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MANUAL OF INSTRUCTIONS

FOR

GUIDANCE IN THE ERECTION AND TESTING OF LIGHTNING CONDUCTORS.

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INSTRUCTIONS

FOR

GUIDANCE IN THE ERECTION AND TESTING OF LIGHTNING CONDUCTORS.

INTRODUCTION.

1. *Thunder clouds.*—A thunder cloud is a mass of vapour charged with electricity at extremely high pressure or potential. The origin of this charge has been variously ascribed to evaporation, to friction of air currents, as well as to the changes in the physical condition of the earth's surface which are incessantly occurring.

2. *Induced charge.*—A thunder cloud acts by induction on the land or water beneath, or on clouds near it, and draws a charge of electricity of opposite kind to the surface. This induced charge reacts upon the cloud in a similar manner, thereby forming a huge electrical condenser.

3. *Disruptive discharge.*—When the difference of pressure between the oppositely electrified cloud and earth, or cloud and cloud, is sufficiently strong to break across the air space which separates them, an electric discharge of a disruptive nature, with consequent disengagement of heat, takes place.

4. *Clouds imperfect conductors.*—Clouds are imperfect conductors, and therefore do not part with all their charge at once. Hence a single discharge does not necessarily deprive a cloud of the whole of its charge; there may be several successive discharges.

5. *Sites least liable to lightning.*—The surface of the earth is formed of fairly good conducting media, but there are some portions, such as sandy deserts and chalk downs, which, after long droughts, form non-conducting areas. Lightning is least to be feared in such situations, the induced charge not being so easily drawn to the surface.

6. *Path of lightning.*—The lightning discharge between cloud and earth follows the line of least resistance, or, in other words, selects the easiest path. Objects which project above the general level are, therefore, *cæteris paribus*, most frequently struck. Dry air is practically a non-conductor of electricity, but moist or hot air possesses a certain conducting capacity. Hence rain or hail, and columns of rising smoke or steam, sometimes determine the direction of the discharge, which does not therefore always strike the highest points. Metals, which are the best conductors of all, generally determine the path of the electrical discharge. Other substances, such as living vegetable or animal matter, offer much obstruction, and only form partial conductors; while dry earth, stone, and wood almost entirely prevent the passage of electricity, and are very bad conductors,—in fact, they are insulators.

7. *Path of lightning.*—The lightning discharge does not always follow a single track; it frequently divides into several lines. When alternative routes are offered for its passage, the electric discharge will divide itself among them in direct proportion to their several conducting capacities, *i.e.*, inversely as their respective resistances. In its passage to earth, however, the discharge will not leave a line of good conductors for an inferior one with which it is unconnected, except when the latter offers a much more direct path to earth, in which case a portion of the discharge may leave it. Again, when a conductor is bent abruptly through a considerable angle, the discharge may seek a shorter path to earth by bridging the air space connecting the nearest portions of the conductor, and a portion of the discharge is then very liable to be diverted to any alternative route which may present itself. Similarly, if the discharge does not find a path prepared for it, it will utilize such partial conductors as may be reasonably near, for example, the iron bars of doors and windows, gas or

water pipes leading to damp earth, or other masses of metal which may enter into the construction of the building, &c.

8. *Effects of discharge.*—Atmospheric electricity is only destructive when overcoming high resistances. If the conductivity of its path to earth be sufficient, the discharge passes off harmlessly. When the electric discharge bridges a gap or sharp bend in a conductor, or jumps from one conductor to another, a considerable mechanical effect is produced, and, should the human body intervene, life may be destroyed; the conductor may be broken, bent, or melted, both at the place where the discharge leaves, and that on to which it jumps, and the effect is greater in proportion to the distance across which the discharge jumps. Hence the importance of ensuring perfect metallic continuity in the joints of all lightning conductors, of leading them to earth by the most direct route, of avoiding sharp bends, and of connecting all masses of metal, in the line of probable discharge, with the lightning conductor, so as to avoid the danger of lateral discharges through the air, or it may be through the building.

CHAPTER I.

Action of Lightning Conductors.

1. *Double function of conductor.*—A lightning conductor fulfils two functions: (1) it tends to prevent a disruptive discharge occurring by silently * neutralizing the conditions which determine such discharge in the neighbourhood of the conductor, and (2) it facilitates the discharge of the electricity to earth so as to carry it off harmlessly.

2. *Preventive action.*—The *preventive* action of a lightning conductor depends on the power of its pointed ends. A thunder cloud in the vicinity of a building draws a charge of electricity to the lightning rod, and this charge will escape from the point as fast as it can be induced, provided there be a sufficient number of sharp points all well connected with the earth. This power of points to dissipate a charge is due to the repulsive action of electricity of the same kind, and to the law of distribution of electricity on a surface "that the density is greatest at points or on portions of the surface of greatest curvature." * It is essential, therefore, to foster this gradual or silent discharge by providing a sufficient number of sharp lightning rods in intimate connection with the earth by means of continuous metallic conductors, so as to collect or tap the induced charge and to oppose the least possible resistance to its escape from the points.

Further, the flow of electricity from the points being directed towards the charged cloud, some of the inducing charge may thereby become neutralized. Hence not only does a lightning rod tend to prevent the accumulation of electricity on the surface of the earth within its sphere of action, but it also tends to restore the clouds to their natural state, both of which concur in preventing lightning discharges.

