# Earthing System

Ir. Hamzah Ismail

# Electricity Regulations 1994

**Peraturan 34(1):**

- Mana-mana penyalut, gagang, peti suis, rangka yang berlogam, kelengkapan elektrik dll. hendaklah dibumikan dengan berkesan

**Peraturan 35:**

- Dalam mana-mana pepasangan sistem pembumian konduktor yang lengkap yang dibuat daripada bahan yang boleh diterima dan mempunyai luas keratan rentas yang mencukupi dengan satu atau lebih rod hendaklah diadakan. Sistem pembumian itu hendaklah disambungkan ke bumi dan disenggarakan dengan berkesan

# Electricity Regulations 1994

**Peraturan 36:**

- Perlindungan terhadap arus kebocoran bumi.

# Standards

**MS IEC 60364-5-54:**

Earthing arrangements, protective conductors & protective bonding conductors

**BS EN 13601:**

Protective conductor, copper tape and earth electrode

# Standards

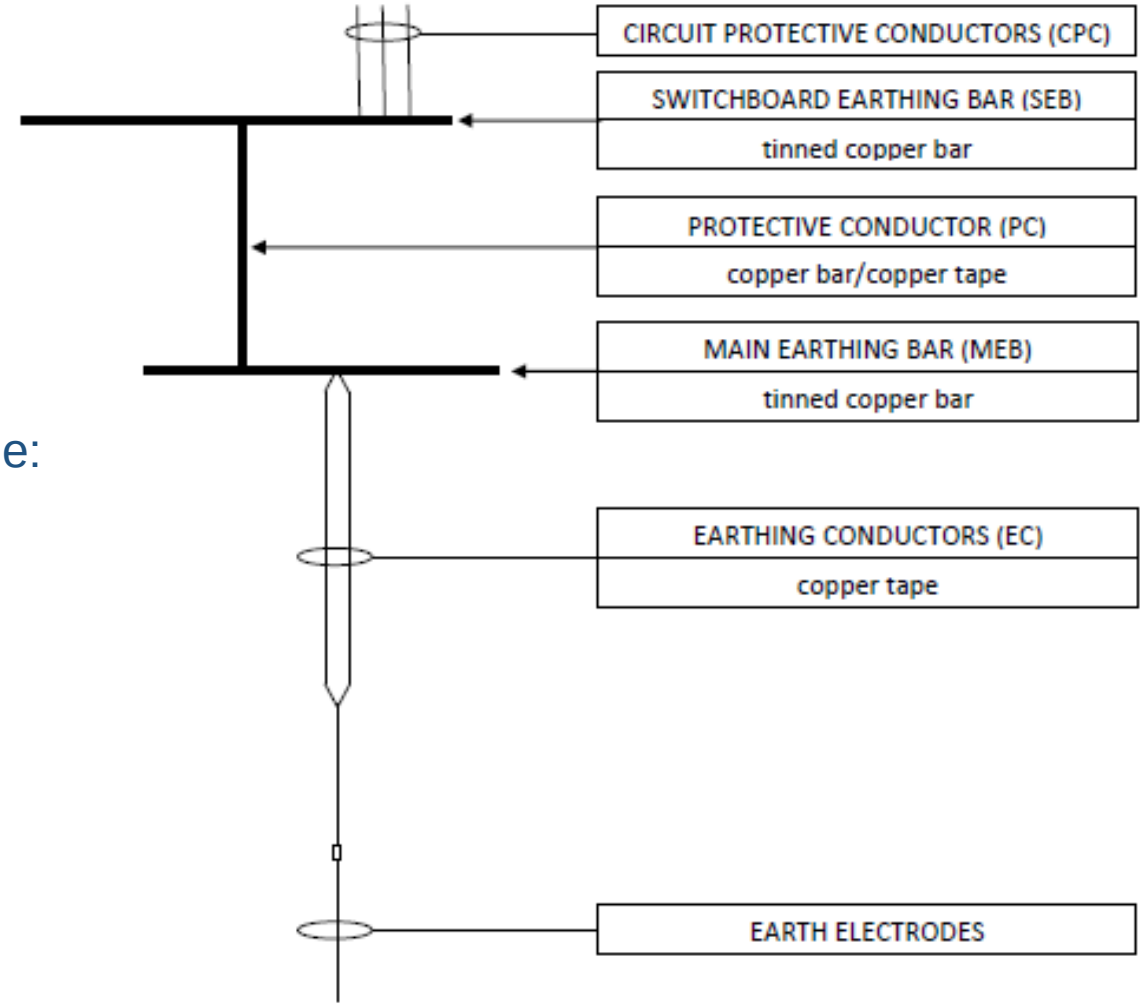
**BS EN 50262:**

**Cable glands for electrical installations**

**IEC 62444:**

**Cable glands for electrical installations**

# Illustration Of Earthing And Protective Conductor Terms




Protective conductors include:

- ✓ CPC
- ✓ SEB
- ✓ MEB
- ✓ EC
- ✓ Bonding conductors

# Protective Conductors

- PCs shall be of high conductivity copper conductor either stranded or solid, continuous throughout the whole lengths and without joints.

- Where joints cannot be avoided, then the joints shall be of exothermic welding type. Mechanical clamps may only be used upon approval of the S.O.

- Every circuit of a switchboard, DB, control board and tap-off units, all lighting points, lighting switches, fan points, fan switches, three pin switched or unswitched socket-outlets, power point etc. shall be provided with CPCs

- All exposed-conductive-parts and extraneous-conductive-parts shall be effectively bonded to earth

## Exposed-conductive-part [1]

Conductive part of equipment which can be touched and which is not normally live, but which can become live when basic insulation fails.

