UNDERGROUND TELEPHONE CABLES.

by

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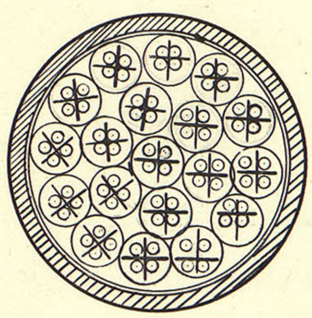 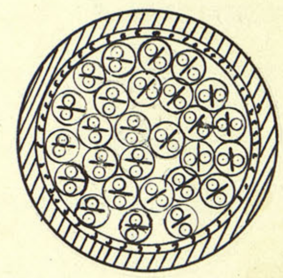

CROSS-SECTION OF PAPER INSULATED CABLES

For many years after the introduction of the telephone the difficulties of working through underground wires seemed almost insurmountable. The electrostatic capacity of the underground wires of early days was so much greater than that of overhead circuits as to materially interfere with telephonic transmission. In late years however, the methods of insulation have been so much improved that the underground construction of telephone circuits is the general rule in large cities, and is rapidly being adopted even in small towns.

The standard type of cable for telephone work contains two hundred pairs of insulated wires. One hundred pairs and fifty pairs and various smaller numbers are used for distribution. The insulation of cables is now mostly of dry paper. The requisite number of pairs of wires to form the desired cable is taken, and each wire insulated from its mate by a loose wrapping of well dried paper. It is usual to color in some manner the individual wires after they are wrapped, in order that the component of each pair may be known without testing. The wires to be wrapped are simply separated by a sheet of paper, and then lightly twisted together, the twist being sufficient to hold both conductors and insulation in their proper relative positions. A single twisted pair of wires is taken to form the core of the completed cable and around that the required number of pairs are assembled in regular layers, each successive layer being wound about the preceding one with a reverse twist, making a complete turn in from eighteen to thirty-six inches. The use of paper gives an insulator of low electrostatic capacity yet strong enough to maintain an insulation of many thousand meg ohms against the weak electro-motive force of telephone currents. By twisting the several pairs of wires very loosely about each other a considerable volume filled with air remains.

Capacity is decreased by leaving as much space between conductors as possible.

To keep such an arrangement of wires in working order some protection is necessary, as the insulating material is not only hydroscopic to the last degree and would retain its insulating properties for a short time after being kiln dried, but is also of a fragile nature and could not withstand the handling needed to place the circuits in their working position. Protection is found by inclosing the paper covered conductors in a lead pipe, which if carefully made is absolutely air tight, sufficiently flexible to be readily introduced into underground conduits or attached to pole lines, and not susceptible to the corrosive influences usually met with. The lead covering of underground cables is generally alloyed with three per cent. of tin, and in many cities where the gases are destructive to the lead a covering of asphalted jute is spread on outside the lead.

The standard size of copper wire for telephone cables is now No. 19 B. & S., which has a resistance of forty-five ohms per mile.

The lead sheaths of telephone cables are particularly sensitive to corrosion by electrolysis, and so long as electric railways employ an uninsulated return such as the third rail system, the current flowing through the earth in its course from the cars and back to the generating station, selects the path of least resistance which will be the lead covering of telephone cables if they are in the immediate vicinity, and at points where the current leaves the cable the lead wastes away until minute perforations appear which will destroy a whole section of cable, by the admission of moisture. The difference of potential necessary to bring about this action is very small, a hundredth of a volt may be sufficient and consequently in districts where potential differences are found between the lead covered cables

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the surrounding earth, electrolysis may be assumed to be taking place, for dampness, and salts necessary to produce electrolytic action are found in all ordinary soils. When the current passes from the earth to metallic bodies in the earth there is no injurious action nor is there any danger so long as the current traverses the metallic body, but when the current leaves the conductor and re-enters the earth injury may take place.