3. *Protective action.*—Should, however, this silent discharge of electricity from the points of the lightning rods be insufficient to prevent the accumulation of a charge and a lightning discharge take place, it would pass to the points, because the density and consequent attraction are greater there than anywhere in the neighbourhood, and also because the flow of electricity from the points reduces the mechanical resistance of the intervening air. The discharge in this case would, in all probability, be greatly modified by the previous escape of electricity from the points, and being conveyed to earth by a continuous conductor of ample capacity, would leave no trace of its passage. This may be termed the *protective* function of a lightning rod.

4. *A perfect conductor.*—Thus to fulfil its two functions a lightning conductor should be surmounted by a point or points, and should offer a line of discharge more nearly perfect, and more accessible, than any other offered by the materials or contents of the building we wish to protect. If these conditions be fulfilled; if the points be

* The word "silent" is the conventional term used to describe a continuous brush discharge, which generally is not audible. The brush discharge, when very rapid, is however accompanied by considerable noise and is frequently visible at nights.

high enough to be the most salient features of the building—no matter from what direction the storm cloud may come,—be of ample dimensions and in thoroughly perfect electrical connection with the earth, the building with all its contents will be safe, and the conductor might even be surrounded with gunpowder in the heaviest storm without fear or danger.

5. *Cause of accidents.*—All accidents may be said to be due to a neglect of these simple elementary principles. The most frequent sources of failure are conductors deficient either in number, height, or conductivity, bad joints, or bad earth connections. There is no authentic case on record where a properly constructed conductor has failed to do its duty.

6. *Defective conductor a source of danger.*—A lightning rod in imperfect connection with the earth, due either to insufficient surface of conductor buried in the ground or to defective joints, although it *may* save a building from actual damage by determining the path of the electric discharge to earth, is generally regarded as a source of danger, inasmuch as the sudden and disruptive discharge would be liable to fuse or scatter some portion of the conductor in its passage, and so leave the building unprotected from further strokes. Again, a lightning rod in such a condition, by allowing the comparatively slow accumulation of an induced charge, tends to attract or invite an electric discharge, while the resistance offered at the defective portions of the conductor may cause a portion of it to seek another path disruptively through the building. A faulty conductor may thus prove worse than useless.

CHAPTER II.

Design of Conductor.

1. *Points.*—The lightning conductor should be designed to fulfil, as far as possible, the two functions mentioned in para. 1 of the preceding chapter, and starting with the extreme top, we have first to deal with the question of points. The decision as to the best form of points is complicated by two opposing requirements—(1) the sharper the point the more rapid the silent discharge of electricity, and therefore the more effective the conductor; but (2) the sharper the point the more easily is it destroyed by oxidation, or fused, should a heavy disruptive discharge fall upon it. Attempts have been made by the use of platinum tips, silver, gold, and various alloys to obtain a sharp resisting point, but they enormously increase the cost, and have not proved reliable. For these reasons it seems best to separate the double functions of the lightning rod, prolonging the upper terminal to the very summit and bevelling it off to a blunt right-angled cone, having its height equal to the radius of its base, so that, if a disruptive discharge does take place, the full conducting power of the rod may be ready to receive it, and, with a view to facilitate the silent discharge, to add three or four very sharp tapered points projecting upwards from a ring fixed about a foot below the top of the lightning rod.

2. *Metal for conductor.*—The metals employed in lightning rod construction are iron, plain or galvanized, and copper. Roughly speaking, they cost the same for equal conductivity; but conductors made of iron are stronger, less easily fused, and less liable to be stolen. Copper conductors, on the other hand, have the advantage of being far more durable, and, being smaller and lighter, they interfere less with architectural features and are much cheaper to erect.

3. *Size of conductor.*—The size of rod to be adopted is the most difficult subject to be determined. The Lightning Rod Conference of 1881 recommended the following as the *minimum* size of conductors to be employed:—

Material.	Section.	Sectional area of metal in square inches.	Weight per square foot. Ounces.
Copper rope	$\frac{1}{2}$" diameter.	·10	7
Do. round rod	$\frac{7}{16}$" do.	·11	7
Do. tape	$\frac{3}{4}$" × $\frac{1}{8}$"	·09	6
Iron round rod	$\frac{9}{16}$" diameter.	·64	35

The size of lightning conductors is, however, practically ruled more by considerations of strength and surface for making good connections than by that of electrical resistance. It may, however, be mentioned that the smallest size of copper tape to be used for main conductors on War Department buildings is $1'' \times \frac{1}{8}''$.

4. *Shape of conductor.*—In this country the forms of lightning rod generally used are rods (round or square), tubes, tape, and rope (wire).

Rods (round or square).—The advantages and disadvantages of rods are easily stated. The advantages are their durability and their rigidity, the latter being of importance for long upper terminals. The disadvantages are the necessity for numerous joints and the difficulty of avoiding serious disfigurement of the building to which they are attached.

Tubes have much the same merits and demerits, with the additional objection that they are necessarily of larger diameter than solid rods, and are therefore the more conspicuous. They have also the additional disadvantage in that they are generally joined together with screw collars; the cutting of the thread on the tube seriously diminishes the sectional area, and the joint so made is liable to easily become electrically defective.

Tape is a form of rod which is of comparatively recent introduction and possesses many advantages. Foremost among these is the length which can be supplied in a single piece.* Where, as at the junction with an upper terminal, a joint is needed, it is easily made by clamping or rivetting the two surfaces together, and painting over to exclude damp, &c. Owing to the flexibility of the tape it can be made to follow the outlines of the building very closely, or may be countersunk in it and painted over, but abrupt bends should be avoided.

