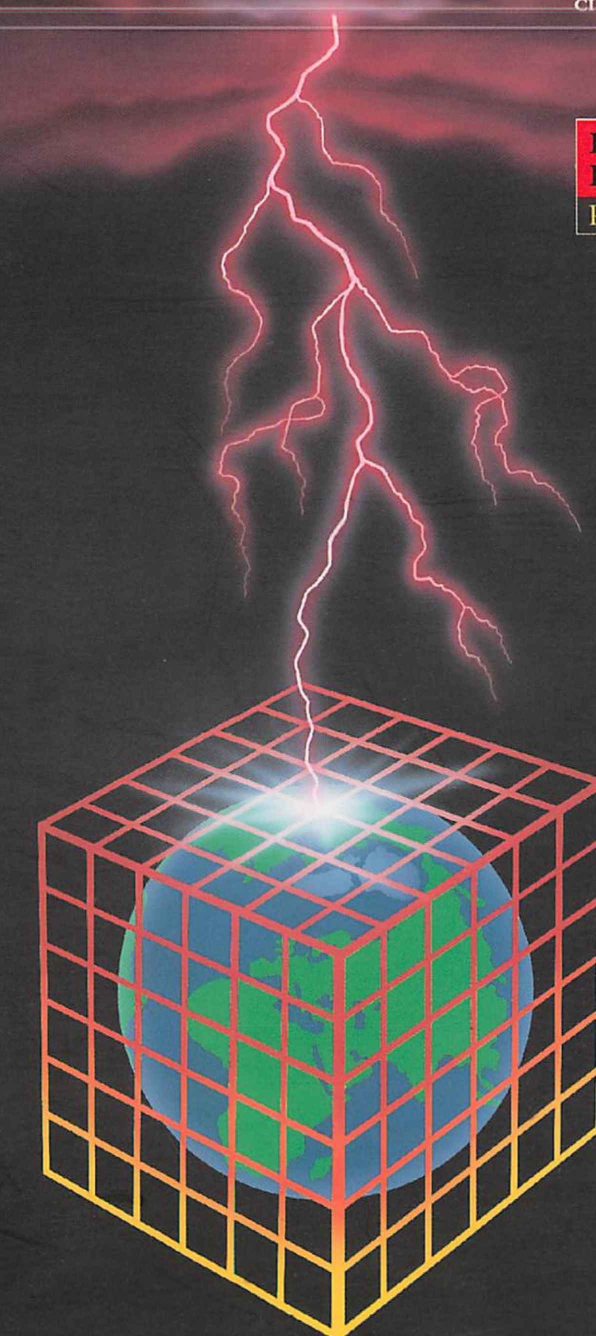
Publication CHB/4/95
CI/SfB 68.6

EARTHING & LIGHTNING PROTECTION

Consultants Handbook



furse

W.J. Furse & Co. Ltd.

W.J. Furse & Co. Ltd. is a world leader in the design, manufacture and supply of earthing and lightning protection systems.

Over 100 years of experience makes us acknowledged experts in the field. The technical support we provide to our customers, ranging from system design advice through to on-site supervision, testing and commissioning, is the envy of our competitors.

Quality approved to ISO9001, we are dedicated to providing cost-effective and highly efficient products and service.

This consultants handbook offers an informative guide for designers, engineers and contractors and has been produced with the following aims:

- **To briefly explain the theory and phenomenon of lightning.**
- **To precis and simplify where possible the British Standard Code of Practice BS 6651 1992 'Protection of Structures Against Lightning'.**

Also included in the handbook are answers to many of the more popular questions on lightning protection put to Furse by consultants, architects and contractors.

All codes of practice or standards are open to individual interpretation. This handbook therefore reflects Furse's own views on good practice and it is not the intention that these views replace in any way the recommendations contained in BS 6651, but rather to be read in conjunction with the code.

We hope you find this handbook useful and should you require assistance or advice, please do not hesitate to contact Furse at the Company's Head Office address shown on the reverse of this handbook.

Certificate No: Q6054

Q What is the minimum distance for spacing earth rods?

A Views vary considerably on this question, but it is generally accepted that the distance between rods should be at least equal to, and preferably greater than, its depth.

Q When should I use a solid copper earth rod rather than a copper covered steel one?

A A solid copper rod has nothing like the mechanical robustness of a copper covered steel rod and so should only be used in soil that is comparatively easy to drive into. One reason for choosing solid copper could be because of the aggressive nature of the soil, where the presence of steel may ultimately create a corrosion problem.

Q How do I know what type of earth electrode to use?

A The choice of earth electrode type is governed, to a large extent, by the prevailing soil conditions. A soil resistivity survey indicating lower soil resistivity at greater depths will make the deep driven earth rod electrode a logical choice.

The ground that has a one metre depth of soil before encountering bedrock would best be suited to a buried radial strip electrode, provided the system is installed below the frost line and below the area that is subject to the influence of seasonal weather changes.

Q Must I bond my lightning protection earth to the main electrical earth?

A BS 6651 in line with other Standards now advocates that all earths, whether they be the lightning protection earth, the main electrical earth, computer earths, etc. should all be bonded. This action minimises the risk of dangerous step and touch potentials.

Agreement of the local electrical supply authority should be obtained before making any connection to the electrical earth.

Q What is an Earth Seal?

A This is a form of gland which is used to seal the earth rod when it is necessary to drive rods through the waterproof membrane under a building. It consists of a galvanised steel plate, which at its centre has a boss through which the rod is driven. This boss incorporates a gland, similar to a cable type, which is tightened round the rod to form a seal.

Q What is a counterpoise earthing system?

A This terminology is sometimes used by consultants to describe a common earth for the whole building, including the lightning protection and the contents.

Q Can stainless steel earth rods be connected to copper earth conductor underground?

A 'Yes', provided the copper conductor below the ground has a protective cover (such as PVC) and the earth rod joint is sealed from any ingress of moisture. For example, by wrapping the complete joint with a bitumastic bandage.

Acknowledgements:

BS 6651: 1992 Complete copies of British Standards can be obtained from BSI Publications,
BS 7430: 1991 Linford Wood, Milton Keynes MK14 6LE
AS 1768: 1983

Q Which is the best type of connection to use in earthing and lightning protection systems – the crimp connector, bolt connector, or a thermit welded connection?

A The final choice will depend on the application. Bolted connections are obviously suitable for fittings such as test clamps, where the conductors have to be removed when testing. Thermit welds are ideal for underground connections, as they possess the following qualities:-
- mechanical strength
- excellent current carrying capacity
- reliability
- low electrical resistance

Furse would be pleased to offer expert technical guidance on the choice and type of fitting to suit your application.

Q When installing a lightning conductor system, how far from a building should the earth rods be placed?

A They should be driven into the ground beneath, or as close as practicable to the structure and down conductor. The aim is to offer a lightning strike as direct a route as possible from the top of the structure to the earth.

Q It is common practice to pour water and salt on a newly installed earth rod, is it good practice?

A No. This action merely creates an artificially low local soil resistivity. As soon as the water and salt have leached out of the local soil the earth resistance value will increase. The addition of salt will also greatly increase the risk of corrosion to the electrode.

Q If I cannot use salt to help me achieve a lower earth reading, is there anything on the market that can?

A Furse use two main conditioning agents – Bentonite and conductive cement.

Bentonite is mixed with water to form a slurry – its resistivity being determined by the amount of water used.

Conductive cement is made with graded granular carbonaceous aggregate in place of the conventional sand or aggregate. It has a resistivity of 10 ohm.cm.

Both agents can be laid in a horizontal bed or poured down a drilled vertical hole, creating a lower resistance between the embedded earth electrode and the surrounding soil.

Q A minimum resistance of 10 ohms is often quoted – what action should be taken if this cannot be obtained?

A A further reduction can be achieved by extending or adding to the number of existing electrodes. Or by installing a ring conductor buried a minimum of 0.6m below the ground. This ring would inter-connect the individual earth electrodes at each down conductor.

Q If I increase the diameter of my earth rod, will it significantly reduce the resistance to earth?

A Increasing the diameter of an earth rod has the effect of only slightly reducing the resistance to earth. Typically increasing the diameter of a copper covered steel rod from 12.5mm diameter to 25mm diameter will increase the cost by 400%, increase the weight by 400%, but only decrease the resistance by 9.5%.

Section Contents

Section 1

The Theory of Lightning

Benjamin Franklin (1707-1790) is generally considered to be the father of modern Lightning Protection theory. His celebrated kite experiment proving for the first time that storm clouds generate, hold and discharge static electricity.

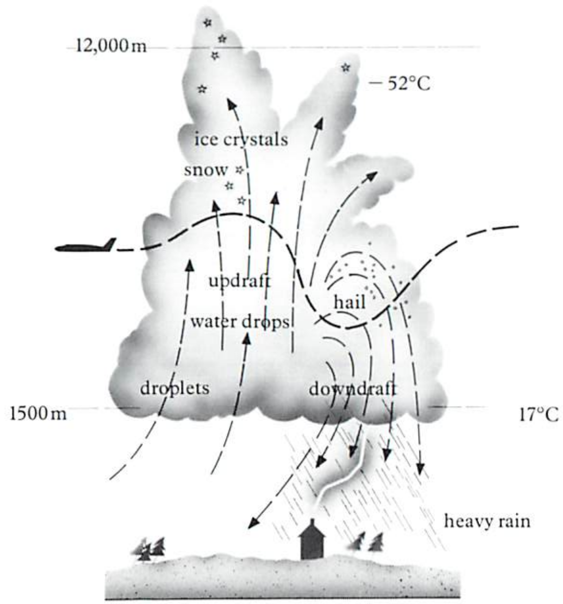
The Characteristics of Lightning

Formation of Storm Clouds

Lightning is formed as a result of a natural build-up of electrical charge separation in storm clouds.

There are two types of storm clouds which generate a static electrical charge: heat storms and frontal storms.

Figure 1 HEAT STORM



The heat or convective storm (Figure 1) predominates in tropical regions and mountainous areas.

On a hot day, warm air rises from warm ground and is replaced by cooler air drifting down. The convection process progressively cools the rising air to form clouds, first as water droplets and then at greater heights as ice crystals.

In this way, a single or multiple cloud 'cell' is formed, the top of which may reach a height of 12km.

Q In what circumstances can I use the re-inforcing bar in concrete structures as a down conductor?

A BS 6651 permits the use of re-inforcing bars as a natural down conductor providing that the bars have multi-crossing points and provide a definite electrical continuity between the air and earth termination networks.

Q How do I route a down conductor in a cantilevered building?

A There is no easy answer to this question. Where possible, the down conductors could be sited at the corners where a straight path may be possible, but if as in many buildings, the cantilever continues around the whole building, then natural down conductors could be used, such as the reinforcing bars or steelwork. Or, if the building is in the course of construction, a fire resistant duct could be built in for the down conductor. In any case the possibility of voltage gradients at the earthing positions must be considered.

Q I have a problem with moving cranes, can they be earthed?

A Assuming that the crane is on rails, it is normal just to earth these at 20m intervals. The crane being all steel, forms a natural conductor, but as the crane has a number of moving joints, these may need to be bonded across to avoid damage to bearings, etc. How this is done depends entirely on the type of crane.

Q Is it dangerous to have a lightning conductor earth where people walk?

A 'Yes', it is potentially dangerous to have an earth electrode in a location where people walk or have access. When a lightning discharge takes place, the potential difference or gradient at ground level could be of a sufficiently high magnitude to be lethal to both humans and animals. This 'step potential', as it is known, can be minimised by burying the earth electrode so that its top is at least 1m below the surface and to insulate the connection between the down conductor and the earth's electrode. Further advice is given in clause A.1.2. of BS 6651.

Q How do I obtain a good earth for a building constructed on rock?

A There is no simple or easy solution to this question. Local soil conditions will have a significant bearing on the result. Guidance is given in clauses 16.5 and A.1.5 of BS 6651 for structures erected on rock.

Q Can copper earth rods be connected to galvanised tape underground?

A 'Yes', providing the galvanised tape, where it enters the ground, has a protective coating to isolate it from the soil and the copper rod. The earth rod joint should be sealed to prevent any ingress of moisture.

Unless it is unavoidable, we would not recommend the use of dissimilar metals in underground applications.

Q When an aluminium system is used, what is the best way to connect to the copper earthing?

A The mating surface of the aluminium should be cleaned thoroughly by wire brushing and an approved grease or jointing compound applied. The copper surface should be hot tinned and two mating surfaces bolted together. The complete joint should then be protected from the ingress of moisture by the application of an approved protective wrapping.

Alternatively a purpose designed friction welded bi-metallic connector manufactured by Furse offers a quick, easy and reliable method of terminating the copper and aluminium conductors.

Q Can I hide the system under the roofing?

A BS 6651 permits the use of air termination conductors to be installed below the roof covering, but advocates that it is used in conjunction with 0.3m high bare vertical rods projecting through the roof.

Q Can I use the flagpole as an air rod?

A Providing the pole is conductive (ie metal) then it should be bonded into the air termination network. It can then be considered as an air terminal.

Q If a roof conductor is painted, does this impair its efficiency?

A In Furse's opinion, any covering that acts as an insulator will impair it's efficiency. The extent of the reduction of efficiency is dependent upon the characteristics and thickness of the material. However, BS 6651 advocates the use of bare conductors for air termination networks wherever possible. If for, say, corrosion reasons, a covering is required, a PVC coating or painting is permitted.

Q The British Code of Practice infers that horizontal roof conductors are sufficient. Why then should I use air rods?

A BS6651 does not regard vertical finials as essential except where dictated by practical considerations. The American Code, however, recommends the use of vertical finials. The choice of use is, therefore, governed, to a large extent, on which Standard is being adopted.

Q If a building has a metal roof, is it necessary to install a roof conductor as well?

A Provided the roof is electrically continuous and meets the thickness requirements of Table 5 in BS 6651 and is connected to the down conductors, there is no need to install roof conductors.

Q Can down conductors be run behind marble cladding?

A This depends upon whether there is sufficient air gap between the outside frame of the structure and the decorative cladding, and how it is fixed. If there is insufficient movement of free air behind the cladding, it may be inadvisable to install the down conductors there, due to the mechanical forces created by the shock wave during a discharge, causing the cladding to be dislodged. Further information regarding these mechnical effects can be found in clause 4.4 of BS 6651.

Q Can down conductors be run inside a building?

A A down conductor should preferably run down the outside of a building. If an external route is inadvisable, for example, buildings of cantilever construction from the first floor upwards should not have their down conductors following the outside contour of the buildings. In these cases down conductors may be housed in non-metallic, non-combustible internal ducts and taken straight to the ground. For further details of this application see clause 15.7 of BS 6651.

