

PREFABRICATED EARTH ELECTRODE**FIELD OF THE INVENTION**

- 5 Embodiments of the present invention relate to a prefabricated earth electrode. In particular, they relate to a prefabricated earth electrode pad.

BACKGROUND TO THE INVENTION

- 10 Earth electrodes are known. Earth electrodes are electrically conductive bodies designed to be buried or driven underground, where they make contact with soil. A good earth electrode offers low resistivity, high corrosion resistance, resistance to mechanical damage, and low cost to purchase and install.
- 15 Earth electrodes can be in the form of rods. Rods are buried underground to a depth of several metres. Therefore, a survey first needs to be undertaken to avoid contact with buried pipes and cables.

- Earth electrodes can be in the form of pads which have a lower ground penetration depth.
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BRIEF DESCRIPTION OF VARIOUS EMBODIMENTS OF THE INVENTION

- According to various, but not necessarily all, embodiments of the invention there is provided a prefabricated earth electrode ("earth electrode" herein) comprising a
- 25 cementitious body and first and second terminals electrically connected to each other by elongate conductors within the cementitious body, wherein the elongate conductors define a plurality of parallel electrical paths each electrically connected to the first and second terminals.
- 30 An overall advantage is that the earth electrode can provide a low resistance ground connection without having to be large and heavy. It can also be connected to further earth electrodes via the second terminal, if required, for achieving a desired overall resistance. The plurality of parallel electrical paths (branches) were found to provide better electrical current dissipation relative to a single meandering electrical path or a plate. There is also
- 35 a mechanical strength advantage because the elongate conductors are spread out across

the cementitious body to provide a widespread reinforcing effect, allowing for the cementitious body to be smaller and lighter while retaining good strength.

5 According to various, but not necessarily all, embodiments of the invention there is provided a prefabricated earth electrode comprising a cementitious body and a first terminal electrically connected to elongate conductors within the cementitious body, wherein the elongate conductors define a plurality of parallel electrical paths each electrically connected to the first terminal.

10 The plurality of parallel electrical paths may be arranged in a horizontal or mostly horizontal orientation.

An advantage is a reduced ground penetration requirement.

15 The earth electrode may be a prefabricated earth electrode pad based on its dimensions. A total height of the earth electrode may be a value less than 150mm or less than 100mm, for example approximately 75mm.

An advantage is a reduced ground penetration requirement.

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The plurality of electrical paths may comprise three or more electrical paths.

25 An advantage of three or more parallel paths over two parallel paths is further improved mechanical strength because there are more elongate conductors spread out across the cementitious body. A further advantage is slower corrosion of each conductor, compared to a single path or two paths, because the electrical current density in each conductor is reduced.

30 The elongate conductors may be arranged to define one or more geometric direction changes within the cementitious body. The plurality of parallel electrical paths may comprise the geometric direction changes.

35 At least some of the geometric direction changes may comprise horizontal direction changes. A subset of the geometric direction changes may comprise vertical direction changes.

A radius of each geometric direction change may be selected from the range 0 mm to 12T, where T is the thickness of the conductor.

5 Some, most or all of the geometric direction changes may be a value selected from the range $\alpha=85$ to 95 degrees, such as 90 degrees or approximately 90 degrees. An advantage is ensuring low resistance and low mutual inductance between the paths at high frequencies.

10 The plurality of parallel paths may comprise a first path within a first half of the cementitious body, and a second path within a second opposite half of the cementitious body. The first and second paths may have equal or approximately equal electrical lengths. The plurality of parallel paths may comprise a third path between the first and second paths.

15 The first path may comprise a first section and a second section, and optionally a third section. The second section may meet the first section at a geometric angle. The geometric angle may be from the range α . The third section may meet the second section at a geometric angle. The geometric angle may be α . The third section may be opposite to the first section. The third section may be geometrically parallel or approximately geometrically parallel to the first section. The first and third sections may meet opposite ends of the
20 second section. The first, second, and third sections may collectively define a generally rectilinear path. The first, second and third sections may individually extend in a substantially straight line.

25 This paragraph refers to the second path. The second path may comprise a first section and a second section, and optionally a third section. The second section may meet the first section at a geometric angle. The geometric angle may be from the range α . The second path may comprise a third section. The third section may meet the second section at a geometric angle. The geometric angle may be α . The third section may be opposite to the first section. The third section may be geometrically parallel or approximately geometrically
30 parallel to the first section. The first and third sections may meet opposite ends of the second section. The first, second, and third sections may collectively define a generally rectilinear path. The first, second and third sections may individually extend in a substantially straight line.

The third path may be between or centrally between the first and second paths. The third path may meet opposite ends of the first and second paths. The third path may extend geometrically parallel to the second sections of the first and second paths.

- 5 The third path may have a shorter electrical length than the first and second paths. The third path may extend in a substantially straight line between the first and second paths.

- 10 The plurality of parallel paths may be geometrically symmetrical. A line of symmetry of the first to third parallel electrical paths may pass through the third path. An advantage is that geometrically symmetrical parallel paths help to achieve a balanced distribution of current among the conductors, increase the overall current-carrying capacity of the system, and maintain the functionality and reliability of the system under conductor failure conditions (in the event of corrosion, for example).

