TRANSACTIONS

OF

The Canadian Society of Civil Engineers.

VOL. X., PART II.

OCTOBER TO DECEMBER,
1896.

Montreal:
PRINTED FOR THE SOCIETY
BY JOHN LOVELL & SON.
1897.

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ERRATA.

Page 125, 7th line, for "made by" read "made for," and after "160" insert "pounds."
12th line, for "weak" read "leaky."
11th, 13th, 15th and 16th lines, for "pounds" read "tons."

Thursday, 8th October.

PROF. H. T. BOVEY, Vice-President, in the Chair.

Paper No. 116.

THE STORAGE OF WATER IN EARTHEN RESERVOIRS.

BY SAMUEL FORTIER, MA.E., M.CAN. SOC. C.E.

The large number of earthen reservoir embankments in use, the widely differing opinions held by engineers in regard to the best method of constructing them, and the fact that the subject has not heretofore been considered by the Canadian Society of Civil Engineers, must plead as an excuse for this paper.

Very many earthen embankments, chiefly known as tanks, have been built in India to store water for irrigation purposes. The high prices of structural materials, the inability to procure and operate modern machinery and the low wages paid to workmen have favored this kind of construction.

* It costs but little to build an earthen embankment of even large dimensions where the materials are abundant and convenient, and where laborers can be procured for eight cents a day for each man, four cents for each woman, six cents for a donkey and fifteen cents for a pair of bullocks. A structure requiring skilled labor and modern machinery, with coal at $20 per ton, timber scarce and iron and steel from $8 to $15 per cwt., would be much more expensive. These peculiar conditions may, in a measure, account for the 37,000 tanks to be found in Mysore, and the 53,000 in Madras, besides smaller numbers in the other presidencies. The past history, however, of these tanks, many of which were built centuries ago, seems to prove the suitability of this material to retain water, and where failures have occurred, they were in nearly every case traceable to imperfect outlet conduits or to faulty design.†

Not only in India, but in all regions where the rainfall is insufficient to mature crops, and where water has to be artificially applied to make up for the natural deficiency, it is only a question of time when the stor-

* H. M. Wilson in 12th Annual Report U.S. Geol. Survey, p. 533.

† Proc. Inst. C. E. Vol. XXXIII. Gordon on the value of water in India.

age of water becomes a necessity. In the Western States of the Union, for example, the average annual run-off from the drainage areas, not to speak of the flood discharges, is from five to ten times greater than the run-off during the dry period of summer, when it is most needed for the raising of agricultural products. It is thus evident that only a small percentage of the total water supply can be utilized without the aid of storage reservoirs. For many centuries these reservoir dams have been built of earth, and there is good reason to believe that in the centuries to come the same material will be used. Upon this assumption the irrigated countries of Cape Colony, Egypt, Spain, Italy and France, and on this continent those of South America, British Columbia, and two-fifths of the United States are, and will continue to be, more or less dependent upon earthen dams to conserve and equalize the flow of the scanty water supply.

In reference to the use of earthen dams to store water for domestic purposes, it may surprise some to learn that the increase in the number of water-works plants in Canada and the United States has been greater than that of railways. In 1830 there were in the United States only 31, and 58 years later there were 1701, while in Canada during the same period the number increased from a few insignificant plants in the larger cities to 68 in 1888.* Since many water-works systems have each a number of earthen reservoirs, it is probable that the increase in the latter has been equally great.

The diversity of opinions among engineers on this subject is remarkable and difficult to explain. The wide differences in the kind and quality of the materials used may partially account for it, but apart from this, one is forced to conclude that the opinions held by many engineers regarding the best way to design and construct earthen embankments to impound water are erroneous. For any given case the problem is: to store with safety to life and property a certain volume of water, on a particular site, within walls of earth. The task seems easy and simple, but in its design and execution the plans and specifications from a dozen or more competent engineers would show great dissimilarities. The general form, content and particular dimensions might differ 100 per cent. One engineer would be willing to incur considerable expense in procuring clay for the entire embankment; another would use clay only as a centre core; while a third would reject it as the most treacherous material in existence for that class of work, and would build a homogen-

* Eng. News. Vol. XXI.

core wall of a mixture of fine and coarse materials. Some would specify that the materials be packed dry, others that they be dampened, while some would call for an abundance of water. In regard to lining or paving, there would likely be as many different kinds recommended as there were specifications. Some would be positive that the structure would be insecure without a heavy masonry core wall, while the advocates of a homogeneous embankment would consider it a waste of money.

The task of reconciling so divergent views is too great for the writer of this paper. The most that he can hope for is that the opinions herein expressed, the suggestions offered, and the consideration of a few practical features relating to reservoir dams and the storage of water may aid, in some measure, our younger brethren.

CHARACTER OF THE MATERIALS.

Earth dams are composed of varying proportions of gravel, sand, silt, clay, organic matter and water. The same ingredients which constitute the cultivated fields and their underlying strata are in nearly every case the most convenient and also the most suitable materials to use. A consideration, therefore, of the nature of the materials forming a reservoir embankment leads us directly to that of soils and subsoils. For this purpose, the physical and mechanical properties of soils are of much more importance than their chemical ingredients. It is not essential, for example, that we know the amount of potash, phosphorus or lime in any given case, but the size and weight of the grains, the amount of air-space they enclose, the percentages of air and water contained in these open spaces, and the effects produced by moisture, heat and frost, as well as the action of such forces as gravity, capillarity and evaporation, are of great importance. To such an extent is this true that one might say without exaggeration that the success of works of this character rests mainly upon the fact that they were designed and built in accordance with an intimate knowledge gained from a close study and carefully made tests of the physical properties of the materials. For twenty years and over men have been testing the physical qualities of iron, steel, cements and the various kinds of timbers, and this knowledge, when coupled with the correct application of the principles of mechanics, has given us our modern structures composed of a minimum amount of materials with a maximum of strength and efficiency. Reservoir embankments on the other hand have been built in most instances without the requisite knowledge, upon mere guess work, brawn and not brain predominating.

The site having been determined upon, samples of the underlying strata can best be obtained by test pits. They cost more than samples obtained by boring, but the additional information gained much more than compensates for the extra cost.

To avoid danger to workmen and shoring, the writer makes these pits elliptical. By having the major axis, say 18 feet, and the minor about 6 feet, it is possible to dig with picks and shovels to a depth of 30 feet by leaving a berm of 6 feet one-third the way down and a second berm of the same width two-thirds of the distance from the top. Samples can then be taken from each pit at every change in the formation. Sieves graduated from 5 meshes to the linear inch downwards in fineness to 10, 15, 20, etc., meshes may be used to grade the materials as to texture. When a portion of each of these graded samples is washed and afterwards examined by a good lens, the size and mineral character of all the larger particles can be determined, whether lime, quartzite, slate, shale, etc. The finer particles of sand, silt and clay, or all less than say one-hundredth of an inch in diameter, can be classified only by some mechanical soil separator like those invented by Doctors Hilgard and Osborne.

The following classification as to the size of particles contained in soils and sub-soils is now used by most authors on soil analysis. The dimensions are given in both millimeters and inches:

TABLE I.

Conventional Names.	Size in M.M.	Size in inches.
Coarse gravel	– to 6	– to $\frac{1}{4}$
Gravel	6 to 2	$\frac{1}{4}$ to $\frac{1}{12}$
Fine gravel	2 to 1	$\frac{1}{12}$ to $\frac{1}{25}$
Coarse sand	1 to .5	$\frac{1}{25}$ to $\frac{1}{50}$
Medium sand	.5 to .25	$\frac{1}{50}$ to $\frac{1}{100}$
Fine sand	.25 to .05	$\frac{1}{100}$ to $\frac{1}{500}$
Silt	.05 to .01	$\frac{1}{500}$ to $\frac{1}{2500}$
Fine silt	.01 to .005	$\frac{1}{2500}$ to $\frac{1}{5000}$
Clay	.005 to .0001	$\frac{1}{5000}$ to $\frac{1}{25000}$

That the reader may get a clearer idea of the approximate proportions of gravel, sand, silt and clay in the soils commonly cultivated, the following table, compiled chiefly from the published works of Prof. Whitney, is herein given. No. 1 is the red clay tile of the Potomac Valley near Baltimore, and No. 2 is a blue clay of the same locality used for making stoneware pipe. No. 3 is a 'clay' soil so-called taken from a truck field on James Island, S. Carolina. No. 4 is a heavy loam, from Hatfield, Mass., and No. 5 a close retentive soil. No. 6 is a sample of the lightest grade of sandy land of Southern Maryland. Nos. 7 and 8 are early truck land from the same State:

TABLE II.

No.	Kind of soil	Organic Matter.	Gravel.	Coarse Sand.	Medium Sand.	Fine Sand.	Very fine Sand.	Silt.	Fine Silt.	Clay.
1	Red clay........	6.24	0.00	0.00	0.50	2.63	9.62	25.13	13.44	42.34
2	Blue clay.......	2.61	0.00	0.00	0.29	1.27	8.93	20.16	16.72	50.02
3	Clay land........	1.62	0.00	0.54	1.03	83.20	3.22	3.22	3.58	3.59
4	Heavy loam.....	3.45	0.00	0.00	0.10	0.43	21.88	67.00	3.41	2.61
5	Meadow land....	4.75	0.00	0.00	0.05	0.50	32.64	49.32	5.46	6.79
6	Sandy land......	0.24	0.45	10.33	46.29	20.15	8.17	7.11	2.29	4.77
7	Light truck soil..	0.00	0.49	4.96	40.19	27.59	12.10	7.74	2.23	4.40
8	Gravelly loam...	3.18	6.06	22.09	29.87	9.82	6.52	10.71	3.86	7.89

According to Schübler, the average weights of one cubic foot of various soils as they exist in nature are as follows:—

Dry silicious or calcareous sand..........	110	pounds.
Half sand and half clay....................	96	"
Common arable soil	80 to 90	"
Heavy clay..................................	75	"
Garden mould rich in vegetable matter.	70	"
Peat soil......................................	30 to 50	"

The difference in weight between a clay and a sandy soil, for instance, is due largely to the greater number of open spaces in the latter and not to any material difference in the specific gravity of the grains.

A cubic foot of a very sandy soil contains about 40 per cent. by volume of air space, while a soil derived from limestone contains about 60 per cent. air space.

According to Whitney the percentage of open spaces in the following typical soils of Maryland are:—

TABLE III.

Light truck land	37 3	per cent.
Pine barrens chiefly sand	40.0	"
Sandy land	41.8	"
Wheat land	42.7	"
Tobacco land	50.0	"
Gummy land	58.5	"

Outside of the laboratory it is impossible to find soils completely saturated, *i e.* with all the spaces filled with water. These open spaces contain air and water in varying amounts. In dry soils there is a large proportion of air and a correspondingly small proportion of water, while in wet soils these proportions are reversed.

In irrigated regions where it is possible to control the soil moisture, long experience has shown that the best crops can be raised when the open spaces contain nearly equal volumes of air and water. Thus the water-holding capacity of heavy clay soils is about 44 lbs. of water in every 100 lbs. of saturated soil, and the most favorable condition for plant growth in such soils is when they contain from 16 to 24 lbs. of water in 100 lbs. of moist soil.

The following table gives the approximate number of grains in each classification of similar weights:

TABLE IV.

Fine gravel	1.4	grains.
Coarse sand	17.0	"
Medium sand	139.0	"
Fine sand	1370.0	"
Very fine sand	17360.0	"
Silt	274000.0	"
Fine silt	17280000.0	"
Clay	449280000.0	"

FORMING A COMPACT EMBANKMENT.

The belief is prevalent among laymen and engineers, inexperienced in this kind of work, that any country road foreman, who is familiar with the handling of earth, is qualified to superintend the building of earthen dams. They fail to understand the difference between an embankment capable of withstanding a load, and one compact and stable enough to retain water. In highways, or railroad fills, little, if any, attention is given to packing the materials. The fill, when completed, is nearly as por us as the soils and sub-soils of which it is composed. When a cubic yard of earth is removed from the pit to the fill, its bulk is increased by about one and one-half in sandy soil to six per cent. in hard clay soil, and the subsequent shrinkage of from 5 to 15 per cent. finally reduces it from 90 to 95 per cent. of its original volume. But soils and sub-soils in their natural state contain from 35 per cent. to 60 per cent. by volume open space, and the ordinary highway, or railroad fills, are thus shown to be porous masses wholly unfit to impound water.

In the building of earthen dams something more is needed than the piling up of a mass of porous materials. The hydraulic engineer who desires to build a safe dam with a minimum amount of earth, must attend closely to the following features :—

1. The relative sizes of the grains.
2. The percentage by volume of open space.
3. The proportions of air and water contained in these open spaces.
4. The best mode of filling the interstices between the larger grains with the smaller grains.
5. The best mode of expelling the greater part of the air contained in the open spaces.
6. Making the embankment proof against the action of extreme drouth, or excessive saturation.

As the hydraulic engineer of the Experiment Station of Utah, the writer recently began to make some experiments on the best mode of compacting soils and sub soils. On account of cold weather these experiments have not been completed, but enough has been done to show the general trend of the investigations.

Sand suitable for cement concrete was carted from a bank, placed under cover and allowed to remain for about two months until quite dry, when it was separated by graduated sieves into four grades—coarse sand, medium sand, fine sand, and very fine sand. In the same way bank gravel was obtained in two sizes. Grains that would pass through round holes one quarter of an inch in diameter and be retained by holes one-sixth of an inch were classed as gravel, and the grains left between sieves one-sixth to one twelfth of an inch were classed as fine gravel.

The silt was a mixture of vegetable matter and extremely fine sand. The clay was a brick fire clay and was air-dried, ground and passed through graduated sieves.

Boxes were made containing some even part of a cubic yard and graduated from bottom to top. The smallest box used was one foot in height and contained .01 cubic yard. The materials were poured into the boxes through a funnel five-eighths inch in diameter from a height of 0.85 ft., and the weight of each determined.

To determine the percentage of open space in each, a given volume was poured from a height of 0.85 ft. into a known volume of water, and the volume of water thus contained in the interstices gave the percentage by volume of open space.

In the following table the percentage by volume of open space in the clay is not given on account of its tendency to "swell" when immersed in water. Assuming the specific gravity of the solid particles of the clay to be 2.40, the percentage of open space would be about 0.65.

TABLE V.

Material.	Size inches.	Weight per cub. yard lbs.	Percentage by volume open space.	Tempera-ture of materials.	Temper-ature of water.
Gravel	$\frac{1}{4}$ to $\frac{1}{6}$	2550	45.0	48° Fahr.	35° Fahr.
Fine gravel......	$\frac{1}{6}$ to $\frac{1}{12}$	2275	45.7	48° "	35° "
Coarse sand.....	$\frac{1}{25}$ to $\frac{1}{5}$	2200	47.7	46° "	44° "
Medium sand...	$\frac{1}{50}$ to $\frac{1}{100}$	2150	50.8	46° "	44° "
Fine sand.......	$\frac{1}{100}$ to $\frac{1}{500}$	2150	48.3	46° "	44° "
Very fine sand...	$\frac{1}{500}$ to $\frac{1}{1500}$	2025	47.7	46° "	44° "
Silt.............	$\frac{1}{1500}$ to $\frac{1}{2500}$	1925	51.7	46° "	44° "
Clay............	$\frac{1}{2500}$ to $\frac{1}{10000}$	1380	....		

CLAY CONCRETE.