Danger areas, that is points where the current is leaving the underground conductor, may be located and protection provided by leading away the injurious currents by some conductor that is not injured thereby. This necessitates a thorough inspection of the underground plant. This examination is usually accomplished by testing each cable in each manhole to see whether it is negative or positive to the surrounding earth, that is, whether the current is flowing from the earth to the cable or from the cable to the earth. This may be ascertained by means of a low reading voltmeter graduated to 1/100 of a volt. From the positive terminal a flexible conductor terminates in a pair of pipe tongs while from the negative terminal the conductor terminates in a long sharp steel rod. The sheath of each cable to be tested is grasped with the tongs thus insuring good contact with the positive terminal, while the sharp steel rod is pushed into the ground near by. When the voltmeter deflects to the right it indicates that the cable is positive to earth and when it deflects to the left the cable is negative to earth. Careful notes of the date, time of day and location of all the cables tested should be made as the record acquired from repeated inspections becomes of great value.

Having from the manhole inspection determined the various situations on the cable system that are in danger the next step is a means of protection. The current must not leave the cable sheath and pass into the earth. Any device that will accomplish this result will suffice. The problem may be attacked from either end; to prevent the current from entering and passing along the cable or provide a good way for it to leave the sheath. In many cases simply the cleaning out of manholes and ducts, lifting the cables off the wet floors and supporting them on insulated pins driven into the wall is sufficient to change many electro-positive spots into electro-negative ones. Sometimes one or two breaks in the continuity of a cable will prevent the current from following the sheath. Another plan is to provide each danger spot with a conductor fastened to the cable sheath which is a better conductor than the earth. This is usually carried out by attaching a copper wire to the cable and carrying it to the railway track or to a railway return feed. If the current traveling over the sheath is not large, a ground plate will afford protection. For this purpose a hole is dug four or five feet in the earth and the bottom covered with charcoal which is a good medium for conveying current to the earth. There may be imbedded in this, old rails and scrap iron tied together with copper wire and connected to the lead sheath with copper wire. The ground plate acts to carry current from the cable to the earth and diverts the electrolytic action from the sheath to the plate.

The installation of underground cables though apparently a simple matter calls for considerable care. The usual method of proceedure is to pull a length of soft manilla rope through the duct by means of a fish wire, following this a brush and scraper is pulled through to clear away all loose obstructions in the duct. The cable reel is placed close to one manhole and the pulling apparatus at the next one. The pulling machine may consist of a winch operated either by man or horse power. However the more modern method is to employ a small hoisting engine. The rope from the pulling machine is attached to the cable, precaution being taken to see that the pull is evenly distributed to the sheath. A good plan to accomplish this is to solder a brass tube, slightly larger than the sheath and having an eye in one end, to the end of the sheath. The rope is attached to this eye and the pull evenly distrinuted thereby. When all preparations are completed the drawing is started and should proceed, slowly and steadily without a stop until the manhole is reached. A gang of men should feed the cable into the duct, the mouth of which must be protected by a leather shield. After the cable is drawn into the duct the next step is to splice the two ends in the manhole. When a length of cable has to be cut it should be immediately spliced or sealed after drawing it into the duct. A short exposure is likely to spoil the insulation of the cable. Because of the hydroscopic and fragile nature of the paper insulation great care must be used in terminating and joining cables in order to keep the body of the cable free from moisture.

When received from the makers each piece of cable has three or four feet of each end boiled in paraffine after which the lead of the sheath is turned over and soldered. When two pieces of cable are to be spliced the sheath is stripped away from each end for eighteen inches or two feet. Then a piece of lead pipe about an inch larger than the cable and two feet long is slipped onto one of the cables. The paper from each wire is then stripped off and each wire in one cable twisted to its proper mate in the other, the wire joint is protected by a paper sleeve. When all the pairs have been connected the lead sleeve is slipped over the splice and one end "wiped" onto the sheath of one piece of cable, the splice is then immersed in boiling paraffine for some time after which the remaining end of the sleeve is "wiped" onto the sheath of the other cable and the splice is complete. To carry the underground wire plant into the central office modern practice continues the underground conduits into the basement of the office building. The termination of the cable is with difficulty made moisture proof, for the individual wires must be brought out in such a way that they may be utilized in any manner. There are two classes of terminals. The Cable head and the Pothead. In the Cable head method the sheath is soldered to an air tight box inside of which the circuits may be fanned out and attached to pins on the inside of the box. These pins extend to the outside of the box. In the Pothead method an auxiliary cable made of rubber insulated wire is spliced onto the paper insulated cable, a lead sleeve is then wiped onto the sheath of the cable and the sleeve filled with a rubber compound. This cable is then run into the terminal box as before but not soldered. The latter method practically insures a moisture proof terminal. However it is the more expensive of the two methods and also the more difficult with which to work.