Ropes (wire).—The ropes used for lightning rods are usually made of wires of very small diameter, and this gives rise to a serious evil by allowing a large number of interstices for the lodgment of dirt, smoke and water, while at the same time the wires are too thin to effectually resist oxidation. The objection to these wires is greater in iron ropes, even if galvanized, than in those of copper, for, irrespective of the doubt as to the perfect galvanizing of every part, there is the greater brittleness and consequent risk of damage from defective continuity.

5. *Joints.*—The most fruitful sources of danger in rods are *bad joints*, not necessarily those that are mechanically bad, but those that are electrically so. A joint is said to be electrically bad when it offers resistance to the passage of electricity through it. *There should be no resistance whatever.* Bad joints in lightning rods are very abundant, though they appear perfectly sound, and this fact is known to all who have tested the electrical conditions of conductors. Bad joints have the same effect as lengthening the conductor; and, in one case, a bad joint has been found to have the same effect on a discharge of electricity as a conductor 1,900 miles long. It is evident that such rods may be worse than useless, for other parts of the building may offer easier paths for the passage of the discharge to earth.—*Vide* para. 6, Chapter I.

6. *Painting.*—Copper conductors should be painted up to within a foot of their points, and iron conductors, even if galvanized, should be painted throughout, except at their points.

7. *Attachment to buildings.*—Lightning conductors should not be insulated from the buildings to which they are attached. In putting up lightning conductors the points needing attention are—

(1) The rod to be attached to the building by fastenings of the same metal as itself.
(2) That the fastenings be of adequate strength.
(3) That they be of such form as not to compress or distort the rod.
(4) That they allow play for its expansion and contraction.
(5) That they hold it firmly enough to prevent all the weight falling on any one bearing.

Where practicable, it is well to take the rod down that face of the building which is most exposed to rain.

* It is now manufactured for the War Department in England in lengths of 200 feet and upwards, and can, I believe, be obtained in long lengths in Calcutta.

8. *Earth connections.*—As regards the earth connections, it is most important that the electrical resistance which they offer shall be very far less than that offered by any alternative route in the line of probable discharge, such as the rain water or gas pipes outside a building.

The earth connections should be the best which the nature of the soil will admit of, and all available means which will assist in tapping a large extent of moist earth in the immediate vicinity of the building should be utilized.

9. *Deep and shallow earths required.*—Except where the permanent water level is very near the surface, both deep and shallow earth connections are required, because after a long period of dry weather the induced charge may be collected on a damp substratum, whilst after rain it may be collected on the surface. The deep earths should be carried down to water-bearing strata or to permanently moist soil, and the shallow earths should be arranged so as to offer a considerable surface of connection with the soil around the building.

10. *Space protected.*—It may be accepted that a lightning rod will protect a space included in a cone having the point for its apex and a base whose radius equals the height from the ground. Buildings protected on this principle would require very lofty lightning rods. It is, however, considered that a number of smaller rods, well connected together by conductors, carried along the salient features of the building, provide a more reliable protection than an equal amount of metal in higher rods, spaced at greater intervals; and this is the system now commonly adopted.

11. *Testing Conductors.*—Periodical examination and careful testing of the lightning conductor are requisite to maintain the system in efficient order. Points will corrode from oxidation and fusion; joints will get loose and bad through the action of weather and workmen; connections will decay both above and below ground; imperfections will develop themselves; and, in spite of every precaution during erection, the conductor will thus lose its efficiency if it be not *maintained* in thorough order. For this purpose inspections should be both visual and electrical; and the efficiency both of the conductor and its earth should be tested annually. In India the best time for testing is just before the rains, as at that time the level of water below the surface of the ground will be at its lowest point.

CHAPTER III.

Rules for the Erection and Testing of Lightning Conductors.

1. *Position of Conductors.*—The angles and prominent features of a building being the most liable to be struck, lightning rods should be fixed on gable ends, chimneys, turrets, &c., and they should be connected together by continuous conductors along the ridges.

2. *Height and spacing.*—Lightning rods should be about 4 feet high, and spaced at intervals not exceeding 50 feet, so that no point of the building is more than 25 feet horizontally from a lightning rod.

3. *Specification of Material.*—The metal to be exclusively employed for the construction of new lightning conductors is copper tape. A conductivity of at least 95 per cent. of that of pure copper should be specified, and the tape should be soft and flexible, so as to admit of its following closely the outlines of the building. Copper tape $1'' \times \frac{1}{8}''$, weighing about half a pound per foot run is the most suitable size for all ordinary conductors, and $1\frac{1}{2}'' \times \frac{1}{8}''$ may be used for very high chimney shafts. In order that copper tape, of long lengths, without joints, may be obtained all future supplies for the use of this Department will be obtained through the India Store Department.

4. *Protection from theft.*—In situations where copper tape is liable to be stolen, it may be let into the walls of the building and cemented over, or otherwise concealed where it is accessible. The practice of protecting the lower portion of copper conductors on buildings by enclosing them in iron pipes at the base of the building is questionable.

5. *Earth connections.*—In order to guard against those accidental defects and disarrangements to which conductors are liable, buildings provided with lightning conductors should have, as a rule, at least two earth connections, the conductors leading to them being connected at the base of the building, either above the ground line, or by a conductor under ground forming a "surface" earth.

Each lightning rod should be connected direct to earth by the shortest path outside the building, and, when practicable, it is well to carry the conductor down that face of the building which is most exposed to rain. In the case of gabled buildings, the conductor should be taken down the barge courses in preference to the gable, so as to protect the angle of the building.