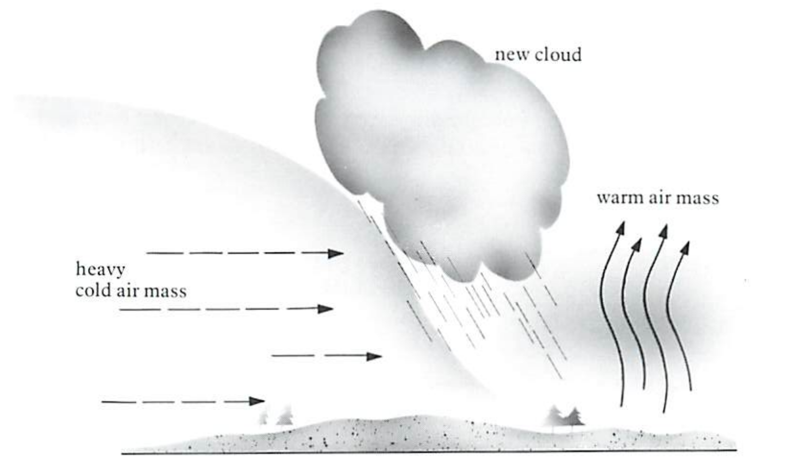
Q As several down conductors are needed can I bring them down in the same place?

A 'No'. All standards state that they should be equally spaced, wherever possible, around the building.

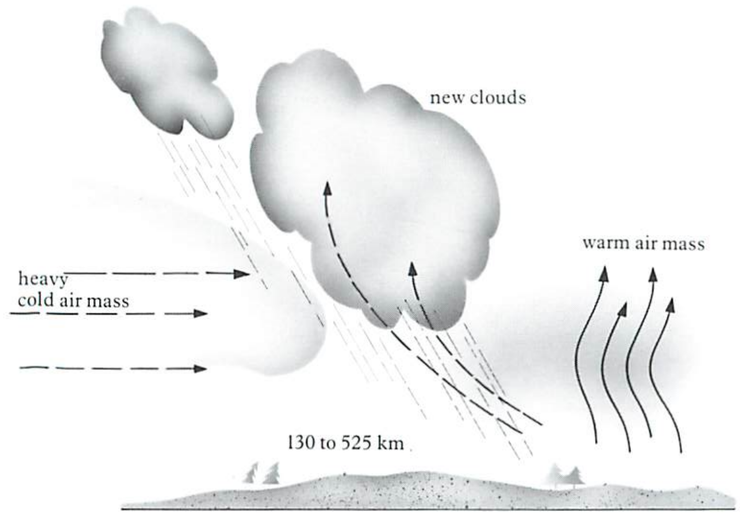
Q Can I run the down conductor through a lift shaft, or use the lift guide rails as a down conductor?

A 'No', BS 6651 strongly advises that lift shafts should not be used for this purpose. Down conductors may be housed in an air space provided by a non-metallic, non-combustible internal duct and taken straight down to ground.

Figure 2 FRONTAL STORM



Advancing cold air mass can wedge warm air upward to start an updraft at the cold front.



Over-running cold front may cause storms over a wide area.

Frontal Storms (Figure 2) which predominate in temperate regions are caused by the impact of a front of cold air on a mass of warm moist air which is lifted above the advancing cold front. As the warm air rises the process described above is repeated but the resulting cumulo-nimbus clouds may, in this case, extend over several tens of kilometres in width and contain a large number of individual cells with heights of between 7.5 km and 18 km.

Charge Separation

How clouds form is well understood. How the cloud separates its charge is not. Many theories have been put forward but everyone seems to agree that in a thunder-cloud, ice crystals become positively charged while water droplets carry a negative charge.

The distribution of these particles normally gives rise to a negative charge building up at the base of the cloud (Figure 3). This build-up at the cloud base gives rise to a positive build-up of charge on the ground. The ground can be as little as 1km away from the cloud base. This build-up continues until the voltage difference between the cloud base and the ground becomes so great that it causes a breakdown of the air's resistance, thus creating a lightning discharge.

Figure 3 CHARGE BUILD UP IN THUNDERCLOUD

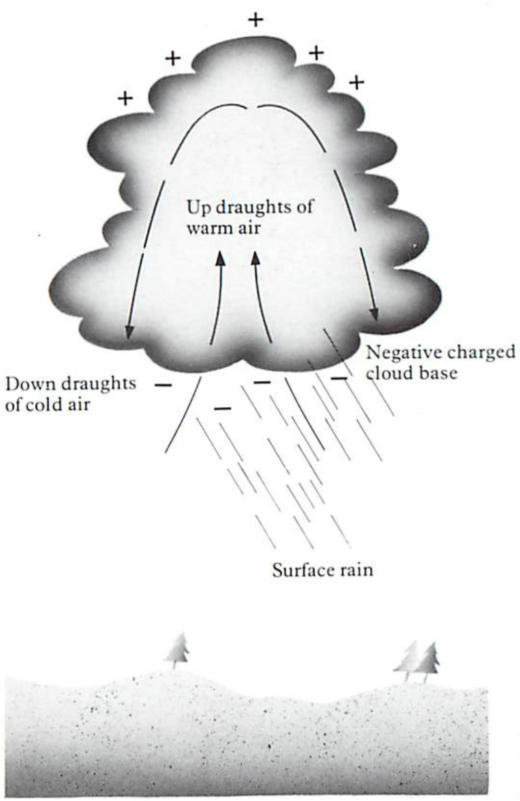
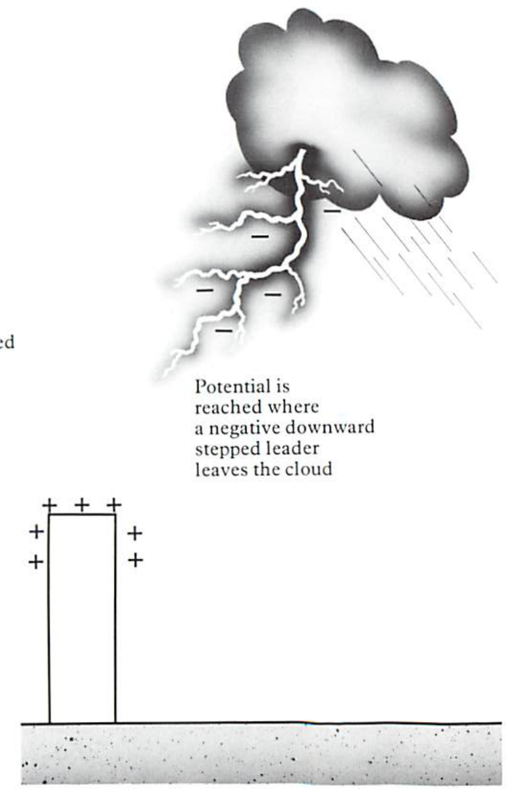


Figure 4 DEVELOPMENT OF THE DOWNWARD STEPPED LEADER



Q When would I use a catenary wire suspended above the area to be protected?

A In instances where a high degree of protection is required. For example, with high risk structures such as explosive factories, etc.

Q Can I mix circular/stranded conductor with tape conductor on my lightning protection system?

A It is not normal practice to mix the various types of conductors, but for instance, circular conductor can change to tape conductor at the test point.

Q The building next door has a lightning conductor, do I need one or will it protect me?

A No reliance should be placed on the possibility that a nearby structure is offering some degree of protection to your building. You should, therefore, through Furse free advisory service, seek expert advice.

Q What is Naval Brass?

A Naval brass is an alloy of copper and zinc, with a small amount of tin. Naval brass contains no lead. Unlike commercial brasses, it exhibits good corrosion qualities and is mechanically robust. It is included in the material section of BS 6651.

Q Does copper attract lightning better than aluminium?

A 'No.' The choice of materials for a lightning protection system is dictated by their resistance to corrosion, overall comparative costs and their compatibility with other metals used on the structure – not by the material's ability to attract lightning. Lightning will be attracted to any earthed conductive (metal) part of a structure in preference to a non-conducting material.

Q When using an aluminium system, does the conductor size have to be greater than when using copper?

A According to BS 6651, 'No.' When lightning strikes a conductor, the lightning current is of a high magnitude, flowing along the conductor for only a fraction of a second. The choice of material is not as important as in a continuous current carrying application. The minimum size recommended in BS 6651 is $50mm^2$ for both copper and aluminium.

Q Furse sell non metallic DC clips. Do they comply with the British Code of Practice?

A The Code merely states that, where non-metallic fixing materials are used, then consideration should be given to their possible degredation due to ultraviolet light, frost, etc. Furse clips are manufactured from a high-grade polypropylene which exhibits excellent mechanical and thermal properties. They provide a high resistance to ageing when exposed to ultraviolet light over many years.

Q Can I use the metal cladding around the parapet wall as part of lightning protection?

A 'Yes,' provided the cladding is of sufficient thickness, is electrically continuous and is bonded into the other parts of the lightning protection system. BS 6651 gives minimum thickness of sheet metal for this application.

Q Can I use the TV aerial as a lightning conductor?

A 'No' the aerial should be within the zone of protection of the lightning protection system. Additionally the aerial should be bonded into the air termination network.

Q What is Radioactive Lightning Protection?

A Radioactive lightning protection is based on claims that a radioactive source around the head of an air terminal enhances its natural ion discharge which naturally takes place during a static build-up associated with lightning storms. This enhancement is claimed to be so great that it improves dramatically the ability of an air terminal to attract to itself a lightning strike.

This form of protection, however, has never been accepted by any international body and is disputed by many leading authorities on the subject.

The reports contained in the Furse document "Papers on 'Exotic' Lightning Protection Systems" confirms the view that a radioactive source has little, or no effect as a lightning protection unit. The foreword in BS 6651 makes the following statement:-

"It is recommended that the materials extent and dimensions of the air terminations, down conductors, earth terminations, bonding, components, etc. as laid down in this standard should be adhered to in full, irrespective of any devices or systems employed which are claimed to provide enhanced protection."

In effect, researchers who have examined the various claims of 'exotic' systems, have found them to have no scientific credibility.

Q If the steelwork of the building is used as part of the lightning protection system, and a person is touching it, i.e. when it receives a strike, will that person suffer injury?

A Providing the path offered to the lightning strike (in this case the building steelwork) is of a sufficiently low inherent resistance (usually less than one ohm) and the earthing system meets the requirement of BS 6651 both in terms of earth resistance and voltage gradient at the surface, then the person should not suffer any injury. The lightning current will prefer to travel down the path of lowest impedance – in this case the building steelwork.

Q What is step potential?

A Step potential is the voltage gradient, or the potential difference measured in volts existing between the feet of a person standing on the ground.

When a lightning strike reaches earth and is being dissipated in the soil, there can exist a difference in potential between a person's (or animal's) feet.

Q If you bond metal window frames, ducting, etc. into a lightning protection system, will these then become 'live' when lightning strikes, therefore, becoming potentially dangerous to any contents or persons nearby?

A By not bonding any metalwork close to the lightning protection systems, if lightning should strike, the voltage difference between the lightning conductor and the metalwork could cause a flashover, therefore, becoming 'live' and finding a dangerous and uncontrollable path to earth from this point.

By bonding all the metalwork into the lightning protection system, the voltage always remains the same, thereby preventing any flash-over and ensuring safety for contents and persons nearby.

Q When can I use an aluminium system instead of a copper one?

A Aluminium could be chosen for a lightning protection system for a variety of reasons. The structure to be protected may, for instance, be sited in a location where a copper corrosive atmosphere is present. The natural colour of the structure may require the choice of aluminium. Certain locations with a salt laden environment may cause verdigris on the copper, which would ultimately cause staining of the building. In these situations, aluminium could be considered.

Lightning Discharges

The first stage of this discharge is the development of a stepped downward leader within the cloud which moves towards the ground. This downward movement continues in approximately 50m steps. It is not visible to the naked eye. When the stepped leader is near the ground (Figure 4) its relatively large negative charge induces even greater amounts of positive charge on the earth beneath it, especially on objects projecting above the earth's surface.

Since these opposite charges attract each other, the large positive charge attempts to join the downward moving stepped leader by forming an upward moving streamer (Figure 5). The two meet and form a complete conducting path along which a massive current attempts to flow in order to equalise the difference in potential between cloud and ground. This is termed the "return stroke" (Figure 6) and is the bright lightning flash we see.

Figure 5 DEVELOPMENT OF THE DOWNWARD STEPPED LEADER AND UPWARD STREAMER

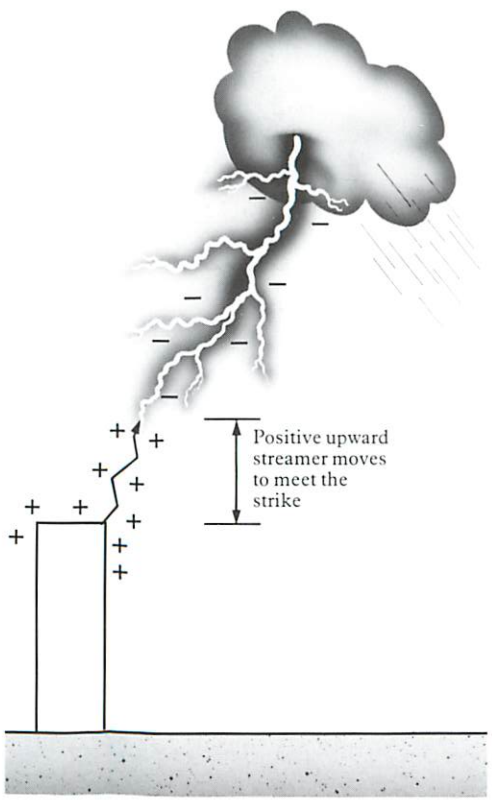
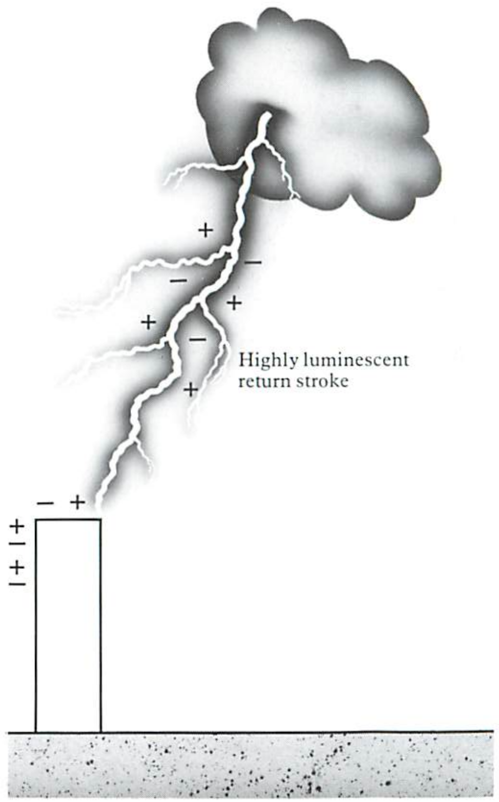


Figure 6 RETURN STROKE



The lightning discharge described is the most common seen by man and is termed a negative descending stroke. Several variations can occur, ie from mountain peaks or from structures. In these situations a positive leader channel may start upward from the mountain peak due to the intense concentration of positive charge at that point.

