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Thursday, 14th October.

W. J. Sproule, Ma.E., Member of Council, in the Chair.

Paper No. 122.

FORTIFICATIONS.

By C. R. F. Coutlée, A.M.Can.Soc.C.E.

"Soldiers in peace are like chimneys in summer." However desirable permanent peace may be, its time has not yet come. Constant watchfulness and preparation, not slothful neglect, will eventually bring cosmopolitan harmony.

Standing armies and fortifications are the price of national liberty. We can obtain the first from Britain, our work as a colony is to delay invasion or rebellion, and this is best secured by fortification of storage centres.

The Canadian volunteer corps, especially those of our cities, are phenomenal in their unselfish devotion. Engineers, from constant contact with emergencies, are exceptionally fitted for officers. During the Crimea "persons of scientific attainments, desirous of serving at Sebastopol," were advertised for, and many civil engineers responded with great honour to their profession too, for these "persons" became noted in our army annals.

Modern war is not made against individuals. Soldiers of all nationalities are considered individually equal; superiority depends on *personnelle* and *materiel*, the former referring to better feeding, drill, and the mental superiority of better cause, and the latter to weapons, forts and money.

The immediate effect of war may be appreciated by supposing this city, the commercial centre, to be held by an enemy; the mayor would immediately be called upon to raise a tribute of more millions of dollars than the city will borrow in many years—a sum sufficient to build such a ring of forts about us as would prevent an incursion (our volunteers manœuvring between the forts), till the St. Lawrence bore us aid from Britain. To locate and build these permanent forts in time of peace, to erect redoubts in the intervals, after a declaration of war, and to entrench on the eve of battle, is the work of the military engineer.

Primarily, fortification, hasty or permanent, protects the smaller from the greater force, the object being to delay an invader in reaching the objective of his campaign.

Cartier found an Indian village, not far from here, protected by a palisade; similar stockaded, savage villages are stormed by our soldiers at the present day. A continuous wall was the first style of fortification to protect partially civilized men from the more warlike and fierce, whose only wish was to plunder and destroy. Examples of this are the Chinese wall against the Tartars, Agricola's walls against the Picts and Scots, and the Montreal wall. Prison walls, with a few wardens, keep many times the number of convicts within the cordon.

A battering ram was the first engine used by assaulters to breach ancient walls, but, to prevent this, a ditch was dug outside the wall, thus holding the assaulter at arm's length, say 20 feet. The modern "arm's length" is about 2 miles. The attacking artilleryman then consulted with his engineer, and this worthy built a covered sap across the ditch, undermined the wall, using timbering, which, at the proper time, was set on fire, and the wall came down. The defenders met these tactics by pouring hot water and molten lead on the devoted heads of the attackers. Corbelled out battlements, from which to fire arrows down the face of the escarp wall, and projecting towers, loop-holed to flank or fire along the face, then appeared and developed gradually into Vauban's bastion trace of the end of the last century, the highest refinement of "tower flanking."

Artillery at first consisted in throwing large stones from catapults and an occasional live captive over the wall. Powder was invented, and at Berwick, in 1405, a castle tower was shattered by a round shot, and the alarmed garrison capitulated. Enormous guns were cast in situ before Constantinople in 1453. In Scotland, the inventive genius and quick wit of the nation vented itself in the building up of Monso Meg at Edinburgh. Needless to remark, the Scot's plan of building up ordnance finally carried the day in artillery, as in many other matters.

With the great velocity and range of powder-propelled projectiles, came the necessity of placing the walls below ground to form walled ditches as obstacles to climbing a bank of earth or rampart, which better resisted breaching by the guns. The slopes of these earthen parapets and their thickness on top prevented the defender behind them from seeing into the ditch in front of him, so the trace or plan of the work was designed with jutting-out portions or bastions from which to see and fire along the ditch. The distance apart of the bastions depended partly on the range of the weapons that fired from them. These bastions became the focus of concentrated artillery fire, to ruin their power of flanking the ditch when the time for assault arrived. Accurate rifled guns and long range rifles (2,000 yards) have rendered cramped bastions untenable, so long straight parapets are now built and flank defence provided from carefully and elaborately designed caponiers, or vaulted chambers set at right angles to the face, and extending across the ditch. This system is known as the Polygonal Trace, each face of the enceinte corresponding to a side of the polygon enclosing the city. This polygon is again surrounded by a belt of forts.

Though field fortification is but the work of a few hours, yet it will serve to illustrate the principles which are obtained in elaborated, permanent works.

The requirements of defensive works are:—

(1) Exposure of the enemy.

(2) Cover from the enemy.

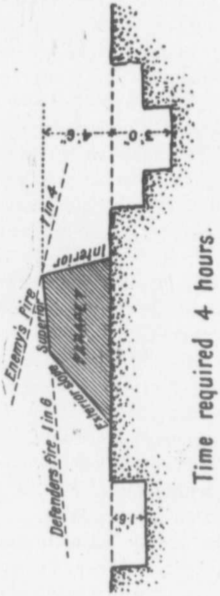
(3) Obstacles to the enemy's approach.

(4) Ease of sortie for the defenders.

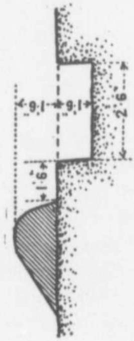
(5) Above all, the works must suit the configuration of the ground, and the force and time available.

If any cover for the enemy exists in front of the defensive lines, such as woods, hedges, fences, houses, ditches, etc., it is removed to ensure his exposure to a withering fire as he advances; especially over the zone for 500 yards immediately in front. There nowadays the decisive struggle takes place. So quick and deadly is the modern rifle-fire that the attack must scatter and retire, or the defenders leave their works, when within 300 yards of each other; the bayonet conflict and shock of charge is generally a thing of the past, in daylight at least.

The course of a modern battle is a great artillery combat in the morning, and a general infantry advance during the afternoon or under cover of darkness. During the artillery duel, movements towards the flanks are made to roll up the line from one end. During the American war, both forces entrenched on opposite sides of a ravine, at times, and, while containing their respective fronts, endeavoured to out-flank each other. Boards painted to represent men were used as a "bogus force" along the front, so real troops might be sent to a flank.



Time required 4 hours.



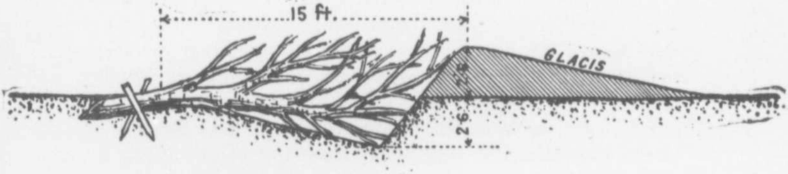
Half-hour

Guns are massed in batteries of twenty or thirty, and prepare the infantry advance by silencing the opposing guns and then destroying earth-works and generally unnerving the occupants, while their noise and success cheers on the attack.

The simplest cover for men is obtained by digging the service "half-hour shelter-trench," which can be enlarged if time permits.

Breast-works against field artillery must be from 6 to 8 feet thick. Direct artillery fire damages parapets by cutting down the crest, or interior edge, by partial breaching and plowing up of the slopes.

Obstacles are used to impede the approach of the attacker and retain him under the most deadly fire. These consist of anything difficult to walk over, either natural, as a swamp, or artificial, as a wire entanglement, or an abatis. The latter is readily applicable to our country with its wealth of bush land and skilled axemen. An abatis consists of trees laid horizontally, tops towards the attack, and the branches sharply pointed; for protection from artillery fire, a small excavation is made, and a glacis formed in front.



A wire entanglement consists of stakes driven chequerwise at 5 foot intervals, and wire strung from picket to picket about 18 inches above the ground; the quantities of barbed wire in the country favour the making of this very efficient obstacle. Pointed stakes, pits and *chevaux de frise* are also commonly used. Pointed stakes driven below water have been discovered in the Thames, placed there 1800 years ago by Cæsar to prevent the Britons fording the river.

Through all obstacles, passages about 150 yards in width should be left to enable sorties, or counter-attacks, to be rapidly made at a critical moment, when the attack may seem to waver. Inundations may be most ingeniously made, and flanks protected thereby. All obstacles should be hidden from distant view, to be as much as possible protected and unexpected.

An army entrenching on one side of a valley has, say, four hours to work; the commander designates to his engineer staff officer the points he wishes to have strengthened, thus generally defining the position. Sappers, under engineer officers, lay off the several works by stakes and ribbons of white tape, erecting frame profiles, when necessary, on these lines of tape; the working parties are marched and set to work; tools are carried by each battalion, and others are furnished by the engineer companies.

Jutting-out points are strongly fortified and protected by abatis. From these points the firing can be directed along the front to take the attacking lines in flank. Between these salient points, the trench work is of slight cross section, and not necessarily continuous; this curtain line, say 1,000 yards long, furnishes the frontal fire. To the front the land is cleared, and obstacles arranged. One flank is, perhaps, protected by a large march, the other strongly entrenched. Guns are massed in batteries on high ground, commanding the likely sites for the opposing artillery.

If the line is extended, and the force holding it, large farmsteads and villages are prepared for defence as strong points; these were always the scenes of the most desperate struggles during the Franco-Prussian war, the French being stubborn locality fighters.

Field positions, of course, must be so placed as to oblige their attack, and not merely their being masked by a small force.

If a position grows in importance, slight field works may be increased, in from fourteen days to three months, to formidable proportions, e. g., Plevna, during the Russo-Turkish war. Such works are known as semi-permanent or provisional fortification. The parapets are thickened, and ditches simultaneouly enlarged. Covered trenches, or blindages, are constructed of wooden frames, covered with logs and earth to a thickness of from 2 to 4 feet; in these bomb-proof sunken sheds, the garrison eat, sleep and live during bombardment; ready to man the parapet very quickly in case of an assault. Concrete and iron are sometimes used in constructing this class of work. Examples of this are seen at Washington.

For prolonged resistance, a second and a third line of defence are arranged, and also an interior stronghold, or keep, for stubborn defence to the last.

The modern idea of permanent fortification is a polygonal enceinte, surrounded by a ring of detached forts, about two miles beyond it. Antwerp is the best example of modern permanent works.

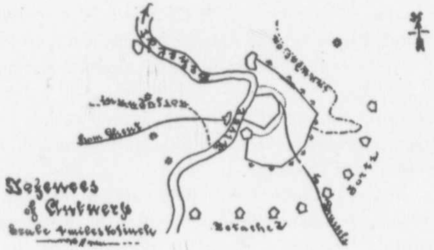
Belgians determined to put all their eggs in one basket, and, if attacked, to make a prolonged defence till combinations of other European powers raised the seige.

Instead of a line of frontier forts, using up all the national army for garrisons, resistance is concentrated at Antwerp, the commercial capital. The army gradually retires within the ring of forts, and forms an entrenched camp capable of supporting 100,000 men. The perimeter of the ring is about 20 miles, in addition to which inundations extend the investment line indefinitely. From one to two miles from the cordon of forts, the besiegers' lines of investment would have to be made and maintained in the face of 100,000 men supported by the guns of the forts. Each fort has a garrison of 1,000 men and about 120 guns. Three forts must be attacked at once by regular siege, as each fort mutually supports one side of the next. Heavy bombardment would be resorted to and every chance taken to surprise. Forcing the line of forts, however, is only the preliminary to a long and tedious siege of the enceinte, and that broken into, the northern citadel still remains for vigourous resistance by patriots at bay.

A general plan of one of these detached forts is shown. The front is tangent to the arc of defence, while the flanks protect adjacent forts and the ground between. The gorge, or rear, is, if possible, constructed so as not to afford much cover from the guns of the fortress, in case the fort is taken.

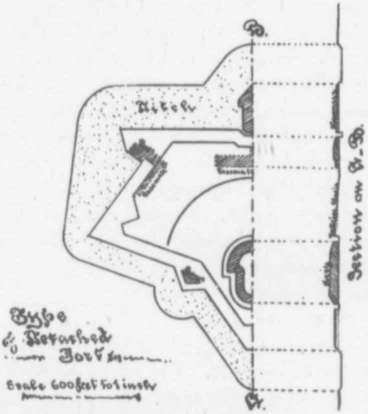
The keep is generally in the centre of the gorge, and furnishes flanking fire; an interior glacis protects the escarpments of the keep, and lays the whole inside open to a scorching fire, if the enemy succeeds in penetrating. Every possibility of surprise must be guarded against. Ample bomb-proof cover for protection of the garrison of, say, one thousand men, is provided, and for a thousand more of the manœuvring army within the ring. To serve these purposes, arched masonry chambers are placed securely under the front rampart, and the keep is a catacomb of heavy concrete masonry chambers well covered with earth; from its top, armoured guns are used.

The quantities of earth to be moved and the amount of masonry



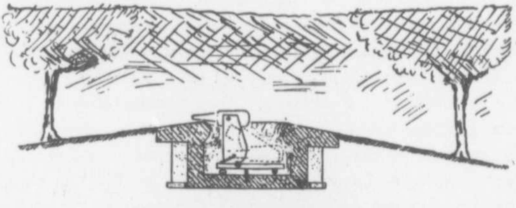
Defences of Antwerp

Scale 4 miles to inch



Type of Detached Fort

Scale 600 feet to inch

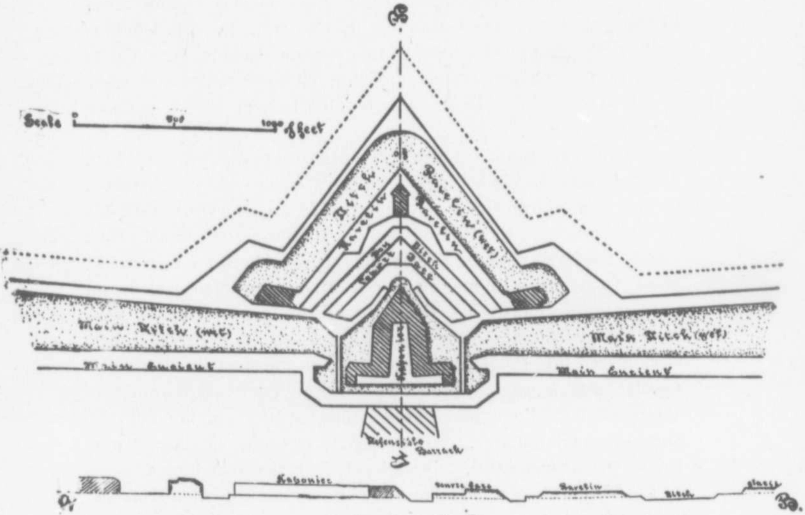


Moncrieff Emplacement

required for such forts would be most attractive to contractors. The professional interest in the problems of descriptive geometry involved, and the design of retaining walls, and other masonry, will be readily appreciated; especially as the number of forts required —about one per mile—enforces economy of design.

The most interesting detail of the enceinte of the fortress proper is the flank defence by caponiers, which must be guarded from the ever-increasing accuracy of long range artillery fire.

The figure shows a half plan and a section of a face of a polygonal system.



Section on A.-B.

The triangular ravelin serves as a salient point to keep the enemy at arm's length—300 yards—from the main face, and, besides, flanks the front from the reverse battery. Next is a *couvre face*, which protects the head of the caponier from breaching by distant artillery fire.

The caponier itself consists of a pointed head and two flanks firing along the main ditch. These flanks are a succession of vaulted gun chambers, about 15 feet wide, and covered by 75 feet of earth to render them bomb-proof. The enceinte is broken inwards at the rear of the caponier, and retreat secured to the last moment into the defensible barrack, which forms a sort of keep for the whole face.

A short sketch of the siege of Belfort during the Franco-Prussian war will serve to illustrate about what may be expected in modern operations of the kind. The able commandant, Col. Deufert-Rochereau, considered the fortress as a great battery round which his garrison of sixteen thousand men were to manœuvre. Three months elapsed before the Germans, coming from Strasbourg, began investment, and, in that time, the commandant built, with the aid of peasants, the semi-permanent forts at Les Perches, etc., besides which out-lying villages and woods were prepared for defence, in all cases tending to keep the Germans as far off as possible.

The Germans came in touch of the place early in November with about 10,000 men, who, after two days' sharp fighting, invested the place, on, however, a perimeter of 25 miles, giving only 400 men per mile, but the French thought the force to be double this. About the beginning of December, the German force was raised to 20,000 men, and, to make a bold front, bombardment was begun with only field guns. By the first week in January heavier guns were brought up, and, after several surprises, the French picquets were forced into the detached forts of Les Perches, upon which a regular attack was made. The garrison had a scant supply of ammunition for their guns, though the energetic commandant organized a shell foundry. An attempt to raise the siege by French troops was unsuccessful. Though the Germans were hard pressed on the 15th, 16th and 17th of January, a demonstration from the bombarding batteries deceived the garrison as to the actual position of affairs in the German lines.

After this, the siege was prosecuted with great vigour, and the trenches of regular attack opened.

An attack on one of the forts, made January 25th, failed, owing to a rocky sided ten-foot ditch. The fire from the fortress itself was now nearly subdued, and another assault was made on Les Perches redoubts only to find them deserted, save for a few men cooking breakfast in a bomb-proof.

Arrangements were then begun for an attack on the enceinte itself, but, by orders from Paris, the place surrendered on 13th February, after over 100 days' resistance, and only two of the outer ring of forts taken. The garrison lost one-fourth of its numbers. About 100,000 rounds were fired by the Prussian artillery.

Belfort was not ready, owing probably to political procrastination, but an energetic commandant built detached forts, and fortified villages and woods about it in three months' time. Worst of all, ammunition for the guns was not on hand. The disadvantage of an invested garrison, in not knowing what is taking place outside, is exemplified by the over-estimation of the German force from the first, and especially on the 15th, 16th and 17th of January.

The detail of earth works executed in connection with a siege will not be entered into here, suffice it to say that trench work is done under cover of darkness, the men being marched into their tasks, which are laid out by pickets, joined by white tape, placed by sappers under engineer officers. A sap is a trench where one man digs forward, throwing the excavation in front of him to cover himself as he advances; others follow, widening and deepening.

Military mining is most interesting, and, owing to the almost utter impossibility of advancing against the modern rifle and machine gun, it is likely to find more extended use in the future.

Field mining consists of sinking a shaft, say 2 x 4 feet, and 10 feet deep, and running a drift gallery, 2 x 4 feet, toward the foe. To meet this, the garrison use counter mine galleries, spreading face like to the front; listeners are placed in the extremities of the tunnels, and, when the vibration of the earth indicates the close approach of an adversary, explosives are packed in the chamber and fired.

Coast defenses, consisting of screened batteries of large calibre modern guns, are the most perfect and scientific branch of protected artillery. Hundreds of heavy guns in a score of unseen batteries, guarding a harbour, can, by electric connection, be simultaneously trained on a moving ship from cowing towers. Their fire thus, *en bloc*, would probably blow a boat to pieces. Beneath the surface, too, automatic and electric mines are placed. Range fenders for this class of work have become very perfect, especially in their automatic signalling features.

The most interesting application of fortification is, of course, to the defence of Canada.

We cannot justify expenditures, with such very remote chances of invasion, to build and equip forts on the scale of the concentrated defence of Antwerp or the frontiers of France, but schemes of defence required to be worked out in detail and kept up with modern advances in artillery. These plans should have the skeleton points marked permanently on the ground, and no better monument can be erected than a Moncrief fort.

These forts are circular pits, lined with 3 feet in thickness of concrete, in which a gun, say 6 inch, is so mounted as to sink out of sight by the force of recoil. The energy is stored to raise it again into the firing position; sighting is done by indirect methods.

This is the cheapest protection for artillery that can be built, and a ring of them to the south of Montreal could, by earth works in the intervals, be made a strong line of defence.

Groves of trees could be planted so as to screen the forts and furnish material for hasty, defensive works. Good roads and tramways within the circle would ensure interior communication and supply. Within this circle, too, the annual camps could be held, and each year familiarize the local troop with the work of defence.

Some of the work of a military engineer in such a locality would be the designing of drainage works, water supply, sanitation and communications, besides electrical and compressed air instalments —work of such interest and importance as to enlist the best services of our leading members as a Canadian Volunteer Corps of Defence.

Thursday, 28th October.

G. H. Duggan, Vice-President, in the Chair.

Prof. J. A. L. Waddell, Ma.E., M.Am.Soc.C.E., delivered an illustrated lecture on Cantilever Bridges and Piers.

Thursday, 11th November.

G. H. Duggan, Vice-President, in the Chair.

Paper No. 123.

RESULTS OF EXPERIMENTS ON THE STRENGTH OF WHITE PINE, RED PINE, HEMLOCK AND SPRUCE.

By Prof. H. T. Bovey, LL.D., D.C.L.

In a paper read before the Canadian Society of Civil Engineers in 1895, the results were given of a number of experiments on the transverse strength of timber beams; but in the calculations it was assumed that the distortion, or diminution of depth, at the bearing surface was sufficiently small to be disregarded. It often happens, however, and especially when the timber contains a large amount of moisture, that the change in depth due to compression is excessive, producing a corresponding increase in the skin-stress.

This increase is theoretically $2 \frac{f}{d} \Delta d$, f being the intensity of the skin-stress, d the depth, and Δd the change in depth.

The method of conducting these experiments was fully described in the Paper referred to, and therefore the following points only are noted :—

All the transverse tests were made with the Wicksteed machine. The middle of the beam was supported on a hardwood bearing of 44 ins. diameter. The two ends were forced down by rams under hydraulic pressure, which can be gradually increased at any required rate or can be maintained constant for any given time.

The end-pressures were kept normal to the surface of the beam by means of spherical joints which allow the end bearings to revolve.

The elasticity coefficients have been calculated from the following formulæ :

(*a*) Coefficients from direct tensile and compressive experiments;

$$E = \frac{L}{A} \cdot \frac{\Delta W}{\Delta L}$$

L being the length of the specimen, A its sectional area and ΔW the increment of force producing a change ΔL in the length.

(*b*) Coefficients from transverse experiments ;

$$E=\frac{1}{4}\frac{L^3}{b\,d^3}\cdot\frac{\Delta W}{\Delta D}$$

L being the length, b the breadth, d the depth and ΔW the increment of force producing an increment ΔD in the deflection.

An error Δd in the depth theoretically corresponds to an error in E, which is approximately measured by $3\frac{E}{d}\Delta d$.

In previous experiments, the wire used in observing the deflections was found to be somewhat coarse, and a special wire was therefore drawn of .002-inch diameter.

The skin-stresses have been calculated by means of the ordinary flexure formula,

$$f=\frac{3\,L\,y}{b\,d^3}(W_1+\tfrac{1}{2}W_2)$$

W_1 being the total load on the beam, W_2 the weight of the beam, and y the distance of the skin from the neutral surface.

The flexure theory is admittedly unsatisfactory, and frequently gives results which are contrary to experience. Possibly, when a certain limit has been passed there is a tendency towards equalization of stress, and the so-called neutral surface may be moved towards that portion of the beam which is best able to bear the stress. It may indeed be more correct to assume that the distances of this surface from the tension and compression faces are in the ratio of the ultimate tensile and compressive strengths of the beam. This assumption, at all events, seems to give results which are more in accordance with practice. For example, in the case of a cast-iron Tee bar, tested in the University Laboratory, the tensile skin-stress should be 22,030 lbs. per sq. in., and the compressive skin-stress 102,050 lbs. per sq. in., whereas the ordinary theory gave 33,000 lbs. per sq. in. as the tensile and 20,800 lbs. per sq. in. as the compressive skin-stress.

