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ELECTRICAL SECTION.

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Telephone Line Engineering.*

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The purpose of all applications of electricity, excepting those of industrial chemistry, is warranted, because it overcomes the impediments of distance.

The amount of capital invested in electric lines, and the rapid depreciation to which they are subjected, renders their construction a matter of importance.

Methods of standard aerial and underground-line construction were shown, and also numerous views showing the methods of overcoming the difficulties through mountains, over rivers, spanning gorges and the savannahs in the southern part of the country.

The growth of the Bell Telephone System has progressed at the annual rate of 29 per cent. compound interest during the past five years, which is over three times the rate of increase during the preceding fifteen years.

The cause of this augmented growth was stated to have been the increased value of the telephone service resulting from the construction of long lines connecting even villages and small towns, as well as cities, in one intercommunicating system, which afforded facilities for that conference which is the fundamental element in commercial transactions.—THE EDITOR.

The wonders of the telephone as the most subtle of physical apparatus, yet so simple as to be the only electric

* Illustrated by lantern slides showing methods of telephone line overhead and underground construction.

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device operated without skill, an invention without precedent which has also escaped improvement, has worthily been the theme of frequent portrayal, which has also been devoted to that concentration of applied science upon the switch-board and the transmitter, each of them essential adjuncts in the development of the telephone system.

The salient characteristic which justifies all commercial applications of electricity, except those of industrial chemistry, is that it overcomes the impediment of distance, and it is essential that the conductors spanning these long extents, free from direct supervision, shall be as permanent as possible in order to maintain conditions of constant service.

The amount of capital amassed in the approximately 4,000,000 miles of line construction necessary to connect together in a unity the subscribers of the Bell telephone system is of itself a warranty as to the importance of the subject; while the rapid depreciation to which most of this property is subjected requires both technical skill and business judgment to decide upon the most judicious methods of construction of this vast plant, amid varying circumstances of natural conditions and commercial use, in order to reach the most economical point of investment.

Analyze the general problem as one may, and standardize the general methods to cover a wide range of circumstances, yet there are exigencies and varying conditions which require the exercise of that type of constructive engineering which "does things."

"The picture is first rate, but we built the bridge last night," said the Maine lumberman in the army to his West Point commander.

The application of mathematical principles is essential to any constructive work which is not merely a repetition of precedents, and the ordinary precedents of safe construction have been established upon the wrecks of past failures perhaps for generations ago.

In this paper it is proposed to submit largely by lantern slides some of the engineering difficulties which have been met in line construction and the manner in which these ob-

stacles have been overcome, as well as ordinary methods of standard construction.

The electrical problems form a subject apart from that of this paper.

The increase of every commercial application of electricity to meet the demands to supply service to patrons has been so great that an essential portion of every problem in constructive electricity must take into consideration provisions for future growth as well as the inevitable depreciation.

POLES.

Although 45 per cent. of the wires are on poles, the total extent of the pole lines exceeds the length of the underground conduits, as the latter are used only in cities where the conduits contain a greater number of lines to reach the concentration of patronage.

The extent of the pole lines is shown by the fact that in the Bell telephone system there are approximately 6,300,000 poles, and about 1,000,000 are required annually for replacement and for extension of lines.

A number of years ago a large collection of logs, known as the Joggins raft, was towed from Nova Scotia to New York, and this raft contained many long poles which were not suitable for masts.

Some of these long poles were used for the largest pole line ever built, at the westerly side of New York City, and carrying 250 wires each. At the present time there are single underground cables comprised of $4\frac{8}{10}$ times as many conductors, and under the main streets in the principal cities are conduits of sufficient capacity to carry 400 times as many wires as one of these pole lines.

The typical methods of setting poles will first be shown by some representations from standard drawings.

Where the soil is not firm enough to sustain a pole imbedded in the usual manner, security may be obtained by extending the supporting area by plank at the bottom of the excavation and filling the hole with concrete, or braces may rest upon a platform placed on the surface of the

ground, and in some instances these platforms rest upon piles.

In other instances these braces rest upon plank placed underground, or, in place of a single pole, they are set in pairs, either vertical or joined at the top and connected by strong wire at the ground, making what is known as an A pole.

When the line changes its direction or there are other causes to make a lateral pressure against a pole, it is secured by braces or by guys, either running to an anchorage in the earth or to some other object.

When a telephone line is built in or near cities, the close connection with supplies and labor renders that portion of the work comparatively easy, but in the construction of long distance lines across country, connecting various cities, towns and villages within speaking distance of each other, it is necessary to provide means for the execution of the work on an independent basis.

In a suitable locality a camp consisting of a number of tents is pitched, one of them being a dining tent; another is where the cook holds sway, and the engineers' tent, where such details as must be left until the work is in progress receive attention, while several tents are necessary to provide for the sound sleep which awaits the close of a good day's work.

If the route runs through a wooded country, a wide swath is cut in the forest and the post holes may be made by the diggers, or in other instances a charge of dynamite deposited in an auger hole makes quick work, the greatest relative gain being in compact clayey soil.

Meantime the poles have been brought to their sites by teams, and then moved to the exact place by the help of an axle mounted on a pair of wheels termed a dinkey; gains are cut and the cross-arms attached before they are raised, either by all hands with pikes giving a long push, a strong push and a hard push all-together, to change the old aphorism, or if the country is not too rough to permit, a portable derrick mounted on a wagon is drawn to the site, then the horses are taken from the pole and pulling at the rope quickly raise the pole.

Then the derrick wagon is drawn to the next pole and the work proceeds rapidly.

When the line changes in direction, the pole is rendered more secure by guys and the pole line is ready for the wires which are payed out from a number of reels in a wagon, thence passing through a set of guiding holes, which prevent snarling.

