MARCONITE® Electrically Conductive Aggregate
An Innovative Earthing Technology

1 INTRODUCTION

In the past, engineers relied on technology, related to generally available minerals, to design the earthing systems for various applications like power stations, buildings, railways, industrial complexes, water & gas plants etc. These earthing systems required presence of water to maintain.

In the late 19th century Marconite® was specifically developed to meet the requirement of all type of earthing applications but without the need of water it. It is electrically conductive black granular, used as backfill material to enhance the effectiveness of the earth to achieve durable, stable and low resistance performing earthing solutions for all types of soil and difficult ground conditions.

Marconite® conducts electricity much the same way as metals, through the movement of electrons. It does not require water to conduct electricity and is not affected by dryness like other ionic based earthing materials such as Bentonite, Charcoal etc. which always require the presence of an effective electrolyte else they dry out and do not conduct electricity.

Marconite® conductive concrete is one of the most suitable materials for treatment of soil. Electrical engineers have been using it to tackle the toughest soil conditions so as to achieve satisfactory earthing solutions throughout the World for over 50 years.

2 SALIENT FEATURES

2.1 Specifications:

a) Fixed Carbon	98.5 %
b) Ash, Volatile and Water	1.5 %
c) Sulphur Content	1.5 % Maximum
d) Size Grading (Approx)	10% below 0.10 mm 5% above 3.15 mm 85% between 0.10 mm and 3.15 mm
e) Thermal Stability	Between (−) 10% and (+) 60% ambient temperature

2.2 Ultra Low Resistivity: The resistivity of Marconite® is 0.001 Ω-m and when mixed with Portland cement it is still 0.040 Ω-m, which is significantly lower than other earthing materials:-

a) Marconite® Aggregate	=	0.001 Ω-m
b) Normal Aggregate	=	30 to 90 Ω-m
c) Marconite® conducting concrete (Mix with Cement)	=	0.040 Ω-m
d) Bentonite	=	3 Ω-m upwards

2.3 Versatile: Marconite® is suitable for all types of soil/ground conditions. It becomes a permanent solid structure and does not shrink or gets washed away. It does not require moisture at all. It performs very well in dry soil and hottest climatic conditions.

2.4 Consistent Performance: Once installed, Marconite® based earthing system gives consistent performance and earth resistance value remains the same year after year or shows very insignificant variations.

2.5 Contact area: Solid structure provides larger surface area for dissipation, thus dissipates current faster.

2.6 Chemically Inert: It's pH value is within the neutral range.

2.7 Non-corrosive: Marconite® does not corrode steel or copper conductor or attacks cement structures. It may be noted:-

a) That effect of DC current spreads to a radius of 30 to 50 kms from the earth electrode stations when DC current back flows (Transformer Saturation) or earth return is used to transmit the power in HVDC, which accelerates the corrosion of Earth Electrodes, pipe lines and other metallic objects within it's vicinity.

b) That GIS equipment uses earthed metal screens / enclosures around individual phase conductors and residual AC current flows continuously via earthing system. This causes additional corrosion of earth conductor.

Marconite® encapsulated electrodes are the best solution to protect such corrosion.

2.8 Life: Marconite® based earthing systems has a life of more than 50 years.

2.9 Maintenance: Absolutely maintenance free and does not need water for life. No need to remove, replace or recharge it in order to maintain the desired earth resistance value.

2.10 Environment friendly: Marconite® does not leach and pollute ground water channels like other earthing systems. Use of Marconite® also saves trees from burning to get charcoal.

2.11 No environmental hazard: Marconite® does not pose any environmental hazard for future generations even after the completion of it's life as it disintegrates with soil like any other concrete structure.

2.12 Cost effective: Especially in high resistivity soils, sandy or water logged areas.

2.13 Lowest ownership cost: Long and maintenance free life of Marconite® based earthing Systems makes it's cost lowest among all other earthing systems.

2.14 Easy to Install: Requires only a bore hole or trench to install.

2.15 No space constraint: Gas insulated substation (GIS) occupies only 15 - 25% of the area occupied by the equivalent AIS. Hence it becomes difficult to achieve the required level of Earth resistance in small areas. Marconite® encapsulated deep driven rods are the best solution to achieve low value of ground resistance in such cases.

2.16 Improvement Factor: In practice, improvement of 40% - 60% is generally obtained with the use of Marconite® conductive concrete. Refer Para 13 of this document for case studies.

2.17 Compressive Strength: Marconite® concrete, once it is set, displays a greater compressive strength than Gr 25 concrete & becomes significantly greater over a period of time.

2.18 Metal conductor saving: In designing an earth grid, Dia of conductor is designed oversized to withstand corrosion. Marconite® encapsulated rods solve this problem and also save steel conductor on two counts:-

a) Provision of over designing of conductor is not required in the absence of corrosion.

b) Increased surface area of Marconite® embedded rods reduces the overall requirement of grid's horizontal conductor, which otherwise would be required if bare rods are used.

3 TECHNICAL REFERENCES

Many standards, technical books & papers and web sites have reference of Marconite® conductive concrete/ concrete-encased electrodes. Few of them are mentioned below:-

3.1 IS: 3043 (1st Rev Draft) Cl 9.2.5 for electrode encased in low resistivity material, e.g. Conducting concrete page 71-73. (Under revision by BIS)

3.2 BS: 7430: 2011 Cl 9.5.7 for electrode encased in low resistivity material, e.g. Conducting Concrete page 74-76.

3.3 IEEE Std 80 -2000 Clause 14.6 for concrete encased electrodes page 68.

3.4 Engineers Hand Book on Sub Station Engineering design, Concepts and Computer Applications by R S Dahiya, Kartson books - *page 180*.