An embankment formed of gravel would be stable and unaffected by the actions of frost, drouth, or moisture, but the 45 per cent. of open space in gravel would allow the water to pass through it. Sand would be more impervious but less stable, and more affected by drought and excessive moisture. Soils containing a high percentage of organic matter might make an impervious embankment, but the necessary weight and compactness would be wanting. The same is true of all clays. Clayey soils are often styled heavy soils, but, as we have seen, such soils are the most porous and are capable of absorbing large percentages of water. The tendency of clay to swell when wet, and shrink and crack when dry, renders it a treacherous material for reservoir embankments when used alone.

Since there are serious objections to each class of the materials named when used alone, the writer has made a few tests of compactness with various mixtures of the above which he has termed *clay concrete.* The object sought being to mix sufficient silt or clay with the sand to more than fill all the open spaces in the sand, and to mix with the gravel a sufficient volume of sand and silt or clay to more than fill all the open spaces in the gravel.

The results of the tests are as follows:

Clay Concrete No. 1.

Gravel........	1.00 cubic yards.
Coarse sand......................	0.25 "
Very fine sand..................	0.27 "
Clay.........	0.43 "
Total	1.95 cubic yards.

(*a*) When No. 1 mixture was thoroughly mixed dry and poured from a height of 0.85 feet, its volume was 1.546 cubic yards.

(*b*) When thoroughly mixed and tamped dry in one-tenth of a foot layers, its volume was 1.240 cubic yards.

(*c*) When poured slowly into water and mixed, its volume was 1.26 cubic yards.

(*d*) When moistened sufficiently to form a stiff paste and tamped in one-tenth of a foot layers, its volume was 1.312 cubic yards.

Clay Concrete No. 2.

Fine gravel.........	0.90 cubic yards.
Fine sand...............	0.56 "
Silt..	0.42 "
Total.....................	1.88 cubic yards.

(*a*) When No. 2 mixture was mixed dry and poured from a height of 0.85 feet, its volume was 1.526 cubic yards.

(*b*) When mixed dry and thoroughly tamped its volume was 1.294 cubic yards.

(*c*) When mixed dry and poured from a height of 0.85 feet into water, mixed but not tamped, and the excess of water drained through holes covered with canvas in the bottom of the box, its volume was 1.256 cubic yards.

(*d*) When mixed dry and moistened with 0.277 cubic yards water at a temperature of 41 degrees Fahr. into a stiff paste and well tamped, its volume was 1.296 cubic yards.

Clay Concrete No. 3.

No. 3 is identical with No. 2, except that 0.58 cubic yards of clay is substituted for 0.12 cubic yards silt.

Fine gravel	0.90 cubic yards.
Fine sand	0.56 "
Clay	0 58 "
Total	2.04 cubic yards.

(*a*) When No. 3 mixture was mixed dry and poured from a height of 0.85 feet, its volume was 1.604 cubic yards.

(*b*) When mixed dry and well tamped, 1.324 cubic yards.

(*c*) When mixed dry and poured from a height of 0.85 feet into water, mixed but not tamped and drained of excess water, its volume was:

1.432	cubic yards	after	experiment.
1.420	"	"	1 day.
1.360	"	"	2 days.
1.356	"	"	4 days.
1.324	"	"	15 days.

(*d*) When mixed dry and moistened with 0.307 cubic yards of water into a paste and well tamped, its volume was 1.348 cubic yards, which shrunk but slightly in four days.

Clay Concrete No. 4.

Fine gravel	1.00 cubic yards.
Medium sand	0.51 "
Silt	0.26 "
Total	1.77 cubic yards.

(*a*) When No. 4 mixture was mixed dry and tamped its volume was 1.26 cubic yards.

(*b*) When mixed dry and poured from a height of 0.85 feet into water, and mixed but not tamped, its volume was 1.204 cubic yards.

(*c*) When mixed dry and moistened with 0.30 cubic yards water into a stiff paste and well tamped, its volume was 1.212 cubic yards.

Water, sewer, and gas mains are laid in trenches excavated in materials somewhat similar to those which may be used in earth dams. Of trenches for water mains the writer has superintended the filling in of over 100 miles. Formerly, city engineers required the trenches in all public streets to be filled in in three inch layers and well tamped. In the three systems of water works recently constructed by the writer in this State, permission was granted to fill the trenches under water instead of tamping the earth in thin layers. The method followed was to keep separate, while excavating, the road metal, gravel, or paving, and the ordinary earth. After the pipe was laid in the trench and caulked, care was taken to tamp sufficient earth beneath, and at the sides of the pipe to give it a continuous and uniform bearing; then earth bridges were thrown in at intervals to prevent floatation and the trench partially filled with water from the hydrants or from irrigating canals. The ordinary earth was then plowed, shovelled, or scraped into the water and the road metal or gravel placed on top.

Trenches filled with dry earth and tamped, invariably settled more or less after a heavy rainstorm, but trenches filled under water, although quite soft for a few days, behaved much better and seldom settled.

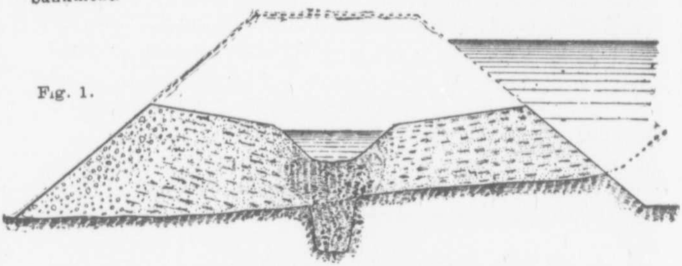
The foregoing statement does not apply to clay soils, since it requires too long for the wet mass to become sufficiently dry to bear up the weight of a horse.

There is every reason to believe, however, that trenches filled with clay placed under water in the manner indicated would, when freed of the excess moisture, be more stable and less liable to subsequent changes.

In building a distributing reservoir for Ogden City, Utah, the writer adopted a mode of compacting the materials somewhat similar to that outlined in filling in trenches under water. The location was below the old beach line of Lake Bonneville, a name given by geologists to the large fresh-water lake of which the present Great Salt Lake forms only a small remnant. The materials were, for the most part, fine sand, with an occasional stratum of coarse gravel, cobble-rock, clay or silt. The capacity of the reservoir is 7,000,000 U.S. gals., width of embankment at flow line 30.5 ft., water slopes one and one-half to one, outer slopes two to one, depth of water 20 feet.

After removing the surface soil, a trench from 4 ft. to 6 ft. wide and 6 ft. deep was dug along the entire centre line of the proposed embankment. The base of the embankment was then formed and allowed to slope slightly towards its center. Instead of filling in the trench at once, it was allowed to remain nearly full of water, and it became the origin of a canal in the center of the entire embankment. The most impervious material was deposited on the inner half of the embankment, while the cobble-rock and more porous material were deposited near the outer edge. The inner and, to some extent, the outer half of the embankment was built up in layers, moistened and packed in the usual manner. The central portion was built up by emptying the wheelers at each edge of the canal and shovelling the material into the water. Fig. 1 shows a sketch of the partially completed reservoir embankment.

Fig. 1.



The mode of compacting reservoir embankments, almost universally followed by American engineers, is to specify that the earth shall be spread evenly over the surface in layers of from 4 to 6 inches in depth, then moistened and rolled with grooved rollers weighing from 100 to 300 lbs. per inch of tread. In most instances the number of times each layer is rolled is left to the decision of the engineer, but some specify a minimum roller travel in miles for each 1000 cubic yards excavated.

Opinions differ as to the amount of water to use. In gravel puddle, or what the writer has termed clay concrete, in which the percentage of clay is small, a large amount of water can be used with good results. This mixture unquestionably makes the safest embankment.

To those who persist in using chiefly clay, it may be said that the addition of water to moisten the layers is of doubtful benefit. The effect of water on comparatively dry clay is to increase its bulk, and no amount of rolling will make it quite so compact as it would be if rolled to the same extent in a dry state.

In reference to compacting materials by depositing them under water, as was done on the Ogden reservoir, by means of a canal in the centre.

the reader will note that this method is applicable only to gravel puddle or clay concrete containing less than 25 per cent. clay. A higher percentage of clay would render the embankment so soft that it could not be traversed by teams, but the method is particularly well adapted to earth containing either no clay or very little.

In so far as the author knows, this method has never been tried before. If the reader, however, compares tests No. 1c, No. 2c, No. 3c and No. 4c, with corresponding tests (*b*) and (*a*), he will find that, when the percentage of clay is small, as compact a mass can be made by simply pouring the earth into water and mixing as by moistening with water and thoroughly ramming.

It is, however, from practical experience rather than from the few preceding experimental tests that the writer bases the following conclusions :

1. Earth deposited under water is freed from the greater part of the air confined in the open space.

2. Earth containing grains of different sizes packs better under water than in air.

3. Embankments built of dry earth, or earth moistened and packed, are more liable to be injuriously affected by capillary action than embankments, or portions of embankments, built under water.

4. Making provision during construction for a canal holding water in the centre of the embankment, is a practical test, before completion, of the safety of the structure.

5. Most of the advantages of a center core are gained by this mode of construction without the disadvantage of having distinct lines of separation between an earth and a masonry wall.

6. Where water is abundant and easily applied, the middle portion of earth dams can be more cheaply compacted under water than by sprinkling and rolling.

THE DIMENSIONS OF RESERVOIR EMBANKMENTS.

The proper widths and slopes to adopt in the building of earthen dams cannot as yet be determined by mathematical calculations. Our knowledge of soil physics is too meagre to admit of limiting the amounts of materials used to the same extent as one would in the construction, for example, of a railroad bridge, or a roof truss. The dimensions in each particular case must be left to the good judgment, practical skill and the knowledge gained from experimental tests, of the designing engineer.

The character of the materials, the purposes for which water is stored, and the natural conditions surrounding each site differ so widely, that it is impossible to lay down precise rules. Generally speaking, however, the dimensions of each embankment will depend to a greater or less extent upon the following conditions:—

1. The danger to life and property in case of failure.
2. The depth of water to be impounded.
3. The height and force of the waves.
4. The angle of repose of the materials.
5. The pressure which the materials can safely withstand.
6. The necessity of a roadway on top of the embankment.
7. The slope paving.
8. The imperviousness of the materials.
9. The existence of a centre core.
10. The manner of construction.

Top Width.—When teams are used to convey the materials, the smallest top-width must be at least six feet, since it requires that space to prevent horses, and particularly mules, from crowding. It is usually desirable to have a roadway paved with rolled gravel and a fence around the reservoir, in which case a top width of twelve feet or more would be required. Where stability and security alone are concerned, the top-width depends upon the elevation of high water.

High Water Line.—In cold climates like those of Canada and the Northern States, it is important that the high water line be kept below the frost line in the upper portion of the dam. Failures have been caused by the earth freezing in the trapezoidal section A B C D Fig. 2, which elevated the section sufficiently to allow the water to pass along the division line C D.

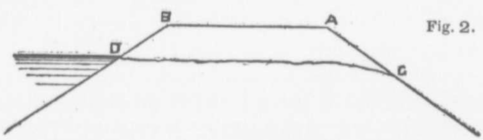


Fig. 2.

Failure might also be caused in weak embankments by the formation of ice at the flow-line. If the force due to the expansion of a stratum of ice were to be exerted at D against a frozen mass A B C D, it might be sufficient to disturb the upper part of the embankment and endanger the whole structure.

In both cold and warm climates there is the danger of waves overtopping the embankment. The maximum height of waves which may occur on the surface of any reservoir of known dimensions may be roughly estimated by Stephenson's formula $H = 1.5 \sqrt{F} + (2.5 \sqrt[4]{F}.)$ in which H is the height of the waves in feet and F the fetch or distance in nautical miles through which the waves act. According to the above formula the heights of waves on ordinary reservoirs would vary from two to three feet. On the smallest the waves would be more than 2 feet high and seldom more than 3 feet on the largest. It is evident, therefore, that this formula does not apply to small surfaces of water, but as the error is on the side of safety, and since the top of even small reservoirs should be raised at least two feet above high water, the formula can be trusted to give approximate results.

Breadth of Embankment at the Flow-Line.—The practice of the writer for years in designing the cross-sections of reservoir embankments has been to determine first the breadth at the flow-line. Then through the extremities of this distance converging lines can be drawn to suit the angle of repose of the material and other necessary conditions. Great differences exist as to this dimension. While writing this article there lie before the author the descriptions of five reservoirs each 30 feet deep, and their respective breadths at the flow-line are 28 ft., 34 ft., 40 ft , 45 ft., and 53 ft. After making ample allowance for a difference in the quality of the materials, there should not be a difference of nearly 100 per cent. in the widths of the embankments, providing the work in each case has been carefully done.

With a view to unifying the results and economizing material, the writer obtained by circular letters, private correspondence and otherwise, descriptions of about 100 reservoirs located in nearly every State of the Union. Out of the hundred, 75 were chosen as typical of existing conditions, and their depths of water and breadths of embankment at the flow-line were plotted on cross-section paper.

The co-ordinates for each of the 75 reservoirs were the abscissa (x), which represented the breadth in feet of the embankment at the flow-line, and the ordinate (y), which represented the depth in feet of the water in the reservoir. The curve formed by joining all the points was so nearly that of a straight line that the following equation of a straight line was adopted.

$$y = x - 5.$$

For outer and inner slopes of 2 horizontal to 1 vertical, and with the top of the embankment from 2 to 6 ft. above the flow-line, the above empirical formula gives top-widths and flow-line widths for depths of water from 10 feet to 45 feet as follows:

TABLE VI.

Depth of water in reservoir.	Outer slope.	Inner slope.	Top width.	Distance between top of embkt. and surf. of water.	Breadth at flow-line
Ft.			Ft.	Ft.	Ft.
10	2 to 1	2 to 1	7	2	15
15	"	"	8	3	20
20	"	"	11	3½	25
25	"	"	14	4	30
30	"	"	19	4	35
35	"	"	22	4½	40
40	"	"	25	5	45
45	"	"	31	6	55

In impounding water to a depth greater than 40 or 50 feet, safe construction requires the introduction of berms. Thus in a reservoir 60 ft. deep, there should be near the middle of each slope a berm of 5 or 6 ft. in width, and when we deduct the width of these two berms, the top width is limited to about 30 ft., while the formula still holds approximately true.

OUTER AND INNER SLOPES.—Regarding the 75 typical reservoirs referred to on a preceding page, it may be here stated that their inner slopes varied from a maximum of 4 to 1 to a minimum of 1 to 1, and averaged 2.61 to 1, while their outer slopes averaged 2.1.

TABLE VII.

Outer slopes.				Inner slopes.			
2 reservoirs	1	to	1	2 reservoirs	1	to	1
23 "	1½	"	1	23 "	1½	"	1
2 "	1¾	"	1	2 "	1¾	"	1
41 "	2	"	1	31 "	2	"	1
1 "	2¼	"	1	1 "	2¼	"	1
3 "	2½	"	1	1 "	2¾	"	1
3 "	3	"	1	11 "	3	"	1
				2 "	4	"	1
75 Res's aver. 2 to 1				75 Res's aver. 2.61 to 1			

It is evident from the foregoing that American practice in adopting slopes to earth embankments does not often vary from 2 horizontal to 1 vertical.

No unprotected earth slope will long withstand the action of waves, even on a 3 to 1 incline, and since some kind of paving is necessary, a 2 to 1 slope of suitable materials and properly constructed is preferable to one flatter. In paving with hydraulic cement concrete, the cost can be considerably lessened by adopting a $1\frac{1}{2}$ to 1 slope on the water side without lessening to any extent the strength or efficiency of the embankment.

PROTECTING THE INNER SLOPE.

