	2.58
39		9	7.7	178.63	14473	2.67
40		9	7.7	177.02	13607	2.83
41		10	8.5	202.30	12347	3.21
42		10	8.5	200.18	11863	3.74
43	6.43	12	10.3	241.04	9900	4.28
44		12	10.3	237.82	9684	4.38
45		15	0	274.40	8016	4.82
46		15	0	273.33	8070	4.38
47		17	1.7	316.37	6725	5.89
48		17	1.7	315.29	6967	6.25
59		19	3.4	359 42	6052	7.94
50		19	3.4	356.18	5918	9.10
51		21	5.1	405.69	5406	10.17
52		21	5.1	403.53	5246	9.46
53		8	6.8	219.52	28140	2.94
54		8	6.8	219.52	27926	2.68
55		9	7.7	244.28	24535	3.31
56		9	7.7	242.12	23562	3.12
57		10	8.5	273.33	21145	2.73
58		10	8.5	271.15	20769	3.21
59		12	10.3	324.98	18078	3.12
60	7.5	12	10.3	323.90	16733	3.56
61		15	0	382.01	14634	4.46
62		15	0	377.72	13828	4.01
63		17	1.7	436.90	11944	5.17
64		17	1.7	433.67	11729	5.62
65		19	3.4	488.55	10163	5.89
61		19	3.4	488.55	10113	6.25
67		21	5.1	653.45	9200	8.39
68		21	5.1	654.55	8608	9.10
69		10	8.5	356.19	29916	3.21
70		10	8.5	356.19	28709	2.41
71		12	10.3	427.22	24619	3.21
72		12	10.3	425.60	23654	3.12
73		15	0	496.08	21575	4.10
74	8.57	15	0	493.93	20894	3.39
75		17	1.7	564.06	18074	5.53
76		17	1.7	563.88	17163	4.01
77		19	3.4	639.21	14526	4.82
78		19	3.4	638.53	13801	4.37
79		21	5.1	712.34	12670	6.96
80		21	5.1	710.23	13128	6.43

19. The strength of beams, subjected to transverse strains, will depend not only upon the absolute strength of the timber, but also upon their *length*, *breadth*, and *depth*. By a comparison of the above experiments, we are enabled to discover the ratio, which exists between the strength of beams, and these several circumstances.

§1. *The strength of beams, as depending upon their length.*

20. By referring to the first of the above tables, we find the strength of a beam C, 24 *inches long*, *one broad*, *and one deep*, to be 276*, and that of a beam A, 15 *inches long*, *and of the same breadth and depth*, to be 439. If we make an inverse proportion, employing the *strengths* of these pieces and one of their lengths, for the three first terms; the fourth term, which we find by calculation, will enable us to find the relation for which we seek.

Strength of A : strength of C : : length of C :
439 : 276 : : 24 : 15.08.

The fourth term thus obtained by calculation, is very nearly the length of A. The conclusion, to which this comparison would lead us, is, that *the strength of beams is in the inverse ratio of their lengths*. By making similar comparisons with other battens, it may be found whether this principle is generally correct.

Compare the battens F, and G.

Strength of F : strength of G : : length of G :
416 : 336 : : 30 : 24.08.

The fourth term varies but very little from the length of F, 24.

In the same manner let the student compare the battens H and I; H and K; N and M; a and d, &c., and he will find results agreeing still more exactly with the experiments.

It may then be considered as sufficiently proved, that *the strength of a beam supported at both ends, and loaded in the middle, is inversely as its length.*

21. It is easy to apply this principle to the solution of *practical examples*.

* *By taking the mean of* 265 *and* 288, *the results of the Table.*

i. If a stick of oak 2 feet long, 1 inch deep, and 1 inch broad, breaks with 482 lbs.; what weight will be required to break a stick of the same breadth and depth, and 3 feet long?

3 : 2 : : 482 : 321, Answer.

ii. If the strength of a stick of beech 2.5 feet long, and 1 inch square, be estimated at 271 lbs.; what will be the strength of a stick of the same wood, of equal size in square, and 3 feet 9 inches long?

iii. A stick of teak 7 feet long and 2 inches square breaks with 820 lbs.: required the weight necessary to break a stick of the same scantling,* and 9 feet long.

iv. The strength of a stick of willow 2.5 feet long and 1 inch square is estimated at 146 lbs.: required the strength of a similar stick 4 feet 7 inches long.

§2. *Of the strength of beams as depending upon their breadth.*

22. The relation, which obtains between the strength of beams and their breadth may be ascertained by comparisons similar to those, which were employed in the preceding section.

The strength of No. 1, Table III, is 406. That of No. 3, which has the same length and depth, and twice the breadth, is 805. That is, the strengths are very nearly as the breadths.

Again, Table I.

Strength of H; 24 in. long, 2 deep, and 1 wide, equal 1119.
do. of M; 48 in. long, 2 deep, and 2 wide, equal 1116.

In order to compare these battens, in reference to their breadth or width, we must make the other dimensions equal, by first reducing the length of the latter to that of the former, which is easily done by the principle established in the preceding section. Then calling the stick M, so reduced, M', we shall have

Strength of M' 24 inches long, 2 deep and 2 wide, equal to 2232.

If we then compare their strength with their breadths, we have

Strength of H : strength of M' : : breadth of H :
1119 : 2232 : : 1 : 1.994,

which is equal to the breadth of M' within .006 of an inch. From

* *Scantling; lateral dimensions, viz. length and breadth.*

this result it would seem that *the strength of a beam is directly proportional to its breadth.*

Let us take another example.

The strength of I, 30 inches long, 2 deep, and 1 broad, being 900; if we reduce it by the rule in the last section to the length 72 inches, and call it I', we shall have

Strength of I', 72 in. long, 2 deep, and 1 broad, equal to 375.
Now compare with

Strength of N, 72 in. long, 2 deep, and 2 broad, equal to 744.

375 : 744 : : 1 : 1.98, which is very nearly as 1 : 2, the ratio of the breadth.

23. These examples may serve to convince us, that *the strength of timber is in direct proportion to its breadth.* This is what we should have expected, without experiment, and is admitted by all writers upon this subject.

Examples.

i. The strength of a stick of American pine 2.5 feet long, and 1 inch square, being 329 lbs.; what will be the strength of a stick, whose breadth is 2 inches, the other dimensions being the same?

329 multiplied by 2, equal to 658, answer.

ii. The medium strength of a stick of larch 2.5 feet long, and 1 inch square is 223 lbs.: what would it be were its breadth increased to 3 inches?

iii. What, if its breadth were 4.5?

iv. A stick of common English elm, length 2.5 feet, breadth 1 inch, and depth 1 inch, is 216 lbs.; required its strength, when its breadth is increased to 2.68?

§3. *The strength of beams, in relation to their depth.*

24. We must now inquire into the effect, which an increase of *depth* has upon the strength of beams.

The breaking weight of the fir batten C, is 276.5 lbs., and of the batten H, of the same length and breadth as C, but of double the depth, is 1119 lbs.

Strength of C : strength of H : : depth of C :

276.5 : 1119 : : 1 : 4.04.

From this it appears that while the depths are as 1 : 2, the strengths are as 1 : 4. But 4 is the square of 2, and we should therefore infer, that the strength is as the square of the depth.

Take another example: the battens D and I are equal in length and breadth, but the depth of D is 1, and of I, 2. Their strengths are 237 and 900.

237 : 900 : : 1 : 3.887, or nearly 4.

In the same manner compare E and K ;—c and g—and d and h of Table II, and 1 and 4, of Table III.

The ratio of the depths being in each of the above cases as 1 : 2, we shall compare F, whose length is 24, depth 1.5, and breadth .75, with H, whose length is 24, depth 2, and breadth 1. The mean strength of F is 416, and of H, 1119. To prepare F for the comparison, we may suppose its breadth to be increased to *one*, and then the breaking weight would be 555. (23)

Then 1119 : 555 : : 4 (square of 2) : 1.98, which differs from 2.25, the square of 1.5 by .27.

25. When we have two beams of unequal breadth and depth, as in the last case, we need not reduce them to a mean breadth before comparing them. We have found the strength of beams to be in proportion to their breadth, and we are led by the above examples to believe that their strength is directly as the squares of their depths. If now we were to compare two beams, one of which is twice as broad and twice as deep as the other, we might double the strength of the smaller on account of breadth, and then quadruple it on account of depth, to obtain the strength of the larger ;—or it would be the same to multiply the strength of the former by 8, which is the product of the breadth into the square of the depth of the larger. We shall have, then, this rule; *the strength of one beam is to the strength of another of equal length, as the product of the breadth into the square of the depth of the former, is to the product of the breadth into the square of the depth of the latter.*

Compare G and I in this manner.

$$1.5^2 \times .75 = 1.6875.$$
$$2^2 \times 1 = 4.$$

900 : 336 : : 4 : 1.4933, which differs from 1.6875 by .1942.

Compare Nos. 5 and 15; 9 and 21, &c. of Table IV.

NOTE. The beams in Table IV. are square. The square of the depth multiplied by their breadth will therefore be the same thing as the cube of their depths.

26. Although there is not a perfect agreement between the experiments and the results obtained in the above comparisons, yet it is sufficient to convince us that *the strength of timber is as the square of the depth.*

Examples.

Repeat the examples under the last section, taking in each case the breadth for the depth and the reverse.

27. It is very obvious from what has now been said, and particularly from the solutions of the last examples, that much more strength is gained by increasing the depth of a piece of timber, than by increasing its breadth. If the *breadth* be doubled, it only doubles its strength; but if the *depth* be doubled, the strength is increased fourfold. If the *breadth* be tripled, the strength is increased in the same ratio, but if the *depth* be tripled, the beam is nine times stronger.

28. *The strength of beams being* (25) *as the products of their breadths into the square of their depths*, the following examples will be easily solved.

i. Suppose a beam whose lateral dimensions are 2 and 1; how much more will it bear when placed edgewise than when it is laid flatwise?

ii. Suppose the two dimensions to be 6 and 4?

29. *The strength of square beams is as the cube of the side of the square.* (25, note.)

Examples.

i. One beam is 6.2 square and another 7.3: they are of the same length; in what proportion will be their strength?

As 238.328 : 389.017, or 1 : 1.63.

ii. Two beams are respectively 6.5 and 6.85 in square: how many times stronger is one than the other?

§4. *Strength of beams as depending upon length, breadth, and depth.*

30. We found a method (25) for bringing the breadth and depth of pieces into one expression, which renders a separate comparison for breadth and depth unnecessary. We may proceed, much in the same manner, with regard to the length. We supposed (25) two pieces of timber, one of which was twice as deep and twice as broad as the other, and we now add, twice as long. In order to find the strength of the larger, we were to double the strength of the smaller, on account of the difference in breadth: then quadruple it, on account of the difference in depth: which would be the same thing as multiplying the strength of the former by twice 4, or 8. But the larger stick is twice as long. We must, therefore, (20) take half the product for the strength of the larger stick, instead of the whole, which amounts to the same thing as if we had divided 8 by 2, and multiplied the strength of the smaller stick by the quotient 4. It appears, therefore, that *the strengths of beams are as the products of their breadths into the square of their depths, divided by their lengths.* Thus:

If a stick of oak *one* foot long, *one* inch broad and *one* inch deep breaks with 964 lbs.; what will be the breaking weight of a stick 3 feet long, 2 inches broad, and 3 deep?

$$\frac{1 \times 1^2}{1} = 1, \text{ and } \frac{2 \times 3^2}{3} = 6.$$

then, 1 : 6 : : 964
6
5784 lbs. answer.

31. It is evident from the example just given, that if we had a Table, containing the weights necessary to break a piece of each kind of timber, ONE FOOT *long*, ONE INCH *broad*, and ONE INCH *deep*, we might easily find the strength of any given stick, by *multiplying the proper tabular weight, by the product of the breadth and square of the depth of the stick, in inches, divided by its length in feet.* Such a Table is the following.

TABLE V. Of the transverse strength of sticks of different kinds of wood, each stick being *one foot* long, *one inch* broad, and *one inch* deep.

	Specific gravity.	*Breaking weight.*
Oak, old English, young tree,	863	964
" old ship timber,	872	660
" from old tree,	625	436
" medium qualities,	748	710
" green,	763	547
Beech, medium quality,	690	677
Alder,	555	530
Plane tree,	648	607
Sycamore,	590	535
Chestnut, green,	875	450
Ash, from young tree,	811	810
" medium quality,	690	635
"	753	785
Elm, common,	544	540
" wych, green,	763	480
Acacia, green,	820	622
Mahogany, Spanish, seasoned,	852	425
" Honduras, "	560	637
Walnut, green,	920	487
Poplar, Lombardy,	374	327
" Abele,	511	570
Teak,	744	717
Willow,	405	365
Birch,	720	517
Cedar of Lebanon, dry,	486	412
Fir, Riga,	480	530
" Memel,	553	545
" Norway, from Long sound,	639	792
" Mar forest,	715	315
" Scotch, English growth,	529	582
" " "	460	392
Deal, Christiana, white,	512	686
Spruce, American, white,	460	570
Spruce fir, British growth,	555	465
Pine, Am. Weymouth, or white,	460	658
Larch, choice specimen,	640	632
" medium quality,	622	557
" very young wood,	396	322

Examples.

i. What is the breaking weight of a stick of birch, 12 feet long, 8 inches deep, and 6 inches broad?

$$\frac{6 \times 9^2}{12} = 40.5.$$

```
   517
  40.5
  ----
  2585
 20680
 -----
20938.5, answer.
```

ii. Required the strength of a stick of chestnut, whose length is 11.5 feet, depth 8 inches, and breadth 6 inches. 6010.2.

iii. Required the strength of a beam of oak, of medium quality, length 7 feet, depth 4.75 inches, breadth 3.5.

iv. Required the strength of a stick of green oak, of the same dimensions.

v. Required the strength of a stick of American white pine, 15 feet long, and 12 inches square.

vi. What weight will break a stick of larch, medium quality, 12 feet long, and 12 inches square?

vii. What is the strength of a stick of Norway fir, 12 feet 3 inches long, 12 inches deep, and 10 broad?

viii. What of a stick of Riga fir, of the same dimensions?

ix. Required the strength of a stick of common elm, 12 feet long, 3.75 inches deep, and 3.875 broad.

32. It is proper to observe, that the foregoing Table does not record the results of experiments, made upon pieces of the size therein supposed. They were made upon pieces, which were longer, but otherwise of like dimensions, except in a few cases. The strength, as stated in the Table, was obtained by reducing the pieces to the dimensions supposed, by the rules which have been given.

The above Table is only part of one, which is contained in Tredgold's Principles of Carpentry. The remainder of his Table is here given.

Table *of experiments on the transverse strength of different kinds of wood.*

	Length in feet.	*Breadth in inches.*	*Depth in inches.*	*Deflection.*	*Breaking wt. in lbs.*	*Authority.*
Oak, English, young tree	2	1	1	1.87	482	Tredgold
" old ship timber	2.5	1	1	1.5	264	"
" from old tree	2	1	1	1.38	218	"
" medium quality	2.5	1	1		284	Ebbels
" green	2.5	1	1		219	"
" from Riga	2	1	1	1.25	357	Tredgold
" green	11.75	8.5	8.5	3.2	25812	Buffon
Beech, medium quality	2.5	1	1		261	Ebbels
Alder	2.5	1	1		212	"
Plane tree	2.5	1	1		243	"
Sycamore	2.5	1	1		214	"
Chestnut	2.5	1	1		180	"
Ash, from young tree	2.5	1	1	2.5	324	Tredgold
" medium quality	2.5	1	1		254	Ebbels
"	2.5	1	1	2.38	314	Tredgold
Elm, common	2.5	1	1		216	Ebbels
" wych	2.5	1	1		192	"
Acacia, green	2.5	1	1		249	"
Mahogany, Spanish, seasoned	2.5	1	1		170	Tredgold
" Honduras	2.5	1	1		255	"
Walnut, green	2.5	1	1		195	Ebbels
Poplar, Lombardy	2.5	1	1		131	"
" Abele	2.5	1	1	1.5	228	Tredgold
Teak	7	2	2	4.0	820	Barlow
Willow	2.5	1	1	3.	146	Tredgold
Birch	2.5	1	1		207	Ebbels
Cedar of Lebanon, dry	2.5	1	1	2.75	165	Tredgold
Fir, Riga	2.5	1	1	1.3	212	"
" Memel	2.5	1	1	1.15	218	"
" Norway, from long sound	2	1	1	1.125	396	"
" Mar forest	7	2	2	5.5	360	Barlow
" Scotch, English growth	2.5	1	1	1.75	233	Tredgold
" " "	2.5	1	1		157	Ebbels
Deal, Christiana, white	2	1	1	.93	343	Tredgold
Spruce, American, white	2	1	1	1.31	285	"
Spruce Fir, British	2.5	1	1		186	Ebbels
Pine, American. Weymouth, or white	2	1	1	1.125	329	Tredgold
Larch, choice specimen	2.5	1	1	3.	253	"
" medium	2.5	1	1		223	"
" very young wood	2.5	1	1	1.75	129	"

33. To shew how the breaking weights in the table, Art. 29, were obtained, we will take the first specimen, oak. For the length 2 feet, breadth and depth each one inch, we have in the last table the breaking weight 432. But the strength is inversely as the length. If therefore the length be reduced to one foot, the strength will be doubled, and the breaking weight will be 964.

§5. *Transverse strength of timber, as depending upon specific gravity.*

34. In the Tables I and II, in the first part of this chapter, there are columns, giving the weights which would be necessary to break the battens, after they were reduced to a common specific gravity.

It might have been supposed, previous to experiment, that the great diversity in specific gravity, which is observed in wood of the same species, would be accompanied with a corresponding difference in strength. Experiment proves this to be the case, and it is important to ascertain, whether any proportion holds between the specific gravity and the strength of timber, and what that proportion may be.

35. Take the experiments Nos. 1 and 2, Table I. Art. 13. The specific gravities of the pieces are 504 and 533, and their corresponding strengths 360 and 388.

504 : 533 : : 360 : 380.4, which does not differ greatly from 388. This example would lead us to conclude that *the strength of timber, of the same species, is directly as the specific gravity.* This is the law which Mr. Barlow has adopted as the result of his experiments, and according to which, he made the reduction of his experiments to pieces of a common specific gravity; and although a slight examination of Mr. Barlow's experiments will convince us, that this law is far from being as accurate as those, which we have before deduced, it will also satisfy us, that no general statement of the ratio between the specific gravity of timber and its strength, can be more accurate.

36. In Table IV. Art. 16, the student will observe that the weights of the pieces are given; and by comparing the weights of

pieces of the same dimensions, with the weights necessary to break them, he will be able to prove the correctness of the above rule.

37. If, as in Table IV, bodies of the same size have different weights, the heaviest are said to be *specifically* heavier, than the others, or to have a greater *specific gravity*; the *specific gravity of a body, therefore, is its weight, compared with the weight of another body of the same size.* The weight of water is adopted as a standard, and its specific gravity is 1; and when we say the specific gravity of a body is .600, we mean that a quantity of it would weigh six tenths as much as the same bulk of water. One cubic foot of water (rain) weighs 1000 ounces, or 62.5 pounds. In order therefore to ascertain the specific gravity of a piece of timber; *weigh it, and divide the weight by its contents in cubic feet. This will give the weight of a cubic foot of the timber. Then say*

62.5 : 1 :: *the weight of a cubic foot* : *specific gravity.*

38. To illustrate the above rule, take the first specimen in Table IV.

90.0 inches (length) × 4.28 × 4.28 = 1648.6.

It contains therefore only $\frac{1648}{1728}$ of a cubic foot.

Divide the weight 64.5 by this fraction; *i. e.* multiply by the denominator and divide by the numerator, and we obtain 72.05 for the weight of a cubic foot. Then

62.5 : 1 :: 67.95 : 1.052.

39. We have not introduced the specific gravity as an element for calculating the strength of timber, into the Rule in Art. 31, because it might not always be convenient for the carpenter to ascertain it. And if he should ascertain it, there is no difficulty in making allowance for it, after the strength of the stick has been computed by the rule.

40. The specific gravity of timber varies with the soil, on which it grows. That which is the produce of a good dry soil is much denser than the growth of soils of opposite qualities. Duhamel states that the density or specific gravity of the same species of timber, and in the same climate, but the growth of different soils, will vary as much as 7 : 5, and that the strength will be as 5 : 4.

The greater specific gravity before seasoning increases the strength of timber. Dry timber will therefore support less than green.

5

CHAPTER III.

Of the stiffness of Rectangular Beams.

41. Timber is rarely subjected to strains sufficient to occasion fracture. It is more frequently exposed to bending, which is always a source of inconvenience, and often of very serious injury. The *stiffness* of timber is therefore a more interesting problem to the carpenter, than the *strength*. Indeed if a carpenter provides for the stiffness of his timber, he secures the strength of his work, and however accurately he may calculate the strength of his materials, if he neglects the stiffness, it is very possible, that the bending of some pieces may occasion such a change of position in his constructions, as will be followed by a total failure.

42. The stiffness of beams depends upon the different circumstances of *length*, *breadth*, and *depth*, and the influence, which each of these exerts, must be examined. The *stiffness* of beams is ascertained by their *deflections*, the manner of observing which was described in the last chapter (13). Instead of speaking of the stiffness of beams, we shall speak of these deflections, for in fact, the great point in regard to the stiffness of beams, is to be able to ascertain the amount of deflection, which a beam would suffer, under any given circumstances.—These deflections will vary, also, with the *weight*, with which the beam is loaded, and this, therefore, will be another circumstance to be regarded in the inquiry contained in this chapter.

43. The following Table is from Mr. Barlow's Essay, page 120.

Experiments on the deflection of fir battens.

No. 1.

	Feet long.	*Inches deep.*	*Breadth.*	*Wt. in lbs.*	*Deflection.*
(a)	3	2	1.5	120	.09
(b)	3	2	1.5	180	.12
(c)	6	2	1.5	120	.68
(d)	6	2	1.5	180	1.00
			The same piece.		
(e)	3	1.5	2	120	.19
(f)	3	1.5	2	180	.28
(g)	6	1.5	2	120	1.38
(h)	6	1.5	2	180	1.91

Table, &c. continued.

No. 2.

	Feet long.	*Inches deep.*	*Breadth.*	*Wt. in lbs.*	*Deflection.*
(i)	3	2	1.5	120	.10
(k)	3	2	1.5	180	.15
(l)	6	2	1.5	120	.72
(m)	6	2	1.5	180	1.05
		The same piece.			
(n)	3	1.5	2	120	.18
(o)	3	1.5	2	180	.28
(p)	6	1.5	2	120	1.30
(q)	6	1.5	2	180	2.00

No. 3.

(r)	3	2	1.5	120	.07
(s)	3	2	1.5	180	.11
(t)	6	2	1.5	120	.65
(u)	6	2	1.5	180	.96
		The same piece.			
(w)	3	1.5	2	120	.16
(x)	3	1.5	2	180	.24
(y)	6	1.5	2	120	1.25
(z)	6	1.5	2	180	1.85

The above experiments were performed with great care upon three pieces of fir, of very "uniform texture."

§1. *Deflection as depending upon the length.*

44. From the experiments *a* and *c*, of the foregoing Table, it appears that the lengths of the battens being 3 and 6, other circumstances the same, the deflections are 9 and 68.

Now, 9 : 68 : : 1 : 7.55.

That is, the lengths being as 1 : 2, the deflections are as 1 : 7.55.

Again, compare the deflections in the experiments *b* and *d*, in which the length of the pieces are in the same ratio of 1 : 2.

12 : 100 : : 1 : 8.333.

The ratio which seems to be indicated by these experiments is 1 : 8, when the lengths are as 1 : 2. But 8 is the cube of 2. The result seems then to be that *the deflection of beams is as the cube of their lengths.*

Let the student compare *e* and *g* : *f* and *h*, &c., and he will find, with as little deviation as could be expected, the same ratio.

45. Prof. Barlow was led to consider the subject of this section with much attention, in consequence of finding himself at variance with M. Girard, who makes the deflections of beams to be as the *squares* of their lengths. In order to satisfy himself, he instituted the following experiments, and neglected no circumstance which could insure their accuracy.

No. 1, props	9 feet apart,	the deflection was	27 parts.
"	6 "	"	8 "
"	3 "	"	1 "

the same weight being used in each case.

Now $9^3 : 6^3 :: 27 : 8$, exactly;

and $6^3 : 3^3 :: 8 : 1$.

No. 2, props	9 feet apart,	the deflection was	40.5.
"	6 "	"	12.5.
"	3 "	"	1.5.
No. 3, props	9 feet apart,	the deflection was	54.
"	6 "	"	16.5.
"	3	"	2.

These experiments agree very exactly with the supposition, that the deflections are as the cubes of their lengths, and leave no doubt of its correctness.

46. This result is confirmed by the experiments of M. Dupin. The following Table is from the Journal de l'ecole polytechnique, Tom. X, p. 202.

Experiments upon OAK *battens of* 2 *centimetres by* 3, *charged with the weight of* 10 *kilogrames. Weight of the battens* 0.94 *kil.*

Distances of the props in metres.	1.	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.
Deflections.	.006	.0081	.0108	.01325	.0167	.021	.025	.0305	.036	.042	.049
Cubes of the distances.	1.	1.331	1.728	2.197	2.744	3.375	4.096	4.913	5.832	6.859	8.0
Deflections divided by .006	1.	1.333	1.8	2.208	2.783	3.500	4.166	5.083	6.000	7.00	8.017

47. The experiments of M. Dupin are recorded in the upper half of the last table: the lower part contains a reduction of them. The third line contains the cubes of the distances of the props, or lengths of the batten. In order to shew that these cubes are proportional to the deflections, the deflections are given in the fourth line, divided by .006. The ratio of the deflections is not chang-

ed by the division, and the agreement of the last two lines therefore, confirms the ratio of the deflection to the cubes of the lengths. M. Dupin has a similar table of experiments on a batten of Fir.

Examples.

i. If the deflection of a beam 4 feet long be .7 inch, what will be the deflection of a similar beam, of 10 feet long, acted upon by a similar weight?

$4^3 : 10^3 :: .7 : 10.93$ inches, Ans.

ii. What would be the deflection of a similar beam 23.5 feet long?

iii. A beam 6 feet long being deflected 1 inch by a certain weight, how much will a similar beam 2.75 feet long be deflected by the same weight?

§2. *Of the stiffness of beams as depending upon* LENGTH and BREADTH.

49. Not being acquainted with any experiments, which exhibit separately the influence of breadth and depth upon the stiffness of timber, I procured several pieces of pine of different dimensions, from which I selected two, which were each three feet and a few inches in length, one being an inch square, and the other an inch by an inch and a half. The larger dimension of the latter piece was successively made the breadth and the depth. The props were 3 feet asunder, the same weights were used in each case, and the deflections were carefully measured by a scale of 55 parts to an inch. The results are recorded in the following Table.

Weights in lbs.	24	36	48
(a) Deflections of the batten 3 ft. long, 1 in. broad, and 1 in. deep.	11	17	22.5
(b) " " 3 ft. long, 1.5 in. broad, and 1 in. deep.	7.5	11	15
(c) " " 3 ft. long, 1 in. broad, and 1.5 in. deep.	3.5	5	7

50. Compare the first deflection of the battens (a) and (b) with their breadths.

$11 : 7.5 :: 1.5 : 1.02.$

In the same manner compare the other deflections, and it will appear that *the deflections are inversely as the breadth*, or, which is the same thing, *the stiffness is directly as the breadth.*

51. Compare the first deflections of the battens (a) and (c) with their depths.

3.5 : 11 : : 1 : 3.14,

which differs but .23 from 3.37 the cube of 1.5.

Compare the second deflections ;

5 : 17 : : 1 : 3.5,

which differs from 3.37 by only .03 in excess.

In the same way compare the third deflections.

These results would indicate, that *the deflections are inversely as the cubes of the depths* ;—or that *the stiffness is directly as the cube of the depth.*

52. At different times I have made other experiments, but doubting their exactness, I have thrown them aside, although some of them agreed remarkably well with the above conclusion.

53. If the above propositions (50 and 51) are correct, it will follow, that *the deflections of rectangular beams will be inversely as their breadths multiplied by the cubes of their depths.* To satisfy ourselves then of their correctness, we may apply this rule to some of the experiments in the Table, Art. 43.

Take the experiments (i) and (n).

(i) $2^3 \times 1.5 = 12.$

(n) $1.5^3 \times 2 = 6.75.$

18 : 10 : : 12 : 6.66,

which differs from 6.75 by .09.

Let the student in the same manner compare k and o, d and h, u and z, &c.

54. The following Table is from the memoir of M. Dupin, before quoted.

Deflections of a rod of Fir,—lateral dimensions 0.03 and 0.04 metres.

Weights, in killograms,	2	4	6	8	10
Deflections, depth .02, breadth .03.	16	32	48	64	80
" " .03, " .02.	6.8	14	21.3	28.5	37.6

These experiments compared in the same manner as the last, will give you the same result.

55. More experiments might be adduced, but the above sufficiently proves the propositions in articles 50; 51, and 53.

Examples.

i. Two beams have the same breadth; but the depth of one is twice as great as the depth of the other: how much greater will be its stiffness? 8 times.

ii. If the lateral dimensions of a beam are 6 inches and 10; how much stiffer will it be laid edgewise, than flatwise? 2.77 times.

iii. Suppose the lateral dimensions are 4 and 9?

§3. *Of the deflection of beams, as depending upon the deflecting weight.*

56. In the last Table, (54) we have a weight of 2 kilograms causing a deflection equal to 16: 4 kil. a deflection equal to 32, and so on; *the deflections increasing exactly in the ratio of the weights.*

In the Table Art. 40, the same thing is shewn by comparing *a* with *b*, &c. and it may be concluded with safety, that *the deflection of beams supported at both ends is as the deflecting weight.*

Examples.

i. If a weight of 2500 lbs. produses a deflection of one inch in a beam; what deflection will 727 lbs. produce?

ii. What will 1895 produce?

57. This ratio of the deflection of beams to the deflecting weight is not true without some limitation.

It will be seen by referring to Mr. Barlow's experiments, marked L, M, and N, in Art. 13, that although the above ratio holds to a certain extent, yet, when the weight increases, so as to be nearly sufficient to produce fracture, the deflection increases in a much higher ratio. The elasticity of the timber is then impaired; there is a new arrangement of the particles, and if the load should be removed from a beam under such circumstances, it would not resume its original position. It is therefore said to have taken a *set.*

For all practical purposes, however, the law is sufficiently exact, for a judicious carpenter will never expose his timber to a strain sufficient to impair its elasticity.

§4. *Deflection of beams as depending upon* LENGTH, BREADTH, DEPTH, *and* WEIGHT, *with rules for scantlings.*

58. We have found in the preceding sections, that the deflections of beams are *directly* as the weights and cubes of their lengths, and *inversely* as the breadths and cubes of the depths. Following the same method of reasoning as in Art. 30, we should sum these particulars in one general rule, as follows. *The deflections of beams are in proportion to the product of deflecting weights by the cube of their lengths, divided by the product of the breadths into the cube of the depths.*

59. If a beam of New-England Fir, 7 feet long, 2 inches broad, and 2 inches deep is bent .97 of an inch by a weight of 150 lbs. what will be the deflection of a beam *one* foot long and *one* inch square, loaded with *one* pound? To solve this question we have the proposition

$$\frac{7^3 \times 150}{2^3 \times 2} : .97 :: \frac{1^3 \times 1}{1^3 \times 1} : .0003.$$

which gives .0003 of an inch for the result.

By obtaining similar results for different kinds of timber, we might construct a Table similar to that in Art. 31. Such a Table would enable the carpenter to ascertain easily, what would be the deflection of a stick under any circumstances; but it would not be found so useful as the one given below. Indeed, without such a table, he may obtain from table Art. 61 the deflection for any stick, as we have above for a stick one foot long.

60. Timber subjected to a cross strain will always bend more or less. A beam therefore is not required to be absolutely inflexible, in order to be stiff. "A deflection of one fourth of an inch in a joist 20 feet long would not be attended with any bad effect," and such a joist might therefore be considered stiff. "In order that two pieces of different lengths may be equally stiff, the deflection should be in proportion to their lengths. Hence, the rules given by mathematical writers, for determining the stiffness of beams, are not adapted to the carpenter's purpose: yet they are perfectly correct on the principle of making the deflection always the same, whatever the length may be."*

* *Tredgold's Elem. Prin. Carp. p. 30, sq.*

61. The ollowing Table was constructed by Mr. Tredgold, on these principles.

Table of experiments on the stiffness of Timber, by Mr. Tredgold.

ON THE STIFFNESS OF OAK.