3.5 Mc Graw Hill Material's handbook by George S. Brandy, Henery R. Clauser & J A. Vaccaril – page *265.*

3.6 Achieving an acceptable Ground in poor soil-Paper by Keith Switzer, ERICO, Inc.

3.7 WALLIS Soil Survey Report of Royal Offices, Oman recommending the use of Electrically Conductive aggregate Marconite®.

4 TESTS/REPORTS

Marconite® conductive concrete and it's electrodes were tested at various independent National and International laboratories besides testing of material resistivity of each batch is carried out by the manufacturer i.e. M/s Carbon International Limited, UK and test report is provided with all the consignments. Results of tests are appended below:-

4.1 Resistivity - Aggregate:

Results: "Ultra low resistivity of 0.001 Ohm-m."

4.2 Resistivity - Concrete: Marconite concrete (2 Parts Marconite + 1 Part Cement) was tested by one of the overseas laboratory i.e. Fugro Middle East, Dubai for their client M/s Trade Circle Ltd., and material was used for world famous building in Dubai i.e. Palm Jumeirah.

Results: "Ultra low resistivity of 0.040 Ohm-m at 20º C degree."

4.3 Short Current - Electrode: The test was carried out by Central Power Research Institute, Bangalore on two specimens of different sizes of Marconite concrete earth electrodes:-

Results:

Specimens	Current (kA) Peak	RMS	Duration (s)	Ambient temp Temp. ° C
a) Cu rod *L* 3 m, *D* 16 mm, Marconite ® Encapsulation *L* 2.9 m, *D* 75 mm	*39.66*	*22.69*	*1.10*	*29*
b) MS rod *L* 3 m, *D* 40 mm, Marconite ® Encapsulation *L* 2.9 m, *D* 100 mm	*80.52*	*40.13*	*1.11*	*29*

4.4 Earth Resistance - Electrode: Central Power Research Institute, Bangalore measured performance of two specimens of Marconite concrete earth electrodes after 38 days of installation with soil resistivity of 468.29 Ω-m of trial ground:-

Results:

Specimens

a) Cu rod *L* 3 m, *D* 16 mm ,
Marconite® encapsulation *L* 3 m, *D* 100 mm = 90.87 Ω

b) MS rod *L* 3 m, *D* 40 mm ,
Marconite® encapsulation *L* 3 m, *D* 200 mm = 55.43 Ω

4.5 Compressive Strength - Cube: Two specimens of 200mm^3 cubes were tested by Central Midland Laboratories Birmingham, UK for compressive strength after 7 & 28 days:-

Results:

Specimen	After 7 Days	After 28 Days
c) One	22.0 N/mm^2	27.5 N/mm^2
d) Two	23.1 N/mm^2	29.5 N/mm^2

Conclusion: "It produced a low resistivity and highly conductive material in its Hardened State"

4.6 Chemical Test – ROH's: Marconite aggregate was tested by Muscot Laboratory Service, Bangalore, (DGQA, Ministry of Defense, GOI approved) for various chemicals:-

Results:

Name of Test	Value Ω
a) Lead (Pb)	<0.10 pp
b) Mercury (Hg)	<0.001 ppm
c) Cadmium (Cd)	<0.1 ppm
d) Nickel (Ni)	<0.1 ppm
e) Arsenic (As)	<0.1 ppm
f) Cyanide (CN)	<0.1 ppm
g) Hexavlent Chromium (Cr^{+6})	<0.1 ppm

Conclusion: *"On the basis of the observed values of the tested marconite earthing material is non hazardous, non polluting"*

4.7 CBIP Technical Report no 78 1991: Evaluation of Concrete Encased Electrodes & Use of Structural Steel for Earthing was carried jointly by CBIP & Dept. of Electrical Engineering, Punjab Engineering College, Chandigarh.

a) Passage of AC current steel electrodes embedded in concrete causes only negligible corrosion.

b) Normal stray AC current do not cause deterioration in the strength of concrete.

c) Short duration large currents (like Lightning surges) have negligible effect on the bond between steel and concrete.

Conclusion: Natural steel under such conditions may be safely used as grounding electrode.

5 PRACTICAL ASPECTS OF USING MARCONITE®

5.1 Methodology: Marconite® conductive aggregate is mixed with cement normally in the ratio of 2:1 [2 Parts Marconite: 1 Part Cement] and add one litre of water per kg of total mix to form a fairly dry mix. Normally a bore hole of up to 100 mm Dia may be used. But if required deeper bore holes may be made rather than increasing the Dia of bore hole because surface area benefits obtained with larger diameters are usually negated by the added costs of drilling larger Dia bore holes and increased quantity of Marconite®.

5.2 Single Electrode: Marconite® concrete is poured around the metal conductor in the augured borehole and left it to set into a permanent solid structure.

5.3 Earth Grid: Horizontal conductor of the grid is embedded in Marconite® concrete for larger surface area. It saves over sizing of steel rods, which is used to counter the effect of corrosion in bare rod designs.

5.4 Earth Grid Joints: Cross, parallel and riser's joints of earth grid conductor are embedded in Marconite® conductive concrete to prevent the opening of welded joints due to corrosion. This keeps connectivity of the grid intact for it's life.

6 COMPARISION OF MARCONITE® BASED SYSTEMS WITH TRADITIONAL SYSTEMS

Parameters		Marconite® conductive concrete based systems	Traditional GI pipe / Plate Earthing with Charcoal and Salt	Pipe in pipe/strip systems with back fill Compounds
Technical				
1	Technology	Natural grey Electrically Conductive Concrete	CI, GI, Cu plate, GI Pipe, Charcoal & Salt.	Pipe in pipe/strip with back fill materials.
2	Design Consistency	Consistency in design	Coal & Salt vary place to place	Backfill materials vary.
3	Resistivity of material.	Ultra low resistivity - 0.001 Ω-m.	Charcoal offer resistivity of 2.6 X 10-4 Ω-m and salt consist 15% - 20% impurities	Resistivity of back fill materials is 3 -5 Ω-m.