- 15 The third path may be central or approximately central within the cementitious body.

- 20 The cementitious body may comprise a first side, a second side, a third side opposite the first side, and a fourth side opposite the second side. The sides may be side walls. The first path may extend proximal to a first portion of the first side, proximal to the second side, and proximal to a first portion of the third side. The second path may extend proximal to a second portion of the first side, proximal to the fourth side, and proximal to a second portion of the third side. The first path may extend parallel or approximately parallel to the first portion of the first side, parallel or approximately parallel to the second side, and parallel or approximately parallel to the first portion of the third side. The second path may extend
25 parallel or approximately parallel to the second portion of the first side, parallel or approximately parallel to the fourth side, and parallel or approximately parallel to the second portion of the third side.

- 30 The cementitious body may comprise opposite upper and lower surfaces. One of the upper and lower surfaces may be convex and the other concave. The lower surface may be convex and the upper surface may be concave. The convexity or concavity may be curved and/or angular. In other examples, the lower surface is substantially flat or flatter than the upper surface, or the upper surface is substantially flat or flatter than the lower surface, or both surfaces are substantially flat.

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The advantages of extending proximal to and parallel to the sides of the cementitious body are mechanical and electrical in nature. Firstly, mutual coupling of the paths is reduced. Secondly, the reinforcing effect of the elongate conductors is widespread across most of the area of the earth electrode.

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The elongate conductors may include four elongate conductors defining at least in part a four-sided shape. The four-sided shape may be quadrilateral. The quadrilateral four-sided shape may be rectilinear.

10 The four elongate conductors may be electrically connected to each other at their respective ends. The four elongate conductors may be mechanically connected to each other at their respective ends. Their respective ends may be overlapping ends. The overlapping ends may be connected to each other by fixings such as rivets.

15 The elongate conductors may further include a fifth elongate conductor connecting opposite sides of the four-sided shape. The fifth elongate conductor may connect or centrally connect the opposite sides. The fifth elongate conductor may be electrically connected to an opposite pair of the four elongate conductors. The fifth elongate conductor may be mechanically connected to the opposite pair of the four elongate conductors. The
20 the fifth elongate conductor may overlie the opposite pair of the four elongate conductors. The mechanical connections may be via fixings such as rivets.

The elongate conductors may be formed from a copper-based material or from a steel-based material.

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The elongate conductors may comprise bars. Each of the elongate conductors may comprise a base side (B side) and a thickness side (T-side) together defining a TxB cross-section where $B > T$.

30 Some or all of the elongate conductors may be orientated B-side-down (wide side down). The four elongate conductors may be orientated B-side-down. The fifth elongate conductor may be orientated B-side down.

An advantage of the B-side-down orientation is suitability for low-resistivity soil. This
35 orientation maximises the effective external area of the earth electrode to provide effective current dissipation into low-resistivity soil. The cementitious body is a conductive body,

which is advantageous in ensuring good contact with soil compared to conventional conductors solely. This contact with soil is ensured with the outer surface of the cementitious body. This outer surface is the external area.

- 5 Alternatively, or additionally, at least some of the elongate conductors may be orientated T-side-down (thin side down). This means they are standing upright on their thin sides. The four elongate conductors may be orientated T-side-down.

- 10 An advantage of the T-side-down orientation is suitability for high-resistivity soil. This orientation considers not only the external area, but also the occupied volume for dissipating the current effectively.

- 15 While the four elongate conductors may be orientated T-side-down, the fifth elongate conductor may be orientated B-side down. Where the fifth elongate may provide the terminals, this orientation maintains a consistent external form of the earth electrode. This avoids altering the position of the connections or terminals, which are located on the top for both the low-resistivity and high-resistivity variants.

- 20 The plurality of parallel electrical paths may be fully embedded within the cementitious body. The elongate conductors may have top cover and bottom cover provided by a material of the cementitious body. The elongate conductors may be fully embedded within the cementitious body, except for the first and second terminals where the first and second terminals may be portions of the elongate conductors. The first and second terminals may be exposed at a surface of the cementitious body.

- 25 The plurality of parallel electrical paths may be closer to a lower surface of the cementitious body than to an upper surface of the cementitious body. The bottom cover may be shallower than the top cover. An advantage is that the elongate conductors reinforce the lower part of the cementitious body to prevent cracking from flexure or expansion.

- 30 The first and second terminals may be in the form of screw terminals. The first terminal may comprise a plurality of screw holes. The second terminal may comprise a plurality of screw holes. An advantage is that a secure connection is provided to an earth conductor.

The first and second terminals may be exposed at a surface of the cementitious body. Leaving the terminals exposed at the surface may provide easier access for inspection, maintenance or future modifications if needed.

- 5 The first and second terminals may be flush or sub-flush with the surface of the cementitious body. This enhances the handling safety of the earth electrode by eliminating protruding parts.

- 10 The first and second terminals may be positioned to opposite sides of the cementitious body. The first and second terminals may be symmetrically opposite each other. An advantage of their positioning is that the earth electrode is 'ambidextrous' and can be connected to other earth blocks to both of its sides.