The tables on the following pages give the breaking weights, skin-stresses, (transverse) coefficients of elasticity and specific weights of a number of air-dried, saturated, frozen and kiln-dried beams, and also the breaking weights, tensile and compressive strengths per square inch, (direct) coefficients of elasticity and specific weights of specimens prepared from these beams.

TABLE I.

WHITE PINE from ordinary stock.

No. of Beam.	Dimensions in inches.			Breaking weight in lbs.	Skin-stress (f) in lbs. per sq. in.			Coefficient of elasticity in lbs per sq. in.	Sp. wt. in lbs. per cub. ft. at date of test.	Per ct. of weight lost when dried at 212° F. at			Character of failure.
	l	*b*	*d*		Max.	Min.	Mean.	*E*		Centre.	Left end.	R't. end.	
15	186	6.225	15.2	23,850	5021	4777	4889	1,296,950	36.43	....	....	....	Crippled.
16	186	6.32	15.25	22,690	4774	4480	4627	1,359,050	38.64	....	....	....	Longitudinal shear.
28	138	9.1	15.21	39,000	4403	4018	4210	1,078,230	27.121	17.29	12.89	13.21	Longitudinal shear.
32	186	6.025	12.25	16,000	5531	5153	5342	1,368,500	27.983	28.262	27.014	27.274	Crippled.
46	186	5.725	5.9	5,200	8967	7312	8389	1,625,220	23.794	....	....	....	Crippled.

TABLE II.

WHITE PINE dried at 212° F.

36	150	5.95	11.925	10,000	2201	2164	2182	1,245,780	22.007	....	....	....	Tensile.
38	75	2.965	5.925	5,000	5911	5569	5740	1,272,440	22.105	....	....	....	Crippled.
42	150	5.7	5.9	8,000	9538	9247	9392	1,282,770	20 674	....	....	....	Tensile.
43	150	6.05	11.725	23,000	9992	7091	8542	1,171,240	22.648	....	....	....	Tensile.

REMARKS ON TABLE I.

Beams 15 and 16 were sawn out of trees felled at Keewatin in 1894, and were received into the Laboratory on the 13th of December, their weights being 415.75 lbs. and 457.78 lbs., respectively. They were both tested on the 2nd of February, 1895, when it was found that beam 15 had lost 36.69 lbs. or 8.8 p.c. of its weight, and that beam 16 had lost 46.59 lbs. or 10.2 p.c. of its weight. When the beams were sawn through after the test they were still found to be completely saturated with water excepting for a depth of 1 inch from the surface. The beams were from the central portions of the trees, the heart running from end to end.

Beams 28 to 43 were sawn from trees felled in the winter 1893-94 in Quinze Lake Co., P.Q. They remained in water one year, and were received into the Laboratory on October the 4th, 1895. They were all first quality timber, and, generally speaking, straight in grain and free from knots and shakes.

In order to determine the excess of moisture in the timber, three slabs, one near the middle and one at each end, were sawn out of the beams immediately after they had been tested and were at once placed in a chamber kept at a temperature of 212° F. by means of steam-pipes. The moisture was also removed from the whole beams by drying them in the same chamber.

Beam 36 failed suddenly under a very small load, the fracture commencing at a knot in the tension surface. On examination it was also found that the grain on the face was oblique to the neutral surface, while there were shakes running from end to end in the neighbourhood of the heart which, on the average, was below the middle of the depth of the beam. The results of this test should be discarded, as the beam was not of fair average quality.

Beam 38 was cut out of beam 36 in such manner that the grain was straight.

Beam 43 failed under a breaking load of 23,000 lbs., but a somewhat long continued and slowly increasing deflection under a load of 22,000 lbs. seemed to indicate that at this point the beam failed in compression, although there were no apparent signs of crippling.

AIR-DRIED SPECIMENS FROM WHITE PINE BEAM 15.

Spec.	Tension Tests.				Compression Tests.					Shearing Tests.				
	Coefficients of elasticity in lbs. per sq. in.		Tensile strength in lbs per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity in lbs. per sq. in.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of rounds.
	Forward.	Return.				Forward.	Return.							
a_1	1,749,520	1,762,500	10,490	......	e_1	....	....	2916	29.358	g_1	395.64	28.529	m_1	516.6
a_2	1,659,770	....	11,444	......	e_2	....	....	3393	27.918	g_2	447.26	27.752	m_2	505.2
b_1	1,932,560	....	15,640	......	f_1	....	....	3754	33.103	g_3	355.21	26.032	m_3	501.7
b_2	1,934,680	1,956,220	13,248	......	f_2	1,572,850	1,572,090	3604	29.025	h_1	419.19	28.409	n	598.7
	1,940,370	1,951,120				1,571,600	1,565,300			h_2	327.81	27.561	o	477.7
c	2,062,680	....	12,686	......		....	....	......	....	h_3	382.38	27.473	p	486
d	1,823,860	....	14,403	......	m	1,731,300	1,746,330	3918	28.033	i	362.75	26.655		
										j	345.24	26.122		
										k	361.26	27.541		
										l	338.11	27.226		

REMARKS ON BEAM 15.

The values of E for specimens a_2, b_1, c and d have been calculated from the first series of readings only, and are consequently smaller than if repeated readings had been taken.

The mean direct tensile strength is 2.68 times greater than the calculated mean skin-stress of the beam and 3.7 times greater than the mean compressive strength of the timber.

Specimens e_1 and e_2 contain the heart and show the least compressive strength. The ratios of length to least transverse dimensions in the compression specimens varied from 6.47 to 9.46, and the failure in each case was due to direct crushing.

The shearing strength of the round specimens is 1.42 times greater than that of the flat specimens.

The several specimens had lost considerably in weight during the interval of their preparation from the beam and the date of test.

Tension specimen b, after the first series of readings, was entirely relieved of load and was allowed to rest for two hours.

Between the two series of readings, compression specimen f_2 remained under the load of 50,000 lbs. for sixteen hours, the final reading varying from .01117 to .01172.

REMARKS ON BEAM 16.

The values of E for specimens a, c, d and f have been calculated from the first series of readings only, and are consequently smaller than if repeated readings had been taken.

The mean direct tensile strength is 2.21 times greater than the calculated mean skin-stress of the beam and 27 times greater than the mean compressive strength of the timber.

Specimens i_1, i_2, i_3, contain the heart, and the heart also passes along one side of specimens g_1, g_2, g_3 These specimens show the least strength. The ratio of length to least transverse dimensions was 37.1 for g_1, 26.73 for g_2, 34.157 for g_3, 24.56 for h, 27.03 for i_1 and 28.88 for i_2.

The mean shearing strength of the round specimens is 1.76 times greater than that of the flat specimens.

The several specimens had lost considerably in weight in the interval between their preparation from the beam and the date of test.

Tension specimen b was entirely relieved of load after the first series of readings, and was allowed to rest for 16 hours.

AIR-DRIED SPECIMENS FROM WHITE PINE BEAM 16.

Tension Tests.					Compression Tests.					Shearing Tests.				
Spec.	Coefficients of elasticity in lbs. per sq. in.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity in lbs. per sq. in.		Compressive strength in lbs. per sq. in	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of rounds.
	Forward.	Return.				Forward.	Return.							
a	1,626,330	....	9,777	......	g_1	1,935.550	1,942,950	3978	......	k_1	321.90	26.552	*u*	552.95
b	1,843,820 }	1,863,540 }	10,021	......	g_2	1,694,000	1,690,900	2880	32.75	k_2	405.40	25.941	*v*	636.74
	1,843,170 }	1,858,240 }			g_3	....	....	3958	34.157	*l*	321.35	25.952	*w*	689.113
c	1,445,900	....	5,772	......	*h*	1,455,090	1,449,670	4737	26.461	*m*	294.81	26.534	*x*	557.18
d	1,635,720	....	12,108	......	i_1	1,574,990	1,569,160	2963	28.668	*n*	375.56	26.807		
e	2,245,130	2,295,170	11,902	.....	i_2	1,560,010	1,635,620	3331	27.102	*o*	331.21	26.072		
f	1,652,480	....	10,884	......	i_3	....	....	2924	34.157	*p*	342.80	26.584		
										q	313.82	25.929		
										r	410.45	27.454		
										s	334.68	26.540		
										t	352.98	27.513		

AIR-DRIED SPECIMENS FROM WHITE PINE BEAM 28.

Tension Tests.					Compression Tests.					Shearing Tests.		
Spec.	Coefficients of elasticity.		Tensile strength per sq. in.	Sp. wt. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.				Forward.	Return.					
1	1,379,800	1,379,510	6,689	24.296	9	1,274,300	1,271,500	3675	24.591	a_1	336.97	25.16
2	1,313.530	1,319,840	6,377	23.51	10	1,293,370	1,298,800	3451	25.096	b_2	374.28	25.887
3	1,157,130	1,162,950	6.381	22.612	11	1,590,700	1,591,210	3187	26.129	d_1	322.11	23.473
4	1,914,310	1,933,220	12,803	......	12	1,336,050	1,325,630	4283	24.004	e_1	343.14	25.448
5	1,290,760	1,298,990	8,704	22.395						f_1	379.89	25.337
6	1,584,760	1,592,740	10,101	24.238								
7	1,368,840	1,381,870	8,402	23.063								
8	1,079,410	1,099,810	5,069	22.656								

SPECIMENS KILN-DRIED AT 212° F. FROM WHITE PINE BEAM 28.

13	2,073,150	2,072,160	13,632	......	20	1,331,010	1,341,750	6518	23.685	a_2	252.00	24.598
14	1,599,550	1,606,100	7,577	22.342		1,437,910	1,436,950			b_2	215.22	24.661
15	1,498,830	1,502,830	6,250	22.652	21	1,730,420	1,734,100	8119	24.68	c	263.18	......
16	1,390,880	1,394,000	6,966	23.261	22	1,255,400	1,252,420	5654	22.057	d_2	243.18	22.491
17	1,556,790	1,547,460	10,050	22.281	23	1,563,120	1,566,180	6108	22.167	e_2	234.27	24.047
18	1,385,880	1,385,880	9.385	......						f_2	221.78	24.616
19	1,711,630	1,703,180	7,560	......								

REMARKS ON BEAM 28.

The mean direct tensile strength of the air-dried specimens was 1.9 times greater than the calculated mean skin-stress of the beam and 2.19 times greater than the mean compressive strength.

By the kiln-drying, the mean co-efficients of elasticity were increased and the mean compressive strength was also increased more than 79 per cent. The mean shearing strength was reduced more than 32 per cent., and there was a slight diminution in the mean tensile strength.

The ratios of the lengths of the compression specimens to the least transverse dimension varied between 6.49 and 7.43, and the failure was in every case due to direct crushing.

The difference between the specific weights of the air and kiln-dried specimens was not great. The specific weight of the beam was 3 or 4 lbs. per cubic foot greater than that of the specimens.

Compression specimen 20, after the first series of readings, was left under 5000 lbs. for 42 hours, the final reading varying from .00137 to .00084.

REMARKS ON BEAM 32.

The mean direct tensile strength of the air-dried specimens was 2.99 times the mean compressive strength and 1.9 times the calculated mean skin-stress of the beam.

By the kiln-drying, the coefficients of elasticity were increased and the mean compressive strength was increased more than 33.6 p. c. There was also a slight increase in the mean tensile strength, but the shearing strength was diminished more than 19.1 p. c.

The ratio of the length of the compression specimens to the least transverse dimension varied between 2.02 and 10.1, and the failure was in every case due to direct crushing, excepting in the case of specimen *h*, in which the ratio was 20 and the failure was partly due to bending.

The injured portion was removed from specimen *g*, which was then re-tested after it had lost in weight 1.08 lb. per cubic foot. Its compressive strength was found to be 6733 lbs. per square inch, or 1.86 times as great as in the first test.

The difference between the specific weights of the air and kiln-dried specimens was not great. The specific weight of the beam was from 2 to 4 lbs. per cubic foot greater than that of the specimens.

AIR-DRIED SPECIMENS FROM WHITE PINE BEAM 32.

Tensile Tests.					Compression Tests.					Shearing Tests.		
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.				Forward.	Return.					
a_1	1,497,090	1,513,680	10,623	24.777	g_1	1,421,490	1,415,500	3,600	26.831	n_1	300.54	27.589
b	1,497,570	1,504,610	10,014	25.001	h	....	....	2,481	26.213	n_2	327.60	27.94
c	1,706,480	1,704,480	9,931	25.855	i_1	....	....	3,338	26.444	o_1	283.27	25.30
					i_2	....	....	3,967	26.561	o_2	299.73	25.285
					i_3	....	....	3,930	26.612	p	318.58	28.034
					m_1	1,435,400	1,437,220	3,799	26.889	r	353.00	24.60
										s	324.00	......

SPECIMENS KILN-DRIED AT 212°F. FROM WHITE PINE BEAM 32.

a_2	1,521,220	1,530,920	8,135	20.089	g_2	1,802,430	1,800,440	5,061	24.112	n_3	251.62	25.549
d	2,341,150	2,363,410	10,446	......	m_2	2,074,340	2,056,860	4,040	24.704	n_4	236.06	26.047
e	1,736,510	1,746,300	9,510	24.04						o_3	269.15	24.054
f	2,123,700	2,136,540	13,065	26.602						o_4	267.63	24.518
										q	264.53	23.618

DRIED SPECIMENS FROM WHITE PINE BEAM 36 KILN-DRIED AT 212°F.

Tension Tests.					Compression Tests.					Shearing Tests.		
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.				Forward.	Return.					
a_1	1,105,780	1,108,750	6236	21.260	f_1	1,581,040	1,579,840	7185	21.546	m_1	235.10	21.806
a_2	1,408,190	1,411,440	7574	21.983	f_2	1,508,830	1,501,22	5006	21.953	m_2	215.02	22.339
b_1	1,378,040	1,385,500	3329	22.072	g	1,330,890	1,325,060	5844	20.60	n_1	272.77	22.021
b_2	1,254,210	1,260,000	4914	22.316	h	1,963,430	1,958,110	5312	20.917	n_2	239.15	21.745
c	....	....	2241	22.180	k	1,441,300	1,436,810	5589	21.416	n_3	267.28	21.931
d_1	1,424,970	1,430,630	7446	20.69	l	1,601,400	1,550,200	6013	21.236	n_4	284.43	21.774
d_2	1,045,480	1,051,080	....	......						o_1	249.85	20.742
e_1	1,205,750	1,214,470	....	......						o_2	257.53	20.687
e_2	1,278,330	1,286,250	....	......						p_1	236.73	21.148
										p_2	308.00	22.844
										q_1	215.82	20.752
										q_2	237.98	22.580
										r_1	200.48	21.173
										r_2	254.79	22.378
										s_1	254.39	21.814
										s_2	325.38	22.547
										t_1	267.94	21.342
										t_2	269.62	21.567

REMARKS ON BEAM 36.

The co-efficients of elasticity, tensile and compressive strength of this kiln-dried beam are all small, possibly on account of the obliquity of the grain in the timber.

The compressive strength, however, is again much greater and the shearing strength much less than the corresponding strengths in similar air-dried specimens.

Owing to some inherent weakness which could not be determined, specimen *c* failed under an abnormally low load, and before the extensometer had been taken off.

REMARKS ON TABLES III and IV.

Beams 17 and 18, containing the heart, were cut from trees felled at Keewatin in 1894, and were ordinary 1st-quality timber. There were shakes in Beam 17, reaching the heart at points. The grain on the lower half of the beam was straight, but ran crosswise on the tension surface. From the time the beam was received into the Laboratory to the date of the test, a period of 57 days, the beam lost 13 p.c. of its weight. After the test a 3-inch slab was cut out, and the weight of this slab on Feb. 15th, 1897, by which time the natural drying can be considered to have been completed, was found to be 28.037 lbs. per cubic foot.

Beam 18 was tested after remaining in the Laboratory 42 days, in which time it was found to have lost 8.79 p.c. of its weight. It failed by crippling and longitudinal shear, simultaneously. The grain for about 10 inches on each side of the centre was clear, straight and free from knots.

The logs from which Beams 31 to 49 were sawn were felled in the Bonnechère district in the winter of 1894-95, and remained in the water for six months. They all contained the heart, and were ordinary 1st-quality timber.

Beam 32 failed by longitudinal shear along a shake in the neighbourhood of the neutral surface, but there were indications that this had been immediately preceded by a slight crippling.

Beam 41 was straight grained, but contained large shakes on the sides and on the compression surface due to seasoning and drying.

Beam 44 was straight grained and comparatively free from knots, but contained shakes which apparently extended from the heart outward to the sides. After remaining in the Laboratory 255 days it had lost 22.4 p.c. of its weight. A 1-inch slab cut from one end of the beam weighed, after being dried at 212°F., 30.31 lbs. per cub. ft.

TABLE III.

RED PINE from ordinary stock.

No. of Beams.	Dimensions in inches.			Breaking weight in lbs.	Skin-stress (*f*) in lbs. per sq. in.			Coefficient of elasticity.	Sp. wt. in lbs. per cub. ft. at date of test.	Per ct. of weight lost when dried at 212° F. at			Character of failure.
	l	*b*	*d*		Max.	Min.	Mean.			Centre.	Left end.	R't end.	
17	186	6.15	15.2	21,350	4531	4322	4426	1,252,700	32.279	……..	……..	…….	Crippled.
18	180	5.75	15.0	21,730	4589	4466	4527	1,351,350	……..	……..	….	……..	Crip'd & long. shear
31	186	5.975	12.275	23,400	7840	7469	7654	1,814,190	35.95	17.38	16.9	12.94	Longitudinal shear.
45	186	6.025	6.025	7,600	10034	9871	9952	2,768,630	37.144	…….	……..	……..	Crippled.
49	188	5.75	14.925	22,700	5240	5100	5170	1,669,010	30.592	8.8	8.7	8.1	Longitudinal shear.

TABLE IV.

RED PINE dried at 212° F.

37	150	5.75	11.875	21,000	6160	5953	6056	2,049,430	30.972	……..	……..	……..	Longitudinal shear.
41	150	5.885	5.925	8,800	9572	9472	9522	2,261,820	30.858	……..	……..	……..	Tensile.
44	150	5.875	11.785	20,000	5732	5617	5674	2,219,550	34.038	……..	……..	……..	Longitudinal shear.

AIR-DRIED SPECIMENS FROM RED PINE BEAM 17.

Tension Tests.				Compression Tests.					Shearing Tests.		
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.			Forward.	Return.					
1	1,469,430	1,478,130	4,229	a_1	1,835,160	1,836,770	3,789	32.248	*d*	290.24	29.667
	1,466,560	1,466,560		a_2	....	....	2,958	29.541	*e*	460.34	31.239
2	2,124,670	2,132,680	13,253	a_3	....	....	3,757	30.988	*f*	492.53	27.702
3	2,273,150	2,264,000	12,808	b_1	1,222,660	1,218,430	2,684	....	*g*	469.93	30.356
4	2,134,060	2,180,350	13.772	b_2	....	....	2,696	26.667	*h*	363.35	32.69
5	1,827,060	1,824,650	8,716	*c*	1,265,440	....	4,421	30.394	*i*	484.60	33.005
6	1,403,940	1,442,340	7,782						j_1	376.53	27.281
	1,450,670	1,463,670							j_2	429.72	27.361
7	1,780,020	1,843,180	10,906						k_1	410.66	29.414
8	1,331,320	1,382,780	5,143						k_2	403.83	29.194
9	2,094,430	2,144,610	12,015						*l*	462.87	32.876
	2,017,040	2,044.880	5,460						*m*	359.61	28.08

Beam 45 was a dense timber of excellent quality with shakes occurring intermittently. A constantly increasing deflection indicated that crippling had taken place under a load of 7600 lbs., although the crippling was not apparent until the load was 8000 lbs.

Beam 49 was straight-grained, with a few intermittent shakes.

REMARKS ON BEAM 17.

The mean direct tensile strength is 2.12 times greater than the calculated mean skin-stress of the beam and 2.66 times greater than the mean compressive strength.

Specimens b_1 and b_2 contain the heart, and shew the least compressive strength. The ratios of length to least transverse dimensions in the compression specimens were 8.62 for a_1, 8.82 for a_2; 5.78 for a_3; 11.98 for b_1, 6.2 for b_2; and 5.84 for c. The failure was in each case due to direct crushing.

The average specific weight of the specimens was about 2 lbs. per cubic foot less than the specific weight of the beam.

Tension specimen 6, after the first series of readings, was left under 1600 lbs. for 2½ hours, and during this interval the final reading varied from .01065 to .0111.

REMARKS ON BEAM 18.

The mean direct tensile strength is 2.84 times greater than the calculated mean skin-stress of the beam and 3.93 times greater than the mean direct compressive strength.

Specimen 11 contained the heart and shewed the least compressive strength.

The ratios of length to least transverse dimension were 6.43 for specimen 11, and 6.71 for specimen 12. In each case the failure was due to direct crushing.

The coefficients of elasticity for specimens 1, 2, 3, 4, 6, 7, 8, 9, were calculated from the first series of readings only, and were consequently smaller than if repeated readings had been taken.

The shearing strength of the round specimens is 1.79 times the mean shearing strength of the flat specimens.

The timber of the beam in question was unusually dense, and the mean specific weight of the beam does not seem to have been much greater than the mean specific weights of the compression and shearing specimens.

Tension specimen 4, after the first series of readings, was entirely relieved of load for 16 hours.

AIR-DRIED SPECIMENS FROM RED PINE BEAM 18.

Tension Tests.					Compression Tests.					Shearing Tests.				
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of rounds.
	Forward.	Return.				Forward.	Return.							
1	1.966,970	....	14,154	......	10	....	....	3,330	42.6	13	427.41	31.982	24	644.71
2	1,998,050	....	....	......	11	936,987	942,214	2,789	34.667	14	439.93	33.394	25	621.65
3	1,943,230	....	....	......	12	1,281,810	1,295,800	3,631	35.039	15	362.66	33.634	26	738.22
4	1,754,840	1,772,000	8,664	......						16	327 95	35.418	27	619.43
	1.801,600	1,804,750	....	......						17	387.01	33.641	28	671.48
5	2,116,110	....	11,949	......						18	380.20	32.627	29	627.66
6	1,819,380	....	10,128	......						19	323.03	33.466		
7	2,387,640	....	17,494	......						20	382.88	34.474		
8	2,080,060	....	16,609	......						21	318.59	33.822		
9	2,018,180	....	13,362	......						22	293.77	34 221		
										23	369.61	32.427		

AIR-DRIED SPECIMENS FROM RED PINE BEAM 31.