e.g.: trunking, cable tray, cable ladder, enclosures of electrical equipment, etc.

## Extraneous-conductive-part [1]

Conductive part not forming part of the electrical installation and liable to introduce an electric potential, generally the electric potential of a local earth.

e.g.: metal water pipes, building metalwork in general contact with the earth, etc.

- Size of a CPC should either be calculated in accordance with sub-clause 543.1.2 of MS IEC 60364-5-54 (adiabatic equation) or determined from Table 54.3

# Sub-clause 543.1.2 of MS IEC 60364-5-54

$$S = \frac{\sqrt{I^2 t}}{k}$$

Where

| | |
|---|---|
| *S* | *the cross-sectional area ($mm^2$)* |
| *I* | *the value (rms) in Ampere of prospective fault current* |
| *t* | *the operating time of the protective device for automatic disconnection in second* |
| *k* | *the factor dependent on the material of the protective conductor (value of k for bare copper conductor = 159)* |
| | *(value of k for 70 $^oC$ PVC copper cable = 115)* |
| | *(value of k for XLPE copper cable = 143)* |

# Table 54.3 (MS IEC 60364-5-54)

| Cross-sectional area of line conductor $S$ ($mm^2$) | Minimum cross-sectional area of the corresponding protective conductor ($mm^2$) | |
|---|---|---|
| | If the protective conductor is of the same material as the line conductor | If the protective conductor is not of the same material as the line conductor |
| $S \leq 16$ | $S$ | $\frac{k_1}{k_2} \times S$ |
| $16 < S \leq 35$ | 16 | $\frac{k_1}{k_2} \times 16$ |
| $S > 35$ | $\frac{S}{2}$ | $\frac{k_1}{k_2} \times \frac{S}{2}$ |

- Size of an EC for ‘RCCB Earth’ should either be calculated in accordance with sub-clause 543.1.2 of MS IEC 60364-5-54 (adiabatic equation) or determined from Table 54.3

- Where an EC is buried in the ground/soil then the min. csa should be in accordance with Table 54.2