To prevent the destructive effects of waves, ice and frost, to facilitate the removal of silt and aquatic vegetation, to prevent animals from burrowing into the bank, and in many cases to prevent percolation through the bottom and sides, some kind of paving is usually required.

The following brief notes obtained by circular letters describing the mode of paving and the materials used in more than thirty reservoirs of the Union will give the reader a fairly correct idea of existing conditions:

WATER WORKS RESERVOIR, 47 FEET DEEP.

Charlottesville, Va.

"Inside slope of dam is paved 12 ins. thick with ordinary stone rip-rap."

E. F. Harris, *Supt.*

LAKE MONTEBELLO RESERVOIR, 31 FT. DEEP.

Baltimore, Md.

"Inside slope is rip-rapped with broken stone for a distance of 2 feet above and 3 feet below the flow-line."

Wm. Benthall, *Ass't Engineer.*

TATNUCK BROOK RESERVOIR, 30 FT. DEEP.

Worcester, Mass.

"Paved 24 ins. thick at top and 18 ins. thick at bottom of inside slope with field stone of large size, having interstices filled with smaller stones."

Fred. A. McClure, *Supt.*

WATER WORKS RESERVOIR, 16 FT. DEEP.

Grand Rapids, Mich.

"Bottom of reservoir is paved 12 ins. thick, inside slope from 12 inches at bottom to 2 ins. at top with cobble stone laid in cement concrete. Frost has loosened some of the cobble stones at the water line."

H. A. COLLAR, *City Engineer.*

INDIAN CREEK RESERVOIR, 50 FT. DEEP.

Boise, Idaho.

"Inside slope rip-rapped with basalt 18 inches thick."

CHAS. L. SWAN, *Engineer.*

STORAGE RESERVOIR, 65 FT. DEEP.

Amsterdam, N.Y.

"Face of dam is rip-rapped 1½ feet deep, hand placed. Frost never affects rip-rap. Don't believe in paving."

S. E. BABCOCK, *Engineer.*

STORAGE RESERVOIR, 15 FT. DEEP.

Rochester, N.Y.

"A berm five feet wide at middle of slope; rip-rap below berm; paved with stone above. Paving laid on gravel lining a few inches thick."

E. KINCHLING, *Chief Engineer.*

DISTRIBUTING RESERVOIR, 17 FT. DEEP.

Rochester, N.Y.

"On bottom of reservoir 4 inches of gravel spread over surface of clay puddle 12 to 18 inches thick hauled from brick yard. Rip-rap 24 inches thick below berm. Stone paving 18 inches thick above berm."

E. KINCHLING, *Chief Engineer.*

SCHUYLKILL RIVER RESERVOIR, 13 FT. DEEP.

Conshohocken, Pa.

"12 inches cement concrete on bottom, 4 inches brick on 12 inches cement concrete on slopes. Concrete composed of 1 cement, 3 sand, 5 broken trap rock."

W. E. FERRIER, *Supt.*

WATER WORKS RESERVOIR, 30 FT. DEEP.

Sherburne, N.Y.

"Paved with stone 12 ins. thick set at an angle of about 60°. Space filled with gravel."

W. E. DAVIS, *Supt.*

STORING AND RECEIVING RESERVOIRS.

New Bedford, Mass.

"The inside slope of storing reservoir dam is protected by a paving of large sized boulders. The inside slope of the receiving reservoir has a lining of granite blocks 1 foot thick."

R. C. P. COGGESHALL, *Supt.*

WATER WORKS RESERVOIR, 15 FT. DEEP.

Waltham, Mass.

"Bottom and water slopes paved with granite slabs 12 inches thick, laid dry as closely as possible."

L. BROWN, *Supt.*

Hartford, Conn.

"We have six reservoirs from 20 to 41 feet deep, paved with stones about what two men can lift, placed close together and filled in with smaller stones."

HENRY A. AYERS, *Supt.*

LOW SERVICE RESERVOIR NO. 2, 21 FT. DEEP.

Portland, Oregon.

"Paved with brick coated with ¼ inch California asphalt laid flatwise in paving pitch."

J. HENRY SMITH.

EASTON LAKE RESERVOIR NO. 2, 51 FT. DEEP.

Bridgeport, Conn.

"Cobble rip-rap 24 inches thick at bottom of slope and 15 inches at top."

S. G. STODDARD, Jr., *Engineer.*

WATER WORKS RESERVOIR, 47 FT. DEEP.

Covington, Ky.

"The water slopes are riveted with stone blocks 12 inches thick, laid in cement on a foundation of broken stone 12 inches deep."

W. H. GLORE, *Supt.*

WATER WORKS RESERVOIR, 26 FT. DEEP.

Erie, Pa.

"Bottom of reservoir puddled with 18 inches of brick clay put on dry and rolled solid every three or four inch course. Paved with brick laid flat on bottom (2 inches thick) and laid on edge on sides (4 inches thick) with cement after being laid."

WM. HINNEL, *Sec.-Treasurer.*

BIRMINGHAM RESERVOIR, 42 FT. DEEP.

Birmingham, Ala.

"Rough sand stone rip-rap 12 inches thick."

W. J. MILNER, *Supt.*

STORAGE RESERVOIR, 24 FT. DEEP.

Peoria, Ill.

"6 inches of concrete laid on bottom in about 10 foot squares separated by two rows of brick placed on edge. Water slopes lined with brick 8 inches thick. Frost in winter occasionally cracks the bricks at the water surface."

DABNEY H. MAURY, *Supt.*

CHERRY VALLEY RESERVOIR, 35 FT. DEEP.

"The inside slope of the dam is covered with rubble paving from 12 to 24 inches in thickness, covered with about 6 inches of selected hard pan to fill the interstices in its surface."

J. C. HANCOCK, *Supt.*

CACHE LA POUDRE RESERVOIR, 30 FT. DEEP.
LARIMER AND WELD " 22 " "

Northern Colorado.

"Inside slope of both reservoirs rip-rapped with mountain sandstone 1 foot thick laid on 2 feet of gravel."

ED. BAKER, *Engineer.*

GREELY, Colo.

WATER WORKS RESERVOIR, 14 FT. DEEP.

Ann Arbor, Mich.

"Slopes protected by rubble or cobble stone."

CHAS. E. GREEN.

MARLETTE LAKE RESERVOIR, -- FT. DEEP.

Virginia City, Nevada.

"Front of dam paved with rubble. Stone and ice sometimes displace or disarrange the rubble but not seriously."

J. B. OVERTON.

STORAGE RESERVOIR, 25 FT. DEEP.

Southington, Conn.

"The water slope of the dam was covered 18 inches in depth with small broken stone, over which was laid a paving of large stone 15 ins. in depth."

J. H. McKENZIE.

Figures 3, 4, 5, 6 and 7 show typical forms of slope paving and include all the kinds common to modern practice.

Fig. 0, not shown, is an illustration of the use of brush or willows tied together and anchored by means of galvanized wire. The small private irrigating reservoirs of Western America are frequently protected from wave action by wheat straw held down by strands of barbed wire. Occasionally brush and stones or slag are used.

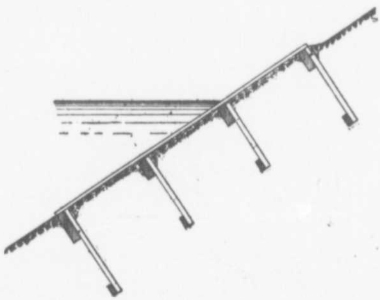


Fig. 3.

Figure 3 was designed by the author as a temporary expedient for the Ogden Distributing Reservoir until a more permanent paving could be put down. It was laid five years ago and has fulfilled all purposes so well that the owners have now no intention of substituting it. Red pine boards extend 3 feet above and 6 feet below the flow line along the slope, and are nailed to joists 3″ x 8″ imbedded in the bank and anchored at intervals in the manner shown.

Fig. 4.

Figure 4 is typical of the most common kind of paving.

The foundation should be, in every instance, a compact, impervious and stable bank, on the inner slope of which is spread a layer of gravel or broken rock of sufficient depth to prevent the water from washing away the earth beneath. Upon this porous layer is laid the stone pitching or rip-rap, which may vary in depth from 1 to 2½ feet, depending upon the height of the waves and the action of ice and frost, the interstices of the stone pitching being filled with gravel spalls or broken stone.

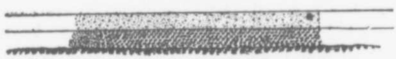


Fig. 5.

The usual form of cement concrete paving is shown in Figure 5, consisting of a layer of screened gravel or broken rock well rammed, upon which is laid the requisite thickness of concrete. For a short distance, both above and below the flow-line, stone-pitching laid in cement mortar upon a thin layer of cement concrete should be substituted for the cement concrete paving.

Fig. 6.

Figure 6 shows a portion of a slope paved with asphalt concrete. This concrete is composed of clean sand, gravel and liquid asphalt in about the following proportions :

Gravel	70	per cent.	by weight.
Sand	30	"	"
Liquid asphalt	10-15	"	"

The sand and gravel are heated to a temperature of over 30° Fahr. and mixed with the liquid asphalt at a slightly lower temperature.

It is put on hot in a manner similar to street paving, and varies from 1 to 4 inches in thickness.

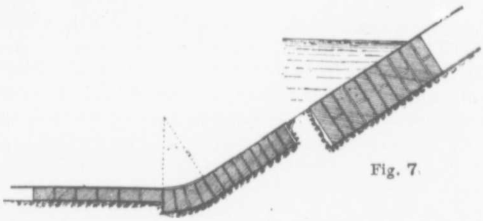


Fig. 7

Figure 7 shows a paving formed of brick and asphalt. The brick on the bottom may be laid flatwise, on the lower portion of the slope 4 inches and near the flow line 8 inches in thickness. To prevent the brick from absorbing moisture a thin layer of asphalt mortar, composed of 90 per cent. by weight of clean sand mixed with 10 per cent. by weight of liquid asphalt, is first spread over the rammed gravel ; the brick are then dipped in hot asphalt, and after being laid grouted with the same material. A thin surface coating of asphalt of about ⅛th of an inch in thickness completes the lining.

In discussing the relative merits and demerits of each type of paving represented above, little need be said of the first two named, since the early decay of both willows and lumber render periodical renewals necessary.

Many failures are recorded of stone pitching or rip-rap, but in nearly every instance they were caused by the washing away of part of the embankment immediately beneath the rip-rap. Under ordinary conditions wash can be prevented by placing a sufficient thickness of gravel or broken rock back of the pitching, and carefully filling all interstices of the latter with coarse sand and gravel. The general success which has attended this kind of paving does not warrant, in the opinion of the writer, the following severe censure from the pen of Samuel McElroy, C.E., of Brooklyn, N.Y.:

"The only way to protect an earth reservoir bank, or floor, is to keep it dry; otherwise pressure, storm wash, motion, leakage, frost or animals may weaken and destroy it.

"Dry work, properly laid, requires much more time for selection and fitting than cement work, for the same section and slope; it requires a better class of stone throughout; and the cost of hydraulic cement mortar, in itself, does not add more than $1.20 per cubic yard, or about the cost of the cement mortar to that of dry work for the same stone. At Ridgewood we paid $1.50 for the dry stone lining, and $2.50 for similar wall in cement with full joints. The repair accounts of dry walls on various public works has been a formidable item.

"Experience also shows that a well puddled and brick covered reservoir floor would have prevented some costly bottom leaks and ruptures.

"In a Report on the Hudson River and Champlain Canal Improvement, made to the State Engineer of New York in 1867, I had occasion to show that a solid masonry canal slope wall one-third to one, with 4½ feet concrete footing and 30 inch wall, could be built and coped for less than the 1¼ to 1 dry slope wall, which has been an endless cause of wash, rupture and repair along the entire canal system of the State.

"If the experience of our reservoirs similarly lined was collected it would certainly end their construction, as it would similar constructions for mill power races, dams and other faces exposed to wash and frost.

"For both Brooklyn reservoirs the following specification was adopted:

"The inside slopes to be carefully puddled for two feet in depth, then covered with a substantial layer of cement mortar and gravel (concrete), not less than three inches thick, over which a wall of brick masonry shall be built eight inches thick to the embankment top, and covered with a flag coping not less than three feet wide, by five inches thick. The bottom of the apartments to be similarly puddled and covered with best paving brick laid on their edges and carefully grouted.

"In the Ridgewood case this theory was fully confirmed by negative experience. A change in the direction took place in 1856, and some changes in plan in 1857. The slope lining was thus specified:

"The water slopes, unless otherwise directed, to be paved with a well laid stone paving one foot thick, the stone used to be sound and of proper shape to make neat and compact work; and openings between said stone to be well pinned and packed; to be equal in every respect to the receiving reservoir of the Croton work. The paving to be laid on a bed of gravel or small stones.

"A considerable length of slope was lined under this specification, under Mr. Kirkwood's personal inspection, as a pattern for the rest; it was as cheap for the sub-contractors to use 15 to 18 inch stone, and the wall was thus laid, with about five inches of small stone backing. When about seven feet of water was pumped into the eastern division in 1858, the wave wash cut the embankment behind the wall so rapidly that the water was drawn down, the injured sections repaired, and the entire lining carefully filled in with cement, grout and pointing.

"This involved a change in the dry wall of the new Croton reservoir, then under contract, to cement stone masonry. The Mount Prospect reservoir, built according to the original specifications, illustrates to-day its advantages. For convenience of construction, however, it is best to increase the concrete thickness and reduce that of the puddling."

In the case of the Ridgewood reservoir, cited by Mr. McElroy, 5 inches of broken stone behind rip-rap is too thin to prevent wash. Again in the paving for the Brooklyn reservoirs, which he recommended, it is not good practice to lay cement concrete on clay since the weight of the water which may accumulate back of the lining, or the liability of both clay and water freezing, will loosen and break the concrete.

Water slopes lined with cement concrete fail usually in one of two ways; either the foundation is insecure or the bank settles. Quite often a layer of clay is first put down with no intermediate porous stratum of gravel or small stones, and when the water is rapidly drawn down in the reservoir the wet mass of clay is liable to slump and carry with it the concrete lining.

Engineers and superintendents frequently build reservoirs in earth and line the inner slopes and bottom with cement concrete before the banks have properly settled, and without first thoroughly soaking the interior walls. In a properly made bank there will be no subsidence to speak of, but to pave a reservoir without first allowing the water to remain up to high-water mark for days and even weeks, is to invite failures.

The Cemetery Hill reservoir of Colorado, built in 1886 87 by the writer as engineer-in-charge, in accordance with plans and specifications prepared by chief engineer Allan, was not lined until 1890. In the spring of that year it was paved with Portland cement concrete, of which the greatest thickness did not exceed four inches. Five years later (1895) the writer examined the lining and found no failures, not even a crack. He attributes the success of this paving to the stable condition of the banks and to the water soaked state of the interior.

In the vicinity of Beaver Brook, Colorado, the farmers can get no water from wells, and they obtain their domestic supply from the irrigating canals in summer which is run into cisterns lined with cement mortar or concrete. After many failures the writer suggested that they soak the bottom and sides of the newly excavated cisterns for weeks, then remove the water, ram gravel over the entire interior and line with cement concrete. It was found that a much thinner coating would suffice when the foundation was prepared in the manner just described.

The toughness, elasticity and imperviousness of asphalt concrete render it a suitable material for reservoir lining. It has, however, one serious defect which engineers have not yet been able successfully to overcome. A hot sun, or warm weather, will cause it to slide down the slope.