Tensile Tests.					Compression Tests.					Shearing Tests.		
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.				Forward.	Return.					
a_1	2,179,100	2,192,170	12,973	34.34	f_1	....	....	4,775	36.04	j_1	341.88	32.265
b	2,387,050	2,383,650	14,275	34.227	f_2	....	....	5,062	35.353	k_1	403.15	33.946
c	2,337,200	2,357,330	12,510	34.427	f_3	....	....	5,063	34.902	k_2	345.94	33.575
d	2,180,150	2,192,110	9,817	32.32	g	....	....	4,489	36.366	l_1	425.43	35.577
e	2,261,920	2,292,290	13,613	34.1	h_1	2,002,780	1,980,670	3,990	35.24			
					i_1	2,428,500	2,421,890	6,337	33.119			

SPECIMENS KILN-DRIED AT 212° F. FROM RED PINE BEAM 31.

a_2	2,659,930	2,677,030	10,470	32.996	h_2	1,549,860	1,540,130	6,098	32.237	j_2	222.94	30.553
					i_2	2,382,530	2,400,150	11,726	31.705	j_3	264.04	30.502
										k_3	300.86	32.021
										l_2	313.10	......
										l_3	331.00	31.945

REMARKS ON BEAM 31.

The mean direct tensile strength is 1.65 times greater than the calculated mean skin-stress of the beam and 1.55 times greater than the mean direct compressive strength.

By the kiln-drying the tensile strength was diminished, the compressive strength was largely increased, and the shearing strength was diminished by 24.1 p.c.

The ratios of the length to the least transverse dimension in the compression specimens varied from 5 to 10, and in each case the failure was due to direct crushng.

Specimens h_1 and h_2 contain the heart and shew the least compressive strength in the air and kiln-dried conditions, respectively. The loss of weight in kiln-drying varied from 1.344 lbs. to 3.003 lbs. per cubic ft.

REMARKS ON TABLES V, VI and VII.

Beams 22, 23 and 35, containing the heart, had lain in the water for a considerable time, and were completely water-soaked. When tested, Beams 22 and 35 were found to be hard frozen. Beam 23 was also frozen, but not throughout, as was shewn when the beam was cut in two at the centre. Beam 22 was straight-grained, free from knots, and failed with a sudden sharp fracture. Incipient decay had commenced near the heart of Beam 23, which, however, was regarded as a fair specimen of ordinary commercial quality. It was full of large knots and the grain was curved from end to end. Beam 35 was straight-grained, clear, comparatively free from knots and of exceptionally good quality. Beam 40 was cut out of beam 35 after the latter had been tested.

Beams 25, 26 and 29 all contained the heart. Beam 25 was a good specimen, and was completely water-soaked. Beam 26 was saturated throughout, excepting for a depth of 1½ inches from surface, and, although an apparently poor specimen, was considered to be of ordinary commercial quality. It was full of knots and its grain was curved.

TABLE V.

Hemlock from ordinary stock.

No. of Beam.	Dimensions in inches.			Breaking weight in lbs.	Skin-stress (f) in lbs. per sq. in.			Coefficients of elasticity.	Sp. wt. in lbs. per cub. ft.	Per ct. of weight lost when dried at 212° F.			Character of failure.
	l	*b*	*d*		Max.	Min.	Mean.						
25	222	8.815	10.1	13,000	5132	4995	5063	1,581,710	53.025	50.43	39.93	47.85	Crippled.
26	186	8.975	10.015	20,000	6615	6371	6493	1,498,640	36.533	... .	....	....	Crippled.
29	186	9.85	11.95	20,040	4133	4058	4096	883,291	36.235	34.6	....	....	Tensile.

TABLE VI.

Hemlock dried at 212° F.

40	87	4.35	4.925	3,500	7946	5054	6500	1,379,860	31.346	....	....	....	Longitudinal shear.

TABLE VII.

Hemlock saturated and frozen.

22	138	9.0	11.875	30,800	5393	5166	5280	1,174,700	38.69	....	....	....	Tensile.
23	138	9.025	11.9	21,000	3482	3450	3466	1,242,150	45.23	....	....	....	Tensile.
35	190	9.175	10.05	22,000	7188	6960	7074	1,633,050	50.707	51.07	49.75	57.42	Crippled.

AIR-DRIED SPECIMENS FROM HEMLOCK BEAM 22.

Tension Tests.					Compression Tests.					Shearing Tests.				
Spec.	Coefficients of elasticity. Forward.	Coefficients of elasticity. Return.	Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity. Forward.	Coefficients of elasticity. Return.	Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of rounds.
a_1	764,414	781,570	4,718	26.80	k_1	1,055,110	1,050,600	3,532	41.875	n_1	452.8	34.993	x	613.22
a_2	881,318	919,122	7,222	30.98	k_2	1,312,200	1,289,860	3,902	41.109	n_2	355.5	36.176		
b	1,147,350	1,159.160	7,967	29.07	l_1	1,315,040	1,284,400	3,128	42.132	n_3	350.91	39.947		
c	939,920	993,213	7,640	29.64	l_2	1,550,510	1,538,950	2,948	38.391	n_4	376.40	39.074		
d	1,086,220	1,099,860	8.468	28.70	m	1,413,050	1,410,110	3,078	36.326	o_1	317.46	38.42		
e	1,099,050	1,141,500	7,076							o_2	307.50	36.985		
f	1,123,780	1.104,380	7,418							p_1	320.04	38.915		
g	1,233,040	1,243,250	8,475							p_2	391.10	41.271		
h	....	....	7,590							q_1	368.99	......		
										q_2	371.93	43.424		
										q_3	364.54	37.558		
										r	400.94	......		
										s	387.80	......		
										t	482.17	......		
										v	519.87	......		

REMARKS ON BEAM 22.

The mean direct tensile strength is 1.43 times greater than the calculated mean skin-stress of the beam and 2.31 times greater than the mean direct compressive strength. The shearing strength of the round specimen is 1.52 times greater than the mean shearing strength of the flat specimens. The ratios of length to least transverse dimension in the compression specimens varied between 5.3 and 7.27, and the failure was in each case due to direct crushing.

The compression specimens had the appearance of being frozen, but the frost in the tension and shearing specimens had thawed, although they still remained very cold and water-soaked. In fact, the specific weight of several of the specimens was even greater than the mean specific weight of the frozen beam.

REMARKS ON BEAM 25.

The mean direct tensile strength is 2.1 times greater than the calculated mean skin-stress of the beam and 3.33 times greater than the mean compressive strength. The mean shearing strength of the round specimens is 1.59 times greater than the mean shearing strength of the flat specimens.

The ratios of the length to the least transverse dimension varied between 6.08 and 9.86, and the failure was in each case due to direct crushing. The results indicate that the tensile and shearing strengths are greatest in those specimens of the greatest specific weight.

Several of the specimens had a greater specific weight than the mean specific weight of the beam.

Tension specimen b_1, after the first series of readings, was left under 400 lbs. for 17 hours, the final reading varying from .00033 to .00017.

Compression specimen *g*, after the first series of readings, was wholly relieved of load for 1½ hours.

Compression specimen d_2, after the first series of readings, was wholly relieved of load for 15 hours.

AIR-DRIED SPECIMENS FROM HEMLOCK BEAM 25.

Tension Tests.					Compression Tests.					Shearing Tests.				
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. inch.	Sp. wt. in lbs. per cubic foot	Spec.	Co-efficients of elasticity.		Compressive strength in lbs. per sq. inch	Sp.wt. in lbs. per cubic ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of rounds
	Forward.	Return.				Forward.	Return.							
1	1,345,310	1,367,250	7,680		d_1	1,011,030	1,000.140	2491	51.442	n_1	393.90	51.144	x_1	537.37
2	1,585,850	1,607,759	10,553	44.34	d_2	1,477.400	1,465,030	3347	51.515	n_2	406.13	51.6	x_2	528.91
3	1,728,280	1,811,670	8,985	39.27		1,517,810	1,507,750							
4	1,826,190	1,856.350	8.079	38.61	e	1,838,000	1,841,500	......	......	o_1	369.92	45.58	x_3	619.28
a_1	2,034,780	2,091,950	13,514	57.10	f	1,576,700	1,564,290	......	48.71	o_2	407.19	47.37	y_1	663.78
a_2	1,706,210	1,753,400	9,409	50.01						p	324.12	52.547	y_2	710.86
a_3	1,668,330	1,708,410	13,000	39.39	g	1,430,680	1,428,860	3148	53.013	q^1	446.77	50.522	y_3	670.34
						1,392,550	1,407,390							
b_1	2,053,630	2,063.210	14,721	48.7	h	1,472,160	1,468,870	3420	54.754	q_2	396.79	49.172	i	670.53
	2,049,900	2,052,410								r_1	423.81	44.208	z_1	606.67
b_2	1,906,590	1,946,310	14,501	58.43	k	1,485,230	1,473.900	3140	51.741	r_2	441.02	45.47	z_2	630.67
c_1	1,704,500	1,732,610	11,759	......	l	1,411,770	1,409,290	3147	55.009	s_1	420.98	51.213	z_3	623.55
c_2	2,096,270	2,113,630	13,619	61.07	m	1,609,900	1,587,800	3714	51.503	s_2	361.48	50.388	j_1	637.80
......	......	......	......	......	......	......	......	......	......	t_1	424.20	38.38	j_2	556.29
......	......	......	......	......	......	......	......	......	......	t_2	428.80	39.791	......	......
......	......	......	......	......	......	......	......	......	......	u_1	405.09	46.268	......	......
......	......	......	......	......	......	......	......	......	......	u_2	444.95	49.975	......	......
......	......	......	......	......	......	......	......	......	......	v_1	362.48	56.402	......	......
......	......	......	......	......	......	......	......	......	......	v_2	382.13	55.526	......	......

AIR-DRIED SPECIMENS FROM HEMLOCK BEAM 26.

Tension Results.					Compression Results.					Shearing Results.		
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Spec.
	Forward.	Return.				Forward.	Return.					
a_1	1,891,870	1,935,760	11,021	30.79	*k*	....	.. ..	3652	37.02	u_1	334.06	38.40
a_2	1,834,260	1,867,730	12,162	28.635	*l*	....	....	3673	35.73	u_2	285.50	38.04
b	1,310,340	1,349,090	4,610	28.622								
	1,265,660	1,277,750			*m*	....	....	4446	37.67	v_1	363.47	31.90
	1,233,050	1,254,760								v_2	393.29	31.50
c	1,832,230	1,853,060	11,636	29.993	*n*	....	....	3305	40.933	w_1	315.26	32.90
d	2,024,800	2,073,450	13,974	33.288	o_1	....	....	3483	32.318	w_2	331.36	34.20
e	1,497,260	1,539,700	5,653	31.647	o_2	1,342,190	1,336,480	3057	34.016	x_1	356.90	33.89
f	1,799,240	1,761,660	11,798	....	o_3	1,736,060	1,754,840	4050	31.755	x_2	306.60	34.11
	1,913,660	1,785,440		....								
	1,991,940	1,897,400		....	p_1	1,457,030	1,461,250	3899	32.294		371.00	32.06
	1,927,100	2,007,250		....	p_2	899,630	912,367	2703	33.073		316.80	29.65
g	2,143,450	2,194,380	10,552	31.395	p_3	1,475,920	1,469,460	3368	32.279			
h	1,287,420	1,314,280	8,580	31.959	......	1,441,020	1,435,360					
i	2,010,210	2,013,870	13,505	30.653	......	1,433,830	1,435,360					
j	1,926,110	1,900,360	13,423	28.665	......							
	1,951,400	1,951,400			*q*	1,634,750	1,634,750	4173	33.785			
......	....	....	....	....	*r*	....	....	4050	33.859			
......	....	....	....	.... ..	.....	1,210,880	1,214,280	4538	35.789			
......	....	....	....	....	......	1.220,710	1,221,270					
......	....	....	....	....	*s*	1,226,920	1,228,050					
......	....	....	....	....	*t*	.. ..	....	3838	35.826			

SPECIMEN KILN-DRIED AT 212° F. FROM HEMLOCK BEAM 26.

......	....	....	....	. ...	*i*	1,833,420	1,833,420	7837	30.82			

REMARKS ON BEAM 26.

The mean direct tensile strength was more than 2.06 times as great as the calculated mean skin-stress of the beam and 3.6 times greater than the mean compressive strength. The kiln-dried specimen shewed a compressive strength more than double the mean compressive strength of the air-dried specimens.

The ratios of the length to the least transverse dimensions in the compression members varied from 2.5 to 7.8, and the failure was in each case due to direct crushing.

Between the first and second series of readings, *b* remained under 400 lbs. for 16 hours, the final reading varying from .00457 to .00372.

Between the second and last series of readings the specimen was left under 400 lbs. for 47½ hours. The reading varied from .001 to .00398 in the first two hours, and the extensometer was then reset at zero. During the next hour it varied from zero to .001; and the final reading before recommencing the test was .00082. The average time occupied in each observation was about one minute. The variation in the value of the coefficient of elasticity was due to the gradual drying of the specimen, and also to the varying hygrometric condition of the atmosphere.

Specimen *f* was left under the load of 400 lbs. for 17 hours after the first series of readings, the final reading varying from .0033 to .01064. After the second test it was left under 400 lbs. for 23 hours, the final reading varying from .00281 to .00995. Between the third and fourth series of readings the specimen was left under 400 lbs for 5 hours, the final reading varying from .00163 to .00284. The variation of the reading was due to the gradual drying of the specimen and to the changing hygrometric condition of the atmosphere.

Between the two series of readings for specimen *j* there was an interval of 90 hours.

The small tensile strength of the specimen was chiefly due to the fact that the grain of the specimen was slightly oblique to the axis.

The compression specimen p_3 was left under a load of 5,000 lbs. after the first series of readings for 42 hours, the final reading varying from .00081 to .00398. After the second series of readings it remained under 5,000 lbs. for 43 hours, the final reading only varying from .00401 to .00398.

The compression specimen *s* was left under 5,000 lbs. for 18 hours after the first series of readings, the final reading varying from .0026 to .00268. After the second series of readings it was left under 5,000 lbs. for 4½ hours, the final reading varying from .00278 to .002805.

After specimen p_2 had been tested the injured portion was removed and the remainder retested, when it had lost 2.4 lbs. per cubic foot of its weight. Its compressive strength was 4,097 lbs. per square inch.

AIR DRIED SPECIMENS FROM HEMLOCK BEAM 29.

Tension Tests					Compression Tests.					Shearing Tests.		
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.				Forward.	Return.					
a_1	1,212,920	1,221,340	4387	25.09	e_1	1,242,410	1,241,540	3673		h_1	390.16	30.916
b	1,368,490	1,378,790	3113	27.813	f_1	....	....	2089	30.51	i_1	360.41	34.58
c	1,115 370	1,140.190	3240	25.194	f_2	....	....	2864	32.70	j_1	424.95	32.661
d	1,137,000	1,149,880	3250	26.852	f_3	....	....	1524	32.715	*l*	398.51	32.719
					g_1	....	....	2468	32.765			
					g_2	....	....	3354	31.146			
					g_3	....	....	3429	28.82			
					k	....	....	2311	31.50			

SPECIMENS KILN-DRIED AT 212° F. FROM HEMLOCK BEAM 29.

a_2	1,310,770 1,298,970	1,321,290 1,300,430	7022	22.473	e_2	1,490,580	1,468,060	4074	23.503	h_2	384.74	24.309
										i_2	324.20	24.364
										j_2	350.17	....
										m	285.87	24.71

REMARKS ON BEAM 29.

The mean direct tensile strength is less than the calculated mean skin-stress of the beam and only 1.24 times as great as the mean compressive strength. This result is doubtless due to the fact that the timber was of very poor quality and full of knots and shakes.

By kiln-drying, the coefficients of elasticity were increased, the tensile strength was doubled, the compressive strength was increased by 18 per cent., and the mean shearing strength was diminished by 9.9 per cent.

The ratios of length to least transverse dimension in the compression members varied from 2.14 to 10.52, and the failure in each case was due to direct crushing, excepting in the case of k, in which the ratio was 19.6 and which partly failed by bending.

In the case of a_2, the interval between the two series of readings, during which the specimen was left under a load of 100 lbs., was 1 hour, and the final reading varied from .00054 to .00059.

After k had been tested the injured portion was removed and the uninjured portion of the specimen was re-tested, when it failed by direct crushing under 4122 lbs. per square inch, the specific weight being 28.4 lbs. per cubic foot, and the ratio of the length to the least transverse dimension 5.2.

REMARKS ON BEAM 35.

The mean direct tensile strength of the cold and water-soaked specimens is 1.4 times greater than the calculated mean skin-stress of the beam and 2.82 times greater than the mean direct compressive strength.

By the kiln-drying the tensile strength was diminished, the compressive strength increased more than 87 p.c., and the shearing strength diminished more than 33 per cent. The coefficients of elasticity were also increased.

The ratios of the length to the least transverse dimension in the compression specimens varied between 4.43 and 5.57, and in each case the failure was due to direct crushing.

After h_1 had been tested, the injured portion was removed, and the specimen was dried at 212 ° F. and re-tested with the following results: coefficient of elasticity = 1,511,000 (forward), 1,517,830 (return); compressive strength = 7107.8 lbs. per square inch; specific weight = 27.017 lbs. per cubic foot.

After h_2 had been tested the injured portion was removed and the specimen was allowed to dry gradually in the laboratory for about a month. It was then re-tested, with the following results:—coefficient of elasticity = 1,526,200 (forward), 1,521,590 (return); compressive strength = 3636.3 lbs. per square inch; specific weight = 38.07 lbs. per cubic foot.

After *j* had been tested the injured portion was removed and the specimen was immediately re-tested, with the following results:—coefficient of elasticity = 1,608,560 (forward), 1,615,300 (return); compressive strength = 3592.5 lbs. per square inch; specific weight = 52.02 lbs. per cubic foot.

The injured portion was removed, and the specimen dried at 212 ° F. when it was re-tested, with the following results:—co-efficient of elasticity=1,662,500 (forward), 1,657,900 (return); compressive strength = 6246 lbs. per square inch; specific weight = 25.33 lbs. per cubic foot.

In the case of specimen j_3.

After 1st series of readings it was left under 20,000 lbs. for $18\frac{1}{2}$ hours, the final reading varying from .00755 to .00766.

After 2nd series of readings it was left under 20,000 lbs. for $47\frac{1}{2}$ hours, the final reading varying from .00678 to .00741.

After 3rd series of readings it was left under 20,000 lbs. for $3\frac{1}{2}$ hours, the final reading varying from .00723 to .00726.

After 4th series of readings it was left under 100 lbs. for $17\frac{1}{4}$ hours, the final reading varying from .00149 to .0018.

After 5th series of readings it was left under 100 lbs. for $3\frac{1}{4}$ hours, the final reading varying from .00176 to .00188.

After j_2 had been tested the injured portion was removed and the specimen immediately re-tested, with the following results:—coefficient of elasticity = 1,284,450 (forward), 1,278,860 (return); compressive strength = 34,328 lbs. per square inch; specific weight = 46.61 lbs. per cubic foot.

The injured portion was removed and the specimen dried at 212 ° F. and re-tested, with the following results:—

From 1st series of readings, coefficient of elasticity = 1,496,940 (forward), 1,503,930 (return).

From 2nd series of readings, coefficient of elasticity = 1,465,810 (forward), 1,459,920 (return).

From 3rd series of readings, coefficient of elasticity = 1,471,140 (forward), 1,473,280 (return); the compressive strength = 7021.6 lbs. per cubic foot; the specific weight = 24.66 lbs. per cubic foot. Between the 1st and 2nd readings the specimen remained under 100 lbs. for about $\frac{1}{2}$ hour, the final reading varying from .00043 to .00021. Between the 2nd and 3rd readings the specimen remained under 100 lbs. for about 1 hour, the final reading varying from .0007 to .00056.

SPECIMENS FROM FROZEN HEMLOCK BEAM 35.

Tension Tests.					Compression Tests.					Shearing Tests.		
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sp. inch.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.				Forward.	Return.					
a_1	1,145,590	1,147,450	7792	40.306	h_1	1,464,480	1,449,300	4119	49.45	k_1	432.76	48.142
b_1	1,363,620	1,382,340	8694	43.822	h_2	1,655,890	1,653,610	3961	52.257	k_2	399.43	49.540
b_2	1,562,710	1,566,260	11366	36.029	h_3	....	....	4131	59.188	l_1	528.39	45.392
c_1	1,824,900	1,833,150	7521	56.112	i_1	841,150	835,046	2951	52.822	l_2	491.92	43.671
c_2	1,248,610	1,250,450	13354	48.892	j_1	1,244,060	1,222,700	3611	52.416	l_3	534.24	51.156
d_1	1,158,230	1,165,680	7580	46.719	j_2	1,440,900	1,444,010	3678		m_1	419.28	49.161
e_1	1,735,800	1,738,940	11725	48.109						m_2	517.25	52.28
f_1	1,605,600	1,666,520	10319	57.25						m_3	468.67	49.806
f_2	1,772,310	1,801,440	9487	55.226						m_4	427.35	48.655
g_1	1,311,950	1,313,760	9906	56.917								

SPECIMENS KILN-DRIED AT 212° F. FROM HEMLOCK BEAM 35.

a_2	2,274,680	2,277,990	4613	26.901	h_4	1,566,450	1,555,800	6645	25.95	k_3	310.24	26.29
c_3	1,582,810	1,585,130	7107	27.198	h_5	1,929,030	1,925,350	8948	27.106	k_4	296.87	26.801
d_2	1,748,500	1,750,920	8073	26.323	i_2	1,379,940	1,380,230	4275	25.81	l_4	334.37	29.067
e_2	2,080,120	2,088,470	7197	28.334	i_3	1,178,510	1,173,020	4833	25.79	l_5	356.49	29.402
f_3	1,586,910	1,602,350	5903	24.210	j_3	1,479,560 1,487,650 1,496,420 1,494,400 1,505,000 1,518,620	1,465,030 1,481,200 1,492,730 1,491,620 1,506,690 1,519,010	7316	25.421	l_6	329.90	29.201
										m_5	366.45	28.868
g_2	1,621,920	1,626,520	8650	25.135						m_6	330.95	28.153
										m_7	288.53	28.448
g_3	1,615,080	1,620,220	2671	26.283								

TABLE VIII.

SPRUCE from ordinary stock.

No. of Beam.	Dimensions in inches.			Breaking weight in lbs.	Skin-stress (*f*) in lbs. per sq. in.			Coefficient of elasticity.	Sp. wt. in lbs. per cub. ft. at date of test.	Per ct. of weight lost in drying at 212° F.			Character of failure.
	l	*b*	*d*		Max.	Min.	Mean.			Centre.	Left end.	R't end.	
24	222	9.175	10.1125	15,800	6208	5846	6027	1,629,050	32.307	26.7	24.7	27.3	Crippled.
27	186	8.725	10.025	14,600	4899	4758	4829	1,458,360	29.354	....	....	....	Crippled.
30	186	8.725	11.875	15,900	3758	3682	3720	2,020,300	30.603	11.1	....	....	Longitudinal shear.

TABLE IX.

SPRUCE dried at 212° F.

39	78	3.775	4.35	5,800	9774	9603	9689	2,373,080	31.606	....	....	....	Longitudinal shear.

TABLE X.

SPRUCE saturated and frozen.