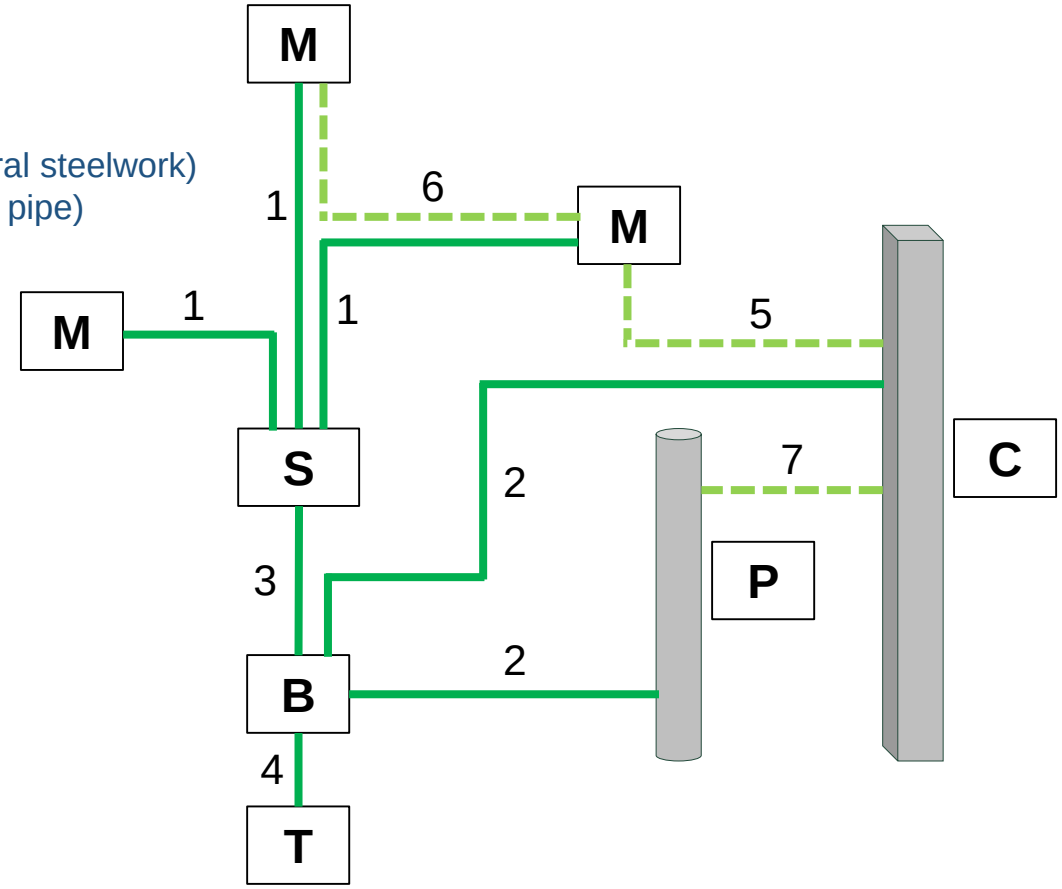
**Table 54.2 – Minimum cross-sectional areas of earthing conductors buried in the soil**

| | Mechanically protected | Mechanically unprotected |
|---|---|---|
| Protected against corrosion | 2,5 mm² Cu<br>10 mm² Fe | 16 mm² Cu<br>16 mm² Fe |
| Not protected against corrosion | 25 mm² Cu<br>50 mm² Fe | |

# Illustration of Earthing Arrangements

M exposed-conductive-part (eg. SSB)
C extraneous-conductive-part (eg. Structural steelwork)
P extraneous-conductive-part (eg. Service pipe)
S switchboard earthing bar (SEB)
B main earthing bar (MEB)
T earth electrode

1 CPC
2 Main equipotential bonding conductor
3 PC
4 EC
5 Supplementary bonding conductors
6 Supplementary bonding conductors
7 Supplementary bonding conductors