6. *Earth coils.*—When the level of water or permanently wet soil lies within a few feet of the surface, the conductors should terminate in earths offering each about 18 square feet of external surface. These may consist of copper plates about $3' \times 3' \times \frac{1}{16}''$ riveted to the ends of the conductors and buried in water or permanently wet soil from 15 to 25 feet from the building. A better plan, however, is to coil the end of the conductor spirally on a wooden frame, the external diameter of the coil being 4 feet, with 6 inch intervals between the turns. About 33 feet of tape are required for this earth connection; it obviates the necessity of any underground joint, taps a larger surface of earth, and the tape being twice the thickness of the plate, it is more durable, besides being a cheaper arrangement.

7. *Wells.*—When the permanent water level is deep, it may be necessary to sink special wells for the earth plates, which should be of the same size as those specified in the previous paragraph. The wells should be carried down several feet below water level in the driest seasons, and the bottom part of the well should be built dry.

If coils of copper tape, however, be employed for earths, special wells are not necessary, because, there being no joints underground, the necessity for visual examination periodically no longer exists. In this case the earth coils may be buried at the bottom of a pit sunk below the level of permanently wet soil.

Where the depth is considerable, two or more conductors may be connected to the same earth plate, and, in the case of a coil of tape, the inner as well as the outer end may be brought up to the surface of the ground so as to form two earth connections. In both cases the size of earths should be made proportionately larger.

8. *Surface earths.*—In addition to these deep earths, it is necessary to provide surface earths laid in trenches from 1 foot deep in clay soils to 2 feet deep in sand or shingles through which the rain percolates more freely.

These surface earths may consist of that portion of the conductor which leads from the base of the building to the well or deep earth, or they may be arranged as separate conductors led in trenches away from the building. In the latter case, the deep and surface earths should be connected together with a conductor carried round the base of the building.

The length of each surface earth trench may be from 25 feet in ordinary soil to 50 feet in dry soil, and the width at bottom should be about 9 inches. A few inches of powdered charcoal should be spread both above and below the conductor, and the trench filled in with light soil. Any rain-water down pipes may with advantage be led into these trenches.

9. *Sea earths.*—In the case of buildings near the sea, good earths can be obtained by laying a length of tape so that at least 5 square feet of it shall always be under water; or a coil of tape may be buried in permanently wet sand.

When the distance to the sea is considerable, these earths should be supplemented by surface ones round the building, so efficiently to tap any induced charge in its vicinity.

10. *Iron pipes.*—Iron water pipes, &c., form good earth connections. Soft metal pipes and gas pipes should not be used, but when they run close to the conductors from a building, they should be connected to the lightning conductor or system. There are many recorded instances in which both water and gas pipes have been damaged by lightning springing on to them from neighbouring conductors, which would have been obviated if they had been connected thereto.

11. *Dry and rocky sites.*—In extremely dry or rocky situations it is almost impossible to obtain good earth connections except at a great distance. In such cases

the best plan to adopt is to bury several hundred-weight of old iron at the foot of the earth coil or plate in a mass of coke or charcoal, leading any rain water pipes or drains so as to discharge into it.

12. *Coke, charcoal, &c.*—Coke, charcoal, or smith's ashes will be found very suitable for improving the earth connections of lightning conductors. A layer of about 3 inches should be spread both below and above the conductors in the trenches, and also round the earth plates or coils.

13. *Flagstaff earths.*—The earth connections of flagstaffs near magazines should be led in a direction away from the building. Should, however, the horizontal distance between the flagstaff and the nearest lightning rod on the magazine be within 50 feet, or should any portion of the building be within the cone (*vide* para. 10, Chapter II) protected by the flagstaff rod, then the magazine and flagstaff earths may be connected, or have an earth common to both. This rule is also applicable to shafts of powder-mills, &c.

14. *External masses of metal.*—Rain water pipes and gutters should never be utilized as a portion of a system of lightning conductors, to which, however, they should be connected. All external masses of metal, such as copper sheeting on magazine doors and ventilators, &c., should also be connected to the nearest conductors by lengths of copper tape.

In the construction of magazines and other buildings in which the manipulation of explosives is carried on, the employment of external masses of metal should be avoided as far as possible.

15. *Lines of rail, &c.*—Lines of rail near buildings protected by lightning rods should be connected to earth direct on both sides of the building, and when the line is carried inside the building it should be connected also to the system of lightning conductors. Iron railings round magazines should be connected direct to earth at intervals of about 50 feet.

16. *Internal masses of metal.*—All large and long masses of metal, such as beams, girders, pipes, water systems, and large ventilators fixed in the interior of buildings, should be electrically connected with the earth as well as with the conductor; but soft metal gas pipes should never be used as conductors, and the lightning conductor should be kept as far as possible from them, and also from all internal gas pipes.

17. *Fixing conductors.*—Lightning conductors should not be insulated from the buildings to which they are attached. The copper tape should be laid on the ridges and walls, and secured by suitable fastenings screwed or nailed to the building. The hold-fast should be of copper or gun-metal, fixed by nails or screws of hard copper, and they should allow for expansion and contraction, at the same time preventing all the weight falling on any one bearing.