Kind of Oak.	*Specific gravity.*	*Length in feet.*	*Breadth in inches.*	*Depth in in.*	*Deflection in inches.*	*Wt. producing deflection in lbs.*	*Values of a.*	*Authorities.*
Old ship timber,	.872	2.5	1	1	0.5	127	.00998	By my trial.
From young tree, King's Langley, Herts,	.863	2	1	1	0.5	237	.0105	Idem.
Oak from Beaulieu, Hants,	.616	2.5	1	1	0.5	78	.0164	Idem.
Ditto, another specimen,	.736	2.5	1	1	0.5	65	.0197	Idem.
Oak from old tree,	.625	2	1	1	0.5	103	.024	Idem.
Oak from Riga,	.688	2	1	1	0.5	233	.0107	Idem.
English oak,	.960	7	2	2	1.275	200	.0119	Barlow.
Canadian oak,	.867	7	2	2	1.07	225	.009	Idem.
Dantzic oak,	.787	7	2	2	1.26	200	.0105	Idem.
Adriatic oak,	.948	7	2	2	1.55	150	.0193	Idem.
English oak,	.748	2.5	1	1	0.5	137	.00934	Ebbels.
Ditto, green,	.763	2.5	1	1	0.5	96	.0133	Idem.
Dantzic oak, seasoned,	.755	2.5	1	1	0.5	148	.0087	By my trial.
Oak, seasoned,		12.8	3.19	3.19	1.06 / 4.25	268 / 803	.008 / .0105	Aubry.
Oak, green,		6.87	5.3	5.3	.433	7587	.005	Buffon.
Oak. green,		23.58	5.3	5.3	2.7	706	.0095	Idem.
Oak,		8.52	5.06	6.22	0.709	4146	.0133	Girard.
Oak (bois du brin,*)		16.86	10.66	11.73	0.67	4559	.0213	Idem.
Oak (quercus sesiliflora)		2	1	1	0.35	149	.0117	By my trial.
Oak, (quercus robur)		2	1	1	0.35	167	.0104	Idem.

* *" Bois du brin," timber the whole size of the tree, excepting that which was taken off to render it square.*

Table of experiments on the stiffness of Timber, by Mr. Tredgold.

STIFFNESS OF FIR.

Kind of Fir.	*Specific gravity.*	*Length in feet.*	*Breadth in in.*	*Depth n in.*	*Deflection in inches.*	*Wt. producing the deflection in lbs.*	*Values of a.*	*Authorities.*
Riga yellow fir, medium.		18	2	7	0.25	103	.0115	By my trial.
Yellow fir from Long Sound, Norway,	.6398	2	1	1	0.5	261	.00957	Idem.
Yellow fir, Riga,	.480	2.5	1	1	0.5	123	.0102	Idem.
	.464	2.5	1	1	0.5	116	.011	Ebbels.
Ditto, Memel,	.553	2.5	1	1	0.5	143	.0089	By my trial.
	.544	2.5	1	1	0.5	145	.0088	
American pine, supposed to be the Weymouth pine,	.460	2	1	1	0.5	237	.0105	Idem.
	.407	3	1	1	0.5	69	.0112	
White spruce, Christiana,	.512	2	1	1	0.5	261	.00957	Idem.
White spruce, Quebec,	.4650	2	1	1	0.5	180	.0138	Idem.
Pitch Pine,	.712	7	2	2	1.33	150	.0166	Barlow.
New-England fir,	.560	7	2	2	.970	150	.0121	Idem.
Riga fir,	.765	7	2	2	.912	150	.01137	Idem.
Scotch fir, Mar forest,	.715	7	2	2	1.560	125	.0233	Idem.
Larch, Blair, Scotland, dry,	.622	2.5	1	1	0.5	93	.0137	By my trial.
Ditto seasoned, medium,	.644	2.5	1	1	0.5	101	.0126	Idem.
	.554	2.5	1	1	0.5	112	.0111	Ebbels.
Ditto very young wood,	.396	2.5	1	1	0.5	45	.0284	By my trial.
Scotch fir,*	.529	2.5	1	1	0.5	89	.01437	Idem.
Spruce fir, British,	.555	2.5	1	1	0.5	03	.0124	Ebbels.
Fir, (bois du brin)		21.3	10.48	10.48	1.02	4389	.0115	Girard.
Fir, (bois du brin)		10.65	10.48	10.48	0.2245	4122	.022	Idem.

* *The tree from which this specimen was taken was grown in Buckinghamshire.*

Table of experiments on the stiffness of Timber, by Mr. Tredgold.

VARIOUS KINDS OF WOOD.

Ash from young tree, white coloured,	.811	2.5	1	1	0.5	141	.009	By my trial.
Ash from old tree, red coloured,	.753	2.5	1	1	0.5	113	.0113	Idem.
Ash, medium quality,	.690	2.5	1	1	0.5	78.5	.0163	Ebbels.
Ash,	.760	7	2	2	1.27	225	.0105	Barlow.
Beech,	.688	7	2	2	1.025	150	.01277	Idem.
Teak,	.744	7	2	2	1.276	300	.0076	Idem.
Elm,	.540	7	2	2	1.42	125	.0212	Idem.
	.544	2.5	1	1	0.5	99.5	.0128	Ebbels.
Cedar of Lebanon,	.486	2.5	1	1	0.5	36	.0355	By my trial.
Maple, common,	.625	2.5	1	1	0.5	65	.0197	Idem.
Abele,	.511	2.5	1	1	0.5	84	.0152	Idem.
Willow,	.405	2.5	1	1	0.5	41	.031	Idem.
Horse chesnut,	.4838	2.5	1	1	0.5	79	.0162	Idem.
Lime tree,	.483	2.5	1	1	0.5	84	.0152	Idem.
Walnut, green,	.920	2.5	1	1	0.5	62	.020	Ebbels.
Spanish chesnut, green,	.895	2.5	1	1	0.5	68.5	.0187	Idem.
Acacia, green,	.820	2.5	1	1	0.5	125	.0102	Idem.
Plane, dry,	.648	2.5	1	1	0.5	99.5	.0128	Idem.
Alder, ditto,	.555	2.5	1	1	0.5	80.5	.0159	Idem.
Birch, ditto,	.720	2.5	1	1	0.5	90.5	.0141	Idem.
Beech, ditto,	.690	2.5	1	1	0.5	97.5	.0131	Idem.
Wych elm, green,	.763	2.5	1	1	0.5	92	.014	Idem.
Lombardy poplar, dry,	.374	2.5	1	1	0.5	56.5	.0224	Idem.
Honduras mahogany,	.560	2.5	1	1	0.5	118	.0109	By my trial.
Spanish, ditto,	.853	2.5	1	1	0.5	93	.0137	Idem.
Sycamore,	.590	2.5	1	1	0.5	76	.0168	Ebbels.
Pear tree, green,	.792	2.5	1	1	0.5	59.5	.0215	Idem.
Cherry tree, green,	.690	2.5	1	1	0.5	92.5	.0138	Idem.

62. "The constant number a is calculated upon the supposition that the deflection is equal to one fortieth of an inch, for each foot in length; *i. e.* when the length is one foot, the weight will produce a deflection of one fortieth of an inch; when the length is 20 feet, the deflection will be twenty fortieths, or half an inch, and so on. Therefore the reader must consider, when he intends to calculate the scantling of a beam, what degree of deflection the beam may take without injury to the work. When the deflection must be less than one fortieth of an inch to a foot, multiply the constant number a by some number that will reduce the deflection to the degree required. If e. g. the deflection should be only half of a fortieth, multiply a by 2; if a third of one fortieth multiply a by 3 and so on. If, again, the deflection may be greater than one fortieth per foot, divide a by 2, 3, or any number of times, that the proposed deflection may exceed one fortieth of an inch per foot."*

63. "To find the scantling of a piece of timber, that will sustain a given weight, when supported at the ends in a horizontal position, the bearing being given."

Rule 1. *When the breadth is given, to find the depth.* Multiply the square of the length in feet by the weight in pounds, and this product by the value of a opposite the kind of wood in the preceding table. Divide this product by the breadth in inches, and take the cube root of the quotient for the depth in inches.

Examples.

i. A beam of Norway fir is wanted for a 24 feet bearing to support 900 lbs, and the breadth to be 6 inches. Required the depth.

$$\frac{24^2 \times 900 \times .00957}{6} = 827,$$

and $\sqrt[3]{827} = 9.38$, the depth required, in inches.

ii. Suppose the above beam to be New-England fir.

iii. What must be the depth of a beam of English oak, to support 1000 lbs.; the length of bearing being 20 feet, and the breadth 4 inches?

iv. Solve these questions upon a supposition that the deflection must not exceed one eighteenth of an inch per foot.

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* *Tredgold's Elem. Princ. Carp. p.* 36.

Rule 2. *When the depth is given to find the breadth*, Multiply the square of the length in feet by the weight in pounds, and this product by the value of a opposite the kind of wood in the preceding table. Divide the last product by the cube of the depth in inches, and the quotient will be the breadth in inches.

Examples.

i. The space for a beam of oak does not allow it to be deeper than 12 inches; what must be the breadth to support 4000 lbs. the bearing being 16 feet?

$$\frac{16^2 \times 4000 \times .0164}{12^3} = 9.75 \text{ inches, nearly.}$$

ii. Bearing of a beam of pitch pine being 14 feet, depth 10 in. and weight 2000 lbs. required the breadth.

64. But generally neither the breadth nor depth is given. In this case, fix on some proportion, which the breadth shall have to the depth, as e. g. .6, then the rule will be as follows:

Rule 3. Multiply the weight in pounds by the value of a; divide the product by .6, and extract the square root, Multiply this root by the length in feet, and again take the square root, which will be the *depth* in inches.—To obtain the breadth, multiply the depth by .6.

Note. If the breadth is to be .4 of the depth, substitute .4 for .6 in the rule, and so with any other quantity, which may be taken to express the relation of breadth to depth.

Examples.

i. A beam of Riga fir is intended to sustain a ton in the middle of its length; bearing 22 feet; what must be the dimensions?

$$\frac{2240 \times .011}{.6} = 41.066;$$

$$\sqrt{41.066} = 6.4,$$

$$6.4 \times 22 = 140.8,$$

$$\sqrt{140.8} = 11.86 = \text{the depth.}$$

$$11.86 \times .6 = 7.116 = \text{the breadth.}$$

ii. Let the same be required as in the last example, except that the breadth of the beam is to be .45 of the depth.

65. The manner in which the foregoing Rules are obtained may be shewn as follows. We use algebraic symbols, for it would not be easy to be intelligible without them.

Let X represent the deflection of a beam, whose *length*, *breadth*, and *depth*, and the *weight* it sustains are L, B, D, and W,

And x the deflection of another beam, whose *length*, *breadth*, and *depth*, and the *weight* it sustains are l, b, d, and w.

$$X : x :: \frac{L^3 \times W}{B \times D^3} : \frac{l^3 \times w}{b \times d^3} \quad (58)$$

$$X : x :: L \quad : l. \quad (60)$$

divide the terms of the former proportion by those of the latter.

$$1 : 1 :: \frac{L^2 \times W}{B \times D^3} : \frac{l^2 \times w}{b \times d^3}.$$

the first terms being equal

$$\frac{L^2 \times W}{B \times D^3} = \frac{l^2 \times w}{b \times d^3}.$$

$\frac{L^2 \times W}{B \times D^3}$ is therefore a constant quantity, and so will be $\frac{B \times D^3}{L^2 \times W}$ which is equal to *a* in the table.

From this equation, $\frac{B \times D^3}{L^2 \times W} = a$, we deduce the foregoing Rules.

To find D;

$$D^3 = \frac{a \times L^2 \times W}{B}$$ which is the same as Rule 1.

To find B;

$$B = \frac{a \times L^2 \times W}{D^3},$$ which is the same as Rule 2.

To find B and D; B being $\frac{1}{x}$ of D, where $\frac{1}{x} = .6$, or any other fraction which shows the ratio of B to D.

$$B \times D^3 = a \times W \times L^2.$$

$$\frac{1}{x} D \times D^3 \text{ or } \frac{1}{x} D^4 = a \times w \times L^2$$

$$D = \sqrt{\left(\frac{\sqrt{(a + W)}}{\frac{1}{x}} \times L\right)}$$ which is the 3d Rule,

for the length; which being obtained, $B = \frac{1}{x}$ D, gives the breadth.

66. The quantity of timber in a beam being given, the stiffness will be increased by increasing the depth (51; 53). If, however, a beam is made very thin, it will be liable to overturn and

break sideways. Unless, therefore, a beam can be held in its position by other means, there must be a limit, a certain proportion between the depth and breadth, which ought not to be exceeded. To find this proportion the following Rule is given by Mr. Tredgold.

Rule. Divide the length in feet by the square root of the depth in inches, and multiply the quotient by the decimal .6, for the breadth in inches.

Example.

The length of a beam being 24 feet, and the depth 12 inches, what should be its breadth by the above Rule.

$$\frac{24}{\sqrt{12}} = 6.9.$$

$$6.9 \times .6 = 4.14, \text{ the breadth required.}$$

67. To find the strongest form for a beam, so as to use only a given quantity of timber, the following Rule is given by the same Author.

Rule. Multiply the length in feet by the decimal .6, and divide the given area in inches by the product: the square of the quotient will give the depth in inches.

Example.

If the bearing be 20 feet, and the given area of section be 48 inches, then

$\frac{48}{20 \times .6} = 4$, and the square of 4 is 16, the depth required. The breadth will of course be $\frac{48}{16} = 3$ inches.

68. The stiffest beam that can be cut out of a round tree, is that, of which the breadth is to the depth as

$$1 : \sqrt{3};\ \text{or as } 1 : 1.732 \text{ nearly; or as } .58 \text{ to } 1;$$

and this is a good proportion for beams that have to sustain a considerable load, when it would be impossible, on account of the size of the tree to obtain them as deep as the foregoing rules would require.

§5. *Of the stiffness of beams when the* WEIGHT *is* UNIFORMLY DISTRIBUTED *over the length.*

69. We have hitherto supposed the weight which causes deflection in a beam to be suspended from the middle of it. If, instead of this, the weight should be divided into small and equal parts, and these distributed uniformly over the whole length of the beam, we should find, that the beam in bending would assume a different curve, and that the descent of the middle part, which we have called the deflection, would be less.

70. To determine the ratio between the deflection produced by the weights uniformly distributed, and that produced by the same weights accumulated in the centre, we have the following table, containing the results of the experiments of M. Dupin.*

Wood.	*Dimensions in metres.*		*Wts. at the centre.*		*Weights diffused.*	
	Vertical.	*Horizontal.*	*Weight in kil.*	*Deflection in metres.*	*Weight in kil.*	*Deflection in inches.*
Oak, rectangular prism.	.02	.03	6	0.033	9	0.032
the same.	.02	.02	6	0.015	9	0.0145
Fir, cylinder.	Diam.	.02	1.9	0.048	3	0.048
the same.	do.	.02	4.75	0.123	7.5	0.123

71. It has been shown above, that the deflections are as the deflecting weights. In the first experiment above, the deflection for 6 kilograms is .003 metres; for 9 kilograms it would have been .050 metres, and

defl. wt. diff.
.032 : .050 :: 19 : 30 very nearly.

The third and fourth experiments give this ratio exactly.

The deflection of a beam, therefore, *when the weights are uniformly distributed over its length, is to the deflection, when a weight, equal to their sum is applied to the centre*, as 19 : 30.

72. If we wish to calculate the deflection of a beam, the weight being distributed through its length; we have only to calculate the

* *Journal de l'Ec. Poly. Tom. X. p.* 201.

deflection, upon the supposition of an equal weight acting in the centre, (59) and take nineteen thirtieths of it, or, which is the same thing, multiply it by .63.

73. In calculating scantlings by the rules Art. 63 and 64, if instead of using the whole weight we employ nineteen thirtieths of it or .63 of it, we shall have the proper scantling for a beam, when the weight is uniformly distributed over it. For nineteen thirtieths of the weight acting at the centre will cause the same deflection as the whole weight uniformly distributed.

Examples.

i. A beam of Norway fir is 20 feet long, 5 inches broad, and is required to support 1000 lbs. uniformly diffused over its length: what should be its depth?

$$\frac{20^2 \times 630 \times .00957}{5} = 482.33,$$

and $\sqrt[3]{482.33} = 7.84$, the depth required.

ii. The examples in Art. 60 may be repeated, upon the supposition that the weights are uniformly distributed.

74. Rafters, purlines, ceiling posts and binding joists, that support ceilings only, have their weight uniformly distributed. Flooring joists have to resist strains at one point. A floor might seem stiff enough to support a uniform load, and yet shake very much by the weight of a single person moving over it.

75. M. Dupin gives a curious problem, for ascertaining the weight of a large stick of timber of uniform depth. Place its ends upon two supports of the same height, and observe the deflection by its own weight;—then add a known weight to the middle, and observe the additional deflection. Then as .63 of the second deflection is to the first deflection, so is the weight added, to the weight of the beam.

76. It will be easy from the above principles to find the deflection, which any given beam would suffer from its own weight. Let the weight of the beam be supposed to be accumulated at the centre, and having calculated the deflection, as in Art. 56, multiply the deflection so found by .63.

Examples.

i. How much will a stick of Weymouth pine be deflected by its own weight; the stick being 15 feet long and 6 inches square, weighing 100 lbs.

$$\frac{2^3 \times 237}{1^3 \times 1} : 5 :: \frac{15^3 \times 100}{6^3 \times 6} : .068 \text{ of an inch.}$$

$.068 \times .63. = .$[illegible], the deflection required. .04284

ii. How much will a stick of yellow Riga fir be deflected by its own weight, supposing it to be 30 feet long, 6 inches deep, and 7 inches broad?

Note. The weight of the stick may be calculated from its dimensions and specific gravity.

iii If a stick of pine, resting on supports at its extremities, bends by its own weight .025 of an inch, and if by the action of a weight of 200 lbs. placed upon its centre, the deflection increases .13 of an inch more; what is the weight of the stick?

Note. Solve this example by Art. 75.

CHAPTER IV.

Of the STRENGTH *and* STIFFNESS *of beams* FIXED *at both ends and loaded at the centre.*

77. The difference between the strength and stiffness of beams merely *supported* at each end, and of those, whose ends are *fixed* so as not to be capable of rising by the action of the weight suspended from the middle, has been alluded to: the inquiry now is, what is the difference.

§1. *Of the* STRENGTH *of beams* FIXED *at both ends.*

78. The following Table is from Barlow's Essay, p. 96.

Experiments on Fir battens, fixed at each end.

No. of experiments.	*Length in inches.*	*Depth in inches.*	*Breadth in inches.*	*Specific Gravity.*	*Deflection.*	*Weight in pounds.*	*Reduced to Sp. Gr. 600.*	*REMARKS.*
1	72	2	2	581	.45	220		The whole of the exp. 34 min.; after last weight 6 min.
					1.00	620		
					1.30	822		
					2.10	1024	1058	
2	72	2	2	581	.41	220		
					.95	620		
					1.25	822		
					2.10	1139	1174	Whole time 28 m.
3	72	2	2	611	.40	220		
					.87	620		
					1.35	822		
					2.20	1090	1070	Whole time 45 m.
4	72	2	2	600	.45	220		
					1.00	620		
					1.20	822		
					2.30	1120	1120	Whole time 18 m.
					Mn.	*Wt.*	1105	

79. If we add together the reduced weights in the 8th column of the preceding table, and divide the sum by 4, we shall have 1105.5 for the mean strength of fir battens 72 inches long and 2 inches square, *fixed* at each end. According to the table, Art. 15, 744 measures the strength of a similar batten supported at each end. But

744 : 1105 : : 1 : 1,5 nearly, or as 2 to 3.

These experiments then give us the ratio of 2 : 3, as the ratio of the strength of two similar sticks, one of which is *supported*, and the other *fixed* at each end. In other words, *a beam merely supported at each end, has only two thirds the strength of a similar beam, whose ends are fixed.*

This ratio is confirmed by the first and second of Belidor's experiments, Art. 17.

80. The strength of a stick of chesnut 11.5 feet long, 8 in. deep, and 6 broad, *supported* at both ends, is 6012 lbs. (Example 2, Art. 31.) What will be its strength if *fixed* at both ends. It is obvious that we obtain the strength required, if we add half of 6012 to itself, thus:

2)6012
3006
———
9018 lbs. answer,

for 6012 is two thirds of 9018. We have then this very simple

Rule. *Find the strength of a beam, whose ends are supported; add one half this strength to itself, and the sum is the strength of the beam when its ends are fixed.*

Examples.

i. A beam, whose ends are supported can bear 10956 lbs. How much will it sustain if its ends are fixed?

ii. What weight will be necessary to break a stick of sycamore, fixed at both ends, whose length is 9 feet, breadth and depth 5 inches?

iii. What is the strength of a beam of oak, medium quality, fixed at both ends; length 10 feet, breadth and depth 6 inches?

iv. Of American pine of tho same dimensions?

§2. *Of the* STIFFNESS *of beams* FIXED *at both ends.*

81. *The same ratio of* 2 : 3, *appears to take place between the stiffness of a beam supported, and that of one fixed at each end.*

In the 56th experiment of the table, Art. 15, we have .75 of an inch for the deflection of a stick 72 in long, and 2 in. square, under a weight of 221 lbs.; while the deflection of a similar stick *fixed* at both ends, is .45 inch, and .75 : .45 nearly as 3 : 2; but the deflections are inversely as the stiffness, which therefore is, in the two cases, as 2 : 3.

82. If we take the average deflection of the experiments N, Art.

15, and of those in the last table, we shall have for that of the *supported* beam .70, and for the *fixed* .4275; the weight in each case being 221 lbs. And

.70 : .4275 : : 3 : 2, within a very small fraction.

If the average deflections in the cases with the weight of 42 lbs. be taken and compared, a very considerable variation from the above ratio will be observed. The deflection of the *fixed* beam would be .69; of the *supported* 1.32.

1.32 : .69 : : 2 : 1, nearly.

The reason of this deviation will be found in Art. 57. The deflection increases in a higher ratio than that of the weight, when the weight is sufficient to impair the elasticity of the timber, and the nearer it approaches to that which causes fracture:—and 421 is a much greater part of the breaking weight of the *supported* stick 744, than of the *fixed* one 1116. To this may be added, that, from a comparison of the tables referred to in this section, it would appear that when the ends of a stick are *fixed*, the increase of deflection before the fracture is not so rapid.

83. "We cannot," Mr. Tredgold observes, "in practice *fix* the ends of a beam into a wall without endangering its stability;—therefore the determination of the stiffness of beams to suit such a case, is not an object of much importance. When, however, a long beam is laid on several points of support, a case of very common occurrence in building, the strength of the intermediate part is nearly twice as much" (or greater in the ratio of 3 : 2, according to the above observations) "as when the beams are cut into short lengths. Hence the carpenter will see the importance of using bridging and ceiling joists, purlines and rafters, *in considerable lengths;* so that a joist may extend over several binding joists; purlines over several trusses, and rafters over several purlines. Also by contriving so that the joinings shall not be opposite one another, a floor or roof may be made tolerably equal in strength. Hence also the necessity of *notching* joists, purlines and rafters *over* the supports, instead of framing them between."

84. Instead of the ratio 3 : 2, some writers, Emerson and Robinson, and Tredgold, as we have just seen, make the strength of a *fixed* beam double that of a supported one. Experiment is, how-

ever, against them; and we have preferred to follow its guidance. We are, also, not unsupported by theory; as the ratio of 3 : 2 is obtained by Prof. Barlow from his analytical investigations.

CHAPTER V.

Strength and deflection of SOLID *and* HOLLOW CYLINDERS *supported at each end.*

35. To ascertain these points by experiments, our materials are limited. The following table of experiments is the only one, I have yet seen. Experiments by Duhamel are referred to by Mr. Tredgold, but he makes no use of them.

Experiments on hollow and solid cylinders, supported at each end.

No of Experiments.	*Woods.*	*Specific Gravity.*	*Length in inches.*	*Diameter external.*	*Diameter internal.*	*Breaking weight.*	*Deflections in inches.*
1	Fir.	581	48	2	solid.	740	2.0
2		603	48	2	do.	796	2.1
3		580	48	2	do.	780	1.9
4	Ash.	590	46	2	solid.	700	2.7
5		590	46	2	do.	730	2.5
6		586	46	2	$\frac{1}{2}$ inch.	650	3.0
7		540	46	2	$\frac{1}{2}$ inch.	664	3.0
8		601	46	2	$\frac{3}{4}$ inch.	646	3.1
9		601	46	2	$\frac{3}{4}$ inch.	654	2.9
10		580	46	2	1 inch.	631	2.8
11		580	46	2	1 inch.	630	3.6

36. Mr. Barlow remarks that the ash cylinders, although of a weak quality, "gave very uniform results, and furnish a good com-

parison between the strength of solid and hollow cylinders among themselves."

The fir cylinders may be compared with the square battens of fir marked M Art. 15. By this comparison, we may ascertain the comparative strength of square and cylindrical battens of the same diameter."

§1 *Comparison of square with cylindrical battens.*

87. The mean weight reqnired to break a square fir batten 48 inches long and 2 inches square is 1112 lbs. That required to break a fir cylinder of the same length and diameter is 789.

1112 : 789 : : 1 : .7095.

Therefore, to find the *strength* of a cylindrical batten to resist a transverse strain, *find the strength of a square batten of the same strength and diameter, and multiply this strength by* .7 or more exactly by .71.

Examples.

i. What will be the strength of a cylinder of American white spruce, 3 feet long and 2 inches diameter?

570 is the breaking weight for spruce, Art. 31.

$$\frac{570 \times 2^2 \times 2}{3} = 1520 = \text{breaking wt. of square batten.}$$

$1520 \times .7 = 1064$, breaking wt. of cylinder.

ii. What will be the breaking weight of a cylinder of ash, 4.5 feet long, and 2.6 inches diameter.

88. The stiffness of square and cylindrical battens probably have the same relation as the strength.

§2. *Comparison of solid and hollow cylinders.*

89. The comparative strength of solid and hollow cylinders may be well shown by comparing together their strength and quantity of matter. It will be seen that nearly one third of the wood may be taken away from the centre, without greatly impairing the strength. The areas of the section of the three classes of ash bat-

tens, of the table at the commencement of this chapter, are given below, with their mean strength.

External diam.	*Internal diam.*	*Area of sect.*	*Strength red. to sp. gr.* 600.
2 inches.	solid.	3.1416	727
2 "	½ inch.	2.9443	691
2 "	1 "	2.3562	652

90. Hollow tubes are stiffer as well as stronger than solid cylinders of the same quantity of matter. We have some instances in nature, illustrative of this principle, as in the bones of animals, and particularly of birds, the quills of birds, the stalks of reeds, and grasses; and "the best engineers now imitate this procedure of nature, in forming their mill axles, uprights, and the like, of cast iron tubes."

This principle has its limits in practice. The sides of the hollow tubes must be sufficiently thick to resist any strain tending to crush them in, to which they may be exposed.

CHAPTER VI.

Of the strength of beams FIXED *at* ONE END.

91. The following table is from Barlow's Essay. The battens in the six first experiments were all two inches square. The *fourth, fifth, and sixth,* whose breadths are marked $\sqrt{8}$, were placed, not with one side, but with one edge down, so that one diagonal of the section became the depth, and the other the breadth. But the diagonal of the section of a square batten, whose side is 2 in. is the hypothenuse of a right angled triangle, whose sides are 2 in. and is therefore equal to $\sqrt{2^2 + 2^2} = \sqrt{4+4} = \sqrt{8}$ as in the Table.

TABLE *of experiments on fir battens, fixed at* ONE END, *the weight being at the other.*

No. of Experiments.	*Length in inches.*	*Depth in inches.*	*Breadth in inches.*	*Specific Gravity.*	*Weight in lbs.*	*Deflection in inches.*	*Weight reduced to length 36, and sp. gr. 600.*	*Position of the Beams, &c.*
1	36	2	2	560	317	5.0	400	Horizontal.
2	32	2	2	609	432	6.0	400	
3	32	2	2	571	417	6.0	389	
4	30	$\sqrt{8}$	$\sqrt{8}$	600	462	4.9	385	Horizontal, but with the diagonal vertical.
5	30	$\sqrt{8}$	$\sqrt{8}$	613	469	4.7	391	
6	30	$\sqrt{8}$	$\sqrt{8}$	620	466	4.9	389	
7	24	2	1	620	279	4.1	180	Horizontal.
8	24	2	1	600	276	3.9	184	
9	24	2	1	596	273	4.3	183	Angle 26 degrees upwards.
10	24	2	1	581	281	4.1	193	
11	24	2	1	600	294	3.9	196	Angle 26 degrees downwards.
12	24	2	1	601	290	4.0	193	

72. Pursuing the same method of reducing the calculations of the strength of timber to as few operations as possible, we shall compare the strength of beams *fixed* as above at one end, with that of those of the same dimensions, *supported* at both ends.

In the table Art. 15, we find the strength of the battens K (length 36 in. depth 2, and breadth 1) to be 745 lbs. By doubling this weight we obtain the strength of a batten of the same length and depth, and 2 inches broad, 1490.

According to the foregoing table, the mean strength of a fir batten fixed at one end, 36 in. long and 2 in. square is 396.

396 : 1490 : : 1 : 3.76.

Take another example. The battens H, table Art. 15, are of the same dimensions with Nos. 7 and 8 of the table in the last Art. The mean breaking wt. of the former is 1119 ; of the latter 277.5.

277 : 1119 : : 1 : 4.04.

These examples indicate that

The strength of a beam fixed at one end and loaded at the other is to that of a beam of the same dimensions supported at both ends as 1 to 4.

93. This proportion being derived from the comparison of very few experiments, it may be satisfactory to the reader to observe, that it is the same, which has been deduced from those theoretical investigations, whose results have been found in other cases to agree most exactly with experiment.

The following Rule then may serve for calculating the strength of timber fixed at one end.

Find the strength of a stick of the same dimensions supported at both ends and loaded in the middle, and take one quarter of it.

Examples.

i. It was found (Ex. 2, Art. 31) that the breaking weight of a stick of chesnut 11.5 feet long, 8 in. deep and 6 broad, is 6010. What weight would break it, if fixed at one end and loaded at the other?

$$\frac{6010}{4} = 1502.5, \text{ Ans.}$$

ii. What weight will break a stick of Lombardy poplar fixed at one end and loaded at the other; the length being 8 feet, and depth and breadth each 9 inches?

94. As beams, fixed at one end and loaded at the other, are very rarely used in building, we shall add no more to this Chapter, than the following quotations from Prof. Barlow.

"We conclude that the deflection of a beam fixed at one end in a wall, and loaded at the other, is double that of a beam of twice the length, supported at both ends, and loaded in the middle with a double weight: that is, the strain being the same in both cases: consequently, when the weights are the same, the deflection in the first case is to that in the second as 4 : 1."

"And when the length and weight are both the same, the deflections will be as 1 : 32." *Essay, p.* 115.

"When a beam or rod is fixed only at one end, the deflection, when the weight is uniformly distributed, is to the same when collected at the extremity, as 3 : 8; whereas, when the beam is supported at the ends, the deflections in the like cases are to each other as 5 : 8."

"Whence, if a rod or plank is, in the first instance, supported in the middle, and the ends be deflected; and in the second, the ends supported and the middle left to descend, the deflection in the latter case is to that in the former as 5 : 3." *Essay, p.* 117.

CHAPTER VII.

Of the mechanism of the Transverse Strain.

95. When a beam is supported at its ends, and is deflected by the action of a load, the fibres in the upper part of the beam are compressed, and those of the under part are extended. Between the compressed and extended fibres there is a stratum of fibres, which suffer neither compression nor extension, and are therefore situated in what is called the *neutral axis* of the beam.

96. The position of the neutral axis in rectangular beams was determined by Mr. Barlow, by observing, after the fracture of the batten, the part which was compressed. In some cases the compressed part was remarkably distinguished from the extended, by the former breaking short, while the latter was drawn out in long fibres. Before the fracture took place, the external appearance of the pressure exhibited itself in a wedge-like form, the lower point of which, when the beam was broken on two props, was commonly found to divide the depth of the beam in the ratio, which was derived from observations on the fracture. This ratio was 5 of compressed parts to 3 extended; *i. e.* the position of the neutral axis was five eighths of the depth from the upper surface.

97. The following curious experiments of Duhamel afford a method of ascertaining, with tolerable exactness, the position of the neutral axis; and they shew strikingly how small a part of a beam contributes to the strength, by its tenacity.

He took 16 bars of willow 2 feet long and half an inch square, and supporting them on props at the ends, suspended weights from the middle. *Four* of them were broken by the weights of 40, 41, 47 and 52 lbs.—the mean being 45.

He then cut *four* of them one third through, across the upper side, and filled up the cuts with a thin piece of hard wood, and they were broken by 48, 54, 50, and 52 lbs.—the mean being 51.

Four others were cut one half through, and the cuts filled. They were broken by 47, 49, 50 and 46,—the mean being 48.

The *four* remaining bars were cut two thirds through, and their mean strength was 42 lbs.

In another set of experiments upon bars of willow 3 feet long and 1.5 inch square, the mean strength of 6 uncut bars was 525 lbs.—of 6 cut one third through and filled as above, 551—of 6 cut one half through, 542—and of 6 cut three fourths through, 530 lbs.