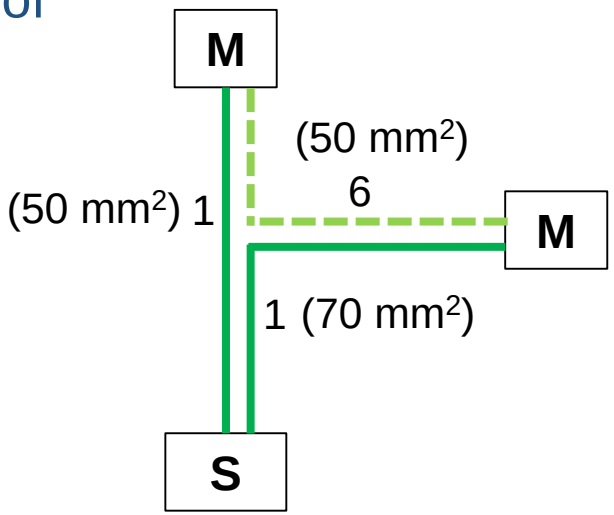


# Protective bonding conductors (equipotential bonding conductors) (2,5,6,7) (clause 544 of MS IEC 60364-5-54)

- For the connection to MEB (2)
  - Csa should not be less than 6 $mm^2$
- For supplementary bonding (5,6,7):
  - connecting two exposed-conductive-parts (6) should have a resistance not more than that of the smaller CPC connected to the exposed-conductive-parts.

    ** the size is depending on the length of cable*

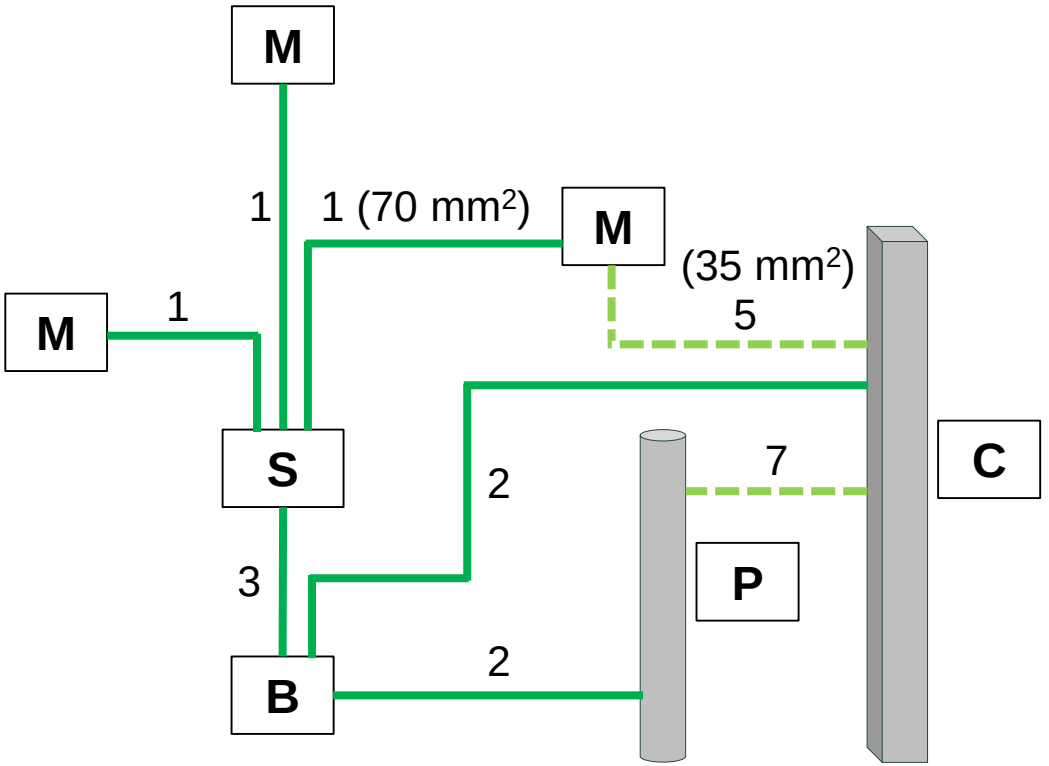
Ex: 6 $mm^2$ = 3.93 Ω/km
10 $mm^2$ = 2.33 Ω/km
50 $mm^2$ = 0.387 Ω/km
70 $mm^2$ = 0.268 Ω/km