Lightning Strokes

As well as different types of lightning discharge different strokes also occur. No two lightning strokes are the same.

Ribbon lightning is a series of successive strokes which appear simultaneously but close to each other. This is thought to be caused by a strong wind blowing the ionised channel sidewards during the intervals between the separate component discharges of the flash.

Beaded lightning (Figure 7) is when the stroke appears to break up into luminous fragments.

Air discharges (Figure 8) emerge from the cloud but do not reach the ground. They can run horizontally for many kilometres. Sometimes they re-enter the cloud base further on, in which case they are regarded as cloud-to-cloud discharges.

Figure 7 BEADED LIGHTNING

Figure 8 AIR DISCHARGE

Cloud flashes take place inside the thundercloud so that only a diffused flickering is seen. These are more numerous than flashes to the ground and a ratio of 6:1 or more is thought probable.

Ball lightning is reported to be a luminous flash with a diameter of between 10-20cm. It is seen to appear after a strike to ground and moves along the ground or through the air. Many mysterious tales have been told relating to ball lightning and many authorities have expressed doubts about its existence.

Section 6

Questions & Answers

Q If I fit lightning protection, am I guaranteed no damage will occur in the event of a strike?

A Provided the installation is carried out to the relevant Code of Practice and correctly installed with approved materials, the risk of damage is likely to be minimal. However, because of the nature of lightning, it is impossible to guarantee total protection.

Q Should the metal scaffolding on a building be protected against lightning?

A BS 6651 strongly recommends that throughout the period of construction, all large and prominent masses of steelwork including scaffolding should be effectively connected to earth.

Q How often should a lightning conductor system be tested?

A It should be tested every 12 months, or preferably slightly less in order to vary the season in which tests are made.

Q If a lightning conductor system on a building has been struck by lightning, does it need to be tested afterwards?

A Most certainly. A thorough examination of all the components and conductors should take place and any items that have suffered damage should be replaced. The system should also be tested to ensure that it still complies with the earth resistance requirements.

Q Can lightning cause damage to my building or interior equipment without a direct strike?

A The proximity and magnitude of the indirect strike will determine whether any damage to the actual building structure occurs. There is a greater chance that the indirect strike will travel into the building via power supply cables or telecommunication or signal cables. In this case the induced voltage spike will cause damage to some or all of the 'sensitive electronic equipment' housed within the building.

This equipment should be protected by surge protection units.

Q What special precautions have to be provided for buildings housing computers?

A Apart from the provision of a conventional exterior protection system to the building, computers or sensitive electronic equipment within the building also need their own 'secondary protection.' This would involve the installation of suitable surge protection devices. These devices, if correctly designed and installed, should protect this type of sensitive equipment from any harmful surges.

Soil Resistivity Measurements

A technique for measuring the earth's resistivity was proposed by the American, Dr. Frank Wenner, in a scientific paper published in 1915. Since that time it has been universally accepted as the most popular method to employ.

The Wenner method gives the average resistivity of the soil between ground level and a given depth. Using this method, Furse site surveys measure the soil resistivity of various depths up to a minimum of 20 metres. This enables the plotting of a soil resistivity v. depth graph to reveal the optimum earth electrode system and where in the soil-strata it should be located.

Earthing Design

If the objective is to achieve a desired resistance to earth for a particular installation, e.g. one ohm, then formulae given in BS 7430 (1991) (shown here on p35) can be used to calculate the required amount of electrodes. If the earthing requirements are more comprehensive, for instance achieving a stipulated resistance to earth and also addressing the problems associated with step and touch voltages, then an internationally accepted standard such as IEEE standard 80 (1986) – Guide for Safety in AC Substation Grounding, should be employed. Other nationally recognised standards on earthing may be used to calculate the earth electrode requirements, but design efforts at Furse have concentrated on BS7430 and IEEE80.

Figure 37 CAD GENERATED PRINT-OUTS SHOWING OPTIMUM EARTHING DESIGNS

A. BS 7430 Calculations B. IEEE80 Calculations C. IEEE80 Schematic

For BS 7430 systems the resistance values are calculated to allow the Designer simply to select the 'bill-of-quantities' which gives his required resistance. IEEE80 designs include a schematic drawing representing the earth grid layout; from this, accurate site installation drawings can then be produced.

Furse Earthing Systems

In order for Furse to design a BS 7430 system, the following information must be provided:-

1. Earth resistance requirement.
2. A site soil resistivity survey and details of local soil conditions. The soil resistivity is often estimated at 100 ohm metres for budgetary purposes only.
3. Site dimensions/restrictions. A ground level plan of piles, walls, service pipes, cables, etc.

IEEE80 designs require, in addition to the above, the following:

4. Design fault current magnitude. Due consideration should be given as to whether the full earth fault current will flow from the earth mesh into the surrounding soil or whether it will be proportioned through the cable sheaths or aerial earth wire of a transmission tower.
5. Duration of fault. This is usually a half to three second rating.
6. Depth of burial of the earth grid (normally 1 metre below ground level).
7. Preferred earth conductor type and dimensions. Copper is the natural choice, its size dependent on fault current and temperature ratings, and the minimum mechanical strength requirements. Reduced conductor size may be acceptable when multiple connections between possible sources of fault current and the earth mesh grid exist.

Long duration currents can cause fire, whilst short duration high current peaks tend to tear or bend metal parts. The electromagnetic force develops in proportion to the square of the instantaneous current.

Because of these mechanical forces, it is necessary that lightning conductor systems are safely fastened to the building they are intended to protect.

Metals which are adequately earthed, generally receive a discharge with little damage.

If insulating or semi-insulating materials receive a strike, an explosive reaction may occur causing severe damage.

Trees for instance are, in many cases, split or stripped of their bark and the damage can extend underground to their roots.

When lightning strikes an unprotected building the stroke seeks out the lowest impedance path to earth which is normally through the electrical wiring or water pipes.

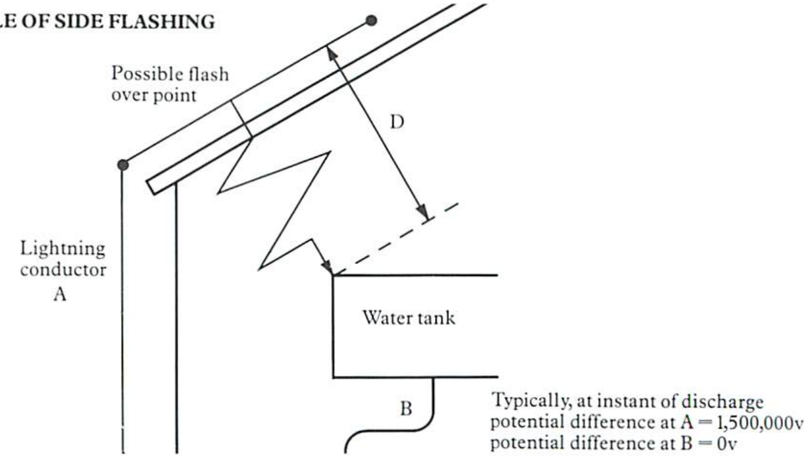
In order to reach these metal paths the discharge must pass through some type of barrier. In penetrating such barriers, explosive damage usually results. The explosive effect can dislodge materials with considerable force sufficient to hurl relatively large pieces of masonry or wood many metres.

Side-Flashing

The problems relating to side-flashing have attracted a great deal of attention in recent years and are a very important consideration when designing a safe lightning protection system. Damage to life and property can occur if the danger of side-flashing is not considered.

The principles of side flash can be explained by the following simple example. (See Figure 12).

Figure 12 EXAMPLE OF SIDE FLASHING



If the lightning protection system on a structure is hit by lightning, then the current flowing through the system and the resistance/impedance offered by the conductor path will determine the magnitude of the potential difference seen by the lightning conductors with respect to true earth. The lightning conductors can, instantaneously, have a potential of magnitude of megavolts (1,000,000V) with respect to true earth.

If there is metalwork in close proximity to lightning conductors which are connected directly to earth, then for the purpose of this example, we can say that it is at zero volts with respect to true earth.

If the current flowing down the lightning conductor path at the time of the discharge sees a high impedance along its route and the nearby metalwork offers a lower impedance path to earth, then the discharge will flash over to the nearby metalwork, provided the magnitude of the potential difference is sufficient to breakdown the gap 'D'.

Some of the reasons why side-flashing could occur include:

- **Faulty lightning protection system**
- **Incorrect routing of conductors**
- **High impedance of lightning protection system**

A faulty lightning protection system may well have an interruption in its electrical path, thus when the discharge occurs, it prefers to travel down a nearby earthed path which offers a lower impedance. An example could be copper piping connecting the water tank in the roof to the water supply underground.

A good lightning protection system should always follow the most direct route to earth. Unfortunately, practical considerations do not always allow this. One example of incorrect routing of conductors is the re-entrant loop (see Section 3 – Figure 27D – Page 33). The example shown in Figure 26 highlights the danger to personnel that side-flashing can cause.

A high resistance in the lightning protection conductors can easily be caused by one poor electrical joint within the system. A badly designed clamp, an incorrectly installed fitting, or inferior quality corroded materials can be sufficient to cause a high resistance spot. A lightning discharge encountering this high resistance could well take a lower resistance path afforded by nearby earthed metalwork, thus creating a potentially dangerous side flash.

Further details of the prevention of side-flashing can be found in Section 3 – Bonding – Page 41.

Step and Touch Voltage

In the event of a lightning stroke, a voltage gradient builds up in the soil where the lightning discharge enters the earth. In homogeneous soil the current rapidly leaves the electrode. The current density is highest near the electrode, rapidly decreasing with distance.

In soil of uniform resistivity a significant voltage gradient will exist between two points that are at varying distances from the electrode (Figure 13).

The voltage difference across the span of a step a man takes can be lethal.

The step potential of a person is significantly lower in comparison with a large four legged animal. The average human step distance is just under one metre whilst the distance between the front and back legs of an animal is much greater. Current will flow through the legs of a man, whilst the current flow will be through the heart region in an animal.

Animals naturally shelter under trees during storms, often with fatal results.

Touch potential works in a similar way but is the term given to the voltage gradient between a person holding or leaning on an electrified object and the point of exit of the current from that person's body.

Section 4

Earthing System Design

General statements regarding earthing have been made in Section 3. This Section however is specifically aimed at assisting the designer with his earth electrode calculations – whether they be for a simple power earth, or for a more complex design, say a high voltage sub-station.

Why do we require an Earth?

The function of an earth system for an electrical installation can be split into three broad bands:

(i) To limit the potential of any part of the installation to a pre-determined value with respect to the general mass of earth.

(ii) To permit the flow of current in the event of a fault to earth so that the protective equipment has time to operate and thus isolate the faulty circuit.

(iii) To ensure that, if a fault occurs, non current carrying metalwork associated with the equipment does not attain a dangerous potential with respect to the general mass of earth.

Points (i) and (ii) are normally essential to the security of the system, and are generally known as system earthing.

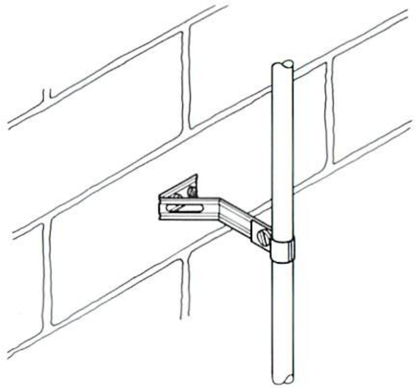
Point (iii) is aimed at ensuring safety of humans, animals and property and is sometimes known as equipment earthing.

How do we choose our Earth Electrode System?

Having determined that there is an earthing requirement, how do we go about deciding what type of earth electrode we should use? The previous chapter elaborated on the various types of earth termination networks available, and their differing properties are a major consideration. However, the most significant factor that will govern our choice is the ground itself. A borehole survey of the ground where the earthing is to be installed will indicate whether rock is present and at what depth, a factor that will not only affect the electrical consideration but will also have a direct bearing on installation costs. The information required by the earth electrode designer, however, is the resistivity of the soil: that value of "rho" that will enable him to calculate the earth resistance – i.e. the resistance of the soil to the passage of electric current.

Compared to a length of copper conductor the soil or earth could be regarded as a relatively poor conductor of electricity; for example, the resistivity of copper is 1.72×10^{-8} ohm metres, whereas chalk in Norfolk, England might register a value of 100 ohm metres. In reality, however, the earth's enormous mass, and, hence, its large cross-sectional area for the current path, gives it quite a low resistance, i.e. – the earth is, in fact, a good conductor. Since soil strata differs significantly from country to country, or even from site to site, it is not possible to be specific about the correct choice of earth electrode system without carrying out a detailed soil resistivity survey.

Figure 36 STAND-OFF CONDUCTOR BRACKET



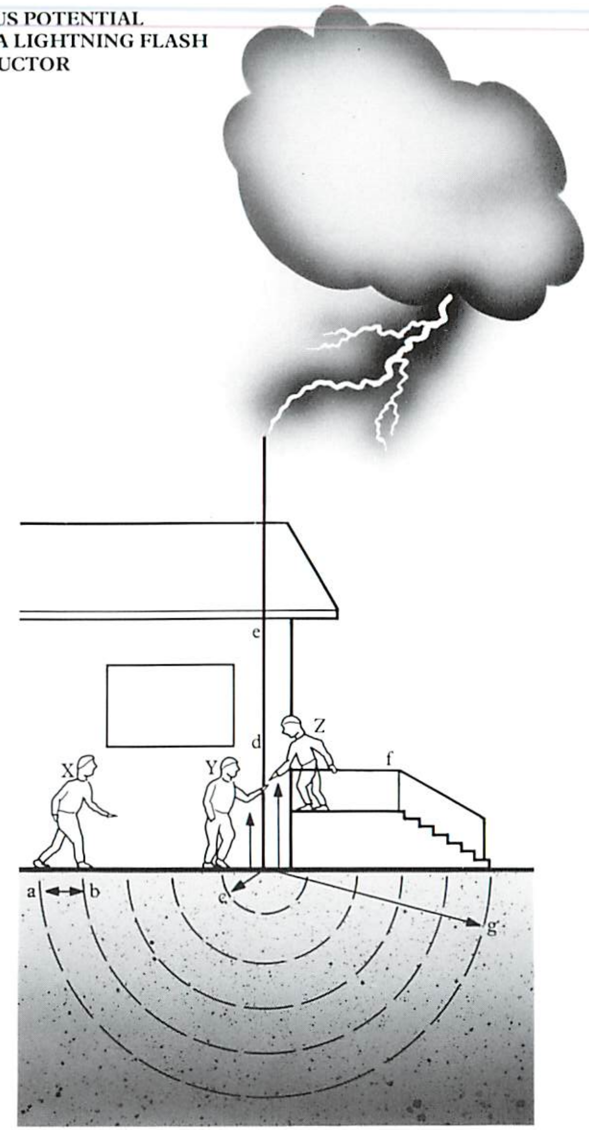
Earth conductors between the test clamp(s) and earth electrodes should be protected against corrosion where they enter the ground for a distance of 0.3m above and below ground level. This can be achieved by using PVC protective sleeving.