Parameters		Marconite® conductive concrete based systems	Traditional GI pipe / Plate Earthing with Charcoal and Salt	Pipe in pipe/strip systems with back fill Compounds
4	Material's ph	Inert	Acidic	Acidic
5	Process	Electronic.	Ionic	Ionic
6	Suitability of Electrode	Good for Granite, Hilly terrains, Sandy soil, Made up ground, Water Logged Areas, River beds, Sea shores & Salty soils etc.	Difficult to install in Granite, Rocks, Hilly terrains, Water Logged Areas, River beds & Sea shores etc.	Difficult to install in Granite, Rocks, Hilly terrains, Water Logged Areas, River beds & Sea shores etc.
7	Easy Installation	Only a borehole is required. In rocky soils it works in low depth tranches also.	Wider excavation is difficult in rocky soils. Thus high cost of installation.	Digging is difficult in rocky soils. Thus high cost of installation.
8	Life	50+ years.	8 years.	10 years.
9	Performance	Constant Electrical Conductivity Un-affe cted by Environment Temp & Moisture. Does not leach or gets washed away even in wet soils Performance permanent & consistent.	Watering dissolves salt into soil. Fails to provide safe discharge path or do not activate fault protection due to corrosion. Fluctuations of Ohmic value results in frequent problems.	Back fill material sweeps away in earth water channels which affects performance.
10	Current Dissipation	Impregnated aggregate greatly increases the conductive surface area of electrode & Current dissipation stages.	Has single stage current dissipation.	Surface of pipe has smaller area for dissipation.
11	Maintenance	Lifelong maintenance free and does not require water.	Requires watering & recharge of salt on regular basis.	Requires watering & recharge of back fill material regularly.
12	Corrosion	No Corrosion since metal rod is embedded in inert neutral material.	Corrodes due to moisture and heat, which affects the performance.	Pipe corrodes due to moisture and heat, which affects the performance.
Environmental				
14	Environment friendly	Conductive concrete does not leach or pollute earth water channel. Save trees.	Trees cut for charcoal. Salt dissolves and pollutes the water channel.	Back fill materials leaches into ground and pollutes the water channel.

7 COST COMPARISION: MARCONITE® BASED SYSTEMS WITH TRADITIONAL SYSTEM

		Marconite Electrode ***D*** 100mm, ***L*** 3 m	GI pipe ***D*** 40 mm, ***L*** 3 m	GI plate ***L*** 0.6 m X ***W*** 0.6 m
1	**Capital Cost**			
a	**<u>On a/c of Surface area</u>** Surface area of one unit [Electrode]	0.958 sq m	0.380 sq m	0.720 sq m
b	Surface area equal-ant to one unit of Marconite electrode	1	2.52 times	1.33 times
c	**<u>On a/c of Life</u>** No of unite required for a life of 50 yrs.	50 yrs / 50 yrs = 1 Electrode	50 yrs / 8 yrs = 6.25 Electrodes	50 yrs / 10 yrs = 5 Electrodes
d	Total no of units required for a life of 50+ yrs [b*c]	One unit	2.52 X 6.25=15.75 or 16 units	1.33 X 5 = 6.65 or 7 Units
e	Cost of one unit with installation	Rs 16,500/- each	**<u>As CPWD DSR 2014</u>** 4.5 m Rs 3,926/- or 3.0 m Rs 2,618/-	**<u>As CPWD DSR 2014</u>** Rs 4,500/-
f	Capital cost of electrode's 50 yrs life	Rs 16.500/- X 1 = **Rs 16,500/-**	Rs 2,618/- X 16 = **Rs 41,888/-**	Rs 4,500/- X 7 = **Rs 31,500/-**
2	**Maintenance Cost**			
a	Cost of Water, Salt and Labor for one unit.	Water or recharge is not required for life. - Yearly Cost Nil - Life Cost Nil	- <u>Water & watering labour</u> Water yrly 6 times : Rs 10 X 6 = Rs 60/- labor one year: Rs 50 X 6=Rs 300/- - <u>Recharge yearly</u> Salt Rs 140/- Half day Labor Rs 315/- - <u>Yearly Cost</u> Rs 815/- - Maint. for life 1 unit Rs 815*7 yrs = Rs 5,705/- - Maint for life 16 unit Rs 5,705*16 = Rs 91,280/-	- <u>Water & watering labour</u> Water yrly 6 times : Rs 10 X 6 = Rs 60/- labor one year: Rs 50 X 6=Rs 300/- - <u>Recharge yearly</u> Salt Rs 140/- Half day Labor Rs 315/- - <u>Yearly Cost</u> Rs 815/- - Maint. for life 1 unit Rs 815*9 yrs = Rs 7,335/- - Maint for life 7 unit Rs 7,335*7 = Rs 51,345/-
b	Total Capital cost + Maintenance of one electrode for 50 yrs	Rs 16.500/- + Nil Maintenance = **Rs 16,500/-**	Cap Rs 41,888/-, Maint. Rs 91,280/- = **Rs 1,33,168/-**	Cap Rs 31,500/-, Maint. Rs 51,345/- = **Rs 82,845/-**