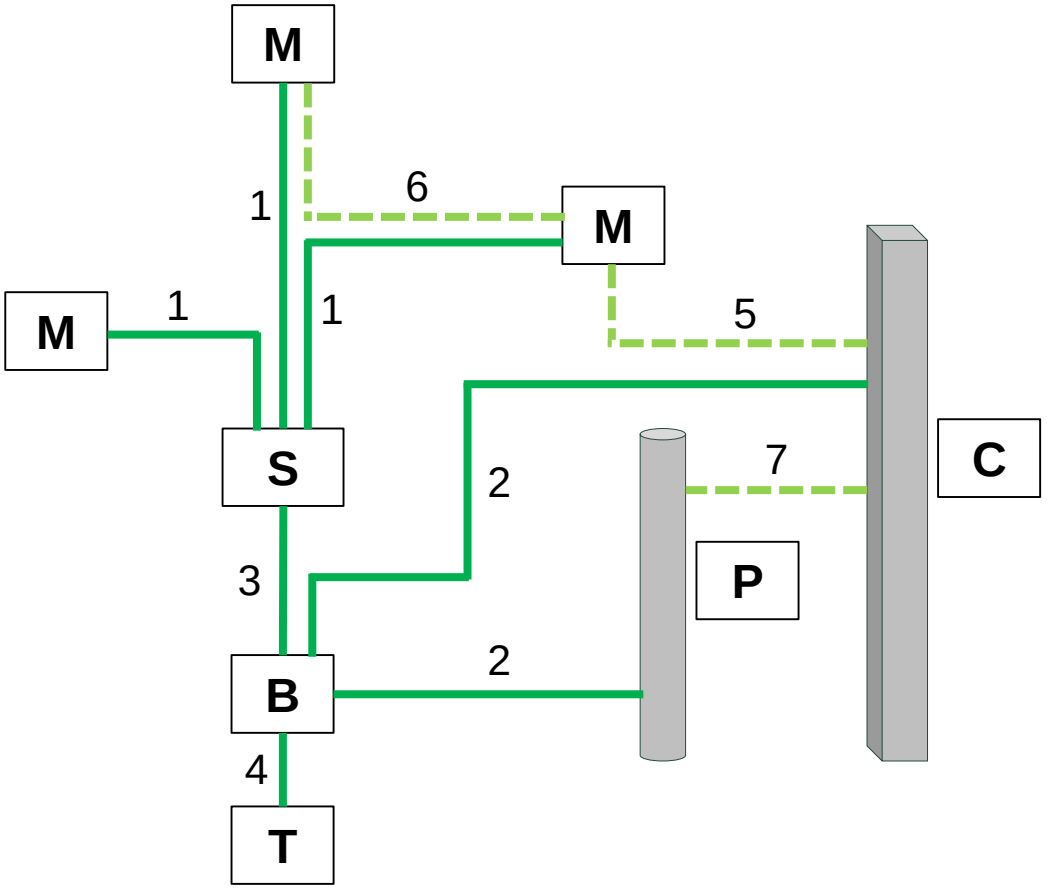
- connecting exposed-conductive-parts to extraneous-conductive-parts (5) should have a resistance not more than ½ of that of the csa of the corresponding CPC.