The final attachment of the wires to the insulators on the cross-arms is very carefully done, because it is necessary that the wires should be drawn to an extent that they should not sway against each other, and yet not so tightly that the contraction in cold weather would put a stress on the wire which would produce danger of breakage, for at these small amounts of dip in the wires a slight difference in the length of the line will cause a great variation in the stress.

The stresses to which a telephone pole is subject are the result of many and variable combinations of live and dead loads upon a beam fixed at one end and loaded near the other end.

There is scarcely anything in engineering construction so actively the subject of depreciating conditions.

The top is exposed to the weather, and the important section near the surface of the ground is the portion most energetically attacked by decay. The wood is assailed by animal life, whether it be gnawing by horses in town, or the perforation by woodpeckers in remote districts. Poles in wild countries are bitten by bears in search of bees, whose humming is imitated by the vibration of wires, and it is said that in India the tigers use the poles to sharpen their claws upon after the manner of their second cousin, the domestic cat, but with so much more vigor that the poles become weakened.

Not only are they wrecked by storms, but freight-car roofs frequently fly off and strike the poles edgewise with destructive results.

Iron poles are but rarely used in this country, the principal condition governing their selection being on some lines in prairie countries in the West where campers are so prone

to cut down wood poles for fuel, that tubular iron poles have been substituted. In Europe there are many iron poles, and in tropical countries infested with white ants it is necessary to use iron poles or to attach the wires to living trees.

In the Philippines the United States authorities are planting large straight trees to serve as living attachments for telephone lines, as seasoned wood poles decay quickly under the conditions of tropical moisture.

Antiseptic methods for treating poles as a preventive against decay and the attacks of insects have not been so general in the United States as in Europe, as the relatively sparse settlement and distances between cities having the elaborate plant necessary for treatment would make the transportation of the poles for treatment and back to the sites where they are to be used a prohibitive expense.

However, poles treated by creosoting have been used in this country wherever transportation conditions between the saw mill, the treating plant and the sites where they are to be used will permit.

These conditions apply to certain portions of the South, where Southern pine is sawed to dimensions and then treated.

As the cost of this treatment is based on the volume of the timber, these poles are sawed to such proportions of taper as to give the most economical volume of timber to resist the stresses to which the pole may be subjected. The weakest section of these poles, as computed, is from 8 to 10 feet above the ground.

While gravelly soil will hold a pole to the limit of its strength, it is necessary to build lines in many places where such conditions do not occur. The New Orleans and Mobile line, along the north shore of the Gulf of Mexico, traverses marshes composed of soft mud which extends to a great depth, upon which a rank sedge grass grows 12 to 15 feet in height, whose coarse roots form a compact mass about a foot in thickness.

In order to prevent this line from being injured by the fires which rage among these marshes in the early spring, the grass is kept cut to a width of 100 feet along the route.

It has been possible to sustain poles along this route by bolting heavy cross-pieces across them at the ground level, having cut an opening among the roots through which the butt of the pole can be inserted, and then the pole is braced as occasion may require, sometimes in four directions, each of these braces being supported on a cross-piece at the marsh level. In some instances a pair of, or even three, poles are used, each being attached to the same cross-arm.

Similar methods are used in building the lines across the New Jersey flats, although the conditions are not so severe as at some places farther south.

At the Tybee marshes, near Savannah, Ga., the ground is so soft that it cannot be walked upon, and the men engaged in building the line were obliged to lay a line of boards to proceed along the route. When a pole was to be set, cross-pieces were temporarily attached to it near the lower end, and men standing upon these supports "jounced" in unison while the pole was held vertically by pikes.

Under this human pile-driving the pole sinks rapidly, but the mud is so adhesive that in a short time the pole is securely held.

When ground is too wet and soft to permit digging, poles are frequently set by hewing their butts to wedges, and while the pole is held in a vertical position it is grasped by cant hooks and twisted back and forth, causing it to sink, like the ordinary motion used in boring a hole in wood with a brad awl.

When once set, the pole is either held securely by braces or guys, or it may be made firm by driving a wood curb around it, excavating the mud between the curb and the base of the pole and filling the space with concrete.

In sandy soils, particularly in New Jersey, poles are set on the principle of the jet pile, wherever there is a supply of water.

A half inch pipe about 6 feet in length is temporarily attached to the side of the pole, with its lower end at the butt. The other end of the pipe is attached to a garden hose, and when the pole is up-ended the stream of water makes a quicksand into which the pole sinks until the water is shut

off, and the pole is sustained by pikes until the water settles, leaving the pole securely held by the sand, which becomes water-packed around it.

In mountainous countries the ledges are an impediment to excavations for poles, and although dynamite is frequently used, yet poles are set upon rock without excavation and a large number of stones are piled around them in such quantities as to grip the poles securely, although guys are generally necessary.

A pole line is not designed merely on the basis of the stresses to which the pole is subjected in drawing the wires to the necessary tension, for in most northern climates the sleet will at times form upon the wires until they become icy cylinders perhaps 3 inches in diameter, and the problem is not that of the mere added weight, for the force of the wind blowing against this icy sail applies a greater horizontal load, which combines with gravity and produces a resultant force in a diagonal direction, greater than either of the contributing units.

An ice-laden line swayed by the wind may be successfully resisted by the poles until the oscillations of the pendulum reach a synchronism with that of the vibration of some pole on the line which responds in like manner to the rhythm of the consecutive blows across the direction of the line, until the cumulative impact breaks this individual pole. Then adjacent poles are relieved of the pull on one side, and the excessive unbalanced stress breaks them.

Such is the story of a wrecked aerial line, broken by stresses not included in the ordinary course of events, and which must be provided for by large factors of safety.

It is indeed fortunate that meteorological conditions furnishing in sequence rain at just above a freezing temperature, and meeting a colder stratum, without wind, near to the earth, but followed by a gale, are rare and generally are limited to a small area, for they present conditions which cannot be fully circumvented.