In the kind of paving shown in Fig. 6, the thin coating of asphalt mortar which complctly surrounds the paving brick renders the lining impervious and difficult to crack, while the rigidity of the brick prevents the wall from sliding upon its base. Stone rip-rap based on a thin coating of asphalt concrete can be substituted for the brick, and the entire wall well grouted with asphalt mortar.

CORE WALLS.

In the New England States perhaps 85 per cent. of all the earthen dams now in existence have been built with core walls of puddled clay, masonry, or concrete. In California, the Rocky Mountain Region, and as far east as Pennsylvania and New York, masonry core walls are seldom introduced.

About a year ago, the writer sent the following questions to a large number of hydraulic engineers and water-works superintendents :

Ques. 1. If the reservoir dam is built with a centre core, state the materials used and mode of construction.

Ques. 2. Give the following dimensions of the centre core, bottom width at original surface, top width, depth of base below original surface, width of base at bottom, height over all.

Ques. 3. Does the water in your opinion percolate through the inner portion of the embankment to the centre core ?

Ques. 4. Speaking generally, do you think the additional security gained by a concrete or masonry core justifies the extra expense ?

The replies received to the above queries were so conflicting that it was impossible to harmonize the opinions expressed. If a classification were attempted it would be something like the folllowing :

(1) Those who consider a masonry core wall essential.

(2) Those who consider any kind of a core wall an element of weakness and a useless expenditure of money.

(3) Those who would insert a masonry core wall as an additional safeguard in all important structures, the failure of which might endanger life or property.

(4) Those who would be guided entirely by the quality of the materials and the conditions connected with each case.

The chief advantages of a masonary core wall are:

(1) It prevents animals from burrowing holes through the embankment.

(2) It may prevent percolation.

The chief disadvantages are:

(1) The additional cost.

(2) The unequal settling of unlike materials of different density and weight.

(3) The liability of the earth in the upper part of the embankment becoming saturated and increasing the pressure on the wall much beyond the designed limit.

(4) The tendency of the wall to crack on account of the expansion and contraction due to changes of temperature, presence of water back of the wall, or on account of the unequal settling.

It has always seemed to the writer that the advantages to be gained from a masonry core wall are in no measure commensurate with the disadvantages arising from its use. A 12 inch brick wall laid in asphalt mortar will prevent the burrowing of animals as effectively as a concrete wall 6 ft. in thickness. Besides, it is doubtful if there is an animal in existence which will burrow, for the sake of the pleasure to be derived from the exercise, through a well made gravel puddle. In the Western States cement concrete costs per cubic yard in place from $6 to $7, while earth suitable for earthen dams can be conveyed in wheel scrapers, puddled and rolled, for from 12 to 20 cts. per cubic yard. A yard of concrete is thus equivalent to nearly 45 yards of puddled earth. The most pronounced advocate of concrete core walls will hardly dare maintain that the relative utility of equal volumes of a concrete wall and the adjacent earthen embankment is as 45 to 1.

In considering the safety of earth dams with masonry or concrete heart walls, the late James B. Francis assumed that the full hydrostatic head would be exerted against the wall, and that as the wall alone was wholly inadequate to sustain this pressure, the earth on the down stream side had to be made of sufficient weight to resist the total pressure.

Desmond Fitzgerald, in describing the high earth dams recently constructed under his supervision for the Boston Water Works, makes a similar assumption. One embankment is 65 ft. high, has an inner slope of 2 to 1, an outer slope of 2 to 1 and 2½ to 1, a berm 6 ft. wide on each side, and a concrete core wall 10 ft. thick at the base and 2 ft. at the top. "In considering," he says, "the stability of this kind of an embankment, we must assume that the full head of the reservoir is carried to the core wall."

The writer fails to see the benefits to be gained by this process of reasoning based on such an assumption. In the first place, hydraulic engineers are nearly unanimous in the opinion that the inner part of the embankment should be the most impervious, and that, if it cannot be homogeneous in structure, the materials should be so placed that the imperviousness of the inner part should change gradually to the porosity of the outer. In following this practice it would be impossible in all well executed structures for the full head, or any head of water, to be exerted against a centre wall.

If the intention is to place all the impervious material near the centre and next to the core wall, the design is one of the worst that can be conceived. In such an embankment there is a porous mass of earth next to the water, through which the latter can readily seep or percolate, then a heart wall encased in clay puddle much too weak to sustain the hydrostatic pressure, and back of this a second porous mass of earth too weak in itself to retain the impounded water.

This method of retaining water reminds the writer of the city engineer of a Western city who built a stand pipe of brick, and, to be doubly safe, lined its exterior with thin sheet iron plates. When the water was first turned in it never rose to the full head, but burst the brick and afterwards the thin sheet iron.

In impounding water one must depend wholly upon one particular class of material to sustain the pressure and prevent see page and percolation.

Thursday, 22nd October, 1896.

HERBERT WALLIS, President, in the Chair.

An illustrated lecture by Mr. J. A. L. Waddell, Ma.E., Bridge Engineer of Kansas City, on bridges built and designed by himself occupied the evening.

Thursday, Nov. 5th, 1896.

HERBERT WALLIS, President, in the Chair.

The President announced that the late Mr. H. G. C. Ketchum, member, had bequeathed five hundred dollars to the Society.

A discussion on questions connected with the proposed legislation on behalf of the Society occupied the evening.

Thursday, 19th November, 1896.

HERBERT WALLIS, President, in the Chair.

Paper No. 117.

EXPERIMENTS ON CONCRETE MADE AT McGILL UNIVERSITY.

By MESSRS. THEO. DENIS, G. G. HARE AND CARL REINHARDT, Students, Can. Soc. C. E.

Of late, monolithic works of great importance have been carried out and every day concrete, as building material, is creeping to a foremost place.

Although cement testing proper has been subjected to elaborate, scientific and practical investigations, very few researches, and especially normally conducted researches, have been made on the strength and behaviour of concretes and betons. This probably is due to the fact that for such experiments heavy and costly apparatus is needed. Investigations on small specimens would be useless, and conditions approaching as nearly as possible to practice have to be followed.

The following are the results obtained from a series of experiments made by students of McGill University, 1895-96 :—

The object of this first series of experiments is to determine the effec of different per cents of water on the strength of the concrete. The limits were 16 and 30 per cent. of water, by weight of cement and sand, which are beyond the extremes of practice on both sides.

CEMENT.

The cement used was, of course, the same brand throughout the series. It was a German Portland of good quality, slow setting, on which separate sand tests were made in connection with this series. The results are tabulated below.

SAND.

This was clean, coarse, angular, dry sand of good quality, of slightly higher grade than usual practice.

STONE.

This was broken limestone of such size that the pieces would have passed through a ring 1¼ inches diameter. They were unscreened, and just as they came out of the breaker. Consequently a slight amount of dust was mixed with them. They had to be broken a little smaller than in actual practice. The blocks of concrete being only one cubic foot, it was thought that more accurate results would be obtained in this way.

MOULDS.

The moulds were made of ¾ inch plank, lined with sheet zinc. They were 5 feet long, 1 foot high and 1 foot wide, divided into four compartments, which would mould four cubes at once, of dimensions 1 x 1 x 1 feet, forming specimens large enough to investigate seriously upon. These were removed by unscrewing one side of the box and sliding them out. Care had to be taken to oil the sides of the moulds slightly before ramming the mixture in them, to avoid trouble in getting them out.

CONDITIONS OF MIXTURE AND PROPORTIONS.

The proportions adopted for this series were one of cement, two of sand, and four of stones, by weight, the proportion of water being based on the weight of sand and cement.

The cement and the sand were first thoroughly mixed dry, then the water added gradually. The stones were then thrown on this mortar, spread out, and the whole vigourously and very thoroughly mixed. The fresh concrete was then placed into the moulds and rammed in 1½ to 2 inch layers.

RAMMING.

The rammer was a block of hard wood 2 feet long by 2 x 2 inches, with a lathe turned handle. It was not very easy with this to ram uniformly, even throughout one block, and this is one of the main sources of discrepancies in this series of experiments.

It was thought that a reduction of the breaking loads to a standard weight of the blocks would be only fair, and would slightly improve the results.

GROUPING OF TESTS.

The tests were made at one week, four weeks, and two months, and the results grouped accordingly, that is to say, the one week tests, with different per cent. of water, compare between themselves, four weeks and two months likewise. Parallels between the results, at different ages, cannot be drawn on account of some specimens having been prepared under widely different conditions. For instance, the results at two months are exceedingly low as compared with those obtained at one and four weeks. This is due to the fact that these two months specimens were the first prepared of all, and this before the cemented trough in which they were to be immersed was completed. Consequently they were kept 8 to 10 days longer than the others in the dry air of the laboratory, which seems to have had a disastrous effect on them. But in spite of these slight drawbacks, the annexed table shows that up to 24 per cent., the percentage of water has not a very great effect on the strength. This is an important point, for below 20 per cent. the mortar obtained is rather dry and very difficult to handle.

But beyond this limit of 24 per cent. a greater proportion of water seems to weaken the concrete considerably.

This limit is very sharply defined in the adjoining table, where an additional 2 per cent. of water, from 24 to 26 per cent., weakens the concrete by almost one-half for the one-week tests. It is, however, interesting to notice that strength is almost completely recovered with time, the four-week tests showing the weakening limit to be between 26 and 28 per cent., and the two months' between 28 and 30 per cent. So that if immediate strength be not required of the concrete structure, 28 per cent. of water will not affect the ultimate resistance if allowed to stand two months.

In the parallel sand and cement tests the weak line is not so sharply defined, but yet it is sufficiently so to show that the same statement applies. The tests in this case show a marked weakening between 14 and 16 per cent. of water for the one week, which strength is ultimately recovered, as is shown by the four weeks' and two months' tests.

The low limit of 14 per cent., as compared with 24 for the concrete, is probably due to the fact that the stones of the concrete, on account of their porosity, absorb a part of the water.

The table shows that the greatest density is obtained with 16 and 18 per cent. The weights of the cubes beyond this decrease up to 24 and 26 per cent., where they are again nearly equal in density to the 16 and 18 per cent. of water. Therefore this 24 and 26 per cent. seems to be the point where the best practical results are obtained, because 16 and 18 per cent. make up too dry a concrete to allow of easy handling.

Another point incidentally comes up. Attention has been drawn to the poor results obtained by the same tests and reason of long exposure to dry air given. This shows up a very important point, namely, the necessity of covering up carefully all concrete and cement works exposed for any length of time to dry air and sun. The bad effect of these agents is plainly demonstrated, and it is doubtful whether much strength would ultimately have been recovered.

It is also interesting to notice the results obtained by the concretes made of 1 part of cement, 2 of sand and 5 of stones, and 1 cement, 2 sand and 6 of stones. The specimens of these compositions gave results equal to concretes, 1, 2, 4, showing that for strength they are as good as the ones containing a less proportion of stones, while being much more economical.

These experiments are as yet very incomplete. But it is hoped that the researches in this subject will be continued, and that valuable information for the engineer in practice derived from them.

CONCRETE TESTS—COMPRESSION.

Proportions by weight: 1 part cement, 2 sand, 4 stone.

Per cent. of water by weight of cement and sand.	Crushing strength per square inch. 1 week. comp. tests.	4 weeks.	2 mos.	Average weight of sp. per c. f.
16	792	677	382	141.5
18	653	679	507	143.0
20	746	626	507	139.5
22	620	615	670	139.5
24	679	542	559	141.5
*26	362	545	500	141.2
28	326	340	823	138.0
30	245	331	361	135.5

Proportion by weight: 1 cement, 2 sand, 5 stone.

20		703

1 cement, 2 sand, 6 stone.

20		728

CEMENT AND SAND TESTS.

Proportions: 1 cement, 2 sand.

10	825	800	1822
12	800	1311	1666
14	750	1000	1100
*16	475	1389	1777
18	395	1110	1266
20	400	913	1633
22	330	844	1233
24	388	——	1230
26	——	——	1000

* Line of weakness due to excess of water.

McGill University, April, 1896.

DISCUSSION.

Mr. C. R. F. Coutlee. Mr. Coutlee remarked that in tests of concrete classification seemed necessary as to whether the material is to be

(1) Of maximum weight, for walls, etc.

(2) Impervious to water under head.

(3) As economic as possible of cement, as for use in filling under structures.

No. (1) requires :

Everything to increase density of mass.

The heaviest kind of broken stone is $\frac{1}{4}$ inch, and less sandstone of this kind weighs 95 lbs. per cubic foot. Of 1 inch and less, only 70-75 lbs.

No. (2) requires :

(*a*) Plenty of best cement and fine but sharp sand.

(*b*) Stone to be small and regular in size.

(*c*) Fine, washed gravel.

No. (3) is made with just enough mortar to coat each stone over. Where the stones touch they adhere. Coarse stone and quarry waste free from clay may be used for this. To know the various combinations that will be strong enough of this latter kind is the important thing.

Wet the stone thoroughly before depositing it upon a swimming mortar paste, for porous stones, and, for non-porous, have paste stiffer, use freely clean water, provided not to such excess as to make insoluble jelly of cement. Better to have enough surplus water to secure complete chemical action, then there is a certainty of all molecules of cement being acted upon. Strength will come with time. Permanent characteristics are generally assumed at end of 30 days.

A cheap concrete is

1 bbl. cement (3.2 c. ft.)
3 sand.
9 broken stone 2″ to 3″ as it comes from crusher unscreened.

Thursday, Dec. 3rd, 1896.

HERBERT WALLIS, President, in the Chair.

A discussion on the general affairs of the Society occupied the evening.

Thursday, Dec. 17th, 1896.

HERBERT WALLIS, President, in the Chair.

The following candidates having been balloted for were declared duly elected :

MEMBERS :

H. S. GREENWOOD, HENRY O'SULLIVAN,
JOHN BONSALL PORTER, WM. F. TYE,
J. W. TYRRELL, G. WHITE-FRASER,

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

H. J. BOWMAN, H. D. ELLIS,
R McCOLL.

ASSOCIATE MEMBERS :

*SAMUEL J. CHAPLEAU, A. R. DAVIS,
A. T. GENEST, H. T. HAZEN,
F. E. SIMONDS, HERBERT W. UMNEY,
JOHN WOODMAN.

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

T. H. JONES, FREDRIC NICOLLS.

STUDENTS :

DAVID BOWMAN, E. F. T. HANDY,
W. P. MORRISON.

A discussion on the possibility of increased accommodation in the rooms of the Society took place.

Thursday, January 7th, 1897.

PROF. H. T. BOVEY, Vice-President, in the Chair.

A committee was appointed to make abstracts from Engineering Journals and Transactions, and to present the same at the ordinary meeting of the Society.

TOPICAL DISCUSSION.

"THAT ENGINEERING WORKS SHALL BE CONSTRUCTED BY DAY'S WORK, INSTEAD OF BEING DONE THROUGH A CONTRACTOR."

W. J. Sproule. Mr. Sproule in opening the discussion said he had hoped to prepare himself for the discussion of the subject, but had not been able to do so, and trusted some others had, and that they would be in a position to deal with the subject better than he could. The subject is one that has been much discussed. It may be looked at from three aspects,—the professional aspect, the moral aspect and the business aspect. The standing of the profession is very much affected by the system of doing work through a contractor. The idea comes up that there may be an analogy drawn between engineering and some other professions in regard to this matter. In doing work by contract the civil engineer often has a very small part in the business. He may outline a scheme, and then contracts are let, and he has very little to do with the actual carrying out of the work except as an inspector, and often not even in that capacity, and this method goes on until it is to be feared, there are many engineers who could not really take a work in hand and direct it themselves. Civil engineers are connected with all kinds of work, and are handicapped if deficient in a knowledge of practical details.