18. *Metal roofs.*—Buildings with zinc or galvanized roofs should be protected by copper conductors laid over them, but protected from actual contact by strips of wood, paint, or tarred felt. The zinc roof itself should be treated like any other external mass of metal, and should be thoroughly well connected to the conductors in several places. The system sometimes adopted of having sheet zinc lightning rods and copper tapes from the eaves of the roofs to earth is very unreliable, because the lightning rods are of ineffective section, the zinc sheets are insulated from one another by a layer of oxide, and the joint between the zinc and copper is liable to failure.

19. *Chimney shafts.*—Chimney shafts should be protected by a ring of copper tape $1\frac{1}{2}'' \times \frac{1}{16}''$ placed round the outside of the top of the cap and a few inches below it, having stout copper points projecting 1 foot above the top of the shaft at intervals of 2 or 3 feet all round. Copper tapes should be carried down on opposite sides of the shaft to earth from the ring; and these conductors should be connected at the base, a test joint being added to enable the continuity of the conductors and the state of the earth connections to be ascertained when necessary.

20. *Joints in conductors.*—Metallic continuity should be ensured at the joints of all conductors. The conductor should therefore, if possible, be made up in one continuous piece, of the proper length, before it is sent out to be erected. The joints between copper tapes should be made by close rivetting and should be carefully

brazed and painted over. When brazing is impracticable, as when it is necessary to make a joint *in situ*, the joint should be rivetted as before and embedded in a mass of solder. In rivetting copper plates, five rivets should be used, and the holes should be bored, not punched; the "arris" being removed, and the surfaces brightened with emery, the joint should be brought together with a hollow punch before rivetting.

21. *Joint between lightning rod and conductor.*—The connection between the lightning rod and the conductor should be made by means of a slotted clamp similar in design to those employed for test and other joints. The lightning rod should terminate at its lower extremity in a $\frac{3}{4}$" bolt, screwed into the clamp, and thereby making firm contact with one or more tapes inside it. The conductor should also be brazed or soldered to the clamp as described in the preceding paragraph. The lightning rod should, if possible, be sent out connected up with the conductor ready for fixing.

22. *Repair of old conductors.*—For the repair of old lightning conductors, however, it may sometimes be necessary to use solder. For copper the solder usually employed consists of equal parts of tin and lead, which has a resistance nearly ten times that of copper. The surface of the joint should, therefore, be not less than $1\frac{1}{4}$ square inches.

Molten zinc should be used for soldering iron conductors. Being nearly twice as conductive as iron, the surface of the joint need not necessarily exceed that of the cross section of the conductor.

In both cases the joint should be put together previously by screws or rivets, and the soldered joint, especially in underground work, should be carefully protected from galvanic action by tarred tape.

23. *Connecting wire rope to copper tape.*—Existing iron wire rope conductors may be connected to copper tapes in the following manner. Take a piece of sheet copper $4\frac{1}{2}$" × 3" × $\frac{1}{8}$", and have one side tinned; cut it down at one end to the size of the tape for a length of $1\frac{1}{2}$", and rivet the tape to the sheet at this part; then bend the remainder of the sheet round the end of the rope, which should have been previously frapped with fine wire, thus forming a tube with the tinned side inwards. Sweat up the joint with zinc solder, and protect it by tarred tape bound tightly over it.

24. *Connection to iron water pipes.*—Copper tape conductors may be connected to iron water pipes laid underground by filing about a foot of the top of the pipe bright, binding the tape on to it by wire, and soldering with zinc, or a short length of iron bar 2" × $\frac{1}{2}$" may be rivetted and soldered to the copper tape, and then bolted to the flange of the pipe by $\frac{1}{2}$" screws passing through both the bar and the flange.

It is a good plan to coil several turns of the copper tape round the pipe (keeping it from actual contact by slips of wood) previous to fastening the end, so as to increase the earth connection should the joint ultimately fail. The greatest care must in all cases be taken to protect the joint from galvanic action by layers of tarred rope, or by embedding the joint in cement.

25. *Expansion of conductor.*—The variations of temperature produce an expansion and contraction in copper conductors which should be provided for by allowing the conductor free play through the hold-fasts employed to fix it to the building, and by leaving a small loop of the tape in some portion of its length. Conductors should never be screwed or nailed down. Vertical conductors on shafts, flagstaffs, or high walls should have small loops above every second or third hold-fast, to take the weight off the conductor while still allowing for expansion and contraction. The hold-fasts in this case should be about 4 feet apart.

26. *Conductors not to be tampered with.*—In carrying out repairs to buildings, maistries and coolies must be specially warned never, under any circumstances, to disconnect, move, or tamper with any portion of a lightning conductor, unless specially ordered to do so, and then only under the supervision of the officer in charge of the work.

27. *Records of conductors.*—Records of all lightning conductors should be kept in every Divisional office, and should contain as many of the following particulars as possible.

(*a*) Date of erection or reconstruction.
(*b*) Character of soil or substrata, and depth of permanent water level or wet soil.
(*c*) Full particulars of lightning rods, conductors, and earth connections, nature of joints and connections, &c.
(*d*) Details of all external or internal masses of metal entering into the construction of the building, and how connected to conductors.
(*e*) Positions of test joints, if any. Nearest earth available for testing, &c.
(*f*) In case of magazines, &c., quantity of powder, &c., usually kept in store.
(*g*) Date of last inspection, and précis of former tests, suggestions, &c., of inspecting officer.
(*h*) In case of buildings not under the immediate charge of the Public Works Department, name or title of person to whom notice of inspection should be sent.

28. *Periodical inspection.*—Lightning conductors should be inspected and tested once a year, and a report drawn up showing the result of such inspection.