Officers of the Weather Bureau reported in connection with a sleet storm of unusual severity, that there had not been similar conditions in that locality for twenty-three years.

The breakages of lines resulting from a severe storm in Southern New England, a few years ago, revealed the fact that the damage was confined to the valleys of the rivers emptying into Long Island Sound, while the storm did not appear to be of sufficient severity to cause any damage to the lines on higher land.

It is claimed that sleet never forms to a destructive extent on the wires in certain portions of the northerly part of the United States, and this may be one of the instances of the rarity of such occurrences.

A pole is not to be compared to a mast upon a vessel, for these extreme conditions of severe exposure to telephone lines occur in winter, when the ground is frozen, and holds the base of the pole rigidly, while a vessel in a gale heels when struck by puffs and the sails "spill the wind," and in this manner the masts sustain exposure to winds which would break them if held rigidly to long-continued impact.

PREVENTION OF CROSSES.

The most undesirable occurrences in connection with the wreckage of aerial lines are the disturbances resulting from the contacts of different electrical systems with each other, when the various lines are so near as to collide, when one or both break.

While the currents used on the telephone system are so minute as to be without power of damage, yet their wires, in crossing the lines of electric lighting or power systems, may in making short circuits cause serious mishaps to the electric lighting or power plant, and in any event materially interfere with the service.

While the imposition of an electric lighting or power current upon a telephone line would destroy the fine apparatus, and perhaps cause other injuries, were it not for the protectors for the purpose of preventing these foreign currents from reaching the subscribers' installations, or the telephone central stations.

It is far better to prevent the occurrence of harmful conditions than it is to abate their injurious results by a temporary sacrifice of the continuity of the service, for the

operation of a protector serves to open the telephone circuit and to prevent the use of the instruments for the time being, until the lines are cleared and the protectors renewed.

The remedy against the liability of such crosses is the simple one stated by a judge of a United States court, in which the decree was given that the distance between the high and low potential lines should be equal to that of the highest pole, so that in the event of the falling of a pole the wires would come short of reaching the other line. In many instances congestion of electric service and narrow streets prevent any such wide separation, and it becomes necessary to take every precaution for substantial construction.

It is necessary for such different lines to cross the others' routes, and in such instances provision against collision is made by the use of extra heavy construction, thoroughly bracing and guying the poles, and arranging against overhauling of the lines in case of their breakage; also guarding the wires so that those on the upper line could not fall over the ends of the cross-arms in case of their separation from the points of support.

As high-tension wires are of larger diameter and fewer in number, their poles should be higher at the crossover.

The crossover span should be so short and at such height that in case of breaking next to an insulator, the remaining portion of the span wire should not be long enough to reach to the lower line.

The necessary height of poles, or the impracticability of placing them in such positions as to provide for the short crossover spans, may sometimes render it unfeasible to adopt this construction, and a grill of hard-wood slats placed at frequent intervals across a pair of steel wires or cables between the two spans interposes a screen which prevents a broken wire on the upper span from reaching the lower span.

In some instances, where there are but few wires in each line, they are attached to the same pole, and the contact is prevented by a frame-work carrying guard wires below the upper line.

It is not as a general principle advisable to use a single pole crossover.

House tops at the first furnished an attractive route for aerial wires, and some of the fixtures for carrying these wires were of great size, but the framing of most buildings is ill-suited to resist the excessive stresses due to such loads, and the introduction of underground conduits has furnished suitable means for such main conductors, but it is necessary to carry branch wires over the tops of houses in order to reach patrons to whom the wires cannot be led in any other manner.

In place of the old timber constructions, suitable iron pipe frameworks are now generally used.

Other continuous structures are used for conveying large numbers of wires, especially bridges and the elevated railways in cities.

AERIAL WIRES.

The aerial wires are so visibly in evidence, and often to an obstructive extent, that they may be cited as the portion of the system which naturally receives especial attention from the public.

Before presenting instances of construction, it is worth while to submit two matters of principles of aerial lines and materials.

The tension on a line suspended between a pair of horizontal supports varies with the sag and is at a minimum when the sag amounts to $\frac{7}{20}$ of the span, and the tension increases whether the sag is greater or less than this proportion.

For example, with No. 12 hard-drawn copper wire, weighing 173 pounds to the mile, and being .104 inches diameter, and having a span of 130 feet, the minimum tension of 3 pounds would occur if the sag was 43 feet 6 inches, while it would slowly augment with increase in the sag, and if nature had furnished a chasm deep enough for the experiment, it would be expected to reach its breaking tension of 550 pounds at a depth of 16,470 feet, or 3.17 miles.

On the other hand, the increase in tension proceeds rap-

idly as the wire is drawn to approach a straight line, the breaking tension occurring at a sag of $1\frac{1}{2}$ inches.

As a comparison with this instance of the stresses in a local line, in the case of the No. 8 hard drawn copper wire, .165 inch in diameter and weighing 435 pounds to the mile, as used on long-distance telephone lines, when the span is 150 feet the minimum tension occurs at a dip of 52 feet 6 inches, when it is only $8\frac{3}{4}$ pounds, and in like manner, as in the foregoing instance, its breaking stress of 1,328 pounds would be reached at the slightly less dip of 16,100 feet, or 3.04 miles, still too great to admit of confirmation by direct experiment; but if the wire was pulled until the sag was $2\frac{3}{10}$ inches, it would require the breaking load of 1,328 pounds.

It is desirable that the wires should be drawn tight enough to prevent them from swaying against each other; but it is important that they should not be drawn so tight that the contraction during extreme cold weather should cause the wire to break.

The temperature is carefully noted when lines are being drawn, and the sag is left in accordance with a table based on a factor of safety of five computed for the usual lengths of span throughout a range of natural temperatures.