Lightning Protection Design

In order for Furse to offer an individually designed lightning protection scheme for your structure, the following information is required:

1. Drawings of the structure requiring protection, showing the roof plan and at least two elevations. These drawings should be clear, precise and have the scale shown.
2. The materials used in the construction of the structure should be stated along with information on the type of fixings permissible (eg can the roof be drilled to take screw plugs).
3. For what purpose is the structure being used? (ie its use will determine the risk category of the structure).
4. The proximity of other structures, trees and its general locality.
5. Information regarding any unusual features such as aerial masts on the roof of buildings, which may not be shown on the drawings.
6. At what stage of construction is the structure (ie complete, partly built, etc).
7. Notification of code that the scheme is to be designed to e.g. BS 6651 (1992).
8. Is there any soil resistivity data available?
9. State whether a quotation is required for supply of materials only or a supply and install quotation.

Figure 13 INSTANTANEOUS POTENTIAL DIFFERENCES DURING A LIGHTNING FLASH TO AN EARTHED CONDUCTOR



Notes:
1. Person *X* is in contact with the ground at *a* and *b*; person *Y* is in contact with the ground at *c* and the conductor at *d*; person *Z* is in contact with the conductor at *e* and a metallic hand rail *f* shown grounded at *g*.
2. Person *X* is subject to step potential.
3. Person *Y* is subject to touch potential.
4. Person *Z* is subject to transferred potential.
5. The potential depends on the current magnitude and the impedence of the path of the lightning discharge.
6. Step potential increases with the size of the step *a-b* in the radial direction from the conductor and decreases with the increase in the distance between person *X* and the conductor.
7. The transferred potential increases with increase in the radial distance between the down conductor and the ground *g*.

Extracts from the Australian Standard on Lightning Protection A.S. 1768-1983.

Hazards associated with lightning can be significantly reduced by the application of basic principles such as that given in 'voltage gradient' (see Section 3 – System Design – Page 39).

Section 2

Basic Considerations

General

This section of the handbook is devoted to highlighting and simplifying wherever possible certain aspects of BS 6651. It is not intended as a substitute for BS 6651 but to be read in conjunction with it.

When a high current is discharged along the path of a lightning conductor, either along parallel conductors in close proximity to each other, or along a single conductor with sharp bends in its routes, considerable mechanical forces are produced.

Secure and robust fixings are essential. Typical designs manufactured by Furse are shown in Figure 14 and below is a table of recommended fixing centres, (Table 1). These are taken from BS 6651 (1992).

Table 1

Recommended fixing centres for conductors

Arrangement	Fixing centres mm
Horizontal conductors on horizontal surfaces	1000
Horizontal conductors on vertical surfaces	500
Vertical conductors	1000
Vertical conductors over 20 m	750
Vertical conductors over 25 m	500

The area over which a lightning conductor can attract a lightning flash is not constant. Discharge severity is now believed to dictate the area of attraction. It is also thought to be minimally affected by the configuration of the lightning protection conductors, so that vertical and horizontal arrangements are considered to be equivalent. The use of pointed air terminations or vertical finials are, therefore, not regarded as essential, except where dictated by practical considerations.

The code also mentions that internal bonds can be half the cross sectional area of external bonds as they are, at most, only likely to carry a proportion of the total lightning current.

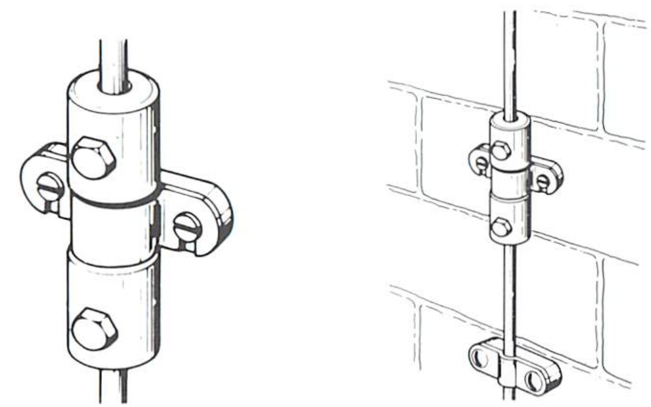
Corrosion

As mentioned in Section 2 under 'Materials Specification' – Page 16 the correct choice of materials for a lightning protection system is vital. Metal fittings must be compatible with the metal or metals used externally on the structure over which the system passes or with which it may be in contact.

Aluminium and copper, the two metals most commonly used in lightning protection systems, are **not** compatible, so great care must be taken when both are used in a system – particularly where they come into contact with each other.

If aluminium is selected as the material for air termination networks and down conductors, it has to be connected to copper at or around the test clamp, (Figure 35). This connection should be positioned at the beginning of the earth termination network. This is because both BS 6651 and the Earthing Code BS 7430 do not permit aluminium to be buried underground.

Figure 35 FURSE BI-METALLIC CONNECTOR



Furse offer a simple and effective means of joining the aluminium and copper conductors in one connector (Figure 35). Ingots of high purity copper and aluminium are friction welded together forming an effective electrical and mechanically robust joint. This termination, if used in conjunction with contax inhibitor grease minimises the effect of corrosion.

The contact surfaces of dissimilar metals should be kept completely dry and protected against the ingress of moisture, otherwise corrosion will occur. A particularly effective means of excluding moisture is to use inhibitor pastes, bitumastic paint, or approved protective wrappings.

As aluminium is prone to corrosion when in contact with Portland cement and mortar mixes, aluminium conductors need to be fixed away from the offending surface with an appropriate fixing.

One of the biggest problems for the installation contractor is of obtaining an earth resistance of, say, one ohm or less in an area of high soil resistivity. Unfortunately, there is no magical solution. However, several options are available to the contractor in the form of soil conditioning agents.

Soil-Conditioning Agents

Introducing a soil conditioning agent into the ground can reduce the soil resistivity and hence reduce the earth resistance.

There are various agents available, the choice of any particular one will depend on the type of earth required – temporary or permanent; the locality; the condition of the soil, etc.

As previously mentioned moisture forms an important part in obtaining a low soil resistivity value and it is the impurities in the water that produce this. One way of reducing the soil resistivity is to pour chemical solutions ie: copper sulphate; sodium carbonate; calcium sulphate, over the local area and allow it to migrate through the soil. The disadvantage of this is the large volume of solutions required, which makes it a cumbersome and time-consuming exercise. Also chemicals will eventually leach out of the local soil, returning it to its original high resistivity. Dissolving chemicals into the soil is also likely to encourage corrosion of the earth electrode. Hence the reason for the British Standard Code of Practice 7430 on Earthing and BS6651 Protection of Structures against Lightning – not recommending the use of salt as a means of reducing the soil resistivity.

Other soil-conditioning agents are available including Bentonite and Marconite.

Bentonite is used as an earth-electrode back-fill to reduce soil resistivity by retaining moisture. The clay consists largely of sodium montmorillonite, which when mixed with water swells to many times its dry volume. It has the ability to hold its moisture content for a considerable period of time and to absorb moisture from the surrounding soil (e.g. from rainfall).

Marconite is a conductive carbonaceous aggregate which when mixed with conventional cement, effectively increases the surface area of the earth-electrode, thus lowering its earth resistance. Ideal for use on sub-stations and transmission/distribution networks or in hot, dry climates, and also has electromagnetic screening and anti-static flooring applications.

Both products have applications with deep-driven electrodes. The ground/soil in question can be drilled using a portable drill rig, transported to the site. Significant depths can be reached depending on the type of ground.

The electrode assembly can then be inserted into the pre-drilled hole and back-filled with Bentonite or Marconite, or any other appropriate conditioning agent.

It is vital with any earthing system that regular inspection is carried out for possible damage. Regular checks on earth electrode resistance to ensure optimum protection are advised.

The key to arriving at a successful earthing electrode system is not to sacrifice quality for cost. Many products currently on the market fall far short of the recommended standards. BS 7430: 1991 Code of Practice for Earthing contains recommendations for material specification to ensure components are corrosion-resistant and provide adequate mechanical strength.

The correct choice of material and installation should ensure a life span of 30 years for the earth electrode.

Choosing fittings manufactured from materials outside the range of recommended materials could render the lightning protection scheme vulnerable to corrosion, making it incapable of withstanding the mechanical and electrical forces of a lightning strike. Table 2 recommends the materials to be used for the manufacture of lightning protection components and Table 3 recommends the minimum dimensions of component parts. Both tables are taken from BS 6651 (1992).

The integrity of components not designed in accordance with these specifications cannot be guaranteed and should not be considered for use in lightning protection systems. All Furse components comply fully with the requirements of BS 6651.

Table 3

Minimum dimensions of component parts

Component	Dimensions	Area
	mm	mm^2
Air terminations:		
aluminium, copper and galvanized steel strip	20 x 2.5	50.0
aluminium, aluminium alloy, copper, phosphor bronze and galvanized steel rods	8.0 dia.	50.0
Suspended conductors:		
stranded aluminium	7/3.0	50.0
stranded copper	19/1.8	50.0
stranded aluminium (steel reinforced)	7/3.0	50.0
stranded galvanized steel	7/3.0	50.0
Down conductors:		
aluminium, copper and galvanized steel strip	20 x 2.5	50.0
aluminium, aluminium alloy, copper and galvanized steel rods	8.0 dia.	50.0
Earth terminations:		
austenitic iron	14.0 dia.	153.0
copper and galvanized steel strip	20 x 2.5	50.0
copper and galvanized steel rods	8.0 dia.	50.0
hard drawn copper rods for direct driving into soft ground	8.0 dia.	50.0
hard drawn or annealed copper rods or solid wires for indirect driving or laying in ground	8.0 dia.	50.0
rods for hard ground	12.0 dia.	113.0
copper-clad or galvanized steel rods (see notes to table) for harder ground	14.0 dia.	153.0
Fixed connections (bonds) in aluminium, aluminium alloy, copper and galvanized steel:		
external strip	20 x 2.5	50.0
external rods	8.0 dia.	50.0
internal strip	20 x 1.5	30.0
internal rods	6.5 dia.	33.0
Flexible or laminated connections (bonds):		
external, aluminium	20 x 2.5	50.0
external, annealed copper	20 x 2.5	50.0
internal, aluminium	20 x 1.5	30.0
internal, annealed copper	20 x 1.5	30.0

NOTE 1. For copper-clad steel rods, the core should be of low carbon steel with a tensile strength of approximately 600 N/mm^2. The cladding should be of 99.9% pure electrolytic copper molecularly bonded to the steel core. **The radial thickness of the copper should be not less than 0.25mm.**

NOTE 2. Couplings for copper-clad steel rods should be made from copper-silicon alloy, with a minimum copper content of 80% or aluminium bronze alloy.

NOTE 3. The use of internal phosphor bronze dowels may give a lower resistance than the external couplings of diameter greater than the rod.

NOTE 4. For galvanised steel rods, steel specified in BS 970: Part 1 should be used, the threads being cut before hot-dip galvanising to BS 729.

NOTE 5. Strandard conductors are not normally used for down conductors or earths.

NOTE 6. Greater dimensions are required for the following:
(a) structures exceeding 20m in height;
(b) special classes of structure;
(c) mechanical or corrosive reasons.

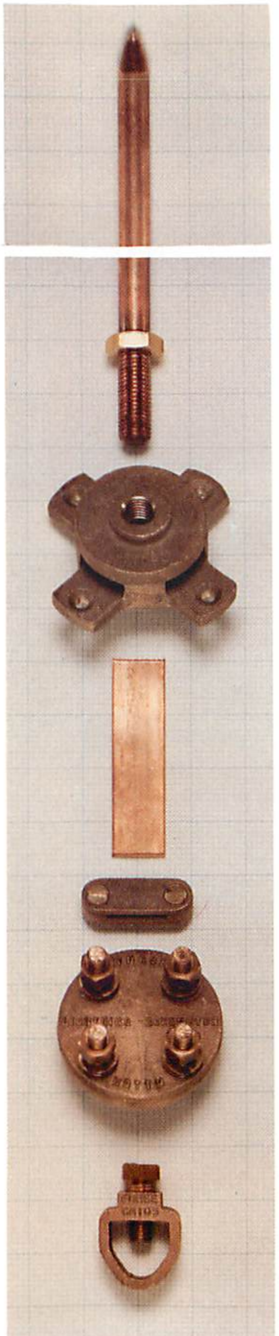
Closer examination of Table 2 will highlight the exclusion from the material specification of any commercial brasses. These may be easy to manufacture and be very competitively priced but are technically inferior.

A comparison of lightning protection components currently available highlights this point (Figure 15).

Table 3 makes particular reference to earthing component specification and provides specific recommendations regarding copper-clad steel rods and couplings (Note 1 & 2).

The difference between good quality and inferior earthing components is highlighted in (Figure 16).

Figure 15 A COMPARISON OF LIGHTNING PROTECTION COMPONENTS



The Furse Lightning Protection System to BS 6651 (1992).

AIR TERMINAL
Solid copper air terminal ensures good corrosion resistance. Thread is roll formed for maximum strength.

BRONZE NUT
A nut with excellent corrosion resistance and mechanical properties.

TERMINAL BASE
Cast gun metal air terminal base designed with appropriate section thickness. Mechanically strong, corrosion resistant with low electrical resistance.

COPPER TAPE
High conductivity annealed copper tape with rounded edges which are soft and easy to work.

TAPE CLIP
Cast gun metal upper and lower sections with countersunk naval brass screws giving good mechanical strength and good corrosion resistance.