29. *Electrical tests.*—The object of electrical tests of lightning conductors is to determine the resistance of the earth connections and to localize the position of any defective joints or connections in the conductors. The resistance of a conductor itself is quite inappreciable (less than $\frac{1}{4}$ ohm per 1,000 yards for copper tapes 1" × $\frac{1}{8}$"), and cannot be detected by the testing apparatus usually employed. The resistance of the earth depends on the nature of the soil and its state of moisture at the time of test. As a rough guide, however, it may be mentioned that the joint resistance of two earths, such as those described in para. 6, 30 yards apart in wet soil, will not exceed 2 ohms, and the greatest resistance offered by any earth must not exceed 10 ohms.

30. *Defective joints localized.*—The resistance of the conductors from summit to ground line, or to that part of the conductor from which the resistance of the earth connections is ascertained, should, therefore, be practically nil. Any resistance in excess of that of the battery and leads must be due to defective joints, and the faults should be localized and marked for repair, and to enable this to be done, test joints should be added to all conductors.

31. *Conductors made in short lengths.*—Conductors made in short lengths and connected by joints must have their metallic continuity ensured by soldering or a good system of rivetting, and the joints, when tested electrically, must give no resistance. Underground joints and earths, the nature of which is not known, should be dug up and examined when practicable.

32. *Test joints.*—Where the system of lightning conductors has more than one earth connection, it is necessary to introduce test joints, to enable the resistance of each earth connection to be ascertained separately. These joints consist of a slotted clamp to which the two portions of the tape are attached by bolts.

Where the cross connections between conductors or external masses of metal are few, these joints can be inserted in these cross connections, but where the system of conductors is complicated, they must be placed on the conductors themselves, the object to be kept in view being that by means of the test joints it shall be possible to isolate each earth separately for purposes of testing.

They must therefore be placed in convenient positions, so that the conductor can be disconnected without difficulty when required.

After the tests have been completed, the test joints must be carefully remade, the contact surfaces thoroughly cleaned with emery and brought into intimate contact with the bolts. The joint should then be covered with waterproof tape and painted over. When the joint has been completed it should be tested for metallic continuity. A space should be formed or left behind the joint to allow the tape to be passed round the conductor.

Single conductors without cross connections to metal down pipes or gas or water pipes do not need test joints.

33. *Test leads.*—In order to test the continuity of conductors fixed to inaccessible places, such as flagstaffs, chimneys, or steeples, an insulated test lead must be led up the flagstaff or other erection; and at its upper extremity attached and soldered

securely to the lightning rod above its junction with the conductor. This lead should be of Hooper's core, metal (lead) covered, resistance not to exceed 10 ohms per mile.

34. All lightning conductors on public buildings should be brought as far as possible into conformity with these rules, but existing arrangements may generally be allowed to stand, provided care be taken to improve defective earth connections and to make good all joints.

CHAPTER IV.

Inspection and Testing of Lightning Conductors.

1. *System of testing.*—The best system of testing lightning conductors is to balance the resistance of each of the earths of the building against the remainder of the system, provided they are not in metallic contact, from which the state of the earths may be inferred with sufficient accuracy for all practicable purposes. When, however, systems are joined up, test joints should be introduced to admit of disconnection being made when necessary for testing.

2. *Measurement of resistance of earths.*—To measure the resistance of a lightning conductor earth, two other earths, neither in metallic contact with one another nor with the earth to be measured, are required;* if there is only one lightning conductor available, the simplest plan is for the inspector to take two copper plates with him, and to use them as auxiliary earths; if, however, there are other lightning conductors in the vicinity, then any two of them may be used, as stated above.

The resistance of the earth connections is to be measured as follows, viz.: three observations are to be made with three independent earths taken two and two together, and the resistance of the several earth connections computed by means of the three resulting equations thus:

Let L = resistance of the leads, X that of the conductor under test, and Y and Z those of the auxiliary earths; then the resistance of the leads, the conductor, and one test earth will be denoted by $L + X + Y$, and is equal to W' say;

the resistance of the leads, the conductor, and the other earth will be—

$$L + X + Z = W''$$

and that of the leads and the two auxiliary earths will be—

then— $$L + Y + Z = W'''$$

$$X = \tfrac{1}{2}(W' + W'' - W''' - L)$$
$$Y = \tfrac{1}{2}(W' + W''' - W'' - L)$$
$$Z = \tfrac{1}{2}(W'' + W''' - W' - L)$$

3. *Instruments for testing.*—Lightning-conductor earths may be tested by a Bucknill's balance, which is a form of Wheatstone's bridge specially designed for testing lightning conductors. Joints and conductors may be tested by the instrument known in the Telegraph Department as a battery detector.

A. Testing with Bucknill's balance.—A form of Wheatstone's bridge has been specially designed for testing lightning conductors by Captain Bucknill, R.E., and is known as Bucknill's electrical balance, Bucknill's test box or more commonly Bucknill's balance.

The instrument consists of a set of resistance coils, a galvanometer, a key and four terminals, and a reversing switch contained in a box.

The connections for using it are as follows:—

(*a*) Connect the two elements of a (Leclanché) battery of about 5 cells to the terminals marked respectively Z and C.

(*b*) Plug the reversing switch on the vertical diameter.

(*c*) Join together the two leads or leading wires, you purpose using for the test, and attach the other ends to the two terminals marked Line and Line.

* They should not be less than 30 yards apart.

(*d*) Insert a plug in the place marked "equal" and adjust, by plugging or unplugging the other resistances so that the galvanometer shows no deflection when the key is depressed.