- 15 The first and second terminals may be exposed on an upper surface of the cementitious body, or to other faces of the cementitious body.

- 20 The first and second terminals may be exposed portions of one or more of the elongate conductors. The first and second terminals may be exposed portions of opposite ends of one of the elongate conductors, which may be a folded elongate conductor. The folded elongate conductor may be folded towards its ends to provide the first and second terminals. The folded elongate conductor may be folded up towards its ends to provide the first and second terminals above the plurality of parallel electrical paths. The folded elongate conductor may be folded towards its ends to expose the first and second terminals at an upper portion of the cementitious body. The folded elongate conductor may comprise a pair of vertical bends towards each of its ends. Each vertical bend may have an angle α .

- 30 The folded elongate conductor may define one of the plurality of parallel electrical paths. The other path or paths of the plurality of electrical paths may be electrically connected to the folded elongate conductor inboard of where the folded elongate conductor is folded. The other path or paths may be mechanically connected to the folded elongate conductor inboard of where the folded elongate conductor is folded. The other path or paths may be electrically connected to the folded elongate conductor between the pairs of vertical bends. The term 'inboard' means closer to the centre of the earth electrode.

- 35 The elongate conductor may be the fifth elongate conductor referred to earlier. The other path or paths may be the first to fourth elongate conductors referred to earlier.

The earth electrode may be prefabricated in the sense that the cementitious body is a cured cementitious body prior to installation in the ground.

- 5 The earth electrode may comprise one or more mounts (sections for lifting tools) to enable lifting of the earth electrode. The earth electrode may comprise a pair of the mounts. The mounts may be anchored to the cementitious body. The mounts may comprise handles.

- 10 The mounts may be located in one or more recesses of the cementitious body. The mounts may protrude by no more than the depths of the recesses.

The cementitious body may have a plan view aspect ratio selected from the range 1:1 to 2:1. An advantage of this square or mostly square aspect ratio is ease of installation.

- 15 The cementitious body may have a side wall arrangement connecting the lower and upper surfaces. The side wall arrangement may define a four-sided shape, such as a quadrilateral shape, such as a rectilinear shape. An advantage is improved space efficiency compared to a disc or cylinder, for storage and transportation. The side wall arrangement may define the first to fourth sides referred to earlier.

- 20 The cementitious body may have a larger base area than top area. That is, the upper surface may have a smaller area than the lower surface. The cementitious body may have inclined sides connecting the larger base area to the top area. The side wall arrangement may define the inclined sides. An advantage is that the cementitious body is easier to mold.

- 25 The earth electrode may have a mass no greater than 25kg, or no more than 10kg.

- 30 The cementitious body may comprise electrically conductive aggregate and a binder. The binder may comprise cement. The electrically conductive aggregate may be at least mostly carbonaceous. The electrically conductive aggregate may comprise a mixture of electrically conductive materials including coal-, petroleum- or biomass-derived material and graphite. The coal-derived material may comprise crushed coke breeze.

- 35 An advantage of the electrically conductive aggregate is that it provides a permanent medium with good electrical conductivity, protective earth, and high mechanical strength.

The electrically conductive aggregate may be not below approximately pH7, for non-corrosive properties.

5 The earth electrode may comprise a tail conductor partially embedded in the cementitious body, electrically coupled to the elongate conductors, and protruding from the cementitious body.

10 The tail conductor may comprise a flexible electrical conductor. The tail conductor may comprise an electrical wire. The tail conductor may be more flexible than the elongate conductors.

15 The tail conductor may have a protruding length from the cementitious body greater than its embedded length. The protruding length may be in the order of tens of centimetres, or more.

20 An advantage is that tail conductor can advantageously be utilised in situations where bolted connections to the first and second terminals are not allowed, and there is no material covering the connection point (first and second terminals). The tail conductor provides a superior connection as it is embedded in the cementitious body. In some examples, the first and second terminals may be covered by an electrical insulator if the tail conductor is to be used.

25 The tail conductor may be physically and electrically coupled to a central elongate conductor of the elongate conductors. The central elongate conductor may be the fifth elongate conductor as described above. An advantage of connecting it here is improved pullout strength because the embedded depth of the tail conductor is greater, compared to connecting it to the first to fourth elongate conductors which are closer to the edge of the cementitious body.

30 The tail conductor may extend substantially horizontally or mostly horizontally within the cementitious body. The tail conductor may extend into the cementitious body through a side wall of the cementitious body. The tail conductor may extend into the cementitious body through an edge of the cementitious body. The tail conductor may extend into the cementitious body through a lower edge of a side wall of the cementitious body.

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According to various, but not necessarily all, embodiments of the invention there is provided a system comprising the earth electrode and an insulating layer placed or configured to be placed above the earth electrode. The insulating layer may be a polymeric-based material. The insulating layer may have a plan view area from 80% to 150% of a plan view area of the earth electrode.

An advantage of the insulating layer is protection against earth potential rise, to protect users from high touch voltages and step voltages.

According to various, but not necessarily all, embodiments of the invention there is provided a multi-electrode system comprising a first of the earth electrodes and a second of the earth electrodes, wherein the first terminal of the first earth electrode is connected or connectable to a customer earth conductor, and wherein the second terminal of the first earth electrode is electrically connected to the first terminal of the second earth electrode.