In another experiment a bar of the same dimensions was cut three fourths through, and after being loaded sometime, and until nearly broken, it was taken down, the thin slip taken out, and a wedge put in to straighten the bar again, and it then bore 577 lbs. Probably by increasing the thickness of the wedge it would have borne still more.

Prof. Barlow repeated experiments similar to the above, with nearly the same results.

98. When beams are fixed at one end, and loaded at the other the fibres of the upper surface are extended, while those of the lower are compressed.

99. In many of the theories, which have been proposed in relation to the strength of timber, the compression of any part of the beam, subjected to a transverse strain, is entirely overlooked. They suppose, that when a beam is supported at both ends, and loaded in the middle, the fibres throughout the depth are extended, and in proportion to their distance from the upper surface. The fibres of the upper surface have to sustain the extension of those below, as a fulcrum, and of course such speculations do not merely neglect the compressibility of timber, but suppose it incompressible.

100. As it might be supposed, theories so deficient, have led to inferences altogether at variance with fact.

It is inferred, e. g. from such speculations, that a triangular beam supported at both ends, will support a greater load with the edge uppermost, than with the base uppermost, because the fibres of the lower surface being farther from the fulcrum, exert a greater influence than the others, and the more there are of them, or the wider the under surface, the stronger the beam.

This inference, if we consider the compressibility of timber, and suppose (as has been shown to be the case with willow and fir) that the compressibility is greater than the extensibility, is manifestly false ; for in such a case the breadth of the base is wanted to resist the compressibility, rather than the extension.

In order, therefore, to ascertain, whether a triangular beam would be stronger with its edge or its base uppermost, it is necessary to have reference to the comparative compressibility or extensibility of the wood, of which it consists. Thus, Mr. Barlow found triangular beams of fir, supported at both ends, to be strongest with the base uppermost; whereas Mr. Couch found triangular oak beams acted upon in the same manner, to be strongest with the angle uppermost.*

101. We have said that hollow tubes are stiffer and stronger than solid cylinders of the same quantity of matter. It is added by some theorists, that the tubes will be stronger, the nearer the opening is to one side; the upper side, if they are supported at both ends—the under side, if fixed by one end. This supposition proceeds from the same false principle, as the inference in relation to the triangular beams, and still worse than that, it is invariably false.

102. What is said above of triangular beams, applies to trapezoidal, or those which have their breadths at the upper and under surfaces different.

103. Although timber is not capable of very great compression, and has no limits to the extension of its fibres, but fracture, it is thought to be generally more easily compressed than extended by the strains, to which we expose it. If so, the position of beams should be just the reverse of that recommended by such theorists as we have just alluded to.

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* *For Mr. Couch's experiments see Barlow's Essay.*

104. From the view we have now given of the nature of the transverse strain, we may see the propriety of several maxims, which have been long familiar to experienced workmen. A mortice should not be cut out of that side of a beam, which will become convex by a strain. It may be cut out of the part which becomes concave, because the place may be filled with the tenon, which, if well fitted, will answer the same purpose as the thin slips of wood in the experiments of Duhamel.—A mortice would be still better near the neutral axis.

A *fish* or *strap* should be applied to the convex side.

CHAPTER VIII.

Of the lateral strength of timber.

105. The strain, which has been considered in treating of the transverse strength of timber is not a *simple* one. The weight, being placed at the middle of a stick, resting upon supports at the extremities, or at one end, when the other is fixed in a wall, acts with the aid of a lever. The pin at the joint of a pair of pincers or scissors, broken by the strain, would present a case of simple transverse fracture.

106. The experiments we have upon this kind of strain, are those of Dr. Robinson. In performing them he made use of "two iron bars disposed horizontally at an inch distance, and a third, which was hung perpendicularly between them, *being supported by a pin made of the substance to be examined.* This pin was made of a prismatic form, so as to fit exactly the holes in the three bars, which were made very exact, and of the same size and shape. A scale was suspended at the lower end of the perpendicular bar, and loaded till it tore out that part of the pin, which filled the middle hole. This weight was evidently the measure of the lateral cohesion of two sections. The side bars were made to grasp the middle

bars pretty strongly between them, that there might be no distance imposed between the opposite pressures. This would have combined the energy of the lever with the purely transverse pressure. For the same reason *the internal parts of the holes should be no smaller than the edges*."*

107. Great irregularities occurred in the first experiments, because the pins were somewhat tighter within than at the edges; but when this was corrected, they were extremely regular. Three sets of holes were employed, a circle, a square and an equilateral triangle. In all the experiments, *the strength was exactly proportional to the area of the section, and quite independent of its figure or position.* It was also found that *the strength was considerably above the direct cohesion.*

108. The difference between the lateral strength, found in this way, and the direct cohesion, was very constant in any one substance, but varied from four thirds to six thirds, or double, in different kinds of bodies, *being smallest in fibrous bodies.*—On account of the insufficiency of the apparatus, no experiments were made upon bodies whose cohesion is very great. Brick and freestone were among the strongest.

107. Although it appears that the lateral strength is proportional to the area of the section, it is advisable that bearing surfaces should be wide and flat, for all matter is compressible, and wood especially is most so, across the fibre. Should the part, therefore, which first receives the strain, be narrow or thin, it may be crippled before the strength of the other fibres be brought into action. This principle should always be kept in view in forming *tenons and mortises*, or joints of a similar kind, and appears well known to the intelligent carpenter. The same thing is frequently aimed at by making the tenon long, and giving it a deep hold in the mortise. Such a practice gives no additional strength, and is even injurious. For if the tenon bear upon the interior of the mortice instead of the outer edge, the strain comes to act upon it with the energy of a lever, and may thus be increased in any degree. The bearing side of a tenon being no longer than sufficient to give a firm hold, the end may be beveled above till flush with

* *Mechanical Philosophy, Vol.* 1, *p.* 413.

the upper side of the beam. *We may trust to every square inch of such a tenon the weight which is given* (Art. 5) *as the measure of the direct cohesion of the kind of timber employed.**

110. Mr. Barlow has made some experiments upon that resistance, which hinders a piece of strait grained timber from *sliding out* in the direction of the fibre. This resistance he calls *lateral adhesion.* He found that of fir to be equal to 592 pounds to a square inch. The only experiments besides his, in relation to this point, which we have seen, are those of Mr. Tredgold, already given in Art. 9; and these do not seem to have been made in the same manner. Experiments on the lateral adhesion of timber might be useful in furnishing the means of calculating the resistance, for example, which an abutment at the end of a tie-beam offers to being crushed off by the horizontal thrust of a rafter; or the distance at which the abutting surface ought to be made from the end of the tie, in order that the resistance might be sufficient to sustain a given pressure.

Examples.

i. Suppose the tie to be of fir, 6 inches broad, and the distance of the abutting surface from the end of it to be 6 inches. The lateral adhesion of the abutment to the beam is therefore by a surface of 36 square inches.† This multiplied by 592, (the lateral adhesion of 1 square inch) is equal to 21312 lbs. the whole lateral adhesion of the abutment, or the resistance it offers to being crushed off. In practice, the strain should not be more than one fourth of this, which is 5328.

ii. Suppose the horizontal thrust of a rafter to be 5600 lbs. and the thickness of the beam 6 inches. How far should the abutting surface be from the end of the tie?

The abutment should be able to support 4 times the thrust, or 22400, which divided by 592 gives the adhering surface, 37.8, and this again divided by 6 (the breadth of the tie-beam) gives 6.3 for the length of the abutment.

Note. The method of calculating the horizontal thrust of a rafter, will be given in the 2d part of this work.

* *Edin Enc. Art. Carp.*

† *It is here, for simplicity, supposed that there is no tenon in the joint.*

CHAPTER IX.

Of the stiffness of timber to resist COMPRESSION *in the direction of its length.*

111. Much has been written upon the resistance of materials to this kind of strain, from which the practical man will derive little satisfaction. Most if not all the theories, which have been published, have not been derived from experiments, or even constructed with any reference to the actual constitution of materials; and whatever credit they may reflect on the ingenuity of their authors, they fail in their practical applications. If we turn to experiments, we are disappointed in our expectations; for their results are too irregular to furnish us with any general conclusions.

Experiments on this strain cannot be made with accuracy, without an expensive apparatus, and unless they are so made, they are useless. The principal experiments are those of Lamande and those of Girard.*

112. The very great resistance of timber to compression in the direction of its length, renders it a less matter of regret, that our acquaintance with its laws is so deficient. Timber is not often broken or bent by a direct pressure of this kind, especially when the load is so placed as to bring the whole resistance into action. It is therefore even more important to attend to the circumstances which favor the resistance, and to the neglect of which many of the irregularities in experiments are owing; than to know the actual amount of resistance, especially in a country, in which timber is not expensive.

113. When a stick of timber is fairly pressed in the direction of its length, we can hardly conceive it possible for it to be bent, except it be by one side being less capable of resisting the compresssion than the other. This is the common cause of bending, and it at once suggests the necessity of avoiding all defects in the sides of

* *The reader may find some experiments of Lamande, in Tredgold's Elem. Pr. of Carpentry, p. 51, copied from Gautheys' construction des ponts. He may also find the most important of Girard's in Rees' Cyclopedia, Art. "Strength of materials."*

sticks, which are to bear a great strain of this kind, or weakening the sides in any other way.

114. The bending may be caused by the load not being over the centre or axis of the stick; for if the load be nearer one side than the other, that side will be most compressed, and will soonest yield. This suggests the necessity of making the ends of posts perfectly square, so that they may bear evenly upon their foundations, and their loads may bear evenly upon them.

115. When a stick is strongly compressed in a longitudinal direction, a slight lateral strain may cause it to bend, and if it continues, will, as experience has often shown, produce a sudden fracture. Lateral strains should therefore be carefully avoided.

116. When a post is square, or its lateral dimensions are nearly equal, it will bend under a load, in two directions. It is often in our power to brace a post in one direction, in a building, so that it shall only be able to bend in the other. If then we increase the dimension, in the direction of which only it can be bent, we may greatly increase its stiffness, without increasing the scantling. For instance, a square upright of 6 inches, in a partition, will not be, at farthest, more than one third as stiff, as one of 4 inches by 9.

117. When a stick of timber is exposed to compression, it yields to the force in a different manner according to the proportion between its length, and the area of its cross section Suppose the piece to be a cylinder, then if its length be greater than 8 or 10 times its diameter, a sufficient force will cause it to bend, and break about the middle of its length. But when the length is less in proportion to its diameter, the piece will bulge out in the middle, and split in several places.*

§1. *When the height of the column or post is more than ten diameters.*

118. That we may not leave this subject, without some rules for calculating the strength of columns, posts, and other beams, pressed in the direction of their length, we quote the following from Mr. Tredgold.

* *Tredgold, p.* 47.

"The strain," he observes, "will be directly as the weight or pressure, and inversely as the strength, which is as the cube of the diameter. The strain will also be directly as the deflection, which will be as the quantity of angular motion; that is, directly as the square of the length, and inversely as the diameter. Joining these proportions we have $\frac{L^2 \times W}{D^4}$ is as the strain."

"The stiffest rectangular post is that, in which the greater side is to the less as 10 to 6: therefore, when a post is insulated, this form should be preferred."†

119. "To find the diameter of a column or a pillar, that will sustain a given weight, when the pressure is in the direction of the axis—*Multiply the weight or pressure in pounds by* 1.7 *times the value of* e *for the kind of wood in the following table; then multiply the square root of the product so obtained, by the length or height in feet, and the square root of the last product will be the diameter in inches.*"

Note. If the column be shorter than ten times its diameter, then the diameter found by this rule will be too small."

Table.

Kinds of Wood.	*Value of* e.
English oak,	0.0015
Beech,	0.00195
Alder,	0.0023
Chesnut, (green)	0.00267
Ash,	0.00168
Elm,	0.00184
Acacia,	0.00152
Mahogany, Spanish,	0.00205
Do. Honduras,	0.00161
Teak,	0.00118
Cedar of Lebanon,	0.0053
Riga fir,	0.00152
Memel fir,	0.00133
Norway spruce fir,	0.00142
Weymouth pine,	0.00157
Larch,	0.0019

* *Tredgold, p.* 48.

Example.

"Let it be required to support 12 tons (26880 pounds) by a cylindrical oak post, of which the height is 8 feet. Then by the table, the value of e is 0.0015; therefore, 26880 × 1.7 × 0.0015 = 68.544, of which the square root is 8.28 nearly. And 8.28 × 8 = 66.24; the square root of 66.24 is very nearly 8.14; therefore, 8.14 inches is the diameter required."

120. "To find the scantling of a rectangular post or beam, capable of sustaining a given pressure in the direction of its length—*Multiply together the weight or pressure in pounds, the square of the length in feet, and the value of* e *for the kind of wood in the foregoing table. Divide this product by the breadth in inches, and the cube root of the quotient will be the thickness in inches.*

Note. "In this rule, as in the last, when the beam or post is shorter than ten times its thickness or least dimension, the scantling found will be too small."

Example.

"Let the height of a post of Memel fir be 8 feet, its breadth 7 inches, and the weight to be supported 12 tons, or 26880 pounds.

The value of e is 0.00133; therefore,

$$\frac{26880 \times 0.00138 \times 8 \times 8}{7} = 327 \text{ nearly};$$

and the cube root of 327 is 6.889 inches, the thickness required."

121. "In the oak and fir, the constant numbers (e) do not differ materially; but in small scantlings, oak is more liable to warp, and besides, oak is seldom so strait grained or so free from knots, as yellow fir; therefore it is usually employed in larger scantlings. But this must depend on the judgment of those who use it."*

§2. *When the height is less than ten diameters.*

122. "According to the experiments of Rondelet, when the height of a square post is about 7 or 8 times its diameter, it cannot be bent by any pressure, less than that, which would crush it. In timber, resistance to crushing is less than the cohesive force. It

* *Tredgold's El. Pr. of Carp. p.* 55.

appears to increase in a ratio higher than that of the area of its section, but writers generally content themselves by assuming it to be as the area."

By Rondelet's experiments, made on cubes of an inch in length it appears that oak requires from 5000 to 6000 lbs. per square inch to crush it, and that under this pressure, its length was reduced more than one third. Fir required from 6000 to 7000, and its length was reduced one half.

Mr. Rennie's experiments afforded results considerably lower. They are as follows.

A cubical inch of Elm was crushed by		1284	lbs.
" "	American pine	1606	"
" "	White deal	1928	"
" "	English oak	3860	"
	do. (4 inches long)	5147	"*

123. To find the load, which a column or stick of timber might sustain, when pressed in the direction of its length—*Multiply the area of the section of the column or stick, in inches, by the weight, which will crush one square inch, and take one quarter of the product.*

In this way, it will be found, that the piece of oak, 3 inches square, will sustain with safety $\frac{5000 \times 9}{4}$ or, 11250 lbs. according to Rondelet, or, $\frac{3860 \times 9}{4}$ or, 8685 according to Rennie.

124. Since a column or post tends to break in the middle, when overloaded, it is generally supposed that an enlargement of that part will add to its strength, and further, that a column or pillar, to be equally strong throughout, must have the form generated by the revolution of two parabolas. Lagrange, however, concludes from his investigations, that this enlargement "adds nothing to the strength of a column, and that the cylinder is the most eligible form."†

* *It would be difficult to assign a reason, why the four inch specimen should be stronger than shorter ones. Mr. Rennie's Experiments were published in the Philosophical Transactions for* 1818. *They may be found in Nicholson's Operative Mechanic.*

† *Barlow, p.* 62.

§3. *On the resistance to compression at the joints of framing.*

125. "There is yet another kind of resistance to compression to be considered; which is, when the end of one piece is pressed against the side of another piece. The strength of the joints of framing depends in some degree on this kind of resistance; for unless the resistance at the joint be equal to the pressure, a degree of compression may take place that would produce considerable derangement in the framing, if not a total failure.

"In order to obtain some information on this important point, I made the following experiments: I prepared two pieces of good Memel fir, and placing the end of one piece upon the side of the other, I loaded it successively with 800, 900, 1000, 1100, 1200 and 1300 pounds upon a square inch, examining the effect of each trial; the impression was faint with 900 pounds, but became very distinct with 1000 pounds; therefore I consider the pressure on the joints of timbers of yellow fir, should never be greater than 1000 pounds per square inch. The position of the annual rings makes a considerable difference, for in some trials the impression was very distinct with 950 pounds.

English oak was next tried; with a load of 1400 lbs the impression appeared to be about the same as 1000 pounds produced in Memel fir; and there was less difference from varying the position of the rings."*

CHAPTER X.

On the construction of Floors.†

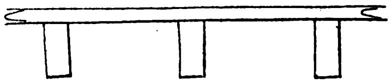
126. The timbers which support the flooring boards and ceiling of a room are called, in carpentry, the *naked flooring*. There are different kinds of naked flooring, but they may all be compris-

* *Tredgold*, p. 60.

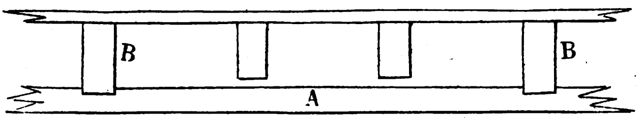
† *This Chapter is extracted from Tredgold's Pr. of Carp. with no other alteration than to adapt the references to the present work.*

ed within the three following ones; viz. single joisted floors, double floors, and framed floors.

i. Single joisted floors. A single joisted floor consists of only one series of joists. The following figure shows a section across the joists of a single joisted floor.

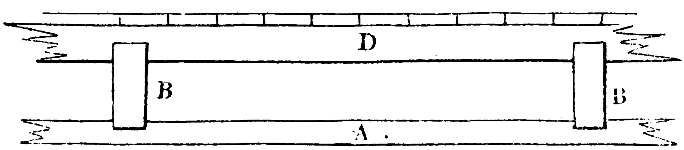


Sometimes every third or fourth joist is made deeper, and the ceiling joists fixed to the deep joists, and crossing them at right angles. This is an improvement in a situation where there is not space for a double floor. The annexed figure shows a section of a



floor of this kind. It increases the depth of a floor very little, and will not allow sounds to pass so freely as a single joisted floor, and the ceilings will stand better. The ceiling joists A, are notched to the deep joists B, B, and nailed.

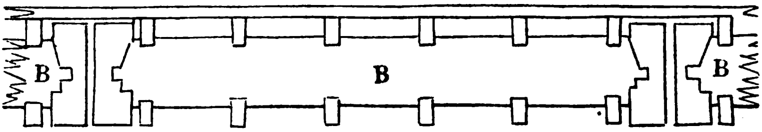
127. ii. Double floors. A double floor consists of three tiers of joists; that is, binding joists, bridging joists, and ceiling joists; the binding joists are the chief support of the floor, and the bridging joists are notched upon the upper side of them; the ceiling joists are either notched to the under side, or framed between them with chased mortises; the best method is to notch them. The figure below shows a section of a double floor, across the



binding joists B, B. The bridging joists D are notched over, and the ceiling joists A are notched under the binding joists.

128. iii. Framed floors differ from double floors only in having the binding joists framed into large pieces of timber called girders.

The next figure shows a section across the girders of a framed floor; where B, B, are the binding joists.



Single joisting makes a much stronger floor, with the same quantity of timber, than a double or framed floor, and may be constructed with equal ease to the same extent of bearing; but the ceilings are more subject to cracks and irregularities; consequently single joisted floors of long bearings can be used only in inferior buildings.

When it is desirable to have a perfect ceiling, a double floor is used; and when the bearing is long, a framed floor becomes the most convenient. The following experiment was made on the comparative strength of framed and single joisted floors by Professor Robison.

129. Two models were made 18 inches square, one consisted of single joists, the other framed with girders, binding joists, bridging and ceiling joists; the single joists of the one contained the same quantity of timber with the girders alone of the other. They were placed in a wooden trunk 18 inches square within, with a projection on the inside for the floors to rest on; and small shot was gradually poured over.

The single joisted floor broke down with 487 pounds, the framed floor with 327 pounds.* The difference would not be quite so much on a large scale, because the girders would not be so much weakened by mortises. This is not the only case where apparent strength has turned out to be real weakness; and shows how necessary it is to distinguish those parts which really support a load, from those which only appear to do so.

§1. *Of single joisted floors.*

130. In order to make a strong floor with a small quantity of timber, the joists should be thin and deep; but a certain degree of

* *Enc. Brit. Art. Roofs*, § 47.

thickness is necessary, for the purpose of nailing the boards, and two inches is perhaps as thin as the joists ought to be made; though sometimes they are made thinner.

To find the depth of a joist, the length of bearing and breadth being given, for a single joisted floor.

Rule. Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 2.2 for fir, or 2.3 for oak, will give the depth in inches.

Note. The constant number in this, and in all the rules for flooring and roofing, are derived from the scantlings of timbers that were found to be sufficiently strong; this I considered to be the best method of obtaining those numbers, because it is difficult to calculate the weight that a floor has to support; yet it is easy to ascertain whether a floor be sufficiently stiff or not, after it is executed. These comparisons have not been made from single observations, but from various ones on bearings of very different lengths. The constant numbers are taken higher for oak, because the oak is seldom straight grained, and very subject to warp.

Example.

Required the proper depth for a fir joist, the bearing being 12 feet and the breadth 2 inches?

$\frac{12 \times 12}{2} = 72$, and the cube root of 72 is 4.16;

therefore $4.16 \times 2.2 = 9.152$ inches, the depth required; or 9 inches is near enough in practice.

On account of flues, fire places, and other causes, it often happens that the joists cannot have a bearing on the wall. In such cases a piece of timber, called a *trimmer*, is framed between two of the nearest joists that have a bearing on the wall. Into this trimmer the ends of the joists to be supported are mortised. This operation is called *trimming*. The scantlings of trimmers may be found by the same rule as those for binding joists, Case 2, Art. 143; the length of the joists framed into the trimmer being equivalent to the distance apart in binding joists.

The two joists, which support the trimmer are called *trimming joists*, and they should be stronger than the common joists. In general it will be sufficient to add one eighth of an inch to the thickness of a trimming joist for each joist supported by the trimmer. Thus, if the thickness of the common joists be 2 inches, and a trimmer supports 4 joists, then add four eighths, or half an inch; that is, make the trimming joists each 2.5 inches in thickness.

When the bearing exceeds 8 feet, single joisting should be strutted between the joists to prevent them turning and twisting sideways, and also to stiffen the floor; when the bearing exceeds 12 feet two rows of struts will be necessary; and so on, adding another row of struts for each increase of 4 feet in bearing. These struts should be in a continued line across the floor, and short ends of boards put in moderately tight, and nearly of the depth of the joists, are quite sufficient; indeed such pieces simply nailed are better than keys mortised into the joists, because they require less labour, and do not weaken the joists with mortises. The well fitting of the struts is an essential part in making a good ceiling.

For common purposes single joisting may be used to any extent that timber can be got deep enough for; but where it is desirable to have a perfect ceiling, the bearing should not exceed 15 feet. Also, where it is desirable to prevent the passage of sound, a framed floor is necessary.

OF FRAMED FLOORS.

§2. *Of Girders.*

131. The girders are the chief support of a framed floor, and their depth is often limited by the size of the timber; therefore the method of finding the scantling may be divided into two cases.

Case 1. To find the depth of a girder when the length of bearing and breadth of the girder are given.

Rule. Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 4.2 for fir or by 4.34 for oak, will give the depth required in inches.

132. *Case* 2. To find the breadth when the length of bearing and depth are given.

Rule. Divide the square of the length in feet by the cube of the depth in inches; and the quotient multiplied by 74 for fir, or by 82 for oak, will give the breadth in inches.

Example to Case 1.

Let the bearing be 20 feet, and the depth 13 inches; to find the breadth, so that the girder shall be sufficiently stiff.

The cube of the breadth is 2197, and the square of the length is 400; therefore

$$\frac{400}{2197} \times 74 = 13.47 \text{ in. the breadth required.}$$

In these rules the girders are supposed to be 10 feet apart, and this distance should never be exceeded; and should the distance apart be less or more than 10 feet, the breadth of the girder should be made in proportion to the distance apart.

Girders should always, for long bearings, be made as deep as they can be got; an inch or two taken from the height of a room is of little consequence compared with a ceiling disfigured with cracks, besides the inconvenience of not being able to move in the rooms above, without shaking every thing in them.

133. When the breadth of a girder is considerable, it is often sawn down the middle and bolted together with the sawn side outwards; the girders in the section, fig. Art. 128, are supposed to be done in this manner. This is an excellent method, as it not only gives an opportunity of examining the centre of the tree, which in large trees is often in a state of decay, but also reduces the timber to a smaller scantling, by which means it dries sooner, and is less liable to rot. The slips put between the halves, or flitches, should be thick enough to allow the air to circulate freely between them. It is generally imagined that it strengthens a girder to cut it down, reverse it, and bolt it together again; it is in fact weakened by the operation, but the method is recommended here for the reasons above stated.

Others suppose that girders are cut down merely for the purpose of equalizing their stiffness; but admitting a girder to be bent considerably, the difference between the deflections at any two points equally distant from the middle would not be sensible in girders of the usual form. The person who first practised cutting girders down the middle, undoubtedly did it with the view of preserving, not of stiffening them. We find that Vitruvius, the oldest author on architecture extant, directs a space of two finger's breadth to be left between the beams for forming the architrave over columns, in order that the air may circulate between and prevent decay.* Every one must have observed that decay begins in the first place at the joints, and other parts where the pieces are neither perfectly close nor yet sufficiently open to allow any dampness to evaporate.

134. When the bearing exceeds about 22 feet it is very difficult to obtain timber large enough for girders; and it is usual in such cases to truss them. The methods in general adopted for that purpose have the appearance of much ingenuity; but, in reality, they are of very little use. If a girder be trussed with oak, all the strength that can possibly be gained by such a truss consists merely in the difference between the compressibility of oak and fir, which is very small indeed; and unless the truss be extremely well fitted at the abutments, it would be much stronger without trussing. All the apparent stiffness obtained by trussing a beam is procured by forcing the abutments, or, in other words, by cambering the beam. This forcing cripples and injures the natural elasticity of the timber; and the continual spring, from the motion of the floor, upon parts already crippled, it may easily be conceived, will soon so far destroy them, as to render the truss a useless burden upon the beam. This is a fact that has long been known to many of our best carpenters, and which has caused them to seek for a remedy in iron trusses; but this method is quite as bad as the former, unless there be an iron tie as an abutment to the truss, for the failure of a truss is occasioned by the enormous compression applied upon a small surface of timber at the abutments.

135. The above remarks are further confirmed by some experiments that have been made by Mr. Barlow, of the Royal Military Academy, at Woolwich, the results of which are shown in the following Table.

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* *Vitruvius, lib.* iv, *cap.* 7.

Table of experiments by Mr. Barlow.

Description.	Length of bearing.	Weight.	Deflection produced by the weight.
Two trusses meeting against a king bolt in the centre, with plate bolts at the abutments.	ft. in. 4 2	lbs. 600	0.87
Piece of the same size, without trusses.	4 2	600	1.00
Three trusses, with two queen bolts with plate bolts at the abutments.	5 8	500	2.25
Piece of the same size, without trusses.	5 8	500	1.55

The pieces were trussed in the manner described by Mr. Nicholson, in his Carpenter's Guide, Plate xxxix; the depth of the pieces 2 inches, and the breadth 1.875 inches. In the experiment with the girder having a king bolt and two truss pieces, there appears to be a slight advantage in trussing; but in the one in three lengths, trussing appears to have had no effect, it being much weaker than the untrussed piece.*

The methods of trussing proposed by Smith,† Price,‡ and Langley,§ are still worse; some in principle, others in the materials. The attempt to make a solid beam stronger in the same bulk, without using a stronger material than the beam itself is made of, is ridiculous; yet such has been the aim of most of these writers.

Though the usual mode of trussing girders cannot be relied upon, nor, indeed, any other timber truss that is made within the depth of the beam; yet, by adding to the depth, there are several methods that may be applied with success in extending the bearing of timber girders. But where the depth is limited, and the bearing considerable, iron must be employed, and the best mode of doing this would be to make the girders of cast iron, each in one piece, if the bearing should not be too long for a casting, and in two pieces if it should be too long. These cast iron girders are simple, and cheaper than any kind of iron framing of the same

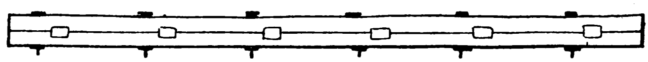
* *See Mr. Barlow's Essay on the strength and stress of timber, p.* 196.
† *Smith's Carpenter's Companion.*
‡ *British Carpenter, Plate B.*
§ *Langley's Builders' Complete Assistant, Plate* lii, *4th edit.*

strength; that is, when they are properly contrived, so as to make the most of the material.

But it often happens that large founderies are not near, and consequently iron girders would be very expensive; and at any rate it is not proper to omit showing how they may be done without, when there is the means of increasing the depth of the floor, which may generally be done without inconvenience.

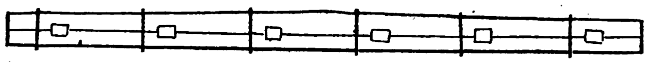
136. The principle of constructing girders of any depth is the same as that of building beams, and when properly conducted is as strong as any truss can be made of the same depth.

The most simple method consists in bolting two pieces together, with keys between to prevent the parts sliding upon each other. The joints should be at or near the middle of the depth. The annexed figure shows a beam put together in this manner. The



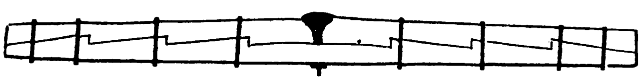
thickness of all the keys added together should be somewhat greater than one third more than the whole depth of the girder; and, if they be made of hard wood, the breadth should be about twice the thickness.

137. The following figure is another girder of the same con-



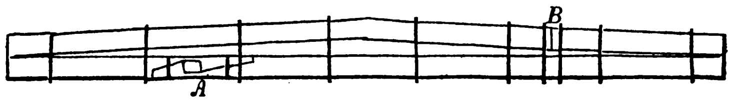
struction, except that it is held together with hoops instead of bolts. The girder being cut so as to be smaller towards the ends, would admit of these hoops being driven on till they would be perfectly tight, and would make a very firm and simple connection.

138. In the next figure the parts are tabled or indented togeth-



er instead of being keyed, and a king bolt is added to tighten the joints, the upper part of the girder being in two pieces. The depth of all the indents added together should not be less than two thirds of the whole depth of the girder.*

139. Another method of constructing a girder consists in bending a piece into a curve, and securing it from springing back by bolts or straps. A girder constructed in this manner is shown by the annexed figure. Mr. Smeaton has adopted a similar method



of strengthening the beam of a steam engine,† and the additional stiffness gained by bending beams in this manner is very considerable. The pieces should be well bolted, or strapped to prevent any sliding of the parts. In this manner a beam might be built of any depth that is necessary in the erection of buildings, and by breaking the joints, of any length that is likely to be needed in the construction of floors.

The thickness of the bent pieces may be about one fiftieth part of the bearing, and as many of them should be added as will increase the depth to that proposed, unless the whole depth of the curved pieces exceeds half the depth of the girder; and in that case straight pieces should be added to the under side, so as to make the whole depth of the straight parts exceed the depth of the curved parts. When pieces cannot be got sufficiently long for the girder, care should be taken to have no joints near the middle of the length in the lower half of the girder.

This last figure shows a girder for a 40 feet bearing, with the lower half scarfed at A, and a plain but joint in the curved part at B.

140. In the construction of floors it would be a great advantage to make each girder only half the breadth given by the rule, and to place them only 5 feet apart; to bridge the upper or floor joists over the girders, and notch the ceiling joists to the under side of them; and to omit the binding joists. There would be a great

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* *A girder similar to this is described by Mathurin Jousse, in his Art de la Charpenterie.*

† *Rees' Cyclopedia, Art. steam engine, plate* i. *Girders constructed in this manner have also been proposed by Rondelet, L'Art de Batir, tome* 4, *p.* 145.

increase of strength and stiffness by adopting this method; and in point of economy, it is decidedly preferable; only it requires a much greater depth of flooring.

141. As the strain is always the greatest at the middle of the length of a girder, it would be well to avoid making mortises there if possible, either for binding joists or any other purpose; and the most straight grained part of the beam should be put to the under side.

Also, timber girders should not be built into the wall, but an open space should be left round their ends, either by laying a flat stone over them, or by turning an arch to carry the wall above.

Girders should be laid from 9 to 12 inches into the wall, according to the bearing.

§3. *Binding joists.*

142. The depth of a binding joist is generally determined by the depth of the floor, but this is not always the case. Therefore the rules must be given for two cases.

Case 1. To find the depth of a binding joist, the length and breadth being given.

Rule. Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 3.42 for fir, or by 3.53 for oak, will give the depth in inches.

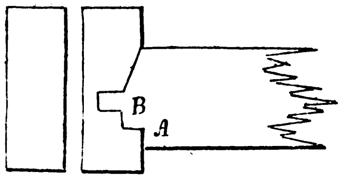
143. *Case* 2. To find the breadth when the depth and length are given.