The value of the holes unplugged will be equal to the resistance of the leads, which will be denoted by the symbol "L" in the equations in para. 2. If preferred, the resistance of the leads can be calculated from the gauge and length of wire used.

Note.—In order to adjust the variable resistance it is necessary to note first in what direction the needle of the galvanometer is thrown when the peg marked ∞ or *LNF* is taken out. Then whenever the needle, on the depression of the key, moves in the same direction it shows that the adjustable resistance is too great and conversely, a movement in the opposite direction shows the adjustable resistance to be too small.

(*e*) Next disconnect the leads where they are joined together and attach them to the two earths to be tested. Care must be taken that these earths are disconnected from all other earths.

Note.—The instrument should have been set up in the first place, so that the needle of the galvanometer points to zero. If, when the leads are attached to the earths, the needle moves away from zero, it shows that an earth current is present which may have a somewhat disturbing influence on the tests.

It is advisable to avoid these earth currents as far as possible by using for the tests earth connections composed of the same metals. If the deflection from zero is not very great from this cause, no notice need be taken of it, an absence of movement in the needle on depression of the key being the indication that true balance has been obtained. If the deflection caused by the earth current moves the needle beyond 45°, it should be brought back to and kept at zero by a magnet.

(*f*) Proceed as in section "*d*" and note the resistance taken out when balance has been obtained.

Then remove the pegs from the vertical diameter of the reversing switch and insert them in the horizontal diameter and adjust the resistances until balance is again obtained and then take a mean of these two values. This will be the value of W' in the equation given in para. 2.

Note.—Should it be found when all the pegs of the adjustable resistance have been removed, with the exception of the ∞ peg, that the deflection still shows the adjustable resistance to be too small, the peg inserted in the hole marked "equal" must be removed and placed in that marked "X ten" and the variable resistance adjusted until balance is obtained. The value of the adjustable resistance thus obtained must be multiplied by ten to get the true resistance of the earth connection.

(*g*) To obtain the value of W'' and W''' proceed as described for W'.

Note.—The resistance of an earth connection should, in damp ground, not exceed 2 ohms for each earth. If it should exceed 10 ohms the defective earth should be examined. In very dry sites, however, it may not be possible to reduce the earth resistance as low as 10 ohms.

5. *Testing conductors.*—Conductors may be tested for electrical continuity as described above, the resistance of the leads first being taken and then the whole length of the conductor, from upper terminal (*above* topmost joint) to ground line, inserted between the ends of the leads. The points of contact of the leads with the conductor should be scraped bright and the contacts made so that no resistance may be made at these points.

The insertion of the conductor between the ends of the leads should not increase the resistance of the circuit by a measurable amount. If any increase of resistance is observed, it must be due to bad joints and these can be localized as follows:—

Leave one lead attached to the conductor at ground line and, after detaching the end of the other lead from upper terminal, attach it immediately below each joint in succession until the resistance obtained is the same as when only the leads were in circuit.

If the joints can be conveniently reached, another simple method is as follows:—

Take a cell of low resistance and connect it with the battery detector by two leads of convenient length and note the deflection from zero. Scrape the conductor on either side of the joint to be tested and make contact with two leads forming a

simple circuit of the cell battery detector and joints, taking care to keep the total length of the leads the same as before. A diminution of deflection will indicate a resistance in the joint.

Note.—If the deflection of the battery detector is excessive, it can be reduced by connecting a piece of wire of suitable gauge and length across its terminals: a deflection of 45° is the most suitable. The circuit should not be closed longer than is absolutely necessary to get a reading on the galvanometer on account of the tendency of the battery to fall off in strength.

6. *Steps to be followed when testing.*—In testing a lightning conductor, the inspector should first examine the conductor, visually and then electrically. In making the visual examination care should be taken to thoroughly examine the mechanical condition of the system. Special attention should be paid to the joints and to the conductor at the ground line.

In making the electrical test the steps to be followed are:—

First.—Balance and find resistance of the leads with their ends joined and call this resistance L.

Second.—Disconnect the ends of the leads and join one to the summit of the lightning conductor and the other to the conductor at ground level and again balance. Denote the resistance of the conductor by R and the resistance in circuit will be $L + R$ and unless the conductor is defective the resistances L and $L + R$ will be equal or $L = L + R$.

Third.—Disconnect the end of the lead from the summit of the conductor, leaving the other connected to it at ground line, and connect it to one of the earths under test or to one of the auxiliary plates which call X, and there will then be in circuit the leads, the conductor earth and one of the other, or auxiliary, earths or $L + X + Y$. Balance and note the resistance with the battery switch plugged up in the vertical diameter and again with it plugged up in the horizontal diameter and call the mean of these resistances W' or—

$$L + X + Y = W'$$

Fourth.—Disconnect the lead from Y and join it to the other earth, or auxiliary plate Z. Balance as before and call the mean of the resistances W'' or—

$$L + X + Z = W''$$

Fifth.—Disconnect the lead from X and join it to Y. Balance as before calling the mean of the resistances W''' or—

$$L + Y + Z = W'''$$

and from these three equations we get, as before,—

$$X = \tfrac{1}{2}(W' + W'' - W''' - L)$$
$$Y = \tfrac{1}{2}(W' + W''' - W'' - L)$$
$$Z = \tfrac{1}{2}(W'' + W''' - W' - L)$$

7. *Test sheet.*—The following is a useful form for use when testing with the Bucknill's balance:—

Tests of Lightning Conductor of *at* *taken on*

X represents Lightning Conductor.
Y represents
Z represents

Tests taken with Bucknill's electrical balance.