33	186	9.2	10	14,000	7212	6887	7050	2,373,080	39.78	30.618	33.55	....	Crippled.

REMARKS ON TABLES VIII, IX and X.

Beam 24 was wet, but was in good condition and comparatively free from knots. Beam 27 was of ordinary commercial quality, with fairly straight grain and a large number of small knots. Beam 30 was of ordinary commercial quality, but with large shakes running from end to end and dividing the beam practically into four sections Beam 33 was water-soaked and hard frozen when tested. It was of exceptionally good quality, free from shakes and had clear, straight grain. Beam 39 was cut out of Beam 33 after the latter had been tested.

REMARKS ON BEAM 24.

The mean direct tensile strength was more than double the calculated mean skin-stress and 4.21 times the mean direct compressive strength.

The mean shearing strength of the round specimens was 1.86 times the mean shearing strength of the flat specimens.

Tension specimen a_2, after the first series of readings, was left under the load of 1600 lbs. for 43½ hours, the final reading varying from .01243 to .01707.

The ratios of length to least transverse dimension in the compression specimens varied between 6.81 and 8.9, and the failure was in each case due to direct crushing.

Between the first and second series of readings g_1 was entirely relieved of load for 17 hours. After two repetitions of loading and relieving from load, specimen f_3 was left under 5,000 lbs. for 1½ hours, and during this interval the reading varied from .00099 to .00092.

AIR-DRIED SPECIMENS FROM SPRUCE BEAM 24.

	Tension Results.					Compression Results.					Shearing Results.				
	Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of rounds.
		Forward.	Return.				Forward.	Return.							
24	a_1	2,161,000	2,181,220	14,603.7	......	f_1	1,538,940	1,530,420	2781.73	32.475	l_1	353.68	30.13	x_1	660.94
	a_2	1,978,840	1,963.710	14,438.2	......	f_2	1,298,130	1,299,530	2772.67	31.90	l_2	352.11	30.227	x_2	576.57
	....	2,030.600	2,045,530		......	f_3	1,717,900	1,711,560	2921.41	31.38	m_1	249.11	30.237	x_3	632.10
	a_3	2,041.130	2,085,110	11,464.7	......	g_1	1.551,350	1,572,860	3218.9	31.156	m_2	326.25	30.607	y_1	549.90
	b_1	2,023,120	1,986,800	12.106.6	......	....	1,603,240	1,591,990			n_1	344.33	......	y_2	598.55
	b_2	1,956,550	1,930,900	10,218.6	......	g_2	1,568,350	1,565,470	2865.37	33.57	n_2	267.33	......	y_3	556.94
	b_3	1,920,180	1,964,320	12,676.1	......	h	1,566,960	1,555,490	2825 98	31.165	o_1	286.79	30.538	z	598.50
	c	2.127,280	2,171,470	14,404.2	......	k	1,523,240	1,524,010	3202.37	32.75	o_2	302.75	30.044		
	d_1	2,086,020	2,117,930	12,112.4							p_1	307.74	32.582		
	d_2	2,148,920	2,175,230	11,880.3							p_2	393.70	32.750		
	e_1	1,731,720	1,761,420	11,020.6							q_1	287.12	33.726		
	e_2	1,872,180	1,894,110	10,906.8							q_2	315.91	32.636		
	e_3	1,679,770	1,749,620	11,587.1							r_1	374.79	31.295		
											r_2	361.36	31.666		
											s_1	258.20	32.937		
											s_2	285.58	31.007		
											t_1	370.73	33.177		
											t_2	334.28	31.987		

AIR-DRIED SPECIMENS FROM SPRUCE BEAM 27.

Tension Results.				
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.		
1	1,383,460	1,381,220	6035.8	30.357
2	1,490,440	1,500,000	8777	29.012
3	1,953,260 1,991,850	1,963,630 2,007,080	14,920	27.06
4	1,432,120	1,439,510	9,405.2	27.121
6	1,909,530	1,918,340	10,797	26.03
a_1	1,174,260 1,194,130	1,197,320 1,198,190	7724	31.814
b_1	2,169,940	2,180,770	12,370	26.69

Compression Results.				
Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.		
1	....	....	3805.9	27.07
2	....	....	3968.4	28.498
3	....	....	3218.9	27.298
4	....	....	3450	28.881
c_1	1,477,850	1,477.070	3499	28.839
c_2	1,106,850 1,127,900	1,109,700 1,126,420	3429.8	28.084
d_1	2,001,680	2,000,220	3671.9	28.393
d_2	1,679,500 1,686,630	1,674,440 1,683,560	4277.6	27.034
5	1,845,250	1,906,760	3741.1	26.791
6	2,011,200	2,011,200	4438.5	26.292
6_1	....	....	4373.0	......

Shearing Results.		
Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.
e_1	410.72	30.865
e_2	417.30	29.90
f_1	421.30	27.80
f_2	394.95	28.16
f_3	374.35	27 893
g_1	427 70	26.12
g_2	357.80	26.43
h_1	414.51	28.635
h_2	398.73	28.546

SPECIMENS KILN-DRIED AT 212° F. FROM SPRUCE BEAM 27.

a_2	1,525,080	1,541,120	6182	.....	c_3	1,565,270	1,562,420	5907.1	26.015	......	....	......
b_2	1,847,430	1,852,130	10,362	25.897	d_3	1,875,380	1,878,550	6430.2	26.152	......	....	......

REMARKS ON BEAM 27.

The mean tensile strength of the air-dried specimens was more than double the calculated mean skin-stress of the beam, and 2.67 times the direct mean compressive strength. By kiln-drying the tensile strength was diminished, and the mean compressive strength was increased more than 65 per cent.

Specimen 3, after the first series of readings, was left under 400 lbs. for 46 hours, and during this interval the final reading only varied from .00258 to .00260.

Specimen a_1, after the first series of readings, was left under 400 lbs. for 22 hours, and during this interval the final reading varied from .00378 to .00567.

The ratios of the length to the least transverse dimensions in the compression members varied between 4.23 and 8.89, and in each case the failure was due to direct crushing, excepting in the cases of specimens 5 and 6, in which the ratios were 18.76 and 14.32 respectively, which failed to some extent from bending.

Specimen c_2, between the two sets of readings, was left under 5,000 lbs. for 41 hours, the final reading varying from .00049 to .00103.

Specimen d_2, between the two sets of readings, was left under 5,000 lbs. for 41 hours, the final reading varying from .00128 to .00079.

After compression specimen 2 had been tested, the injured portion was removed and the remainder re-tested, when its specific weight was 25.965 lbs. per cubic foot and its compressive strength 4849 lbs. per square inch.

The injured portion was removed from this last, and the remainder again tested, when its weight was 26.024 lbs. per cubic foot and its compressive strength 6621.2 lbs. per square inch.

Specimens 3, c_1, c_2, c_3, all contain the heart and shew the least compressive strength.

REMARKS ON BEAM 30.

The mean direct tensile strength of the air-dried specimens was 3.9 times the calculated mean skin-stress of the beam, and 2.35 times the mean direct compressive strength.

By the kiln-drying, the mean tensile strength seems to have been increased, but specimen c_1 failed under an abnormally small load probably because of some inherent weakness. The compressive strength was increased 77 per cent., and the mean shearing strength diminished more than 22 per cent.

The ratio of the length of *d* to its least transverse dimension was 20.025.

The ratios of the length to the least transverse dimension in the remainder of the compression members varied between 2.06 and 10.1, and in each case the failure was due to direct crushing.

AIR-DRIED SPECIMENS FROM SPRUCE BEAM 30.

Tension Tests.					Compression Tests.					Shearing Tests.		
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub. ft.
	Forward.	Return.				Forward.	Return.					
a_1	2,293.580	2,305,180	13,380	29.666	d_1	....	....	6051	32.447	g_1	375.88	32.012
b_1	2,585,260	2,629,010	22,153	30.592	e_1	....	....	6933	31.257	g_2	377.29	32.076
c_1	2,370,480	2,386,600	8,053	30.347	e_2	....	....	4986	32.005	h_1	376.54	31.18
1	2,139,490	2,151,460	12,570	30.367	e_3	....	....	7660	31.352	h_2	391.12	29.899
3	2,323,210	2,343,300	14,397	29.203	f_1	2,262,770	2,263,600	5183	31.076			
4	2,372,570	2,404,210	16,571	31.843								
SPECIMENS KILN-DRIED AT 212° F. FROM SPRUCE BEAM 30.												
a_2	2,759,620	2,765,020	13,932	29.571	f_2	2,243,550	2,237,150	9202	28.674	g_3	233.66	31.241
b_2	2,647,040	2,650,330	19,492	30.284						g_4	246.40	31.173
c_2	2,847,550	2,868,760	16,797	29.925						g_5	324.56	31.173
										h_3	307.21	28.729
										h_4	347.09	29.240
										h_5	303.03	29.243

WET AND FROZEN SPECIMENS FROM SPRUCE BEAM 33.

Tension Tests.					Compression Tests.					Shearing Tests.		
Spec.	Coefficients of elasticity.		Tensile strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft.	Spec.	Coefficients of elasticity.		Compressive strength in lbs. per sq. in.	Sp. wt. in lbs. per cub. ft	Spec.	Shearing strength in lbs. per sq. in. of flats.	Sp. wt. in lbs. per cub ft.
	Forward.	Return.				Forward.	Return.					
a_1	2,219,600	2,273,580	16,202	36 243	1.	1,813,380	1,833,110	3403.4	38.019	g_1	287.76	36.027
b_1	2,268,750	2,261,770	15.610	37.209	2.	1,780,710	1,786,120	3347.7	38.07	g_2	301.05	36.017
b_2	2,233,170	2,241,170	7234.3	43.092	f_1	2,088,870	2,096,050	3635.0	36.859	h_1	490.94	36.876
c_1	2,115,850	2,127,810	10,681	37.945						h_2	444.27	37.758
d_1	2,026,110	2,057,910	12,115	40.629						h_3	437.32	39.957
e_1	2,499,660	2,505,940	12,605							k_1	367.65	35.122
m_1	1,963,180	1,964,210	15,454							k_2	409.78	36.392
n_1	2,025,160	2,027,170	15,686	38.706						k_3	425.72	38.756
										l	430.58	38.285

SPECIMENS KILN-DRIED AT 212° F. FROM SPRUCE BEAM 33.

a_2	2,971,240	2,992,750	9453.8		f_2	2,975,420	2,974,780	6571.8	33.302	g_3	291.11	30.817
b_3	2,514,630	2,516,340	9728.6	32.27						g_4	278.81	29.612
c_2	2,689,700	2,704,750	19,168	32.711						h_4	379.78	31.648
c_3	2,833,350	2,872,170	9592.3	32.213						h_5	379.56	31.643
d_2	2,641,050	2,654,570	12897.	33.563						k_4	371.86	29.704
e_2	2,489,330	2,496,680	18,678	30.356						k_5	381.23	30.952
m_2	3,452,300	3,473,810	8713.7	30.07								
m_3	2,802,680	2,810,900	20,780									
n_2	2,266,790	2,278,640	13,226	31.816								
n_3	2,252,020	2,254,870	18,384	28.507								
o	2,768,430	2,789,900	17,910	30.836								

REMARKS ON BEAM 33.

The mean direct tensile strength of the saturated specimens was nearly double the calculated mean skin-stress of the beam and 3.88 times the mean compressive strength.

By the kiln-drying, the tensile strength seems to have been slightly increased, the compressive strength was increased 80 per cent. and the shearing strength was diminished more than 12 per cent. The coefficients of elasticity were also increased.

The ratios of the length to the least transverse dimension in the compression members varied from 4.07 to 5.85, and failure was in each case due to direct crushing.

After compression specimen 1 had been tested the injured portion was removed and the remainder re-tested, when its specific weight was 37.457 lbs. per cubic foot, its coefficient of elasticity 1,627,890 (forward) and 1,634,960 (return), and its compressive strength 3700 lbs. per square inch. The injured portion was removed from this last, and the remainder was dried at 212 ° F. and then tested with the following results:—

Coefficient of elasticity from 1st series of readings
= 2,402,710 (forward), 2,400,340 (return).
Coefficient of elasticity from 2nd series of readings
= 2,415,620 (forward), 2,411,810 (return).
Coefficient of elasticity from 3rd series of readings
= 2,419,940 (forward), 2,421,360 (return).

Between the first and second readings the specimen was under 100 lbs. for 3 hours, the final reading varying from – .00005 to + .00002. Between the second and third readings the specimen was left under 100 lbs. for 25 minutes, the reading varying from – .00005 to + .00002. The specific weight of the dried specimen was 32.559 lbs. per cubic foot.

After f_1 had been tested the injured portion was removed and the remainder retested, with the following results :—

Coefficient of elasticity = 1,972,390 (forward), 1,962,020 (return) ; compressive strength = 3521.4 lbs. per square inch ; specific weight = 36.777 lbs. per cubic foot.

After 2 had been tested the injured portion was removed and the remainder re-tested, with the following results :—

Coefficient of elasticity = 1,733,480 (forward), 1,727,000 (return) ; compressive strength = 3736.7 lbs. per square inch ; specific weight = 37.602 lbs. per cubic foot.

The injured portion was removed from the last and the remainder dried at 212° F., when it was tested, with the following results :—

Coefficient of elasticity = 2,690,130 (forward), 2,699,970 (return) ; compressive strength = 8465 lbs. per square inch ; specific weight = 30.253 lbs. per cubic ft.

Specimen 2 contained the heart, and shews the least compressive strength.

Remarks on E.—It may be observed that the coefficient of elasticity and strength often differ widely in value, even in the case of specimens which were in the same alignment in the original beam, and which had been treated, as far as practicable, in a precisely similar manner. This may be due to a number of uncontrollable causes, as, for example, an inherent weakness or a want of parallelism in the grain, but it is certainly largely due to the proportion of moisture present in the specimen, and perhaps to some, but a much smaller, extent to a variation in the temperature.

Again the difference between the means of the forward and return observations diminishes as the moisture is eliminated, and as the material approaches the normal state, that is, the state in which it contains the greatest amount of moisture consistent with the hygrometric condition of the surrounding atmosphere. The same is true also of kiln-dried specimens, but the latter, on account of their small section, rapidly absorb moisture until the normal state is reached. The rate of loading was kept as uniform as possible, the average time per reading being ½ minute for tension and ¾ minute for compression specimens. The following examples will serve as illustrations :—

A.—SPECIMEN OF WHITE PINE MARKED I. (KILN-DRIED).

This specimen was taken out of the kiln on March the 28th, 1895, and allowed to cool in the Laboratory during the night.

Its sectional area = .7288 square inches, and its specific weight = 24.788 lbs. per cubic foot.

Date.	No. of readings.	Mean forward reading.	Mean return reading.	Temp. (Fahr.) of Laboratory.	Mean pressure of vapour.	Mean relative humidity.	Dew point.
Mar. 29	96	694.702	698.572	28°8 to 30°1	.2		
" 30	30	699.143	699.267	45°3 to 46°8	.2152	88.3	36.2
" 30	54	705.153	704.463	68°1 to 68°3	"	"	"
" 31	40	688.342	688.175	67°4 to 68°	.1793	87.3	31.5
Apr. 1	50	673.958	673.6	33° to 37°5	.1082	83.0	19.7
" 2	30	686.5	686.066	67° to 68°	.170	93.7	30.3
" 3	20	685.111	685.3	64°5	.1173	88.7	22
" 4	20	670.65	670.25	34°5 to 37°8	.1202	89	22.2
	26	669.5	669.5	33° to 35°3			
" 7	30	682.5	682.	64° to 67°8	.1557	89	28.3
" 8	30	678.857	678.228	65°2	.1498	86	27.3
" 9	34	666.469	666.147	35°	.1382	80	25.3
" 9	15	676.643	676.143	61°5		74.7	

Tensile strength of specimen = 12,294 lbs. per sq. inch.

B.—SPECIMENS OF RED PINE MARKED GI. (KILN-DRIED).

Specimen 1.—Sect. area = .6874 sq. ins.; sp. wt. = 30.9 lbs. per cub. ft.; tensile strength = 14,620 lbs. per sq. in.

Specimen 2.—Sect. area = .71775 sq. ins.; sp. wt. = 33.17 lbs. per cub. ft.; tensile strength = 12,023 lbs. per sq. in.

SPECIMEN 1.

Date.	No. of readings.	Mean forward reading.	Mean return reading.	Temp. (Fahr.) of Laboratory.	Mean pressure of vapour.	Mean relative humidity.	Dew point.
Mar. 28	14	654.34	654.37	55° to 64°	.0945	85.0	17.0
" 29	48	649.28	649.56	28° to 30°			
" 29	25	650.32	650.	25°5 to 27°			
" 30					.2152	88.3	36.2

SPECIMEN 2.

Mar. 27	22	605.9	64.72	33°	.082	86.5	13.3
" 28	42	600.625	600.309	27°5	.0945	85.0	17.0
" 28	21	617.65	616.95	65°			

Again, a kiln-dried tension specimen, with a sectional area of .658 square inches, was placed in the testing machine on April the 10th, 1896, and was subjected to a load which was gradually increased up to 1000 lbs. Under this load, the extension during the first day was at the rate of 6.1 hundred-thousandths of an inch per hour. On every succeeding day this rate diminished, but irregularly, until the test piece had reached its normal state. At this point, the slightest change in the humidity produced a corresponding change of length in test piece. The maximum amount of extension, viz., .00708 inch, occurred on the 11th of May.

The greatest observed rates of extension and recovery per hour were 7 and 8 one hundred-thousandths of an inch, respectively. On the 16th of May the load was reduced to 200 lbs., when the extension was also reduced to .0024 inch. One hour later the reading had fallen to .00233 inch, but an increase in the humidity then caused a corresponding increase in the extension of .00017 inch.

In the transverse experiments the greatest possible care was taken to increase the load at the same uniform rate, the average time occupied in adding each increment and in taking the corresponding reading being slightly greater than 1 minute. In many cases the beam was loaded, then relieved of load, and reloaded again, the readings in all cases being carefully noted. This operation was sometimes repeated more than once. Whenever a beam or a specimen under tension or compression was subjected to repeated loadings, the first series of readings were almost invariably discarded as the increments of deflection, and changes of length were found to be more uniform *after* the preliminary loading. The initial loading seems to eliminate certain inequalities of resistance.

In Beam 15 there was an increment of .401 in. in the deflection, corresponding to an increment of 7,000 lbs. in the load. On reducing the load to 500 lbs., there was an apparent set of .006 in., which would have undoubtedly disappeared in a very short time. Upon re-loading the beam the increment of deflection for the same increment of load was .4 inch.

In Beam 17 the increments of deflection under the first and second loadings were exactly the same, viz., .415 inch for an increment of 7,000 lbs. in the load. When the load, after the first series of readings, was reduced to 500 lbs., there was an apparent set of .005 inch, which would have certainly disappeared had the beam been allowed to rest for a few minutes.

In Beam 24 (Spruce) for an increment of 6,000 lbs. in the load, the increment of deflection was 1.04 in. in the first loading and 1.034 in. in the second. Upon being entirely relieved of load, there was an apparent, but evidently only apparent, set of .01 in.

In Beam 25 (Hemlock), for an increment of 6,000 lbs. in the load, the increment of deflection was 1.165 in. in the first loading and 1.155 inch in the second, the apparent set when entirely relieved of load being .01 inch.

In Beam 27 (Spruce), after being loaded and then entirely relieved of load, there was an apparent set of .005, which in two hours had fallen to .002 inch.

In Beam 26 (Hemlock), after being loaded and then entirely relieved of load, there was an apparent set of .004 inch, which had entirely disappeared after an interval of about two hours.

In the case of Beam 28 (White Pine) there were three sets of loadings, the increments of deflection corresponding to an increment of 12,000 lbs. in the load, being:—

.238 in. and .234 in. for the first set,
.237 in. and .232 in. for the second set,
.237 in. and .232 in. and .232 in. for the third set.

When the beam was entirely relieved of load after the first set, there was an apparent set of .002 in., which had entirely disappeared in 25 minutes. The second set of loadings commenced after an interval of 18 hours. The mean increment of deflection = .2344 in.; the mean compression = .0827 inch, and, using the ordinary formula, the corresponding value of $E = 1,066,980$ lbs.

The increments of deflection for repeated loadings corresponding to an increment of 6,000 lbs. in the load were:—

.675 in., .660 in., .650 in. for Beam 29 (Hemlock),
.335 in., .330 in., .337 in. for Beam 30 (Spruce),
.492 in., .485 in., .487 in. for Beam 31 (Red Pine),
.675 in., .655 in., .653 in. for Beam 32 (White Pine),
.313 in., .308 in., .305 in., .306 in. for Beam 49 (Red Pine).

The increments of deflection for repeated loadings, corresponding to an increment of 7,000 lbs. in the load, were:—

.625 in., .620 in., .620 in., .625 in. for Beam 33 (Spruce).

The increments of deflection for repeated loadings, corresponding to an increment of 5000 lbs. in the load, were:—

.590 in., .556 in., .555 in. for Beam 35 (Hemlock).

For beams dried at 212° F., the increments of deflection for repeated loadings were;—

.420 in., .400 in., .405 in., .405 in., .405 in. for Beam 36 (White Pine) and an increment of 6,000 lbs.

.178 in., .173 in., .173 in. for Beam 37 (Red Pine) and an increment of 4,000 lbs.

.039 in., .042 in., .040 in., .040 in. for Beam 38 (White Pine) and an increment of 300 lbs.

.048 in., .048 in., .048 in., .0.49 in. for Beam 39 (Spruce) and an increment of 300 lbs.

.071 in., .070 in., .070 in., .070 in. for Beam 40 (Hemlock) and an increment of 300 lbs.

.363 in., .358 in., .358 in., .363 in. for Beam 41 (Red Pine) and an increment of 1,200 lbs.

.669 in., .672 in., .675 in. for Beam 42 (White Pine) and an increment of 1,200 lbs.

.411 in., .416 in., .408 in., 402 in. for Beam 43 (White Pine) and an increment of 6,000 lbs.

.243 in., .240 in., .238 in., .241 in. for Beam 44 (Red Pine) and an increment of 6,000 lbs.

From these results and from the further observations up to the point of fracture, the following inferences may be at once drawn :—

(*a*) The increment of deflection diminishes and therefore the co-efficient of elasticity increases with the elimination of the moisture from the beam.

(*b*) The increments of deflection are much more uniform in amount in the case of kiln-dried beams.

It is, of course, impossible to maintain a beam in a kiln-dried state. As soon as it is exposed to the atmosphere, it at once commences to absorb moisture, and the absorption continues until there is an equilibrium between the hygrometric conditions of the beam and atmosphere. The beam is then in its normal state, and the experiments indicate that the increments of deflection, corresponding to this state, are approximately uniform. The rate of absorption depends essentially upon the nature of the timber, and proceeds more slowly as the density increases. The weight of a central 2 inch slab of beam 30 (Spruce) increased 3.6 per cent. in 24 days and 8.5 per cent. in 47 days.