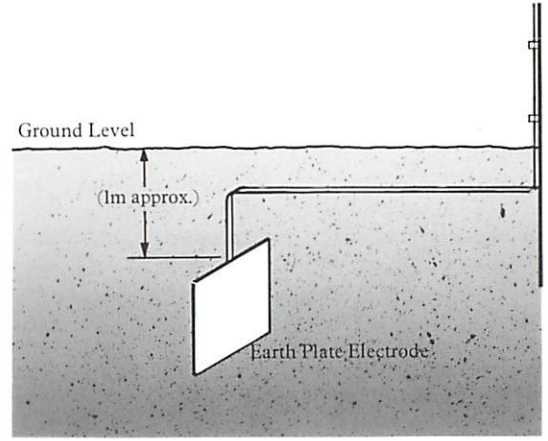
PLATE TYPE TEST CLAMP
Cast gun metal upper and lower sections, phosphor bronze nuts, washers and screws. Clamp is mechanically strong, corrosion resistant with low electrical resistance.

ROD TO TAPE CLAMP
Cast gun metal body and phosphor bronze bolt providing good mechanical properties to ensure a strong connection which will not corrode or loosen.

Solid Plates or Mats

Earth plates or mats can be buried instead of driving rod electrodes but installation is expensive and time consuming.

Figure 32 BURIED EARTH PLATE ELECTRODE



Reinforcing bars in foundations as natural earths

This is an economical method of using the mass of metal already underground in the form of the re-inforcing bars, within the structure's foundations. Precautions should be taken to ensure there is electrical continuity between these re-inforcing bars and the earth/lightning protection connections above ground.

Underground Pipe Work System

Buried water pipes were previously considered to be a reliable method of earthing but the increasing use of plastic pipes or replacing metal joints with plastic ones now makes this method unreliable.

Other forms of earth electrode can be used, including ring conductors or radial strips emanating from a particular point, or a combination of conductors with earth rods.

Voltage Gradient

A further factor affecting the choice of an electrode system is the electrical considerations.

Step and touch voltages on the surface of the ground in the vicinity of earth electrodes must be restricted to safe values.

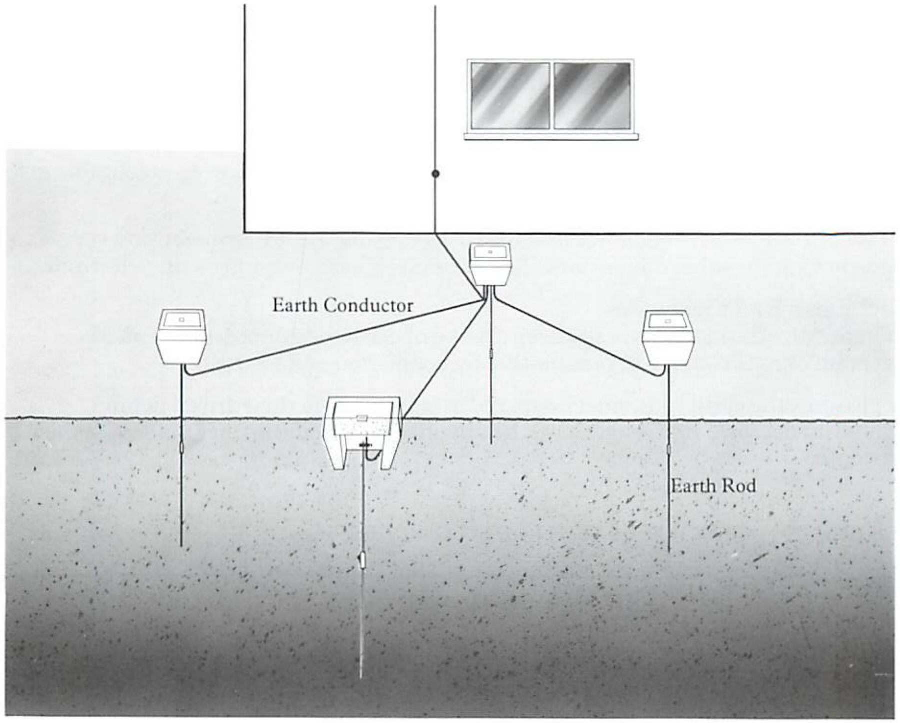
This can be achieved by using electrodes to form a ring around the area to be protected. The electrodes must be buried sufficiently deep to reduce surface potential.

An effective method of reducing the voltage gradient of rod electrodes is to install them with the top of the electrode some distance beneath the surface of the soil. The connection between the electrode and down conductor being made with insulated conductor.

An example of how effective this can be is illustrated by tests which gave the following results.

The maximum voltage gradient over a two metre span adjacent to a 25mm diameter earth electrode was 85% of the total electrode potential when the top of the assembly was at ground level. This electrode potential was reduced to 20% when the electrode was buried 0.3 metres below ground level and 5% when buried 1.0 metres below ground level.

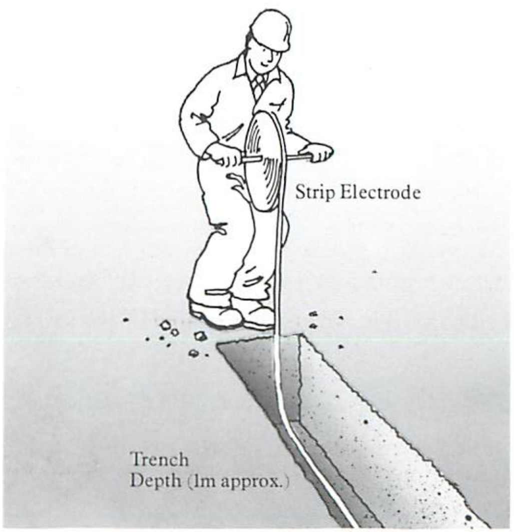
Figure 30 CROWS FOOT EARTH CONFIGURATION

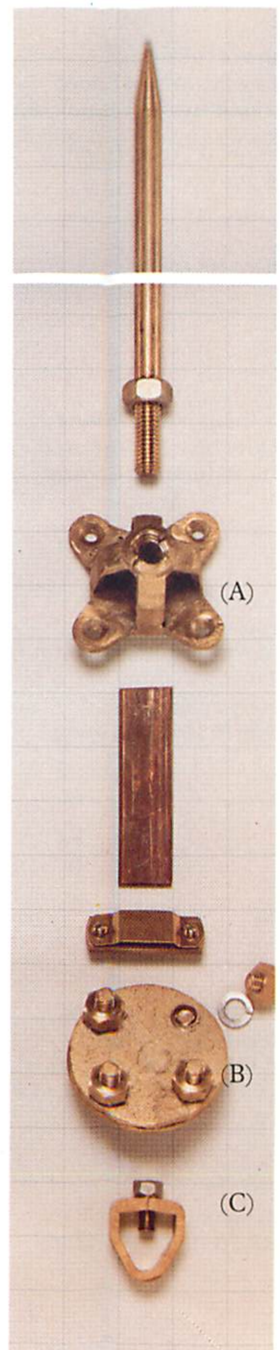


Radial Strip Electrodes

Ground that has one metre depth of soil before encountering bedrock will best be suited to a buried radial electrode, provided the system is installed below the frost line and below the area that is subject to seasonal weather changes.

Figure 31 BURIED STRIP EARTH ELECTRODES





Inadequate lightning protection components

AIR TERMINAL
60% copper 40% zinc air terminal with poor corrosion resistance. Thread is die box cut and is easily stripped when tightened.

STEEL NUT
Badly plated steel nut providing little corrosion resistance.

TERMINAL BASE
Cast brass air terminal base with serious defects. Poor mechanical strength causes casting to fracture when air terminal is tightened into base (A).

COPPER TAPE
Low quality copper tape not fully annealed – hard and difficult to work.

TAPE CLIP
Cheap brass strip upper and lower sections with steel screws badly electroplated giving poor mechanical strength and little resistance to corrosion.

PLATE TYPE TEST CLAMP
Cheap brass upper and lower sections. Plated steel bolts, nuts and washers. Clamp has poor mechanical strength causing the bolts to fracture when tightened (B). This assembly will easily corrode and has high electrical resistance.

ROD TO TAPE CLAMP
Cheap brass extruded body with steel plated bolt. Poor corrosion resistance and mechanical strength. The clamp body fractured when earth rod was tightened onto tape (C).

Figure 16 A COMPARISON OF COPPERBOND EARTH ROD SYSTEMS

With the copperbond rod being so popular now many different designs are available worldwide.

Consultants, specifying bodies and installers should be fully aware of the design considerations, including the benefits and possible problems. Choosing the lowest priced components can prove expensive in terms of fatalities and damage to buildings at a future date.

Rod systems A, B, C and D shown here have all been recently obtained. Apart from cleaning and sectioning for photographic purposes they are exactly as shown.

Furse (System A)

Correctly Designed and manufactured Rod System to BS 6651.

DRIVING HEAD
High strength steel driving head can be used many times over. Driving head is in contact with rod. The driving force therefore being transferred directly to the rod, allowing power hammers to be used for deep driving.

COUPLING
Long length silicon & aluminium bronze coupling counter bored to completely enclose threads, protecting them from damage and corrosion. Coupling is high strength and also corrosion resistant.
Rod to rod contact ensures the driving force is directly applied and does not pass through coupling threads, which can cause them to strip and good elecrical and mechanical contact to be lost.

ROD
99.9% pure electrolytic copper, molecularly bonded into steel core minimum thickness 0.25 mm. No interface so no disimilar metal reaction is possible. Copper cannot be separated from the steel. Low carbon steel core with high tensile strength. Highly resistant and hard to bend. Allows power hammers to be used for deep driving.

THREADS
Rolled onto rod for strength and to ensure uniform layer of copper. This copper covering is maintained even at root of thread. Rolled threads are considerably stronger than cut threads.

A common misconception is that increasing the diameter/width of the rod/strip electrode will give a significant reduction of earth resistance.

Tests have shown that increasing the diameter of a rod electrode from 12.5 to 25mm has increased the weight by 400%, increased the cost by 400%, but only reduced the earth resistance by 9.5%.

To obtain a low overall resistance, current density should be as low as practicable in the soil which is in contact with the electrode.

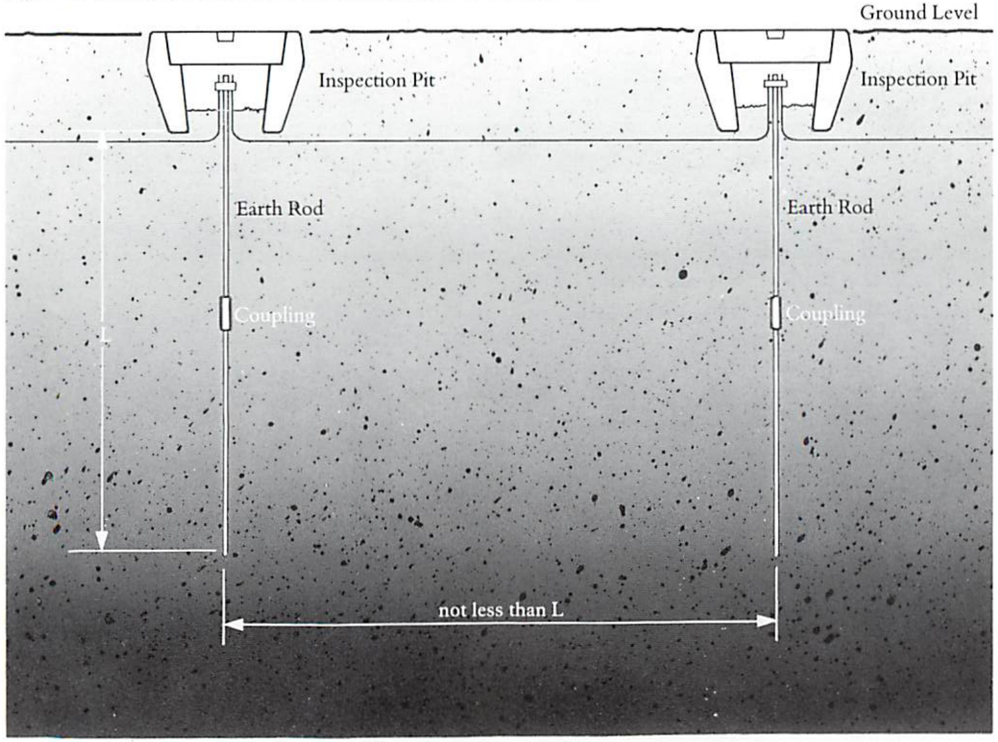
This can best be achieved economically by having one electrode dimension very large in comparison with the other dimensions. This is best achieved by a rod or strip electrode.

Parallel Earth Rod Electrodes

Where ground conditions make deep driving of earth rods impossible, a matrix arrangement of rods coupled to one another by conductors can be used.

If possible, the earth rods must be spaced at least equal to their driven depth.
No significant decrease in resistance will be obtained by spacing greater than twice their driven depth.

Figure 29 SPACING OF PARALLEL EARTH ROD ELECTRODES



If earth rods cannot be driven in a parallel line a 'Crows Foot' configuration can be used, ensuring that the spacing/depth ratio is still maintained. (See Figure 30 – Page 38).

Assume we use a standard 5/8" diameter rod (nominal diameter 14mm)
Actual shank diameter 14.2mm

Thus d = 1.42cm
L = ?

If we let L = 6m and substitute to see what value of R is obtained

$$R = \frac{10,000}{275 \times 6} \times \text{Log}_{10} \frac{400 \times 6}{1.42}$$

$$= 6.0606 \times 3.228$$

$$= 19.56 \text{ ohms}$$

Thus 6m of extensible rods (5 x 1.2m) can be used to obtain the desired resistance value of 20 ohms.