Natural Temperature Fahrenheit.	Length of Span of Hard-Drawn Copper Wire in Feet.					
	75	100	115	130	150	200
Sag in Inches.						
— 30	1	2	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{2}$	8
— 20	$1\frac{1}{2}$	$2\frac{1}{2}$	3	4	5	9
+ 10	$1\frac{1}{2}$	3	$3\frac{1}{2}$	$4\frac{1}{2}$	6	$10\frac{1}{2}$
+ 30	2	3	4	$5\frac{1}{2}$	7	12
+ 60	$2\frac{1}{2}$	$4\frac{1}{2}$	$5\frac{1}{2}$	7	9	$15\frac{1}{2}$
+ 80	3	$5\frac{1}{2}$	7	$8\frac{1}{2}$	$11\frac{1}{2}$	19
+ 100	$4\frac{1}{2}$	7	9	11	14	$22\frac{1}{2}$

When a wire is laden with sleet, the strain lengthens the wire and the increased sag diminishes the tension some-

times to an extent sufficient to save the wires, which would otherwise be broken were it not for this elongation.

HARD-DRAWN COPPER WIRE.

The electrical advantages of copper over iron could not be utilized for aerial wires, because commercial copper has so little resilience that it will continually stretch under its own weight and become attenuated to an extent that it will break, until Thomas B. Doolittle produced the hard-drawn copper wire which is now in universal use on aerial lines. The treatment consists in omitting the annealing processes during the latter portion of drawing the wire, but it deviates from the usual method by attenuating the wire by smaller gradations at the latter die plates. The rate of diminishing the wire is wholly an empirical one, at first determined by long and thorough experimentation, and as the hardening occurs for the most part near to the surface, the tensile strength per square inch of section is greater with smaller than with larger wires.

For example, No. 8 wire is .165 inch diameter and has a tensile strength of 62,100 pounds to the square inch, while No. 12 wire, .104 inch diameter, has a tensile strength of 64,600 pounds to the square inch.

In comparison with commercial copper wire, which has a tensile strength of about 32,000 pounds per square inch, the strength is nearly doubled. The modulus of elasticity is increased from 12,000,000 pounds to 19,000,000 pounds, or about 60 per cent., while the elongation before rupture is reduced from 35 per cent. to $1\frac{1}{4}$ per cent.

It will be noted that this remarkable change in the mechanical properties of copper wire is produced entirely by manipulation and without the admixture of any alloy.

Its electrical conductivity is practically the same as that of commercial wire drawn from the same ingots, the slight increase being due to the change in the molecular condition of hard copper.

Mr. Doolittle did not patent this valuable process of the manufacture of hard copper, which has extended the limit of electrical transmission of speech four times the distance

available with iron wire, and has been of incomparable value in other electrical service, and the award to him of the Edward Longstreth Medal by the Franklin Institute in 1898 was an act of most suitable recognition of an invention which has been usefully applied to the service of mankind throughout the world wherever electric wires are spanned.

The relative cost of iron and copper wire is not a measure of the comparable expense of such lines in actual service, as copper does not have, under these conditions of exposure, an oxide of high resistance, and its life has not yet been determined. The value of copper scrap from wrecked or reconstructed lines is about 2 cents a pound less than that of new wire, while galvanized iron line wire costs about 4 cents a pound, and when taken down is of no value, and is generally thrown upon a dump.

The rusting of iron wire at the joints adds materially to the resistance of the line.

A few years ago an iron telephone line crossing swamps near Norfolk, Va., was reported open after a thunder storm, but an inspection showed that there was no break in the continuity of the wires; however, electrical tests revealed that the joints insulated the various sections of the wires from each other, the strokes of lightning having produced oxides of high resistance.

LONG SPANS.

Where lines traverse mountainous districts or water courses it is frequently necessary to build spans of great length, using either one of the special bronzes or steel wire for the purpose.

The Connecticut River at Middletown is crossed by wires having a span of 1,350 feet, suspended between a steel-trussed tower 185 feet high on the east side, and a similar tower on the bluff on the west bank is 85 feet high.

From Enfield to Windsor locks the Connecticut is spanned by a suspension bridge consisting of two steel cables 1 inch in diameter and 955 feet long, to which are fastened 2-inch by 3-inch joists 4 feet 4 inches long set 12

inches on centers. On this bridge are laid four cables containing 100 pairs of wires. The tower on the west bank shown in the foreground is 45 feet high, and the one on the east bank 33 feet high.

The St. Francis River, near Madison, Ark., is crossed by a span of 1,000 feet, with the wires supported upon steel-trussed towers 100 feet in height, as it was necessary that the wires should be clear of steamers on the river, which has a varying level of 30 feet between flood and drought.

At the Raritan Canal crossing, near New Brunswick, N. J., a 60-foot span is raised 112 feet above the canal to avoid the shipping.

There are numerous long spans crossing ponds and rivers not used for navigation at which it is not necessary to erect such high towers or to draw the wires up to a small dip to avoid masts.

Long spans are frequently strung in cases of emergency, as when the flood of June 2, 1903, carried away the bridge crossing the Kaw River at Kansas City, Mo., and also the wires attached to it, a span of wires 900 feet in length was immediately suspended between high spars erected on either bank.

The Missouri River at this city is crossed by a span of 1,500 feet, consisting of fifty No. 8 bronze wires suspended between steel-trussed windmill towers 80 feet in height.

The Delaware River at Yardley, Pa., is crossed by an aerial span of 1,300 feet in length with a dip of 10 feet. In all instances, it is necessary to use great care in the anchorage of these long spans, for a rigid attachment would cause the wires to become broken when swayed by the wind.

In some instances it has proved sufficient to carry the wires through semicircular grooves cut into a curved wood saddle upon each of the towers at the ends of the span, but the recurrence of breakages has been stopped in other cases only by attaching the saddles to springs which will yield to the impact resulting from swaying wires.