Rule. Divide the square of the length in feet, by the cube of the depth in inches; and multiply the quotient by 40 for fir, or by 44 for oak, which will give the breadth in inches.

These rules suppose the distance apart to be 6 feet; if the distance be greater or less than 6 feet, the breadth given by the rule must be increased or diminished in proportion. The breadth of the binding joists next the wall may be two thirds of the breadth of the others; but in general they are made the same breadth, or such as are defective are selected for that purpose.

144. The binding joists may be from 4 to 6 feet apart, but should not exceed 6 feet; and about 6 inches bearing on the wall is sufficient.

The manner of framing binding joists into girders is shown by the annexed figure; and in fitting them great care should be taken



that both the bearing parts, A and B, should fit to the corresponding parts of the mortise. This is the most important part of fitting in a binding joist, yet is often the least attended to. The tenon should be about one sixth of the depth, and at one third of the depth from the lower side.

145. Binding joists that have only to carry a ceiling may have their scantlings found by the same rule as for ceiling joists (see Art. 147) except that the quotient must be multiplied by 1.2 instead of 0.64 for fir, and by 1.25 instead of 0.67 for oak joists.

§4. *Bridging joists.*

146. The rule for bridging joists is the same as that for single joisting (see Art. 130). They seldom need be more than 2 inches in thickness, except for ground floors, where they are laid upon sleepers; in which case the depth may be found to a breadth of 2 inches, and an inch may be added to the breadth, on account of the situation; as when proper care is not taken to drain and ventilate the under side of a ground floor, the joists are subject to very rapid decay. It is a good practice to strew smiths' ashes, or even common ashes, under such floors, to prevent the growth of fungi. The ashes and scoriæ from a foundery, or any ashes that contain much iron are the best. Mr. Batson found this an effectual

remedy for the dry rot. He filled a space below the floor of two feet in depth, with anchor smith's ashes, and also charred the sleepers.*

§5. *Ceiling joists.*

147. Ceiling joists require to be no thicker than is necessary to nail the laths to; two inches is quite sufficient for that purpose.

To find the depth of a ceiling joist, when the length of bearing and breadth are given.

Rule. Divide the length in feet by the cube root of the breadth in inches; and multiply the quotient by 0.64 for fir, or by 0.67 for oak, which will give the depth in inches required.

Example.

Let the bearing be 6 feet and the breadth 2 inches; to find the depth of a ceiling joist of fir.

The cube root of 2 is nearly 1.26; and the length, 6 feet, divided by this number, that is, $\frac{6}{1.26} = 4.76$; which being multiplied by the decimal 0.64, gives 3 inches, the depth required.

148. If two inches be fixed upon for the breadth, the rule for ceiling joists of fir becomes very easy; for then half the length in feet is the depth in inches: that is, if the length of bearing be 10 feet, the depth of the joist should be 5 inches. The distance apart in the clear is generally from 10 to 12 inches, according to the length of the laths.

It is better to notch ceiling joists to the under side of the binding joists, and nail them, than to mortise and chase them in; because it requires less labour, it does not weaken the binding joists, and the ceiling stands better. Oak is not so good a material for ceiling joists as fir, because it is more subject to warp; particularly if it be not well seasoned.

* *Transactions of the Society of Arts, vol.* xii. *p.* 265.

§6. *General observations respecting floors.*

149. Girders should never be laid over openings, such as doors or windows, if it be possible to avoid it; and when it is absolutely necessary to lay them so, the wall-plates or templets must be made strong, and laid low enough to throw the weight upon the piers. It is, however, a bad practice to lay girders very obliquely across the rooms ; and it is better to put a strong piece as a wall plate.

In the bearings of floors the caution of Vitruvius must be attended to; that is, when the ends of the joists are supported by external walls of considerable height, the middle part of the joist should never rest upon a partition wall that does not go higher than the floor ;* otherwise the unequal settlement of the walls will cause the floor to be unlevel, and most likely fracture the cornices.

150. Wall-plates and templets should be made stronger as the span beeomes longer; the following proportions may serve for general purposes :

For a 20 feet bearing,	wall plates	4.5 in.	by 3 in.
30	"	"	6	by 4
40	"	"	7.5	by 5.

151. Floors should always be kept about three fourths of an inch higher in the middle than at the sides of a room when first framed; and also the ceiling joists should be fixed about three fourths of an inch in 20 feet higher in the middle than at the sides of the room ; as all floors, however well constructed, will settle in some degree.

In laying the flooring, the boards should always be made to rise a little under the doorways, in order that the doors may shut close without dragging; and at the same time it assists in making them clear the carpet.

The following observations, from Evelyn's Sylva, are worthy of notice. "To prevent all possible accidents, when you lay floors, let the joints be shot, fitted, and tacked down only the first year, nailing them for good and all the next; and by this means they will lie staunch, close, and without shrinking in the least, as if they were

* *Vitruvius, lib. 7, cap.* I.

all of one piece: and upon this occasion I am to add an observation that may prove of no small use to builders, that if one take up deal boards that may have lain in the floor an hundred years, and shoot them again, they will certainly shrink (toties quoties) without the former method."*

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* *Evelyn's Sylva, Dr. Hunter's ed. vol. 2, p. 217.*

CARPENTRY.

PART II.

STATICS APPLIED TO CONSTRUCTIONS OF TIMBER.

CHAPTER I.

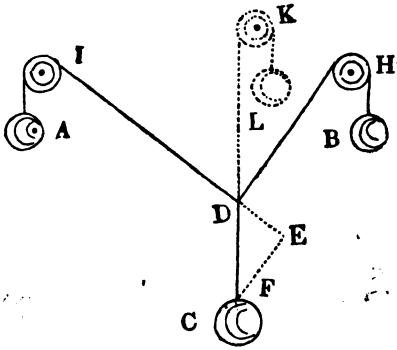
STATICS.

Statics is a part of the Science of Mechanics. It treats of the equilibrium of forces at rest. The student will perceive its relation to Carpentry, by reflecting upon the different forces, which act upon timbers in a roof or any other construction. They are acted upon by their own weight; they are pressed in one direction by their supports, and in others by timbers, which rest upon them or lean against them. The strength and the stiffness of timber, which have been investigated in the former part, are also forces, which are constantly brought into action. These different forces must be so opposed as to produce an equilibrium, or constructions cannot be permanent.

§1. *Of the composition and resolution of forces.*

152. *Experiment.* Take 2 pullies I and H, and having fixed them against the face of a vertical board or wall, let two weights be suspended over them by one string, as A and B; attach to this

Fig. 1.



string, at some point D between the two pullies, another string from which is suspended a third weight C. This weight C must not be equal to the sum of A and B. The point D will assume a certain position, and the weights being the same, this point will be found to assume the same position, as often as the experiment is attempted, but will change its position if either of the weights be changed.

Farther, let us suppose the weight C to be 8 ounces, the weight A 4, and B 6; then, if we measure on the line D C, 8 inches from D to F, and then draw F E parallel to D H, until it meets D E, (which is I D continued) F E will be 6 inches, and D E 4; that is, the three sides of the triangle will be respectively proportional to the three weights; and to determine, to which weight any side is proportional, we have only to consider which weight draws in the direction of that side. Thus, B we supposed 6 oz. and F E, parallel to H D, the direction in which B acts upon the point D, is found to be 6 inches.

The student should perform this experiment repeatedly, and with different weights, until it is perfectly familiar to his mind, and he is completely satisfied, that

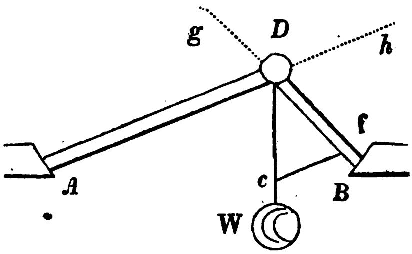
If three forces act upon one point and keep it at rest, then those three forces are proportional to the three sides of a triangle, to which sides also the directions, in which they act, are parallel.

153. In the foregoing experiment, C balances A and B, and it therefore appears, that, *if two forces proportional to, and in the direction of two sides of a triangle, act upon any point; they will be balanced by a third force, which is proportional to, and in the direction of the third side of the same triangle.*

Again; if a weight D, exactly equal to C, be suspended over a pulley, K, in such a manner as to act upon the point D in a vertical direction, D will be at rest, as when acted upon by A and B. It might therefore supply the place of A and B.

154. We may suppose, that the point D, instead of being supported by weights acting in the directions D h and D g, is sustained by the rods A D and B D, pressing against it. The same weight

Fig. 2.



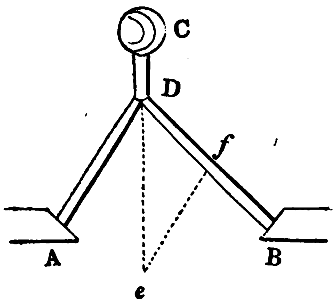
C being suspended from the point D, the rod B D will have to sustain a force equal to that, which was exerted in the former case in the direction D g; and A D a force equal to that, which was exerted in the direction D h. If the rods A D and B D are able to sustain the forces thus assigned them, the weight C will be sustained, otherwise not.

Let D c represent the weight D; then draw c f parallel to A D, c f represents the force sustained by A D, and D f that sustained by B D.

155. We may farther suppose the weight C to act upon the point D by pressure, as in fig. 3, instead of being suspended, as in the former cases. But it is evident, that if C D is perpendicular to the horizon, tbe weight C acting upon the point D in the same direction, and with the same force, as if suspended as in the last case, must require the same force to be exerted by A D and B D

to sustain it. If therefore we wish to know what force each of the supports, A D and B D, will have to sustain, in consequence

Fig. 3.



of the pressure of the weight C, we have only to draw the vertical line D e, of a convenient length to represent the weight C, and then from the point e to draw e f parallel to A D; and as in the former case, e f will represent the force, which must be exerted by A D; and D f that which must be exerted by D B.

156. From these two last examples, we may infer, that *if any force act upon a point, it may be balanced by any two other forces acting upon the same point, provided the three forces are proportional to the three sides of any triangle, and act in directions parallel to those sides.*

157. It appears then, that *we can find one force, which will balance any two given forces.* (153)

Or, *we can find two forces, which will balance any one given force.* (156)

The former is called *the composition of forces*, and the latter *the resolution.*

This one force, which, by the composition, is found equal to the two others, is called their *resultant.*

We are not limited to two forces. We can, as will be shown farther on, find a resultant to any number of forces: or we can resolve one force into any number of forces.

Examples.

i. Let the weight C be 1000 lbs., the beam A D (fig. 3) 6 feet, A B 8 feet, and resting upon supports at A and B, which are upon a level with each other, and 9 feet apart; what pressure does each beam sustain?

To solve this question, let the student take any scale of equal parts, and make a line A B equal to 9 parts. Then let him open his compasses 6 parts, and with one foot in A, describe a curve with the other foot near where he supposes D will come. Then with the compasses open 8 parts, and one foot in B describe a curve cutting the former one. The point, in which these curves cut each other, will be D. He may then proceed as in Art. 155 to draw a vertical line D e, &c. Answer, upon A D 772 lbs.
upon B D 499.

ii. Other circumstances being the same, let the weight be 6500 lbs.; required the force sustained by each beam.

iii. Let the beams be 13 and 15 feet in length, and distance asunder at A and B 20; weight 1000.

iv. Let the circumstances in Ex. iii be the same, except that the support A be supposed 3 feet above the level of B.

v. Let the two beams A D and B D be of equal length, each 20 feet, the weight 1000, the two supports A and B on a level, and distant from each other 15 feet. Required the pressure upon each.

vi. Circumstances the same, save the distance A to B 30 feet.

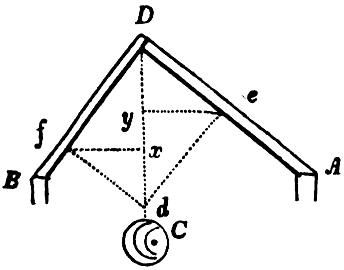
158. By comparing the results of the last two examples, it will be apparent how much the strain upon the beams is increased by increasing the angle of their opening. This is a point of importance, and should be well impressed upon the mind of the student.

§2. *Of the horizontal thrust of rafters, loaded with a heavy weight at the ridge.*

159. In the last section we have shewn the method of ascertaining the pressure produced upon the rafters of a roof by a weight upon the ridge. These rafters, acting obliquely upon the walls of a building, must have a tendency to push them outward. This tendency is easily estimated by the principles we have established.

Let C be a weight suspended from the ridge of a roof; we obtain as in section first the force D e, which it exerts upon D A, and

Fig. 4.



the force d e, which it exerts upon D B. We may draw d f parallel to D e, and then D f will be equal to d e, and may be taken instead of it.

If we resolve D e into two forces, D y vertical, and therefore producing no horizontal pressure, and y e, horizontal; D y will represent the *vertical pressure* occasioned by the weight upon A, and y e the *horizontal thrust* occasioned by the same weight. In the same manner, D x will represent the vertical pressure, and f x the horizontal thrust, upon the point B.

If the question is, how great is the strain produced upon the tie beam which connects A and B, then the solution is the same, if the tie beam is horizontal. If not, the lines f x and y e must be drawn parallel to it; for the sides of the triangle, by which we seek to estimate a strain, must be in the same direction as the strain. The lines f x and y e are equal, and either will represent the whole strain upon the tie.

Examples.

i. The points A and B being on a level, their distance apart 20 feet, length of each beam A D and B D 15 feet, and the weight C 1000 lbs.; required the horizontal thrust and vertical pressure on each wall.
447 horizontal.
500 vertical.

ii. Other things the same, distance A B 25 feet?

iii. A B 30, A D 20, B D 18, and weight 500 lbs.; required the same.

iv. Required the strain upon a tie beam 25 feet long, and inclined at an angle of 5 degrees with the horizon; the rafters being 16 feet each, and weight 1000 lbs.

To give the tie beam the inclination required, draw any line for a horizontal line. Open the compasses to 60 degrees on the line of chords (marked C. or Cho.) and with one foot in the horizontal line, describe a curve crossing the horizontal line. On this curve, set off 5 degrees from the horizontal line, upwards, and through the point thus obtained and the point used as a centre, draw a line, which will represent the tie beam, inclined as required.

v. Inclination of the beam 8 degrees, other things the same; required the same.

160. If we suppose the beams A D and B D, in the last figure, to be two bars united by a joint at D, above which they could move, they would constitute a mechanical power, which has been used in many machines with great effect. The power, or moving force is applied at D; one end, as A, rests against some firm support, and the thrust of B, when the two bars come nearly in a straight line, is very great.

Example.

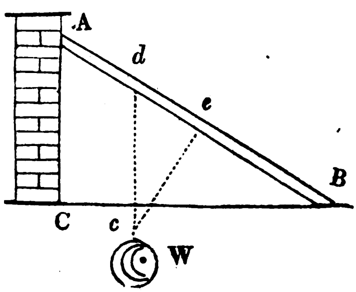
Let the two bars be 10 feet in length, each; the angle at D 175 degrees; the power at D 100 lbs.; A being stationary, what is the thrust of B?

Printing presses, brick presses, &c. have been constructed upon this principle.

§3. *Of the transverse strain upon inclined beams, and the* INCLINED PLANE.

161. If a beam, as A B, rest against a wall, and a weight W be suspended from the centre or any other part of it, it will be easy

Fig. 5.



to ascertain, by means of the principles investigated in the preceding sections, how much force it exerts in producing a directly transverse strain.

If we set off d c to represent the weight W, and from c draw c e perpendicular to A B, we form a triangle d c e. And two forces acting upon the point d in the direction of d é and c e, and proportional to these two sides, will (156) exactly balance, or be equivalent to the weight W. But of these two forces, d e acts in the direction of the beam, and therefore can have no effect in producing a transverse strain. The force c e, acting perpendicularly, exerts its whole power in producing this strain, and therefore is the measure of the transverse strain produced by W.

Examples.

i. Let the angle A B C be 35 degrees, and the weight 1000 lbs.; required the transverse strain. 820.

ii. Let the angle A B C be 25 degrees, and the weight 1000 lbs.

iii. Let the angle A B C be 65 degrees, and the weight 1000 lbs.

A comparison of these examples will show how much the load may be increased upon a beam, if we increase its inclination to the horizon.

iv. Suppose the angle of elevation, A B C, 40 degrees, the length of the beam 20 feet, and 4 inches square; the beam being of ash, and the weight 600 lbs. applied at the centre; what will be the deflection?

Note. First calculate the force, which acts transversely, as in the preceding examples, and then the deflection as in Part I, p. 40.

v. What weight would be required to break the above beam?

Note. First calculate the weight, which would be required to break it when horizontal; then draw e c perpendicular to A B to represent this weight, then from c draw c d vertically till it meets the beam; c d will be the answer.

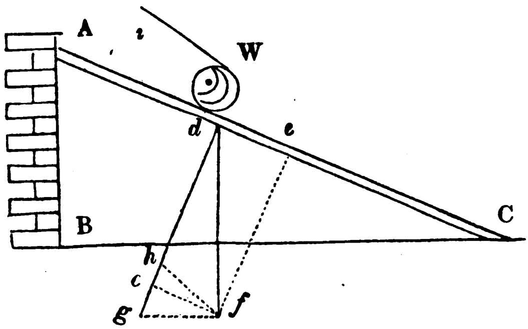
vi. Repeat the two preceding questions, supposing the beam to be oak.

vii. Repeat them, supposing the beam to be pine, and 5 inches square.

An inclined rafter is strained not only transversely, but is compressed in the direction of its length. The necessity of considering this, in finding its scantling, will be apparent from what has been said, Art. 115.

162. The question of transverse strain is solved in the same manner, if we suppose the weight W to rest upon the beam, as in the annexed cut, instead of being suspended as in the last.

Fig. 6.



The line f e still measures the transverse strain.

But another question here occurs. The weight W has a tendency to roll down the inclined beam A C; how shall we measure this tendency, or in other words, how shall we ascertain the force, with which it would move down the plane, and consequently the force necessary to keep it at rest.

We observed (161) that if d f, representing the weight of W, be resolved into the two forces f e perpendicular to the beam and d e in the direction of it, d e will represent the force exerted by W in the direction of the beam. d e therefore will represent the force with which a spherical weight W will move down the plane.

Examples.

i. Let the angle of elevation be 20 degrees; what force will be necessary to sustain a spherical weight of 100 lbs.? 34.2.

ii. Angle 25 and ball 250?

iii. A plank 20 feet long is elevated at one end 2 feet; what force will sustain a barrel of flour upon it, supposing the barrel and flour to weigh 220 lbs.?

iv. What, if the plank be 10 feet long, and elevated 2 feet at one end?

163. A plank or beam, &c. employed as supposed in the last examples is called, in mechanics, an *inclined plane.*

It appears then that on an inclined plane, the power and weight will balance each other, when the former is to the latter as d e : d f. But d e : d f as A B : A C. Therefore the power and weight balance each other, or are in equilibrium when *the power* : *the weight* : : *the height of the plane* : *its length.*

The most obvious use of the inclined plane is for raising heavy weights, as is suggested in the above questions. In those questions we have supposed the force with which the weight would tend to roll down the plane, to be the exact measure of the power necessary to preserve it at rest. But this can only be when the power acts in the direction of the plane, or parallel to it. There is no difficulty, however, in ascertaining the power necessary to preserve the equilibrium, in whatever direction it may act. Let this direction be supposed to be i W; we have only to draw f h parallel to i W till it meets d g (which is perpendicular to the plane) in h; f h will represent the power required.

It is evident that we might have represented the force with which the body W tends to move down the plane by f c, drawn parallel to the plane, till it meets d g, which is perpendicular to it.

Suppose the power acts in a direction parallel to the base of the plane C B. We have only to draw f g parallel to the base, till it meets d g, and then d f is resolved into two forces, d g perpendicular to the plane, and f g parallel to the base, which (f g) therefore represents the force necessary to preserve the equilibrium, when it is parallel to the base of the plane, or horizontal. In this case the power : weight as g f : d f, or, which is the same thing, as A B : C B, or as the height of the plane : the base.

Examples.

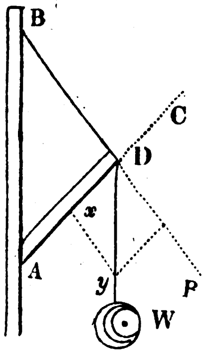
i. Solve each of the four preceding questions, supposing the power to act in such a direction, that i W makes an angle of 10 degrees with the plane.

ii. Solve them upon the supposition, that the force is in each case horizontal.

§4. *Of the strain upon ties and struts.*

164. Instead of substituting for both the ropes I D and H D of Fig. 1, the beams B D and A D of Fig. 2, we may substitute a beam in place of one, and permit the other to remain, as in Fig. 7. In this figure the point D is supported precisely as if a rope in the

Fig.7.



direction D C were substituted for the beam A D; or as if the rope B D were replaced by a second beam p D. The method of obtaining the amount of strain exerted by the weight W upon the rope B D and the beam A D, is therefore precisely the same as that employed in Art. 164. Set off D y, of a suitable length to express the quantity of the weight, and draw from y the line x y, parallel to B D. D x will represent the strain upon the beam, A D and x y the strain upon the rope B D.

165. We might place a beam or joist in the situation of the rope B D, and it would be subjected to the same sort of strain, i. e. it would be drawn by W in the direction of its length, and the amount of this strain must be calculated as above.

Examples.

i. What stress will be produced by a weight of 5000 lbs. upon A D and B D; A D being 12 feet long, and B D 15, and distance A B 17?

ii. A D being 5 feet, B D 4, and A B 3?

iii. A D and B D being each 10 feet, and A B 12?

iv. A D and B D being each 10 feet, and A B 6?

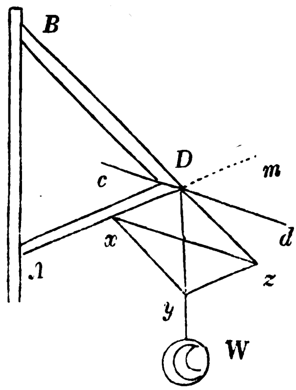
v. A D and B D being each 10 feet, and A B 18?

vi. A B and B D being each 5 feet, and making a right angle?

166. Although B D might be replaced by a beam, A D could not by a rope, because it acts by its *stiffness*. A beam in the situation of B D, in which it acts by its direct cohesion, and in which a rope might be used, is called in general a *tie*; while a beam situated like A D, and acting by its stiffness to resist pressure in the direction of its length, is called a *strut*.

A *tie* may be distinguished from a *strut*, by a little reflection upon the manner in which it acts. It may not, however, be useless to give a simple method of distinguishing between them, which we take from Mr. Tredgold's *Elementary Principles*.

Fig. 8.



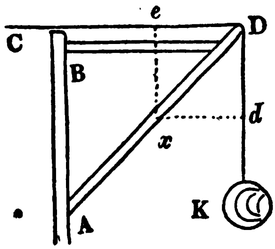
Form the triangle D x y as before. Draw D z parallel to x y, and z y parallel to D x. Draw z x, and then draw c d through the point D parallel to it. Whatever part of a framing acts upon the point D and is below c d, is a *strut*; if above it, it is a *tie*. The reason is evident. If we wish to substitute a *strut* in place of B D, we should make it act in the direction z D: and again, if we would substitute a *tie* for A D, we should arrange it in the direction of m D. (164)

§5. *Of the strain upon the jibs of cranes.*

167. In the jibs of cranes there is some peculiarity of action, which we shall here consider. The weight W is not simply sus-

pended from the point D, but is drawn over it by the rope D C. The rope D C acts therefore as a tie, and the jib A D may be so

Fig. 9.

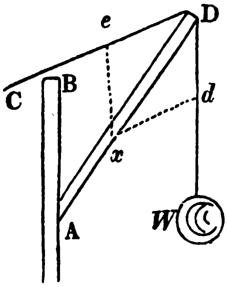


placed as to need no brace B D, except to keep it stiff. In this case its position must be that of the resultant of the two forces, viz. the weight K, and that which acts at C to raise the weight. These two forces are equal. Let them be represented by D d, and x d which is equal to D d, and parallel to D C. If C D is perpendicular to B A or D K, then the angle d is a right angle, and the resultant D x makes an angle of 45 degrees with the vertical part B A.

The forces acting in the supposed directions, it is manifest that the above is the proper position for the jib of a crane. For these forces tend to produce upon it no strain but one of compression in the direction of its length. There is no strain upon the piece B D. The quantity of pressure upon A D is measured by D x.

168. If the directions, in which the forces act, make any other angle with each other, as C D W in the next figure, the position of A D and the strain upon it may be found in the same way, and the comparative advantage of different positions may be easily es-

Fig. 10.

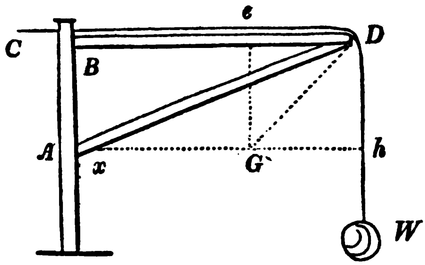


timated. C D being the direction, in which a power applied at C, acts, and D W that in which the weight acts; let D d represent the weight, and d x, equal to it and parallel to D C, the power. D x is the resultant, and gives the proper direction for A D. In this position, the compression of the jib, measured by D x, is greater than in the preceding case.

In the two last figures, suppose e x to be parallel to D d. The figure D e x d will be a square or rhombus, and D x will divide the angles D and x into equal parts. The angle B A D is equal to one of these parts. Hence in all cases the angle which the jib makes with the vertical, A B, should be half that, which is made by the direction of the forces, in order to avoid unnecessary strains.

169. We will now suppose the power and weight to act at right angles as in Art. 167, but the jib not placed in the resultant.

Fig. 11.



We take as before D e and D h, equal and representing the forces. Their resultant is D G. The strain therefore, which is produced by these two forces, is the same as would be produced by the single force D G.

If now we wish to find this strain, we draw G x parallel to D C till it meets D A (as in Art. 164) D x represents the strain upon D A, and G x that upon B D.

From this position there results not only a very great strain upon A D, but there is also a strain upon B D, so great, that if the weight W be large, B D, which acts as a tie, could not be made secure without the use of iron.

In the same manner let the student draw a figure in which B A D shall be less than half a right angle.

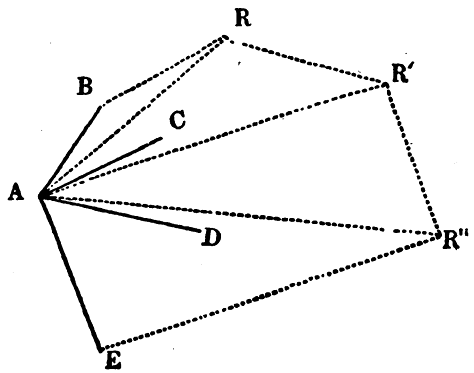
§6. *Of the resolution and composition of more than two forces.*

170. In Art. 169, in order to find the strain upon A D and B D, we first resolved the two forces D e and D h into a single force D G. and then inquired, as in the preceding section, into the action of this force.

On this same principle we may always proceed to find the resultant of any number of forces. We may first find the resultant of any two of them; then the resultant of that resultant and another of the forces, and so on to the last; and the last resultant thus obtained will be the resultant of the whole system.

171. Let us take an example to illustrate this remark.

Fig. 12.



The forces B A, C A, D A, and E A, are supposed to act upon the point A, Fig. 12. What will be the direction and quantity of the single force equivalent to them?

Draw B R parallel to A C and equal to it, and join A R. A R is the resultant of these two forces, and we may suppose that the forces A B and A C vanish, and A R takes their place. Then from R draw R R' parallel and equal to A D, and join A R'; A R' is the resultant of A R and A D, *i. e.* of A B, A C, and A D, (A R being equivalent to A B and A C) therefore all three of the forces, A B, A C, and A D, may be supposed to vanish, and their place to be supplied by A R'. which will produce precisely the same effect. We proceed now to find the resultant of A R' and the remaining force A E, by drawing R' R'' parallel and equal to

A E, and drawing A R''. A R'' is the resultant, and since A R' is equivalent to the three forces A B, A C, and A D, and A R'' is the resultant of A R' and A E; A R'' is the resultant of all the forces A B, A C, A D, and A E.

172. It will be seen by examination of figure 12, that if we had simply drawn B R parallel and equal to A C, and from its extremity R, had drawn R R' parallel and equal to A D, and from R, R' R'' equal and parallel to A E; the line A R'', from this last point to the point on which the forces act, would have given us the resultant.

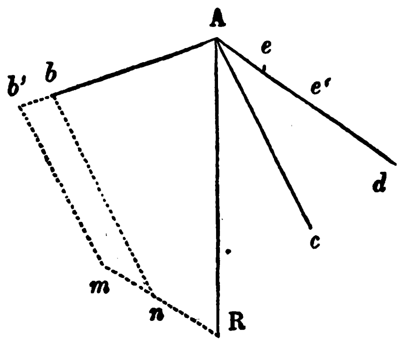
This is a general result, and is applicable to all cases. Let the student apply it to examples till it is familiar.

173. It may sometimes be convenient to be able to separate one force into two or more, which shall act in given directions.

A weight e. g. is to be supported in a certain position, and a perpendicular support is impracticable. Let C, Fig. 3, be such a weight. A D and B D may be the supports required. The student will easily ascertain the quantity of the two forces, or the amount of pressure each will have to sustain, by the method in Art. 155.

174. Neither will it be difficult to resolve one force into three or four others, and to estimate the magnitude of each. Let A R represent the force to be resolved into three others, which shall be in the direction of A b, A c, and A d. From R draw R m parallel

Fig. 13.



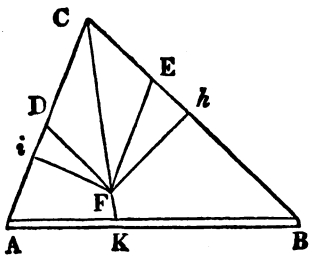
to A d,; from n or m draw n b or m b' parallel to c A, meeting A b, extended if necessary. If the forces A b, A c, and A d are proportional to A b, b n, n R, or to A b', b' m, m R, A R will be their resultant, according to what has been said, Art. 172, and therefore this resultant has been properly resolved into three forces, having the directions of A b, A c, and A d, and in either of the proportions above named.

175. It will appear from this, that if the directions of any number of forces into which a single force is to be resolved, be given, the quantities of these forces admit of unlimited variety. Hence, as the directions too may vary, and the number also; there is no limit to the number, the directions, or the quantity, of the forces, into which any single force may be resolved.

§7. *Centre of gravity.*

176. We may suppose the beam A B (Fig. 14) to be acted upon by two forces, at the points A and B, and the directions of

Fig. 14.



these forces be represented by the lines A C and B C, and their quantities by C D and C E. We wish to find the *resultant* of these two forces, its *magnitude*, *direction*, and *point of application*.

From D draw D F equal and parallel to C E, and draw C F. C F is the resultant, and gives at once the magnitude, direction, and point of application, K, where it crosses the beam; so that if a single force, equal to and in the direction of F C, should act upon the beam at the point K, it would have precisely the same effect as the simultaneous action of the two forces C D and C E; and if it should act on the other side of the beam, at the point K, it would precisely balance the two forces C D and C E.

177. If we examine the figure farther, we shall find a method of determining the point of application, K, without constructing the figure in each case.

Draw F h and F i perpendicular to C B and C A, the directions of the forces C E and C D; it can be demonstrated, that these lines *are to each other inversely as the forces, to the directions of which they are perpendicular; i. e.*

F i : F h : : C E : C D;*

and if C E is 9 and C D 8, then

F i : F h : : 9 : 8.

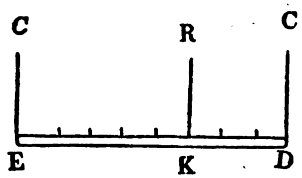
This property does not belong to the point F only, but to any point in the resultant. If then perpendiculars be drawn from K to the lines A C and C B, these perpendiculars will be in the same proportion of 9 : 8.

The student, who is unacquainted with geometry, will satisfy himself of the truth of this by constructing figures, with the magnitude and direction of the forces varying in each case, and then measuring the perpendiculars drawn from K to the direction of the forces.

In some of these constructions let the forces be made nearly parallel, and they will prepare the student for the next article.

178. Let us suppose that the two forces C E and C D are parallel to each other (Fig. 15). It is required, as before, to find

Fig. 15.



their *resultant*. The lines C E and C D, being parallel, cannot meet, and the resultant cannot be obtained by the construction of a

* The following demonstration is added for the satisfaction of the student, who has made some attainments in Mathematics.

The angles i D F and F E h are equal, being supplements of the equal angles C D F and C E F; the angles at i and h are equal, because they are both right angles: therefore, the triangles D i F and E h F are similar, and D F : F E : : i F : F h.