8 THEORETICAL CALCULATIONS OF PERFORMANCE OF VARIOUS EARTHING SYSTEMS IN DIFFERENT SOIL RESISTIVITY

Resistivity Ω	*Expected Earth Resistance Ω*			
	Marconite Embedded	***Driven Rod***	***Pipe***	***Plate***
	D.1, L 3 m	***D.016,L3m***	***D.04,L3m***	***.6 X .6 m***
1	0.24	0.33	0.29	0.52
2	0.48	0.67	0.57	1.04
3	0.71	1.00	0.86	1.57
4	0.95	1.34	1.14	2.09
5	1.19	1.67	1.43	2.61
6	1.43	2.01	1.72	3.13
8	1.90	2.68	2.29	4.18
10	2.38	3.35	2.86	5.22
12	2.85	4.02	3.43	6.27
14	3.33	4.69	4.01	7.31
16	3.80	5.36	4.58	8.36
18	4.28	6.03	5.15	9.40
20	4.75	6.70	5.72	10.45
22	5.23	7.37	6.30	11.49
24	5.70	8.04	6.87	12.54
26	6.18	8.70	7.44	13.58
28	6.65	9.37	8.01	14.62
30	7.13	10.04	8.59	15.67
32	7.60	10.71	9.16	16.71
34	8.08	11.38	9.73	17.76
36	8.55	12.05	10.30	18.80
38	9.03	12.72	10.88	19.85
40	9.50	13.39	11.45	20.89
42	9.98	14.06	12.02	21.94
44	10.45	14.73	12.59	22.98
46	10.93	15.40	13.17	24.03
48	11.41	16.07	13.74	25.07
50	11.88	16.74	14.31	26.12
52	12.36	17.41	14.88	27.16
54	12.83	18.08	15.45	28.21
56	13.31	18.75	16.03	29.25
58	13.78	19.42	16.60	30.29
60	14.26	20.09	17.17	31.34
62	14.73	20.76	17.74	32.38
64	15.21	21.43	18.32	33.43
66	15.68	22.10	18.89	34.47
68	16.16	22.77	19.46	35.52
70	16.63	23.44	20.03	36.56
72	17.11	24.11	20.61	37.61
74	17.58	24.77	21.18	38.65
76	18.06	25.44	21.75	39.70
78	18.53	26.11	22.32	40.74
80	19.01	26.78	22.90	41.79
82	19.48	27.45	23.47	42.83
84	19.96	28.12	24.04	43.87
86	20.43	28.79	24.61	44.92
88	20.91	29.46	25.19	45.96
90	21.38	30.13	25.76	47.01
92	21.86	30.80	26.33	48.05
94	22.34	31.47	26.90	49.10
96	22.81	32.14	27.48	50.14
98	23.29	32.81	28.05	51.19
100	23.76	33.48	28.62	52.23
105	24.95	35.15	30.05	54.84
110	26.14	36.83	31.48	57.46
115	27.33	38.50	32.91	60.07
120	28.51	40.18	34.34	62.68
125	29.70	41.85	35.78	65.29
130	30.89	43.52	37.21	67.90
135	32.08	45.20	38.64	70.51
140	33.27	46.87	40.07	73.12
145	34.45	48.54	41.50	75.74
150	35.64	50.22	42.93	78.35
155	36.83	51.89	44.36	80.96
160	38.02	53.57	45.79	83.57
165	39.21	55.24	47.22	86.18
170	40.39	56.91	48.65	88.79
180	42.77	60.26	51.52	94.02
185	43.96	61.94	52.95	96.63
190	45.15	63.61	54.38	99.24
195	46.33	65.28	55.81	101.9
200	47.52	66.96	57.24	104.5
210	49.90	70.31	60.10	109.7
220	52.27	73.65	62.96	114.9
230	54.65	77.00	65.83	120.1
240	57.03	80.35	68.69	125.4
250	59.40	83.70	71.55	130.6
260	61.78	87.05	74.41	135.8
270	64.15	90.39	77.27	141.0
280	66.53	93.74	80.14	146.2
290	68.91	97.09	83.00	151.5
300	71.28	100.4	85.86	156.7
325	77.22	108.8	93.02	169.8
350	83.16	117.2	100.2	182.8
375	89.10	125.5	107.3	195.9
400	95.04	133.9	114.5	208.9
175	41.58	58.59	50.09	91.41
425	100.98	142.3	121.6	222.0
450	106.92	150.7	128.8	235.0
475	112.86	159.0	135.9	248.1
500	118.80	167.4	143.1	261.2
550	130.69	184.1	157.4	287.3
600	142.57	200.9	171.7	313.4
650	154.45	217.6	186.0	339.5
700	166.33	234.4	200.3	365.6
750	178.21	251.1	214.7	391.7
800	190.09	267.8	229.0	417.9
850	201.97	284.6	243.3	444.0
900	213.85	301.3	257.6	470.1
950	225.73	318.1	271.9	496.2
1000	237.61	334.8	286.2	522.3
1050	249.49	351.5	300.5	548.4
1100	261.37	368.3	314.8	574.6
1150	273.25	385.0	329.1	600.7
1200	285.13	401.8	343.4	626.8
1250	297.01	418.5	357.8	652.9
1500				
2000				

9 TECHNICAL ASPECTS OF DESIGNING EARTHING SYSTEM

9.1 General Requirement: Designing of proper grounding is a necessity for any electrical power system. A good grounding system provides a low-impedance path for electrical system's fault & lightning induced currents to enter the mother earth and also provides safety. Effectiveness of a buried grounding system depends on many factors like:-

Soil characteristics such as moisture content, soil temperature and type; which determines the resistivity of the earth.

Resistance of the earth (or earth resistivity); which significantly impacts overall impedance of the buried conductor.

9.2 Typical Soil Conditions and Resistivity: Typical soils across the World clearly show that a totally homogeneous soil is difficult to find. Layers of soils consist of differing materials having different resistivity are found in it's strata, which can also be repeated at lower depths. It is also possible to even find irregularities such as rocks and other deposits accumulated over a number of years. In essence it is necessary to first carry out a thorough soil investigation for designing an appropriate earthing system. *Table 3* of IS 3043, reproduced below, illustrates not only the ranges of soil resistivity typical of different soil types, but also clearly shows that soil resistivity can further vary according to climatic conditions, particularly in relation to moisture. Hence it is necessary to obtain a more precise knowledge of local soil conditions.