The cost of telephone cables will vary with the price of copper and lead. Also with the electrostatic capacity of the cable. Underground cables are slightly cheaper than aerial cables due to the fact that slightly thinner leaden sheaths are used for underground cables than for aerial cables. In figuring the cost of the cable plant it is necessary to allow for the cost of erecting the cable in the ducts, splicing, and terminals.

In spite of the apparent protection of conduit and leaden sheath underground cables will gradually fail. Some authorities give from five to seven per cent. as a reasonable annual charge to cover depreciation. The cost of maintenance depends very much upon the growth of the exchange. Where this is rapid there is a constant necessity for rearranging the plant. Under these circumstances maintenance charges vary from two to five per cent. on the cost of installation. Where growth is slow and there is little change these charges may fall as low as one and a half to three per cent. Combining the charges for both depreciation and maintenance the annual expense for the underground wire plant should be taken between five and ten per cent. depending upon the conditions named.

The great problem in the design of underground telephone cables is to eliminate capacity in the cable. The practical effect of capacity is to prevent successful transmission by interfering with the distinctness of speech. Telephone currents are very complex being composed of the fundamental and a great many overtones. It is by means of the blending of these overtones with regard to their relative loudness and relative phase relation with each other that articulate speech is produced. Now when a line of fluctuating direct current contains capacity, the effect of an increasing current is to charge the line but when the current decreases the capacity of the line will be discharged into it. These charging and discharging currents interfere with the current waves formed by speaking into the telephone transmitter, with the result that some of the waves are neutralized or destroyed which results in indistinctness at the opposite end of the line.

The capacity of a cable depends upon the area of the conductors, their distance apart, and the character of the insulating material between them. The general formula for capacity in microfarads is as follows, -

$$C = .000225 \frac{A\ n\ k}{t}$$

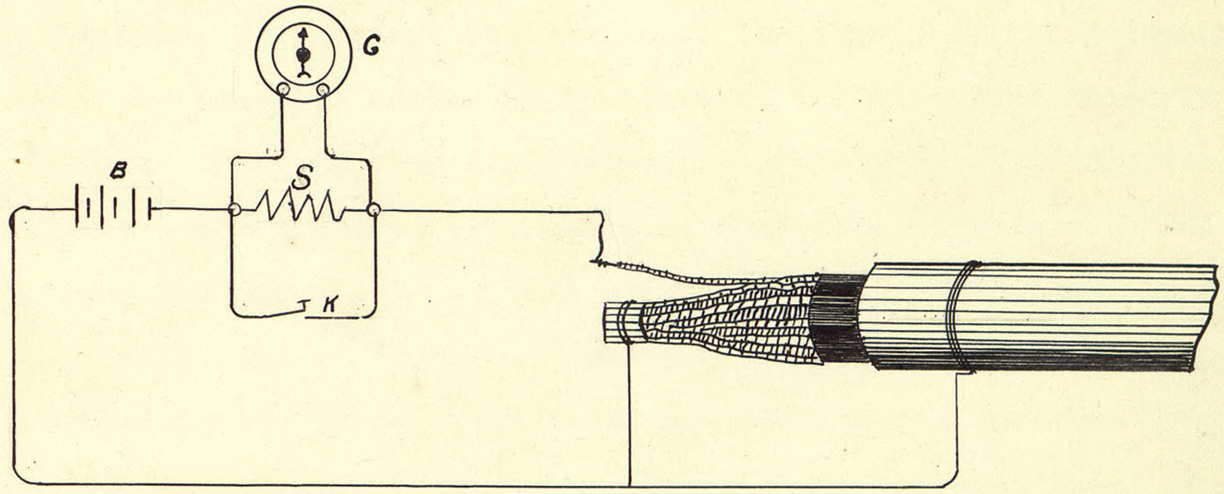
Where C is the capacity in microfarads. The decimal is a constant to reduce the expression to practical units. A is the area of the insulating material separating the conductors, n = the number of insulated wires in the cable, t = the thickness of the insulating material and k is the specific inductive capacity of the insulating material. Thus it will be seen that the larger the wires and the nearer they are together in any circuit the greater is the capacity. As air has the least inductive capacity of any insulator known, the use of air as an insulator will cut down capacity. The effect of using small wires is to increase the resistance of the circuit. Increased resistance decreases the volume of sound produced by decreasing the flow of the current. The aim of the cable designer must be then to use the largest wire consistent with reasonable installation cost, to place the wires in the cable as far apart as possible, and to use the least possible amount of insulating material other than air. The invention of the paper insulated, air spaced cable complies quite well with these conditions. The standard specifications for this cable call for an electrostatic capacity not to exceed .080 microfarads per mile, which capacity shall be guaranteed not to increase for five years.