But D F and F E are equal to C E and C D, and therefore

F i : F h : : C E : C D.

triangle, as in the preceding case. We may however suppose the triangle of the preceding case to have its vertex C removed from the beam till the sides *C* E and C D become almost parallel; the principle of finding the resultant is the same. And it is the same too if the lines become exactly parallel and no triangle can be formed, for the existence and place of the resultant does not depend upon the possibility of constructing the triangle, although by the help of the triangle, when it may be constructed, the resultant is found. This premised, we may infer, that the resultant, as it is between the sides of the triangle, in all its forms, so it will be between these sides when they become parallel, and the triangle vanishes. It must therefore be *parallel* to the two sides *C* E and C D; otherwise it would somewhere cross one of them.

To find its *point of application*, K, we refer to the principle in Art. 177, viz. *the perpendicular distances of the point of application to the direction of the forces are inversely as the magnitudes of the forces;—i. e.* supposing in this case, that C E and C D are perpendicular to E D.

K E : K D : : force C D : force *C* E;

and to find K, say

E D : K D : : sum of the forces *C* E and C D : force *C* E.

Suppose the force acting at E to be 3, and that at D to be 5, we shall have

(5 + 3) or 8 : 3 : : E D : K D.

We have now to ascertain the *magnitude* of the resultant. To do this, let us examine Fig, 16.

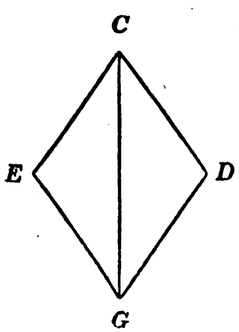
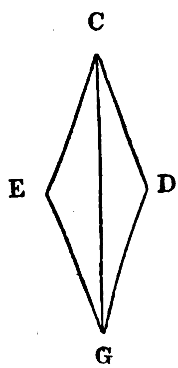


Fig. 16.

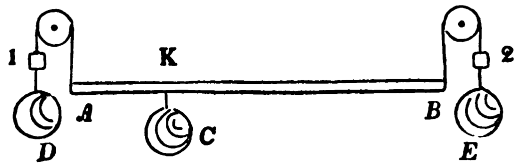


The nearer the directions of the forces C D and C E approach to parallelism, the longer is the resultant C G, and it is easy to see that if these directions exactly coincided, C E and E G would be in a straight line, and C G would be exactly *their sum.* When forces are parallel the case is the same, and *the resultant is equal in magnitude to the sum of the forces.*

Thus it appears, that *the resultant of two parallel forces, divides the perpendicular distance between their directions into parts inversely proportional to those forces; is parallel to their direction; and equal to their sum.*

179. This result is easily proved to be correct by the following experiment. Take a rod A B, and support it at the ends by strings passing over pullies, and let small weights, as 1 and 2

Fig. 17.



be hooked to the strings to balance the weight of the rod, then add weights at pleasure to represent the forces acting at A and B. If D of 9 pounds be added to one side, and E of 3 at the other, then by the above reasoning, C of 12 pounds ought to be hung upon the rod, and its place K to be thus found.

12 : 3 : : A B : A K.

Now if the weight be appended at the place K, found in this manner, the whole wi.l be in equilibrium, proving that the above reasoning is correct.

180. We might indeed have commenced this chapter with this experiment, but we have preferred to give it in this manner, as a confirmation of the principle of the composition and resolution of forces, and that we might shew the extent of its application.

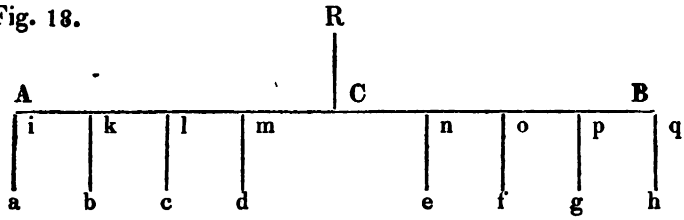
181. In the same manner as we have found the resultant of two parallel forces, we may find the resultant of more: first finding the resultant of two, and then of that resultant and another.

182. All bodies are attracted by gravitation towards the earth, in a direction perpendicular to the surface.

The gravitation of bodies is made up of the gravitation of all their particles. And gravity acts upon the particles in the manner of parallel forces, drawing them to the earth.

183. Let us represent the force of gravity acting upon the several points in the line A B, by the lines a i, b k, c l, d m, e n, f o,

Fig. 18.



g p, and h q; we may find the resultant by Art. 181; or thus— the forces at i and q being equal, their resultant will divide A B into equal parts at C: k and p being equally distant from i and q, and of course from C, will likewise have their resultant at C; and so of the rest. This resultant R C, applied at C, will support the beam A B. This point C is called the *centre of gravity*, because the forces a, i, &c. representing the weights of the different particles, their sum must represent the whole weight of the beam, and C being *the point about which these forces balance each other*, is therefore the *centre of these forces*, *i. e. of gravity*.

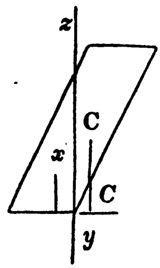
184. *The centre of gravity then is that point, about which all the parts of a body balance each other.* It is of course the same, whatever may be the position of the body, because it depends upon the relative situation of the parts of the body with respect to each other, and not upon the position of the whole mass. If then an axis pass directly through the *centre of gravity* of a beam, or any other body, it will be at rest, whatever its position. This cannot be said of any other point, for there can be but one point about which the parts of a body will all balance.

185. If an axis pass through a beam, directly above or directly under the *centre of gravity*, the beam will be at rest in a horizontal position, but in no other. For if a vertical line be drawn through the axis, and the *centre of gravity* be in this line, the quantity of matter on each side will be equal; but if the *centre of gravity* be

on one side of this vertical line, the quantity of matter on that side must be greater, and it will preponderate.

186. In the same manner, if a vertical line drawn through the centre of gravity, called the *line of direction*, fall without the base of any body, that body must tip over or fall. In the annexed figure C is the centre of gravity, and C C the line of direction. If z y be drawn, it will be seen that the greater part is unsupported.

Fig. 19.



187. If the height of the body were reduced so as to bring its centre of gravity to x, its line of direction would fall within the base, and the greater part of the weight being within the vertical z y, the body will stand.

The same effect will be produced, if the centre of gravity be brought lower by increasing the weight of the lower end of the body, without diminishing its height.

188. On this principle a carriage is not so liable to upset, if the load be low, as when it is high. And where it is necessarily high, the centre of gravity may be kept low by loading the axle.

If a carriage is tipping, the passengers should not rise, for by that means the centre of gravity is raised, and it will fall, even when it would have kept its position, had they remained on their seats.

189. From these remarks on the centre of gravity, it will appear not to be difficult to ascertain practically the centre of gravity in many bodies. For example; To find the centre of gravity of a piece of board, place it across the edge of a triangular prism, and make it balance. The centre of gravity will be somewhere over the line which rests upon the prism. Place it in another direction across the prism, and another line is obtained. The intersection of these two lines will give the centre of gravity.

Instead of the triangular prism, the board may be laid over the edge of a bench, so that the part on the bench shall just balance the part which projects over. Draw a line along the edge of the bench. Place it in another direction and do the same. The intersection of the two lines will give the centre as before.

190. Another method is by suspending the board by a peg driven into any part of its surface; from this hang a plumb line, and it will cross the centre (185). Suspend the board in the same manner from a peg in another part, and by a plumb line another line crossing the centre will be obtained, and the intersection will give the centre of gravity.

In each of the above cases the intersecting lines should cross each other nearly at right angles.

191. It will be useful to the student to be informed of the position of the centres of gravity in bodies of different forms, although we cannot here give the proofs, since they require more mathematical knowledge than all our readers are supposed to possess.

i. The centre of gravity of a uniform cylinder or prism is in the middle of its length.

ii. The centre of gravity of a triangle is in a line drawn from the vertex or top of the triangle to the middle of the base or opposite side, and it is situated at the distance of one third of the length from the base.

iii. In cones or pyramids it is at the distance of one fourth of the height from the base.

§8. *Of the Lever, and the Wheel and Axle.*

192. We have seen, that if two forces act upon the ends of an inflexible rod, (Figs. 14 and 17) a third may be found, which, acting upon the other side, will exactly balance them. Here there are three forces in equilibrium.

We may suppose, that, instead of the weight hung on at K, (Fig. 17) a pin passes through at that point. The weights or forces D and E will balance each other about that point, and the strain which they produce upon the pin, will be just equal to C.

The weights D and E, instead of passing over pullies might hang directly from the ends of the rod A and B, without disturbing the equilibrium. The resultant would then act upward.

A rod or bar in this situation is called a *lever*. K is the *prop* or *fulcrum*. The load at one extremity is termed the *weight*, and the force at the other the *power*.

Let the load at A be the weight, and E, applied at B, the power. We have seen, (180) that

E : D : : A K : B K;

i. e. When the weight and power are in equilibrium, they are to each other inversely as their distances from the fulcrum.

Note. When the power and weight do not act perpendicularly upon the lever, we must suppose lines to be drawn from the fulcrum, perpendicularly to the directions, in which they act, and these lines will give their true distances (177).

Examples.

i. With a lever 20 feet long, and the prop 4 feet from the weight, how much can a man lift, who can press upon the other end with a force of 150 lbs.?

4 : 16 : : 150 : 600, the answer.

ii. If a lever be 10 feet long, and the prop 3 feet from the weight, what power on the longer end will balance a weight of 1250 lbs.?

iii. A joist 14 feet long rests upon supports at its extremities: if a weight of 1000 lbs. be laid upon it at 4 feet from one end, what part of this weight will press upon each support?

193. There is no difficulty in conceiving the prop A to be the fulcrum, W the weight, and E the power (180). In this case

E : W : : A K : A B,

and therefore the ratio between the power and weight is the same as when the fulcrum is between them. This is called a lever of the second kind. A crow thrust under a stone for the purpose of raising it is of this kind.

Example.

A bar 11.5 feet long rests at one end upon a support. A man at the other end lifts with a force equal to 160 lbs. How large a weight can he raise, placed 2 feet 4 inches from the support?

194. With the two kinds of lever, which have been mentioned a small power is able to lift a great weight. But the motion of the weight is less than that of the power in the same ratio.

If however the power be applied between the prop and weight, a quick motion will be produced by a slow one, but the power will be larger than the weight.

The ratio between the power and weight will be the same as in the last case; indeed the cases will pass into each other with the simple exchange of names, *power* and *weight*. The raising of a ladder, one foot being fixed against a support, is an instance of this kind.

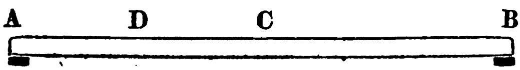
195. In theory the lever is considered as an *inflexible rod, without weight*. In fact it can be neither. But the weight of the lever is usually so small in relation to the weight and power applied to it, that in an essay like this, which does not profess to treat of mechanics, but in the most simple manner, and subservient to carpentry, it would not be proper to enter farther into the discussion.

196. The steelyard and the balance are among the useful applications of the lever.

It may be well to say a word upon the *false balance*. The false balance has its arms slightly unequal, and the scales which are attached to it, are also slightly unequal in weight, so that when they are empty they balance. Let one arm be supposed 10 inches long, the other 9. A weight of 10 lbs. in the scale affixed to the latter, would balance but 9 lbs. in the other. In this manner the false balance may be used for purposes of dishonesty. Nothing is more easy however than the detection. Place the 9 lbs. in the latter, and the 10 lbs. in the former of the above mentioned scales, and they will not balance if the scale beam be false.

197. When a beam is supported at both ends, the strain arising from the action of a weight laid upon it, is greatest when the weight is at the middle of the length. For the strain caused by a weight at C is to the strain caused by the same weight at D, as $AC \times CB$ is to $AD \times DB$, *i. e.* as the product of the two parts into which

Fig. 20.



C divides the beam, is to the product of the two parts into which D divides it. And the product of the two parts is the greater the nearer they are to equality, and greatest of all when they are exactly equal.

Since then the strain arising from a load is directly proportional to the product of the two parts into which it divides the beam; the ability of a beam to bear a given load at different points is inversely as this product.

Examples.

i. The beam A B being 20 feet long, and the load which it is able to snpport in the middle being 500 lbs; how much will it support at 3 feet from one end?

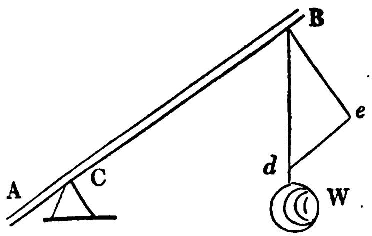
$$3 \times 17 : 10 \times 10 : : 500 : 980.39.$$

ii. How much will it support at 5 feet from one end?

iii. How much at 7 feet?

198. It will be apparent upon the slightest reflection, that the direction in which the power is applied is a matter of importance.

Fig. 21.



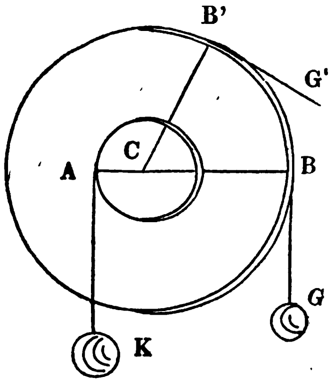
Let the weight W be suspended from one arm B of a lever, and let it be represented by B d. Resolve B d into B e, perpendicular to B C, and d e parallel to it; d e can do nothing toward bringing down that arm of the lever; in fact its tendency is to slide the lever along the support in the direction from B to A. B e is the whole effective part of the weight.

From this it appears, that in order to prevent loss of power in the lever, the power should be made to act at right angles with the lever.

199. With the common lever this would be difficult, for every change of place of the lever would require the place of the power to be moved, as in the last figure; for if B were brought down and e remained fixed, the line e B would cease to be perpendicular.

If however we should apply the power at the circumference of a large wheel, (Fig. 22) and the weight at the circumference of the axle, we should obviate this difficulty.

Fig. 22.



The wheel and axle act on the same principle as the lever, for the power G being applied at B has the same effect, as if it were attached to the arm C B of a lever A B, and the weight K applied at A may be considered as applied at the shorter arm A C of the same lever. If the power is applied at B' it still acts perpendicularly to the longer arm of the lever, which then becomes C B'.

200. *The ratio between the power and weight, which balance in the wheel and axle, is* (as in the lever) *inversely as the perpendicular distances of the direction in which they act, from the centre*;—or, *the power is to the weight, as the radius of the axle to the radius of the wheel.*

Examples.

i. The radius of a wheel being 5 feet, and of the axle 5 inches: what power on the wheel will balance 1250 lbs. on the axle?

60 : 5 : : 1250 : 104.16, the answer.

ii. The radius of the wheel being 6 feet 2 inches, and of the axle 6.5 inches: what weight on the axle will be balanced by 130 lbs. on the wheel?

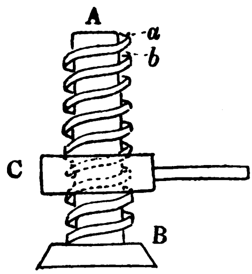
201. Since it is plain, that the power acts with equal force at B and B', this may satisfy us, that the bent lever acts upon the same principles as a straight one.

§9. *Of the Screw.*

202. The screw consists of a cylinder, with a spiral *thread*, passing round it. This thread may be considered as an inclined plane. Indeed, if a triangle, whose hypothenuse represents an inclined plane, be wrapped round a small cylinder, this hypothenuse will form a spiral line.

Let A B be a screw, —C a *nut*, or hollow screw, which turns on the screw by a handle. Let this nut be turned once round, it will slide upon the spiral line, which surrounds the screw, and

Fig. 23.



which is called the *thread*, and rise through a space equal to the *thread distance* of the screw, *i. e.* the distance between two contiguous threads, measured on a line parallel to the axis of the screw, as a b. Each part of the nut will have risen through this space, and each part, contiguous to the thread of the screw, will have slid upon this thread or spiral inclined plane, through a space equal to the length of one circuit of the spiral about the body of the screw.

203. This inclined plane may be represented by a plane right angled triangle, whose perpendicular is equal to the *thread* distance of the screw, and whose hypothenuse is equal to one circuit of the spiral, and whose base is equal to the circumference of the screw.

If the power be applied at the circumference of the screw, the mechanical advantage of the screw may be calculated in the same manner as we have shewn how to calculate the power gained by the inclined plane.

One thing however is to be observed. In turning the nut (or the screw) the power acts at right angles with the axis of the screw, and obliquely to the thread; precisely as if the power to raise the weight W, Art. 162, up the plane C A should be applied in the direction parallel to the base; in which case, the power : the weight :: the height or thread distance : to the base or circumference of the screw (163).

The power is never applied, however, at the circumference of the screw, but at the end of a lever. The advantage gained by the lever, in this case, is in proportion to its length, compared with the semidiameter of the screw; or to the circumference of the circle, which the end of the lever describes, compared with the circumference of the screw. The power gained by a screw, therefore, is in proportion to the circumference which the power describes, compared with the thread distance of the screw; or

Power : weight :: thread distance : circumference described by power.

Examples.

i. The thread distance of a paper mill screw being 1.5 inches, the lever 15 feet long, and the power applied at the end of it 150 lbs.; to what is the pressure equal?

The lever being 15 feet, the diameter of the circle, which the end of it describes is 30, and the circumference is $30 \times 3.1416 =$ 94.248 feet, or 1130.9 inches. Then

1.5 : 1130.9 :: 150 : 113090 lbs. the answer.

ii. Suppose the thread distance had been 1.75 inches, and the length of the lever 19 feet?

204. It may be observed, that the motion of the screw is attended with great friction. 1st. because it is one inclined plane rubbing upon another. 2d. because from the direction in which the power acts (Fig. 6) the pressure of the weight upon the inclined plane, is W g, greater than W f, its whole weight. At least one half the pressure gained by the screws in the above examples must be deducted for friction. The material of the screw, and its being dry or well oiled, however, occasions great variety in the amount of friction.* Notwithstanding, great mechanical advantage may be gained by this instrument. And even this friction has its uses, and those not unimportant: for the screw will remain at

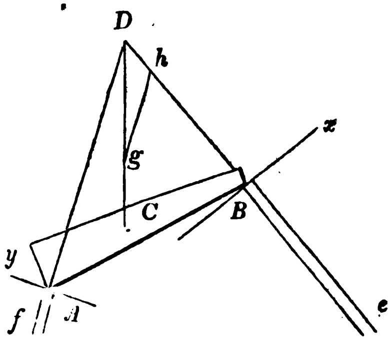
* *In the same way may be shewn the greater friction of a triangular, than of a square thread.*

rest, the friction preserving an equilibrium with the weight, after the power is removed.

§10. *Of the pressure of inclined beams, arising from their own weight.*

205. If a beam A B be suspended by a rope A D B, fixed at each end to the ends of the beam, and passing over a support at D,

Fig. 24.



the beam will assume such a position, that a plumb line from D will cut the centre of gravity C. This readily follows from what has already been said in Art. 185 and 190.

206. If instead of the ropes A D B, joists were placed in the positions f A and e B (f A being in a line with D A, and e B in a line with D B) the beam would be sustained without any tendency to move to either side, and would produce no strain upon either joist, but one of direct compression.

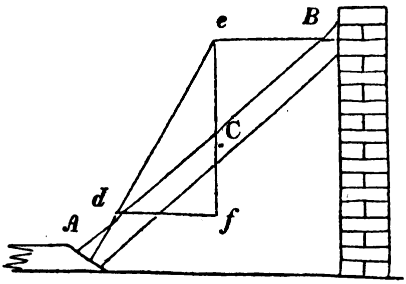
If the position of the beam A B were given, and that of one of the joists, as f A, and it were required to find the position of the other; we should draw a vertical or plumb line D C through the centre of gravity,—continue f A till it meets the vertical in D, and then from D draw D e through the point B, and B e will be the position of the other support.

To ascertain by what force each support is compressed, let D g on the vertical represent the weight of the beam; draw g h parallel to D A, and g h will represent the strain upon A f, and D h that upon B e.

207. Again, we might substitute planes, as x and y, instead of the joists, and if these planes are perpendicular to the direction of the ropes or joists, the beam will have no tendency to slide either way.

208. If a beam A B leans against a wall, we may easily find the

Fig. 25.

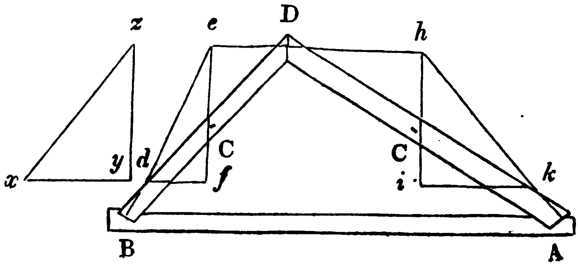


direction of the abutment at A, which will sustain it without any tendency to slide. Draw the vertical e C through the centre of gravity, C: draw e B perpendicular to the wall at the upper end of the beam, and then from e, where this line cuts the vertical, draw e A to the foot of the beam. This line e A represents the direction in which the beam presses upon the abutment, and the abutment A must therefore be perpendicular to this line.

If we represent the weight of the beam by e f, and draw d f perpendicular to it, d f will represent the horizontal pressure both against the wall at B and the abutment at A, and e d will represent the pressure upon the abutment in the direction e A.

209. We may in the same manner find the direction, in which rafters press by their own weight upon the ends of a tie beam.

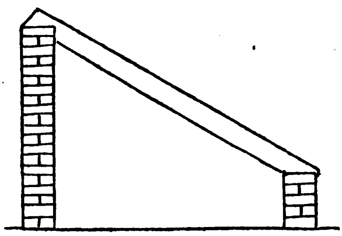
Fig. 26.



The directions, in which the rafters press upon the ends of the tie are e B and h A. The horizontal thrust d f and i k, &c.

210. If the rafters are unlike in their dimensions, the horizontal pressures derived in this way will be unlike. If, for example, D A were longer than D B, and its weight the same, i k would be greater than d f, and the horizontal pressures at D would be unequal. If they were not put together, therefore, at D, so as to prevent sliding, the larger beam would prevail, and the framing fall. Being secured at D, they will stand, but d f will not represent the horizontal thrust at B. B will be pressed not only with the force d f, but with the excess of i k, above d f. i k will therefore represent the horizontal thrust at each end of the tie. The abutment at B must likewise, in order to prevent sliding, have an inclination equal to that at B, for by drawing a horizontal line x y, equal to i k, and a perpendicular y z equal to e f, the third side x z will have the same inclination as h k, and the pressure of the beam will be in the direction z x

211. If a roof be inclined only one way, as the covering of sheds, &c. the horizontal thrust may be entirely removed by beveling one end of the beam and notching the other, so that the bearing part shall fit the horizontal tops of the walls: as is represented in the present figure.



CHAPTER II.

OF ROOFS WITH TIE BEAMS.

§1. *General remarks.*

212. The great object of the roof is to form a covering for the house. Its form must depend on various circumstances. The same roof, which serves well in a warm climate, would be improper in a cold one.

213. Trusses* for roofs are generally made too heavy, or perhaps we should say, it is not an uncommon fault. Timber is sometimes added, which not only gives no additional strength, but by increasing the load upon the walls, diminishes the stability of the structure. Not a stick should be used without some definite purpose. Although timber must not be spared where great strength is necessary, and the weight of timber is of small consideration, yet where the strain is light, it should be recollected that the work is stronger, when it is light.

214. In the pitch of roofs, very great diversity of practice has obtained. The Gothic architects gave them great elevation, which was in harmony with the aspiring character of their style. In Greek and Roman architecture the pitch was less. Roofs of high pitch are less apt to leak than those which are lower. The rain which falls upon them, runs off more rapidly. They are not so liable to be stripped of their covering by winds. The snows, too, do not lie so long upon them, and hence they are preferred in cold climates. They are also chosen in small houses, in which economy of room is an object.

There are however some advantages in low roofs. They require less timber, and press therefore with less weight upon the walls.

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* *By a truss we mean one of those frames of timber, generally triangular, which support the covering of the roof. The figures in following sections represent trusses.*

215. In favour of high pitched roofs it may also be mentioned, that the weight of their covering, or the mass of snow, which rests, in this part of the world, upon them, for several months in the year, presses with less force than upon flatter roofs. But on the other hand, if the rafters are not supported by braces, their increased length will so increase the strain, as to compensate for this advantage.

216. We have seen, in the first part of this work, that beams support much greater weights, when pressed or drawn in the direction of their length, than when subjected to transverse strains. It should therefore be an object continually in view, to *avoid as much as possible all transverse strains*, and to make all necessary strains act in such directions as the timbers are best able to support them.

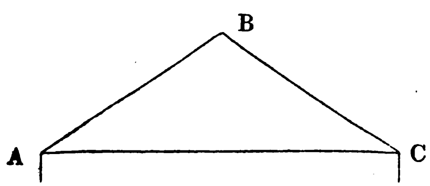
This remark will be illustrated by almost every thing we shall have to say on the subject of roofs, and indeed, *to make the load as light as it can be securely done,—and to dispose of the necessary strains in such manner as the timber is best able to bear them,—and to provide for the permanency of the parts in the situation in which they are placed,—constitute the great business of the carpenter.*

His work is subject, however, to necessary imperfections, and he must therefore provide against possible derangement, and foresee the changes of position to which it is liable, that new and destructive strains may not arise from such changes.

§2. *Of the tie beam.*

217. If a roof should be made with rafters only, as A B and B C, it would have a tendency to press the walls of the building at A

Fig. 27.



and C, outward. To prevent such a strain upon the walls, there is commonly in roofs a beam stretching across from A to C, connecting the feet of the rafters. This is called a *tie beam*, and by its means the roof becomes a perfect frame of itself, and acts upon the walls of the building only by its weight, in vertical pressure.

218. By the principles before laid down, we can readily ascertain the horizontal thrust of the roof, and then ascertain the size of the tie beam necessary to sustain this thrust. It will be found that the strength of a very slender beam is altogether sufficient to serve the purpose of a *tie*, even in a large roof; and had it no other office to perform, a slender beam would be preferable to a large one. A tie beam has generally, however, a ceiling to support, and sometimes rooms are constructed in the roof upon it, and therefore in calculating the size of the beam, reference must be had to these offices.

219. In calculating the horizontal thrust of a roof, when it consists only of rafters abutting against each other at the ridge, and connected at their feet with a tie, the principles developed in Art. 209 must be followed. When trusses are adopted, like those which follow, a different method must be adopted.

220. The direction in which the ceiling and other weights act upon the tie is vertical, and so far, a thin and deep beam is preferable to a square one. It must however have thickness enough to admit the framing of rafters into it, without being too much weakened.

221. "It is a common practice in framing roofs to force the tie beam to a certain degree of camber,* which appears to have been introduced under the idea that a cambered beam partakes of the nature of an arch: this, as has been justly observed by a late writer, (Robison) is one of the fallacies, which it is the business of the mathematical theory of carpentry to dispel. It is obvious that when a cambered beam settles it has a tendency to thrust out the walls, instead of being a bond to tie them together. The Gothic builders sometimes laid naturally crooked timbers with the round side upward, for tie beams; but then their walls were capable of supporting a considerable pressure. In some of the tie beams of the Durham Cathedral this curvature is very considerable. Modern walls are constructed on different principles, and require all

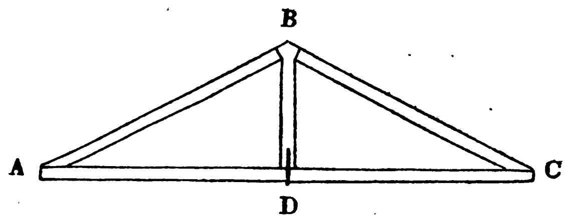
* *A beam is cambered when it is made convex upwards.*

the connexion a roof can be made to give them, instead of being sufficient to withstand the thrust of a cambered beam. When there are ceiling joists, it is easy to keep them a little higher in the middle of a ceiling, at the rate of about an inch in twenty feet, which prevents the settling from offending "the eye of the beholder," and consequently accomplishes all that Mr. Price and others propose to do by cambering the tie beam."*

§3. *Of the king post.*

222. When the tie beam is long, or the weight it has to sustain is so great as to expose it to bending, it is necessary to support it. In dwelling houses, and often in other buildings, this is done with convenience by the partitions, which separate the rooms; but in many situations, no support can be given to the tie beam from beneath, and we must find some means of sustaining it from above.

Fig. 28,



The tie beam A C may be sustained by a vertical beam B D, whose foot is secured to the tie beam by a strap, or otherwise, and whose head is sustained by the abutting of the rafters, A B and C B, against it. B D is called a *king post*. The term post is hardly consistent with its office, for it will readily be perceived that it acts only as a tie. It is drawn in the direction of its length, and is therefore capable of sustaining a great weight, and it is supported in such a manner by the rafters, as to press them in the direction of their length.

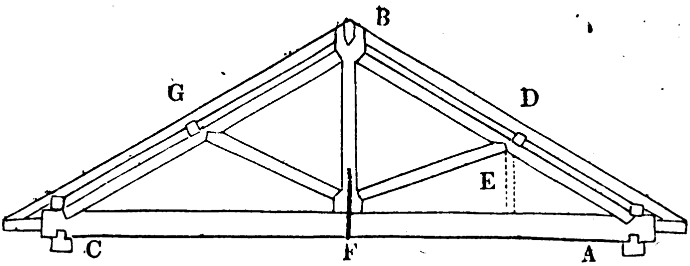
* *Tredgold, p.* 82.

We see therefore that the strain upon the tie, which was transverse, is transferred to the king post, where it becomes longitudinal; and great strength is thereby added to the roof.

§4. *Of Braces.*

223. In a wide roof the rafters will also need support. To furnish this support, we sometimes see a perpendicular brace as E mortised into the beam. But this is only transferring a transverse strain from the rafter to the tie; it does not remove it.

Fig. 29.



The braces G F and D F, which abut against the foot of the king post, furnish the necessary support to the rafters A B and C B, while they produce no strain but a longitudinal one on the king post, and are themselves compressed in the directions of their length.

In order that the student may be fully convinced of the impropriety of the perpendicular brace D E, let him calculate first the effect of the transverse strain upon the oblique rafter A B, and then upon the horizontal tie F A.

224. We have introduced into the above design other new ~~new~~ timbers besides the braces. Of the two sets of rafters, the under ones are called the *principal rafters;* those above them *small rafters.* The sole office of the latter is to receive the boarding. At G and D are seen sections of timbers called *purlines,* which stretch across from truss to truss, and support the small rafters. As we have before remarked (83) purlines should be used

in considerable lengths, and notched over the principal rafters, and the small rafters over the purlines. The purlines should rest upon those parts of the principal rafters, which are supported by braces, by which means nearly all the strain upon the principal rafters is avoided.

Prof. Robison calls in question the propriety of using purlines and small rafters, in cases where they can be avoided, and fortifies his opinion by the experiment before quoted (129) in relation to the comparative strength of single and double floors. Doubtless in the above truss the purlines and small rafters might be dispensed with, and the boarding placed directly upon the principal rafters. In the following trusses, they are more essential.

225. It will be perceived in the above truss, that the weight of the rafters is, by the interposition of the braces, sustained by the king post, and the king post with all the load which rests upon it, is sustained by the rafters, abutting against the head of it. In trusses of this form, therefore, the whole weight of the roof acts upon the rafters, much like a heavy weight upon the ridge.

226. A truss of the above construction will serve for a span of 20 to 30 feet. The following Table of Scantlings is given by Tredgold.

Span. feet.	*Tie beam.* inches.		*King post.* inches.		*Prin. rafters.* inches.		*Braces.* inches.		*Purlines.* inches.		*Small rafters.* inches.	
20	9.5 by	4	4 by	3	4 by	4	3.5 by	2	8 by	4.75	3.5 by	2
22	9.5	5	5	3	5	3	3.75	2.25	8.25	5	3.75	2
24	10.5	5	5	3.5	5	3.5	4	2.5	8.5	5	4	2
26	11.5	5	5	4	5	4.25	4.25	2.5	8.75	5	4.25	2
28	11.5	6	6	4	6	3.5	4.5	2.75	8.75	5.25	4.5	2
20	12.5	6	6	4.5	6	4	4.75	2	9	5.5	4.75	2

In this and the following tables the trusses are supposed to be not more than 10 feet apart:—the pitch 27 degrees—covering slate, and timber *good yellow fir*. "Inferior timber will require to be of larger dimensions, but the addition of one fourth of an inch to each dimension will be sufficient for any difference in quality, except it be knotty timber."* In the table, page 42, the value of *a* for Riga fir of a medium quality is .0115. That for Long Sound and Memel fir is lower, showing them to be stiffer. The value of

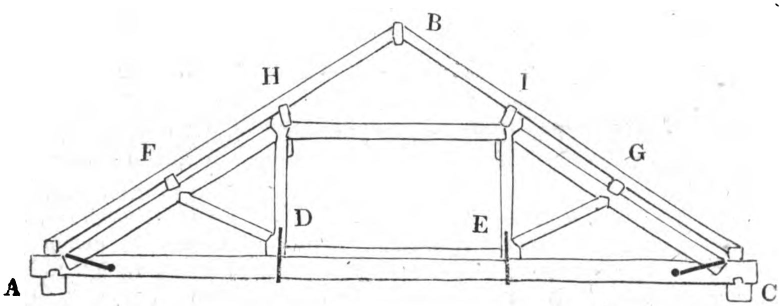
* *Tredgold*, p. 224.

a for New-England fir, in the same table, derived from Prof. Barlow's experiment, agrees very nearly with that obtained from the experiments, page 37, for the common white pine of New-England.