A doctor might visit a patient, examine and diagnose his case. He might say this man has typhoid fever, get somebody to doctor him. The second doctor would act in the capacity of the contractor in engineering. But the doctor does not do this. He does the work and gets the credit of it. The lawyer not only says you had better sue the city of Montreal for $20,000, but he sues the city and conducts the case, and it would be an advantage to the civil engineer, if he conducted the case right through, if he not only made an outline of the scheme but also conducted the work. The speaker thought that the limit at which the civil engineer stops is too far removed from the actual conduct of the work. He wished to emphasize the fact that in important works carried out by a contractor, the civil engineer often merely indicates what is to be done, that the profession would be in a better condition if the work were carried out by the civil engineer, and that the work would be better done.

The whole tendency is for the contractor to slight the work, in order to do it as cheaply as he can, and get as much money as possible out of it. Contracting makes the work more expensive. The contractor must have his profit out of it, and the profit that he makes out of it is in the capacity of the middle man. It has become the custom for a large contractor to take a contract for a whole railway at certain prices, and to sublet the work to others who do it at a great deal lower price than he receives. He stands aside, and takes perhaps 30 per cent., while that percentage should be distributed between the company who are having the work done and the men who are doing it.

It is almost impossible to get some classes of work done thoroughly by contract. There is an example of contract work in the Montreal harbour. A certain portion of wharf was built by contract many years ago, and when the water went two feet lower last summer than ever before there was visible a good object lesson in contract work.

The business aspect of the case is of course in connection with the cost of the work. It may be argued that contracting gives scope for individual energy and enterprise, and for men of ability to come forward and undertake works. A large contractor can keep on hand valuable and costly plant that a small work would not be justified in investing in, and in that way a large contractor can do work more cheaply than a small concern can. But if it were a general thing for work to be done by day's work under the supervision of the engineer, the work could be done and the plant would be saleable, or plant might be hired. In any case the work must bear its proportion of the cost of plant, and interest on that cost, whether the work be done directly under the engineer or by a contractor.

Another aspect is the moral one, that is, the difficulty the engineer finds in doing justice to both employer and contractor on account of the want of information on which the contractor often tenders. To provide full information on which to tender would often be a very expensive work in itself. Here the difficulties of classification are encountered.

With regard to classification, the speaker considered the Canadian Pacific Railway on the north shore of Lake Superior furnished the most prominent example that we have ever had in this country. There was an attempt to make the classification as comprehensive as possible, and nine classifications or a classification of nine different kinds of materials was tendered for, and the result was that great difficulty arose between the contractors and the railway as to the classification of the different materials. The speaker did not think that it was altogether due to the specifications, but thought there was dishonesty in the matter. On the other hand, certain engineers advise that there should be only two classes of materials paid for, and that the contractor should put in prices that would provide for meeting anything. The difference in cost of dealing with different materials is so great that the latter advice seems like admitting that engineers cannot cope with the difficulty. If the work were done under the direction of the civil engineer without the intervention of the contractor, there would not be any need for specifications and classifications, and the cost of the work would be lessened. Thus, returning to the professional aspect of the question, there would be a great deal more employment for civil engineers. Engineers who would be employed in supervising directly would be preparing for more difficult work, and this would tend to make a better class of engineers.

H. Irwin.

Mr. Irwin said he did not know how engineers were going to bring about any change for the better in the matter. If engineers could have charge of construction of works, it would of course be better for them, and it would be a great advantage to every one that a large number of capable engineers should exist. There could be no doubt that in such works as those alluded to, very large plant would be required; even the very largest railways for instance could not profitably construct the iron work of their own bridges. The cost of the machinery and plant of the kind required for the construction of the substructure of large bridges would be lost altogether if they were used only for one bridge or so. Where the plant required is not too large or expensive, a piece of work could probably be done much more economically by the railroad companies themselves under an experienced engineer. No doubt the original engineers carried out their own works, but men like Stephenson and his contemporaries had to acquire the experience to carry out their plans, and their pupils learnt under them. Here engineers who have the chance to do so go off into contracting, because the salary of most engineers is insufficient for their maintenance.

H. Wallis, President.

The President.—A railway company as a rule undertakes such new work as the plant at its disposal will admit of. A contractor working upon various railways can employ and keep in use valuable machinery which it would not pay a railway company with limited requirements to purchase. It is quite feasible, and would probably be advantageous, for any company to undertake its own new work, or work on its own extensions, if there should be enough to make it an object to do so.

Rolling stock, both locomotives and cars, are built at the Grand Trunk Railway works, at prices with which contractors either in Canada or the United States cannot successfully compete, and it has been customary for years for that company to supply from its own workshops all the rolling stock required for use in Canada. It has been usual to purchase for use in the United States, because the requirements are limited.

Mr. Sproule said in the matter of steel bridges for small municipalities, of course it would be perfectly absurd for the municipalities to attempt to make bridges by day's work; but there is a class of engineering works that do not come under that head, and which might be well done by day's work. W. J. Sproule.

The President.—Take railway work as an example. Nearly all work of maintenance is undertaken by the various companies' engineers; but new work requiring expensive machinery is usually let under contract, to save the expense of purchasing special plant which would stand idle for long periods. The President.

Mr. Sproule.—The plant would be required from time to time. It is most desirable that an engineer should have experience of this kind. Mr. Shanly remarked at the Annual Meeting that it would be difficult to enforce any kind of conditions of a close corporation because the practical man will get the work nine times out of ten. If an engineer is not a practical man, what is he? And yet it is a common thing to hear a distinction drawn between an engineer and a practical man. W. J. Sproule.

The President recollected that upon English railways there are in some cases two engineers. They have one for construction and one for maintenance. The engineer of construction lays out new railways, and the contractor works to his specifications. It cannot be said that the engineering profession is dying out in England, and it is doubtful if any extensive engineering work there is carried out other than by a member of the Institution of Civil Engineers or by a member of one of the other recognised societies. The President.

Mr. Sproule.—Once the construction is done, they have no more use for civil engineers, and the business man takes hold of the thing. If the civil engineer is not a business man, he should be. There is no class of men that should be better prepared to conduct work than engineers. He thought there was a want in the training of engineers, that an important part of the engineer's training should be to the business part of it. W. J. Sproule.

The President.—Contractors are useful helps to the engineer, but do not supersede him. The President.

C. B. Smith. Prof. Smith.—The difference lies between constructive work and maintenance. If the civil engineer only designs the work, he does not get the experience in superintending its construction, and it is a gradual process by which we have conducted ourselves out of the knowledge of being able to superintend. The tendency on the best American railways is for civil engineers to take care of the maintenance, and he thought that if we looked forward, the value of the civil engineer would increase in this respect, while his value as a superintendent of construction would be less. On the Baltimore & Ohio Railway, for instance, engineers are engaged in supervising, but never in constructing, by day's work. It is thought better to let the contract even at a small loss than to buy the plant and have it done by a civil engineer.

D. MacPherson Mr. MacPherson said it would be well to decide first of all from what point of view the question is to be considered; but assuming that it is to be viewed in the light of being beneficial to the engineering profession and the engineer's employer, it appears too general a resolution. Circumstances would at times make it almost imperative to do work by day's labour, which under other circumstances might be done by contract more advantageously for all concerned. If a work is of any importance there must be an engineer in charge, and if it is of the engineer's own designing, he must have a better conception of it than anyone else; and if he is a man capable of economically directing the work by day's labour, he will none the less be the controlling influence if the work is under contract. The contractor will only be a well organised machine entirely controlled by the engineer. It is a great fallacy to state, as has been stated in this discussion, that the contractor is the artist and the engineer only the critic. As well might you call the mechanic greater than the inventor when putting in material from the ideas of some great invention under the direction of the inventor. A capable engineer in charge of work will be the controlling power, whether it is being done by day's work or by contract; in the latter case the contractor has the all-powerful incentive to economise time and material, and if a reputable man he will also wish to do really good work. The engineer, on the other hand, knows that good and reliable work must be done, at the risk of his own reputation. Really good work depends upon many details, some of which appear unimportant to the unprofessional mind, and therein lies one danger in day's labour. The engineer may carefully instruct a competent foreman how some special part of the work should be done, and then feeling that there is no incentive for the man to do otherwise than directed, the engineer may not think it imperative to give this special detail the personal supervision he would if the work were under contract. The foreman may try some ideas of his own which he thinks more practical, and the result may be bad work, though all concerned think they have done their duty.

For a young engineer it certainly appears better training to be on contract work, as it not only ensures his careful and accurate personal attention, but also allows him to learn by observation the practical methods of contractors which he will find of great assistance to his theoretical training. In special cases, where comparatively small undertakings require expensive plant, it is manifestly of advantage to do work by contract to avoid excessive cost and delay. In other cases where a large amount of work is being done, and there is time to get together the necessary men and plant, it might be well to do it by day's labour ; but even then it is well to have the labourers interested in doing it quickly, and the men supervising interested in doing it well ; in other words, tasks might be assigned to individuals under a competent foreman, which is virtually contracting on a small scale, in which the labourer gets the full benefit of his own exertions.

It does not appear possible to lay down any absolute rule as to which method shall be adopted, but each case must be decided by the peculiar circumstances surrounding it. The speaker, however, favours contract work whenever special circumstances are not against that method, which they would not be in the majority of cases.

Mr. Marceau.—It is not always practicable to have a piece of work done by day's labour, as for instance, in the case of extensive works requiring costly plant. E. Marceau.

As far as Government works are concerned, the desire on the part of the public to have them let out by contract for the sake, it is alleged, of economy, has made this the general practice. A rule in the Department of Railways and Canals, and for that matter in all the Departments at Ottawa, makes it compulsory to call for tenders whenever the estimated cost of the work exceeds $4,000. However, this rule has sometimes to be departed from, as was the case when the Carillon Dam was repaired under the speaker's supervision some years ago. This being a submerged dam, the extent and even the nature of the work to be performed could only be ascertained after the structure had been unwatered, so that no specification could be drawn for intending contractors. The repairs were therefore done by day's work, and it may be stated at a cheaper cost than would have been the case with a contractor, the average rate per cubic yard of the new crib work put in being $2.50 as against $3.50 for the original structure, although the conditions were very much the same in both cases. This goes to show that contract work is not always less costly than work done by the day. However, in the opinion of the speaker, it would not be advisable to lay down such a broad general rule as the one forming the subject of the present discussion, as in a great many cases, such a rule could not be carried out, and in other cases day labour would obviously be more costly than contract work.

W. Kennedy. Mr. W. Kennedy, said as a rule he agreed with the resolution, but there were cases in which it was impossible to carry out the work by day's work. First, he assumed the engineer capable of properly carrying it out, and then he did not see the necessity for the contractor. Sometimes work was done more cheaply by contract than by day's work, but if so it either meant that the work was not well done, or if well done that the contractor had lost by it. Work was always worth its cost if it was properly carried out. Very often corporations want work done by contract, because they say it is cheaper; but, as a rule, the speaker advised work being carried out by day work, because we get better work with less trouble if the work is well managed. The speaker had experience where the contractor had taken work too low, and before it was started he had to advise the corporation that the prices were not sufficiently high, and the contractor would not carry it out, or else he would lose money. Hence the speaker advised the carrying out of work by day's work just as much as possible. Where there was material to be purchased there was less trouble in carrying out work by day's work. Every person that has had charge of work knows the difficulty of doing good work under contract.

The President. The President advocated the principle of piece work. His own experience in locomotive and car building and repairing clearly pointed in that direction. He did not see why the principle should not hold good in railway and other constructive work. Men who had a pecuniary interest in doing work generally would of necessity do it economically, and it was for the foremen and engineers in charge to see that it was done well. Such a system encouraged good men to earn good wages, and certainly tended to reduce the cost of work.

D. MacPherson Mr. MacPherson took the President's remarks as being in favour of the method of contracting.

The President. The President.—He would not lay down a hard and fast rule. Contracting out a whole undertaking might in many cases be desirable, but he was advocating the subletting under the constructing engineer of various parts of the whole to workmen on the basis of wages only, tools and plant being provided and material purchased by the employer, in the same way as is done in locomotive and car repair shops. A great deal of the work in the shops of the Grand Trunk Railway is done in that way. It is found that better work is done, and the men obtain better wages.

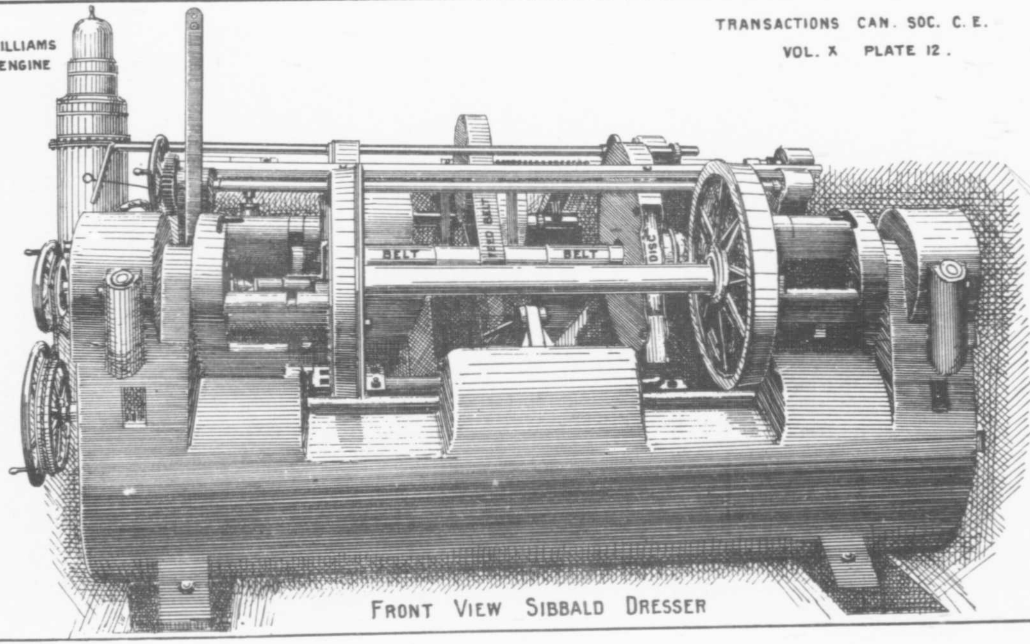
Mr. Irwin said that this method of piece work on large jobs would have all the disadvantages of time work. It was just like contracting for labour. The corporation or company would have to rent or buy plant and employ contractors to furnish men or hunt round for them. H. Irwin.

Mr. Duggan said there was one point that had not been mentioned, that was the organization. The contractor to get good work done must depend as much upon his organization as upon his plant; he must see that he has good men and a good foreman. Certainly contractors have better facilities for buying than engineers have. They understand the market better, and are generally more fitted to cope with the direction of work. G. H. Duggan.

Mr. W. Kennedy said contractor work such as the President has spoken of applied more to mechanical work and the repetition of the same kind of work. Organization was certainly a very great matter. It was one of the great points for an engineer to be able to organize well. He had lately been connected with the building of a large dam across the Winnipeg River, and the thought had come to him as to how that work would have been done if it had been let out by contract. In a case such as he had just mentioned, it was one of the principal points to get first-class foremen. If this was attended to, all would go well. In the particular case spoken of they had no mishaps, they had a splendid foreman, and the work went along smoothly. He had talked with contractors about the work, and from the prices which they gave he was sure they had saved at least 25 per cent. When he told these contractors the cost of the work, they said it was very low. They had no mishaps, they paid for no risks. If they had had a contractor he would have asked a considerable sum to cover risks. But organization is a very great matter, and from some little experience the speaker had had, he thought that very often engineers fail in not being able to select first-class men to carry on the work; and unless the foremen are given full control over their work they have very little opportunity for success. The prime object is to get a first-class foreman, and hold him responsible in the same way as an engineer is held responsible by the company which employs him. W. Kennedy.