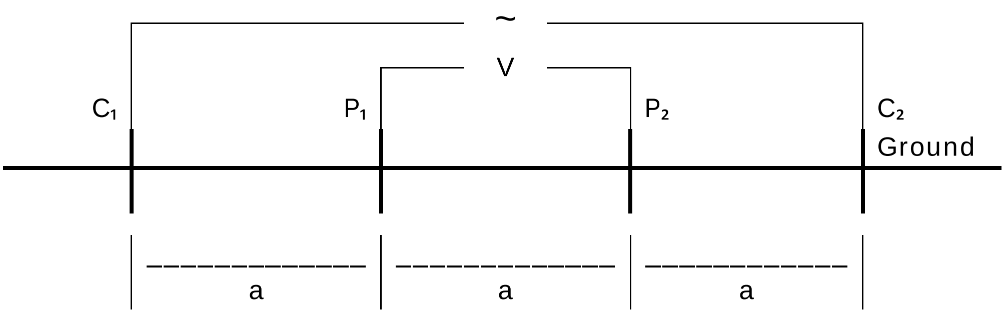
Table 3: Examples of Soil Resistivity

Type of soil	Probable values	Climate condition		
		Normal and high rainfall (i.e. greater than 500 mm a year)	Low rainfall & desert conditions (i.e. less than 250 mm a year)	Underground Waters (saline)
		Range of values encountered		
	Ω-m	Ω-m	Ω-m	Ω-m
Alluvium and lighter clays	5	* See note	*See note	1 to 5
Clays (excluding alluvium)	10	5 to 20	10 to 100	
Marls (e.g. Keuper marl)	20	10 to 30	50 to 300	
Porous limestone (e.g. chalk)	50	30 to 100		
Porous sandstone(e.g. Keuper sandstone and clay shale's)	100	30 to 300		
Quartzite, compact and crystalline lime stone (e.g. carboniferous marble)	300	100 to 1000		
Clay slates and slate shale's	1000	300 to 3000	1000 upwards	30 to 100
Granite	1000			
Fissile slates, schist's, gneiss and igneous rocks	2000	1000 upwards		
Note: * Depends on water level or locality				

9.3 Measurement of soil resistivity: Many methods are applied for soil resistivity measurements but one well documented method of determining soil resistivity is the Wenner's Survey – 4 electrodes method as per IS 3043, as reproduced here.

a) Wenner's Survey: Four electrodes are driven into the ground in a straight line at equal distance from each other, as shown in *Fig 1.* Electrode C_1 and C_2 are connected and current is made to flow through it. The difference in potential values at P_1 and P_2 is then measured. The difference in potential is then divided by the applied current value to determine the resistance R (Ω). If the distance between the electrodes "a" is in m, then soil resistivity ρ shall be also be determined in Ω-m using the Formula as mentioned below. Generally, as explained earlier, soil is found in layers and resistivity varies from layer to layer. By changing the spacing "a" of the electrodes, it is possible to develop a profile of the soil resistivity at various depths.

Figure 1



Formula: $\rho = 2\Pi aR$

Where

ρ = Soil Resistivity in Ohms-m

a = Distance between probes

R = Reading of earth tester in ohms

b) One rod test method: This is a simpler test method than the Wennner's test method. The resistance of a single rod, which is driven into the ground for a known depth, is measured. The resistance measurement and rod dimensions may then be used to calculate the average soil resistivity. The resistance measurement is done by using the 61.8% method. The formula for calculating the resistance to earth resistance (R) of a vertical rod given may be used:

$$\rho = \frac{2\Pi RL}{\{\log_e(\frac{8L}{d}) - 1\}}$$

Where:

R is the resistance to earth of a vertical rod;

L is the length of the rod in meters (m);

d is the diameter of rod in meters (m);

ρ is the resistivity of the soil (assumed uniform), in ohm meters (Ω-m);

10 MAXIMUM ACCEPTED EARTH RESISTANCE

A paper by US AID India has addressed this issue and indicated the generally accepted resistance value for different applications which may be based on prevailing established practices. Reference of various other standards, documents and books has also been reproduced here below:-

10.1 US AID | INDIA Earthing Practices by MVS Brinchi,

a)	Power stations (generating station)	0.5 ohms
b)	EHT Sub-station	1.0 ohms
c)	33 KV Stations	2.0 ohms
d)	D/t Structure	5.0 ohms
e)	Tower Foot resistance	10.0 ohms

10.2 Modernization of power distributions
Page 92 — Same as above.

10.3 IEEE standard 142-2007 - Chapter 4, page 164
Resistance generally found suitable for industrial
Plant Sub-station and buildings and large installations — 1 ohm to 5 ohms

10.4 IS 2309: 1989 and BS 7430:1998 - Cl 12.3.1 & 9.4.3
Lightning arrestors ground resistance for
Protection of buildings and allied structures — 10 ohms

10.5 Guide for control of Undesirable Static Electricity
Lightning arrestors ground resistance for
Protection of buildings and allied structures — 10 ohms

10.6 IS 2689:1989 - Table 4 page 28 (Reaffirmed Mar10)
Lightning arrestors ground resistance for
Protection of buildings and allied structures — 10 ohms

11 EARTHING SYSTEM FOR DIFFERENT CONFIGURATIONS

11.1 Electrodes or Earth matt: Once the soil resistivity has been determined then effective earthing system can be designed to meet the earth resistance requirement by using IEEE 80: 2000 Standard - Safety in ac sub-station grounding or such other standards. Any particular earthing system can be: -

a) A single or array of electrodes

b) An extensive ground grid system or earth mat

Earthing electrodes are often installed in straight lines, but it is not always essential. In case the space is limited, then a zigzag system can also be installed by ensuring necessary distance between the electrodes.