§5. *Queen Posts, Straining Beams, and Sills.*

227. If the roof be very wide, the tie beam requires more supports than the single king post. But how shall these be secured? The king post being supported by the ends of the rafters abutting against them, must necessarily be in the middle. We may imagine a very wide king post composed of a frame, equal in width to about one third the span of the roof, and we shall be led to the method, which is adopted in such cases.

Fig. 30.



228. The frame H I E D may represent the wide king post which we have imagined. The short rafters A H and C I abut against the heads of the supports D H and I E, and would crowd them together were they not kept asunder, and in their places by H I, which is therefore called the *straining beam*. But with the help of this straining beam, the short rafters support the two parts H D and I E, in the same manner as the king post receives its support. These two posts, H D and I E, therefore, perform the offices of ties to support the tie beam, and are called *queen posts*. The braces F D and G E abut against the feet of the queen posts, and to prevent them from being pressed towards each other, the beam D E is introduced, and is called the *straining sill*. Instead of the straining sill the queen posts might be strongly mortised into the tie beam,

but this mode is not to be preferred, for the mortises would diminish the strength of the tie.

229. This truss will serve for a span from 30 to 46 feet in extent.

Table of Scantlings; from Tredgold.

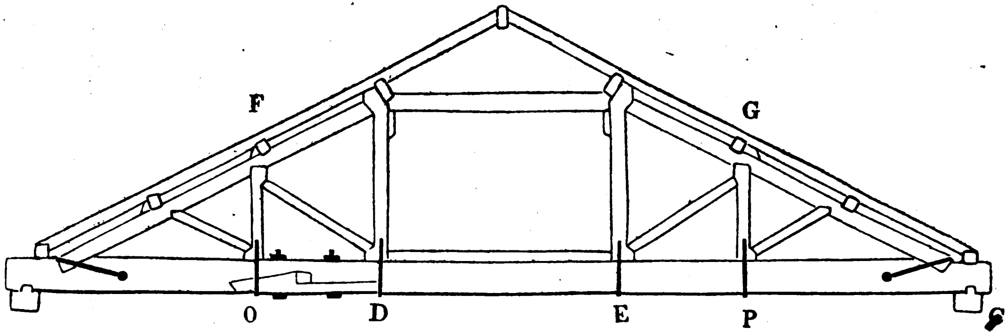
Span. ft.	*Tie beam.* in.		*Queen posts.* in.		*Principal rafters.* in.		*Straining beam.* in.	
32	10	by4.5	4.5	by4	5	by 4.5	6.75	by4.5
34	10	5	5	3.5	5	5	6.75	5
36	10.5	5	5	4	5	5.25	7	5
38	10	6	6	3.7	6	6	7.25	6
40	11	6	6	4	6	6	8	6
42	11.5	6	6	4.5	6.25	6	8.25	6
44	12	6	6	5	6.5	6	8.5	6
46	12.5	6	6	5.5	7	6	9	6

Span. ft.	*Braces.* in.		*Purlines.* in.		*Small rafters.* in.	
32	3.75	by2.25	8	by4.75	3.5	by2
34	4	2.5	8.25	5	3.75	2
36	4.25	2.5	8.5	5	4	2
38	4.5	2.5	8.5	5	4	2
40	4.5	2.5	8.75	5	4.25	2
42	4.5	2.75	8.75	5.25	4.5	2
44	4.5	3	9	5	4.75	2
46	4.75	3	9	5.5	5	2

230. For a span of from 46 to 60 feet, the tie beam and rafters will require more supports. These supports may be introduced between the queen posts and the wall plate, as is seen in the following figure.

This truss Fig. 31, is constructed upon the same principles as the last, and is in fact the same, with the addition of the supports F O and G P, against the heads of which the braces G E and F D abut on one side, while on the other they are sustained by the principal rafters. The foot of each supports a brace, and instead of a straining sill between O D and E P, the feet of these supports are mortised into the tie beam. A mortise may be made at O with more safety than at D, because the beam is more able to support a strain (197) in that part.

Fig. 31.

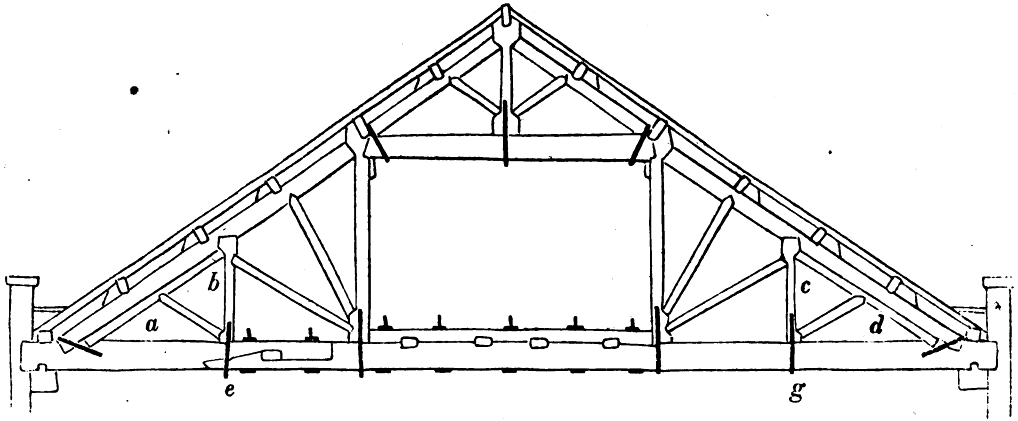


231. *Table of Scantlings; from Tredgold.*

Span. ft.	Tie beam. in.	Queen post. in.	Posts OF & GP. in.	Prin. rafters. in.	Str'g. beam. in.	Braces. in.	Purlines. in.	Small rafters. in.
48	11.5 by 6	6 by 5.75	6 by 2.25	7.5 by 6	8.25 by 6	4.5 by 2.75	8.5 by 5	4 by 2
50	12 6	6 6.25	6 2.5	8.5 6	8.5 6	4.5 2.75	8.75 5	4.25 2
52	12 6.5	6 6.75	6 2.75	9.25 6	8.75 6	4.75 2.75	8.75 5.25	4.25 2
54	12 7	7 6.25	7 2.25	6.5 7	9 6	4.75 2.75	8.75 5.25	4.5 2
56	12 8	7 6.75	7 2.5	7.5 7	9.25 6	5 2.75	8.75 5.25	4.5 2
58	12 8.5	7 7.25	7 2.75	8.25 7	9.5 7	5 2.75	9 5.25	4.75 2
60	12 9	7.5 7	7 3	9 7	10 7	5 3	9 5.5	4.75 2

232. For a roof of a large span, from 75 to 90 feet, the following is a good form for a truss.

Fig. 32.



233. *Table of Scantlings; from Tredgold.*

Span.	*Tie beam.*		*Queen posts.*		*Posts b&c.*		*P. rafters.*		*Str. beam.*		*King post.*		*Braces.*		*Purlines.*		*S. rafters.*	
ft.	in.		in.		in.		in.		in.		in.		in.		in.		in.	
65	15by	10.5	8	by7	5by	3	8	by7.5	10.5	by8	5by	3	5by	3.5	8.25by	5	4	by2
70	15	11.75	9	6.5	5	3.5	9	7	10.5	9	5	3.5	5	4	8.5	5	4.25	2
75	15	13.75	9	7.5	5	4	9	8	11.25	9	5	4	5	4.5	8.75	5	4.5	2
80	16	13	9	9	6	4	10.5	9	12	9	6	4	6	3.5	8.75	5.25	4.5	2
85	16	13.5	9.5	9	6	4.5	12	9	12.75	9	6	4.5	6	4	9	5.25	4.75	2
90	16	14	10	9.75	6	4.5	10.5	10	13	10	6	4.5	6	4	9	5.5	5	2

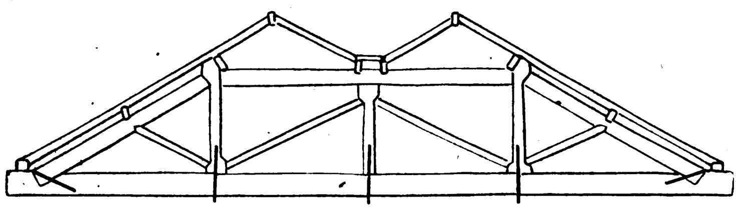
This roof needs no particular explanation. It differs from the preceding by having the supports e b and c g sustained on one side by short rafters, a b and c d; *two* braces springing from the foot of each queen post to support the rafters; and in the greater extent of the straining beam, and the support of the straining beam by a king post above it, with braces abutting against its foot.

If the straining beam in this roof be shortened, and the king post omitted, it will then serve for a span of 60 to 75 feet.

234. To give a clear view of the offices performed by the different parts of a roof, we may briefly recapitulate what has been said thus far. To prevent a horizontal thrust upon the walls, the tie beam is introduced. This however is not merely a tie, but sometimes carries a load, and is therefore exposed to flexure. To prevent this, a king post is added, which is sustained by the abutting of rafters against its head. If the rafters are long, they too need support, and they obtain it from braces which abut against the foot of the king post. If more than one support for the tie beam is necessary, two posts, called queen posts, are introduced, which exactly resemble a king post cut lengthwise, its parts being kept asunder by the straining beam and straining sill; other supports are added if necessary, and braces, but the same principle governs their use throughout.

235. The following truss is from Price's British Carpenter, and it may be used where it is desired to avoid a large expanse of roof. But instead of this, the trusses, Figs. 30, 31, or 32, might be used, the part above the straining beam being omitted. The top of the roof

Fig. 33.



would then be flat, and there would be a gain of room in the roof, the central part of the truss being free from braces. Roofs like the above from Price are called M roofs, on account of their resemblance to that letter.

236. Table of Scantlings to Fig. 33; from Tredgold.

Span.	*Tie beam.*		*Queen posts.*		*P. rafters.*		*Str. beam.*		*Mid. posts.*		*Braces.*	
ft.	in.		in.		in.		in.		in.		in.	
55	12by	8	8 by	6	8 by	8	10by	8	6by	4	6by	4
60	12	9	9	6	9	7	10	9	6	4.5	6	4.5
65	13	9.5	9.5	6.5	9.5	8	11	9.5	6	5	6	5

237. For a span that exceeds 65 feet, a truss of the following form is considered one of the best of its kind, that can be devised.

Fig. 34.

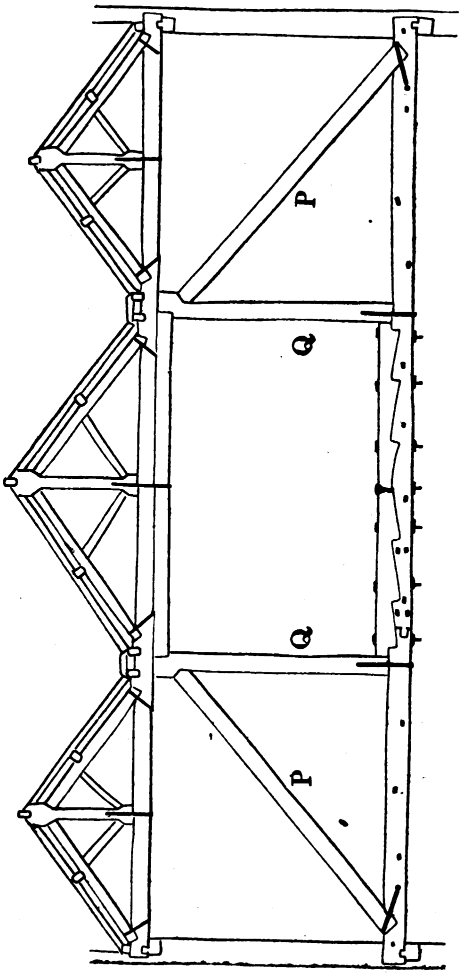


Table of Scantlings; from Tredgold.

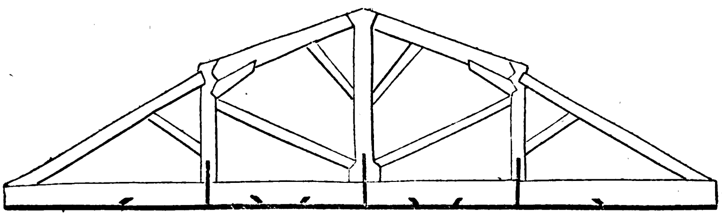
Span.	*Tie beam.*		*Queen posts.*		*Prin. rafters P.*		*Straining beam.*	
ft.	in.		in.		in.		in.	
70	15by	11.5	9.5by	8	13 by	9.5	12by	9.5
75	15	14	10	8.5	13.5	10	12	10
80	16	13	10.5	9	14	10.5	13	10.5
85	16	14.5	11	10	14.5	10	13	11

Scantlings of the upper parts may be got from Table Art. 226.

It is the same in principle with the roof of Drury Lane Theatre, executed by Mr. Saunders, over a span of 80 feet 3 inches in the clear. Robison says of this roof, that it probably "has not its equal in the world for lightness, stiffness and strength."

238. The following figure exhibits "the celebrated roof of the theatre of the University of Oxford, by Sir Christopher Wren. The span between the walls is 75 feet. This is accounted very ingenious, and is a singular performance. The middle part of it is almost unchangeable in its form; but from this circumstance, it does not distribute the horizontal thrust with the same regularity as the usual constructions. The horizontal thrust on the tie beam is about twice the weight of the roof, and is withstood by an iron strap below the beam, which stretches the whole width of the building in the form of a rope, making part of the ornament of the ceiling."*

Fig. 35.



239. There is considerable difficulty in erecting roofs, in which the joints are numerous, and the timbers of large dimensions, and they are liable to derangement by the shrinking of king and queen posts; for it is manifest, that if the king and queen posts, against the heads of which the rafters abut, shrink or are compressed, they will settle, and instead of supporting the tie beam, they will strain it transversely. To obviate these inconveniences, it has been proposed to make the principal rafters "in a continued series of pieces abutting end to end against each other," in such a manner as to form a curved rib, as in the next figure.

* *Robison*, *Vol.* 1, p. 605.

Fig. 36.

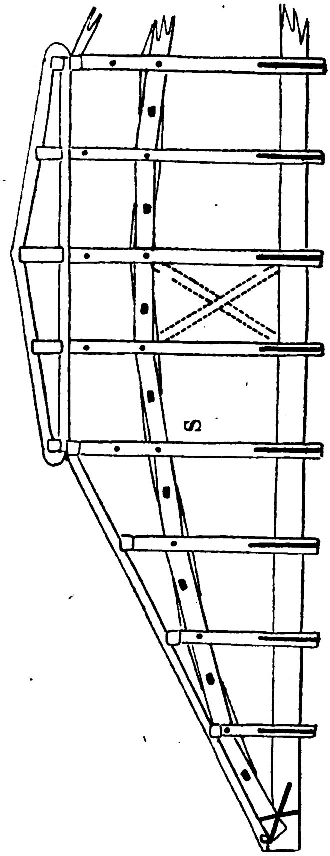
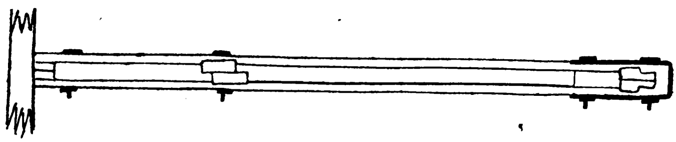


Fig. 37.



These pieces are double, and placed side by side, and bolted or keyed together, and so disposed that the joints on one side come against the middle of the lengths on the other side. Crooked timber would be preferable to straight, because fewer joints would be necessary.

The supports, S, for the tie beam, consist each of two pieces, one on each side of the rib, and notched and bolted both to the rib and the tie beam, as shewn in Fig. 37. This mode of construction admits of a firmer connexion with the tie beam than the common method of king and queen posts, and the number of suspending pieces can be increased at pleasure. The best situation for the suspending pieces is at the joints of the ribs. Diagonal braces, as shewn by the dotted lines, may be added if necessary.

240. Roofs on this plan may be executed for any span from 35 to 100 feet. The following is a Table of Scantlings, from Tredgold. Trusses supposed to be 10 feet apart—covering slate.

Span.	*Tie beam.*		*Curved rib.*		*Suspending pieces.* *No. of pairs.*	*Scantlings of each piece.*	
ft.	in.		in.			in.	
35	11 by	6	6 by	6	4	4 by	2.5
40	11	6	7	6	4	4	2.75
45	11	6.5	8	6.5	5	4	2.75
50	11	7	9	7	5	4	3
55	11	7	10	7	6	4	3
60	11	8	10	8	6	4	3.25
65	11	9	10	9	7	4	3.25
70	11	9.5	11	9.5	7	4.5	3.25
75	11	10	11	10	8	4.5	3.25
80	12	10	12	10	9	4.5	3.25
85	12	11	12.5	11	9	4.5	3.5
90	12	11	14	11	10	5	3.25
95	12	12	14	12	11	5	3.5
100	12	12	15	12	11	5	4

Purlines 9 by 5 inches. Small rafters 5 by 2 inches.

241. Smaller roofs may be constructed in a similar manner; but the curved rib, instead of being made of short pieces, may be formed by bending a long stick upon Mr. Hookey's plan for bending ship timber.

"If the depth of a piece of timber does not exceed about a hundred and twentieth of its length, it may be bent into a curve that will rise about one eighth of the span, without impairing its elastic force. And if two such pieces be laid one upon the other and then bent by means of a rope fixed at the ends, they may be easily bent to the form of the required curve, by twisting the rope, as a stone sawyer tightens his saw, or as a common bow saw is tightened. The pieces may then be bolted together; and if this operation is performed in a workmanlike manner, the pieces will spring very little when the rope is gently slacked; and it is advisable to do it gradually, that the parts may take their proper bearing without crippling.

"If the piece is of about one sixtieth part of the span in thickness, it may be sawn along the middle of its depth with a thin saw from each end toward the middle of its length, leaving a part of about eight feet of the middle uncut. The piece may then be bent to the proper curve and bolted.

"In either case the rise of the ribs should be half the height of the roof, and they should be bent one fourth more, to allow for the springing back, when the rope is taken off."*

242. A roof of this kind for a 30 feet span is shewn in the annexed diagram. The suspending pieces are notched on each side in pairs, and bolted or strapped together.

Fig. 38.

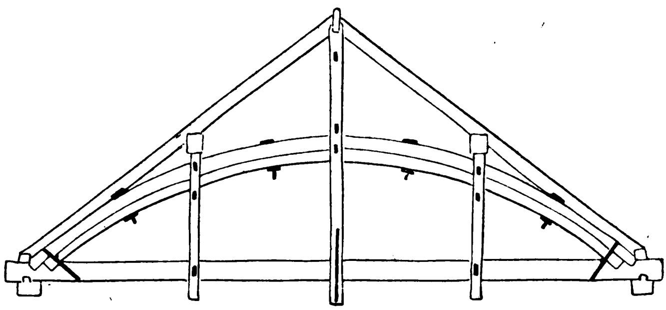


Table of Scantlings; from Tredgold.

Span.	*Tie beam.*	*Curved rib.*	*Suspending pieces.* *No. of pairs.*	*Suspending pieces.* *Scantlings of each piece.*	*Purlines.*	*Common rafters.*
ft.	in.	in.		in.	in.	in.
20	8 by 4	4 by 4	3	4 by 2	8 by 5	3.5 by 2
24	8 4	4.75 4	3	4 2	8 5	4 2
28	8 5	5.25 5	3	4 2.25	8.5 5	4.5 2
30	8.5 5	6 5	3	4 2.25	8.5 5	4.75 2
32	9 5.5	6 5.5	3	4 2.5	8.5 5	5 2

* *Tredgold's El. Pr. of Carp. p. 77.*

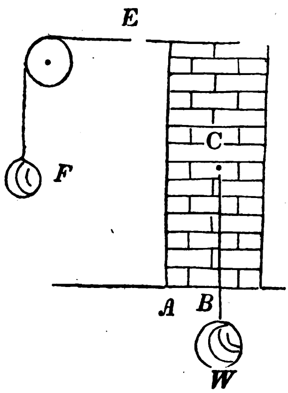
CHAPTER III.

OF ROOFS WITHOUT TIE BEAMS.

243. It is sometimes required, that roofs be executed so as to admit arched ceilings to ascend into them. In such cases the tie beam cannot be employed to prevent the lateral pressure against the walls; and to construct a truss, which shall exert no horizontal thrust, and that without the assistance of tie beams, is a problem of no small difficulty. Indeed, considering the necessary imperfections of the best executed roofs, arising from the shrinkage of timber it is altogether impossible. Attention to the principles of equilibrium, and the resolution of forces, will however enable a skilful carpenter to make the horizontal thrust comparatively light, and such as well built walls may sustain.

244. The amount of horizontal thrust which a wall is able to sustain may easily be calculated.

Fig. 39.



The lateral pressure of the roof upon a wall would produce the same effect as a weight equal to the pressure, supposing it to be suspended as F, (Fig. 39) over a pulley, in such a manner as to exert its whole force in drawing the wall outward.

If the wall is tipped outward by the weight F, it must turn over the corner A.

The whole weight of the wall may be considered as concentrated at the centre of gravity C, and it would act in resisting the outward pressure, precisely as an equal weight W would act, if suspended from the centre of gravity.

A being the fulcrum, F acts at the end of an arm of a lever equal to A E, the height of the wall. W acts in the direction of C W, and the perpendicular distance of the fulcrum A from this direction is A B, half the thickness of the wall.

When an equilibrium exists between these forces, *i. e.* when the horizontal thrust is exactly equal to what the wall can sustain

$$F : W :: A\,B : A\,E \quad (192).$$

$$\text{or, } F = \frac{W \times A\,B}{A\,E}.$$

in other words, *the greatest horizontal thrust, which a wall can support, is equal to the weight of the wall multiplied by half the thickness of the base, and divided by the height.* This rule supposes the two faces of the wall perpendicular and parallel. When this is not the case, A B (the multiplier) is always equal to the perpendicular distance of A from the line of direction of W, and A E (the divisor) equal to the perpendicular distance of A from the direction of F, where it acts upon the wall.

245. This mode of calculation supposes that the wall is secured upon its base by its weight only, and that the wall is so well built, as to act like one mass, and to tip from the bottom rather than to have its parts separated.

246. In order to calculate the weight of walls, *find their solid contents in cubic feet, and multiply them by the first number set against the material in the following Table.*

Table of the weights of a cubic foot of materials for walls.

Materials.		*Wt. of a cubic foot in lbs.*	*Sp. gr.*
Bricks,		97.31	1.557.
		135.00	2.000.
Marble,		161 25	2.580.
		177.50	2.840.
Granite,		158.68	2.538.
		187.47	2.999.
Sandstone,		112.00	1.800.
		156.00	2.506.
Brickwork may be estimated		95.00	
Stonework " "		107.00	
Mortar " "	mean	107.00	1.715.

Examples.

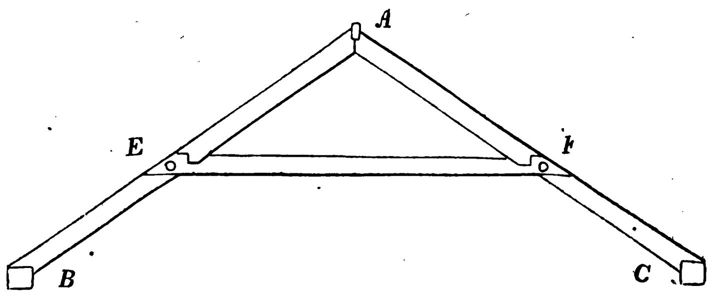
i. Let a wall be supposed 4 feet thick, 25 high, and 40 long, and built of stone; what is the greatest lateral pressure it can sustain from a roof?

ii. Let the same wall be of brick?

iii. The wall 1.5 feet thick, 30 feet high, and 40 long, of brick?

247. A method of supplying the place of a tie beam, not unfrequently employed, is that of the *collar beam*, as E F.

Fig. 40.



But if the roof be not very light, and if the whole lateral strain come upon the collar beam, it will not be sufficient. This kind of roof has frequently failed, and a slight inspection will point out its defects.

i. Each of the rafters A B and A C may be considered as levers, whose fulcrums are at A. The load acts at B and C, and the power to sustain it at E and F. The collar beam acts at a mechanical disadvantage, therefore, and although there would be no difficulty in making the beam itself strong enough to support this augmented strain, it is difficult to make a joint, which will be sufficient.

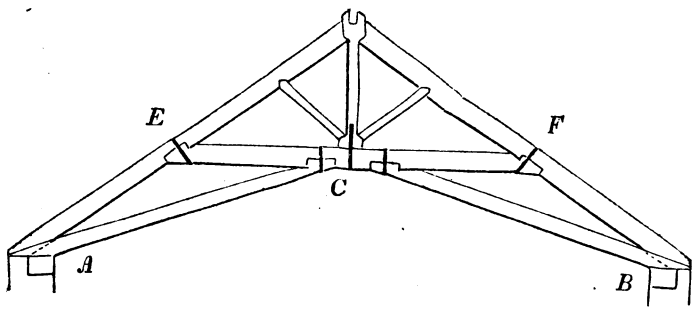
ii. Again, the collar beam acting upon the points C and F, brings a very heavy transverse strain upon the rafters.

iii. In forming the joints F and E the rafters must be very much weakened, just where they require to be strong.

Considering the imperfections of the best roofs, it will not appear strange, that this, by the failing of the joints, or the bending of the rafters, should be found entirely ineffectual in removing the transverse strain from the walls.

248. The next specimen is from Price's British Carpenter. It is much to be preferred to the last, although it cannot possess the stability of roofs with ties.

Fig. 41.

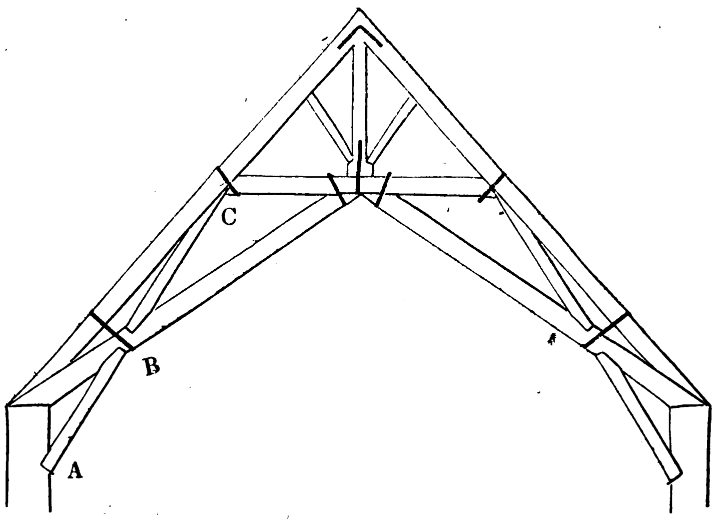


The beams A C and B C act as ties, confining the feet of the rafters. The joints at E and F are not so much strained, and the transverse strains upon the rafters are diminished. A C and B C being ties, tend to produce a downward flexure of the collar beam, which is prevented by the king post D C.

The position of the beams A C and B C renders the strain upon them very considerable. This strain can be very well sustained by the beams themselves, but the joints at C will be likely to fail unless they are extremely well executed.

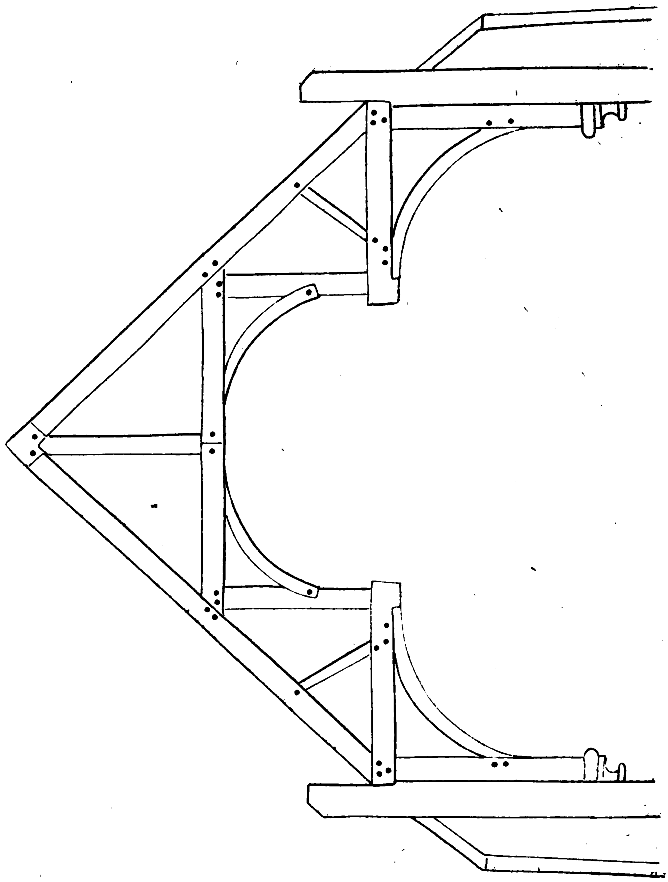
249. The following design is commended by Dr. Robison, and "has been executed with great success in the Circus, or Equestrian Theatre in Edinburgh, the width being 60 feet." This roof is the same as the last described, with the addition of the pieces A B and B C. These pieces "help to take off some of the weight, and by their greater uprightness exert a smaller thrust on the walls."

Fig. 42,



250. Figure 43 is a sketch of a roof in Westminster school, taken from Smith's Specimens of Ancient Carpentry. It exhibits one of the most common forms of trusses used by the Gothic architects. The timbers are so disposed as to throw the pressure a considerable way down the walls, and at the same time in a vertical direction.

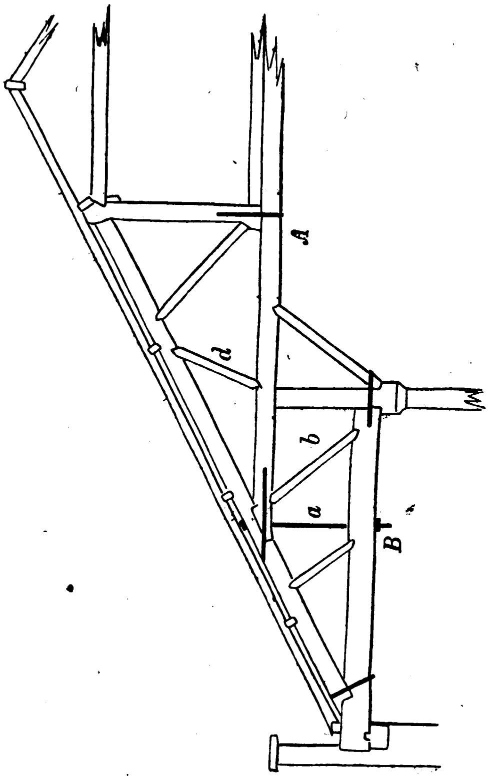
Fig. 43.



251. "The centre aisles of churches being often higher than side ones, the same effect as when a tie continues through may be produced by connecting the lower beams by means of braces to the upper ones." The following sketch illustrates this principle. It represents half a truss. "The lower tie B is so connected with the principal tie beam A, by means of braces b, that the foot of the principal rafters cannot spread without stretching the tie A. The

iron rod a performs the office of king post to the tie B, and is better than timber, because the shrinkage of timber ones would be particularly objectionable in that situation. The oblique position of d renders it efficient in opposing the spread of the rafters"*

Fig. 44.



252. We have now given the common and the most ingenious methods, which have been devised for the construction of roofs without ties. However perfectly they are made, they will always produce some strain upon the walls. This strain, where the walls are very massive, is of little consequence. The Gothic builders, many of whose roofs have stood for centuries, and will yet outlast many modern structures, did not depend wholly upon the skilful

* *Tredgold.*

adjustment of their trusses, but made their walls of prodigious thickness, or else sustained them by heavy buttresses. Had their roofs been placed upon such walls as are commonly erected at the present day, they would not have outlived their authors.

"A wall 60 feet high and 3 feet thick could not withstand the action of a wind, blowing at the rate of 30 feet a second." Thin walls depend very much for their stability upon cross walls, cross beams, and roofs, and if an arched ceiling is desired in the building, it would in most cases be better to obtain it by increasing the elevation of the walls, than by omitting the tie beam, and thus endangering their stability. This is with more confidence recommended, as very little height is usually gained by omitting tie beams.*

CHAPTER IV.

OF PROPORTIONING THE PARTS OF ROOFS.

Note. This Chapter is taken with little alteration from Tredgold's Carpentry.

253. The proportions of the timbers depend so much upon the design of the framing of a roof, that it would be impossible to furnish rules that would apply directly to all cases; nevertheless, by considering a few cases, the method that may be adopted will be seen, and consequently may be applied to designs made on other principles than those already shown. In roofs, as in floors, I have taken the constant number from a comparison of roofs already executed, and known to stand.