Electrostatic or magnetic induction plays no important part in the design of cables for the twisting of the pairs of wires the one about the other effectually destroys all induction.

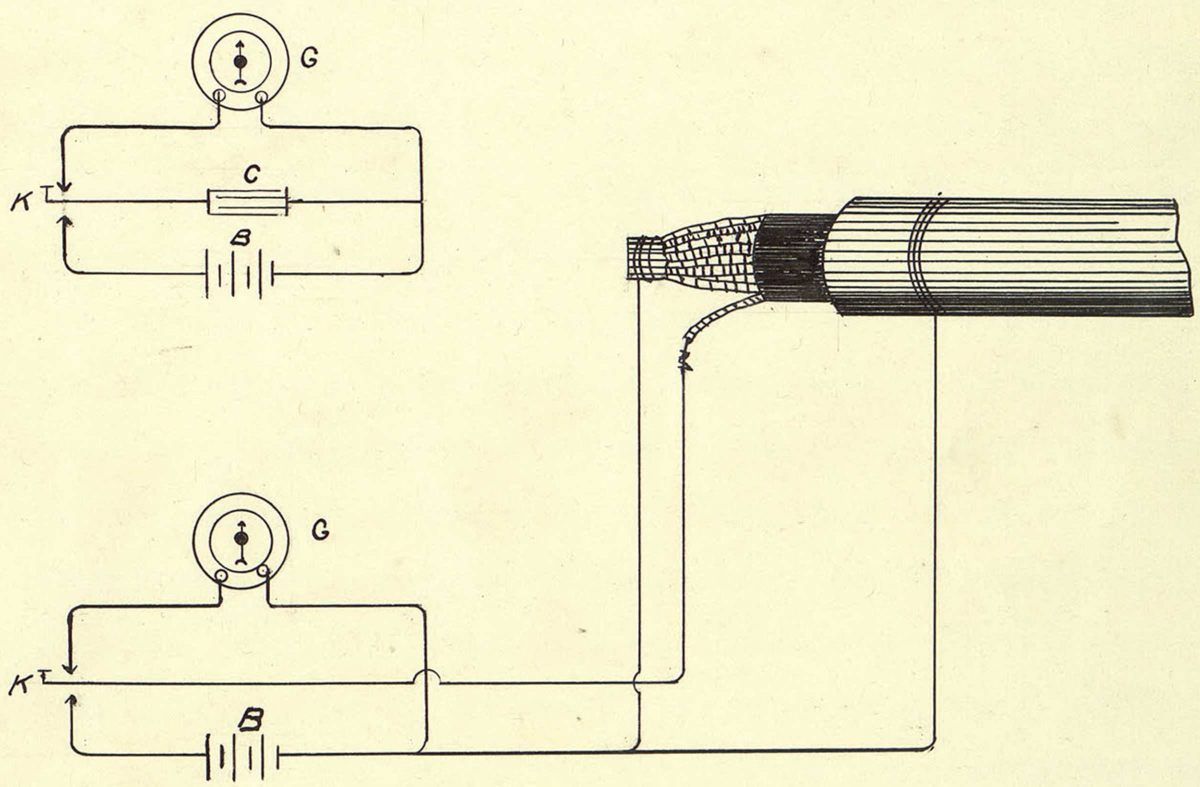
There are two general classes of tests for underground cables. The purpose of those of the first class is to show that certain conditions exist. Under this head may be mentioned tests for grounds, crosses and breaks. The object of the tests of the second class is to measure quantitatively the extent in which certain conditions exist. These include tests for resistance and conductivity, capacity, and insulation tests.