The first and second earth electrodes may be located side-by-side and electrically connected to each other via wiring or a busbar.

One or both of the earth electrodes may be for low-resistivity soil as described earlier. The other or both of the earth electrodes may be for high-resistivity soil as described earlier.

The multi-electrode system may comprise a third of the earth electrodes, wherein the second terminal of the second earth electrode is electrically connected to the first terminal of the third earth electrode. The first to third earth electrodes may be electrically interconnected in series.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of various examples of embodiments of the present invention reference will now be made by way of example only to the accompanying drawings in which:

FIG. 1 illustrates a perspective view of a prefabricated earth electrode;

FIG. 2 illustrates the earth electrode of FIG. 1 with the cementitious body made transparent to reveal a plurality of elongate conductors;

FIG. 3 illustrates the plurality of elongate conductors of FIG. 2;

FIGS. 4A-4B illustrate alternative orientations of an elongate conductor;

FIG. 5 illustrates an example of a system and a multi-electrode system; and
FIG. 6 illustrates an example earth electrode with a .

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS OF THE INVENTION

- 5
- FIGS. 1-5 illustrate an example of a prefabricated earth electrode 100 which is manufactured cost-effectively, while being designed to provide effective dissipation of currents into the soil, in both normal and abnormal conditions. The illustrated earth electrode 100 provides several benefits:
- 10
- a. Low electrical resistance;
 - b. Adequate for numerous applications;
 - c. Not too heavy for personnel;
 - d. Equipped with a lifting tool;
 - e. Modular interconnection option; and
- 15
- f. Reduced mutual inductance at high frequencies (e.g., up to 10MHz).

The earth electrode 100 can be adjusted to fit specific customer requirements. The earth electrode 100 is suitable for a wide range of earthing applications, but more effective for those with space constraints, low electrical resistance requirements, and high frequency

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fault currents.

Electric vehicle charging points (both AC and DC) represent a good use case since a low resistance is required over a small covered area. Further, the fault current may be characterised by high frequency components associated with switching faults, especially

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in DC chargers. The earth electrode 100 can be used to dissipate currents effectively into the soil, in both normal and abnormal conditions. The earth electrode 100 can provide a permanent solution to many problems in electrical/construction use cases. These include, but are not limited to, the following use cases:

- 1. Photovoltaic installations;
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- 2. Enhancing tower footing impedance;
- 3. Telecommunication systems;
- 4. Distribution poles;
- 5. and more.

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A single earth electrode 100 may be enough to satisfy a low resistivity requirement. The illustrated earth electrode 100 can provide a 7.5 ohm earthing resistance for a soil of 10

ohm-metre resistivity. The earth electrode 100 can be used to reduce the Earth Potential Rise (EPR) when hot spots are identified.

5 For high resistivity conditions, a modular version shown in FIG. 5 involves interconnecting several earth electrodes 100 to achieve a low earthing resistance. Further, different overall dimensions of the earth electrode 100 can be considered in accordance with soil resistivity.

10 The illustrated earth electrode 100 is suitable for domestic applications where it is difficult and sometimes not practical to drive long earth rods into the ground to achieve the desired resistance.

15 High frequency currents induced from electrical switching currents and from lightning currents are considered in the design of the illustrated earth electrode 100, such that impedance does not rise as frequency increases. Therefore, the earth electrode 100 can be used not only in cases where no sufficient space exists to install a large-scale earthing system, but also as a high frequency reinforcement electrode.

20 The earth electrode 100 illustrated in FIGS. 1-4B comprises a cementitious body 102 and a plurality of elongate conductors 107 mostly embedded within the cementitious body 102. As shown in FIGS. 2-3, the elongate conductors 107 define a plurality of parallel (electrically parallel) electrical paths 118, 120 122 each electrically connected to first and second terminals 104, 106.

25 First, the cementitious body 102 is described in more detail. The cementitious body 102 comprises a side wall arrangement of side walls 140 defining a first side 124, a second side 126, a third side 128 opposite the first side 124, and a fourth side 130 opposite the second side 126. The cementitious body 102 further comprises a base and top defining a lower surface 136 and an upper surface 138 opposite the lower surface 136, respectively. The lower surface 136 is connected to lower edges of the first to fourth sides 124, 126, 128, 130. The upper surface 138 is connected to upper edges of the first to fourth sides 124, 126, 128, 130. A square or rectangular plan-view shape is defined as a result.

35 The length, width, and height of the cementitious body 102 depend on implementation, and are not limited to the values given below. The height from the lower surface 136 to the upper surface 138 is less than the length and width. In examples, the height is approximately 75mm or another value less than 150mm or less than 100mm. The height

may be at least 50mm. The length of the cementitious body 102, along the second and fourth sides 126, 130, may be approximately 325mm or another value less than 750mm. The width of the cementitious body 102, along the first and third sides 124, 128, depends on the number of parallel electrical paths and the spacing therebetween. The width may
5 be approximately equal to the length, or no greater than double the length. This defines an aspect ratio from the range 1:1 to 2:1.