The very long spans constructed across the Mississippi, Hudson and Susquehanna Rivers have been advantageously replaced by submarine cables.

The most spectacular work in line construction has been done among the mountain ranges of the West.

Lines have been built against the face of cliffs bordering deep canyons, where it was necessary to incline the poles so that the tops carrying the wires overhang the deep abyss, in order to avoid icicles and avalanches falling down the precipice.

In building telephone lines through this mountainous country, a couple of poles are slung like panniers on the sides of two or three mules tandem, and these sure-footed animals will carry them along the rough trails.

The wire is wound in great lengths in connecting coils, which are placed on the sides of the saddles of a train of pack mules, which are thus connected on one side by wire from coil to coil, around the front of the foremost mule and thence back along the other side of the train.

By removing the last pair of coils and unreeling, and thence in turn to the next coil, the pair of wires for a metallic circuit can be laid down along a route.

The Mosquito Pass, near Leadville, Colo., was crossed at an elevation of 13,130 feet by a line of poles which were set only 15 feet apart at the more exposed places, but even this construction did not resist the storms of winter.

Telephone lines were afterwards maintained through this Alpine exposure by an expedient as far out of the ordinary as the celebrated venture of Lord Timothy Dexter in sending warming-pans to the West Indies, and that was by replacing the line of poles by submarine cable carried to this elevated site in continuous coils, as in the case of wire transportation over the mountain trails upon a train of mules, and laid in trenches among the rocks to avoid any disturbances from avalanches.

There have been instances when it was necessary to make expeditions to these altitudes in severe weather to made repairs.

The rough valleys through which the routes pass are picturesque in summer, but in winter the snow accumulates to such depths that linemen attend to their duties on snowshoes, reaching the lines on 25-foot poles as if they were wire fences.

Among these mountains are ravines which can be crossed only by long spans, where the difficulties are increased by the inclination between the opposite ends of the span, which produces severe end thrusts at the points of support, which are built of three poles capped by cross-beams, which must be held by the most secure guying.

A few of these spans will illustrate the conditions necessary to be overcome in order to extend the telephone to these isolated mountain towns, at all times difficult of access, and during the long winter a hermitage were it not for this telephone service.

Imogene Basin, Col., at an elevation of 13,700 feet, is crossed by a span of 950 feet, which inclines at an angle of 27° . Near Telluride and the Tomboy mines, ravines are crossed by similar long spans.

A surveying party, arranging for the extension of some of these lines, found the snow to be 20 feet deep in these basins in the middle of July, while avalanches had rolled down opposite sides of a valley, leaving a narrow pass bordered by snow and ice 100 feet in height.

These lines, running from the valleys up to great elevations on the mountains, are charged with atmospheric electricity, particularly in winter, which is discharged to earth by bridging retardation coils across the lines and grounding the central part of the coils.

The surveying party noted that these disruptive discharges of static electricity occurred about sixteen times a second, producing a continuous sound which could be heard by one near to the wires. The mountain appeared to be enveloped by static electricity, the poles and the engineers' transit glowed with St. Elmo's fire, and an irritation was felt at the head, and the hair would fly up if the hat was removed.

This electric envelope did not appear to extend to the ground, as one was entirely free from any sensations when lying down, but if, while in such a position, a hand was raised to about 3 feet above the ground, a sharp sputtering sound of static electrical discharges would occur.

IMPEDIMENTS TO WIRES.

Trees are a serious impediment to wires, and although it is at times feasible to arrange for a severe trimming, yet for the most part such excisions must be made in moderation and the lines arranged to go over or under, or, like the priest and the Levite, "pass by on the other side."

At one of the electric light conventions, a speaker was asked what method was used by his company for trimming obstructive branches, and he replied: "For the most part the electrical method."

While a high-tension circuit, carrying sufficient current, will burn its way through a branch of a living tree, yet the self-interest of all electrical companies, without regard to other important considerations, impel them to the utmost care in avoiding trees.

Considerable damage is done to electric lines by trees felled during gales, and at St. Louis, May 27, 1896, and also at Minneapolis, August 20, 1904, tin roofs have been bodily stripped from buildings and placed upon the telephone wires, the metal contacts connecting various telephone lines causing confused jabber at any listening telephone unequalled since the days of Babel.

Telephone lines are patrolled by inspectors alert to observe incipient conditions of weakness, threatening decay of poles, trees growing too near approach to the lines, possible hazards to the service from other electrical wires, and especially in cases of severe storms is the utmost vigilance necessary to take prompt measures in case of any occurrence which will prevent the subscriber, perhaps a thousand miles away, from having the conference which he has the right to expect when he takes the telephone from the hook.

Useful as the telephone may be in affording facilities for communicating between different portions of a city, there are other methods of reaching one's townspeople—messenger, mail, or, like the leader in a child's game, "send myself;" but there is no equivalent for the question and the answer which can be exchanged between persons 1,500 miles apart, their voices reaching each other in less time than if they were conversing across a room; or, to give a

concrete example, the time for telephonic transmission over the 1,064 miles between Boston and Chicago is .006 second, while the distance that the voice is transmitted through the air in that time is $6\frac{1}{2}$ feet.

There are many thousands of miles of telephone lines without poles, for the business of lumbering and the wood-pulp industry is conducted over telephone lines traversing the forests from tree to tree through the wilds.

By the use of the telephone the methods of log-driving have been changed for the better. The facility of communication between different gangs along a stream enables the logs to be conveyed without the disturbances caused by jams, which can be prevented by prompt action, and also avoids the destruction of timber, which would otherwise result from the use of dynamite to relieve these jams.

Smaller and more rapid streams, hitherto unsuited for lumbering, have been utilized by the construction of dams, which husband and release the water as may be considered necessary by the men perhaps miles below, who speak through the telephone to those operating the gate at the dam.