In testing for grounds the magneto testing set is a very convenient instrument to employ. This consists of a powerful magneto generator so wound as to ring its own bell through a resistance of from twenty-five to seventy-five thousand ohms resistance. The first thing to do in testing for a ground is to see that the far end of the line is open. One end of the magneto bell is then connected to the near end of the line, the other end is grounded. The ringing of the bell would indicate that the line is grounded. This test will sometimes fall down on a long cable on account of the fact that the static capacity will sometimes allow enough current to pass to and from the line to the ground in charging and discharging to ring the bell. A more reliable method is to connect a galvanometer in series with several cells and ground one terminal, then with the other terminal make contact with the near end of the line. A kick of the needle will take place on any event upon closing the circuit due to the current flowing to charge the line but a permanent deflection indicates a ground. In testing for a cross with some other line in the cable one terminal of the magneto bell or galvanometer and batteries should be connected to the wire under test and the other to all the other wires in the same lead. If it is not convenient to bunch them the test may be made between the suspected line and each of the others in succession.

The test for broken wires may be made with the same instruments as were used in the two preceding tests. The wires to be tested should be grounded or connected by a return wire to the far end. At the near end one pole of the magneto or of the battery and galvanometer or a telephone receiver may be used in place of the galvanom-



INSULATION RESISTANCE TEST



CAPACITY TEST

eter, should be connected to the return wire or ground and the other terminal connected to the terminals of the line. A ring in the case of the magneto, a permanent deflection of the needle of the galvanometer or a continuous clicking in the case of the telephone receiver will indicate that the line is continuous. Sometimes it is desirable to pick out a certain wire in a cable at some intermediate point without cutting the cable. To do this ground the wire desired at the distant end being sure it is free from all other wires at both ends, then having loosened the bunch of wires at the point where the wire is to be picked out test each by means of a needle pointed instrument connected to a ground through a magneto or galvanometer and batteries. There are two principal methods of measuring the resistances of cables. The Wheatstone bridge is accurate for all resistances except very large ones or those very small. In the second method for very high resistances a sensitive galvanometer is used in series with a battery. The insulation resistance of a line is usually measured by the galvanometer and battery method. Connections for such a test are shown in sketch. One terminal of the circuit connected as shown with the sheath and all the wires except the one under test, the other terminal is connected to the wire under test. The throw of the galvanometer with the shunt S alone in the circuit is first taken then the shunt is cut out so the full current may pass through the galvanometer. Before completing the circuit with the cable and sheath the key K should be closed - parallel with the galvanometer to prevent a rush of current through the instrument. The key is then opened and all the current sent through the galvanometer which receives only that current that leaks through the insulation. The constant of the galvanometer being known the resistance equals $K\theta$ where K is the constant of the galvanometer and θ the throw of the needle.

The usual method of making tests for capacity is to note the deflection produced when a condenser of known capacity, after being charged to a known potential, is discharged suddenly through a galvanometer, and to compare this with the deflection obtained when the cable under test after being charged to the same potential is discharged through the galvanometer. The deflections are proportional to the charges and therefore proportional to the capacity of the standard and the cable. In the sketch C is the standard condenser, B the battery and G the galvanometer. When the key is depressed the condenser is charged to the potential of the battery B, the key is then suddenly released allowing the charge from the condenser to pass through the galvanometer, causing a throw of the needle. The connections are then made placing the cable in the place of the standard condenser when the key is pressed the cable is charged and when released the charge of the cable flows through the galvanometer. The capacity of the cable and condenser are directly proportional as the throws of the galvanometer.