FIG. 1 illustrates the lower surface 136 of the cementitious body 102 optionally having a larger plan view area than the upper surface 138. The sides (side walls 140) are therefore
10 inclined inwardly at a draft angle from the range 5 to 15 degrees. The length and width values quoted above may be of the lower surface 136.

The earth electrode 100 may have an overall mass of 25kg or less, or 10kg or less. When combined with the above dimensions, the earth electrode 100 is easy for an installer to
15 carry.

However, the illustrated earth electrode 100 has been further provided with mounts to assist with lifting. FIG. 1 shows a pair of recesses 144 formed in a surface of the cementitious body 102, where mounts in the form of handles (not shown) can be provided.
20 The handles may be overmolded, for example.

Each handle may protrude by no more than the depth of the recess 144, so that the overall height of the earth electrode 100 is not increased. Therefore, the handles are flush with or recessed relative to rims of the recesses 144.
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In FIG. 1, but not necessarily all examples, the recesses 144 are formed in the upper surface 138 of the cementitious body 102, so that the handles enable the earth electrode 100 to be lifted from above. One recess 144 is proximal to the second side 126 whereas the other is proximal to the fourth side 130. In other examples, the recesses 144 are formed
30 in one or more other surfaces.

The composition of the cementitious body 102 considers thermal expansion properties, mechanical strength, corrosion resistance, and ease of recycling.

35 In examples, the cementitious body 102 comprises Marconite(TM) which is an electrically conductive aggregate to replace sand. Portland cement may be used as a binder, and

deionised water may be used to achieve the required workability. Marconite is a granulated material comprising a mixture of electrically conductive carbonaceous materials including crushed coke breeze and graphite. Marconite provides a permanent medium with good electrical conductivity, protective earth capabilities, and high mechanical strength. In other examples, other electrically conductive aggregates are used, or sand.

FIG. 1 further illustrates a first terminal 104 and a second terminal 106 exposed towards opposite ends of the upper surface 138 of the cementitious body 102. The rest of the elongate conductors 107 are embedded within the cementitious body 102.

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Each of these electrical terminals 104, 106 is a screw terminal comprising two screw holes 142 (FIG. 1), or alternatively one screw hole. Screws (not shown) can therefore securely electrically clamp an earth conductor to the terminals 104, 106. Alternatively, other connection methods may be used.

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The first terminal 104 is shown proximal to the third side 128 of the cementitious body 102 and the second terminal 106 is shown proximal to the opposite first side 124 of the cementitious body 102. The first and second terminals 104, 106 may be within 20mm of the respective third and first sides 128, 124, to maximise their physical separation. The first and second terminals 104, 106 may be symmetrically opposite each other. The terminals 104, 106 are also centrally located between the second and fourth sides 126, 130 of the cementitious body 102. Both terminals 104, 106 are equally suitable to receive an earth conductor.

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Each terminal 104, 106 is shown as being flush with the upper surface 138 of the cementitious body 102. In other examples, they may be sub-flush. In further examples, the terminals 104, 106 may be exposed on other surfaces of the cementitious body 102 and/or may protrude from or extend away from the cementitious body 102.

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Turning now to FIGS. 2-3, the internal elongate conductors 107 can be seen. In FIG. 2, the cementitious body 102 is represented as a transparent wireframe, and in FIG. 3 the cementitious body 102 is omitted.

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The elongate conductors 107 shown are flat linear bars 134, of a copper or steel/galvanised steel material. The use of flat bars 134 further helps to minimise electrical resistance at high frequencies.

FIGS. 2-3 also show that the elongate conductors 107 are arranged into three parallel electrical paths 118, 120 122 each electrically connected at each end to the first and second terminals 104, 106. Therefore, electrical current flow between the terminals 104, 106 flows through the three parallel electrical paths 118, 120 122. Further, the three parallel electrical paths 118, 120 122 can be arranged in a geometrically horizontal orientation as shown.

In another example, two parallel electrical paths are used. In a further example, more than three parallel electrical paths can be provided, for example where the width of the earth electrode 100 may be greater than the length.

The three parallel electrical paths 118, 120 122 include a first path 118 within a first half of the cementitious body 102, a second path 120 within a second opposite half of the cementitious body 102, and a third path 122 between the first and second paths 118, 120. The first and second paths 118, 120 have equal or approximately equal electrical lengths and are symmetrically opposite each other, with the third path 122 extending centrally therebetween.

FIG. 3 labels the elongate conductors 107 as comprising five elongate conductors 108, 110, 112, 114, 116 which provide the three parallel electrical paths 118, 120 122 and the terminals 104, 106. Four of the elongate conductors 108, 110, 112, 114 extend parallel and proximal to the sides of the cementitious body 102, therefore defining a square or rectangular shape. The fifth elongate conductor 116 is centrally located, connecting an opposite pair of the four elongate conductors 108, 110, 112, 114, and is folded up towards its ends to provide the terminals 104, 106.

Specifically:

- A first elongate conductor 108 extends parallel and proximal to the first side 124 of the cementitious body 102. The first elongate conductor 108 has top cover, bottom cover, and side cover of at least 5mm of the cementitious material, providing protective cover of cementitious material. The side cover may be less than 20mm. A second end of the first elongate conductor 108 is connected to an overlapping first end of a second elongate conductor 110 by a fixing 132 (e.g., rivet), with an angle (geometric direction change) of α formed between the first and second elongate conductors 108, 110, where α is 85-95 degrees such as 90 degrees.