The President. The President said he was speaking from his own experience, that if men have an interest in the work it is done better and more cheaply, His idea was that work should be sublet to more than one contractor. the engineer being the head in all cases. Where a man is given a whole contract there is always a tendency to endeavour to make up for loss by straining the measurements.

TRANSACTIONS CAN. SOC. C. E.
VOL. X PLATE 12.



FRONT VIEW SIBBALD DRESSER

Thursday, January 7th, 1897.

PROF. H. T. BOVEY, Vice-President, in the Chair.

Paper No. 118.

ON A NEW AND CHEAP METHOD OF DRESSING CAR WHEELS, AXLES, ETC., ETC.

By R. ATKINSON, M.CAN.SOC. C.E.

The art of dressing the harder kinds of metal, such as iron, in the cold state has within historic periods depended upon the grindstone, and it is not until comparatively recent years that other means have become known which reduce the length of time required by the expenditure of more power, or, in other words, since hand labour has been replaced by machinery.

The working of iron in the cold state by means of machinery to cut or dress it has largely supplemented the art of working hot iron for more than a century, and has been until late years the only known means except the grindstone for dressing or finishing iron and its various alloys. The greatest departure from the work of the grindstone was probably made by the introduction of the emery wheel, which differs from the grindstone in being revolved very rapidly, and there fore in doing more work in the same time, thereby replacing time be power; but, on the other hand, it is like the grindstone, in that it loses much more of its own substance than it removes from the material operated upon. A further advance was made in the art by the introduction of the blind saw for cross cutting bars of iron or steel, such as rails, etc., in the cold state. In its operation, the most notably feature is, that less of the operating material is displaced than is removed from the material operated upon, even though the latter is the harder substance. This may be looked upon as being, until recently, the latest form of the attempt to substitute power for time in the manipulation of cold iron or steel.

The author will, however, endeavour to give a description of what appears to be a further distinct advance, inasmuch as the effect is not only to remove more metal in a given time, but also to leave the surfaces so dressed in more perfect state than heretofore for the work they are intended to perform. This is accomplished by the Sibbald machine and process which was primarily intended for dressing journals or other forms of finished work. Such a machine has been built and operated in actual commercial form in the presence of some members of this Society, but it has been developed still further in England after more experience and with better source of power, under instructions from its present owners. The first occasion on which the writer had the pleasure of seeing the first crude machine in operation was in May, 1886, at the works of Mr. W. G. Miltimore at Arlington, Vt., when it was used to dress cast iron car wheels. A heavier and improved machine was afterwards built by Messrs. J. Laurie & Bro. of this city, under the direction of Mr. W. C. Farnam, and operated in a shed at the old Canadian Pacific Railway works at Hochelaga. In this case the source of power was not at all satisfactory, for when it is considered that from 100 H.P. to 200 H.P. are required, there is obvious necessity for both reliable and economical motive power.

A description of the machine may be given as follows. A ring about 33 inches diameter of mild steel (of about .65 per cent. carbon) is fixed like the tyre of a locomotive driving wheel on a suitable centre, which is mounted on a heavy shaft, and has its periphery turned to produce the proper profile on the wheel to be operated upon, and very carefully balanced. The disc thus formed is driven at a speed of about 3,000 revolutions per minute. The wheel is set in a suitable carrier and is revolved slowly, about two or three revolutions per minute, so that the surface when brought against the operating disc will move in an opposite direction. The wheel and disc are then pressed together with a force sufficient to cause friction enough to consume a great part of the power which is driving the disc, and thus convert the power into heat. The disc cuts or rubs off the metal of the wheel operated upon, and leaves a smooth finished surface, which by the pressure and heat is closed and hardened to a considerable degree and to a depth of 100th of an inch or more, depending on the grade of the steel worked upon.

The principal constructive feature in the machine itself is the manner in which the friction on the journals of the disc, which would result from the combined great pressure and high speed, is overcome by a system of forced lubrication, carried out by pumping oil into the bearings at the point of contact, thus causing the shaft to revolve upon a film of oil which flows out at the ends where it is collected by centrifugal force and returned to the pumps.

In the latest form of this machine as operated at the works of Messrs. Easton, Anderson & Goolden, Erith, Kent, it was found that by sending an electrical current through the point of contact of the fusing disc and wheel, so as to heat the wheel at that point, a very great reduction in the power could be made, or much more material removed by the same power in a given time. The following extract from a report made by that firm will explain this fully :

"The reason why the disc cuts metals harder and tougher than itself is apparent when the operation is analyzed. The mechanical equivalent of heat, as demonstrated by Dr. Joule and others, equals about 42 units of heat per horse power per minute, thus giving at the periphery of disc a heating effect directly in proportion to the horse power applied, as all the net power delivered to disc is converted into heat by frictional resistance and disturbance of metal under operation. As the power is consumed and the heat generated where the disturbance of metal under operation takes place, it follows that a greater part of the heat is generated in the metal being removed. The disc being kept cool by conduction and radiation into the atmosphere, or by application of water, its surface is not disturbed, and consequently very little heat is generated within the disc. The high velocity of the disc, viz., 33,000 feet per minute, requires only 1 lb. frictional resistance to the movement of the disc per horse power applied. Thus in the consumption of 100 horse power, 100 lbs. frictional resistance to the movement of the disc is given ; this distributed over the surface of contact between the metal under operation and disc, which exceeds one square inch at all times, is not sufficient to abrade or injure the surface of the disc. With 100 net horse power, we have a total heating capacity of 4,200 calorics or English units of heat per minute, equal to raising the temperature of 4,200 lbs. of water one degree Fahrenheit, and as the specific heat of steel is 0.12, it follows that this horse power will raise the temperature of 35,000 lbs. of steel one degree ; this equals 14 lbs. heated to 2,500 degrees, the temperature to which steel is heated in removal by this process. The percentage of the total heat equivalent to net power delivered to disc utilized in actual work is indicated in last column in accompanying report of test made at Erith Iron Works, April 6th, 1892."

"ELECTRICAL SUPPLEMENT.

"It is indicated by experiments at Erith Iron Works and elsewhere, that a greater heating efficiency can be got from the electrical current applied at points of contact between heating disc and object being dressed than from the power frictionally consumed, and that considerable saving can be made by applying a large percentage electrically, sufficient power only being applied to the disc to remove the metal heated by electrical current. The effect of the current is not destructive, owing to the distribution over its whole peripheral surface; and as current is passed through the heated spot in the metal under operation, where the greatest resistance takes place, owing to high temperature and small surface, we consume most of current within the body of the metal being removed, consequently the higher percentage of efficiency. The current applied in very small quantities appears to greatly increase the co-efficient of friction, and thus less friction between surfaces is required to consume the power and generate its equivalent in heat; consequently a gain is made in reduced frictional resistance throughout the journal bearings of machine, in addition to the heating effect of current.

"The gain in mileage life of car wheel tires hardened by this process over those in ordinary condition (as indicated by the greatly reduced wear of tires dressed by this process and the increased durability of chilled iron wheels over those of soft iron) must be great, and if the advantages of this process are fully utilized by re-dressing soon after the hardened surface is worn off, the mileage life of tires will be at least doubled. The cost of dressing when only sufficient metal is removed to reproduce the hardened surface will be considerably less than is shown in the report of tests made April 6th, 1892, at Erith Iron Works.

"In addition to the dressing of railway wheel tires, the process is particularly well suited to the finishing and hardening of journal surfaces in all classes of machinery where journals are subjected to considerable pressure and speed. The journals of railway axles are rendered very much more durable, and will give proportionately less trouble when dressed and hardened by this process. It is only necessary in dressing journals to remove a small amount of stock, $\frac{1}{32}$ being quite sufficient to harden surface, and this does not distort or spring the journal, as is the case where journals or spindles are case hardened or tempered throughout, although the surface produced by this process is much harder, more dense, and in every way more perfect than is possible to get from any other method of hardening. Milling rolls of suitable steel (which may be softly annealed if desired) may be dressed, and a surface produced much harder and more durable than that of chilled iron; rolls of chilled iron can also be most economically dressed by this process, when electrical current is used to increase friction and heat metal being removed. The expense of hardening journals by this process is slight, as very little metal is removed. The report of car wheel dresser trials, with and without the electrical current, is entirely based upon observations and data made by two competent experts, acting quite independently of each other in taking observations and indicator cards alternately throughout the trial. The reports from each expert were made independently, the result showing only a very slight percentage of difference between the two. The conclusions in foot note of report are entirely based upon actual results attained during these trials, and as a trial machine is very imperfect in many essential points, it is expected that a much higher percentage of efficiency can be attained with the proposed new machine, although this is not assumed or indicated in the report."

The report alluded to in the above extract was made by Mr. Dickinson, C.E., of Messrs. Easton & Anderson, and reads as per attached statement marked "B".

It may therefore be assumed, allowing for the difference in cost of labour, that 15 cents per wheel would be ample allowance even for removing the large amount of 16 pounds per wheel. This would give 60 wheels in a day of 10 hours. The output of an ordinary wheel lathe is from 1½ to 4 pairs per day, depending upon the work necessary and the build of the machine. The number of cast iron wheels which may be dressed per day is so variable that it is almost impossible to form an estimate of the average, depending as it does upon the condition of the wheel.

The great importance to railways of some means of dressing car wheels, both cast and wrought iron, at less expense than is now incurred, has been also shown in the following report by F. R. F. Brown, Esq., M.Inst. C.E., W. Laurie, Esq., M. Can. Soc. C. E., and the writer, marked "A."

Questions have often been asked as to whether any damage could result to the cast iron wheel, but the writer cannot say that there is any probability of damage occurring. These questions may be formulated as follows:—

(1) Does the pressure of the dressing disc against the wheel while being dressed have any detrimental effect upon the body of the wheel?

(2) Does the heat generated by dressing cause disintegration of the surface metal when cold, or do the chilled portions of cast iron wheels crack, shell out or separate from the grey portion, as a result of the operation of this machine?

(3) In the case of steel tires, will the film of metal which has apparently been fused separate from the wheel, *i.e.*, "peel off"?

The writer had occasion to inspect the pair of second hand cast iron wheels alluded to on page — which had been dressed to remove flat spots about 2 inches diameter, and after being replaced in service had been run 14,000 miles until worn through the clear chill, and began to show the mottled metal beneath, and were then still in good condition as to shape and surface.

From this inspection the writer would say as follows, viz.:—

(1) Since the pressure of the disc is less than the load when in service, and all the shocks of service are avoided, it is manifestly impossible for the pressure during the operation of dressing to be in any way detrimental to the body of the wheel.

(2) The wheels in service showed no defect or disintegration of the chill whatever, and are in no way to be distinguished from other wheels (not dressed) in any respect except superior form.

(3) The writer has not seen any steel tired wheels in service which had been dressed on this machine, but he is strongly of the opinion that not the slightest cracking or peeling off can possibly take place—in fact, he views it as utterly impossible, since he has had pieces broken out of steel tires repeatedly without any indication of such defect.

The economic value of this machine lies in substituting power for time, and the saving depends of course upon the cost of power. What this cost should be has been the subject of much discussion, but in the writer's opinion a well-designed steam plant in favourable locality should develop one horse power for a cost of one cent per hour.

APPENDIX A.

WHEEL DRESSING MACHINE. ITS ACTION AND ADVANTAGES.

(*Being a report by Messrs. F. R. F. Brown, R. Atkinson and W. H. Laurie.*)

INCREASED DURABILITY OF TIRE.

When an ordinary steel tired wheel is turned in a lathe, the effect of the tool is to break or open up the surface to a greater or less depth beyond the point of the cutting tool, the depth so disintegrated being very variable and depending upon the hardness of tire, shape and condition of cutting tool, and so on. The obvious result is that the surface of a turned tire is not solid material, but is more or less spongy, and must be hammered or rolled down to a smooth face when put into service by the effect of the load carried, consequently the actual useful diameter of a turned tire is appreciably less than the apparent diameter. On the other hand, the surface of a tire submitted to the process of dressing by fusing or grinding is as perfectly smooth as if it had rolled on the track for months, and its hardness is not approached by anything so nearly as by the process of case hardening, which is so well known as producing the most perfect surface to withstand friction.

The effect of this is to cause a corresponding increase in the mileage of the wheel before even the slightest signs of wear are to be detected, one pair of the wheels having shewn a record of 10,000 miles without perceptible wear, so far as any alteration of form of tread shewed.

The process of turning exaggerates the effect of any difference in hardness between two tires of wheels on the same axle, so that the softer tire rapidly becomes the smaller wheel, and causes tendency to "sharp-flange." On the other hand, the process of dressing by fusing puts an approximately equally hard and equally durable surface on both tires. When in the course of time the hard surface is worn through and the softer tire begins to get smaller and shews wear on the flange, the two wheels can be dressed and the action stopped. The dressing by fusing in this way makes tires of unequal hardness practically as good as those of equal hardness. When a steel tire is turned, its apparent diameter, as above shewn, is greater than its actual useful diameter by an amount varying with the amount of porosity or sponginess produced in turning, and which may be set down at $\frac{1}{32}''$ on the thickness of the tire. Some kinds of tool finish may produce less depth of porosity, but they require a greater thickness of steel to be turned off to produce their results. It is necessary also to cut below the lowest spot in order to make the tool stand. The depth necessary for this depends much on the hardness of the material, but in any case it may be taken at $\frac{1}{32}''$ below the lowest spot. When the wheel has made say 500 miles, and regained the hard surface with which it came into the shop, it will have lost another $\frac{1}{32}''$ or in all $\frac{1}{16}''$ due to the turning. It may be taken that a tire requires on the average not less than one turning for every quarter of an inch of its useful or wearable thickness, of which the above loss of $\frac{1}{16}''$ forms a part, and it therefore loses 25 p. c. of its useful thickness in turning only.

The operation of grinding or dressing by fusing avoids all this loss, since the fusing disc can be done so perfectly as to either leave a "witness" at the lowest spot of a skidded wheel, or to just take it out sufficiently to harden the surface at that point and make it to conform to the other portions of the wheel.

If we consider the effect of turning on the mileage, we may take as a basis that a 40″ tire would be reduced ¼″ per 40,000 miles run, which is an ordinary figure; and that if the tire is 2½″ thick when new, and rejected at 1¼″ thick, it would receive five turnings, or its life would be 200,000 miles. If these five operations were done by fusing there would be a saving of 25 per cent. of steel, or an increased life of 33 per cent., which would make the total mileage 266,000. The lowest estimate at which the effect of hardening the tread at these five fusings and hardenings could be placed would be to double the mileage which would therefore be 532,000 miles. And as the original basis of 40,000 miles per ¼″ wear includes all tires taken out for sharp flanging, which would be also largely obviated, a low estimate of the life of 40″ steel tire is that it would be raised to upwards of 600,000 miles.

The shape of the tire after being turned depends to some extent upon the care which the turner bestows upon it, and as usual the human factor succeeds in frequently introducing errors of greater or less extent which are not always found out till too late. In the fusing process the shape of the fusing disc itself determines the shape of the tread of the wheel, and gives no opportunity for errors. The machine also admits of being adjusted to give absolutely equal diameters in pairs of wheels on the same axle, and there can therefore be no loss from sharp flanges caused by unequal diameters of wheels. Any inclination to sharp-flange would at once shew the necessity of further examination, and would materially assist the supervision of the work.