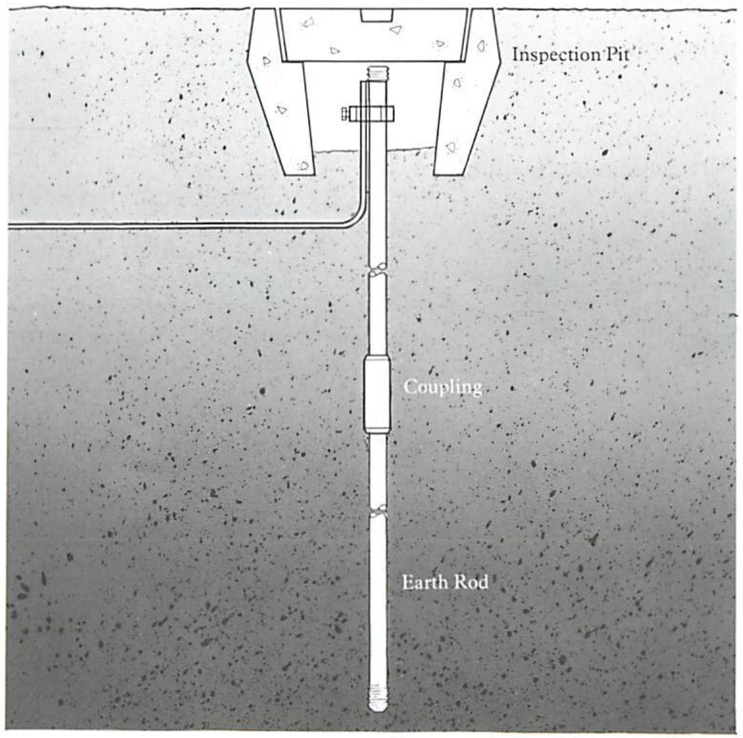
The above example illustrates the importance of the accuracy of the soil resistivity figure. If the survey is inaccurate, then the calculated apparent earth electrode resistance R will be inaccurate and misleading.

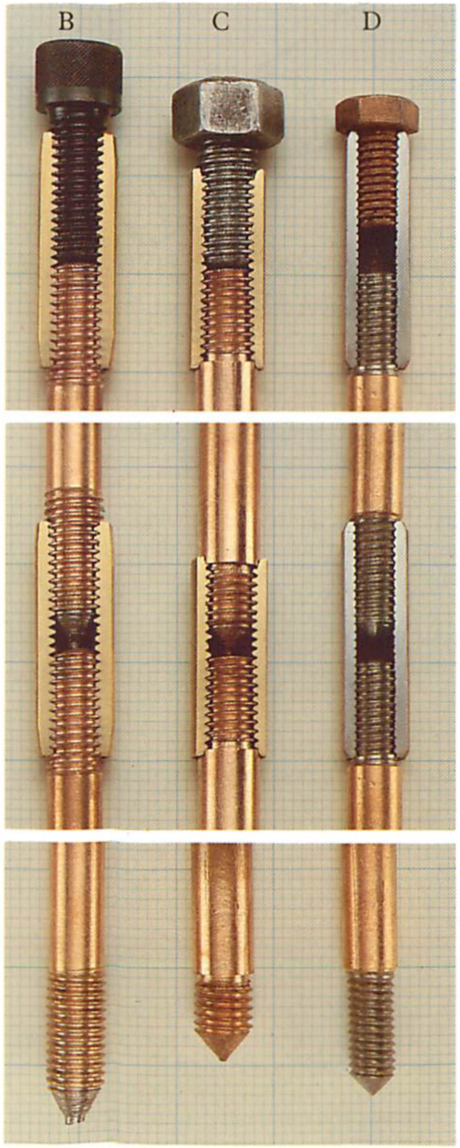
Types of Earth Termination Networks

Deep Driven Earth Electrodes

A soil resistivity survey indicating lower resistivity at greater depths will make the deep driven earth electrode a logical choice. Deep driven earth electrodes are more likely to reach permanent moisture unaffected by seasonal changes.

Figure 28 DEEP DRIVEN EARTH ELECTRODE





(B, C and D) Dangerously inferior rod systems

DRIVING HEADS

C & D Driving heads soft steel can only be used a few times.

D No head to rod contact, would cause coupler to fail and would not therefore be suitable for power driving.

COUPLINGS

B & C Short brass couplers.

D Mild steel coupler. The brass would suffer from dezincification and corrode. The mild steel would rot away in a very short time. None would be strong enough for deep driving in rocky conditions.

B Does not enclose threads and steel core can be seen at root of threads. Damage and corrosion is probable. Coupler C is threaded so badly that threads would easily be stripped.

ROD & THREADS

B Poor thread rolling, with steel core exposed.

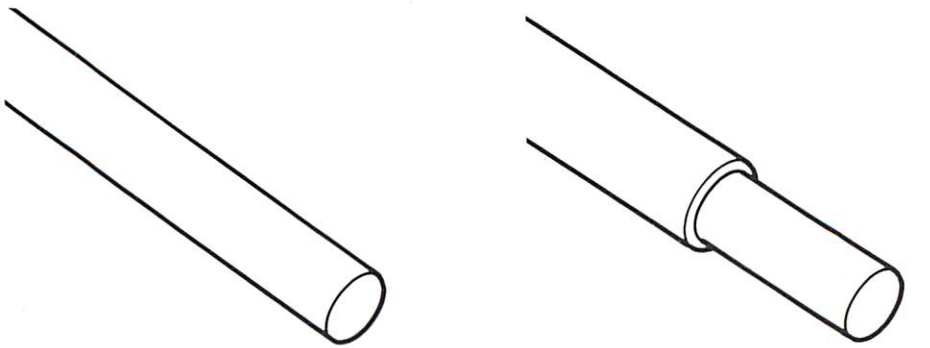
C Thread cut into core through copper layer, the flash coating would offer very little resistance to corrosion. Soft steel core could bend in rocky areas.

D Thread cut into steel core with no protection at all. All would quickly corrode at coupling, making system totally ineffective.

Circular Conductor

As with international practice, BS6651 now permits the use of circular section conductors for all aspects of a lightning protection system (Figure 14). Specifically, 8mm diameter ($50mm^2$) solid circular conductor can be used for the air termination network, down conductors and part of the earth termination network.

Figure 17 CIRCULAR CONDUCTOR



SOLID CIRCULAR CONDUCTOR PVC COVERED SOLID CIRCULAR CONDUCTOR

The use of solid circular conductors has many advantages over conventional 'Flat Conductor Systems.'

Easier and less costly to install

The Furse Solid Circular Range is the only system designed specifically to cater for the 8mm diameter conductor and incorporates ease of installation with cost economy. Even on small installations, significant savings can be achieved.

Less conspicuous installations

Circular conductors and fittings are more compact than flat tape conductors and less conspicuous when installed. This is particularly important to architects where the aesthetic appearance of the building is a prime consideration.

Easier to handle and work

A coil of circular conductor is much easier to handle than a flat 'pancake' of tape. Unlike tape, a circular conductor can be bent in any plane and straightened quickly and easily with a straightening tool.

The Need for Protection

Before proceeding to design a detailed lightning protection system, first carefully consider if the structure needs protection.

In many cases, it is obvious that some form of protection is required. High risk structures ie explosives factories, oil refineries, etc. will require the highest possible class of lightning protection to be provided. In many other cases the need for protection is not so evident.

BS 6651 provides a simple mathematical overall risk factor analysis for assessing whether a structure needs protection.

It suggests that an acceptable lightning strike risk factor is 10^{-5} per year ie 1 in 100,000 per year. Therefore, having applied the mathematical analysis to a particular set of parameters, the scheme designer will achieve a numerical solution. If the risk factor is less than 10^{-5} (1 in 100,000), for example 10^{-6} (1 in 1,000,000) then in the absence of other over-riding considerations, protection is deemed unnecessary. If however, the risk factor is greater than 10^{-5} (1 in 100,000) for example 10^{-4} (1 in 10,000) then protection would seem necessary.

NOTE: Although Table 11 quotes figures for salt laden soil, it is now deemed bad practice to use salt as a chemical means of reducing soil resistivity, because of its very corrosive nature. Salt along with other chemicals, has the disadvantage of leaching out of the surrounding soil after a period of time, thus returning the soil to its original resistivity.

Table 12

Effect of Temperature on Resistivity
For sandy loam, 15.2% moisture

Temperature C	Temperature F	Resistivity ohm-cm
20	68	7,200
10	50	9,900
0	32 (water)	13,800
0	32 (ice)	30,000
− 5	23	79,000
−15	14	330,000

(c) temperature. Please note that, if your soil temperature decreases from + 20°C to −5°C, the resistivity increases more than ten times.

Once the soil resistivity has been calculated from the local soil measurements, the appropriate earth electrode system can be chosen by using typical formulae listed below:

Horizontal Strips (Rectangular Section)

$$R = \frac{\rho}{275L} \operatorname{Log}_{10} \frac{200L^2}{wD}$$

Horizontal Strips (Circular Section)

$$R = \frac{\rho}{275L} \operatorname{Log}_{10} \frac{100L^2}{dD}$$

Vertical Strips (Rectangular Section)

$$R = \frac{\rho}{275L} \operatorname{Log}_{10} \frac{800L}{w}$$

Vertical Strips (Circular Section)

$$R = \frac{\rho}{275L} \operatorname{Log}_{10} \frac{400L}{d}$$

Where:

R = Apparent earth electrode resistance in ohms.
ρ = Soil resistivity in ohm.cm.
D = Depth of electrode in metres.
d = Diameter of electrode in centimetres.
L = Length of electrode in metres.
w = Width of electrode in centimetres.

For Example

If we require an earth electrode resistance of 20 ohms and we have established by a soil resistivity survey that ρ = 10,000 ohm.cm.

If for this example we assume that the soil is suitable for deep driven rod electrodes then we can calculate the depth of rod required to obtain the desired 20 ohms resistance.

From above, for vertical strips (circular section)

$$R = \frac{\rho}{275L} \operatorname{Log}_{10} \frac{400L}{d}$$

Thus R = 20 ohms and

ρ = 10,000 ohm.cm.

Sharp bends in down conductors at the edge of the roofs are unavoidable and are permitted in BS 6651; however, re-entrant loops in a conductor can produce high inductive voltage drops which could lead to the lightning discharge jumping across the side of the loop. To minimise this problem BS 6651 recommends that the length of the conductor forming the loop should not exceed eight times the width of the open side of the loop (Figure 27).

Earthing - General

Earthing plays a vital role in all electrical systems. The main reasons for earthing are:-

- **To protect people and livestock**
- **To protect equipment**
- **To permit the equipment to function correctly**
- **To ensure the reliability of electrical services.**

A good earth connection should possess the following characteristics:

- Low electrical resistance between the electrode and the earth. The lower the earth electrode resistance the more likely the lightning or fault current will choose to flow down that path in preference to any other, allowing the current to be conducted safely to and dissipated in the earth.
- Good corrosion resistance. The choice of material for the earth electrode and its connections is of vital importance. It will be buried in soil for many years so has to be totally dependable.
- Ability to carry high currents repeatedly.
- Ability to perform the above functions for a minimum of 30 years.

Soil Conditions

Achieving a good earth will depend on local soil conditions. A low soil resistivity is the main aim and factors that effect this are:

- **Moisture content of the soil.**
- **Chemical composition of the soil, eg. salt content.**
- **Temperature of the soil.**

The following tables illustrate the effect these factors have on the soil resistivity.

Table 10

Effect of Moisture on Resistivity

Moisture content % by weight	Resistivity ohm-cm	
	Top Soil	Sandy loam
0	1,000 x 10^6	1,000 x 10^6
2.5	250,000	150,000
5	165,000	43,000
10	53,000	18,500
15	31,000	10,500
20	12,000	6,300
30	6,400	4,200

Table 11

Effect of Salt on Resistivity
For sandy loam, 15.2% moisture

Added salted (per cent by weight) of moisture)	Resistivity (ohm-centi-metres)
0	10,700
0.1	1,800
1.0	460
5	190
10	130
20	100

A suitable analogy could be made with the odds in horse racing. The shorter the odds, (eg 5 to 1) the more likely the horse will win the race. The longer the odds (eg 100 to 1) the less likely the horse will win.

The shorter the risk factor (eg 1 in 10,000) the greater the risk that a structure will be hit by lightning. The longer the risk factor (eg 1 in 1,000,000) the less likely the structure will be hit by lightning.

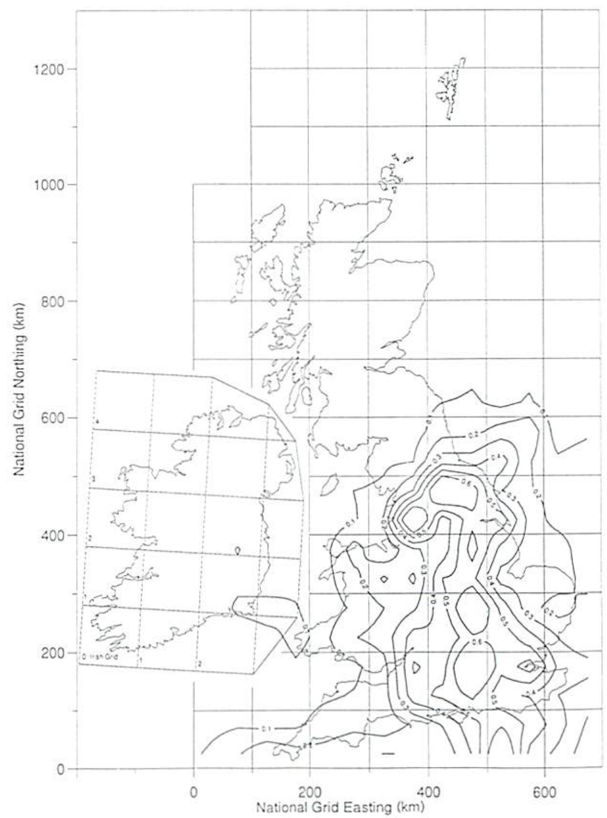
It is acknowledged that certain factors cannot be assessed in this way and these may over-ride all other considerations. For example, if there is a requirement that there should be no avoidable risk to life or a requirement for occupants of a building to always feel safe, then this will favour the installation of protection, even though it would normally be accepted that protection is unnecessary. These are decisions that perhaps only the consultant/architect and client can make.

The factors which should be considered for determining an overall risk factor can, be summarised as follows.