- The second elongate conductor 110 extends parallel and proximal to the second side 126 of the cementitious body 102. The second elongate conductor 110 has top cover, bottom cover, and side cover of at least 5mm of the cementitious material. The side cover may be less than 20mm. A second end of the second elongate conductor 110 is connected to an overlapping first end of a third elongate conductor 112 by a fixing 132, with an angle of α formed between the second and third elongate conductors 110, 112.
- The third elongate conductor 112 extends parallel and proximal to the third side 128 of the cementitious body 102. The third elongate conductor 112 has top cover, bottom cover, and side cover of at least 5mm of the cementitious material. The side cover may be less than 20mm. A second end of the third elongate conductor 112 is connected to an overlapping first end of a fourth elongate conductor 114 by a fixing 132, with an angle of α formed between the third and fourth elongate conductors 112, 114.
- The fourth elongate conductor 114 extends parallel and proximal to the fourth side 130 of the cementitious body 102. The fourth elongate conductor 114 has top cover, bottom cover, and side cover of at least 5mm of the cementitious material. The side cover may be less than 20mm. A second end of the fourth elongate conductor 114 is connected to an overlapping first end of the first elongate conductor 108 by a fixing 132, with an angle of α formed between the fourth and first elongate conductors 114, 108.
- The fifth elongate conductor 116 extends parallel to and centrally (e.g., equidistant) between the second and fourth elongate conductors 110, 114, and is connected to midpoints of the first and third elongate conductors 108, 112 by respective fixings 132, and is folded up twice towards each end, where each fold is an angle of value α , so that each end of the fifth elongate conductor 116 is a corresponding terminal 104, 106 exposed at the upper surface 138 of the cementitious body 102 and extending in an inboard direction.
- The fifth elongate conductor 116 has bottom cover, and side cover of greater than 5mm. The side cover may be less than 20mm.

The above configuration of overlapping perpendicular elongate conductors 108, 110, 112, 114, 116 means each angle α has a zero effective radius. This is advantageous because it helps minimise the overall inductance of the earth electrode, resulting in reduced impedance. Additionally, it is easier to manufacture and install compared to other shapes.

Regarding the fifth elongate conductor 116, it would be appreciated that the configuration of the folds (if any) depends on the desired locations of the terminals 104, 106. For the illustrated earth electrode 100, it was found that two 90-degree folds is better than a 180-degree curve because this allows for a more compact and space-efficient product. This

reduces the occupied volume and has a positive impact on factors like packaging. Secondly, the 90-degree angles help with safety by preventing the exposure of metal outside the cementitious body in the form of protrusions or lumps. This design consideration improves the overall functionality of the earth electrode.

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Based on the above elongate conductors 108, 110, 112, 114, 116, the three parallel electrical paths 118, 120, 122 can be defined as follows:

- The first path 118 comprises three linear or approximately linear sections 1181, 1182, 1183. The first section 1181 is the section (e.g., approximately half) of the first elongate conductor 108 extending from the connection between the fifth and first elongate conductors 116, 108 to the second end of the first elongate conductor 108. The second section 1182 is the second elongate conductor 110. The third section 1183 is the section (e.g., approximately half) of the third elongate conductor 112 extending from the first end of the third elongate conductor 112 to the connection between the fifth and third elongate conductors 116, 112. The three sections 1181, 1182, 1183 are geometrically perpendicular, having an angle of α therebetween, with the third section 1183 being opposite and geometrically parallel to the first section 1181.
- The second path 120 comprises three linear or approximately linear sections 1201, 1202, 1203. The first section 1201 is the other section (e.g., approximately half) of the first elongate conductor 108 extending from the connection between the fifth and first elongate conductors 116, 108 to the first end of the first elongate conductor 108. The second section 1202 is the fourth elongate conductor 114. The third section 1203 is the other section (e.g., approximately half) of the third elongate conductor 112 extending from the second end of the third elongate conductor 112 to the connection between the fifth and third elongate conductors 116, 112. The three sections 1201, 1202, 1203 are perpendicular, having an angle of α therebetween, with the third section 1203 being opposite and parallel to the first section 1201. Therefore, the first sections 1181, 1201 of the first and second paths 118, 120 are different sections of a same elongate conductor 108, the second sections 1182, 1202 of the first and second paths 118, 120 are opposite elongate conductors 110, 114, and the third sections 1183, 1203 of the first and second paths 118, 120 are different sections of a same elongate conductor 112.
- The third path 122 comprises a single linear or approximately linear section 1162. The single section 1162 of the third path 122 is the section of the fifth elongate conductor 116 extending from the connection between the fifth and first elongate conductors 116, 108 to the opposite connection between the fifth and third elongate conductors 116, 112. The single section 1162 of the third path 122 is parallel to and between or centrally between

the second sections 1182, 1202 of the first and second paths 118, 120. The third path 122, i.e., the single section 1162, has a shorter electrical length than the first and second paths 118, 120.