The influence of moisture on the deflection of a beam was well illustrated in the case of 15 inch × 6 inch Douglas fir beam on 186 inch centres. On June 15th, 1895, it was placed in position and was loaded with a weight of 1000 lbs. at the centre, producing a deflection of 071 inch. The daily observations, extending over several months showed a continually increasing deflection, until, by the evaporation of the moisture, the beam had attained its normal state. The average deflection now remained constant, varying, for example, between .09 inch on August 24th, and .082 inch on September 2nd, the greater deflection of course corresponding to an increase of moisture in the atmosphere. On the 4th of September, the load was increased to 2000 lbs., which produced a deflection of .127 inch. This load remained on the beam until January 8th, 1896, the deflection during the same period varying between .129 inch and .114 inch.

Changes of temperature produced no appreciable effect upon the deflection, but its sensitiveness to the presence of moisture is shown by the following table of daily observations, taken at 12 p.m., from August to December.

UNDER A LOAD OF 1,000 LBS. DURING AUGUST.

Temp.	Def.	Remarks.	Temp.	Def.	Remarks.	Temp.	Def.	Remarks.
72°5	.080		75°3	.089	Cloudy and showery.	70°4	.085	Dull, cold and showery.
73°5	.080		74°9	.088	Cloudy.	70°6	.090	Continuous rain.
71°8	.081		74°0	.088	Fine.	72°2	.089	Showery, then fine.
73°0	.083		75°9	.088	“	72°5	.089	Fine.
75°0	.083		76°7	.086	“	73°8	.089	“
74°4	.088		76°4	.088	Stormy.	74°6	.089	“
73°0	.087		75°3	.088	“	71°3	.089	Dull and cool.
75°0	.087		73°5	.086	“	75°5	.082	Fine.
75°8	.087		72°0	.086	Fine and showery	74°9	.086	Showery.
74°9	.088		70°8	.085	Dull, cold and showery.			

UNDER A LOAD OF 2,000 LBS. DURING SEPTEMBER.

Temp.	Def.	Remarks.	Temp.	Def.	Remarks.	Temp.	Def.	Remarks.
77°3	.127		71°0	.129	Cloudy and cold.	71°3	.126	Fine and warm.
76°9	.129	Cloudy.	68°75	.129	“	77°3	.126	“
56°2	.129	“	58°0	.125	“	71°5	.128	Fine, but cooler.
77°0	.129	Rain.	69°5	.126	Fine and warm.	71°0	.126	“
75°8	.126	Fine and stormy.	66°0	.124	Fine and cold.	71°6	.128	Wet and stormy.
75°3	.126	Stormy.	69°4	.121	Fine and warm.	70°0	.128	Fine.
75°0	.129	Cloudy.	69°0	.125	“	67°1	.128	“
						65°8	.126	“

UNDER A LOAD OF 2000 LBS. DURING OCTOBER.

Temp.	Def.	Remarks.	Temp.	Def.	Remarks.	Temp.	Def.	Remarks
65°0	.127	Dull, cold and showery.	75°0	.123		68°0	.118	Fine and cold.
68°0	.125	Fine and warm.	65°8	.123	Stormy.	68°0	.116	“ “
68°5	.125	“ “ “	64°3	.126	“	61°8	.119	Damp and cold.
66°2	.125	“ “ “	66°0	.120	Fine and cold.	63°5	.116	Fine and cold and dry.
66°0	.125	“ “ “	66°4	.120	“	65°0	.114	“ “
65°0	.125	“ “ “	67°0	.122	“ “	65°0	.115	“ “
70°0	.125	Dull and cold. Laby. heated.	65°8	.120	“ “	68°0	.115	“ “
67°0	.125	Dull and cold. Laby. heated.	68°5	.120	“ “	69°0	.111	“ “
			60°0	.120	“ “			
			65°0	.120	“ “			
			66°2	.120	“ “			

UNDER 2000 LBS. DURING NOVEMBER.

68°5	.115	Rain.	66°0	.120	Cloudy and cold.	62°0	.118	Cold. Laby. heated.
70°0	.114	Cloudy and cold.	69°0	.119	“ “	66°0	.115	Snow. “ “
58°6	.114	Fine and cold.	68°5	.119	Fine and cold.	57°8	.120	Fine.
65°0	.115	“ “	69°0	.119	Rain.	60°0	.115	Snow.
67°8	.115	“ warm.	70°3	.119	Fine and warm.	67°5	.118	Rain and warm.
68°0	.115	“ “	63°7	.120	Fine.	69°7	.118	Cloudy & warm.
66°3	.120	Rain and warm. Laby. door open.	66°0	.120	Dull and wet.	69°0	.118	Fine and warm.
60°0	.120	“ “ “	67°5	.120	Rain and warm.	69°3	.118	Fine.
53°0	.120	Continuous rain.	68°0	.120	Cloudy and warm	70°0	.115	Fine and cold.
57°0	.122	Snow & freezing.	59°0	.120	Snow and cold.			
58°0	.120	Cloudy and cold.						

UNDER 2000 LBS. DURING DECEMBER.

Temp.	Def.	Remarks.	Temp.	Def.	Remarks.	Temp.	Def.	Remarks.
60°0	.115	Fine and cold.	62°6	.115	Fine and cold.	56°5	.115	Warm and dull.
62°5	.115	Snowstorm.	62°5	.114	“ “	66°0	.115	“ fine.
64°5	.115	Fine and cold.	65°3	.114	“ “	59°8	.120	Dull and cooler.
61°0	.114	“ “	58°0	.114	“ “	64°0	.120	“ “
68°0	.115	“ “	67°0	.114	Warm and rain.	64°5	.120	“ “
62°5	.115	Snow and milder.	67°0	.115	“ “	63°0	.120	“ warm.
61°5	.115	“ “	67°4	.115	“ “	64°5	.120	“ “
63°0	.115	“ fine.	67°9	.115	Warm and fine.	65°0	.120	“ “
62°3	.115	Fine and cold.						

Remarks on f.—It will be observed that of the 20 non-kiln dried beams, 11 failed by crippling on the compression side, 6 failed by longitudinal shear, and 3 hemlock beams only failed by the fracture on the tension side. The experiments on the direct tensile and compressive strength of the timbers show that this is precisely what might be expected to take place. In every case the direct tensile strength is very much greater than the direct compressive strength, and failure by crippling is likely to take place under a load much less than the material could bear in tension. Under all circumstances, therefore, in practice it is advisable to place a beam so that the portion of the timber which is strongest and in the best condition should be in compression. Again, the experiments conclusively show that kiln-drying enormously increases the direct compressive strength, but greatly diminishes the shearing strength, while the direct tensile strength does not appear to be much affected, although in the majority of cases it was diminished, and sometimes considerably.

The large increase of strength in compression due to kiln-drying might have been naturally expected, as in the process of drying the walls of the cells are stiffened and hardened, and thus become better able to resist a compressive force. The walls, however, are at the same time much more brittle, and it is possible that a sudden blow might cause the failure of a kiln-dried column, which would have remained uninjured had the moisture not been eliminated. It may also be of interest to note that in the re-tests of specimens after the injured portion had been removed, the compressive strength was, almost without exception, increased.

Hence, by kiln-drying a beam its compressive strength is made to approximate more closely to its tensile strength, and its transverse strength is consequently sometimes considerably increased. It must be remembered, however, that this kiln-drying invariably largely diminishes the shearing strength, and therefore proportionately increases the tendency to shear longitudinally. Thus, of the nine kiln-dried beams in the preceding tables, only *one* failed by crippling, while *four* failed by fracture on the tensile side and *four* failed by longitudinal shear. Indeed, generally speaking, kiln-dried beams will fail either by a tensile fracture or by a longitudinal shear, and this result has been further verified by experiments subsequent to those referred to in the present Paper.

In practice, of course, beams cannot be maintained in a kiln-dried state, but they rapidly pass into the normal state. The question of how far it is desirable to eliminate the moisture depends essentially on the balance to be maintained between the tensile, shearing and compressive strengths, and a beam should always be placed so as to exert its relative strengths to the best advantage. Kiln-drying, unless some special method of prevention is adopted, develops shakes in the timber and causes existing shakes to become more pronounced. Some of these shakes often extend to a great depth and run the whole length of the beam, so that it not infrequently happens that only a slight layer is left to hold the beam together. Such a beam, although otherwise sound and clear, offers very little resistance to longitudinal shear, and might more justly be regarded as being made up of two or more superposed beams.

DISCUSSION.

Prof. Bovey.

Professor Bovey stated that the direct tensile strength of timber was much greater in every case than the direct compressive strength, and for that reason, as his experiments shewed, it was always best and safer to put the best side of the timber in compression.

Mr. Peterson.

Mr. Peterson said that, while Prof. Bovey's tests indicated that the failure usually took place on the compression side, he found that in actual practice the timber invariably failed on the tension side. And that it was a well recognized rule on railways to put the good side of the stringer on the bottom, that is, if a stringer had a large knot, or any other imperfection in or near one side of its greatest dimension, that side was always put up so as to be in compression; and failures of stringers were generally found to be the result of this rule being neglected and the side of the stringer with a knot or other imperfection having been put on the bottom.

Prof. C. B. Smith.

Prof. C. B. Smith said, incipient failure having occurred on the compressive side, the neutral axis probably shifted its position and threw an additional strain in tension.

Prof. Bovey.

Prof. Bovey—A beam which had apparently failed on the tension side, had in reality been first weakened by the crippling in compression (which is not always visible), and this threw an additional strain in the tension side, which thereupon ruptured first. He also pointed out that no two pieces of timber gave the same results; they varied greatly; e.g., if you cut a piece of timber into three parts longitudinally, you would find they varied largely as far as strength is concerned.

Mr. Irwin.

Mr. Irwin pointed out that, after a stick of timber had failed on the part injured in compression, if the distortion were not too great, it would apparently return to its original condition, so as to escape observation easily and to look as if the rupture took place on the tension side.

Mr. Peterson.

Mr. Peterson speaking of bridge trusses said that he had never known the top chord to fail, and that it was not nearly so liable to do so as the bottom chord, and that this did not coincide with the experiments made.

Prof. Bovey replied that the cases of a bridge truss and a beam were not parallel, and that the top chord of a bridge truss was subject to direct compressive strains very different from those in a beam under a transverse load. Prof. Bovey.

Mr. Duggan said that a bridge truss never failed in the solid, but only in the joints, these being the weakest points. Mr. Duggan.

The Discussion continued Dec. 9th, 1897.

Prof. C. B. Smith said that the paper contained one or two features which should be of special interest to the society. He reminded those present that the last time Prof. Bovey wrote on this subject his paper was very severely criticized, particularly by American testing experts, because he had not actually determined the moisture and its influence on the strength of timber, and they thought that because he had not done so his tests were of little value. But their experiments had been chiefly on the compressive strength of timber, which was certainly increased by lowering the percentage of moisture, while on the other hand the tensile and shearing strengths were reduced by abstracting moisture, and cross-bending strength being a combination of all these was sometimes made greater and sometimes less according to which strength was deficient in a special kind of timber. So that the abstracting of moisture, besides being difficult to obtain in practice, was of less value than had been supposed. Besides this, once a timber was fairly well seasoned the percentage of moisture varied very slowly under natural treatment, being chiefly a surface effect and not penetrating to any extent; and, being less as the timber was denser, Professor Bovey's paper must be considered a very valuable addition to our literature on the testing of large sized timbers. The other point of interest which Professor Smith mentioned was the subject of the flexure theory. It seemed a pity to be dependent on a theory which was so unsatisfactory, and he emphasized the fact that it was more correct to assume that the distance of the so-called neutral surface from the tension and compression faces was inversely proportional to the tensile and compressive strengths of the beam. This assumption he said had been used in some of their experiments at McGill with results more nearly in accordance with what might be expected than if the ordinary flexure formula had been applied. Prof. C. B. Smith.

Mr. Irwin said that there was no doubt at all about the first point in Prof. Smith's remarks as to moisture, and that he considered Prof. Bovey's tests to be very carefully made. But he thought that the mathe- Mr. Irwin.

matical theory of flexure as defined long ago was so absolutely correct as to be indisputable, and he very much disliked to hear it attacked as being unsatisfactory.

Prof. C. B. Smith. **PROF. C. B. SMITH** asked how then was the fact to be accounted for that this theory frequently produced results that were contrary to experience.

Mr. Irwin. **MR IRWIN** replied that such could not be the case if the theory were properly applied. The trouble was not in the *theory* but in the *application* of the theory. The theory, he said, was based on three assumptions that could be proved step by step mathematically, without any flaw in the process. If certain assumptions were made and from these a theory was deduced, and there could be no flaw in the reasoning which deduced that theory, then did it not follow that the theory was correct?

Prof. C. B. Smith. **PROF. SMITH** said this was so only if the assumptions were correct. He asked what the three assumptions were.

Mr. Irwin. **MR. IRWIN** replied that he thought they were to be found in Euler's theory of flexures as follows:—

1. Any plane section remains a plane after bending.
2. The elongation on compression varies directly according to the stress.
3. The material in question is homogenous.

Any theory based on these three assumptions was absolutely and rigidly correct, but then there were cases where the theory could not possibly be applied, since the assumptions would not hold good in regard to them. It would not apply directly the point of elasticity had been passed. The consideration of the material did not enter into the theory, but only the assumptions in regard to it. And though Mr. Irwin held that the theory was absolutely correct, he did not think it could be applied rigidly to the material in question since it was not at all homogenous. But, if the theory could be applied to the material, it would be found to work out correctly. With regard to cast iron, the high existing stresses after the casting should be borne in mind.

Prof. C. B. Smith. **PROF. SMITH** asked if it would not be well to work on some theory which *could* be applied to material which *does* exist. He also pointed out that Professor Bovey in his Paper had not stated that the theory was incorrect but that it was unsatisfactory as regards timber. He then proceeded to explain the theory of horizontal stresses at the centre section of a beam subjected to vertical loads producing cross bending as given in Johnson's "Modern Frame Structures", which had in turn been derived from Saint Venant and other European mathematicians, viz.:—That the stress after the elastic limit was passed varied similarly in intensity to the direct compressive and tensile stress-strain diagram curves, and that the area of those portions of the diagrams used must evidently be equal to each other. This, he said, gave a ready means of determining the position of the neutral surface when we constructed normal direct stress strain curves and cut off equal areas.

Mr. Irwin.

MR. IRWIN was quite willing to concede that there was a neutral axis in a homogenous material, but would not accept the shape of Mr. Smith's stress strain areas, as no one knew how the stress was distributed, and he said that, while he considered Prof. Bovey's tests very valuable and most useful as practical tests which involved a vast amount of work, yet he maintained that the theory of flexure was correct. And, in sifting the subject out after a former Paper by Prof. Bovey, he had pointed out in a discussion (which had not been printed along with the rest of the discussions on that subject) that the discrepancy between the skin stress of material calculated from transverse bending tests and the stress from direct breaking varied according to the relative depth of the beams. This was to be accounted for by local pressure, and better results might be obtained by placing the beams on their sides in testing them transversely in order to avoid as far as possible excessive local compression at the centre.

Thursday, 9th December.

JOHN KENNEDY, Past President, in the Chair.

A special general meeting of the Society was held to approve of the proposal of Council to lease certain rooms recently added to the building, the furnishing thereof, and other arrangements in connection therewith. It was resolved that the rooms should be leased as recommended by Council, and that the sum of $510.00 should be appropriated for furnishing and providing addition to bookshelves.

A discussion took place as to arrangements in connection with the Annual Meeting, and a committee was appointed in connection therewith.

Messrs. E. S. M. Lovelace and F. P. Shearwood having been appointed Scrutineers of the Ballot, declared the following elected:

MEMBERS.

GUSTAVUS ADOLPHUS BERNASCONI, ALEXANDER FORRESTER STEWART.

ASSOCIATE MEMBERS.

GEORGE FORRESTER HANNING, NATHANIEL HANSON GREEN,
JOSEPH ABRAHAM MARION, ANGUS MATHESON STEWART.

STUDENTS.

ELIAS JOHN BOSWELL, CASIMIR STANISLAUS GZOWSKI.
WILLIAM M. MCPHAIL.

Transferred from the class of Associate Member to class of Member:

NOEL EDGHILL BROOKS, JAMES MILNE,
GUY CRAMP BELL DUNN, ALEX. BELL ROSS.

Transferred from the class of Student to class of Associate Member:

VICTOR FREDERICK WILLIAM FORNERET.

Thursday, 23rd December.

G. H. DUGGAN, Vice-President, in the Chair.

In view of the small attendance, no paper was read, and the meeting was adjourned at an early hour.

Thursday, 6th January, 1898.

H. Irwin, Member of Council, in the Chair.

Paper No. 124.

SEWAGE DISPOSAL BY SUBSOIL IRRIGATION.

By E. Mohun, M.Can.Soc.C.E.

In October, 1894, the author received instructions from the Hon. the Chief Commissioner of Lands and Works to devise some means for disposing of the sewage of Government House, at Victoria, B. C., and though the work undertaken is but on a small scale, he trusts that it may prove of interest to some of the members.

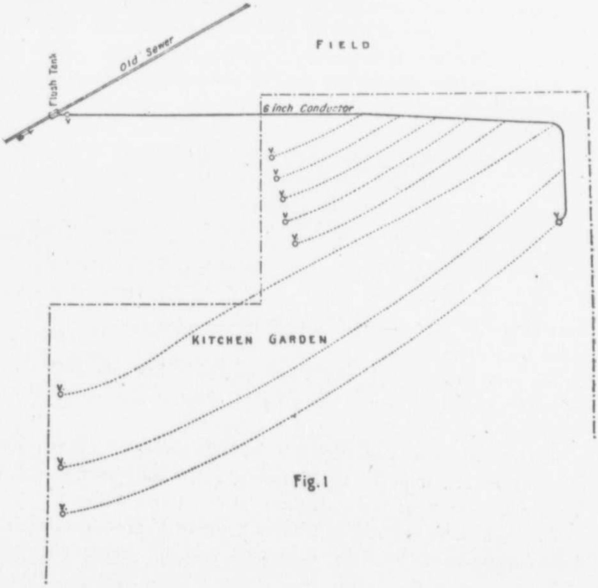


Fig. 1

It was found that the sewage of the building had been disposed of by the simple expedient of running a 6 in. pipe across a field and discharging into the street ditch, thereby creating an intolerable nuisance.

The Sewerage System of the city had not been extended in that direction, and to make connection with the nearest point it would have been necessary to construct a sewer about 3,600 ft. long, nearly all the trenching for which would have been through solid rock.

The contour of the ground being adapted to the purpose, it was decided to dispose of the sewage by subsoil irrigation. Reference to the books of the Water Department showed that the house consumption as taken by metre was remarkably small, frequently not exceeding 300 gallons a day.

The only pipes available were 6 inch circular drain pipes, T pipes and 3 inch circular drain tiles. At a convenient point in the field the old sewer was cut (Fig. 1) and an automatic flush tank built, from which the sewage passed down a tight 6 inch conductor to the inlet ends of the 3 inch drain tiles shown in the dotted lines.

In laying the drain tiles the following method was adopted. Contour lines having been set out with the level and the trench cut along them, bricks were laid with a carpenter's level, 8 ft. long, so as to form level and solid bearings beneath the ends of the drain tiles (Fig. 2), laid upon them.

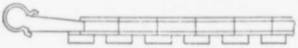


Fig. 2

The connection with the 6 inch conductors was made by turning down a 4 × 6 T, and making connection with the drain tile by means of a galvanized iron taper. The ends of all the drain tiles are provided with air vents, v, v, made by galvanized iron, and connected with the drain by quarter bends.

The area irrigated is nearly one acre, and it has not been found necessary to underdrain, as the whole of the discharge appears to be absorbed by the earth.

The total length of the drain tiles is 1,463 feet, and the upper surfaces of the tiles are from 10 to 12 inches below the ground surface. Their alignment is marked on the ground by lettered stakes.

The flush tank is provided with an [screen ¼″ mesh, divided into three compartments by weirs; into the first the sewage discharges directly through the old pipe; as the screen becomes clogged with paper it overflows into the second compartment and similarly into the third. It has not been found necessary for the scavenger to clear the screen oftener than once in six weeks, though for other reasons it is done once a month.

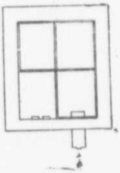


Fig. 3.

No offensive smell can be detected either at the flush tank or on the lines of pipes, nor is there any indication of excrement sodden soil.

The gardener states that the ground never before produced vegetables equal to those of the present year.

The ground to the north-west is considerably higher than the field and garden, and is very rocky. Shortly after the completion of the work, snow fell, and within a few hours a rapid thaw took place, accompanied by heavy rain, the water actually running over the surface in a sheet. Under the circumstances the tile drains became surcharged, and when the rush from the flush tank took place it can hardly be considered wonderful if three or four of the tiles were broken. They were of course easily replaced, and a similar occurrence guarded against by cutting an intercepting ditch across the field to lead the surface water into the street ditch.

An object sought to be arrived at was to so proportion the tank that each discharge would fill all the drains, practically, simultaneously.

The cost of labour was high, a good deal of rock being met with in laying the 6 inch conductor.

The work was performed by day labour under the author's instructions, and its cost was

Material	$255.68
Labor, engineering, etc.	244.30
	$499.98

It may be added that the estimate furnished the Government was $500, and the close result may be denominated a fluke.

ABSTRACTS.

100 FEET STANDARD OF LENGTH OF BOSTON WATERWORKS.

By Chas. W. Sherman.

(*Journal of Association of Engineering Societies*, April, 1897.)

This paper describes the setting up and standardizing of a 100 feet bar. A steel bar $\frac{1}{4} \times 1$ inch in cross section and 105 feet long, rolled in one piece, was obtained from the Crescent Steel Company, of Pittsburg, Pa. The bar was placed upon a stiff wooden bench with hinged cover along the side of an open shed and rested on composition rollers $\frac{9}{16}''$ in diameter and spaced one foot apart. The bar and rollers are enclosed on each side by a strip of $\frac{7}{8}''$ planking. Holes $\frac{3}{4}''$ in diameter and $\frac{3''}{32}$ deep and 10 feet apart were drilled in the bar, and discs of silver hammered into them. The bar was graduated from two steel tapes, the errors of which had been determined by the United States Coast Survey. A straight line was lightly marked along the discs with the aid of a transit, and the end graduations of one of the tapes lightly transferred to the bar. The tapes and the cords of the tension weights passed over circular surfaces having a common centre, so that the lever arms and the tension would be the same in any position of the tension apparatus. The length on the bar was compared with the tapes in a set of sixteen series, each series usually consisting of twenty observations. Two observers were required; one to set the zero of the tape coincident with the zero of the bar, which was done by the aid of a set screw and common magnifying glass, and the other to read off the discrepancy by means of an engineer's scale with fifty divisions to the inch. Reliable readings to .002″ were claimed. The settings and readings were made for each observation separately; personal equation was eliminated by changing the positions of the observers after each five observations, and the effect of friction between the tape and the bar was tested and found to be inappreciable. Thermometers were placed with their bulbs in contact with the bar and about seventeen feet apart, the mean of the readings giving an approximation of the temperature of the bar. As the assumption was made that the bar and tapes have the same coefficient of expansion, the temperatures do not affect the result.