A) The geographical location of the structure

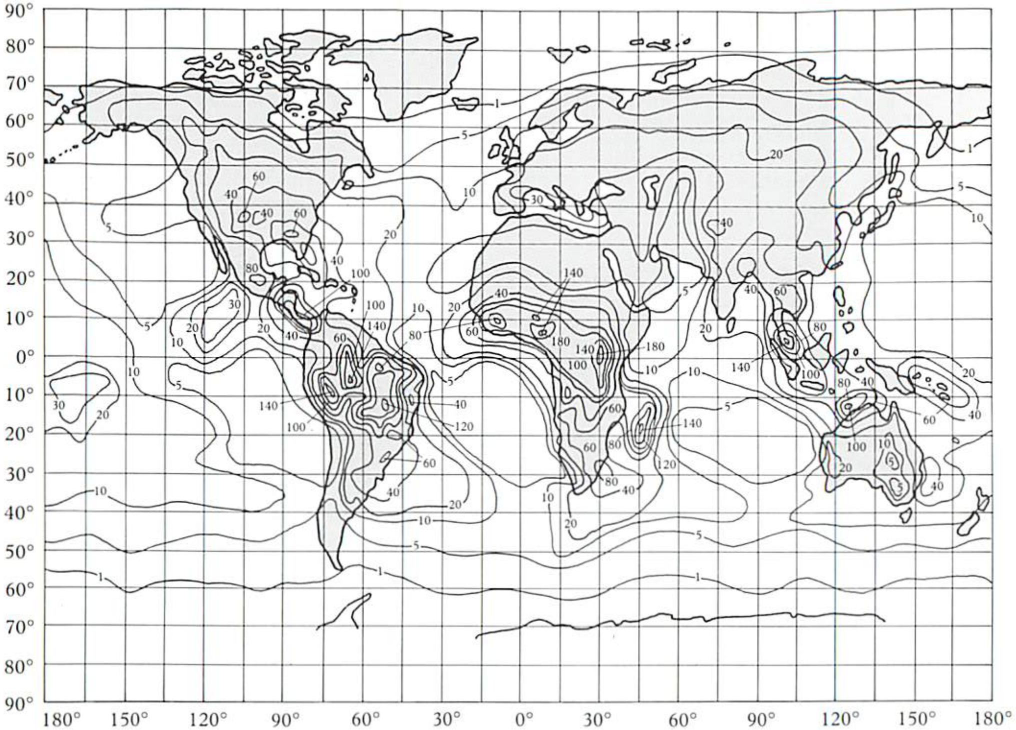
This pinpoints the average lightning flash density or the number of flashes to ground per km^2 per year. For structures sited within the United Kingdom this figure can be taken from the map (Figure 18).

Figure 18 NUMBER OF LIGHTNING FLASHES TO THE GROUND PER KM² PER YEAR FOR THE UK



For structures outside the United Kingdom, (Table 4) can be used in conjunction with the world map (Figure 19) taken from BS 6651.

Figure 19 MAP SHOWING THUNDERSTORM DAYS PER YEAR THROUGHOUT THE WORLD



NOTE. This map is based on information from the World Meteorological Organisation records for 1955.

Table 4

Relationship between thunderstorm days per year and lightning flashes per km² per year

Thunderstorm days per year	Flashes per km² per year	
	Mean	Limits
5	0.2	0.1 to 0.5
10	0.5	0.15 to 1
20	1.1	0.3 to 3
30	1.9	0.6 to 5
40	2.8	0.8 to 8
50	3.7	1.2 to 10
60	4.7	1.8 to 12
80	6.9	3 to 17
100	9.2	4 to 20

NOTE. The data for this table has been extracted from information in Anderson, R.B. and Eriksson, A.J. (Conference internationale des grands reseaux electriques (CIGRE)) Lightning Parameters for Engineering Application. *Electra*, 1980, **69**, 65-102.

For less complex tall structures of varying heights, the 'rolling sphere method' as described (Section 1 – Page 9) should be employed. The rolling sphere method is a simple means of determining where the zones of protection should be located. Wherever the sphere touches the structure determines the extent of the air termination network.

There is a reference in BS 6651 to the use of covered conductors for air termination networks. Although it advocates that, wherever possible, bare conductors should be used, it permits the use of PVC covered or painted conductors.

Down Conductors

The function of a down conductor is to provide a low impedance path from the air termination network to the earth termination network, to allow the lightning current to be safely conducted to earth.

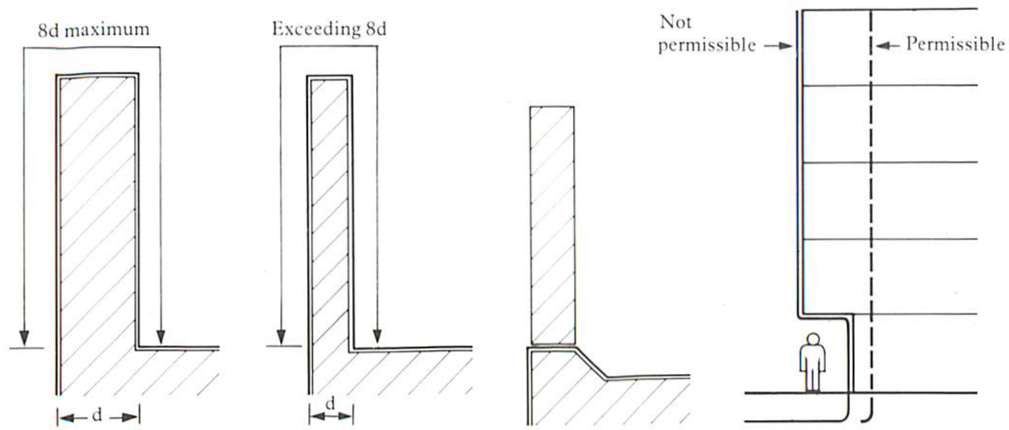
BS6651 advocates the use of various types of down conductors. A combination of strip and rod conductors, reinforcing bars, structural steel stanchions, etc. can be used as all or part of the down conductor system – providing they are appropriately connected to the air and earth termination networks, and are known to offer good electrical conductivity.

The Code suggests there is no advantage in using 'shielded' coaxial cables as down conductors. In fact there is thought to be the disadvantage that potentials up to hundreds of kilo-volts can occur between the inner and outer conductor (shield) at the top of the down conductor so triggering a side flash.

Down conductor systems should, where possible, take the most direct route from the air termination network to the earth termination network. Ideally they should be symetrically installed around the outside walls of the structure starting from the corners. Routing to avoid side-flashing should always be given particular attention in designing any installation.

Down conductors should be positioned no more than 20m apart around the perimeter at roof or ground level, whichever is the greater. If the structure is over 20m in height, then the spacing is reduced to every 10m or part thereof.

Figure 27 RE-ENTRANT LOOPS



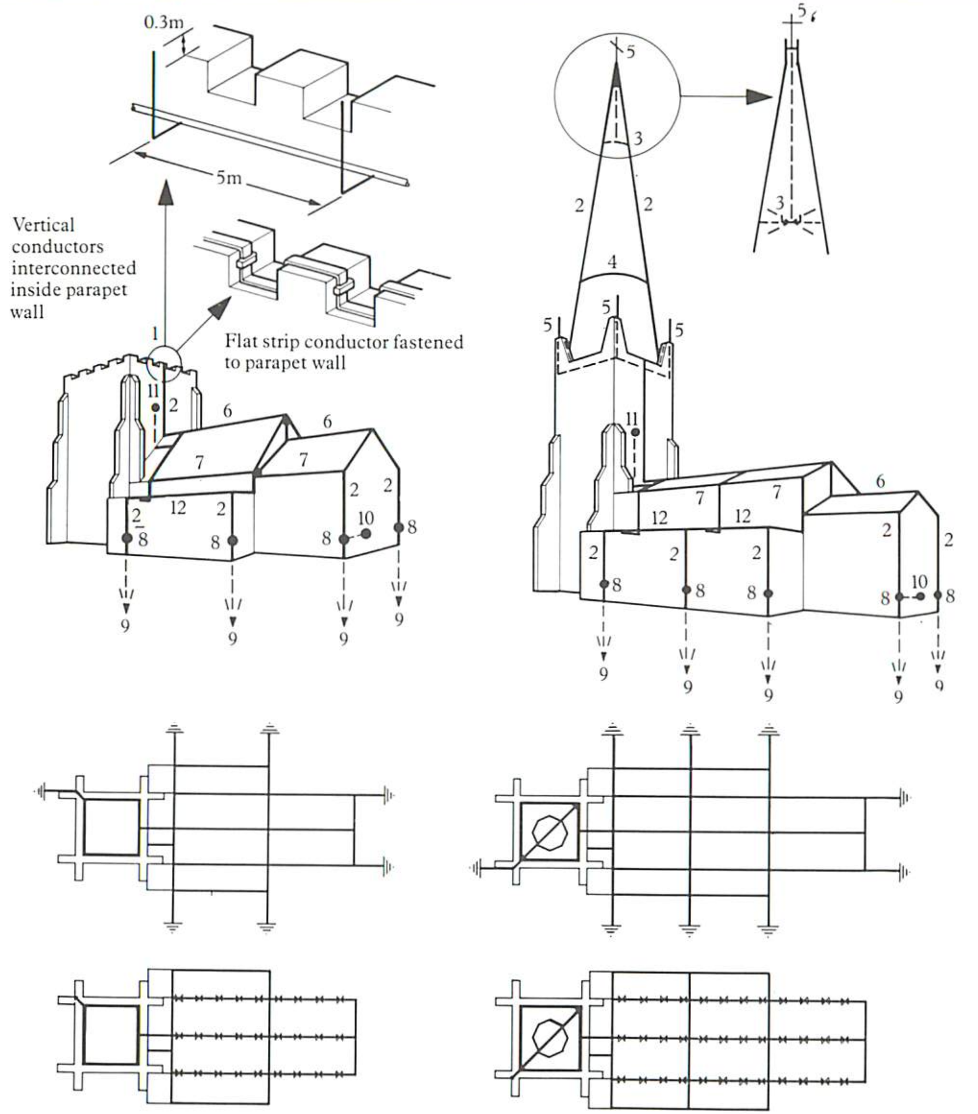
(a) Permissible arrangement

(b) Arrangement that is not permissible

(c) Permissible method of taking conductor through a parapet wall

(d) Routes for down conductors in a building with cantilevered upper floors

Figure 26 CHURCH TOWERS AND SPIRES



Key

1 Air termination
2 Down conductor
3 Bonds to holding down rod
4 Horizontal conductor
5 Vertical conductor
6 Ridge conductor
7 Eaves conductor
8 Test point
9 Earth electrode
10 Main earthing terminal of electrical installation
11 Bond to bell-frame
12 Peripheral conductor

NOTE 1. The air termination network should have a 10m x 20m mesh. For structures below 20m high, there should be down conductors every 20m of periphery and for structures over 20m high, every 10m of periphery; horizontal conductors should be every 20m from the top.

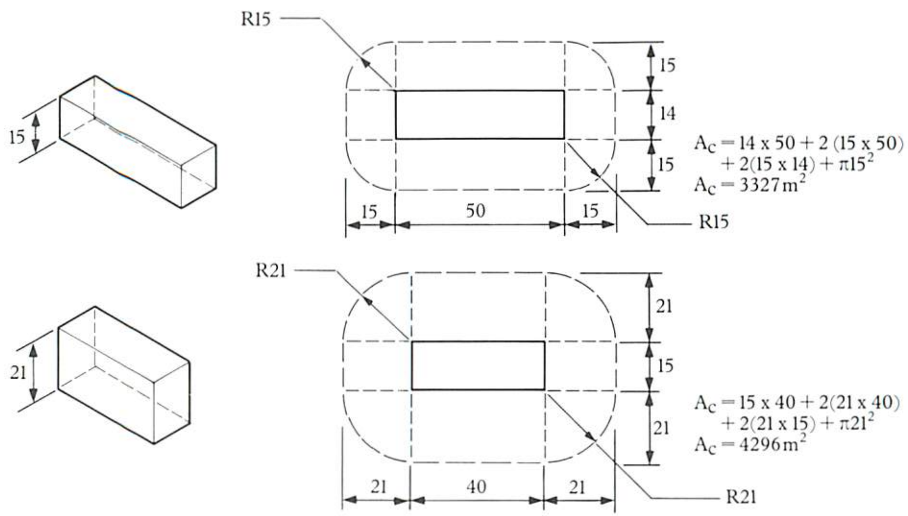
NOTE 2. Metal roofs may be suitable as air terminations (see table 5 and figure 17) in BS6651.

NOTE 3. On shingle spires, metallic soakers and gullies should be bonded at the top and bottom.

B) The effective collection area of the structure

(Figure 20). This is the plan area projected in all directions taking account of the structure's height. The significance being, the larger the structure, the more likely it is to be struck.

Figure 20 DETAILS OF STRUCTURES AND COLLECTION AREAS



For a simple rectangular box shaped structure as illustrated in Figure 20, the collection area (Symbol Ac) is simply the product of:-

$$Ac = LW + 2LH + 2WH + \pi H^2$$

Where: L = Length
W = Width
H = Height

The probable number of strikes to the structure per year (Symbol P) is the product of the flash density and the collection area, thus

$$P = Ac \times Ng \times 10^{-6}$$

(The 10^{-6} figure is included because Ac is in metres squared whereas Ng is per kilometre squared).

C) The intended use of the structure. ie: is it a factory or an office block, a church or perhaps a hospital?

D) The type of construction. Is it built of brick or concrete? Does it have a steel frame or a reinforced concrete frame? Does it have a metal roof?

E) What is housed within the structures. Does it contain valuable paintings, or a telephone exchange with important equipment, or is it maybe an old peoples' home?

F) The location of the structure. Is it located in a large town or forest or on an isolated hillside?

G) The topography of the country. Is the structure located in generally flat countryside or in a mountainous area?

Items B to G inclusive are interpreted from Tables 5, 6, 7, 8 and 9 in BS 6651 and are termed 'the weighting factor values'. They denote a relative degree of importance in each case.

Table 5

Weighting factor A (use of structure)	
Use to which structure is put	Value of factor A
Houses and other buildings of comparable size	0.3
Houses and other buildings of comparable size with outside aerial	0.7
Factories, workshops and laboratories	1.0
Office blocks, hotels, blocks of flats and other residential buildings other than those included below	1.2
Places of assembly, e.g. churches, halls, theatres, museums, exhibitions, department stores, post offices, stations, airports and stadium structures	1.3
Schools, hospitals, children's and other Homes	1.7

Table 6

Weighting factor B (type of construction)	
Type of construction	Value of factor B
Steel framed encased with any roof other than metal*	0.2
Reinforced concrete with any roof other than metal	0.4
Steel frame encased or reinforced concrete with metal roof	0.8
Brick, plain concrete or masonry with any roof other than metal or thatch	1.0
Timber framed or clad with any roof other than metal or thatch	1.4
Brick, plain concrete, masonry, timber framed but with metal roofing	1.7
Any building with a thatched roof	2.0

*A structure of exposed metal which is continuous down to ground level is excluded from the table as it requires no lightning protection beyond adequate earthing arrangements.

Table 7

Weighting factor C (contents or consequential effects)	
Contents or consequential effects	Value of factor C
Ordinary domestic or office buildings, factories and workshops not containing valuable or specially susceptible contents	0.3
Industrial and agricultural buildings with specially susceptible* contents	0.8
Power stations, gas installations, telephone exchanges, radio stations	1.0
Key industrial plants, ancient monuments and historic buildings, museums, art galleries or other buildings with specially valuable contents	1.3
Schools, hospitals, children's and other Homes, places of assembly	1.7

*This means specially valuable plant or materials vulnerable to fire or the results of fire.