- 5 Based on the above, it can also be said that the first path 118 extends proximal to the second side 126 and portions of the first and third sides 124, 128, of the cementitious body 102. The second path 120 extends proximal to the fourth side 130 and other portions of the first and third sides 124, 128, of the cementitious body 102.
- 10 Folded sections 1161, 1163 of the fifth elongate conductor 116 do not form part of the parallel electrical paths 118, 120, 122 and instead electrically connect the paths 118, 120 122 to the terminals 104, 106. Therefore, in use, electrical current flows between the folded sections 1161, 1163 via the three parallel electrical paths 118, 120 122 simultaneously.
- 15 Referring to FIG. 2, the three parallel electrical paths 118, 120 122 are shown as being closer to the lower surface 136 of the cementitious body 102 than to the upper surface 138 of the cementitious body 102. In other words, the bottom cover of cementitious material is less than the top cover of cementitious material. Therefore, the lower part of the cementitious body 102 is reinforced against tension and expansion.
- 20 Referring now to FIGS. 4A-4B, two variants of earth electrode 100 may be provided. The version shown in FIGS. 2-4A is for relatively low soil electrical resistivity. The version shown in FIG. 4B is for relatively high soil electrical resistivity.
- 25 Each of the elongate conductors 107 is a flat bar 134 comprising a base side (B side) and a thickness side (T-side) together defining a TxB cross-section, whereing the cross sectional area is TxB, and the base side B is longer than the thickness T.
- 30 In the first version, some or all of the elongate conductors 107 are orientated B-side-down (wide side down) as shown in FIG. 4A. This is designed to maximise the external area of the earth electrode 100 and provide an effective dissipation of currents into the soil. This technique is more effective for soil with relatively low resistivity.
- 35 In the second version of FIG. 4B, at least some of the elongate conductors 107 may be orientated T-side-down (thin side down). This means they are standing upright on their thin sides. This may include the first to fourth elongate conductors 108, 110, 112, 114. In the

second variant, we consider not only the external area, but also the occupied volume for dissipating the current effectively. Both parameters B and T have been optimised to find a good combination of features that give the desired resistance, cost, installation time, and so on.

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Turning now to FIG. 5 (in-situ side view), an accessory can be provided in the form of an electrically insulating layer 202, wherein the insulating layer 202 comprises a flat pad of a polymeric material. The insulating layer 202 can adjust the potential distribution on the earth surface in order to ensure the safety of individuals. An insulating layer 202 is used to reduce earth potential rise and protect individuals from touch and step voltages. Polymeric material can be used for the insulating layer 202, with characteristics in accordance with the given application. The insulating layer 202 may be buried or placed at a height of at least 10cm above the upper surface 138 of the earth electrode 100.

According to various, but not necessarily all, embodiments of the invention there is provided a system 200 comprising the earth electrode 100 and the insulating layer 202 placed or configured to be placed above the earth electrode 100. The insulating layer 202 may have a plan view area from 80% to 150% of a plan view area of the earth electrode 100.

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FIG. 5 also shows that multiple earth electrodes 100 can be electrically interconnected in series. For example, if an installer wishes to achieve a desired resistance, they can connect multiple earth electrodes 100 until the desired resistance is achieved. The earth electrodes 100 are modular not least because each one has multiple terminals 104, 106, interconnected by a plurality of parallel electrical paths 118, 120 122.

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The installer connects an earth conductor 302 to either terminal 104, 106 of one of the earth electrodes 100. The other terminal 106, 104 of the earth electrode 100 is connected or connectable to any one of the terminals 104, 106 of the second earth electrode 100, via conductor 304 such as a wire or busbar. If a third earth electrode 100 is desired, the series can be extended in this manner.

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Therefore, according to various, but not necessarily all, embodiments of the invention there is provided a multi-electrode system 300 comprising a first of the earth electrodes 100 and a second (or more) of the earth electrodes 100, connected as described above. The earth electrodes 100 may be located side-by-side and buried. The insulating layer 202 may

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optionally be provided as part of the system 300, with each earth electrode 100 covered by a corresponding insulating layer 202 or portion of a single insulating layer 202.

One or both of the variants of FIGS. 4A-4B may be used in the multi-electrode system, depending on the soil resistivity.

FIG. 6 illustrates a variant of FIGS. 1-5 which further comprises a tail conductor in the form of a partially-embedded flexible electrical wire 146.

The embedded part of the electrical wire 146 is physically connected to the fifth elongate conductor 116 via a weld, exothermic weld, or other type of joint.

The electrical wire 146 is shown connected to the middle region of the fifth elongate conductor 116.

The electrical wire 146 extends horizontally within the cementitious body to the side 130 (or 126) that is parallel to the fifth elongate conductor 116.

As shown, the electrical wire 146 may emerge from the lower edge of the side 130, the lower edge connecting the side 130 to the base.

The electrical wire 146 has a flexible protruding length of tens of centimetres, or more, from where it emerges from the cementitious body 102. The electrical wire 146 may be flexed upwardly, so that the earthing electrode 100 is placed underground while keeping the end of the electrical wire 146 above. This allows a non-bolted electrical connection to be made to the earth electrode 100, without the need to bolt anything to the terminals 104, 106. The terminals 104, 106 may or may not be in use. If not in use, they may be covered by an electrical insulator (not shown).