PREVENTION OF SHARP FLANGES AND CONSEQUENT DANGER.

So long as a pair of wheels can be kept from running to one side, and sharp-flanging be prevented, they can cause no derailment; but if from any defect, either in the wheels themselves or in the truck or frame in which they run, one wheel of a pair commences to sharp flange, there is immediate danger of derailment, and, what is much worse, danger from the breaking of an axle, an occurrence which unfortunately is only too common.

This is due to the effect of excessive side pressure producing a bending moment in the axle, an effect which with due care may be very largely diminished, though not of course entirely overcome. When sharp flanging occurs to any extent, it is an imperative reason for wheels being taken out and turned afresh. From neglect of this an enormous loss in mileage arises, wheels having frequently to be turned $\frac{3}{16}''$ smaller in radius or thickness of tire merely to make a new but still defective flange. Wheels thus taken out and turned because of sharp flanges would probably have made a further mileage of 20,000 miles before requiring to be turned on account of wear of the tread as distinct from that of the flange.

This loss due to sharp flanging cannot be stopped by turning, because the cost for wheel turning plant and the loss of thickness in tires would be too great. On the other hand, sharp flanging would be almost unknown in wheels dressed by the fusing process. When it did occur it would be from a defective truck or other cause outside the wheels, and any damage sustained from it by the wheels could be remedied at the cost of a few cents and almost no loss of steel while they are out of the truck to allow of its being repaired.

REDUCTION OF WEAR AND TEAR OF CARS AND TRUCKS.

The great wear and tear on trucks, boxes, brasses, hangers, etc., due to wheels not running freely on the track, is something not generally realized. At least 10 per cent. of the bearings put in axle boxes are spoiled by end wear, which is principally due to wheels running to one side. Nothing will put a truck "out of square" more quickly than a pair of wheels forming a sharp flange, and then it follows that the other pair in the same truck will become sharp flanged too. And when one truck or a car is running badly, the effect of the pull of the other cars is to cause it to rebound from the side of track and to increase its side motion, and thus they react upon and damage each other.

The wear and tear on rails sideways must be at least equal to the wear on the flange of the tire, the rail being the softer metal, and thus the rail deteriorates rapidly. A wheel with a sharp flange is also very destructive to frogs and switches, and the other wheel of the pair is equally severe upon guard rails, while in turn tremendous shocks are given to the axle.

DECREASED COST OF HAULAGE.

It follows also that the cost of haulage is greatly increased by the friction thus induced. The difference in pull between a free running train in good shape and a hard pulling one in bad condition is evident, and very easily felt by those in charge. It may be fairly estimated that the increase in cost of fuel from such causes is not less and is often more than 10 per cent., and that the cost of repairs is increased in like proportion.

INCREASED COMFORT TO PASSENGERS.

The effect of wheels in bad condition is very irritating to some classes of passengers, and is more or less trying to all, and the opposite is quickly noted by them. With good wheels, windows, sashes and doors do not need to be made nearly tight to prevent rattling, and can be operated with comfort. The coaches lose a great portion of the unpleasant side swing with its consequent wear and tear, and faster time can be made This is a point of minor importance, but not to be disregarded.

COST OF DRESSING AS COMPARED WITH TURNING.

The operation of the machine at Hochelaga has shewn that with proper arrangements for power and handling, only two men will be required to work it. One man—the machine man—will operate the machine exactly as a lathe is operated,—that is, he will put in and take out wheels by the aid of a crane, and do the grinding. The other, the engineer, will stand by the engine, and assist in operating the crane when required.

The output of wheels would vary with the condition of the tread. From six pairs would be done in a day if the flanges are bad, and there is much, say $\frac{3}{16}''$ to be taken off, to probably 20 pairs would be turned out if the full benefit of not allowing the wheels to get into bad shape is thoroughly appreciated.

A good wheel lathe, such as commonly used in railway shops, will turn down an average of $1\frac{1}{4}$ pair of steel tired wheels per day of 10 hours, if not shewing more than $\frac{3}{8}''$ wear on the total diameter, that is not requiring a cut of over $\frac{3}{16}''$ to true them. The cost for wages, power, interest and other working expenses is about $2.05 per day, or about $1.64 per pair, two wheels being turned at once.

In dressing by fusing, Mr. Walter H. Laurie, M.E., calculates the cost of operating a wheel grinding machine at $12.00 per day of 10 hours, covering cost of power, wages of three men, interest and other working expenses. Such a machine would have a capacity, as before mentioned, of not less than six pairs of steel tired wheels in the worst condition that could be found in service, and 20 pairs slightly worn, or say 10 pairs of wheels per day of average bad wear. The maximum power required would not be over 120 H. P., and the average during the day not over 80 H. P. The cost per pair of 10 pairs would therefore be $1.20, and if 20 pairs, or, in other words, if the full benefit of early dressing by fusing were secured, it would be 60c per pair. The saving by dressing over turning is therefore about 27 p.c. on average wheels, and at least 50 p.c. on those requiring less work.

CAST IRON WHEELS.

The dressing of chilled cast iron wheels is also successfully and economically done by the fusing process, the power required being much less than for steel tired wheels. The time required is of course as variable as for steel tires, but much shorter in all cases. The dressing of new wheels not on axles could be done almost as fast as they could be put in the machine, if no more were done than is done by the emery grinding processes in use; that is, to just clean the face of the tread for a width of about 3″ not more than five minutes actual grinding time per pair would be required for two wheels mounted on a double self-centering chuck. This grinding of wheels separately, however, does not obviate the trouble of "mating" them when required for use, nor does it ensure that the wheel shall be true with the axle when put on. The greatest benefit of dressing can only be derived when wheels can be put on their own axles and turned out in first class condition for service. All the arguments in favour of dressing wheels before the defects which arise in service, such as sharp flanges, skidded spots, shelling out, etc., can do any serious damage, apply to the care of cast iron wheels quite as forcibly as to steel tired wheels. As an instance, it has been found that a pair of well worn wheels rejected for flat spots actually made 14,000 miles after grinding, and were still in fair order.

SUMMARY.

The advantages to be gained by the use of the wheel dressing machine are therefore briefly as follows:

1. Steel tires would be increased about 33 per cent.

2. Increased safety to passengers and rolling stock by prevention of bad flanges.

3. Reduced wear and tear on rolling stock and on rails by keeping of wheels in perfect condition.

4. Locomotive expenses will be reduced by the easier haul of good wheels.

5. Increased comfort to passengers.

6. The cost of dressing steel tires is 27 to 50 per cent. less than turning them.

7. The benefits in dressing cast iron wheels are nearly as great as in steel tired ones.

APPENDIX B.

THE FRICTIONAL AND ELECTRICAL PROCESS FOR SHAPING, HARDENING AND FINISHING METALLIC SURFACES, AS APPLIED IN THE SIBBALD RAILWAY WHEEL DRESSING MACHINE.

In this process a revolving steel disc designed to stand high centrifugal strains is given a peripheral velocity of say 33,000 feet per minute, against which the carriage wheel or other object to be dressed is slowly revolved, enough pressure being applied to cause frictional resistance sufficient to consume power transmitted to the disc, and convert it into heat. The disc cuts or rubs off the heated metal, leaving a smooth hard surface. The hardening effect depends upon the percentage of carbon in metal being worked, and the manner of handling during operation, varying with these conditions from $\frac{1}{100}''$ to $\frac{1}{16}''$ in depth.

It has long been known that a rapidly revolving disc of soft iron would heat and cut its way through iron and steel without injury to itself; little practical use was made of this principle, however, although in use to some extent, for cutting railway rails, tubing, and merchant bars, and other special purposes.

The reason why the disc cuts metal harder and tougher than itself is apparent when the operation is analysed. The mechanical equivalent of heat as demonstrated by Dr. Joule and others equals about 42 units of heat per horse power per minute, thus giving at the periphery of disc a heating effect directly in proportion to the horse power applied, as all the net power delivered to disc is converted into heat by frictional resistance and disturbance of metal under operation. As the power is consumed and the heat generated where the disturbance of metal under operation takes place, it follows that a greater part of the heat is generated in the metal being removed. The disc being kept cool by conduction and radiation into the atmosphere, or by application of water, its surface is not disturbed, and consequently very little heat is generated within the disc.

The high velocity of the disc, viz., 33,000 feet per minute, requires only 1 lb. frictional resistance to the movement of the disc per horse power applied. Thus in the consumption of 100 horse power, 100 lbs. frictional resistance to the movement of the disc is given. This distributed over the surface of contact between the metal under operation and disc, which exceeds one square inch at all times, is not sufficient to abrade or injure the surface of the disc. With 100 net horse power, we have a total heating capacity of 4,200 calorics or English units of heat per minute, equal to raising the temperature of 4,200 lbs. of water one degree Fahrenheit, and as the specific heat of steel is 0.12, it follows that this horse power will raise the temperature of 35,000 lbs. of steel one degree ; this equals 14 lbs. heated to 2,500 degrees, the temperature to which steel is heated in removal by this process.

The percentage of the total heat, equivalent to net power delivered to disc, utilized in actual work, is indicated in last column in accompanying report of test made at Erith Iron Works, April 6th, 1892.

ELECTRICAL SUPPLEMENT.

It is indicated by experiments at Erith Iron Works and elsewhere, that a greater heating efficiency can be got from the electrical current applied at points of contact between heating disc and object being dressed, than from the power frictionally consumed, and that considerable saving can be made by applying a large percentage of the power electrically, sufficient power only being applied to the disc to remove the metal heated by the electrical current. The effect of the current upon disc is not destructive owing to the distribution over its whole peripheral surface, and as current is passed through the heated spot in the metal under operation, where the greatest resistance takes place owing to high temperature and small surface, we consume most of the current within the body of the metal being removed, consequently the higher percentage of efficiency. The current applied in very small quantities appears to greatly increase the co-efficient of friction, and thus less pressure between surfaces is required to consume the power and generate its equivalent in heat ; consequently a gain is made in reduced frictional resistance throughout the journal bearings of machine, in addition to the heating effect of current.

The gain in mileage life of car wheel tires hardened by this process over those in ordinary condition (as indicated by the greatly reduced wear of tires dressed by this process and the increased durability of chilled iron wheels over those of soft iron) must be great, and if the advantages of this process are fully utilized by redressing soon after the hardened surface is worn off, the mileage life of tires will be at least doubled. The cost of dressing when only sufficient metal is removed to reproduce the hardened surface will be considerably less than is shown in the report of tests made April 6th, 1892, at Erith Iron Works.

In addition to the dressing of railway wheel tires, the process is peculiarly well suited to the finishing and hardening of journal surfaces in all classes of machinery where journals are subjected to considerable pressure and speed. The journals of railway axles are rendered very much more durable, and will give proportionately less trouble when dressed and hardened by this process.

It is only necessary in dressing journals to remove a small amount of stock, $\frac{1}{32}''$ being quite sufficient to harden surface, and this does not distort or spring the journal, as is the case where journals or spindles are case hardened or tempered throughout, although the surface produced by this process is much harder, more dense, and in every way more perfect than is possible to get from any other method of hardening. Milling rolls of suitable steel (which may be softly annealed if desired) may be dressed, and a surface produced much harder and more durable than that of chilled iron ; rolls of chilled iron can also be most economically dressed by this process, when electrical current is used to increase friction, and heat metal being removed. The expense of hardening journals by this process is slight, as very little metal is removed.

The report of car wheel dresser trials, with and without the electrical current, is entirely based upon observations and data made by two competent experts, acting quite independently of each other in taking observations, and indicator cards alternately throughout the trial. The reports from each expert were made independently, the result showing only a very slight percentage of difference between the two. The conclusions in foot note of report are entirely based upon actual results attained during these trials ; and as a trial machine is very imperfect in many essential points, it is expected that a much higher percentage of efficiency can be attained with the proposed new machine, although this is not assumed or indicated in the report.

RESULTS OF CAR WHEEL DRESSER TRIALS WITH AND WITHOUT THE ELECTRICAL CURRENT AT ERITH IRON WORKS, ERITH, KENT, 6TH APRIL, 1892.

Condition of Trial.	I. H. P.		Reduction in Net I.H.P. over mean of Nos. 5 & 6, by using Electrical Current.	Steel removed per 100 I.H.P. per minute.		Efficiency of Machine. See Note.	Remarks.
	Total.	Net including 2 E.H.P. for Current.		cubic ins.	lbs.		
Engine only....	27.56			Nil	Nil		3168 revs. per min.
Engine driving discs	67.36			Nil	Nil		3276 " " " running light.
With current.	104.86	39.5	21 p.ct.	10.92	3	21 4 p.c	3150 " " " } cut ⅛" deep traverse 3" per min. diameter of wheel, 36".
Ditto	110.66	45.35	13 p.ct.	9.35	2 61	18.6 p.c	3123 " " " } cut ⅛" deep traverse 3" per min. diameter of wheel, 36".
Without current......... / Ditto	Mean 119.57	52.21		8.11	2.27	16. 2 p.c	3141 " " " / 3132 " " " } same feed as in 3 & 4

NOTE.—The efficiency of the machine indicates the percentage of work equivalent to the heat generated at disc to the net horse power delivered to the disc.

With proposed new machine and engine indicating 166 H.P. = say 100 I.H.P. net, 6 wheels per hour could be dressed, removing 16 lbs from each. Allowing 40 per cent. of total time for handling wheels, etc., the mean I.H.P. with machine at constant work being 125, and the estimated cost per wheel, including 1½ lbs. coal per I.H.P. per hour, fireman 25s, machine attendant 35s per week each, and interest and depreciation on plant of £90 per annum, b.ing 5¼d per wheel.

DISCUSSION.

Professor J. T. Nicolson

Professor Nicolson considered the method a most interesting one, not only from a practical, but even more so from a theoretical point of view. He had been much surprised to find from the experiments recorded in the paper, which were no doubt reliable as having been made at the Erith works, that it was found economical to obtain the required temperature electrically, rather than by the direct process of friction.

It had seemed to him unlikely that the roundabout process of obtaining heat by converting the mechanical energy into electric energy en route could be less wasteful than the method of direct friction. The laws of friction, so far as they were known, seemed to him, however, to afford a clue to the explanation.

It was known from the experiments of Kirchweger, of Bochet, and of Galton on the friction of brake-blocks on tires, of tires on rails, and of "sledged tires" on rails, that the co-efficient of friction diminished as the velocity of the rubbing surfaces increased, according to a formula somewhat as follows:

$$\mu = \frac{C}{v + K}$$

where μ is the co-efficient of friction, v is the speed in feet per sec., K is constant depending on the materials. C is another constant depending on the pressure between the rubbing surfaces.

For a steel tire on a steel rail under ordinary loading C would be about 5 and k about 22, so that μ would vary continuously from about $\frac{1}{4}$ for rest, to about $\frac{1}{25}$ for a speed of 60 miles an hour of the rubbing surfaces.

The heat generated in this wheel dressing machine by the agency of which it is enabled to do its work of abrasion of the surfaces of the tire, is proportional to the work wasted in friction per sec. (if no electric current is used). This work is proportional to the mutual pressure between the grinder and the tire, to the co-efficient of friction of their surfaces (at that pressure, temperature and speed) and to the speed itself. We have, however, seen above, that as the speed increases the co-efficient of friction diminishes, so that a much larger mutual pressure must be exerted between the grinder and the tire to produce the same waste of work in friction (that is heat) per revolution of the grinding disc at high speeds than at low speeds.

As this large force reacts on all the bearings, it is obvious that the loss by increased friction of these bearings will soon become so important an item of lost work as to permit the application of the electric current as an economical alternative, in spite of the loss due to transformation of energy.