A temperature curve was plotted and used in weighting the observations, and the result was finally reduced bythe method of least squares; the errors of the standard tapes being taken into consideration at the same time. The correction to the bar was found and laid off on the bar from the light, preliminary graduations. The permanent graduations were made by marking the silver with a centre punch and rubbing down the surface until only a fine point was left. The subdivision marks were laid off by dividing the 100 feet into ten equal parts by beam compasses, and were afterwards tested by comparison with every ten foot length of each tape and their corrections then reduced. The coefficient of expansion of the bar was deduced as .000006397 per degree Fahr., a correction being made for the difference of temperature between the upper and lower sides of the bars and the expansion being measured by aid of a transit set up on a line at right angles to the tape. The errors of several steel tapes as tested on the bar are given, and the discussion relates the various other standards of length that have been used in Boston.

J. G. K.

THE MANUFACTURE AND USE OF SAND CEMENT.

(*Engineering News*, Vol. XXXV., April 16th, 1896.)

This editorial cites the increased use of this material in Europe, and particularly in Denmark (where it was invented), during the past five years, and states that it has been tested by several American Engineers, with satisfactory results, and has been used in the proportions (1 to 1) to 3, in the concrete for the foundations of St. John's Cathedral, New York, in which 3,000 yards were used, and in other places.

The advantages claimed for the material are, that where great strength is not required, mortars will be more dense, stronger and will work more smoothly on the trowel, in which a portion of the sand has been ground together with the cement, before use in the mortar. Another claim is that the cheaper grades will replace lime mortar in plastering, as it will set and dry quicker, and also, again, that in dock walls a very dense concrete can be produced which will prevent the destructive percolation of sea water.

Tests made at St John's Cathedral foundations gave the following results in compression :—

(1) concrete (1 to 1) sand cement 2 sand 3 gravel	1 week—2,144 lbs. per sq. in. 2 weeks—2,312 lbs. per sq. in. 4 weeks—2,588 lbs. per sq. in.
(2) Sand cement Mortar. (1 to 1) sand cement. 3 sand.	1 week's tension 156 lbs. 2 weeks' tension 188 lbs. 4 weeks' tension 200 lbs.
(3) Portland cement. Mortar (average of 1,500 bbls.) 1 cement. 3 sand	1 week's tension 137 lbs. 2 weeks' tension 170 lbs. 4 weeks' tension 179 lbs.

The article concludes with a description of the plant at Glen Falls, N. Y., where tube mills and flint pebble balls are used in grinding, and a statement, that the American sand-cement output is ground very fine (5 per cent. residue on 180 mesh sieve), the tests will show higher results than those in the table which is added, giving tests made in Europe on sand cement mortars of various proportions.

The usual proportions in America are (1 to 1) and (1 to 6), the former competing with Portland cement and the latter with lime.

N.B.—A (1 to 1) sand cement, for instance, is a material composed of one part Portland cement and one part of Silica sand, ground together.

C. B. S.

EXTRACT FROM EUROPEAN TESTS

On Sand Cement Mortars.

	Tensile strength per square inch (water).					Compressive strength per square inch (water).				
Mortar.	1 wk. lbs.	4 wks.	3 mos.	6 mos.	1 year.	1 wk.	4 wks.	3 mos.	6 mos.	1 year.
(1 to 2) to 2	142	242	299	384	400	1,080	1,795	2,148	2,578	3,365
(1 to 3) to 2	114	185	228	271	326	497	1,080	1,637	2,008	2,485
(1 to 6) to 2	57	114	156	—	220	200	384	667	—	1,050
(1 to 12) to 2	43	114	128	157	142	171	384	726	796	866
(1 to 24) to 2	28	57	57	57	57	128	270	370	370	383

TESTS ON SAND CEMENT

AT THE McGILL COLLEGE LABORATORIES.

(*a*) (1) Iron clad brand Glen Falls (1) Sand :—

	Tension.			Compression.		
	1 week	4 weeks		1 week	4 weeks	
Neat	475	602		3380	4650	
(1 to 1) to 3	73	105	pressed			
(1 to 1) to 3		185	rammed	1060	1120	rammed.

Blowing test good, Residue 1.5 per cent. on No. 100 sieve.

(*b*) (1) Aalborg, Denmark 1 Sand (Cathedral brand).

(1 to 1) to 1	279	398	1375	2012
(1 to 1) to 3	44	66		300

This is from a barrel which was supposed to be damaged.
Residue 1.2 per cent. on No. 120 sieve. 0.7 per cent. on 100 sieve.
" 18.0 per cent. " 180 sieve.

(*c*) (1) Star (Rathbun) 1 Sand (Ensign brand).

Neat 4 months 800 lbs.

	1 week	2 weeks	1 week	2 weeks.
(1 to 1) to 3	66	95 pressed		400 pressed
(1 to 1) to 3	183	192 rammed		880 rammed

Residue 0.6 per cent. on 100 sieve.
" 1.0 " 120 "

(1) Star (Rathbun) 6 Sand (Jubilee Brand).

Neat 4 months, 340 lbs.

	1 week	2 weeks	1 week	2 weeks.
(1 to 6) to 1	213	230 pressed		1350 pressed
(1 to 6) to 1	242	292 rammed		2112 rammed
(1 to 6) to 2	184	215 rammed	1225	rammed

0.3 per cent. Residue on No. 100 sieve.
1.3 per cent. " " 120 "

(1) Star (Rathbun) 1 Sand (Citadel brand).

	Tension		Compression.	
	1 week	4 weeks	1 week	4 weeks.
Neat (1 to 1)	332	475	1800 (?)	3837
(1 to 1) to 3	135	141 rammed	470	687 rammed.

0.2 per cent. Residue on 100 sieve.
0.5 per cent. " " 120 "

C. B. S.

SOME EXPERIMENTS ON THE CONDENSATION OF STEAM.

A New Apparatus for Studying the Rate of Condensation of Steam on a Metal Surface at Different Temperatures and Pressures.

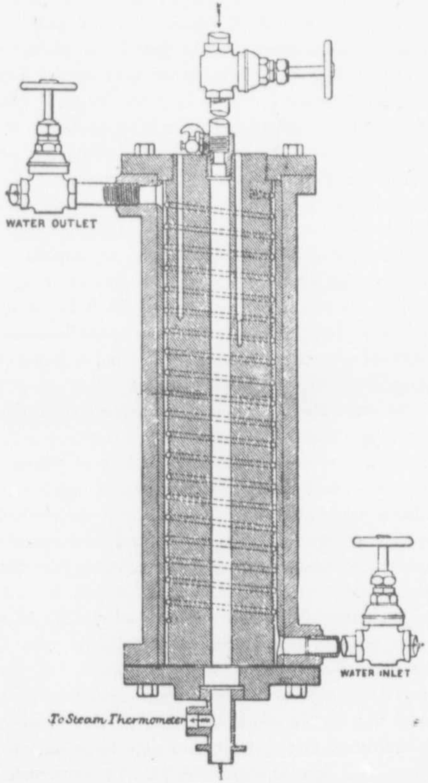
By H. L. Callendar, M.A., F.R.S., Professor of Physics, and J. T. Nicolson, B.Sc., Professor of Mechanical Engineering of McGill University, Montreal.

Part I.

As the result of some experiments by electrial methods on the measurement of the temperature changes of the walls and steam in the cylinder of a working steam-engine, which were made at the McDonald Engineering Building of McGill University in the summer of 1895, the authors arrived at the conclusion that the well-known phenomena of cylinder condensation could be explained, and the amount of condensation in many cases predicted from a knowledge of the indicator card on the hypothesis that the rate of condensation of steam, though very great, was not infinite but finite and measurable. An account of these experiments was communicated to the Institution of Civil Engineers in September, 1896, and will, it is hoped, be published in the course of the ensuing session. In the meantime, the authors have endeavoured to measure the rate of condensation of steam under different conditions by a new and entirely different method, with a view to verify the results of their previous work, and also to estimate the influence, if any, of the film of water adhering to the walls of the cylinder.

In considering the condensation of steam on a metal surface it is usually assumed that the surface exposed to the steam is raised up to the saturation temperature corresponding to the pressure of the steam, and that the amount of condensation is limited by the resistance of the water films to the passage of heat from the steam to the metal and from the metal to the water. If the steam contains air, there may also be a considerable resistance due to the accumulation of a film of air on the surface, but it is comparatively easy to exclude this possibility in experimental work.

In the steam-engine experiments above referred to, it was practically certain that the water film due to the cyclical condensation never exceeded one thousandth of an inch in thickness, and that the resistance offered by it was unimportant. At the same time, it appeared clear that the temperature of the surface of the metal at its highest was considerably below the saturation temperature of the steam; a condition which could only be explained by supposing the rate of condensation of steam on a surface to be limited by some physical property of steam itself, apart from the resistance of the condensed film of water. Interpreted in this manner, the experiments led at once to the conclusion that the rate of condensation at any moment was simply proportional to the difference of temperature between the saturated steam and the surface on which it was condensing.



The limit thus found was shown to be capable of explaining many of the phenomena of cylinder condensation in a rational manner; but the method by which it was established was of an indirect and somewhat intricate character, and appeared to require some simple and more direct confirmation.

If the rate of condensation of steam were really infinite, it should be possible by a suitable modification of the surface-condenser method to obtain values of the condensation considerably in excess of those given by the formula deduced from the temperature cycle observations.

To accomplish this, it is necessary to eliminate as completely as possible the resistance to the passage of heat through the water films between the steam and the metal, and between the metal and the circulating water, and at the same time to measure as accurately as possible the temperature of the metal.

These considerations led to the form of apparatus shown in the figure. The resistance to the passage of heat from the metal to the condensing water in this apparatus is practically eliminated by employing a thick cylinder, 5 in. diameter and 2 ft. long, with a screw thread cut on its outer surface. Water from the high pressure mains is forced to circulate round this surface with a very high velocity in the narrow space between the cylinder and the surrounding tube. In this manner it is possible to obtain a very uniform temperature for the external surface differing but little from that of the circulating water.

If the cylinder is made sufficiently thick, its temperature may be approximately determined at any depth by inserting mercury thermometers. In was intended at first to use thermo-couples for this purpose, but the apparatus in this form would have been unsuitable for students' use in the ordinary course of laboratory work, which was one of the primary objects in view in the construction. It would also have been desirable to make the cylinder of nearly pure copper, which would have reduced the resistance of the metal to the lowest point. The authors were compelled, however, to content themselves for the time with cylinders of cast iron and of mild steel.

The internal surface of the cylinder, upon which the steam was condensed, was a hole 1 in. diameter, drilled in the solid metal. In order, as far as possible, to minimise the resistance of the surface film of condensed water, a revolving brush was constructed of very thin strips of steel to wipe the surface five or six times a second. This wiper was found to wear in a very short time to so perfect a fit and the water film must have been so energetically stirred that its resistance to the passage of heat must have been far less than that of the best conducting metal.

Under these conditions, if the rate of condensation of steam were infinite, it should have been possible to obtain a rate of condensation many times greater than the limit deduced from the cylinder-condensation experiments above mentioned, where there was some small film present.

On making the experiment, however, it was found that the wiper made very little difference to the amount of condensation. With the wiper revolving at the rate of 160 per minute, the condensation was increased by about 5 per cent. on the average of several experiments. It may be concluded from this that the drops of condensed water with which the surface is partially covered are in such rapid motion that they do not appreciably obstruct the passage of heat from the steam to the metal. A film of the same average thickness, if it were absolutely quiescent, and if its conductivity, as generally estimated, were only one-hundreth of that of cast iron, would no doubt prove a serious obstacle; but, as a matter of fact, the viscosity of water at these temperatures is so small, and the motion so rapid, that the drops cannot be treated as a quiescent film.

The temperature at various distances from the inner surface of the cylinder was determined by means of mercury thermometers inserted to a depth of 8 in. or 9 in. in holes drilled parallel to the axis. From the temperatures so observed the conductivity of the metal and the temperatures of its inner and outer surfaces could be approximately inferred. It was found, however, that the presence of the holes interfered materially with the flow of heat through the metal, and that the readings of the thermometer under these conditions were not altogether trustworthy.

From a number of observations on the cast-iron cylinder a conductivity of 5.5 thermal units Fahr. per square foot per minute per deg. Fahr. per inch was deduced, a result which agrees very closely with the authors' previous determination by a different method. For the steel cylinder a conductivity of 5.8 was similarly deduced. These results apply to a mean temperature of about 140 deg. Fahr., and are much lower than the values generally assumed for iron.

In order to verify the previous result as to the rate of condensation of steam derived from the steam-engine experiments, the temperature of the inner surface of the metal was calculated on the assumption of a rate of condensation equivalent to 0.74 thermal unit Fahr. per second per square foot per deg. Fahr. difference of temperature. The values so found agreed with the observed temperatures within the limits of error of the observations. Owing to the inferior conductivity of the iron the test was not absolutely conclusive, as the difference of temperature between the steam and the surface rarely amounted to as much as 30 deg. With a cylinder of pure copper, and thermo-couples for determining the temperature at a given depth, it should be possible to obtain a more certain confirmation by this method.

In performing the experiments, a number of variations in points of detail were introduced from time to time. The flow of the circulating water was varied in velocity, and directed in different ways. In order to secure uniformity in the distribution of temperature measured in different directions from the centre, the spiral circulation was found to be essential. In the second apparatus the screw thread was at first replaced by a baffle-plate, which was intended to direct the water into a spiral course, but the results found were unsatisfactory.

In some cases steam was admitted from the top of the apparatus, and in other cases from the bottom. With the steam supply at the bottom, it was found that condensed water refused to drain down the vertical 1-in. tube in opposition to the current of steam, although the maximum velocity of the steam could not have exceeded 10 ft. per second.

The following set of observations, each of which represents the mean of several taken on similar conditions, will sufficiently indicate the general nature of the results.

Condensation Results Summary. Mild Steel Bar. Wiper Removed.

Condensation. Thermal Units per Square Foot Second.	Steam Temperature Observations.	Surface Temperature Calculations.	Difference, Steam and Surface.	Temperature in Metal at Distances.					Conductivity. K.
				1 In.		1.5 In.		2 In.	
				Calculations.	Observations.	Calculations.	Observations.	Observations.	
	deg.	deg.	deg.	deg.	deg.	deg.	deg.	deg.	
20.0	330	303	27	208	214	154	152	113	5.84
17.8	300	277	23	193	198	143	142	109	5.66
15.¼	274	253	21	179	184	136	134	103	5.81

The temperatures of the metal at distances of 1 in., 1.5 in., and 2 in. from the axis of the bar were observed by means of mercury thermometers, which were very carefully centred by small iron washers in holes filled with mercury. The hole fitting the bulb of the thermometer was $\frac{3}{16}$ in. in diameter. The other holes were $\frac{5}{16}$ in.

It will be observed that in this particular set of experiments the temperatures at 1 in. in the metal, when calculated to agree with the assumed rate of condensation, are all too low as compared with those observed, whereas the temperatures similarly calculated at 1.5 in. are all too high. This might at first sight appear to indicate a very rapid diminution of the conductivity with rise of temperature; but after making various tests the effect was traced partly to the disturbance of the heat flow caused by the presence of the holes, and partly to differences of density of the bar in directions at right angles. The latter differences were not observable in the case of the cast iron.

The observations taken at different pressures do not indicate any marked difference in the rate of condensation per degree second. These results, so far as they go, are in agreement with the authors' previous work, but they hope to be able to obtain more conclusive evidence.

An Electrical Method of Measuring the Temperature of a Metal Surface on which Steam is Condensing.

By H. L. CALLENDAR, M.A., F.R.S., Professor of Physics, McGill University, Montreal.

PART II.

The object of the following experiments, which were made at the McDonald Physics Building with a different apparatus, was the measurement of the temperature of the metal surface itself by a more direct and accurate method. It was also desired to verify as exactly as possible whether the rate of condensation of steam at atmospheric pressure was the same as at the higher temperatures and pressures at which most of the preceding experiments were made.

The condenser used for these experiments was a very thin platinum tube, $\frac{1}{4}$ in. in diameter and 16 in. long. The thickness of the tube was only six thousandths of an inch, and the greatest difference of temperature between its inner and outer surfaces at the maximum rate of condensation observed in the experiments could not have been greater than $\frac{1}{4}$ deg. Cent.

The mean temperature of the metal itself was determined in each case by measuring the electrical resistance of that portion of the tube on which the steam was condensing. The author has had considerable experience in the employment of this method, which, moreover, is very easily applied if suitable apparatus is available.

The platinum tube was enclosed in an outer tube of brass or glass, and steam was admitted to the space between the two tubes. A steady current of condensing water was maintained through the platinum tube. The amount of condensation could be inferred by measuring the flow of water, and observing the difference of temperature between the inflow and the outflow. In many cases the condensed water was also measured. Applying a small correction for radiation, the two methods always agreed within one-half of 1 per cent. The pressure of the steam in the outer tube, which was never far from the atmospheric, was observed by means of a mercury column.

The conditions of the experiment as to flow of water and steam, size and length of the external tube, etc., could be varied within certain limits. The following is a summary of the more interesting results obtained:

1. With a short length of condenser and a very free escape of steam, the condensation observed was equivalent to 22.2 thermal units Fahr. per square foot per second, for a difference of temperature of 28.5 deg. Fahr. between the steam and the metal surface. This is equivalent to a rate of condensation of 0.78 thermal unit Fahr. per degree second, reckoned per square foot of the surface of the metal. This was the smallest value of the rate observed. The platinum tube was vertical, and the current of steam downwards, conditions which tended to keep the surface of the metal comparatively clear of condensed water.

2. With the same conditions, but with a length of tube nearly twice as great exposed to the steam, the condensation observed was 22.3 thermal units Fahr. per square foot per second, for a difference of temperature of 25.3 deg. Fahr. This gives a rate of 0.88 per degree second. The lower half of the tube was more thickly covered with water than the upper half, the steam also was full of flying spray, which may have assisted in conveying heat to the metal, and in maintaining the same rate of condensation on the lower half of the tube as on the upper half, in spite of the somewhat higher temperature of the circulating water in the lower half.

3. With the same arrangement, but with the steam current reversed and reduced until the escape was as gentle as possible consistently with keeping the tube full of steam and entirely excluding air, a some-

what larger rate of condensation was observed, namely, 23.6 thermal units Fahr. per square foot per second. The pressure throughout the tube was very nearly atmospheric, and the gentle upward current of steam tended to keep the tube very thickly covered with drops and rivulets of water. The difference of temperature was only 22.0 deg. Fahr., giving a rate of condensation of 1.07 thermal units Fahr. per degree second. This is equivalent to 2.25 watts (joules per second) per square centimeter per 1 degree Cent., and was the largest value observed throughout the work. It would appear probable that the surface exposed by the drops is so much greater (in the present instance about twice as great) than the surface of metal, and the drops themselves are in such rapid motion, that the increase of surface, by facilitating condensation, more than compensates for any resistance which the water film may offer to the passage of heat to the metal.

4. To verify this view the outer glass tube was replaced by a much smaller tube so as to leave very little space for the steam current. The pressure of the steam was thus raised to nearly 4 in. of mercury above the atmospheric at the entrance of the tube, and the surface of the platinum was violently scoured by a spiral rush of steam and spray. Under these conditions the condensation observed was reduced to 19.2 thermal units Fahr. per sq. ft. per second, instead of being increased as might naturally have been expected with so strong a current of steam. The effect of the energetic scouring of the metal surface was shown by a slight rise of temperature of the metal as compared with previous experiments. The observed difference of temperature between the metal and the steam in this case was 19.8 degrees Fahr., giving a rate of condensation of 0.97 thermal unit Fahr. per degree per second.

From these and similar observations in which the conditions of the experiments were varied to a certain extent in points of detail, it may be concluded that the presence of water on a metal surface may tend to increase rather than diminish the amount of condensation. The rate of condensation of steam at 212 deg. Fahr., allowing for the fact that in these experiments the surface was unduly increased by the presence and the motion of the water drops, would appear to be at least of the same order of magnitude as the value deduced from experiments on the cyclical condensation in the cylinder of a working steam engine, in which the temperature of condensation varied from 290 degrees to 330 degrees Fahr., and the rate deduced was 0.74 thermal unit Fahr. per square ft. per degree per second. Since, however, it is not impossible that the latter value was diminished to an uncertain extent by a slight film of grease on the hot and dry surface, and since the value deduced from the surface condenser method is, perhaps, a little too large owing to the presence of the water film, it would be unsafe to conclude that the rate of condensation is the same at different temperatures, although the evidence, so far as it goes, appears at present to point in that direction. Comparing the three different methods of experiment, which all lead to a similar result, it may be regarded as highly probable that the old view of an infinite rate of condensation requires revision, and that the value of the rate of condensation of steam on a metal surface, as determined by the authors' previous experiments, is at least a first approximation to the truth. The question at issue is one of fundamental importance in the theory of the steam engine, and the authors have shown in the paper already quoted that, if the law of condensation there proposed be admitted, a number of interesting practical deductions can be made, and problems may be solved, which have not hitherto been regarded as amenable to other than empirical treatment.

DISCUSSION.

Prof. Durley.

Prof. Durley said that these Papers were likely to impress any hearer of them with the great care and skill with which the experiments had been carried out. But he thought that perhaps in their present form they would not appeal to the practical men, because their bearing on actual practice was not at once apparent. The experiments described, especially when taken in connection with other recent investigations by the same authors, gave results which were of great importance to any one trying to understand what went on in the cylinder of a steam engine. He hoped that Prof. Nicolson would go a step further and explain the way in which such results would probably enable the designer to lessen the losses in an engine. He would like to ask with reference to the sentence (page 4 Advance Proof), "A condition which could only be explained by supposing the rate of condensation of steam on a surface to be limited by some physical property of the steam itself." Under what conditions of surface and temperature would the rate of condensation be less than the limit? Had the velocity of the steam over the condensing surface any influence on the rate of condensation?

Prof. Nicolson.

Prof. Nicolson.—With regard to Professor Durley's question as to what the conditions were, under which the rate of condensation was "less than the limit," Prof. Nicolson confessed he hardly understood the question. It had commonly been supposed that the rate of condensation of steam on a metal surface colder than itself was infinite. The Authors had shown that, on the contrary, it was not only not infinite but measureable. The rate found by them was about 31 lbs. per hour per sq. ft. of surface per degree Fahrenheit difference of temperature between steam and metal.

To ask if the rate was ever less than this was therefore to ask simply whether there were circumstances under which the Author's law was not true?

Professor Durley probably had in his mind when asking the question "when could the rate of condensation be less than the limit," an entirely different phrase used by the Authors in their larger paper on the Law of Condensation of Steam read before the Institution of Civil

Engineers (London) in November last. In that paper the Authors had shown that, as the temperature of the cylinder walls of a steam engine were lowered by the abstraction of more and more heat from them externally, the quantity of steam condensed per revolution went on increasing until it attained a definite value, which could not be exceeded without enormously increasing the rate of heat abstraction. They termed this the "limiting value of the cyclical condensation." The condensation always took place at the rate given by the experiments above; but the resulting weight condensed per cycle was limited by the rate at which heat could be abstracted from the walls. To get beyond this "limiting value" it would be necessary to apply some such process as playing a cold water hose on the cylinder.