* *Vide Tredgold, p.* 77.

§1. *Of King posts (sometimes called crown posts), queen posts, and suspending pieces.*

254. The king post is intended to support the ceiling, and, by means of the braces, to support part of the weight of the roof. The weight suspended by the king post will be proportional to the span of the roof; therefore, to find the scantling,

Rule. Multiply the length of the post in feet, by the span in feet. Then multiply this product by the decimal 0.12 for fir, or by 0.13 for oak, which will give the area of the king post in inches; and divide this area by the breadth, and it will give the thickness: or by the thickness for the breadth.

255. Queen posts and suspending pieces are strained in a similar manner to king posts, but the load upon them is only proportional to that part of the length of the tie beam suspended by each suspending piece or queen post. In queen posts the parts suspended by each is generally half the span.

Rule. Multiply the length in feet, of the queen post or suspending piece, by that part of the length of the tie beam it supports, also in feet. This product multiplied by the decimal 0.27 for fir, or by 0.32 for oak, will give the area of the post in inches; and dividing this area by the thickness will give the breadth.

Example.

In the roof, Fig. 30, each queen post supports one third of the tie beam, or 13.3 ft. of it,* and the length of the queen post is 6 ft.; therefore $13.3 \times 6 \times 0.27 = 21.546$, the area in the shaft in inches. If the thickness of the truss be six inches, then

$$\frac{21.546}{6} = 3.6, \text{ nearly,}$$

and the queen posts should be 6 inches by 3.6. I have put it 6 by 4 in the table, Art. 229.

256. These rules give the scantling in the *smallest part of the pieces*, and in order to avoid the bad effects arising from the shrinking of the king or queen posts, *the heads must be kept as small as possible*, and the timber should be well seasoned. Hard oak makes

* *Supposing the span to be* 40 *feet.*

the best, because it will be least compressed by the ends of the principal rafters.

257. It has been proposed to let the ends of the principal rafters abut against each other, and to suspend the king post by straps of iron; but a piece of good carpentry should depend as little on straps as possible, and it would be better, and less expensive, to make a king or queen post wholly of cast iron, than to depend on wrought iron. The breadth of a cast iron king or queen post should be about one fourth of an oak one, to be equally strong. By a method to be described in the chapter on joints, &c. the rafters abut against each other, and the tie beam is suspended by pieces bolted on each side; which is perhaps the best in use.

§2. *Tie beams.*

258. A tie beam is affected by two strains, the one in the direction of the length from the thrust of the principal rafters, the other is a cross strain from the weight of the ceiling. In estimating the strength, the thrust of the rafters need not be considered, because the beam is always sufficiently strong to resist this strain. The pressure or the weight supported by the tie beam will be proportional to the length of the longest part of it that is unsupported. But there are two cases, one where the weight is merely the weight of the ceiling; the other where there are rooms in the roof.

Case 1. To find the scantling of a tie beam that has only to support a ceiling, the length of the longest unsupported part being given.

Rule. Divide the length of the longest unsupported part by the cube root of the breadth; and the quotient multiplied by 1.47 will be the depth required for fir, in inches; or multiply by 1.52, which will give the depth for oak, in inches.

Case 2. In the case where there are rooms above the tie beam, the rule is the same as that for girders. See Art. 131, 132.

Example to Case 1.

The length of the longest unsupported part of the tie beam in the roof Fig. 33 is 17 feet; and let the thickness of the truss be 9 inches. Then the cube root of 9 is 2.08 very nearly; therefore,

$$\frac{17 \times 1.47}{2.08} = 12 \text{ inches, the depth required.}$$

259. Tie beams are often unnecessarily cut to pieces with mortises, where the king or queen posts join them. It is much better to make very short tenons to the lower end of these posts, and to support the beam by means of straps.

§3. *Principal rafters.*

260. In estimating the strength of principal rafters, I suppose them to be supported by struts either at or very near to all the points where the purlines rest upon them. The pressure on a principal rafter is in the direction of its length, and is in proportion to the magnitude of the roof; but this pressure does not bear the same proportion to the weight when there is a king post, as when there are queen posts; therefore the same constant number will not answer for both cases.

Case 1. To find the scantling of the principal rafter, when there is a king post in the middle.

Rule. Multiply the square of the length of the rafter in feet, by the span in feet; and divide the product by the cube of the thickness in inches. For fir multiply the quotient by 0.96, which will give the depth in inches.

Case 2. To find the scantling of a principal rafter, when there are two queen posts.

Rule. Multiply the square of the length of the rafter in feet, by the span in feet; and divide the product by the cube of the thickness in inches. For fir multiply the quotient by 0.155, which will give the depth in inches.

The thickness is generally the same as the king or queen posts, and tie beam.

Example.

The length of the principal rafter in Fig. 30 is 14.5 feet, and the span is 40 feet, the thickness of the truss 6 inches. The square of the length is 210.25, and the cube of the thickness 216; therefore,

$$\frac{210.25 \times 40 \times 0.115}{216} = 6 \text{ inches, nearly};$$

that is, the principal rafters should be six inches by six inches.

§4. *Straining beams.*

261. A straining beam is the horizontal piece between the heads of the queen posts.

In order that this beam may be the strongest possible, its depth should be to its thickness as 10 to 7.

Rule. Multiply the square root of the span in feet, by the length of the straining beam in feet, and extract the square root of the product. Multiply the root by 0.9 for fir, which will give the depth in inches. To find the thickness, multiply the depth by the decimal 0.7.

§5. *Struts and braces.*

262. The part of a roof that is supported by a strut or brace is easily ascertained from the design, but the effect of the load must depend on the position of the brace; when it is square from the back of the rafter, the strain upon it will be the least; and when it has the same inclination as the roof the same strain will be thrown on the lower part of the principal rafter as is borne by the strut, but as the degree of obliqueness does not vary much, I will not attempt to include its effect in the rule for the scantling.

Rule. Multiply the square root of the length supported in feet, by the length of the brace or strut in feet; and the square root of the product multiplied by 0.8 for fir, will give the depth in inches; and the depth multiplied by the decimal 0.6, will give the breadth in inches.

Example.

In the roof Fig. 30, the part supported by the brace or strut is equal to half the length of the principal rafter, or 7 feet; and the length of the brace is 6 feet. Therefore
$\sqrt{(\sqrt{7} \times 6)} \times 0.8 = \sqrt{(2.646 \times 6)} \times 0.8 = 3.985 \times 0.8 = 3.188$, the breadth; and $3.188 \times 0.6 = 1.9128$, the depth; or 3.25 by 2 nearly.

If a piece intended for a brace, a principal rafter, or a straining beam, be crooked, the round side should be placed upwards.

263. I have now laid down rules for the principal parts of a truss, but in so doing I have not taken into the account the different weights of different kinds of roofing, nor the different degrees of inclination, lest the rules should become too complicated. It only remains now to give the rules for purlines and common rafters.

§6. *Purlines.*

264. The stress upon purlines is proportional to the distance they are apart; and the weight being uniformly diffused, the stiffness is reciprocally as the cube of the length.

Rule. Multiply the cube of the length of the purline in feet, by the distance the purlines are apart in feet; and the fourth root of the product for fir, will give the depth in inches; or multiplied by 1.04, will give the depth for oak: and the depth multiplied by the decimal 0.6 will give the breadth.

§7. *Common rafters.*

265. Common rafters are uniformly loaded, and the breadth need not be more than from 2 to 2.5 inches. The depth may be found by the following rule:

Rule. Divide the length of bearing in feet, by the cube root of the breadth in inches; and the quotient multiplied by 0.72 for fir, or 0.74 for oak, will give the depth in inches.

Example.

Let the length of bearing of a rafter of Riga fir be 7 feet, and the breadth 2 inches. The cube root of 2 is 1.26 nearly; therefore $\frac{7 \times 0.72}{1.26} = 4$ inches, the depth required.

266. Fir makes the best common rafters and purlines, because it is not so subject to warp and twist with the heat of roofs in summer as oak; much however depends on the quality of the timber, as oak from old trees often stands very well.

CHAPTER V.

OF DOMES.

267. The construction of domes "appears to be the most difficult task in the art of carpentry. But the difficulty lies entirely in the mode of framing." "The truth is, that a round building, which gathers in at top, like a glasshouse, a potter's kiln, or a spire steeple, instead of being the most difficult to erect with stability is of all others the easiest. Nothing can show this more forcibly than daily practise, where they are run up without centres and without scaffoldings: and it requires gross blunders indeed in the choice of their outline to put them in much danger of falling from a want of equilibrium. In like manner a dome of carpentry can hardly fall, give it what shape or what construction you will. It *cannot* fall unless some part of it flies out at the bottom: an iron hoop round it, or straps at the joinings of the trusses and purlines, which make an equivalent to a hoop, will effectually secure it. And as beauty requires that a dome shall spring almost perpendicularly from the wall, it is evident that there is hardly any thrust to force out the walls. The only part where this is to be guarded against is where

the tangent is inclined about 40 or 50 degrees to the horizon. Here it will be proper to make a course of firm horizontal joinings.

268. "We doubt not but that domes of carpentry will now be raised of great extent. The old Halle au Bled at Paris, of 200 feet in diameter, was the invention of an intelligent carpenter, the Sieur Molineau. He was not by any means a man of science, but had much more mechanical knowledge than artisans usually have, and was convinced that a very thin shell of timber might not only be so shaped as to be nearly in equilibrio, but that if hooped or firmly connected horizontally, it would have all the stiffness that was necessary; and he presented his project to the magistracy of Paris. The grandeur of it pleased them, but they doubted of its possibility. Being a great public work, they prevailed on the Academy of Sciences to consider it. The members, who were competent judges, were instantly struck with the justness of Mr. Moulineau's principles, and were astonished that a thing so plain had not been long familiar to every house carpenter. It quickly became an universal topic of conversation, dispute, and cabal, in the polite circles of Paris. But the Academy having given a very favorable report of their opinion, the project was immediately carried into execution, and soon completed."

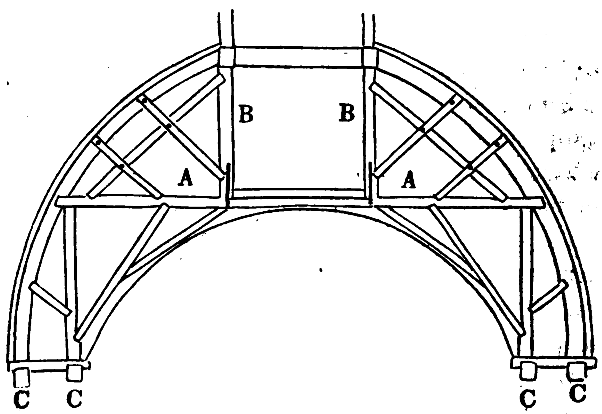
269. "The construction of this dome is the simplest thing that can be imagined. The circular ribs which compose it consist of planks nine feet long, 13 inches broad, and three inches thick: and each rib consists of three of these planks bolted together in such a manner that two joints meet. A rib is begun, for instance, with a plank of three feet long standing between one of six and another of nine, and this is continued to the head of it. No machinery was necessary for carrying up such small pieces, and the whole went up like a piece of bricklayer's work. At various distances these ribs were connected horizontally by purlines and iron straps, which made so many hoops to the whole. When the work had reached such a height, that the distance of the ribs was two thirds of the original distance, every third rib was discontinued, and the space was left open and glazed. When carried so much higher that the distance of the ribs is one third of the original distance, every second rib (now consisting of two ribs very near each other) is in like manner discontinued, and the void is glazed. A little above this

the heads of the ribs are framed into a circular ring of timber, which forms a wide opening in the middle; over which is a glazed canopy or umbrella, with an opening between it and the dome for allowing the heated air to get out. All who have seen this dome say, that it is the most beautiful and magnificent object they have ever beheld."

270. "The only difficulty which occurs in the construction of wooden domes is, when they are unequally loaded, by carrying a heavy lanthorn or cupola in the middle. In such a case, if the dome were a mere shell, it would be crushed in at the top, or the action of the wind on the lanthorn might tear it out of its place. Such a dome must therefore consist of trussed frames."*

271. The following figure represents a truss for a dome, when the interior dome is not required to be open to a great height, and a tie A A can be introduced. C C are curved ribs in two thicknesses, with the joints crossed and bolted together. It is calculated for a span of 60 feet, but may be extended to 120 feet. B B are posts which may extend upward to form the lantern.

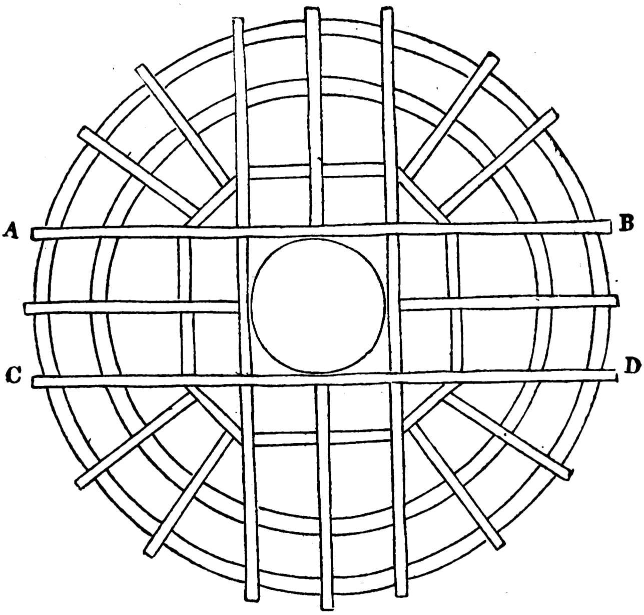
Fig. 45.



272. Two principal trusses may be placed across the opening parallel to each other, and at a distance apart equal to the diameter of the lantern, as A B and C D in the next figure; with a sufficient number of half trusses to reduce the bearing of the rafters to a convenient length.

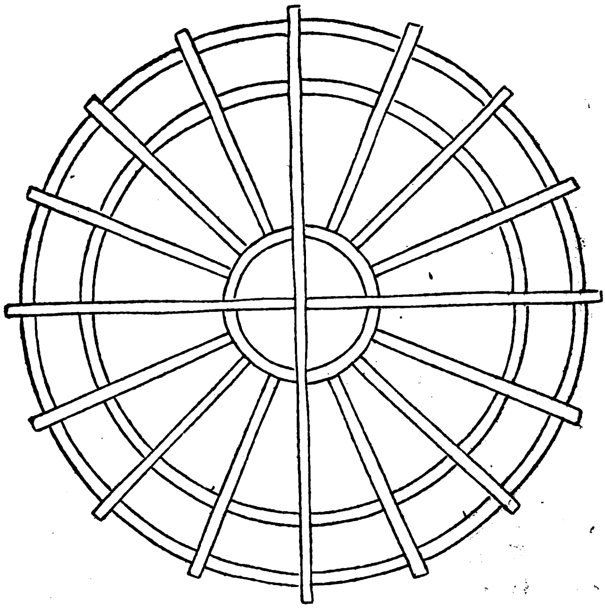
* *Robison's Mechan. Phil. Vol.* 1, *pp.* 610–612.

Fig. 46.



273. If no opening is required at the top of the dome, two principal trusses may cross each other at right angles, in the centre of the dome, one being placed so much higher than the other as to prevent the ties interfering.

Fig. 47.



274. "The construction of domes without horizontal cross ties is not difficult when there is a sufficient tie round the base. The most simple method, and one which is particular useful in small domes, is to place a series of curved ribs so that the lower ends of those ribs stand upon the curb at the base, and the upper ends meet at the top.

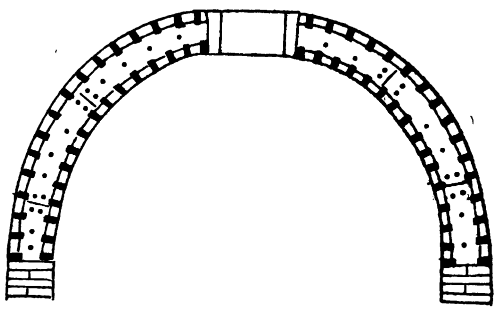
When the pieces are so long, and so much curved that they cannot be cut out of timber without being cut across the grain so much as to weaken them, they should be put together in thicknesses, with the joints crossed, and well nailed together: or, in very large domes, they should be bolted or keyed together. The manner of forming these ribs has been already described, as applied to roofs, (See Art. 239). The method of making curved ribs in thicknesses has been used in the construction of centres for arches from the earliest periods of arch building; and it was first applied to the construction of domes by Philibert de Lorme, who gives the following scantlings for different sized domes:

For domes of 24 feet diameter, 8 inches by 1 inch.

36	10	1.5
60	13	2
90	13	2.5
108	13	3

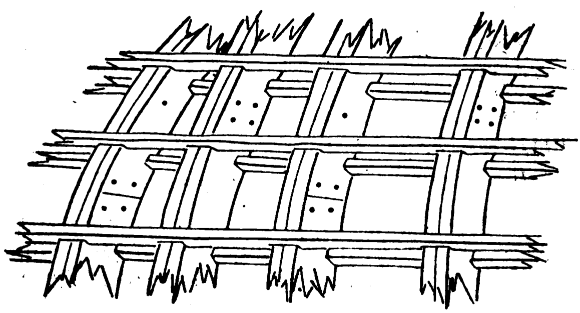
These ribs are formed of two thicknesses of the scantlings given above, and are placed about two feet apart at the base. The rafters are notched upon them for receiving the boarding, and also horizontal ribs are notched on in the inside, which gives a great degree of stiffness to the whole.* Fig. 48 is a section of a dome con-

Fig. 48.



structed in this manner; and Fig. 49 a projection of a part of the dome, with the rafters and inside ribs."†

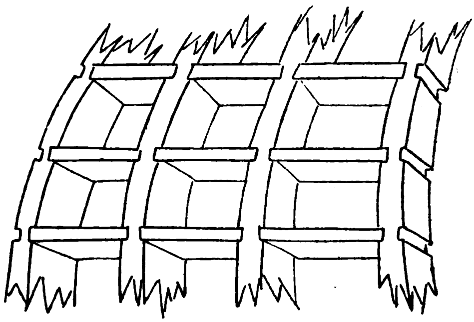
Fig. 49.



* *Mr. Price proposes a similar mode of forming bridges and domes in his British Carpenter, p.* 26 *and* 28. † *Tredgold, p.* 89.

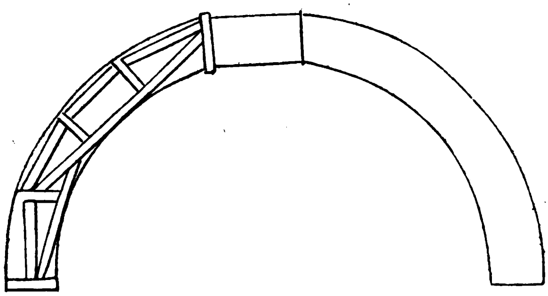
275. When a light dome is wanted, without occupying much space, the ribs may be so near each other that the boards may be nailed to them without rafters, or short struts may be put between the ribs, as in the annexed figure.

Fig. 50.



276. The following sketch "represents a dome executed for the Register office of Edinburgh, by James and Robert Adams, and is very agreeable to mechanical principles. The span is 50 feet clear, and the thickness only 4.5."*

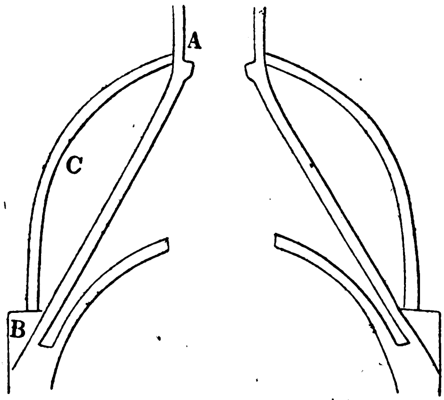
Fig. 51.



277. The following figure shews the principle upon which the dome of St. Paul's, in London, was constructed by Sir C. Wren. A cone is introduced, which supports the heavy lantern at the top.

* *Robison.*

Fig. 52.



It is evident, that a heavy weight at the top of a dome, when supported by the straight wall of a cone, or a straight stick of timber, as A B, produces no transverse strain; but if it be supported by the curved sides of the dome only, as A C B, the transverse strain upon A C B is very considerable. The introduction of the cone, therefore, in the dome of St. Paul's, to support a heavy cupola, was very judicious. But in constructing domes of less magnificent dimensions, it would be entirely sufficient to surround them with iron hoops about the parts where the strain would be most considerable.

CHAPTER VI.

OF THE CONSTRUCTION OF PARTITIONS.

Note. This Chapter is taken entire from Tredgold's Elementary Principles.

278. Partitions, in carpentry, are frames of timber for dividing the internal parts of a house into rooms: they are usually lathed and plastered, and sometimes the spaces between the timbers are filled with brick work.

In modern carpentry there is no part of a building so much neglected as the partitions. A square* of partitioning is of considerable weight, seldom less than half a ton, and often much more; therefore a partition should have an adequate support: instead of which, it is often suffered to rest on the floor, which of course settles under a weight it was never intended to bear, and the partition breaks from the ceiling above.

If it be necessary to support a partition by means of the floor or roof, it should rather be strapped to the floor or roof above it, than be suffered to bear upon the floor below; because in that case the cracks along the cornice would be avoided; and in such cases the timbers of the floor or roof must be made stronger. A partition ought, however, to be capable of supporting its own weight; for even when doorways are so placed that a truss cannot be got the whole depth, it is almost always possible to truss over the heads of the doors.

279. Partitions that have a solid bearing throughout their length do not require any braces, indeed they are better without it, as it is easy to stiffen them by struts between the uprights, and thus the shrinking and cross strains occasioned by braces are avoided. When braces are introduced in a partition, they should

* 100 *square feet, or* 10 *feet square.*

be disposed so as to throw the weight upon points that are sufficiently supported below, otherwise they do more harm than good.

But though it be often practicable to give a partition a solid bearing throughout, it is better not to do so, because all walls settle; therefore the partition should always be supported only by the walls it is connected with, so that it may settle with them. If the partition have a solid bearing, and the walls settle, fractures must necessarily take place.

Also, when a partition is supported at one end by the wall of a high part of the building, and by the wall of a lower part at the other end, it will always crack either close by the walls or diagonally across.

I state here the consequences that may be expected in the usual kinds of foundations; there may be some where the settlement is so small as to produce no sensible effect; but such instances are rarely met with. Much may be done by making the base of a wall in proportion to the whole weight it is intended to support; but this belongs to another department of the building art.

In a trussed partition, the truss should have good supports, either at the ends or other convenient places, and the framing should be designed accordingly; that is, so that the weight may not act on any other points than those originally intended to bear it. The best points of support are the walls, to which the plastering of the partition joins.

280. Partitions are made of different thicknesses, according to the extent of the bearing; for common purposes, where the bearing does not exceed 20 feet, 4 inches is sufficient; or, generally, the principal timbers may be made

4 inches by	3 inches for a bearing not exceeding	20 feet.
5	3.5	30
6	4	40

And partitions should be filled with as thin stuff as possible, so that it be sufficient to nail the laths to. Two inches is quite a sufficient thickness. When these filling in pieces are in long lengths, that is, when they exceed 3 or 4 feet, they should be stiffened by short struts between them; or, what is much better, to notch a continued rail across the uprights, nailing it to each.

It should be borne in mind, that in all cases useless timber is only an unnecessary load upon the framing, and increases the risk of failure at a considerable expense.

The thicknesses above mentioned apply only to partitions that have no other than their own weight to bear. When a floor is to be supported by a partition, it must be prepared for that purpose. It would, however, be impossible to give any rules for such partitions, as the design must be varied according to circumstances, which differ so materially in almost every case as to render particular rules useless.

281. The pressure in the direction of any of the pieces may be found by applying the principles given in the preceding parts of this work; and also the scantlings of the timbers that would be able to sustain such pressures. The following data will assist in forming an estimate of the pressure on the framing of partitions:

The weight of a square of partitioning may be taken at from 1480 pounds to 2000 pounds per square.

The weight of a square of single joisted flooring, without counter flooring, at from 1260 to 2000 pounds.

The weight of a square of framed flooring, with counter flooring, at from 2500 to 4000 pounds.

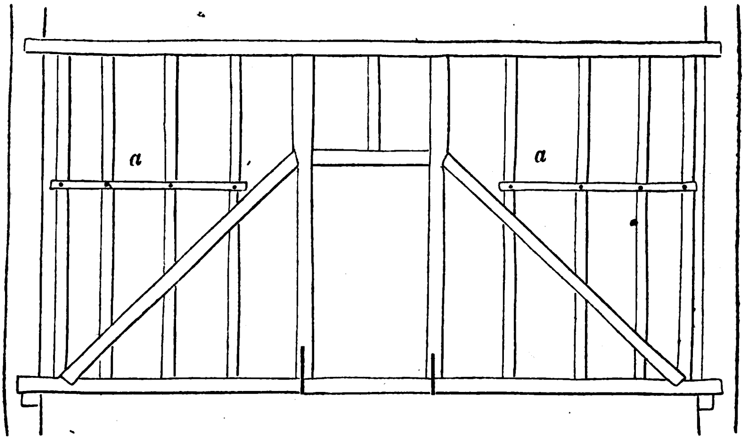
As great nicety is not required in calculating the scantlings, the highest numbers may be taken for long bearings, and the lowest for short ones; as the one gives the weight in large mansions, and the other that in ordinary houses.

The shrinkage of timbers, and still more often imperfect joints, cause considerable settlements to take place in partitions, and consequently cracks in the plastering; therefore it is essential that the timber should be well seasoned, and also that the work should be well framed, as a slight degree of settlement in a partition is attended with worse consequences than is produced by a like degree of settlement in any other piece of framing.

282. Fig. 53 shows a design for a trussed partition with a doorway in the middle; the tie or sill is intended to pass between the joisting under the flooring boards. The strongest position for the inclined pieces of the truss is shown by the figure. The inclination of the trussing pieces should never greatly differ from an an-

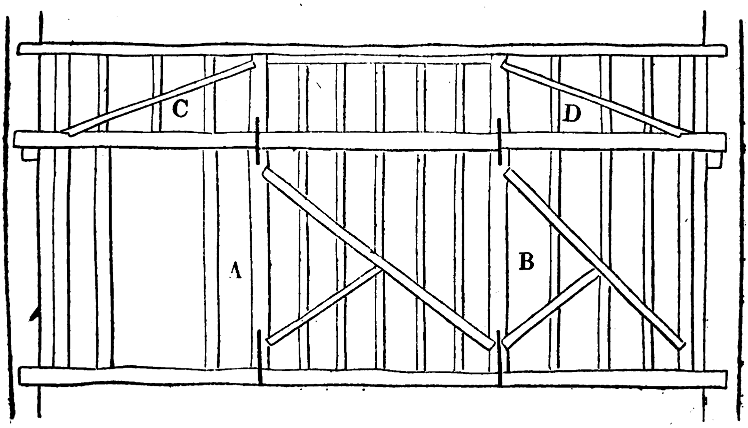
gle of 40 degrees with the horizon. The horizontal pieces, a a, are intended to be notched into the uprights, and nailed: in partitions for principal rooms, one on each side might be used.

Fig. 53.



283. When a doorway is near the side of a room, which is often necessary, in order to render a room either convenient or comfortable, the partition should be trussed over the top of the door, as shown in the following figure. The posts, A, B, should be strap-

Fig. 54.



ped to the truss, and braces may be put in the lower part of the truss in the common way; but it would be better to halve these braces into the uprights which would bind the whole together.

In order to save straps the posts A, B, are often halved into the tie C D; in that case, the tie should be a little deeper; and as the tie may be always made strong enough to admit of halving, perhaps this is the best method.

Partitions should always be put up some time before they are plastered; that the timbers, should they cast, may be put right again. This precaution is not so necessary where the timber has been a considerable time cut to the proper scantlings, or well seasoned.

The arrises of all timbers exceeding 3 inches should be taken off, to allow room for a sufficient key for the plaster.

CHAPTER VII.

OF SCARFING, JOINTS AND STRAPS.

Taken (with a few omissions) from Tredgold's Elementary Principles of Carpentry.

284. The joints having to support whatever strains the pieces joined are exposed to, should be formed in such a manner that the bearing parts may have the greatest possible quantity of surface; provided that surface be made of the best form for resisting the strains.

For, should that part of the joint which receives the strain be narrow and thin, it will of course either indent itself into the pieces to which it is joined, or become crippled by the strain; and whichever of these happens, a change must be produced in the form of the framing.

The effect of the shrinkage and expansion of timber should be considered in the construction of joints. On account of the shrinkage of timber dovetail joints should never be used in carpentry, as the smallest degree of shrinking allows the joint to draw out of its place; and, consequently, it loses all its effect in holding the parts in their proper situation. Dovetail joints can only be used with success when the shrinkage of parts counteract each other; a case which seldom happens in carpentry, but is common in joinery and cabinet-making.

Joints should also be formed so that the contraction or expansion may not have a tendency to split any part of the framing. The force of contraction or expansion is capable of producing astonishing effects where the pieces are confined, and may be sometimes observed in framing that has been wedged too tightly together in improper directions. The powerful effect of expanding timber is well known to quarry-men, as they sometimes employ its force to break up large stones.

285. In forming joints the object to be attained should always be kept in view, as that which is excellent for one purpose may be the worst possible for another. This consideration then must guide me in the division of this section, which will be considered under the following heads:

i. Of lengthening pieces, that are strained in the direction of their length.

ii. Of lengthening pieces exposed to cross strains; and building beams.

iii. Of lengthening beams that have to resist compression.

iv. Of joints for framing.

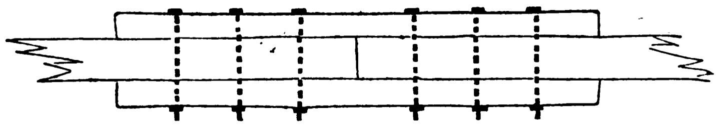
v. Of joints for ties and braces.

§1. *Of lengthening pieces of Timber, that are to resist strains in the direction of their length.*

286. The simplest and perhaps the best method of lengthening a beam is to abut the ends together, and place a piece on each side; these, when firmly bolted together, form a strong and simple connexion. Such a method of lengthening a tie is shown by the

following figure; and is what ship carpenters call *fishing* a beam. It is obvious, however, that the strength in this case depends on

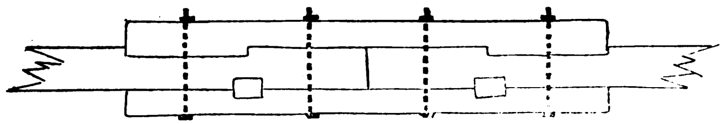
Fig. 55.



the bolts, and the lateral adhesion and friction produced by screwing the parts together.

The dependence on the bolts may be much lessened by indenting the parts together, as shown by the upper part of the annexed figure; or by putting keys in the joint, as shown by the lower side

Fig. 56.



of the same figure; but the strength of the beam will be lessened in proportion to the depth of the indents.

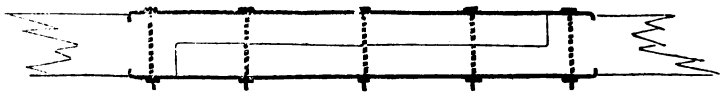
The only reasons for not depending wholly on bolts are, that should the parts shrink ever so little, the bolts lose a great part of their effect; and the smallness of the bolts renders them liable to press into the timber, and thus to suffer the joint to yield.

The sum of the areas of the bolts should never be less than two tenths of the area of the section of the beam; and it is not a good practice to put the bolts near to the end of the pieces.

287. The most usual method of joining beams is that called *scarfing*, where the two pieces are joined so as to preserve the same breadth and depth throughout; and wherever neatness is preferable to strength this method should be adopted.

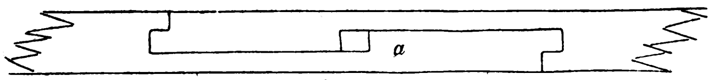
From Fig. 57 to Fig. 60 four methods of scarfing are shown. The first, Fig. 57, is the most simple; it depends wholly on the bolts, and in this and like cases, it is best to put a continued plate of iron on each side for the heads of the bolts. The ends of the plates may be bent and let into the beams.

Fig. 57.



288. The annexed figure is a joint that would do without bolts, but it is clear that the strength would not be quite so great as half

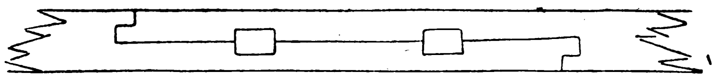
Fig. 58.



the strength of an entire piece. The key or double wedges, at a, should only be driven so as to bring the parts to their proper bearing, as it would be better to omit it, than to drive so as to produce much constant strain on the joint. It is not necessary that there should be a key, except when bolts are to be added, and then it is desirable to bring the joints to a bearing before the bolts be put in. The addition of bolts and straps makes this an excellent scarf.