** the size is depending on the length of cable*

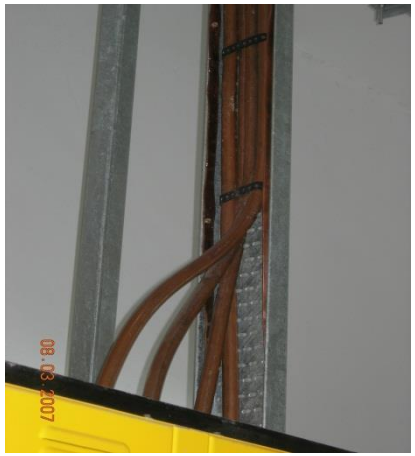
Ex: 6 mm² = 3.93 Ω/km
10 mm² = 2.33 Ω/km
35 mm² = 0.524 Ω/km
50 mm² = 0.387 Ω/km
70 mm² = 0.268 Ω/km

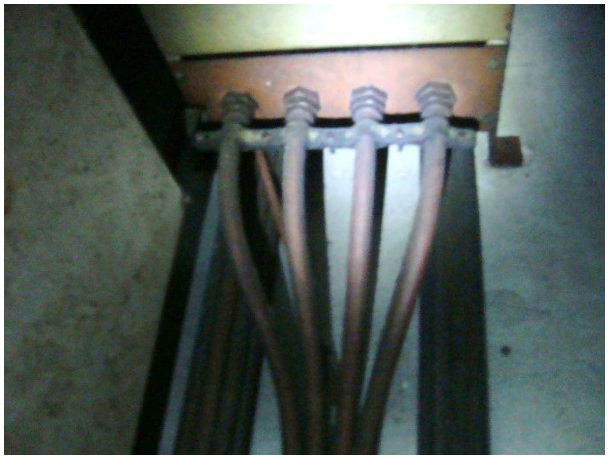


- connecting two extraneous-conductive-parts (7) should be not less than 4 $mm^2$