L represents resistance of leads or leading wires.
R represents resistance of conductor from summit to ground line.

$L =$ } Mean =

$L + R =$ } Mean =

In earth testing.

$L + X + Y$ in circuit = } Mean = $= W'$
Do. do. with poles of battery reversed = }
$L + X + Z$ in circuit = } Mean = $= W''$
Do. do. with poles of battery reversed = }
$L + Y + Z$ in circuit = } Mean = $= W'''$
Do. do with poles of battery reversed = }
$X = \frac{1}{2}(W' + W'' - W''' - L) =$
$Y = \frac{1}{2}(W' + W''' - W'' - L) =$
$Z = \frac{1}{2}(W'' + W''' - W' - L) =$

APPENDIX.

List of Instruments, &c, required for testing Lightning Conductors.

Name of article.	No.	Purpose for which required.
Leclanché battery of 4 or 5 cells. (The Burnby dry cell made by the Electrical Construction Corporation, Wolverhampton, is a convenient form of cell for this purpose)	1	For testing conductors, wires, &c.
Bucknill's balance	1	For ascertaining resistances.
Insulated copper wire; old field cable core 3, 5 or 7 thin wires, insulated with gutta percha and bound with primed tape mile.	¼	For leads and connections between instrument and conductor or earths.
Copper plates not less than 1′ × 1′ with copper connecting wires rivetted and soldered to each	2	As auxiliary earths.
Coupling or connecting screws, large ...	6	For joining leads to conductors &c
Do. do. small ..	6	For joining wires.
Cotton covered No. 16 or No. 18 copper wire, yards.	100	For connecting battery and instrument.
Battery detector	1	For testing joints.
Smooth flat file 6″ to 10″	1	For cleaning points of connections.
Clasp knife	1	For scraping ends of thin wires and cutting string, &c.
Magnet horse shoe, small	1	For use with Bucknill's balance.
Pliers bell-hangers or cutting	1	For cutting and bending wires.
Chamois leather*	1	For cleaning apparatus.
Boxes	2	For containing apparatus.
Primed tape yards	150	For re-covering test joints.

* Note.—The leads or insulated wire should be kept on drums or rollers and not in coils. If kept in coils the insulating material becomes broken very soon.

1300/8

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PUBLIC WORKS DEPARTMENT.

CIRCULAR.

The Chief Engineer has the honour to circulate, for the information and guidance of officers of the department, the accompanying manual of instructions prepared by Sergeant Reynolds for the erection and testing of lightning conductors. The appendix to the manual contains a list of instruments requisite for testing. It will be seen that the Bucknill balance has been adopted for ascertaining resistances in preference to the tangent galvanometer. The latter should, therefore, be replaced by the former in all divisions where the tangent galvanometer is in use.

2. Superintending Engineers will maintain in their offices a list of the divisions in possession of sets of instruments and Executive Engineers will see that the sets are kept complete and the instruments well cared for.

3. A description of each lightning conductor should be drawn up and filed in Divisional offices and all conductors should be tested at least once a year, the results being consecutively filed with the descriptive memoir of the conductor.

4. It should, if possible, be arranged that at least one officer and one upper subordinate in each division is instructed in the use of the instruments, and all conductors hereafter erected should be inspected and passed by a duly qualified officer or subordinate. The record of this inspection will be filed with the descriptive memoir referred to in the previous paragraph.

(Signed) J. PENNYCUICK, Colonel, R.E.,
Chief Engineer, P.W.D.

10 June 1892

To Superintending Engineers.
„ the Consulting Architect to Government.
„ the Superintendent of Works, Periyár Project.

Exd. A. D. Xavier.
Spare Copies

[G 53]

Financial Department.

1300/16

CHIEF SECRETARIAT MADRAS

PROCEEDINGS OF THE MADRAS GOVERNMENT.

READ the following paper:—

From the Presidency Port Officer, Madras,
dy 14th April 1893, No: 1636/119 G

I have the honor to request that a sum of Rs (220) Two hundred and twenty, together with the usual per centage for supervision and tools and plant may be placed at the disposal of the Superintending Engineer II Circle, from Port Funds for putting up a new Lightning Conductor at Point Divi Lighthouse.

Order dy 25th April 1893, No: 405.

The Accountant General will be requested to place the sum of Rs (274) Two hundred and Seventy four at the disposal of the Public Works Department from Port Funds.

(True Extract)

W. Wightwick
Under Secretary, P.W.D.,
for Chief Secretary.

× 220 + 54

To The Public Works Department.
" Accountant General, Madras
" Presidency Port Officer - Madras.

× 2.8

[6/15] M. CURRENT No. 413/

Govt. of {18} Madras.

To

The Public Works Dept

Recd 3.5.93

Proceedings, dated 25 April 189 3
No. 405.

Subject.

Requesting the Accountant General to place Rs 274 at the disposal of the P.W. Dept from Fort. funds for putting up a new lightning conductor at Point Due Light-house.

P.C. 17/5 With Order

By
No. 1300 Wdf 15 May 1893

Communicated to the Suptg. Engineer II Circle and the Examiner of P. W. Accounts.

PH
4.5.93

OCB
8.5.93

DESPATCHED
16 MAY 93

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8 of 17/5

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To

The Suptg. Engr. II Circle
- Examiner of P. W. Accounts

2/15 Sent
Old 64-5
Mr 9-5

12.8.93