289. The following figure is a slight modification of the last described scarf, where the keys are supposed to be of hard wood;

Fig. 59.



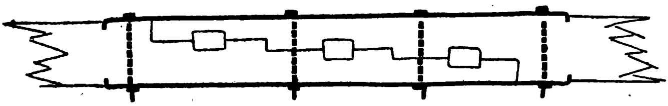
if of a curled grain so much the better. In this form the scarf is easier to execute, and equally as good as the last, when bolts are used.

290. The next figure represents a scarf where the oblique joints* in the last examples are avoided, and the same degree of

* *The examples with oblique joints, here alluded to, are omitted in this work, as inferior to those which are retained.*

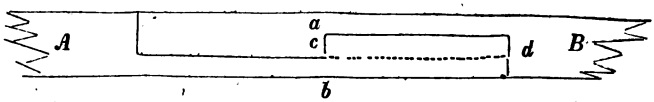
strength is obtained; at the same time it is very simple and easy to execute.

Fig. 60.



291. To determine the length of a scarf, in joining beams, it is necessary to know the force that will cause the fibres of timber to slide upon each other. The researches upon this subject have already been laid before the reader in Chap. VIII, Part I. To apply them to our present object, let A B, in the succeeding figure,

Fig. 61.



be part of a scarfed beam, strained in the direction of its length, and put together without bolts. Now it is plain that the strength of the part c b must be exactly equal to the force that would cause the fibres to slide at the dotted line c d; for if the part c d were shorter, the joint would be less strong than it is possible to make it.—Also, if the depth of the indent a c be too small, it would be crushed by the strain; consequently, the parts must have a certain proportion, so that the joint may be equally strong in each part.

292. In the first degrees of extension and compression the resistance is equal, therefore the depth of the indent a c must be equal to the part c b, in order that the strain may be equal; and it is evident, that when there is only one indent, as in this example, the depth a c should be one third the whole depth. Also, let d be the depth of the beam, and m the number of indents; then $\frac{d}{3m}$ = the depth of each indent. Or the sum of the depth of the indents must be equal to one third of the depth of the beam.

293. To determine the length of the part c d, we must know the ratio between the force to resist sliding, and the direct cohesion of the material. Let the ratio be as 1 : n; then c d must be equal to n times c b; that is, in oak, ash, or elm, c d must be equal to from 8 to 10 times c b.

In fir, and other straight grained woods c d must be equal to from 16 to 20 times c b.

294. Hence may be derived some maxims that will be sufficiently accurate for practical purposes:

i. In oak, ash, or elm, the whole length of the scarf should be six times the depth or thickness of the beam when there are no bolts.

ii. In fir the whole length of the scarf should be about twelve times the thickness of the beam, when there are no bolts

iii. In oak, ash, or elm, the whole length of a scarf depending on bolts only, should be about three times the breadth of the beam; and for fir beams it should be six times the breadth.

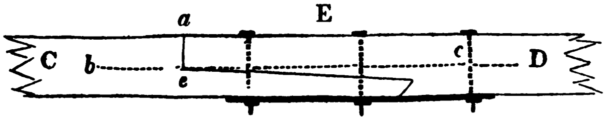
iv. When both bolts and indents are combined, the whole length of the scarf for oak and hard woods may be twice the depth; and that for fir, or soft woods, four times the depth.

§2. *Of lengthening beams that are intended to resist cross strains.*

295. Beams to resist cross strains require to be lengthened more frequently than any others, and, from the nature of the strain, a different form must be adopted for the scarf from that which is best for a strain in the direction of the length. There are cases where beams are exposed to both strains at the same time, but the cross strain is generally that of the most importance. Of this we have an example in the tie beam of a roof, where the strain in the direction of the length is very small compared with the cross strain.

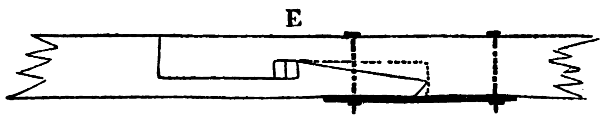
Let C D, Fig. 62, represent a beam strained by a load at E, and supported at the ends. All the parts above the middle of the depth, b c, will be compressed, all below will be extended; therefore. the square abutment a e is better for the upper side than any complicated joint whatever; and it is evident, that all oblique joints should be avoided on the compressed side. In this figure the whole of the strength of the lower side depends on the bolts and strap.

Fig. 62.



296. The following figure shows another form, where the lower side is indented so as not to depend wholly on the strap and

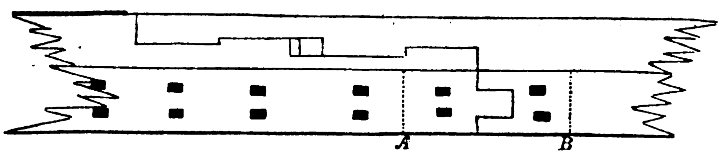
Fig. 63.



bolts; and a key is introduced to tighten the scarf. It will readily appear, that had the joint been cut to the dotted line instead of the oblique line, the strength would have been much impaired.

297. The annexed figure represents an angular view of a scarf, where it is jointed the contrary way. An iron plate at A B is sup-

Fig. 64.



posed to be removed, which shows the tongue at the end of the scarf. This method appears to me to employ more of the strength of the timber than any other, and is very well adapted for a tie beam where it is strained both across and in the direction of its length.

In all these cases the depth of the indents, and the length of the scarf, will be obtained by the same rules as for beams strained in the direction of their length. See Art. 292 to 294.

In scarfing beams to bear a cross strain it would be a great advantage to apply hoops or straps instead of bolts, as the coach makers and ship carpenters do. It would be easy to form the scarf so that hoops might be driven on perfectly tight.

There is no part of carpentry that requires greater correctness in workmanship than scarfing; as all the indents should bear equally, otherwise the greater part of the strength will be lost. Hence we see how very unfit some of the complicated forms shown in the old works on carpentry were for the purpose. It is certainly very absurd to render the parts difficult to be fitted, when the whole of the strength depends on their fitting well. "But many," says professor Robison, "seem to aim at making the beam stronger than if it were one piece; and this inconsiderate project has given rise to many whimsical modes of tabling and scarfing.*"

§3. *Of Building beams.*

298. The manner of building beams has already been considered in Art. 136 to 139. It may not be superfluous here to remark, that the position of the indents is not a matter of indifference. If two plain pieces were laid upon one another, and supported at the ends, the pressure of a weight applied in the middle would cause them to bend, and the touching surfaces would slide against one another; the upper piece sliding towards each end upon the lower one. This sliding is effectually prevented by indenting the surfaces, as shown in figure 65, when the pieces are bolted

Fig. 65.

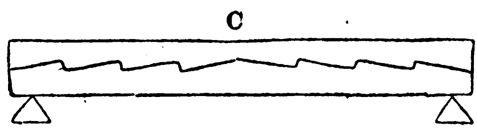
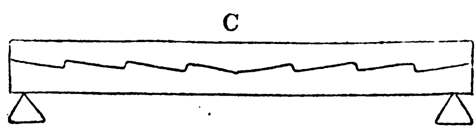


Fig. 66.



* *Art. Carpentry, supplement to the Enc. Brit.*

together; but if the same indents be reversed, as in Fig. 66, they produce scarcely any effect, and nearly the whole strain is upon the bolts.

Wherever the principal strain on the beam may happen to be, to that point, as at C, Fig. 65, the indents should direct their square abutments; that is, towards the straining force. When the beam is uniformly loaded, the greatest strain is at the middle.

I have often seen, in drawings, all the indents put the same way, and sometimes as in Fig. 66; otherwise the preceding remarks would have appeared to have been unnecessary.

If the depth of the indents be too small in a built beam, they will not be capable of resisting the pressure; and if they be made too deep, the number of fibres will be diminished, and consequently the strength of the beam; therefore there is a depth for the indents, by which a maximum of strength will be gained. Duhamel undertook to ascertain the proper depth by experiments*; and the general rule I have given in Art. 138, agrees extremely near with the case he tried.

§4. *Of lengthening beams that are intended to resist compressing forces.*

299. When a post or strut is required to be longer than timber can be procured, as sometimes may occur in the construction of wooden towers, spires, wooden bridges, or centres, the same form of joint or scarf is applicable as when the piece is pulled in the direction of its length, with this difference, that there must not be any inclined or oblique parts in the scarf.

Figs. 57, 58, 59, 60, 61, and 64, will answer equally well for posts or ties, only it would be better to tongue the ends, as in Fig. 64.

In Fig. 55 a piece on each of the four sides would be necessary, without some other mode of strengthening it should form a part of the framing to which is to be applied. It is not a very neat method of piecing a strut, but it is one that is very convenient, espe-

* *Transport des Bois, p. 498.*

cially in temporary structures, such as centres, where it may generally be braced in one direction, and where a more laboured form of joining would be much out of place.

§5. *Of joints for framing.*

300. *Of joints for bearing purposes.* The joint of a binding joist into a girder is an example of this kind of joint. The greatest strains upon the fibres of a girder are at the upper and lower surfaces, and the strain gradually decreases towards the middle of the depth, where it becomes insensible; hence the most suitable place for a mortise is at the middle of the depth.

The upper side being compressed, it is imagined by some writers, that the tenon might be made to fill so tightly that the strength of the girder would not be impaired by it, but this is a mistake; for any one who knows any thing of the practice of carpentry knows that it cannot be done in an effectual manner: besides, the shrinkage of the joist would soon render it loose, however tightly it might be fitted in the first instance.

Considering then that the best place for a mortise in a girder, or other beam in a like position, is at the middle of its depth, the next point is to consider the best place and form for the tenon.

If the tenon be near the lower side, it will evidently have the advantage of employing most of the strength of the joist; but this on account of the strength of the girder cannot be adopted; therefore, the form in general use, represented in Fig. Art. 144, appears to combine all the advantages required. The tenon being one sixth of the depth, and placed at one third the depth from the lower side.

301. Binding joists, or any other beams in a like position, should never be made with double tenons; for, as Mr. Price has judiciously remarked, it weakens the timber framed into, and both tenons seldom bear alike; besides, in pinning it rarely happens that there is a draft on both tenons, unless the pin be as tough as wire.*

* *British Carpenter, introduction.*

All horizontal timbers for bearing purposes should be notched upon the supports rather than framed between, wherever it can be done, as much additional strength is gained by preserving timbers in continued lengths. The same observation applies to inclined timbers, such as common rafters. See Art 83.

302. *Of the joints of framing.* The object to be obtained by a system of framing is to reduce all the pressures into the directions of the lengths of the pieces composing the frame; therefore the form of the joint should be made so as to direct the pressures into the axes of the pieces. As when the direction of the strain does not coincide with the axis of the piece strained, the strain will be much increased. Now, from the form of the joints commonly employed, it must generally happen, that by skrinkage, or settlement, the joints will bear only upon the angular points of the joint; which not only gives a considerable leverage to the straining force, but also, by the whole bearing being upon an angle, that angular point must be either indented or crippled by the strain, which of course causes a further settlement. The extent of the evil of partial bearings becomes very manifest when the strains are considerable. In the centres of the Bridge of Nuilly seven or eight pieces in each frame were split from end to end, and many others bent considerably; and in these centres the joints were not very oblique, otherwise the effects would have been more serious. Perronet was sensible of the cause, and in order to correct it, he formed the abutments according to an arc of a circle, of which the other extremity of the piece was the centre.

This method was adopted for the joints of the centre for the Bridge of Sainte Maxence, and also in that for the Bridge de la Concorde, at Paris; and it was effectual in preventing the splitting and bending of the pieces.

Circular abutments have been strongly recommended by Prof. Robison, and they certainly might be employed with much advantage. The principle is similar to the well known contrivance called the ball and socket; and to the joints of animals, where with considerable latitude of motion, uniformity of pressure is preserved. That they require more labour, I am well aware, but were the labour doubled, it would be comparatively a trifling object in in framing of importance; and for any other purpose it is not recommended.

It is obvious, that when the one end of the piece moves, a corresponding movement will take place at the joint, and when the radius of curvature at the joint is small, as it is in the joints of animals, the motion at the joint will be scarcely perceptible. For in a roof of a 30 feet span a sinking of six inches in the middle would not cause the joints to slide more than one tenth of an inch.

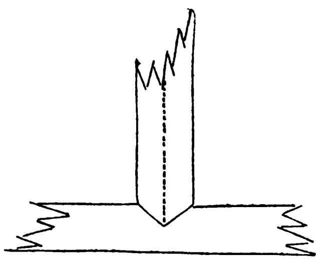
I will now proceed to notice some of the joints of most common occurrence, and point out the advantages to be obtained by altering the forms of them.

When one piece is perpendicular to another, as, for example, a post upon a sill, the most usual, as well as the most easy method, is to make the joint square, with a short tenon of about one fourth of the thickness of the framing, to retain it in its place.

But if the joint be not very accurately cut, the whole load will bear upon the projecting parts; consequently, the centre of pressure will seldom coincide with the axis of the post, and its power to resist the pressure will be much lessened.

If, instead of cutting the joint square, it were cut to form an angle, as is shown by the following figure, then a very little care in cutting the joint would make the centre of pressure coincide with the axis.

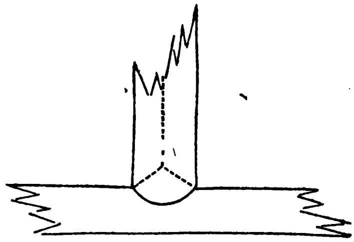
Fig. 67.



303. Now whether the joint be square or angular, a slight inclination from the perpendicular will throw the pressure upon one corner; but if the joint be described from a centre situate in the axis, and with a radius not much greater than half the breadth of the post, as is shown in the following figure, then, with any change

of position, the joint will slide till the pressure be uniform upon the joint; and if the joint be moderately well made, the pressure will not act with any sensible leverage upon the post.

Fig. 68.

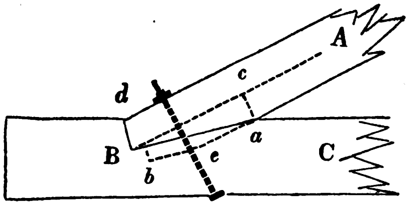


304. When the pieces to be joined are not at right angles to one another, the joints may be of two kinds; the principal rafter of a roof affords an example of each. Before proceeding to show the nature of these joints, it is necessary to state, that the direction of the strains, as well as their magnitude, as determined by the principles laid down in Chap. I, Part II, remain sensibly the same, whatever may be the form of the abutting joints, except in as far as the form of the joint alters the point of bearing; which may in some cases cause the pressure to act with a leverage nearly equal to half the depth of the beam. The strength of the joint itself depends upon its form, as it may be so made that there will be a tendency to slide, which it would be well to avoid, without having recourse to straps.

The resistance at the joint is always most effectual when the abutment is perpendicular to the strain, but where the angle formed by the inner sides of the pieces is very acute, this kind of abutment cannot be obtained, at least not without wounding the tie too much.

Let A B C, Fig. 69, be the joint of a principal rafter upon the tie beam; where the dotted line A B shows the direction of the straining force, and B a is one of the abutting surfaces. Draw a c perpendicular to B a; then, by the principles of the resolution of forces, c a will represent the force pressing on the inclined part, B a, of the joint; and there will be a force represented by B a to be sustained by the abutment B d. And, as this abutment will resist the force most effectually when it is perpendicular to it, therefore B d should always be perpendicular to B a; the same will be true in whatever direction the straining force acts.

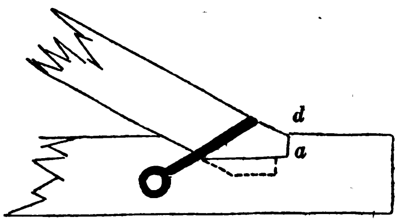
Fig. 69.



The foregoing figure shows one of the most common joints; B a and B d are the abutting surfaces, which are to be perpendicular to each other; and b e shows the tenon, the thickness of which may be about one fifth of that of the framing. This joint might always take better hold of the tie beam than it is generally made to do, without any risk of weakening it. In general B d should somewhat exceed half the depth of the rafter, and the joint should be left a little open at a, in order that it may not be thrown off at B by the settling of the roof.

305. The following figure is a form that is approved by some writers, but by others it is considered inferior to the one already

Fig. 70.



described. The dotted line shows the form of the tenon; but it would be better put together in the same manner as the joint to be described in the next article.

306. Fig. 71 is a very good form for a joint, as b c is perpendicular to the strain, considering the strain to be in the direction of the rafter, which is near enough to the truth for our present purpose. The best method of forming this joint is shown by the pro-

jected sketches A and B; as by this method it is easy to see when they are accurately fitted; whereas in a mortise and tenon joint this cannot be done, and they are often very imperfectly fitted, because it is easy to conceal any defect.

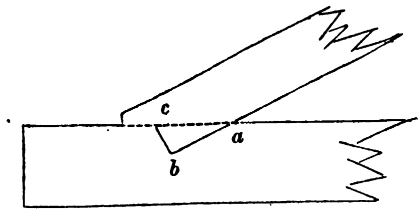
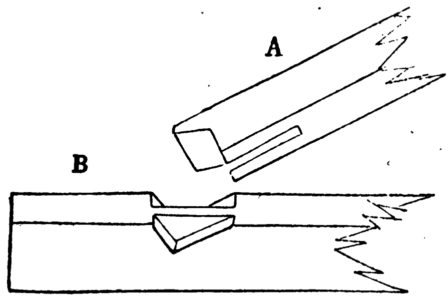


Fig. 71.



307. Fig. 72 shows a joint with a curved abutment; the line B A represents the direction of the strain; and c the centre, which should be in this line. The radius for describing the joint should be greater than half the depth of the rafter; and the part between a and b, of the joint, should be left open, to admit of any degree of settlement that may take place. The projected sketches C and D show the manner of forming the joint.

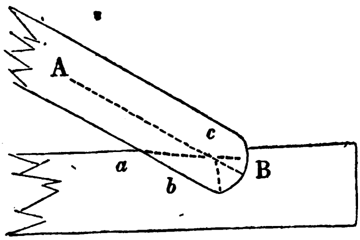
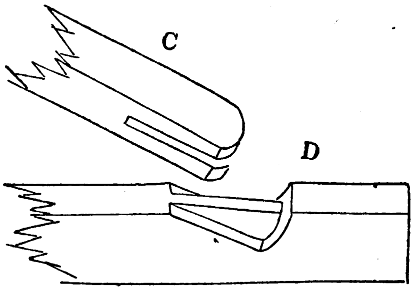


Fig. 72.

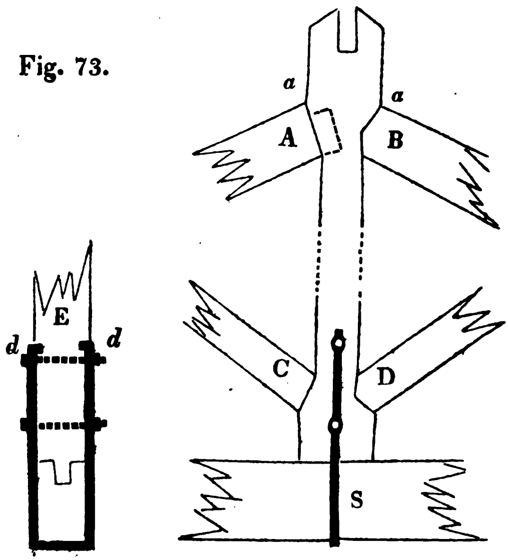


Sometimes double abutments are used in joints, but it requires both great accuracy in workmanship, and also that the roof should not settle more or less than the workman allows for, in order to make both abutments bear equally; therefore I consider one good abutment preferable to two. Prof. Robison very justly remarks, that "because great logs are moved with difficulty, it is very troublesome to try the joints frequently to see how the parts fit; therefore we must expect less accuracy in the interior parts. This should make us prefer those joints whose efficacy depends chiefly on the visible joint." But to make double abutments still further increases the difficulty, without adding any thing to the security of the joint.

308. The joint at the upper end of a principal rafter differs from that at the lower end in some respects; but the difference is not material in respect to the principle of forming the joint. Making the king post larger at the head enables us to get a more effectual abutment: and this abutment should be, in common joints, square to the back of the rafter, as at A, in Fig. 73, with a short tenon shown by the dotted lines. When the head of the post is

not sufficiently large to get the abutment square to the back of the rafter, it is usual to cut it as at B. In either case the joint should be left a little open at a; so that when the roof settles it may not bear upon the acute angle. It is obvious that when the roof settles, unless it be provided for the change, the whole bearing will be on the upper angles of the joints, as at a. and these sharp angles will indent into the king post, or become bruised in proportion to the degree of settling, and of course increase it. And as all roofs will settle more or less, the carpenter will see how important it is to make the joints bear on the opposite corner when first fitted. To remedy this defect, I would propose to make the joint in the form of a circular arc, in order that the pressure on every part may be equal, whatever degree of settling may take place. A joint of this kind is shown below, by Fig. 75.

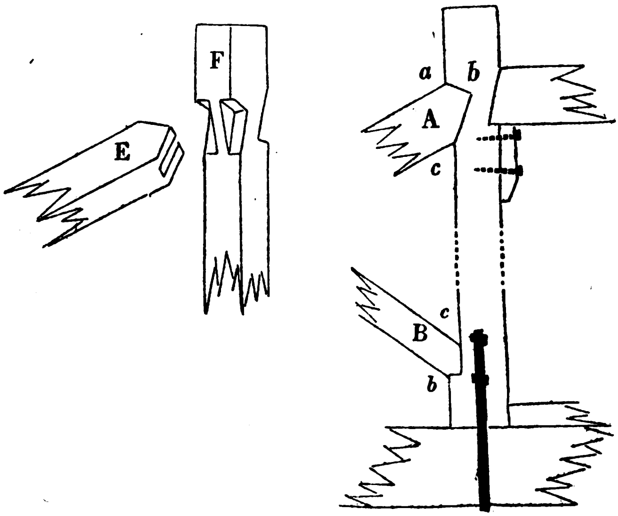
Fig. 73.



The same remarks will apply to all similar joints; such, for example, are the joints between the braces or struts and king post at C and D in the preceding figure.

But the joints D and B would be better formed in the manner shown at A and B, Fig. 74, where a b is at right angles to b c. The reason for this form is given in a preceding article. (Art. 306.) The joints may be made as shown by the projected sketches E and F.

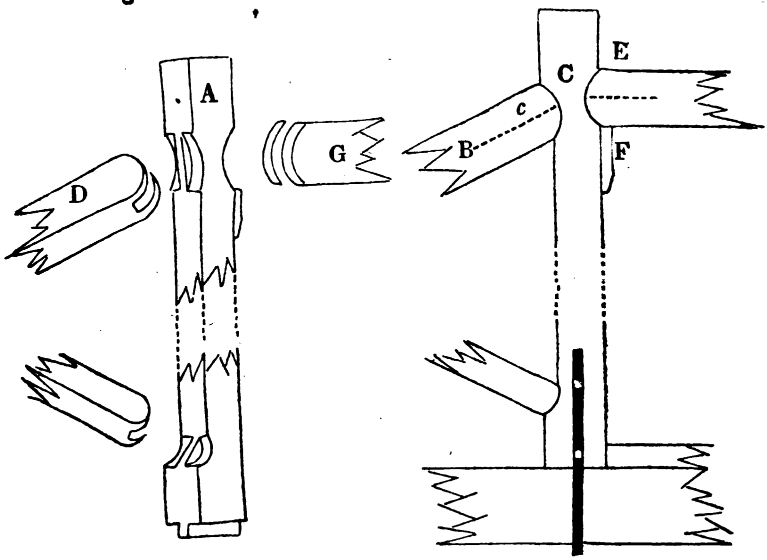
Fig. 74.



309. A joint with a curved abutment is shown in the following figure; B C represents the middle of the depth of the rafter, and c the centre from which the curve is described; the radius C c should not be less than half the depth of the beam. A and D are projected sketches of the joint.

In Fig. 75, E shows a joint for the straining beam of a roof, and G is a projected sketch of the joint. As a further security, the

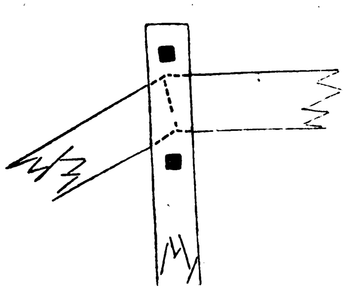
Fig. 75.



piece F might be nailed upon the queen post C. The lower part of the figure shows the joint for struts or braces.

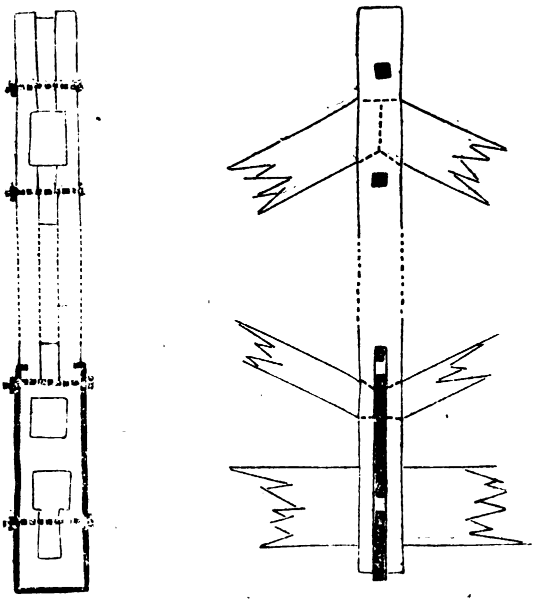
310. Instead of the common method of framing the king or queen posts between the ends of rafters and the like, it is much better to make the rafters abut against one another, end to end; and to notch a piece on each side and bolt through these pieces. I have called these pieces *suspending pieces*, because they serve to

Fig. 76.



suspend the tie beam. (The term post is ridiculous, because it conveys a false notion of the office of the piece; but it is difficult to change a term in common use.) Fig. 76 and 77 show this

Fig. 77.



method of joining. It has been long in use for centres, bridges, and roofs, as may be seen in the plates of the bridge at Schaffhausen, the bridge of Ritter, near Berne, the roof of the Riding House at Moscow; and in some very good roofs lately executed in this country.

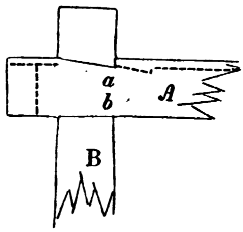
The German carpenters, and, I believe, many others, put a piece of lead between the abutting surfaces of their joints, in order to equalize the pressure. This method is not, however, so useful in timber work as it is in stone work; and I would, for the joints of carpentry, give the preference to putting a plate of cast iron between the abutting surfaces.

§6. *Of joints for ties and braces.*

311. There is no part of carpentry where defective joints are attended with such serious inconveniences as the joints of ties, nor are there any other joints so often ill constructed. It is not easy to make a good tie joint, from the very nature of timber, and therefore many ties should not be used where it is possible to avoid them. I have before stated, that "dovetail joints should never be used in carpentry" (Art. 284); and the maxim cannot be too strongly urged, wherever the joint is intended to hold the parts together.

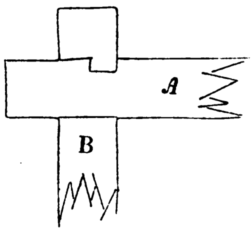
For let A, in the following figure, represent the angle of a building, where the wall plates are joined by a dovetail joint; the part

Fig. 78.



a b being the crossway of the wood, will shrink in drying; and as the other piece is the lengthway, its shrinking will be insensible; therefore a very small degree of shrinkage will allow the joint to draw considerably, as is shown by the dotted lines. A joint made as shown in the annexed figure, avoids any danger of giving way from the shrinking of the timber, and is better than any dovetail joint whatever.

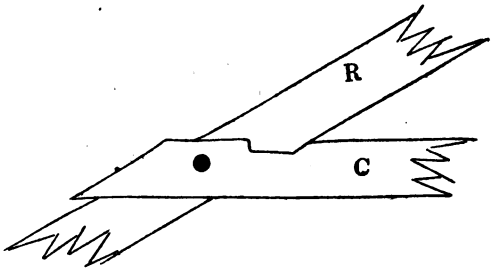
Fig. 79.



Dovetail joints, or dovetail tenons, have been used in various parts of carpentry; such as the collar beams of small roofs, the lower end of king and queen posts, and for joining plates and the like. In all these cases they are the worst kind of joints that can be used. The *carpenter's boast* must also be classed as a dovetail joint equally as defective as any.

312. The following figure shows a method of notching a collar beam, C, into the side of a rafter, R, which is far superior to a dovetail joint.

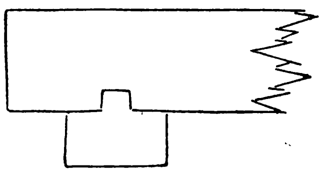
Fig. 80.



A stout pin, of tough but straight grained oak, is an excellent addition to a tie joint, and is more economical than iron bolts. The excellence of wooden pins is fully shown by their extensive use in ship carpentry, as they form the chief connexion of ship timbers.

313. The best method of *cocking or cogging the tie beam* upon the wall plate, is shown by Fig. 81.

Fig. 81.



§7. *Of Straps*.

314. "A skilful carpenter," says Prof. Robison, "never employs many straps, considering them as auxiliaries foreign to his art;" and indeed they are seldom necessary, except to suspend the

tie beam to the king post, and to secure the feet of the principal rafters to the tie beam of a roof.

Strap for king or queen post. In Fig. 73 a shows a strap for suspending the tie beam to a king or queen post; its hold of the post may be improved by turning the ends, as at d d, in the section E; these, when well fitted, will, with the addition of bolts, give the strap a firm hold; or staples, as in Fig. 74, may be used for a slight roof. The strengths of straps for different bearings are stated below. When the longest unsupported part of the beam is

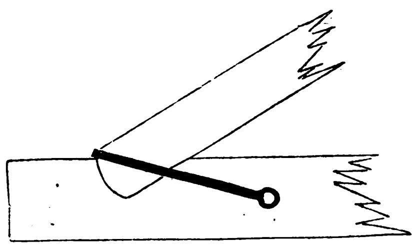
10 feet, the strap may be	1 inch wide by	3 sixteenths of an inch.
15	1.5	1 fourth
20	2	1 fourth.

These dimensions are quite sufficient for common purposes; but where the machinery of a theatre, or other heavy loads, are to be borne by the tie beams, the straps must be made stronger in proportion to the load.

Where suspending pieces are used instead of queen posts, the same kind of strap will apply, as is shown in Fig. 77.

315. *Strap at the foot of a principal rafter.* A strap at the foot of a principal rafter is intended to form an abutment for it, in case the end of the tie beam should fail. If the strap be put too upright, it will, instead of forming an abutment, become quite loose when the roof settles; and as it is intended to prevent the rafter foot sliding along the tie beam, an oblique position, as shown by Fig. 70 and the one annexed, will be the most effectual. Straps

Fig. 82.



of the same size as are used for the king post will be sufficient. In bolting on straps they ought to be drawn tight; Mr. Price recommends square bolts for this purpose; he says, "for this reason, if you use a round bolt it must follow the augur, and cannot be helped; but by helping the augur hole, that is, by taking of the corners of the wood, you may draw a strap exceedingly close, and at the same time it embraces the grain of the wood in a much firmer manner than a round pin."

Sometimes a bolt is used put through square from the back of the rafter, with cross plates at the head and nut. Fig. 69 shows this method, the dotted lines representing the bolt.

316. It must be remembered that thin plates of iron decay very rapidly, particularly in damp situations; therefore they should be well secured against rust by being painted as soon as they are made. Mr. Smeaton, writing on this subject, says, "I had observed, that when iron once gets rust, so far as to form a scale, whatever coat of paint or varnish is put over this, the rust will go on progressively under the paint." The method he used to prevent iron rusting was to heat the whole of the iron work to about a blue heat, and immediately strike it over the surface with raw linseed oil; the next day, if properly done, it appears as if a coat of varnish had been laid on. By this method the pores of the iron become filled, and effectually protected from corrosion.

Another method, that is easily applied to small articles, consists in heating the metal, and rubbing it over, while hot, with wax. By this process the iron acquires an extremely uniform coating.

Nails and other small fastenings might be rendered much more lasting by boiling them in linseed oil. This is often practised by slaters, to protect their nails from rust.

As it is difficult to heat large articles, a coating that can be applied in a cold state is much better. One that dries quickly, and, it is said, perfectly preserves from rust the metals upon which it is laid, is described in the Repertory of Arts, Vol. 27 of the second series. It is prepared as follows: Grind to an impalpable powder one part (by weight) of black lead (plumbago), with which mix four parts of sulphate of lead, and one part of sulphate of zinc; to this mixture add, by degrees, sixteen parts of boiled linseed oil.

As strapping is often applied to prevent accidents, and to connect the parts when the timber itself is likely to decay, it is obvious that the iron work should be rendered as durable as possible, and particularly where it is exposed to the weather. I lay the more stress upon this point, because it is often neglected, and is of importance.