In general the problem of conduit building is to get the best conduit for the smallest amount of money. Unfortunately "the best" is not usually the cheapest in initial outlay of money. The ideal conduit must first of all be moisture and gas tight. It should be indestructible when laid in the soil and strong enough to resist sharp blows from pick or shovel. Moreover it must be easily and cheaply laid. The duct surface must be smooth to facilitate the introduction of the cable and contain no substances that can injure the lead sheath. Finally high electrical insulation is desirable as a protection to the sheath against electrolysis. There is probably no material or form of conduit which perfectly fulfills all these conditions. However all the manufacturers offer a material which if carefully selected may be safely used.

The duct material now on the market that is worth consideration will fall under one of three classes; Cement, Vitrified clay and alphalted paper tubes.

The first cement ducts placed upon the market were made by taking a thin tube of sheet iron, similar to stove pipe and about four inches in diameter. Inside of this tube was placed a mandrel about an inch less in diameter than the iron pipe. The space between the mandrel and pipe was rammed full of hydraulic cement. When the cement set the mandrel was removed leaving a cement pipe with an outside covering of sheet iron. These pipes were made with male and female ends. The cement ducts are laid in a bed of concrete and the joints packed with mortar.

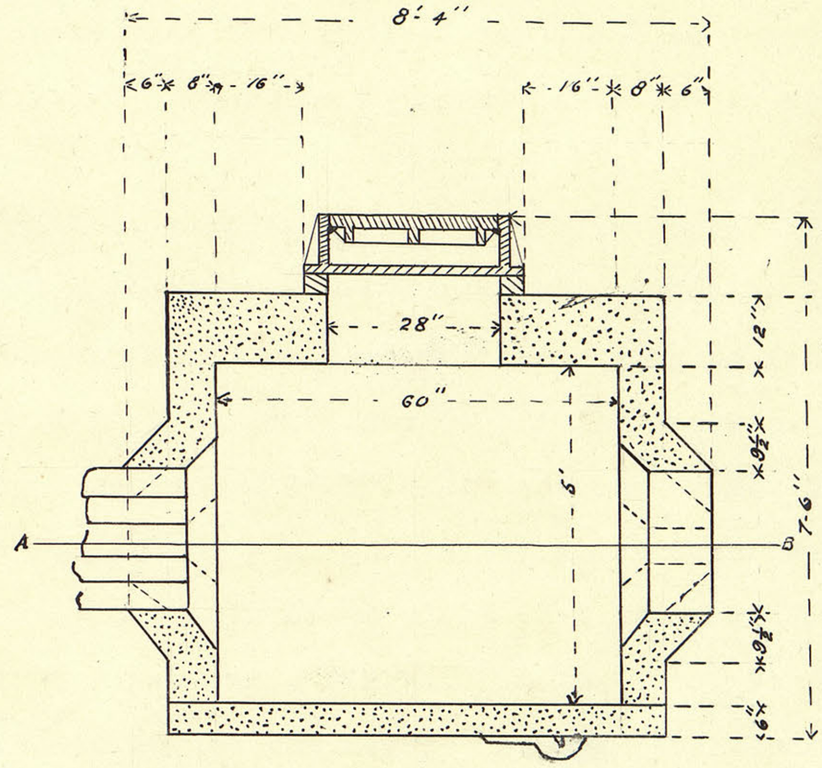
Another cement duct called the Francis, is made by pressing a mixture of the best Portland cement into tubes by means of a mold or die. The pieces are four or five feet in length and have no socket joints. The duct material is laid in cement and the joints simply butted. A tight rubber mandrel being placed at each joint while the concrete is tamped around it, thus assuring good alignment. Cement pipe meets many of the specifications for ideal duct material, it forms with its concrete incasement a strong and indestructible conduit. It is easily laid without skilled labor and while not moisture or gas proof is as near so as most any other material. It has excellent insulating qualities. The great drawback to cement pipe conduits has been its price which is greater than that of some other materials. Vitrified clay is probably the most generally used conduit material today. The general type of vitrified clay duct now in use is the multiple duct. The clay sections are made in lengths of about five feet and contain two, four, six, eight or more ducts as the purchaser may desire. Each length is provided with one or more half inch holes molded in the clay partitions, into which iron pins forming dowels may be fastened thus facilitating good alignment. Joints are best made by wrapping tightly about each joint several layers of asphalted burlap. The standard method of laying vitrified clay ducts follows: A three inch layer of concrete is laid in the trench. The sides are lined with cheap lumber so as to form a trough about six inches wider than is necessary to hold the proper number of multiple ducts. These are then joined and placed on the concrete bed, leaving three inches on each side between the planking. As each piece is placed a thin layer of mortar is applied to the surfaces in contact. When all the ducts are in place the side spaces are tamped full of concrete. A three inch cover of the same material then completes the work. Following is a table of vitrified clay conduit sizes:

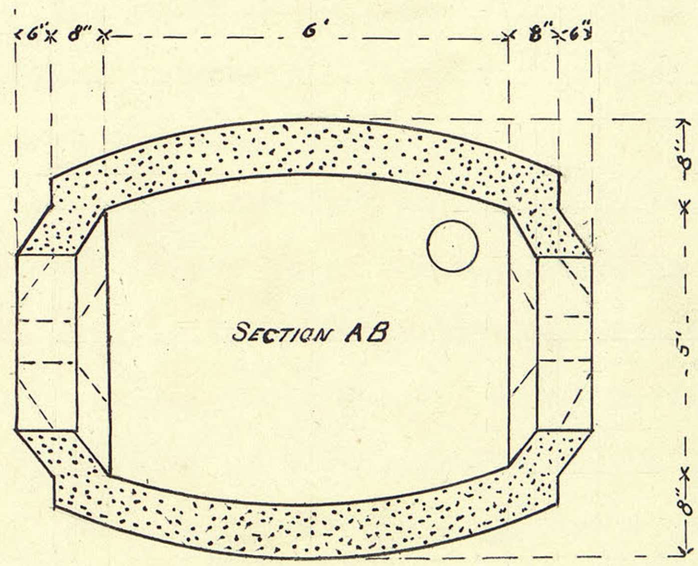
Type of Conduit,	Size of end,	Standard Length,	Approx. wt. per foot.
Three inch duct,	inches	inches	lbs.
Single dowel	4 1/2 x 4 1/2"	18	10
Square	5 x 5	18	14
Round	4 7/8 diam.	18	10
Octagon	4 7/8 "	18	10
Two duct	4 3/8 x 8 3/4	24	8 3/4
Three duct	4 5/8 x 13	24	8 1/2
Four duct	4 3/4 x 8 3/4	36, 48, 72	8
Four duct	4 3/4 x 17	24	8
Six duct	8 3/4 x 13	36, 48, 72	8
Nine duct	13 x 13	36	7 1/4
Twelve duct	13 x 17	30	7 1/4
Sixteen duct	17 x 17	30	7 1/4

Type of Conduit, Two inch ducts	Size of end, inches	Standard Length, inches	Approx. wt. per foot. lbs.
Six duct	6 x 9	36	4 1/2
Nine duct	6 x 9	36	4 1/4

One of the most recent suggestions for duct material is a tube composed of paper pulp saturated with asphalt. The tube is tightly rolled and compressed. It is made in lengths of ten feet or more provided with male and female ends. The joints are made by dipping each length as it is laid in hot asphalt and driving it home upon the preceding piece. The subway for this form of material is the same as for cement pipe. It is claimed for this material that it possesses the advantages of being indestructible underground, of extreme lightness, rapidity of construction, entirely waterproof and a good insulator. It is claimed to be electrolysis proof.