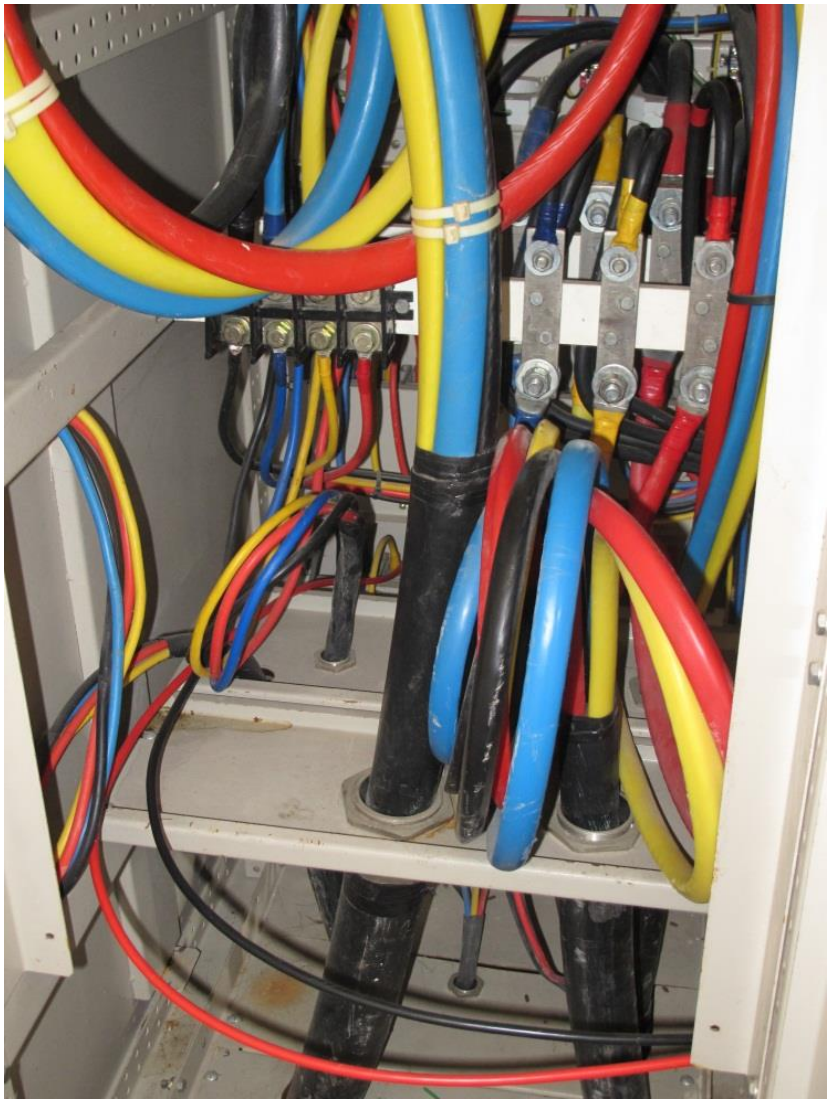


- In the case of mineral-insulated copper clad (MICC) cables, the copper outer sheath may be utilised as cpc provided that at the termination of each cable run the copper sheath is effectively bonded to earth.



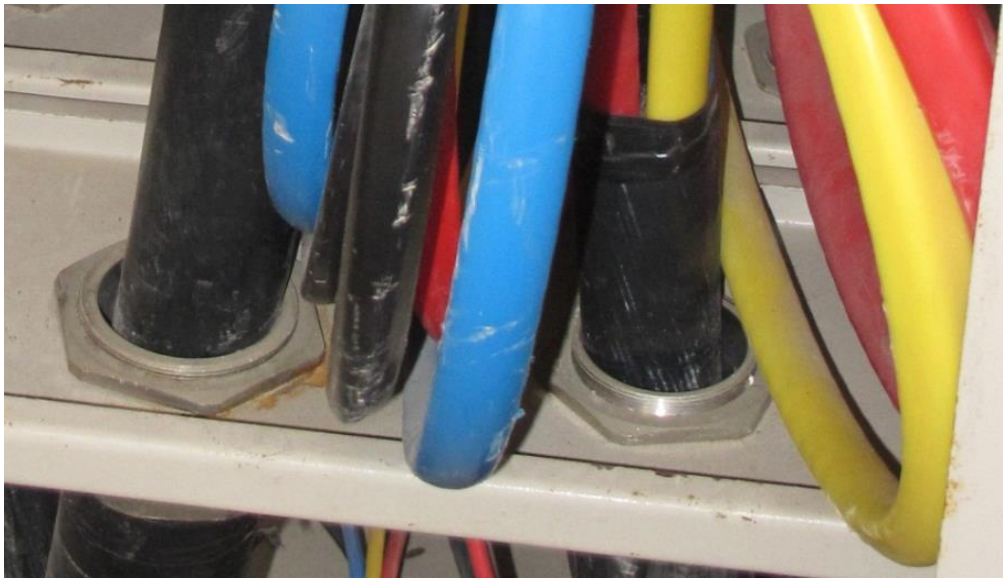


- Cable glands shall be installed for termination of armoured cables
- Comply to BS EN 50262 or IEC 624444