Table 8

Weighting factor D (degree of isolation)	
Degree of isolation	Value of factor D
Structure located in a large area of structures or trees of the same or greater height, e.g. in a large town or forest	0.4
Structure located in an area with few other structures or trees of similar height	1.0
Structure completely isolated or exceeding at least twice the height of surrounding structures of trees	2.0

Table 9

Weighting factor E (type of country)	
Type of country	Value of factor E
Flat country at any level	0.3
Hill country	1.0
Mountain country between 300m and 900m	1.3
Mountain country above 900m	1.7

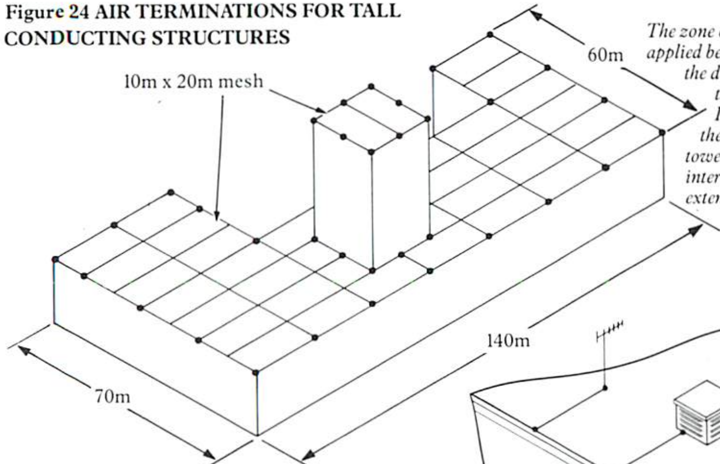
BS 6651 advises the use of a rolling sphere to determine zones of protection. To minimise the likelihood of a lightning strike damaging the side of a building, it is suggested that the rolling sphere method be applied to identify those areas where an extension of the air termination network should be considered. This recommendation could be summarised as follows:-

Where there is a risk that a lightning strike to the sides of a structure may cause masonry to be dislodged, then an extension of the air termination network should be considered.

To ensure complete continuity of the lightning protection system BS 6651 recommends that:

Where structures vary in height and have more than one roof termination network, (Figure 24) the lower roof network should not only be joined to its down conductors, but also joined to the down conductors of the taller portions of the structure. This will ensure that a lightning strike to a lower portion of the structure will not lead to side-flashing to other 'remote' down conductors and will provide a multi down conductor path for the lightning current to disperse.

Figure 24 AIR TERMINATIONS FOR TALL CONDUCTING STRUCTURES



The zone of protection does not seem to be applied because of the need to interconnect the down conductors of the tall block to the air termination of the lower block. In such cases it is necessary to connect the lower air termination up to the tower down conductors to facilitate this inter connection, even though this extension is within the zone of protection of the tower.

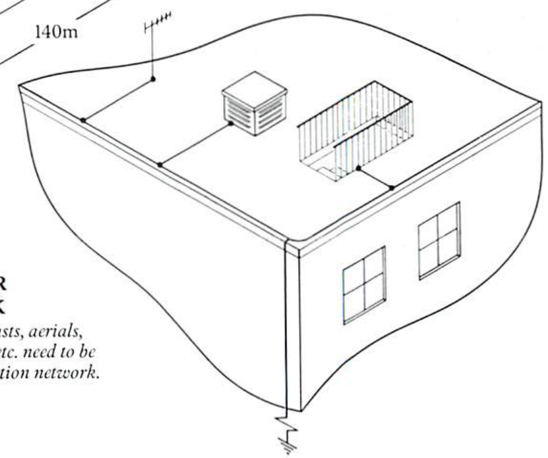


Figure 25 BONDING TO AIR TERMINATION NETWORK
All metal projections including masts, aerials, air conditioning units, handrails, etc. need to be correctly bonded to the air termination network.

The protective systems of churches and similar non-conducting structures (Figure 26) should include air termination networks, down conductors and earth termination networks. It is, however, very difficult to design protective systems for these structures collectively. BS 6651, therefore, advises that such structures should be treated as special cases: that the presence of a tower or spire should be disregarded when designing the protection of the lower parts of the structure.

If metallic components in a building are not used, then the structure will require externally fitted conductors. A Lightning Protection System can incorporate all natural conductors, all externally fitted conductors, or a combination of both. BS 6651 does not, however recommend the routing of conductors inside the structure.

Major Components

The principle components of a lightning protection system should comprise the following:

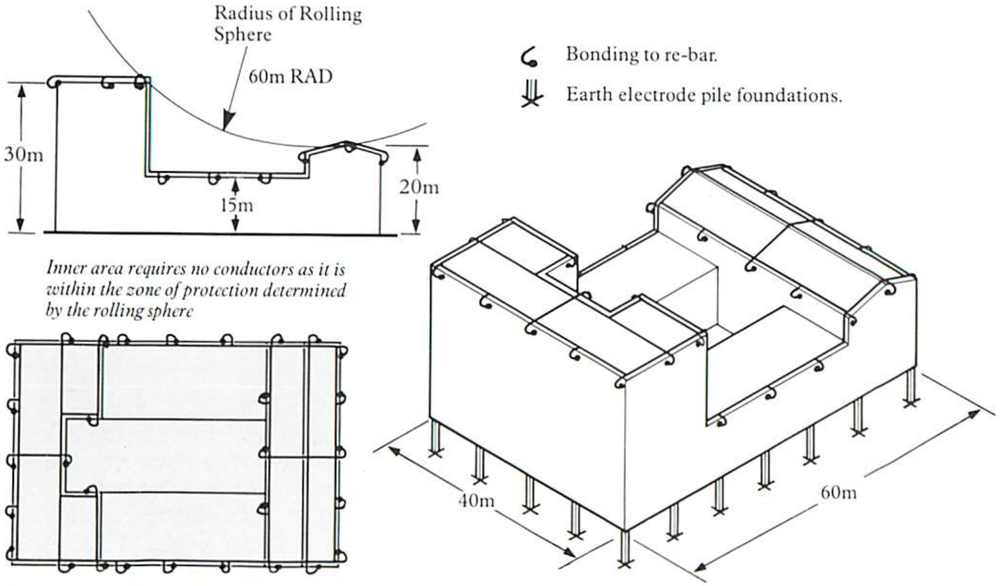
- **Air termination networks**
- **Down conductors**
- **Earth termination networks**
- **Bonding to prevent side flashing**

Air Termination Networks

As stated earlier it is now accepted that lightning can strike the upper part of tall structures. BS 6651 now introduces the concept of air termination networks on all sides of tall buildings (ie, vertical air termination networks). No part of the roof within the air termination network should be more than 5m from a conductor. For large flat roofs, this will be achieved typically by a network mesh of 10m x 20m. For high risk structures, ie, explosive factories, etc. the air termination mesh is reduced to 5m x 10m.

If a building's metal reinforcing bars are to be used as down conductors, these should be connected to the air termination network in the correct number of positions (Figure 23). Furse can supply purpose designed clamps (Figure 22B) for this connection.

Figure 23 LIGHTNING PROTECTION SCHEME TO BS6651 USING THE RE-INFORCED CONCRETE WITHIN THE STRUCTURE FOR DOWN CONDUCTORS



A sample Calculation of overall Risk Factor

For example:-

A small factory in the Midlands with brick walls and a metal roof, located in an area with few other structures or trees at a similar height, where the dimensions of the factory are:-

L = 40m
H = 6m
W = 15m

The risk factor can be calculated as follows using the maps and tables shown above.

Step 1

Determine the number of flashes to ground per km squared per year (Ng). (From the map in Figure 1 = 0.6).

Step 2

Determine the collection area (Ac) of the school building.

$$\begin{aligned} Ac &= LW + 2LH + 2WH + \pi H^2 \\ &= (40 \times 15) + 2(40 \times 6) + 2(15 \times 6) + \pi \times 6^2 \\ &= 600 + 480 + 180 + 113 \\ &= 1373\text{m}^2 \end{aligned}$$

Step 3

Determine the probability of being struck (P)

$$\begin{aligned} \text{When } P &= Ac \times Ng \times 10^{-6} \\ &= 1373 \times 0.6 \times 10^{-6} \\ &= 8.238 \times 10^{-4} \\ &\quad (\text{or } 0.0008238) \end{aligned}$$

Step 4

Applying the relevant weighting factors from (Tables 5, 6, 7, 8 and 9).

Factor A = 1.0
B = 1.7
C = 0.3
D = 1.0
E = 0.3

The overall weighting factor = A x B x C x D x E = 0.153

Step 5

Therefore, the overall risk factor
= Probability of being struck x overall weighting factor
= $8.238 \times 10^{-4} \times 0.153$
= 1.261×10^{-4} (or 0.000126)

Or expressing this answer as a reciprocal we obtain 1 in 7933.

As the 10^{-5} (1 in 100,000) is the criteria for determining whether protection is necessary, we can see that 1 in 7933 is "shorter odds" and so protection is necessary.

Having determined that lightning protection is necessary, we must now consider the actual design of the installation. To do this we must understand the principles of the Zone of Protection.

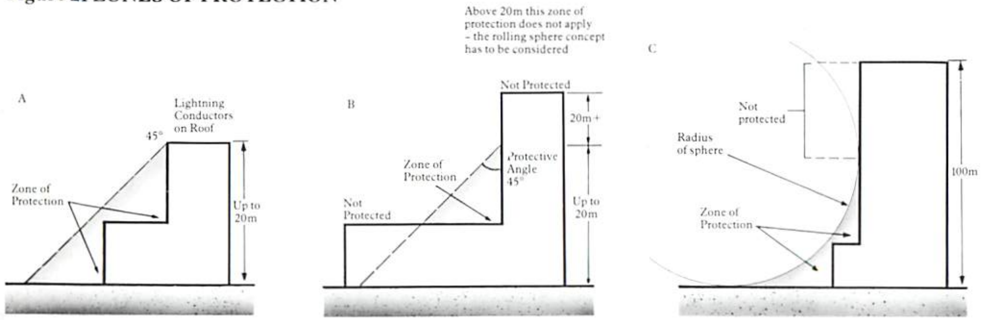
Zones of Protection

BS6651 qualifies, in detail, the meaning of 'Zones of Protection' and the 'Protective Angle'. It is sufficient to say that the 'Zone of Protection' is simply that volume within which a lightning conductor provides protection against a direct lightning strike by attracting the strike itself (Figure 21).

As can be seen in (Figure 21A) structures below 20m are regarded as offering a 45° protection angle. For structures greater than 20m in height (Figure 21B) the protection angle of any installed lightning protection conductors up to the height of 20m would be similar to the structures in (Figure 21A).

For tall structures above 20m in height (Figure 21C), BS 6651 recommends the use of the Rolling Sphere for determining the areas where lightning protection may be advisable.

Figure 21 ZONES OF PROTECTION



Furse offer a free advisory service including assistance in determining if a structure requires protection or indeed help with any aspect of lightning protection scheme design or equipment specification.

Construction Sites

When a structure is being erected, it is very easy to neglect the fact that all large and prominent masses of steelwork should be effectively connected to earth. This applies to all metal items including:- steel framework, scaffolding and on-site cranes.

Similarly, once work has commenced on the installation of a lightning protection system, an earth network should be connected at all times. This also applies to the installation of overhead power lines and railway electrification. It is very important to install and maintain at the early stages of construction, an adequate earthing system.

Inspection, Testing, Records and Maintenance

The Code adequately details the requirement for inspecting a lightning protection system, the testing required and the detailed records that should be maintained.

Observance of Section 6 of the code will highlight any maintenance of the system required. Of particular importance is the regular detailed examination of the complete lightning protection system for any evidence of corrosion. If this check is not carried out then vital components within the lightning protection system, which may have suffered from corrosion and which could exhibit a high resistance joint could be missed. This will have a detrimental effect on the whole lightning protection system making it an unattractive high impedance path for the lightning current to follow.

To minimise this problem, along with regular inspections, the selection of the correct materials should be made in accordance with the recommendations of BS 6651.

Section 3

System Design

Design Considerations

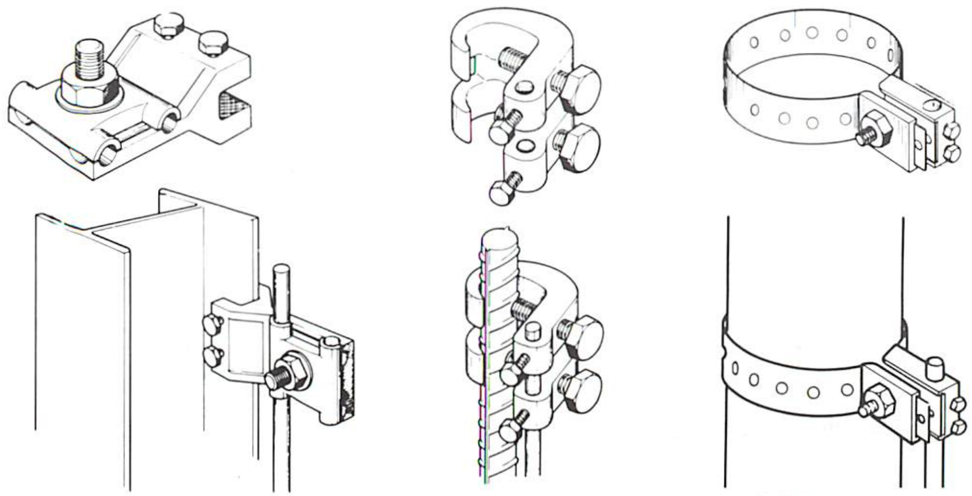
The foreword of BS 6651 clearly advises strict adherence to the provision of a conventional lightning protection system throughout its pages – to the total exclusion of any other device or system which claims to provide enhanced protection.

This is based on research that has been unable to substantiate the enhanced performance these devices or systems are claimed to give.

If it has been established that a structure requires lightning protection, certain general design considerations need to be made.

Could, for instance, any of the metallic components in or on the structure be incorporated into the lightning protection scheme? Could the metal in and on the roof be used? Should window cleaning rails, window frames, handrails surrounding the structure be incorporated in the protection network? The reinforcing bars or the steel frame of a structure may well provide a conductive path within the lightning protection system. With the use of natural conductors in mind, Furse have designed a range of clamps specifically suited to these applications – The Furse Solid Circular Range of Lightning Protection Equipment (Figure 22).

Figure 22 ILLUSTRATIONS OF TYPICAL FURSE CLAMPS USED IN METALWORK BONDING



A. Metalwork Bond B. Re-bar Clamp C. Pipe Bond