Manholes are necessary to permit the introduction, removal and arrangement of the cables. They must be large enough to permit workmen to cut and splice cables while inside. As conduit systems usually follow the streets in cities it is necessary to have access to the duct at such points as come at the intersection of diverging runs of ducts. The frequency of these points depends partly upon the design of the cable system but principally upon the length of the street blocks. Blocks in cities vary in length from four to twenty to the mile, but it is usual that block subdivisions are uniform so that any definite arrangement of conduit plan can be worked out for itself. It is generally given as good practice to place manholes about three hundred and fifty feet apart in the heart of the cities while five hundred feet is close enough in suburbs or outskirts of the city.





STANDARD MANHOLE

It is not practical from a cable standpoint to place manholes further apart than five hundred feet, cables longer than this become too heavy and cumbersome to handle with safety to the cable itself.

The manhole must be strong enough to support street traffic, it should be gas and moisture proof and not subject to decay. High insulation is essential. The present tendency is to reduce manhole design to a standard type which may be briefly described as an approximately rectangular chamber of brick or concrete about four feet wide by six long on the ground plan and having about five feet head room. The bottom usually consists of an eight inch layer of concrete with a floated coat of cement as a finish. In the floor there should be a sewer trap connecting to the nearest sewer. The floor should be graded toward the sewer trap. The side walls and top may be either brick or concrete and are built as sections of circular arcs to avoid sharp bends. It is often necessary to depart from the standard design but each case would need a special plan.

The brick manhole is the most expensive to build and is the least durable. However it possesses the advantage of flexibility inasmuch as it can be usually squeezed in between street obstacles with more success than can any other form of construction. For brick manholes a first class quality of hard sewer brick should be used.

The concrete manhole is made by preparing a collapsible form the size and shape of the hole. After the bottom layer of concrete has been placed the mold is set upon it and concrete rammed between its sides and top and the earth walls of the hole. This gives a chamber of great strength and cheapness and is the best and most economical construction if street obstacles are not too numerous.

There are three forms of roof common to brick manholes. These can be used equally well on concrete constructions though they usually have their own moulded roof. In the first type the walls are covered with old rails or angle iron set back to back about three inches apart, the space being filled with brick on edge over which a second or even third course of iron and brick is placed, depending on the required strength of the roof.

The more modern type of manhole roof consists of two or more I-beams or channels set across the top of the wall between these brick or tile arches are sprung. The third form of roof for brick manhole is of concrete, which needs no metal reinforcements and is very satisfactory. In cities of not over forty thousand population where street traffic is not great and where cheapness is desired a much smaller and less expensive manhole may be employed than we have heretofore considered. Such manholes are provided with rectangular cover frames which frames are made of angle iron joined at the corners with knee braces. The cover itself is made of angle iron filled with oak plank. The manhole itself may be of brick, concrete or plank, preferably the first. The depth need not be more than three feet while four by three is suitable for the other two dimensions. These manholes are too small for cable splicing inside of them so cables are drawn into place and spliced in the streets by allowing a large U bend to extend out of the manhole entrance.

The cost of a conduit system will be directly proportional to its length and depends upon though not exactly proportional to the number of ducts.

The cheapest form of duct material is hollow brick depending of course on distance from factory and freight rates. To this must be added the expense of inspection, handling, breakage, etc. Multiple duct material stands second in cost. Cement pipe and creosoted wood follow in order.

Hollow brick is the most expensive material to lay inasmuch as trade unions consider it brick work. Multiple duct is the cheapest to lay while cement pipe and wood follow. Considering original cost and cost of laying, multiple duct is the cheapest conduit material on the market.

As actual experience with underground conduit does not extend over many years rates of depreciation must be largely estimated. The present materials used have great durability, in fact concrete and clay if undisturbed would last almost forever. However an account of defective work, necessity of rearrangment and prospects of improved methods of construction, authorities give three and one third per cent. as the least admissable rate. The annual charge for maintenance for large systems is given as about two per cent., for small plants three or four per cent. should be set aside for maintenance. Adding depreciation and maintenance charges the annual expense for large subway systems will be from four and one half to five per cent., while for small plants five to seven per cent. is required.