Prof. Nicolson preferred not to go further into the question that evening, pending more extended reference to the subject on some future occasion when the Author's larger paper might come up for discussion.

The velocity of flow of the steam over the condensing surface had only an indirect influence on the rate of condensation. It removed the condensed steam more or less quickly, and exposed more or less water-drop and metal surface to the steam, as had been pointed out in the paper. The speed of translation of the steam as a whole was so small relatively to the molecular speed of the steam particles that it could not be expected to have any direct influence.

Thursday, 20th January, 1898.

P. W. St. George, Vice-President, in the Chair.

Paper No. 125.

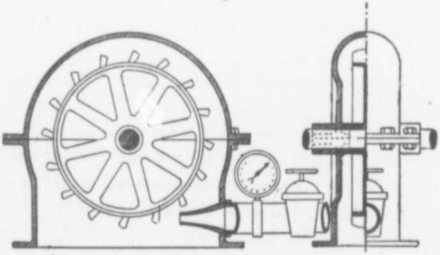
IMPULSE WATER WHEELS.

By J. T. Farmer, Ma.E., Stud.Can.Soc.C.E.

The development of power by means of impulse water wheels has been receiving considerable attention during the past ten years. Water power is to be met with under varying conditions and in various surroundings; and the means best adapted for the utilization of the power vary with those conditions and surroundings.

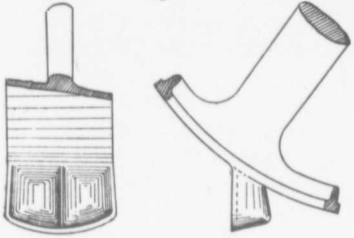
Among the means devised by man at different times before the advent of the impulse wheel for utilizing the water power that was going to waste around him, one has easily taken the foremost place, and indeed has, by a process of the survival of the fittest, practically ousted all other methods from a position of being worthy of serious consideration. The turbine has at the present day almost entirely taken the place of the earlier devices in use, which have either been consigned to museums as curiosities or are regarded as picturesque additions to the landscape.

Fig. 1



The impulse water wheel probably differs as much from the various forms of turbine in construction and in action as the turbine does from an overshot or breast water wheel. The previous statement with regard to the turbine must therefore be further modified so far as it is found that the impulse motor is finding favour with those who utilize water power.

Fig. 2



PELTON BUCKET

It has been said that "countless wealth is being squandered in all the torrents and water courses of the world." But it might be added that unless the proper means are taken for its utilization that wealth of energy avails little more to man than that of the tides in Jupiter.

It seems at first sight a very simple matter to place a wheel in position to take up the energy of water; but in practice that arrangement is generally found to involve more or less costly construction in the way of dams, basins, canals, flumes and even tunnels. This is particularly the case where the use of turbines is contemplated, and this consideration is frequently sufficient to annihilate the expediency of thus attempting to utilize a known and otherwise available source of power.

These adverse conditions are forcibly illustrated in the mountainous districts of the North American Continent. Water power is there in abundance, but it is that of mountain torrents; as a rule inconsiderable in volume of water, but, on account of the configuration of the country, affording large heads. The latter circumstance makes any constructive work very costly, and in most instances would put the use of an ordinary turbine out of the question.

It was from such causes that the Western States became the birth place of that system of water power of which the essential feature is an impulse water wheel. The simplification made possible in this system is that of the substitution of a pipe and nozzle of insignificant dimensions for the massive head race and wheel pit associated with the use of a turbine.

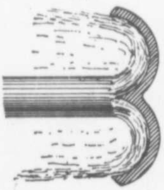
The first impulse wheels brought into use were of the very crudest description; with the increasing use of the system, however, came the development which attends every invention which has a large field of usefulness open to it. The impulse wheel of the present day ranks as fairly efficient among the various means of utilizing natural energy.

At this stage it becomes a question to what extent it may be desirable to employ the impulse wheel outside the conditions under which it first sprang into existence. This problem is specially interesting in a country where there is an abundance of water power, and at a time when the utilization of water power is assuming the place of one of the most important engineering questions of the day. The object of this paper is to record the results of some experimental research on this subject and also to discuss the question by the light of those results and from other considerations.

The history of the development of the impulse water wheel may advantageously be sketched briefly. The first wheels of this class were simply provided with flat projections on the rim of the wheel, and the jet was arranged to impinge normally on these flat surfaces. This was what was known as the hurdy-gurdy. It can easily be shown from theoretical considerations that the ideal efficiency of such a wheel is 50 per cent., but it is probable that most of those in use did not give a greater efficiency than from 20 to 30 per cent.

Fig. 3

Fig. 4



The first notable improvement was that of substituting hollow cups for the flat vanes, so that the jet struck the interior part of the cup and was deflected back again until it left the vane, travelling, with respect to the vane, in almost the opposite direction to that in which it was travelling before impact, as shewn in fig. 3. This formation at once largely increased the efficiency, but in practice the efficiency was still far from what it theoretically might be.

The next modification was that of so curving the surface of the cup that the jet might follow the surface with very little deviation at the first point of contact. Thus some wheels are formed with a conical projection in the interior of the cup at the point where the jet strikes the surface, so that the water on striking may begin to pass along the generating lines of the cone, and may gradually be deflected further to follow the curved sides of the interior of the vane. This formation is illustrated in fig. 4. The more common construction is to place a wedge shaped projection across the interior of the cup or vane. This modification was introduced about 1880. It may be seen in the bucket illustrated in fig. 2. The function of the wedge is two-fold.

(1) To prevent the heaping of dead water upon the vane during its passage through the arc of action, or the part of its path in which the vane receives the jet of water.

(2) To give the diverted streams a direction of motion which will finally carry them clear of the wheel.

In a bucket unprovided with any conical or wedge-shaped projection, there is no sudden angular deflection of the water. Some of the water is heaped upon the flat surface upon which the jet is impinging, thereby forming a curved surface over which the following water is deflected, as shewn in fig. 3. With a stationary vane on which the stream is continuously playing, the loss of force due to this cause is very slight. When, however, the impact is taking place intermittently on a moving vane, the dead water is discharged after very inefficient action at the end of every short period of action, and the total loss in effective work may be considerable. This loss is reduced by placing a solid projection in the bucket, which takes the place of that formed by the

Fig. 5

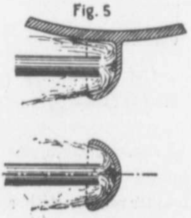
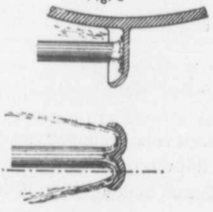


Fig. 6



water and leaves all the water free to be deflected in the most efficient manner. See fig. 4.

As regards the second function of the wedge, it is well known that when a stream of water strikes normally upon a surface it is deflected equally in all directions. This is illustrated in the wheel bucket, of which two views are shown in fig. 5. The same action takes place when the stream strikes centrally upon the apex of a cone. This is undesirable in the case of the vane of a water wheel, as the water which is deflected towards the centre of the wheel gets into position to strike the back of the following vane, thus opposing the useful effect of the action. When the jet strikes a wedge, as in fig. 6, it is cut into two portions, which are deflected away from one another in a plane perpendicular to the cutting edge of the wedge. In a wheel this motion causes the water to be discharged at each side of the wheel where it is free from all liability to interfere with any following parts of the wheel.

Numerous modifications of the form of the curved surfaces of the buckets have been brought out at different times by inventors with a view of modifying the passage of the water over the vane in some particular, but it is not necessary to describe them more particularly.

Of the impulse wheels in use at the present day the best known is probably the Pelton water wheel. These wheels are made in sizes varying from 6 in. to 6 ft. in diameter, according to the head of water available and the velocity required. These wheels have been applied under heads ranging up to 1,700 feet and, as has been said, there is no doubt that under such conditions the highest efficiency is realized. On the other hand, there are said to be instances in which Pelton wheels are running with good results under heads of from 50 to 75 feet.

The writer recently made a series of tests on a small wheel of this class, catalogued as the Pelton Motor No. 3. This wheel is approximately 18 in. in diameter, and the weight of the whole machine is given as 320 pounds. Two elevations of this motor are given in fig. 1.

The tests were made in the Hydraulic Laboratory of McGill University, and a brief description of the methods employed will be given. It was impossible to make tests with heads as high as some of those under which these motors run. The maximum head employed was that afforded by the city supply from the high level reservoir, which gives a pressure of 125 lbs. per square in. in the laboratory, equivalent to a head of 290 feet. Lower pressures were also obtained by throttling the supply from the same source.

These trials will give an idea of what may be expected of this type of motor when used under ordinary heads of from 100 to 300 feet. In many districts these are as large heads as are commonly met with. Also, where it is proposed to take power from a water-works system, the pressure under which water is supplied would rarely exceed 125 lbs. per square inch.

In the present series of trials the wheel tested was small compared with many in use; the effective work done did not in any case exceed 7 horse-power. There is no doubt that with a machine designed on a larger scale, as with larger heads, the efficiency would show some increase over the values found in the present case.

The results obtained in these experiments are offered as bearing directly on the question of the utilization of this system for small amounts of power under the conditions usually met with in districts outside those referred to as abounding in very high falls of water. With reason and judgment, the general conclusions arrived at by the consideration of these results may be extended to cases where the machinery and the generation of power is on a larger scale.

For the purposes of trial the wheel was set up as received from the makers, and the auxiliary apparatus was fitted in accordance with their instructions. The water, after passing through the valve which was used to regulate the pressure, was led along a length of 2½ inch pipe straight for 8 or 10 feet before reaching the nozzle. A Bourdon gauge was fitted on the supply-pipe less than one foot from the mouth of the nozzle-tip. This gauge was arranged on a pressure-chamber, enveloping the pipe and communicating with the interior through a series of small holes. Before being used the gauge was calibrated by means of a gauge tester. In the experiments the pressure in the pipe of course varied slightly. The pressure was read at intervals of one or two minutes, and the mean value during the whole trial was accepted as the pressure under which the flow took place. The extreme variation of the pressure was about one pound per square inch.

Three different sized nozzle tips were supplied with the wheel. These nozzles tapered gradually on the inside from the diameter of the supply pipe to that of the actual orifice. The outlet diameters were:

.5277″ .6307″ .7532″

Sets of trials were made using the largest and smallest of these nozzle tips, the largest giving the more satisfactory results.

The water was discharged from the motor into a flume beneath, whence it ran into measuring tanks, and all the water used was thus actually measured. For the purposes of these trials two tanks were used, each of the capacity of 1,000 gallons; these had both been previously calibrated.

The power given by the wheel was estimated by means of an absorption brake and a revolution counter.

The shaft was provided with an 18″ diameter brake wheel of special design, and the power was taken off this. In the earlier trials the brake consisted of one or more cords embracing a suitable arc of the periphery of the brake wheel, and having spring balances attached to the tight and slack ends to indicate the corresponding tensions in the cord. As the power varied slightly all the time, both readings were taken at intervals of one or two minutes, and the means used in calculating the final result of the trial. Later a direct-reading, self-adjusting brake, designed by Mr. Withycombe, was substituted for the cords and spring balances with very satisfactory results.

An ordinary revolution counter was used, but arranged to be thrown in and out of engagement with the shaft at the beginning and end of each trial. The necessary readings could thus be made at leisure, ensuring greater accuracy.

In addition to the revolution counter a tachometer was connected to the shaft. This served as a guide when adjusting the load on the brake wheel previous to a trial to give a desired speed of running. It also served to indicate any considerable departure from the intended speed which might take place during a trial, and which would vitiate the accuracy of the calculated results.

Before passing to the examination of the experimental results of the trials, it may be well to make a brief theoretical analysis of the subject.

The elementary theory of an impulse wheel is very simple—so simple indeed that no attempt seems to have been made to consider to what extent known and observable phenomena may modify theoretical calculations; but rather the elementary theoretical result is generally taken as the last word which can be said on the subject from a theoretical point of view.

In the following investigation the efficiency is deduced from a consideration of the circumstances, as far as they can be mathematically expressed, under which the mechanical action takes place.

In the elementary theory of the impulse water wheel the assumptions generally made are substantially as follows:—

1. That the jet has the theoretical velocity due to the available head of water.

2. That the jet strikes the vane centrally and tangentially to the wheel.

3. That the jet passes over the surface of the vane without any loss of relative velocity.

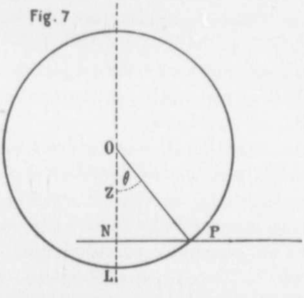
4. That the vane is so formed as to turn the stream through an angle of 180° completely back on itself.

In all these particulars there are some modifications which can be more or less exactly stated:—

(*a*) The velocity of the impinging jet is reduced in the ratio of a coefficient of velocity depending on the pipe line and nozzle.

(*b*) Instead of striking the vane tangentially, the jet generally, as in the case particularly alluded to, strikes at a point nearer to the nozzle. Thus suppose a horizontal jet is applied underneath a wheel. If O in fig. 7 be the centre of the wheel and L its lowest point, the jet strikes at P, where $L\ O\ P$ makes an angle θ say. Of course the water begins to play on the vane before it reaches P, and continues for a short space afterwards until the stream is cut off by the next approaching vane; but P may be taken as a mean position.

Fig. 7



The wedges of the vanes then are formed normal to the jet at this point instead of being radial to the wheel. This involves their being inclined at an angle θ to the radius of the wheel.

(*c*) The force of impact is reduced owing to the velocity lost by the water in passing over the surface of the vane. Some previous experiments on this subject afford data which will be used in approximating to the loss due to this cause.

(*d*) It is impossible, practically, to turn the water completely back on itself on account of the reaction which would take effect on the back of the succeeding vane.

Let u be the resolved velocity of the vane at P in the direction of motion of the jet.

v that of the jet.

The water strikes the vane with relative velocity $(v - u)$ and leaves it with relative velocity $c_w\ (v - u)$, where c_w is the ratio of final to initial relative velocities.

The force exerted on the vane in the direction of motion of the water is equivalent to the momentum of water destroyed per unit time, which is :—

$$\frac{m}{g} \left\{ (v - u) - c_w (v - u) \cos \delta \right\}$$

where δ is the angle of deflection of the water

$$\therefore F = \frac{m}{g} \ (v - u)\ (1 - c_w \,.\, \cos \delta)$$

Now $u = OP \,.\, \omega \,.\, \cos \theta$.

ω being the angular velocity of the wheel.

If the line of the jet cuts OL in N, and ON be called z,

$$\frac{ON}{OP} = \cos \theta$$

$$\therefore OP = \frac{z}{\cos \theta}.$$

$$\therefore u = \frac{z}{\cos \theta} \ \omega \,.\, \cos \theta$$

$$= z\,\omega$$

$$\therefore F = \frac{m}{g} \ (v - z\omega)\ (1 - c_w \cos \delta)$$

The moment of this force about the centre of the wheel is

$$Fz = \frac{mz}{g} \ (v - z\omega)\ (1 - c_w \cos \delta)$$

which is constant.

The work done per second is

$$F\,z\,\omega$$

$$= \frac{m\,z\,\omega}{g} \ (v - z\,\omega)\ (1 - c_w \cos \delta)$$

The energy available per second is mh,
h being the available head of water. The efficiency therefore is

$$\eta = \frac{z\omega}{gh} \, (v - z\omega) \, (1 - c_w \cos \delta).$$

If N be the number of revolutions per minute

$$\frac{N}{60} = \frac{\omega}{2\pi}$$

$$\therefore \eta = \frac{2\,\pi\, N\, z}{60\, gh} \left(v - \frac{2\,\pi\, N\, z}{60}\right) (1 - c_w \cos \delta) \text{ (I).}$$

In calculating the value of v to be inserted in this expression it must be remembered that the velocity of the issuing jet is less than that theoretically due to the head.

In practice there will be a reduction of velocity due to two causes :

(1) Resistance of pipe line.

(2) Loss in discharge from the nozzle.

If l be the length of pipe,

d the diameter,

The loss h_1 due to pipe friction is calculable by the well-known formula

$$h_1 = 4f \frac{l}{d} \frac{V^2}{2g}$$

V being the velocity of the water in the pipe and f the coefficient of frictional resistance of pipes.

If A_1 a be the areas of the pipe and nozzle respectively,

$$A_1 V = av$$

$$\therefore h_1 = 4f \frac{l}{d} \frac{a^2}{A_1{}^2} \frac{v^2}{2g}.$$

Other losses due to bends, etc., can be considered included in a coefficient K, which would have to be derived from consideration of the special circumstances in every case. This would make the total loss of head in the pipe line

$$h_1 + h_2 = \left(4f \frac{l}{d} \frac{a^2}{A_1{}^2} + K\right) \frac{v^2}{2g}$$

The remainder of the available head is spent in producing the velocity v, and part is absorbed in the resistance of the nozzle. If the nozzle offered no resistance the velocity would be increased in the ratio of $1 : c_v$, and therefore the velocity equivalent to the remaining head is $\frac{v}{c_v}$.

The energy remaining is therefore

$$\frac{v^2}{c_v{}^2\, 2g}$$

$$\therefore\ h = h_1 + h_2 + \frac{v^2}{c_v{}^2\, 2g}$$

$$= \left(\frac{1}{c_v{}^2} + 4f\frac{l}{d}\frac{a^2}{A_1{}^2} + K\right)\frac{v^2}{2g}$$

Numerical values inserted in this formula will give

$$h = (1.06 + .026\frac{l}{d}\ \frac{a^2}{A_1{}^2} + K)\ \frac{v^2}{2g}$$

The results given by this formula would only approximate more or less closely to the actual state of affairs, which would best be determined by actual measurement of the pressure close to the nozzle by means of a gauge, when the conditions of flow are those actually occurring in practice.

In the trials under discussion the heads given are those measured close to the point of discharge, so that no loss due to the pipe line need be considered. The only loss of velocity is that which occurs in the discharge from the nozzle, and the value of v therefore is calculated from the formula

$$v = c_v\sqrt{2\,gh}$$

where c_v is the coefficient of velocity for the nozzle used.

In the nozzles used in the experiments the stream issued from a parallel throat, and consequently there would be no appreciable contraction of the jet. On this consideration it is reasonable to attribute all the deficit in discharge to the loss in velocity or

$$c_v = c_d\,.$$

The co-efficients of discharge were determined for these nozzles for heads up to 20 feet, above which point the variation becomes very slight. The results obtained therefore give an approximation to the true velocity of the jet.

In addition to these determinations the co-efficient of discharge was calculated from the data afforded by each of the trials. These co-efficients agreed very closely with those obtained directly in the case of the $\frac{3}{4}$ in. nozzle. The mean values were .972 and .980 respectively.

The discrepancy is not surprising when it is considered that in the former case the outflow was from the end of a long pipe, while in the latter it was from a large body of water at rest.

The discrepancy is more marked in the case of the nozzle $\frac{1}{2}''$ diameter, where the two values are .909 and .976. It is suggested that this difference is due to the fact that the interior of this nozzle was covered with rust at the time of its being used in the water wheel, as it had been in place for some time. The coating of oxide on the interior would diminish the actual area of outlet, so that the co-efficient would appear to be smaller than it actually was. In addition to this there can be no doubt that the rough surface of the oxide would diminish the velocity of the outflowing water; this may be partly the reason why the trials with the $\frac{1}{2}''$ nozzle show a smaller efficiency than those made with the $\frac{3}{4}''$ nozzle.

If this explanation is correct, it would point to the desirability of having the interior surfaces of the nozzle-tips clean and free from rust. To accomplish this, it would probably be worth while to have detachable nozzle-tips made of brass or some other metal not so liable to be acted upon as iron in the presence of moisture. It would also be advisable for the user to periodically take out and clean the nozzle-tip, especially if made of cast or wrought iron.

With a dirty nozzle there is a direct loss of efficiency corresponding to whatever loss of velocity is caused by the rough surface of the nozzle. More than this, there is a diminution in the area of the outlet, and therefore in the discharge, with the result that the power developed by the motor falls off. This may become a serious consideration if the motor is not much more than equal to the demands usually made upon it.

The particular values will now be inserted in the expression for the efficiency.

Pressures = 75 and 100 lbs. per sq. in.

Corresponding heads = 175 and 235 ft.

$$v = 103.1 \text{ and } 119.6 \text{ ft. per sec.}$$

$$z = .666 \text{ ft.}$$

$$\delta = 170^\circ$$

$$\cos \delta = -.9848$$

The value of c_w can be deduced, as mentioned previously, from an expression derived from a series of experiments on vanes of this description,

$$r = \frac{w}{v_o} = .0266 \; \frac{A}{a} \; \frac{1}{v_o^{\;.3}}$$

where w is loss of velocity, v_o the mean velocity of the water, a the sectional area of the jet and A the wetted area of the vane.

$$c_w = 1 - r \text{ approximately.}$$

The ratio $\frac{A}{a}$ is about 6.6

$$\text{whence } r = .176 \frac{1}{v_o^{.3}}$$

The quantity expressed by v_o here is the mean velocity with which the water passes over the surface of a bucket and may be taken as

$$\left(v - \frac{2\ \pi\ Nz}{60}\right)$$

in expression (I).

Substituting values for the different conditions under which the wheel is run, the following table of values of c_w can be deduced :—

TABLE I.

N	h = 175 ft.	h = 235 ft.
300	.953	.955
400	.952	.954
500	.950	.953
600	.948	.952
700	.946	.951
800	.944	.949
900	.941	.947
1000	.937	.945

These values lead to values of the factor $(1 - c_w \cos \delta)$ as given in the following table :—

TABLE II.

N	h = 175 ft.	h = 235 ft.
300	1.939	1.940
400	1.938	1.940
500	1.936	1.939
600	1.934	1.938
700	1.932	1.937
800	1.930	1.935
900	1.927	1.933
1000	1.923	1.931

The following values are thus obtained for the theoretical efficiency of the wheel with a $\frac{3}{4}$ in. diam. nozzle :—

TABLE III.

N	h = 175 ft.	h = 235 ft.
300	59.3	53.0
400	72.3	65.7
500	81.8	75.8
600	88.0	83.4
700	90.9	88 5
800	90.3	91.0
900	86.6	91.2
1000	79.4	88.8
	max. 91.1 @ 738	max. 91.5 @ 857

The differences between these calculated values and the actual values obtained are exhibited in Table IV. These results are illustrated graphically in figures 16 and 17.

TABLE IV.

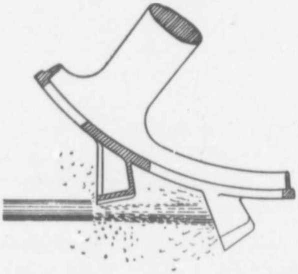
N	h = 175 ft.			h = 235 ft.		
	MATHEM	ACTUAL	DIFF.	MATHEM	ACTUAL	DIFF.
300	59.3	......	......	53.0	......	......
400	72.3	58.4	13.9	65.7	52.5	13.2
500	81.8	64.8	17.0	75.8	59.3	16.5
600	88.0	68.2	19.8	83.4	65.0	18.4
700	90.9	69.2	21.7	88.5	69.5	19.0
800	90.3	66.2	24.1	91.0	70.0	21.0
900	86.6	......	......	91.2	66.2	25.0
1000	79.4	......	......	88.8	......	......