11.2 T Piece system: This system combines a borehole of appropriate size with a horizontal trench. It can be used in areas with limited space and is useful in low resistivity soils. There is also an option for connecting T piece systems together to achieve the required earth resistance value. If necessary, a combination of bore holes and T pieces systems can also be used to further reduce the earth resistance. This system is used at a minimum depth of 1 meter to minimize the effects of frost.

12 METHOD OF CALCULATION OF RESISTANCE OF VARIOUS EARTHING SYSTEMS

12.1 Plate Earthing

$$R_g = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \qquad ohms$$

Where

ρ = Soil Resistivity in Ohm – Meters

A = Area of the Plate in M^2 (Both sides)

12.2 Pipe / Rod Earthing

$$R = \frac{\rho}{2\pi L}\left[1n\left(\frac{8L}{d}\right) - 1\right]$$

Where

R = Earth Resistance in ohms,

L = Length of Pipe / Rod in meters.

D = Diameter of Pipe /Rod in meters,

ρ = Soil Resistivity in Ohm – meters

12.3 Strip / Flat Earthing

$$R_g = \frac{\rho}{2\pi l}\log_e \frac{2l^2}{wt} \qquad ohms$$

Where

l = Length of the strip in meters

w = Depth of burial of the electrode in meters

t = Width (in the case of strip) or twice the diameter (for round conductor) in m

12.4 Conducting Concrete Encased Electrodes

RCE= 1/2 ∏Lr (ρC [Ln(DC/d)]+ρ[Ln(8Lr /DC)-1])

Where

RCE = Resistance of Concrete encased earth electrode.

ρ = Soil resistivity Ω-m

PC = Resistivity of concrete – Marconite Ω-m

DC = Diameter of the Marconite shell in mm

d = Diameter of ground rod

Lr = Length of the rod in m

Ln = Log natural

12.5 Mat Earthing

$$R_g = \frac{\rho}{4r} + \frac{\rho}{L_T} \text{ Ohms}$$

$$R_g = p\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{\frac{20}{A}}}\right)\right]$$

Schwarz's

$$R_g = \frac{R_1\,R_2 - R_{12}^2}{R_1 + R_2 - 2R_{12}}$$

Where

r = is the radius of a circle with same area or that occupied by grid in meters

ρ = Resistivity of the soil (assumed uniform) in ohm-m

LT = Total effective length of grounding system conductor, including grid & rods m.

h = Depth of grid burial (m)

A = Total area enclosed by ground gird (m2)

R1 = Ground Resistance of gird conductors in Ω

R 2 = Ground Resistance of all ground rod in Ω

R12 = Mutual Ground Resistance between the group of gird conductors R1 & group of ground Rods R2 in Ω

12.6 Ring Electrode - HVDC Ground Electrode:

$$R_g = \frac{\rho}{4\,\pi^2 b}\log_e\left(\frac{8b}{a}\right)$$

Where

ρ = Apparent Resistivity of Soil in Ohm – m

a = Twice the diameter of the Rod (m)

b = Radius of the Ring (m)

13 CASE STUDIES

In order to demonstrate the practical benefits of use of Marconite® many studies were carried out to compare Marconite® encapsulated electrodes with other earthing systems, which clearly shows better performance. Few cases are mentioned below:-

13.1 CPRI Campus, Bangalore, India: Marconite® embedded electrode was installed for measurement of Earth resistance at Central Power Research Institute, Bangalore

a) Parameters:

Size of metal conductor – Cu rod	= *L* 3 m, *D* 16 mm
Size of Marconite® encapsulation	= *L* 2.9 m, *D* 100 mm

b) Measurements taken:

Apparent soil resistivity of the trial ground	= 468.29 Ω-m
Earth resistance of Marconite encapsulated electrode	= 90.87 Ω

c) Theoretical Calculations of Earth Resistance:

Bare Cu rod - *L* 3 m, *D* 16 mm	= 156.78 Ω
MS Plate - L 0.6 m X *W* 0.6 m, *T* 5 mm	= 244.60 Ω
GI strip/Flat – *W* 50 mm x *T* 5 mm, *L* 3 m	= 163.45 Ω

d) Comparison of performance – % of Improvement :

i) Bare Cu rod - *L* 3 m, *D* 16 mm and;
Marconite encapsulation - *L* 2.9 m, *D* 100 mm

$$\frac{156.78 - 90.87}{156.78} = 42.04\ \%$$

Improvement in Ground Resistance by 42%

ii) Plate earthing - *L* 0.6 m X *W* 0.6 m, *T* 5 mm &;
Marconite encapsulation - L 3 m, D 100 mm

$$\frac{244.60 - 90.87}{244.60} = 62.84\%$$

Improvement in Ground Resistance by 63 %

iii) GI strip/Flat - *W* 50 mm x *T* 5 mm, *L* 3 m and;
Marconite encapsulation - L 3 m, D 100 mm

$$\frac{163.45 - 90.87}{163.45} = 44.41\%$$

Improvement in Ground Resistance by 44 %

13.2 <u>CPRI Campus, Bangalore (II):</u> Marconite® embedded electrode was installed for measurement at Central Power Research Institute, Bangalore

a) <u>Parameters:</u>
Size of metal conductor – MS rod = *L* 3.1 m, *D* 40 mm
Size of Marconite® encapsulation = *L* 3 m, *D* 200 mm

b) <u>Measurements taken:</u>
Apparent soil resistivity of the trial ground = 468.29 Ω-m
Earth resistance of Marconite encapsulated electrode = 55.43 Ω