The speaker asked for further information as to the practical method of applying the current, and as to the rationale of the hardening effect produced on the dressed surface (even when previously of chilled cast iron). He suggested that this hardening was due to the very rapid cooling of the white hot film of surface metal by the cool mass of metal behind it.

He would like to know what colour effects were observed on steel tires after the process. He considered this method superior from every point of view to the old wheel lathe.

Mr. Wallis had on several occasions tested cast car wheels both old and new, which had been dressed by the Miltimore process. During 1887 trials were made under his direction upon the Grand Trunk Railway with the object of determining to what extent the lives of worn car wheels could be prolonged by the application to them of the dressing process described by the author. Ten old wheels from various foundries were submitted to trial in passenger train service, and under brake vans of freight trains. Of these wheels, eight, of which six were removed from baggage cars and two from brake vans, ran till worn through the chills, the other two being discarded for other defects. The average additional mileage obtained from the eight wheels was 6,931 each, which would probably be 12 per cent. more than the miles obtained before dressing. An examination of wheels removed from axles during five days at the Montreal wheel press showed that out of 276 wheels $12\frac{3}{4}$ per cent. could apparently be dressed to advantage. Mr. H. Wallis.

Assuming the value of a cast wheel, less that of the old material, to be $3.50, the prospective gain was therefore only 42 cents, while the estimated cost of dressing (which included the inventor's royalty) at the time the test was made was $1.00 per wheel. The essential features in the manufacture of cast-iron wheels to be subjected to this process would necessarily be depth and uniformity of chill, and in such case no doubt better mileage results might be obtained.

He was quite in accord with the views expressed by the author, that something more expeditious is required for turning tires than the ordinary wheel lathe, and that the process of grinding is preferable to that of cutting. He was not so clear, although it ought to be the case with steel tires, that there is any advantage in wear derivable from grinding the chill of cast-iron wheels; indeed his past experience failed to show any, but it is apparent that the nearer the approach to circumferential accuracy or true circularity, the less will be the wear and tear both of road and rolling stock, and to this extent, at any rate, the application of the process would undoubtedly be beneficial.

Mr. Peterson. Mr. Peterson, Past President, in closing the discussion said:—

The Society is very much indebted to Mr. Atkinson for his paper on the "Sibbald wheel dressing machine," and for shewing as he has in it, and the attached appendices, the great saving that may be made by the use of this method of dressing car wheels.

When the machine was being tried in the Canadian Pacific Railway shops at Hochelaga, he had a great many opportunities of seeing it in operation, and of examining the work performed by it, and was very much surprised and pleased to find that a machine had been invented that would do away with the old crude method of dressing wheels by tearing off the old surface and leaving the new surface which had been followed by Mechanical Engineers for so many years—a method so expensive that in most instances wheels were allowed to become grooved to such an extent that they wore out the rails and did a vast amount of injury to frogs and crossings.

The study which he had made of the machine and its work at the time, led him to the conclusion that the dressing of the wheels could be done for very much less than half the cost at which it could be done by the best lathes; that the life of the wheels would be increased at least 25 per cent., and that the life of the rails, frogs, etc., would be very much lengthened if this machine were brought into general use, inasmuch as wheels could be so cheaply and quickly dressed that there would be no excuse left for the Mechanical or Car Department to allow wheels to run that were not in perfect order.

He believed that, putting aside the economy in the cost of wheel dressing and the economy gained in the longer life of the wheel, the increased life of the rails, frogs, etc., which would be given to them by the wheels being kept in perfect order, would amount to, at least, one per cent. a year on their value; and one per cent. on the value of the rails, frogs, etc., now in use on the Canadian Railways at the rate of $20 per ton of rails amounts to $330,042.00 per annum, or $21.12 per mile of railway.

He was aware of the difficulties in the way of getting anything new like this introduced upon a railway; but, judging from what he had heard expressed by the leading Mechanical Engineers of the country, he felt confident that a committee of them would unanimously declare in favor of the adoption of this system of dressing wheels; and he was quite sure that a committee of the Engineers engaged upon the maintenance of way would unanimously report in favor of the adoption of a system of wheel-dressing that would enable the Mechanical Department to keep its wheels in better order, so as to avoid the wear and tear the rails are subject to from grooves and imperfect wheels. This is a matter of so much importance, in connection with the working of railways, that he thought the Society should appoint a Committee of Mechanical Engineers, and of Engineers employed in connection with the maintenance of way, to report upon the benefits that would accrue to railways arising from wheels being kept in perfect order at a reasonable price such as would be easily attainable were this machine generally adopted. He felt confident that such a Committee would report that the benefits to be derived from such a condition of wheels would be so great that it would lead to the general adoption of the "Sibbald" Machine.

In conclusion, he regretted that, while Mr. Wallis had fully discussed the dressing of cast iron wheels, he had said nothing whatever regarding the dressing of steel wheels. This is very much to be regretted, as his opinion upon this subject would be a very valuable addition to the discussion.

OBITUARY.

William Haskins.—William Haskins, City Engineer and Manager of the Hamilton Water Works, died at Hamilton, July 5th, 1896. He was born at Coolkeno Hall, County Wicklow, Ireland, on May 29th, 1828, and was educated at Dublin, where he studied the profession of Civil Engineering at Trinity College under Sir John MacNiel. Coming to Canada in 1852, he obtained a position as Assistant Engineer on the survey and construction of the Great Western Railway, and in 1856 was appointed City Engineer of Hamilton, which position he held until his death. In 1860 he was appointed to the charge of the Hamilton Water Works. In this capacity he was not only Manager of the engineering, construction, and operation of the Works, but for many years was also financial agent, having full charge of the collection of water rates, etc.

Mr. Haskins was a member of the Institution of Civil Engineers, an Ontario Land Surveyor. He was elected a member of the Canadian Society of Civil Engineers in 1891, and served on the Council in 1894.

Job Abbott.—Job Abbott was born at Andover, Mass., August 23rd, 1845. He attended the district schools and Phillips' Academy before entering Harvard University, where he studied engineering in the Lawrence Scientific School. After graduating in 1864, he was connected for a time with the Manchester Locomotive Works, but his active engineering work began when he was appointed Assistant Engineer on the Glen Cove branch of the Long Island Railroad. At the termination of this engagement he went to the Pittsburgh, Fort Wayne, and Chicago Railway, where he became interested in the city of Canton, O., a large part of which he laid out. In Canton he had an office as Civil and Mining Engineer and patent expert, from 1866 to 1872, during which time he studied Law and was admitted to the Ohio bar.

While practising patent law in Canton he was retained on certain matters by the Wrought Iron Bridge Company, and became so interested in these affairs that he dropped his legal practice to take up engineering again. He was Vice President and Chief Engineer of the Wrought Iron Bridge Company from 1872 to 1880 and remained a Director until his death. During this time he built some bridges in Canada, and, believing the Canadian business to have a bright future, he helped to organize the Toronto Bridge Company, of which he was President and Chief Engineer from 1880 to 1884. The business in Toronto soon outgrew the capacity of the shops there and Mr. Abbott accordingly organized the Dominion Bridge Company of Montreal, of which he was President and Chief Engineer from 1884 to 1888, and President until 1890. The shops of both these companies were designed, erected and equipped under his direction, and in connection with them he built some of the largest bridges in Canada, notably the Lachine Bridge for the Canadian Pacific Railway over the St. Lawrence River.

In 1889 he gave up his Montreal office in order to remove to New York, where he established an office as consulting engineer, which he maintained until April, 1896.

In 1889 and 1890 he designed and had charge of the Ohio River Bridge at Wheeling, West Virginia, and was appointed Chief Engineer of the Wheeling Bridge and Terminal Railway Company. The work done by this Company was very heavy, the bridge alone being a double track structure 2,097 ft. long with a 525 ft. channel span.

After the completion of the Wheeling Works, Mr. Abbott was retained as Consulting Engineer for the Bangor and Aroostook Railroad in Maine, the longest line built in New England since the Central Massachussetts was finished. While engaged in Maine his health failed and he returned to Andover, where he died on Tuesday, August 18th, 1896.

Mr. Abbott was a member of the American Society of Civil Engineers, and was elected a member of the Canadian Society of Civil Engineers on January 20th, 1887.

HENRY G. C. KETCHUM.—Henry George Clopper Ketchum was born at Fredericton, N.B., on February 26th, 1839. He was educated at the Collegiate Grammar School under the late Dr. George Roberts, M.A. He studied Engineering at the King's College University, and obtained the first diploma issued by that Institution in Civil Engineering. He subsequently passed an examination as Deputy Land Surveyor for the Government of New Brunswick. After this he spent some time in the study of Telegraph operating, which was then in its infancy in Canada, and he was one of the first to read messages transmitted by sound instead of by the "tape" then in vogue. In 1856 he received the appointment of "axe-man" under Mr. H. F. Perley, who was at the time Resident Engineer of the European and North American Railway. On the purchase of this road by the New Brunswick Government, Mr. A. L. Light was appointed its Chief Engineer, and he constituted Mr. Ketchum his Chief Draughtsman and afterwards his Chief Assistant Engineer on the road from St. John to Shediac. When this work was finished Mr. Ketchum was offered an appointment in the Empire of Brazil on the celebrated Railroad of San Palo. During this time he assisted in the construction of the famous Mogy Inclines, the large Mogy Viaduct, and the Cachoeira tunnel.

Leaving Brazil in 1865 Mr. Ketchum was offered a lucrative position in India under Mr. Berkley, afterward President of the Institute of Civil Engineers, but he refused it in order to return to Canada to conduct Surveys for the Moncton and Truro (afterwards the Intercolonial) Railway in New Brunswick. He was afterwards appointed the agent of the International Contract Company of London, to construct a Railway in New Brunswick. This Company failed and liquidators were appointed, under whom Mr. Ketchum retained his position and subsequently became the Contractor for the completion of the road on his own estimate, made as engineer.

Mr. Ketchum's name as an Engineer will, however, be chiefly associated with the great project for a Ship Railway over the Isthmus of Chignecto, which, in so far as its engineering features are concerned, he demonstrated to be entirely practicable, and financial difficulty only intervened to prevent the completion of the work.

He was associated in the work of the Chignecto Ship Railway with Sir John Fowler and Sir Benjamin Baker. Mr. Ketchum undertook this work only after years of careful investigation and having made surveys in connection with it at his own expense. A full description of the work will be found in the Transactions of this Society for 1892, Vol. V. Part II.

Mr. Ketchum was a member of the Institution of Civil Engineers. He was elected a member of the Canadian Society of Civil Engineers on Oct. 20th, 1887, and served as a Member of Council in the years 1890 and 1892.

He was awarded the Gzowski gold medal for his paper on the Chignecto Ship Railway in 1891.

JAMES R. PEDDER.—Mr. Pedder was a resident of Doone, Ont., where he was born on June 5th, 1868. After having passed through the Berlin High School, he attended the School of Practical Science in Toronto and graduated in the course of Civil Engineering in 1891. In 1892 he obtained a diploma as Ontario Land Surveyor. During his professional life he was chiefly engaged in Sewerage and Water Works and in Land and Railroad Surveying. In 1895 he was elected Provisional Director of the Grand Valley Railroad. In the autumn of 1895, while engaged on a survey of this road, he contracted a severe cold which confined him to the house during the remainder of the winter. The following summer his health was somewhat restored, but with the return of colder weather he gradually lost strength and died on 17th Jan., 1897.

Mr. Pedder was elected student of this Society in 1889 and associate member in 1894.

MR. N. J. GIROUX.—Mr. N. J. Giroux, late of the Geological Survey Department, Ottawa, died at his father's residence, River Beaudette, on Dec. 1st, 1896, after a short illness. Mr. Giroux was born at River Beaudette on Oct. 22nd, 1859, and after a course in L'Ecole Polytechnique, Montreal, graduated from that institution with distinction, taking the gold medal for his year. He was subsequently attached to one of the Dominion Lands and Survey parties in the Northwest Territories, and, on his return, was employed as assistant engineer on the Grenville Canal works.

In 1883 he was attached to Geological Survey Staff as assistant to Dr. Ells, and with him spent several years in Gaspé, Nova Scotia, New Brunswick and Prince Edward Island, and afterwards, till 1890, was assistant in the Survey of the Eastern Townships of Quebec. In 1891 he took charge of the work to the north of the St. Lawrence in the vicinity of the Upper St. Maurice River, where he spent three years in the preparation of the geological map of that region ; and then began the detailed examination of the area between the lower Ottawa and the St. Lawrence, in the study of the lower Palæozoic formations, which he continued for two years or to the time of his death. In all his work Mr. Giroux was exceedingly painstaking, always striving to secure the most accurate results possible, and his latest field of work was of very great geological interest. It is to be regretted that he was not spared to give to the public the results of his most recent investigations. Mr. Giroux became a fellow of the Geological Society of America in 1889. His published works appear principally in the summary reports of the Geological Survey Department from 1891 to 1896; but in addition to this he prepared two other interesting papers, one of which on "The Serpentines of Canada" was published in the Ottawa Naturalist for 1890-91, while the other on the "progress of Metallurgy in Canada" has not yet been published. Mr. Giroux was a diligent student and had laid broad and deep the foundations of a useful scientific career, and among his comrades in the Geological Survey he was always held in high esteem, both for his many excellent personal qualities as also for his scientific attainments. Mr. Giroux was elected an associate member of this Society, June 25th, 1887.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

H. S. GREENWOOD............Box 365, Peterboro, Ont....Dec 17th, 1896.
HY. O'SULLIVAN..............Indian Lorette, P.Q.......Dec. 17th, 1896.
J. BONSALL PORTER, PH.D....McGill University, Montreal. Dec. 17th, 1896.
W. F. TYE... ....C. & N. Ry. Rossland, B.C. Dec. 17th, 1896.
J. W. TYRRELL......... ....42 James St., Hamilton, Ont................Dec. 17th, 1896.
GEO. WHITE-FRASER..........18 Imperial Bldg., Toronto. Dec. 17th, 1896

ASSOCIATE MEMBERS.

S. J. CHAPLEAU........, ... 267 O'Connor St., Ottawa..Dec. 17th, 1896.
A. R. DAVIS........... ......Peterboro, Ont............Dec. 17th, 1896.
A. T. GENEST................79 Mackay St., Montreal...Dec. 17th, 1896.
H. T. HAZEN.................C. N. P. Ry., Coburg, Ont. Dec. 17th, 1896.
F. E. SIMONDS...............Portage La Prairie, Man...Dec. 17th, 1896.
H. W. UMNEY................McGill University, Montreal. Dec. 17th, 1896.
JOHN WOODMAN...............Winnipeg, Man...........Dec. 17th, 1896.

ASSOCIATES.

T. H. JONES............. ....65 Front St., Toronto.....Dec. 17th, 1896.
F. NICHOLLS........... ......65 Front St., Toronto.....Dec. 17th, 1896.

STUDENTS.

DAVID BOWMAN...............Berlin, Ont...............Dec. 17th, 1896.
E. F. T. HANDY........ ......Emsdale, Ont.............Dec. 17th, 1896.
W. P. MORRISON........ ......Box 338, Halifax, N.S.....Dec. 17th, 1896.

TRANSFERRED FROM CLASS OF ASSOCIATE MEMBER TO CLASS OF MEMBER.

H. J. BOWMAN..................Berlin, Ont..........Dec. 17th, 1896.
H. D. ELLIS.....................Toronto, Ont........Dec. 17th, 1896.
R. McCOLL.......................Halifax, N.S.........Dec. 17th, 1896.

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