From this last table it is apparent that there is still a waste of from 15 to 25 per cent. of the original energy of the water which has not been accounted for. The loss due to friction of bearings would be small in a simple machine of this sort, and the greater part of the 15 to 25 per cent. loss must be due to some departure in practice of the phenomena of action from those assumed.

It is suggested that the loss arises wholly or in part from the imperfect action of the vanes or buckets in turning back the water.

It will be remembered that one of the functions of the wedge was described to be to cause the water to be discharged to the side of the wheel. A little consideration, however, will show that during a part of the period of action the wedge does not perform this function.

Fig. 8

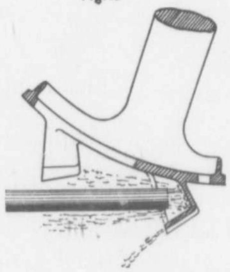


When the vane begins to intercept the jet, as in fig. 8, it is the outer lip or scoop which first comes in contact with the jet. The small amount of water which strikes the blunt edge of this outer lip is scattered, and thus only gives up a proportion of its energy to the wheel. More than this, it probably causes considerable disturbance and consequent loss of energy in the rest of the stream.

Fig. 9

As the vane passes further into the path of the jet, as represented in fig. 9, the water strikes on the interior curved surface of the outside scoop portion of the bucket on each side of the outer end of the wedge. The curve of the bucket at this point is such that the water is mainly deflected in an inward and backward curve in the plane of the wheel, so that it emerges from the vane surface in a plane tangential to the wheel rim ; it proceeds in the same direction until it strikes the back of the following vane, producing upon it a force of impact opposite to the direction of motion of the wheel.

Fig. 10



As the wheel moves into such position that the jet plays upon the central portion of the wedge, the stream is deflected to each side in a plane parallel to the axis of the wheel ; and it is then and only then that the conditions of action assumed are approximately fulfilled. This position is shewn in fig. 10.

It may be estimated that the action of the water is not what it is assumed to be while the vane moves over from 1-5 to 1-3 of the total arc of action. During this interval the action of the water is more or less inefficient.

Fig. 11

It will be noticed that the deficit of the actual from the calculated efficiency increases steadily as the speed is increased. It is suggested that this may be attributed to two causes.

(1) The best effect of the impact occurs when the sharp edge of the wedge is perpendicular to the line of the impinging jet. This condition only occurs at one point in the arc of action. At all other points the position of the edge of the wedge departs more or less from the perpendicular position, as in fig. 11, and the deflection does not take place in the manner assumed with the consequence that the efficiency of the impact is more or less impaired. The higher the speed of the wheel the greater is the arc of action, and consequently the greater will be the departure of the cutting edge of the wedge from perpendicularity to the line of the jet. This would mean that the loss of efficiency of the impact is less when the arc of action is smaller, or the speed small, and that the loss of efficiency increases as the arc of action increases or as the speed is increased.

(2) It was pointed out how the action of the outer lip or scoop at the beginning of the arc of action tended to impair the efficiency of the wheel. It will be seen that if the arc of action is large enough the same effect will take place at the end of the arc of action, as well as at the beginning. If, therefore, the speed is increased to such an extent as to allow this to occur, there will be a further cause of loss of efficiency at high speeds.

It is estimated that the efficiency would not suffer diminution from this latter cause until the velocity reaches a value of 800 revolutions per minute with the 175 foot head or a value of 900 revolutions per minute with the 235 ft. head. It will be noticed on reference to table IV that the discrepancy between the theoretical and actual efficiencies shows a marked increase for those respective speeds. It may be remarked here that for constant dimensions of jet and bucket, as the diameter of the wheel is increased, the angle subtended by the arc of action will be diminished. With larger wheels, therefore, the departure of the cutting edge of the wedge from the position of perpendicularity to the line of the jet will be less, and the efficiency may reasonably be expected to be found greater.

In addition to the trials quoted and compared with the theoretical results, trials were also made with the small ½ inch nozzle. Complete tables of all the results obtained are given.

I.—NOZZLE .5277″ DIAMETER.

(*a*) Pressure 50 lbs. per sq. inch.
Equivalent head = 115 feet.
Discharge = 45 galls. per minute.

Speed.	Horse Power.	Efficiency.
252	.79	50.7
322	.76	48.5
398	.93	59.1
400	.86	57.0
407	.84	53.5
438	.87	56.7
450	.94	59.9
497	.96	62.8
506	.94	60.4
545	.95	60.6
551	.95	61.0
565	.84	55.7
585	.76	47.3
588	.83	52.6
625	.91	55.7
638	.91	58.3
665	.83	52.2

(*b*) Pressure 75 lbs. per sq. inch.
Equivalent Head = 175 feet.
Discharge = 53 galls. per minute.

Speed.	Horse Power.	Efficiency.
345	1.38	49.8
409	1.52	54.9
477	1.68	60.7
523	1.68	61.4
582	1.80	64.7
594	1.79	65.8
632	1.75	64.4
632	1.76	63.1
672	1.78	64.1
677	1.56	55.3
725	1.63	58.3
726	1.65	59.6
737	1.61	59.7
768	1.55	55.1
779	1.57	57.0
847	1.40	51.2
879	1.31	47.7

(*c*) Pressure 100 lbs. per sq. inch.

Equivalent head = 235 ft.

Discharge = 63 galls. per minute.

Speed.	Horse Power.	Efficiency.
276	1.70	37.9
306	1.85	41.2
345	1.98	44.4
387	1.90	44.5
459	2.[illegible]2	49.7
470	2.36	52.8
541	2.52	56.0
605	2.67	60.0
644	2.80	63.2
698	2.76	64.0
760	2.96	65.0
834	2.65	59.5
858	2.78	61.8
914	2.76	58.6
939	2.76	57.9

(*d*) Pressure = 125 lbs. per sq. inch.

Equivalent head = 290 ft.

Discharge = 70 galls. per minute.

Speed.	Horse Power.	Efficiency.
494	3.25	52.0
536	3.32	53.6
592	3.50	57.5
664	3.79	62.1
708	3.83	63.3
765	4.00	65.2
813	3.89	62.8
867	3.93	64.8
918	3.95	64.0

II.—NOZZLE ·7532″ DIAMETER.

(*a*) Pressure 75 lbs. per sq. inch.
Equivalent Head = 175 feet.
Discharge = 120 galls. per minute.

Speed.	Horse Power.	Efficiency.
402	3.68	58.5
501	4.10	65.0
618	4.34	68.8
675	4.34	68.9
750	4.33	68.7
770	4.30	67.7

(*b*) Pressure 100 lbs. per sq. inch.
Equivalent Head = 235 feet.
Discharge = 138 galls. per minute.

Speed.	Horse Power.	Efficiency.
370	4.82	49.4
371	4.86	50.0
475	5.67	58.4
515	5.95	60.7
588	6.20	63.9
654	6.60	67.8
698	6.66	68.6
756	6.88	70.8
815	6.72	69.3
911	6.35	65.6

The results given in the foregoing tables are represented graphically in figures 12–17.

In connection with the above results it is interesting and important to notice that the highest actual efficiency appears at a speed which is about ·9 of that which theoretically should give the maximum efficiency.

Fig. 12

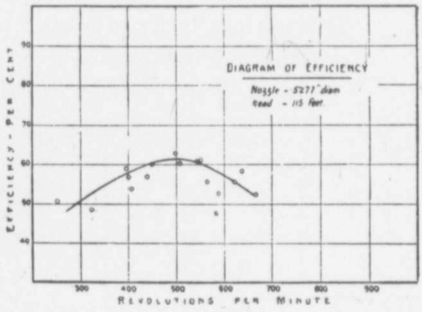


Fig. 13

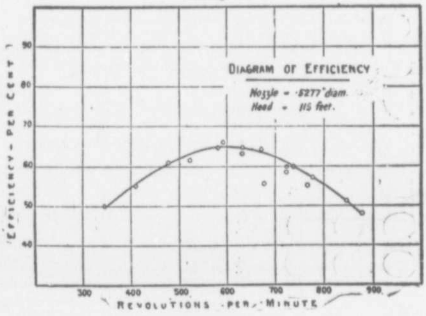


Fig. 14

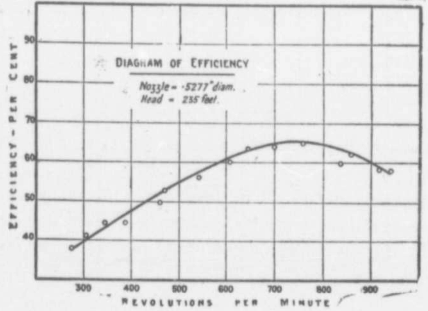


Fig. 15

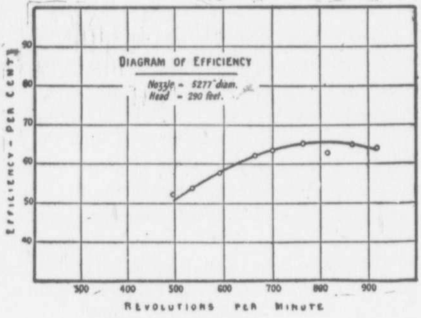


Fig. 16

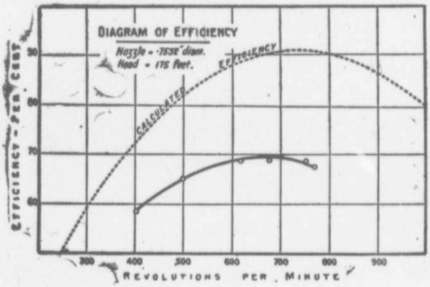
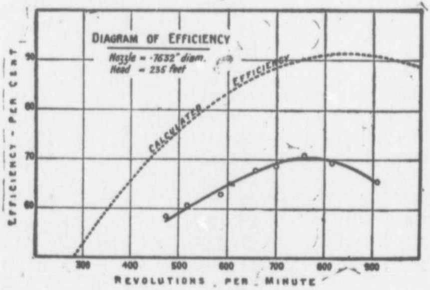


Fig. 17



A most important difference between an impulse water wheel and a turbine of either the impulse or pressure type is that the construction of the latter allows a larger area of water to be applied to the wheel for the same dimensions of wheel. In the turbine the wetted surfaces bear a much larger proportion to the size of the wheel than in an impulse wheel, and those surfaces in the turbine are constantly in action, while in the impulse wheel their action is intermittent. When the head of water is small, a correspondingly large quantity has to be used to give a required horse-power, and in this case the turbine has the advantage of passing a much larger quantity than the impulse wheel. When the head is very large this feature of the turbine becomes a disadvantage, as it becomes a difficult problem to curtail the total discharge of water so that the total power developed may be handled without mechanical inconvenience by the working parts of the motor.

For a given area of outlet the horse-power of the issuing stream varies as $h^{\frac{3}{2}}$. To illustrate this the horse-power of a stream one inch in diameter is given in the following table for a series of heads and also the number of such jets which would have to be applied to aggregate 1000 horse-power.

TABLE V.

Head.	Horse power.	Jets to give 1000 H.-P.
100	4.96	202
200	14.02	72
300	25.75	39
400	39.65	26
500	55.41	18
600	72.84	14
700	91.79	11
800	112.15	9
900	133.82	8
1000	156.73	7
1100	180.82	6
1200	206.03	5
1300	232.31	5
1400	259.63	4
1500	287.94	4
1600	317.21	3½
1700	347.40	3
1800	378.50	3
1900	410.48	2½
2000	443.31	2½

In order to develop considerable power, with a comparatively small head using an impulse wheel, one of two things must be done; either the area of the nozzle and consequently that of the vanes must be made very large, which is only practicable to a limited extent, or else the number of nozzles and wheels must be multiplied. Thus the use of impulse wheels under small heads involves a large amount of machinery for the power obtained.

On the other hand, the impulse wheel has many points in its favour, chief among which is its simplicity of construction, which leads directly to the absence of mishaps and to ease of maintenance. The bearings are simple, being merely those on the horizontal shaft, in such a position as to be easily got at when necessary to make any repairs or adjustments. There are no bearings running under water; and the bearings are not subject to any other reaction than that due to the useful effort of the water on the wheel; no difficulty is met with corresponding to that of balancing the static pressure of the water on a turbine, which becomes such an important problem when large heads are being used. The impulse wheel has no water-tight joints, as there is no water pressure to be maintained among the working parts. The mechanism also does not contain any parts which are likely to work loose or otherwise become deranged and so lead to trouble.

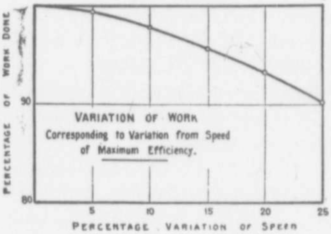
Another good feature is the absence of passages in the working parts of the motor, which would be liable to become choked by debris carried through by the water. Once through the orifice the water has a perfectly clear and open course until it falls into the tail-race.

It is an easy matter in designing an impulse motor to arrange the diameter of the wheel so as to give a desired speed of rotation under an available head with the most efficient results. Small departures from this speed do not affect the efficiency to any great extent, as may be judged from an examination of the tabulated results. The following table is compiled to show the percentage loss of output of work due to a subsequent departure from the pre-arranged speed. This is illustrated graphically in fig. 18.

TABLE VI.

Percentage. Increase or Decrease of speed.	Percentage. Decrease of output of work.
5	$\frac{3}{4}$
10	$2\frac{1}{4}$
15	$4\frac{1}{2}$
20	$6\frac{3}{4}$
25	$9\frac{3}{4}$

Fig. 18



An important point in determining the practical usefulness of water motors is their adaptability to be run with a fair degree of efficiency under a fraction of the full load. This state of things is generally liable to occur either intermittently, as where a number of loads are being continually put on and off the mechanism driven by the motor; or periodically, as where for portions of a day or week or year the work required from the motor is heavier than at other times.

Three methods will be mentioned which are employed to vary the output of work from the wheel.

It was mentioned that three nozzle tips of different sizes were supplied with the wheel with which the tests were made. By changing these the quantity of water discharged under a given pressure can be varied as the area of the orifice. The power of the jet will consequently vary in the same ratio; and so any change of load which can be anticipated and will last for a considerable period can be provided for.

The changing of the nozzle tips need not be a very difficult operation. It it, however, a very inconvenient plan to have to resort to to regulate the output of power from the wheel.

These wheels are sometimes built with several nozzles placed at intervals round the periphery of the wheel. When this is the case the power can be reduced by shutting off the stream from one or more of the nozzles.

The third method is to employ a valve or gate in the supply pipe which can be shut off to any desired extent by hand or by some automatic regulating machinery. This method is almost always necessarily employed in addition to those aforementioned. It will be noticed that the effect of the valve to reduce the power is reached by throttling the water as it passes the gate, thus reducing the pressure of the water as it reaches the orifice and consequently reducing also the discharge. It need hardly be pointed out that there is a great loss of efficiency when the motor is running under a light load, as the pressure energy which is not required to drive the machine is all absorbed without useful effect in the resistance of the partially closed valve.

An idea of the actual efficiency reached can be gained from a consideration of the foregoing results, obtained for the small nozzle, for the range of heads from 120 to 300 feet. In calculating the efficiencies previously given, the available work was calculated on the assumption that the pressure under which the test was made was the total pressure available. But if that pressure is not the total available pressure, as when the pressure is reduced by throttling from 125 to 100 or 75 lbs. per square in., then the total available work must be considered to be the product of the weight of water used and the head equivalent to the total available pressure before any throttling took place.

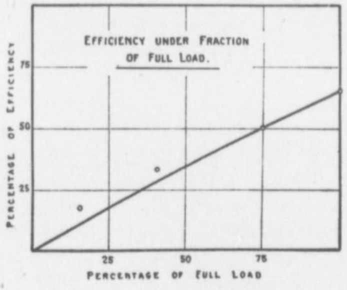
Proceeding in this way, and using the amounts of work done obtained in the trials for the various heads, but considering the energy available in every case to be that due to a pressure of 125 lbs. per square in., gives result as follows:

TABLE VII.

Pressure.	Load.	Efficiency.
125	Full	65%
100	.75	50%
75	.40	33%
50	.17	about 18%

This is illustrated in fig. 19.

Fig. 19



Besides the fact that a large amount of energy is wasted in the throttling in the pipe, a further cause of loss of efficiency under a light load exists in the fact that the motor is probably working under unfavorable conditions of pressure and velocity. In general it is desirable to keep the velocity constant, although the work done may vary. This means that if the motor is designed to run at the most efficient speed under full pressure, it will exceed the best speed for lower heads.

It will thus be seen that the efficiency obtained on the total expenditure of water will be considerably less than that indicated by the previous tables if there is any considerable variation in the load put on the motor.

In the preceding remarks an attempt has been made to describe and discuss the action of impulse water wheels, and more particularly of the wheel on which the experiments described were carried out; the question of efficiency has been illustrated and examined, and the advantages and disadvantages connected with the use of such a system have been pointed out. It is hoped that these notes may throw some light on this interesting and important subject.

The writer wishes to express his indebtedness to Prof. Bovey for his kind co-operation in allowing the use of apparatus and every facility for carrying out the experiments at McGill University, and also to Mr. Withycombe for useful advice and assistance with regard to many practical details connected with the trials.

OBITUARY.

Donald Alexander Stewart was born at West Bay, Richmond County, N.S., on 2nd of November, 1851. He graduated at McGill University with the degree B. A. Sc. in 1873, and for the following three years he was engaged as rodman, leveller and transit man on the Canadian Pacific Railway, Lake Superior District. He was Assistant Engineer on the construction of the same road until 1881. From April, 1881, to April, 1882, he was in charge of Surveys on the International Railway (now the Canadian Pacific Railway), from Lake Megantic, Que., to Greenville, Maine. From May, 1882, to December, 1884, he was Division Engineer on the location and construction of the Canadian Pacific Railway from Nepigon to Jack Fish Bay, Lake Superior.

From January to April, 1886, he was engaged on the survey of the Ontario and Quebec Railway, and for the remainder of that year he was in charge of the survey and construction of a portion of the Manitoba South Western Colonization Railway. During the year 1887 he was engaged in various exploratory and location surveys for railways, and from August to December of that year he was Division Engineer on the construction of the Great Northern Railway. From January, 1888, to November, 1889, he was engaged in various *reconnaissances* in Southern British Columbia, and elsewhere. For the remainder of the year 1889 and a portion of 1890 he had charge of surveys and construction on the Columbia and Kootenay Railway. In September, 1890, he was appointed engineer of the Western Division of the Canadian Pacific Ry., which position he held until August, 1897, when his failing health compelled him to seek rest and change in Halifax, where he remained until the time of his death in October, 1897.

Mr. Stewart was a man of simple habits, and was always ready to extend sympathy and help to the unfortunate. His professional career was marked by straightforwardness and exceptional ability, combined with a devotion to duty rarely met with. His uniform kindness and thorough honesty of purpose won the friendship of all with whom he came in contact.

As a Member of the Society, to which he was elected in January, 1893, he took a most active part. He contributed two valuable papers to the Transactions, and was on all occasions ready to do whatever lay in his power to advance the best interests of the Society and the profession to which he devoted his life.

LIST OF MEMBERS.

ADDITIONS AND CORRECTIONS.

MEMBERS.

Bernasconi G. A.	Antigonish, N.S.	Dec. 9th, 1897
Buck, L. H	Box 43, Londonderry, N.S.	May 6th, 1897
Desbarats, G. J	Iroquois, Ont.	May 20th, 1897
De Gurse, J.	Windsor, Ont.	May 20th, 1897
Earle, W. Z.	133 Union st., St. John, N.B.	Mar. 11th, 1897
Ross, R. A	17 St. John st., Montreal	May 20th, 1897
Stewart, A. F	(57) Bloemfontein, South Africa	Dec. 9th, 1897
Williams, David	St. Johnsbury, Vt	May 20th, 1897

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Durley, R. J	McGill University, Montreal	May 6th, 1897
Green, N. H	Sherbrooke, Que	Dec. 9th, 1897
Hanning, G. F	Crow's Nest Pass, B. C	Dec. 9th, 1897
Jardine, H	Kingston, N. B	May 20th, 1897
Marien, L. J	Road Dept., City Hall, Montreal	Mar. 11th, 1897
Marion, J. A	Standard Bdg., St. James st.	Dec. 9th, 1897
McMullen, W. E	C. P. R., St. John, N.B.	May 20th, 1897
MacCunn, J	C. P. R., Montreal	May 20th, 1897
Moore, J. H	Smith's Falls, Ont.	May 20th, 1897
Perley, G. E	Dept. Public Works, Ottawa	May 6th, 1897
Pigot, C. J	Q. M. & C. Ry., Quebec	Mar. 11th, 1897
Ross, J. W. LeB	Cornwall, Ont	Mar. 11th, 1897
Stewart, A. M	Kentville, N. S.	Dec. 9th, 1897

STUDENTS.

Alexander, R. C. F	63 Victoria st., Montreal	Mar. 11th, 1897
Benny, W. W	McGill University, Montreal	May 20th, 1897
Burnett, J. A	19 Shuter st., Montreal	May 6th, 1897
Boswell, E. J	Rat Portage, Ont.	Dec. 9th, 1897
Colpitts, W. W	McGill University, Montreal	May 20th, 1897
Farmer, J. T.	Dept. Agriculture, Ottawa	Mar. 11th, 1897

Gzowski, C. S., Jr.	32 St. Joseph St., Toronto	Dec. 9th, 1897
MacLeod, G. R.	McGill College Observatory, Montreal	Mar. 11th, 1897
Mattice, G. L.	29 Park Avenue, Montreal	Mar. 11th, 1897
Matheson, E. G.	McGill University, Montreal	May 20th, 1897
MacCarthy, G. A.	McGill University, Montreal	May 20th, 1897
MacPhail, W. M.	216 Peel Street, Montreal	Dec. 9th, 1897
Newcombe, A. B.	South Africa	May 6th, 1897
Russel, A. M.	469 Guy Street, Montreal	Mar. 11th, 1897

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Brooks, N. E.	Calgary Hotel, Calgary, N. W. T.	Dec. 9th, 1897
Dunn, G. C. B.	Ottawa, Ont	Dec. 9th, 1897
Jones, T. H.	Brantford, Ont	Mar. 11th, 1897
Jonah, F. G.	Springfield, Ill	May 6th, 1897
Milne, James	219 University St., Toronto	Dec. 9th, 1897
Ord, Lewis	Miami, Florida	May 6th, 1897
Ross, A. B.	3 Walmer Road, Toronto	Dec. 9th, 1897
True, Abbott	Crow's Nest Pass, B. C.	May 20th, 1897
Woodman, John	Winnipeg, Man.	May 20th, 1897

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Copeland, L. B.	Berthier en haut, Q.	May 20th, 1897
Forneret, V. F. W.	Berthier en haut, Q.	Dec. 9th, 1897
Lordly, H. R.	St. John, N. B.	Mar. 11th, 1897

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