The electrical wire 146 optionally has an electrically-conductive cross-sectional area smaller than that of the elongate conductors 108, 110, 112, 114, 116. The electrical wire 146 is optionally electrically insulated.

Although embodiments of the present invention have been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications

to the examples given can be made without departing from the scope of the invention as claimed.

5 Features described in the preceding description may be used in combinations other than the combinations explicitly described.

Although functions have been described with reference to certain features, those functions may be performable by other features whether described or not.

10 Although features have been described with reference to certain embodiments, those features may also be present in other embodiments whether described or not.

15 Whilst endeavoring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

CLAIMS

1. A prefabricated earth electrode comprising a cementitious body and a first terminal electrically connected to elongate conductors within the cementitious body, wherein the elongate conductors define a plurality of parallel electrical paths each electrically connected to the first terminal.
2. The prefabricated earth electrode of claim 1, wherein the plurality of parallel electrical paths are each electrically connected to another terminal.
3. The prefabricated earth electrode of claim 1 or 2, wherein the prefabricated earth electric is a pad, and wherein the plurality of parallel electrical paths are arranged in a horizontal orientation.
4. The prefabricated earth electrode of any of the preceding claims, wherein the plurality of parallel electrical paths comprise three or more parallel electrical paths.
5. The prefabricated earth electrode of any of the preceding claims, wherein the elongate conductors are arranged to define one or more geometric direction changes within the cementitious body.
6. The prefabricated earth electrode of claim 5, wherein the geometric direction changes have a value selected from the range $\alpha=85$ to 95 degrees.
7. The prefabricated earth electrode of any of the preceding claims, wherein the plurality of parallel electrical paths comprises a first path within a first half of the cementitious body, and a second path within a second opposite half of the cementitious body.
8. The prefabricated earth electrode of claim 7, wherein the plurality of parallel electrical paths comprises a third path between the first and second paths.
9. The prefabricated earth electrode of claim 8, wherein the third path is centrally between the first and second paths.
10. The prefabricated earth electrode of claim 8 or 9, wherein the third path is approximately central within the cementitious body.

11. The prefabricated earth electrode of any of the preceding claims, wherein the plurality of parallel electrical paths are geometrically symmetrical.

5 12. The prefabricated earth electrode of any of the preceding claims, wherein the cementitious body comprises a first side, a second side, a third side opposite the first side, and a fourth side opposite the second side.

13. The prefabricated earth electrode of claim 12, wherein:

10 the first path extends proximal to a first portion of the first side, proximal to the second side, and proximal to a first portion of the third side; and

the second path extends proximal to a second portion of the first side, proximal to the fourth side, and proximal to a second portion of the third side.

15 14. The prefabricated earth electrode of claim 12 or 13, wherein:

the first path extends approximately parallel to the first portion of the first side, approximately parallel to the second side, and approximately parallel to the first portion of the third side; and

20 the second path extends approximately parallel to the second portion of the first side, approximately parallel to the fourth side, and approximately parallel to the second portion of the third side.

15. The prefabricated earth electrode of any of the preceding claims, wherein the elongate conductors include four elongate conductors defining at least in part a four-sided shape.

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16. The prefabricated earth electrode of claim 15, wherein the four elongate conductors are electrically and/or are mechanically connected to each other at their respective ends, and/or wherein the elongate conductors further include a fifth elongate conductor connecting opposite sides of the four-sided shape.

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17. The prefabricated earth electrode of any of the preceding claims, wherein the plurality of parallel electrical paths are fully embedded within the cementitious body and wherein the plurality of parallel electrical paths are closer to a lower surface of the cementitious body than to an upper surface of the cementitious body.

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18. The prefabricated earth electrode of claim 17, wherein the elongate conductors are fully embedded within the cementitious body, except for the first terminal and a second terminal, wherein the first and second terminals are portions of the elongate conductors.

5 19. The prefabricated earth electrode of claim 18, wherein the elongate conductors are folded towards their ends to provide the first and second terminals.

20. The prefabricated earth electrode of any of the preceding claims, wherein the prefabricated earth electrode further comprises one or more mounts to enable lifting of the
10 prefabricated earth electrode.

21. The prefabricated earth electrode of any of the preceding claims, wherein the cementitious body comprises an electrically conductive aggregate and a binder.

15 22. The prefabricated earth electrode of any of the preceding claims, wherein the prefabricated earth electrode further comprises a tail conductor partially embedded in the cementitious body, electrically coupled to the elongate conductors, and protruding from the cementitious body.

20 23. The prefabricated earth electrode of claim 22, wherein the tail conductor is physically and electrically coupled to a central elongate conductor of the elongate conductors.

24. A system comprising the prefabricated earth electrode of any of the preceding claims and an insulating layer placed or configured to be placed above the prefabricated earth
25 electrode.

25. A multi-electrode system comprising first and second prefabricated earth electrodes each as claimed in any one of claims 1 to 24, wherein the first terminal of the first prefabricated earth electrode is connected or connectable to a customer earth conductor,
30 and wherein the second terminal of the first earth electrode is electrically connected to the first terminal of the second prefabricated earth electrode.