c) <u>Theoretical Calculations of Earth Resistance:</u>
Bare MS rod - *L* 3.1 m, *D* 40 mm = 130.49 Ω

d) <u>Comparison of performance – % of Improvement :</u>
Bare MS rod - *L* 3.1 m, *D* 40 mm and;
Marconite encapsulation - *L* 3 m, *D* 200 mm

$$\frac{130.49 - 55.43}{130.49} = 57.52\%$$

Improvement in Ground Resistance by 58 %

13.3 <u>NDMC, New Delhi:</u> Marconite® embedded electrode was installed and connected to 11kV substation at Chanderlok Building, New Delhi:-

a) <u>Parameters:</u>
Size of metal conductor – Cu rod = *L* 3 m, *D* 16 mm
Size of Marconite® encapsulation = *L* 2.9 m, *D* 100 mm

b) <u>Measurements taken:</u>
Apparent soil resistivity = 14.56 Ω-m
Earth resistance of Marconite encapsulated electrode = 00.15 Ω

c) <u>Theoretical Calculations of Earth Resistance:</u>
Bare Cu rod - *L* 3 m, *D* 16 mm = 4.87 Ω

d) <u>Comparison of performance – % of Improvement :</u>
Bare Cu rod - *L* 3 m, *D* 16 mm and;
Marconite encapsulation - *L* 2.9 m, *D* 100 mm

$$\frac{4.87 - 0.15}{4.87} x\,100 = 96.92\%$$

Improvement in Ground Resistance by 97 %

13.4 Indian Air Force, Palam, Delhi: Marconite® embedded electrode was installed and connected to electronic laboratory of 73 RMU of Indian Air Force, Palam Airport Delhi:-

a) Parameters:
Size of metal conductor – MS rod = *L* 30.5m, *D* 16 mm
Size of Marconite® encapsulation = *L* 30.4m, *D* 100 mm

b) Measurements taken:
Apparent soil resistivity = 38.28 Ω-m
Earth resistance of Marconite encapsulated electrode = 00.76 Ω

c) Theoretical Calculations of Earth Resistance:
Bare MS rod - *L* 30.5 m, *D* 16 mm = 1.72 Ω

d) Comparison of performance – % of Improvement :
Bare MS rod - *L* 30.5 m, *D* 16 mm and;
Marconite encapsulation - *L* 30.4 m, *D* 100 mm

$$\frac{1.72 - 0.76}{1.72} x\,100$$

= 55.91 %

Improvement in Ground Resistance by 56 %

13.5 Apollo Hospital, New Delhi: Marconite® embedded electrode was installed and connected to DG set of Indraprastha Apollo Hospital, Sarita Vihar, and New Delhi.

a) Parameters:
Size of metal conductor – MS rod = *L* 10.1 m, *D* 16 mm
Size of Marconite® encapsulation = *L* 10 m, *D* 100 mm

b) Measurements taken:
Apparent soil resistivity = 22.00 Ω-m
Earth resistance of Marconite encapsulated electrode = 00.51 Ω

c) Theoretical Calculations of Earth Resistance:
Bare MS rod - *L* 10.1 m, *D* 16 mm = 2.61 Ω

d) Comparison of performance – % of Improvement :
Bare MS rod - *L* 10.1 m, *D* 16 mm and;
Marconite encapsulation – *L* 10 m, *D* 100 mm

$$\frac{2.61 - 0.51}{2.61} x\,100$$

= 80.45 %

Improvement in Ground Resistance by 80 %

13.6 Indian Oil Corp. Ltd., Panipat: Marconite® embedded electrode was installed and connected to electrical system of Panipat Refinery of IOL Ltd., Panipat, Haryana

a) Parameters:
Size of metal conductor – Cu rod = *L* 3 m, *D* 16 mm
Size of Marconite® encapsulation = *L* 2.9 m, *D* 100 mm

b) Measurements taken:
Apparent soil resistivity = 19.50 Ω-m
Earth resistance of Marconite encapsulated electrode = 1.84 Ω

c) Theoretical Calculations of Earth Resistance:
Bare Cu rod - *L* 3 m, *D* 16 mm = 6.52 Ω

d) Comparison of performance – % of Improvement :
Bare Cu rod - *L* 3 m, *D* 16 mm and;
Marconite® encapsulation – *L* 2.9 m, *D* 100 mm

$$\frac{6.52 - 1.84}{6.52} x\,100$$

= 71.82 %

Improvement in Ground Resistance by 72 %

13.7 All India Radio, New Delhi: Marconite® embedded electrode was installed and connected to electrical system of NBH, All India Radio, New Delhi.

a) Parameters:
Size of metal conductor – MS rod = *L* 4.56 m, *D* 16 mm
Size of Marconite® encapsulation = *L* 4.50m, *D* 100 mm

b) Measurements taken:
Apparent soil resistivity = 10.35 Ω-m
Earth resistance of Marconite encapsulated electrode = 0.76 Ω

c) Theoretical Calculations of Earth Resistance:
Bare MS rod - *L* 4.56 m, *D* 16 mm = 2.43 Ω

d) Comparison of performance – % of Improvement :
Bare Cu rod - *L* 4.56 m, *D* 16 mm and;
Marconite encapsulation – *L* 4.5 m, *D* 100 mm

$$\frac{2.43 - 0.76}{2.43} x\, 100$$
= 68.74 %

Improvement in Ground Resistance by 69 %

13.8 Bhushan Steel Ltd., Sahahibabad, UP: Marconite® embedded electrode was installed and connected to IT system.

a) Parameters:
Size of metal conductor – Cu rod = *L* 15 m, *D* 16 mm
Size of Marconite® encapsulation = *L*14.950m, *D*100

b) Measurements taken:
Apparent soil resistivity = 33.00 Ω-m
Earth resistance of Marconite encapsulated electrode = 1.69 Ω

c) Theoretical Calculations of Earth Resistance:
Bare Cu rod – *L* 15 m, *D* 16 mm = 2.77 Ω

d) Comparison of performance – % of Improvement :
Bare Cu rod - *L* 15 m, *D* 16 mm and;
Marconite encapsulation – *L* 14.95 m, *D* 100 mm

$$\frac{2.77 - 1.69}{2.77} x\, 100$$
= 39.05 %

Improvement in Ground Resistance by 39 %

13.9 Bhushan Steel Ltd., Bhikaji Kama Place, New Delhi: Marconite® embedded electrode was installed and connected to IT system.