The first telephone line of anything beyond a local line was in a wild country, for during the winter of 1878 telephones were used on the telegraph line connecting the signal service observers at the station on the summit of Mount Washington, N. H., to the base, while the first telephone central station with subscribers, in the present sense of the term, was opened at New Haven, Conn., January 28, 1878, although switchboards were used by associated groups of a few persons prior to that date.

One of the most useful applications of the telephone is in connection with the life-saving service, whose telephone lines extend along the shore, and the patrolman carries a small portable telephone which he can connect at fixtures upon the side of frequent poles, and in this manner communicate to the life-saving station for routine report and to summon help in case a vessel is in peril off the shore.

A telephone is a portion of the elaborate system of police signal in cities, while in smaller towns the simpler form of a telephone in a box serves the purpose.

For the household it bestows an assurance of safety in the facility which it gives to all, the opportunity to summon the fire department or other help in case of emergency.

UNDERGROUND CONDUITS.

The number of wires necessary to supply the patronage in cities so far exceeded the possible capacity of pole lines along the streets that it became necessary to place them underground, and this required the development of the underground conduit and the telephone cable as new arts.

While 55 per cent. of the telephone exchange wires are underground, yet the great number of wires in these conduits in comparison with those on poles makes the number of miles of pole lines throughout the country seventy times the length of the streets occupied by underground conduits.

While no other ratio may give an adequate impression of the predominant use of the telephone for communication over long distances, yet in comparison with the length of steam railroad rights of way in the United States, the length of Bell telephone pole lines exceeds that of the railway system by over 26 per cent.

The first experimenters upon underground systems attempted to make them water-tight, and also insulators, such as a solid mass of asphalt concrete in which wires, frequently without insulation, were imbedded.

The lack of satisfactory results caused the Bell Telephone Company to begin the development of the work under Mr. Joseph P. Davis, Chief Engineer, on the principle of providing a conduit of substantial construction containing ducts in which the cables could be placed or withdrawn, and relying upon the conduit merely to provide a protection against injury.

A conduit was built in Boston in which the ducts consisted of 3-inch iron casing pipes, treated by the hot coal tar process to defend against rusting, which were imbedded in a concrete of eight parts of fine roofing pebbles to only one of cement, and this has remained in good order for twenty-two years.

The manholes were made of brick, covered on the out-

side with coal tar, and the foundations laid on plank covered with coal tar before the bricks were laid.

This construction was afterwards used in New York, but there was not a sufficient supply of iron casing pipe in the market to supply the demand, and as it was necessary that the work should proceed as rapidly as possible, other materials for ducts were also used.

Logs were bored from end to end and then squared parallel to this core, and sockets and plugs to fit cut at alternate ends to bring the cores securely in line. The wood was treated by the creosoting process before the logs were laid.

Cement-lined sheet-iron pipe imbedded in concrete was also used in large quantities.

At a later date vitrified clay conduit was introduced, and has been extensively used.

Other materials and methods have been used, notably wood pulp tubes treated with indurating materials to render them impervious to water and a defence against decay.

Tunnels for underground cables have been dug through the soft limestone underlying the city of St. Paul, and one of the largest engineering works of the day is the extensive system of tunnels under the streets of Chicago, which has provision for cables as well as the transportation of material.

In rare instances short tunnels are built, as under the canal and railroad at Trenton, N. J.

In addition to the usual difficulties which beset all constructions under highways, the size of the manholes or underground chambers which afford places for splicing cables or changing their direction, as well as leading them from the conduits to centers of distribution, where the individual pairs of wires branch to the service of patrons, the size of these manholes render other occupants under the streets serious obstructions.

When underground conduits were first built in an Eastern city, the engineer prepared sets of standard drawings, and so many were the modifications rendered necessary by other underground work that only one manhole was built in conformity to the standard design.

A conduit 260 feet long, containing 13 ducts, at Seventeenth Street and Allegheny Avenue, Philadelphia, was successfully lowered 12 inches at one end and 18 inches at the other, on account of a change in the street grade.

When large underground work, such as subways, are built in cities, the changes in conduits as well as lines of pipes and sewers present difficulties of which it can only be said in the present available limits, that the changes were made.

While a trench was being dug for an underground conduit in Rochester, an unexpected ledge was uncovered, there were no facilities for that work at hand, and a steam roller was hired to supply steam for the drills, and the ledge was soon blasted away.

Underground conduits have wrought a great change in the housing of the telephone central station plant, as the rigidity of an underground system requires that the distributing centers should be of equivalent permanency, and the telephone plant could not in such cases be subject to the mutations of leased property, but must own the buildings.

Therefore fireproof buildings have been constructed by telephone companies all over the country, until the Bell Telephone system owns the greatest number of fireproof buildings of any single interest in the country, and its holdings of buildings and land in cities make it a vast realty enterprise.

If the underground conduits remove conductors from vicissitudes of decay of poles, and exposure to storm and the hazards of foreign currents, yet the underground conduits have their share of mishaps.

Breaks in water pipes or sewers disturb the foundations of these conduits, rain storms flood them, illuminating gas percolates into them, waiting to be ignited by a spark from a horse's shoe at some leak around a manhole cover, or it may be lighted by men going to work in a manhole with a lantern looking for trouble—and finding it.

The superficially attractive proposition of joint conduit systems, particularly in connection with a scheme of muni-

icipal conduits for electric wires, has been attended by serious occurrences.

Crosses among high tension conductors in cables occur from time to time, and if the wires of signalling systems were exposed in the narrow limits of a manhole, they would be disabled.

In one city where an inclusive conduit was laid by the municipality, the work was fortunately in good hands, and the manholes were built very large, with the cables of various classes placed on supports upon opposite sides of the manholes, and the cables containing high tension wires enveloped with split underground tile conduit tied together.

The attempt of a municipality to force a Bell Telephone Company into an inclusive underground conduit system under circumstances which were considered to expose their cables to hazardous conditions, gave rise to litigation in which the contentions of the Telephone Company were fully sustained by the Supreme Court of that State.

CABLES.

The necessity for cables was coincident with the decision that underground conduits must be constructed on the "drawing-in" and not on the "built-in" system, and at about the same time it was foreseen that aërial cables must replace the open wiring in cities wherever there were a great number of local wires, on account of their compactness, and greater resistance to storms. For electrical reasons, it is necessary that open wiring must be used for long telephone lines.

The first telephone cables, both aërial and submarine, are believed to have been those used at Philadelphia in 1881, and at that time experimental constructions were being made at Providence, Brooklyn and Boston.

In the latter city parallel rubber-covered wires, giving conditions of such great electrostatic capacity that a mile was the utmost limit of telephonic transmission, were tried, but when about a third of a mile was inserted in a telephone line, subscribers complained that their instruments were becoming worn out, as they could barely hear; and the in-

duction between the parallel wires was so great as to transmit cross-talk between the various circuits.

The induction was stopped by placing the wires in twisted pairs, but the problem of insulation with a low static capacity required long experimentation by many persons. Mr. W. D. Sargent, of Brooklyn, tried paper insulation and found that the static capacity was reduced and the transmission correspondingly improved, which Mr. T. D. Lockwood found to be due to the occluded air among the loosely twisted fibrous paper, and not to the paper as an insulating material.

Mr. John A. Barrett, of New York, was intimately engaged upon experimentation and manufacture of cables, and to him are due many improvements in cable design.

At this time Mr. W. R. Patterson, now of Chicago, was working along independent lines, and made a form of hydraulic press for drawing on the lead cable sheath, which is still in use as the standard method of manufacture, although many changes of detail in the conductors have been introduced, with the result of improving telephonic transmission to over five times that of the first cables using twisted pairs.

The drawing in of underground cables is like the traction of locomotives, an instance of the occurrence of the unexpected. They can be drawn through devious ducts, around turns and across manholes, to an extent which was not anticipated. The early cables were wound with steel wire twisted on a long pitch to carry the stress of drawing in the cable.

Experiments on one drawn through an irregular conduit showed that the pull was about 20 tons, but such severe treatment is now avoided as unnecessary.

The cables are usually drawn in by man-power, either direct or applied to hand winches, but of late mechanical power has been applied to this work. Automobiles have been used for this work, but a cheaper and more efficient means has been reached by a 7-horse-power gasoline engine on a platform wagon, which also carries a winch.

In advance of a cable, the ducts must be first traversed

by a wire to draw the cable, and the forerunner of this wire is either a number of wood rods hooked together and pushed along as section by section is added, and when the length to the next manhole is completed, a strong wire is attached to the last rod, and as the first rod is pushed into the next manhole it is inserted in the corresponding duct on the other side of the manhole and pushed and pulled along, or if it is at the end of the cable run, the rods are pulled along and disjointed section by section.

A fine wire is sometimes drawn through a duct by a conical piece of wood with a thin leather washer filling the duct, and forced ahead by the air pressure at the rear, which is exerted through the application of an air pump at the front end of the duct at the next manhole.

This piece of wood is termed the "mouse," and the name is probably responsible for the persistent story that lines are first drawn through the conduits by a fine string tied to the tail of a tame rat who has been taught to do this work.

Cables are applied for miscellaneous other uses outside of conduits wherever the lines need protection against water, moisture or accidental violence. They are used for submarine lines at bridge draws and river crossings, where they appear to be the especial targets for fouling anchors and snarling propellers. The cables across the Mississippi at New Orleans become overlaid by the soft viscous mud of the river, which is so tenacious that it is impossible to pull them up again.

They are applied in tunnel work and in mining, and have even been led to a stranded steamship.

At Honolulu there are especial facilities for laying temporary cables to vessel anchored in the harbor, furnishing them with telephone service when in port.

In all United States seaports, vessels moored to wharves can promptly obtain temporary telephone service, for which wires already are placed upon the wharves ready to be extended to telephones to be installed in the cabin.

The subscribers are reached from underground cables by leading the cable through a pipe from the manhole, thence

turning upward at the side of a pole, near the top of which the cables terminate in a cable box and the wires are separated into their several pairs, distributing to their respective instruments, generally by twisted pairs hung upon poles in rear alleys or attached close to buildings to avoid articles falling from windows or ice from roof cornices.

An entire underground system by which these laterals enter a basement, and thence by inside conductors extend through a building or perhaps an entire block is rare, except in the congested portion of large cities, where the number of patrons is sufficient to require the wires of a cable, and even then it is not always feasible to obtain permission from the several owners to make holes through division walls or to place in a building other wires than those used for the service of the occupants.

The modern office buildings are provided with channels in the walls for telephone wires, and also parallel grooves under the floors in multiples of 3 feet from the front side of rooms, so that wires can be run from the wire entrance of the building up through the floors to positions convenient to reach desk telephones, for as the telephone connections are made in less time than any other service, such as passenger elevators in buildings, or attention by salespeople in stores, so it takes too much time for the average business man to step to the telephone many times a day, and the electrical mountain must go to the commercial Mahomet, by placing the telephone on his desk.

These laterals and distributing pipes conveying the cables branching from the main system are sources of trouble in cold climates, for water penetrates them, usually by backing up from a flooded manhole, and by freezing in the space between the pipe and the cables, crush them until the insulation becomes impaired.

The former course required the expensive method of using a portable steam boiler, generally a city fire engine, to blow in steam from twelve to thirty-six hours to melt the ice, and then cut out the cable, which must be replaced by another one.

The Chicago Telephone Company equipped a wagon with

step-down transformers and conductors, which could be attached to the electric light wires and furnish a current of 700 amperes at a low voltage.