a) Parameters:
Size of metal conductor – MS rod = *L* 25 m, *D* 16 mm
Size of Marconite® encapsulation = *L* 24.9m, *D* 100 mm

b) Measurements taken:
Apparent soil resistivity = 20.52 Ω-m
Earth resistance of Marconite encapsulated electrode = 0.86 Ω

c) Theoretical Calculations of Earth Resistance:
Bare MS rod – *L* 25 m, *D* 16 mm = 1.01 Ω

d) Comparison of performance – % of Improvement :
Bare MS rod - *L* 25 m, *D* 16 mm and;
Marconite encapsulation – *L* 24.90 m, *D* 100 mm

$$\frac{1.01 - 0.86}{1.01} x\, 100$$
= 21.91 %

Improvement in Ground Resistance by 22 %

13.10 The Kalgidhar Society, Bru Sahib, HP: Marconite® embedded electrode was installed at their Akal Academy, Cheema, Dist. Sangrur Punjab & connected to DG set Neutral.

a) Parameters:
Size of metal conductor – Cu rod = *L* 6 m, *D* 16 mm
Size of Marconite® encapsulation = *L* 5.9m, *D* 100mm

b) Measurements taken:
Apparent soil resistivity = 23.28 Ω-m
Earth resistance of Marconite encapsulated electrode = 0.99 Ω

c) Theoretical Calculations of Earth Resistance:
Bare Cu rod – *L* 6 m, *D* 16 mm = 4.32 Ω

d) Comparison of performance – % of Improvement :
Bare Cu rod - *L* 6 m, *D* 16 mm and;
Marconite encapsulation – *L* 5.90 m, *D* 100 mm

$$\frac{4.32 - 0.99}{4.32} x\, 100 = 77.11\ \%$$

Improvement in Ground Resistance by 77 %

14 CUSTOMER REFERENCES

Marconite® conductive concrete was first introduced by us in India to Rajasthan Rajya Prasaran Nigam Limited, Jaipur (RRVPNL) four years back and they immediately incorporated the same in specifications of their eleven GIS sub stations & Two 765/400 kV sub stations. Subsequently many other power and other companies have used Marconite for their plants. Few of them are listed below:-

a) Power Plants
Pune Municipal Corporation, Pune : 10 MW waste to energy plant in Pune
Karnataka Power Corp. Ltd., Bangalore : 700 MW Bellary Thermal Power Plant
NTPC Ltd., New Delhi : Gas power plant in Faridabad

b) Sub Stations - GIS
Rajasthan RVPNL, Jaipur : 2 nos 132 kV ESS at Pratap Nager & Kuri in Jodhpur
Rajasthan RVPNL, Jaipur : 2 nos 220/132 kV ESS at MNIT & NPH in Jaipur

c) Sub Stations - AIS
Rajasthan RVPNL, Jaipur : 2 nos 765 kV ESS at Phagi in Jodhpur & Anta in UP
Tata Power New Delhi : 2 nos 33 kV ESS at Shalimar Bagh, Shakti Ngr Delhi
NDMC, New Delhi : 2 nos 11 kV ESS at Rohit house & Jan path, N Delhi
MES, Delhi Cantt : 11 kV ESS at Kabul Lane, Delhi Cantt.
ZESCO Ltd., Zambia : 330/132/33 kV ESS at Lusaka, Zambia
Torrent Power, Agra : Street Lighting at Agra

d) Signal Applications
Indian Air Force, Palam : 73 RMU at Technical Area , Palam Airport, Dli
HQ 5 Signal Group, India Army : ACON Facility at Delhi Cantt.
Military Collage of Telecom Engg. Mhow : Army Mobile Communications Lorry
Prasar Bhartti, New Delhi : Jam Nagar House, New Delhi
Vodaphone : Facility at Karnal, Haryana

e) Medical
Apollo Hospital, New Delhi : MRI and DG set
Saket City Hospital, Saket : MRI, CT Scanners & x-ray equipment
Sadhu Vaswani Mission Med Ctr : IT applications

	Army's R R Hospital, Dli Cantt	: Medical equipment
	Venketeshwar Hospital, Delhi	: Under Execution
f)	<u>Industrial Plants</u>	
	Indian Oil Corporation	: Refinery at Panipat
	National Fertilizer Ltd.	: Plant at Panipat.
	Hindustan Prefab Ltd.	: Plant at New Delhi
	Bhabha Atomic Research Centre	: At Navi Mumbai
	Bhushan Steel Ltd. Sahibabad	: Plant at Sahibabad
	The Kalgidhar Society	: More than 50 schools in Punjab & Haryana
	Ahuja Radio Ltd.	: Factory at Okhla, New Delhi.
	Vulcan Industries	: Factory at Ph III Okhla, New Delhi.

SUMMARY: This Technical Bulletin documents the significant benefits that can be obtained by designing and using an earthing system based on Marconite® conductive concrete. We believe that Marconite® would provide a cost effective solution to your earthing requirements.

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