The secondary wires from this wagon were attached by long clamps to the cable sheath at the distributing pole and at the manhole to furnish a current which warms the cable, and in a few minutes the melted ice runs into the manhole.

In some places, where there are not any electric lighting wires within an available distance, an automobile boiler is used to give a supply of steam, at far less cost than a steam fire engine, for which the hire is \$5 an hour.

The cable is not disturbed, as it has been found that, although the ice pressure may have collapsed the cable to an extent sufficient to short circuit the conductors, yet the elasticity of the paper insulation is such that in a short time the insulation will be restored.

The damage by freezing does not take place in the horizontal pottery laterals of 3-inch sewer pipe leading from the manholes, but occurs in the iron pipe which comes down the side of the distributing pole and connects to this pottery pipe by an elbow of 3 feet radius and a straight run of 12 feet to the sewer pipe. It is proposed in the future to use sewer pipe runs and elbows.

Although lead-covered underground cables entering buildings or kept in storage are frequently gnawed by rats, who receive a swift retribution in case of cables containing high-tension circuits, yet aerial cables have of late received the attacks of insects which cut through the lead sheaths with their sharp mandibles for the purpose of laying eggs in the interior.

In China and Japan such perforations occur near the bamboo thickets, where an insect which lays its eggs in the bamboo stalks abounds.

This difficulty is met by wrapping such cables with burlap soaked in linseed oil.

In Australia similar difficulties have occurred over a wide expanse of territory, where it has been found that four species of beetles have in this manner perforated lead cable sheaths.

In Texas perforations are quite frequent, but it has not been found what insect produces these holes.

THE RATE OF TELEPHONE DEVELOPMENT.

It has been the endeavor to submit, as far as facilities for illustration provide, some of the obstacles presented by natural conditions to the construction and maintenance of telephone lines, in order to secure an appreciation of the engineering skill which has overcome these obstacles to the extension of telephone service which now knits together in one system over 26,000 different settlements throughout this country.

The establishment of this vast plant from small beginnings was attended for some years with a rate of increase which may appear slow in the light of later events, until the full development of long line service unified the whole into one connecting system, the value of whose service is far in excess of what could have been derived from isolated plants in separated towns.

These wider facilities endowed the telephone service with a higher value whose worth was appreciated, and the installation of telephones became stimulated to such a degree as to tax the resources of the various departments engaged on the work.

During the last five years the number of telephones in the system has increased at over three times the rate during the fifteen preceding years. This increase has been building upon itself like compound interest at the usurious rate of 29 per cent. a year, and compounding each year at this rate would double the number in $2\frac{3}{4}$ years, or the number of telephones has actually increased over $3\frac{1}{2}$ times during the last five years.

Each of these instruments, as soon as installed, comes into full service for connection with other instruments, and thus reciprocally each new telephone adds to the availability and therefore the value of those with which it may be in communication.

During this last five years these additions of 29 per cent. a year have required corresponding amounts for the enor-

mous increase in construction of new plant, which is entirely separate from the maintenance and repairs of the existing property.

Truly the fabric of mental fleece,
Resembles a weaver's masterpiece,
Where a thousand threads one treadle throws,
Where fly the shuttles hither and thither,
Unseen the threads are knit together,
And an infinite combination grows.

GOETHE—FAUST, Sc. IV.

DISCUSSION.

MR. W. C. L. EGLIN.—The section is to be congratulated in having this subject of "Telephone Line Engineering" so ably and beautifully presented this evening. To-day the telephone is no longer looked upon as a luxury but as an everyday necessity. It fills a most important function in the business and social life of not only the cities, but also the suburban and country sections, and it may be looked upon as a necessity on account of the large percentage of the population of the United States which uses the telephone daily. Mr. Woodbury's very broad field has carried us over a wide and extended range of country, from the extreme south, up the "eastern shore" and across the continent to the Pacific Coast. From the illustrations seen it would appear that the principal difficulties to be overcome in telephone line engineering are more mechanical than electrical. Evidently the early constructors were misled, and had in mind putting the wires as high in the air as possible, with the intention, first, of having them as unsightly as possible, and, second, in getting them above the limbs and branches of the trees; overlooking the fact that the trees continued to grow, and it was only a matter of a few years before some of the branches would come in contact with the wires; and, further, that the higher the pole line the weaker the mechanical construction. For example, the illustration of the pole line in the city of New York, which fortunately has now been removed, carried over 200 wires which towered above the surrounding buildings. The unsightliness and danger of this great mass of wires in the

city thoroughfare is forcibly impressed upon you by the illustration. A single cable, or a pair, supported on short poles would have carried all of the conductors in a much more satisfactory and, certainly, in a more permanent and substantial manner than the method used.

The other illustration of large poles were common a few years ago, viz., the distributing poles to which usually an underground cable was attached and the individual lines were run to the subscribers' premises. These poles were mostly unsightly, and in the case of a number of services, when placed in small streets, the wires would spread out like an umbrella over the entire area. This brings out one of the most important considerations, viz., the objections on the part of the property owner or the subscriber to having attachments made to his premises. The citizen frequently complains of the unsightliness of overhead construction, but offers no assistance in the abatement or lessening of the evil. The civic duty of citizens and property owners should prompt them to co-operate and assist the supply companies in maintaining the necessary service-wires in the least objectionable manner. Fortunately, these objections are being removed on account of the greater number of subscribers and the greater familiarity of the public with this class of construction. It can readily be appreciated that these lines could be carried more safely at the rear of the houses, and this would entirely remove the objection of unsightly appearances of distributing poles and wires.

From the illustrations of underground construction we see again that careful mechanical construction is of the first importance. Cables should not only be installed in proper conduits, but in the manholes they should also be properly arranged and carefully installed.

I am sure we all feel indebted to Mr. Woodbury for this most interesting lecture.