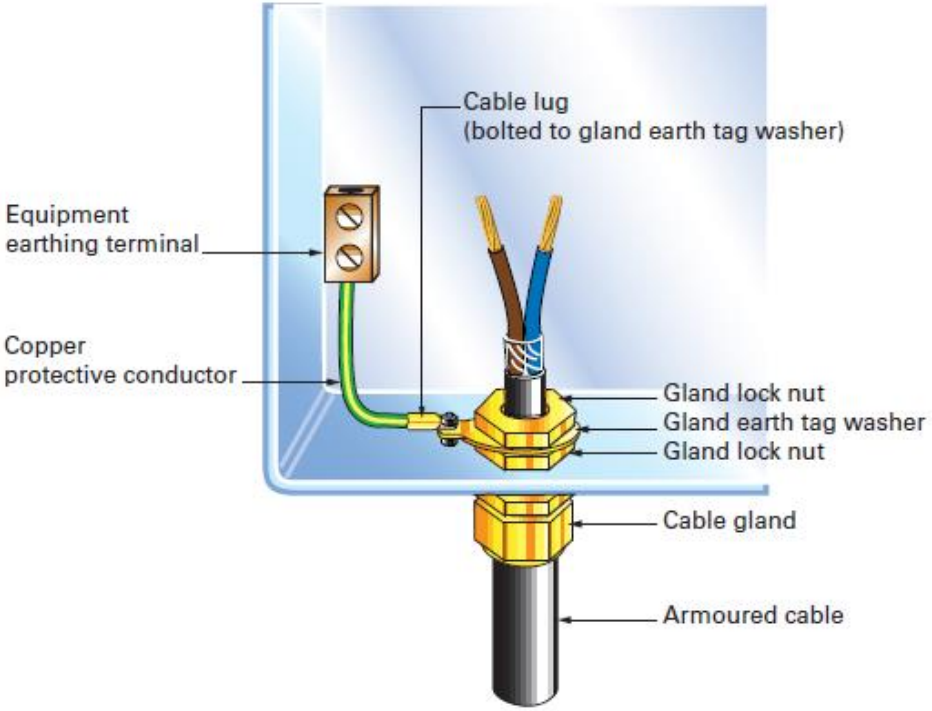


- Each cable gland shall be installed with back nuts (lock nuts) for plain hole fixing and <u>complete with an earth tag washer</u>

Lock nut is used in securing cable gland to a gland plate or into equipment /enclosure



# Gland Earth Tag Washer




- The csa of a PC connecting a gland earth tag washer to the earth terminal/SEB of an enclosure shall be selected in accordance with table 54.3 of MS IEC 60364-5-54

- A gland earth tag washer and PC arrangement should be provided where there is doubt that the metal-to-metal contact between the gland and the metallic enclosure is sufficient to provide durable electrical continuity

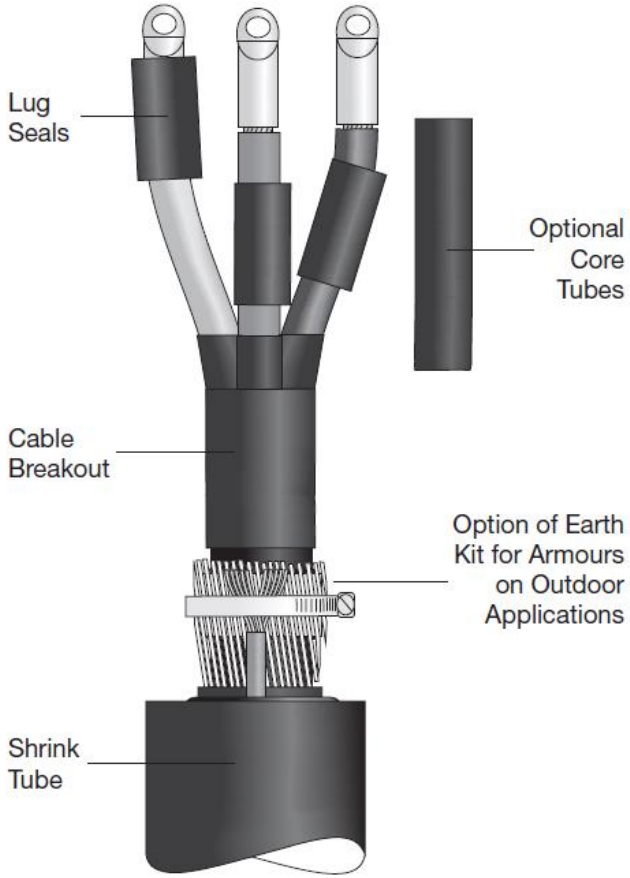

- This may be the case, for example, where the enclosure has a powder epoxy resin coating. Generally such coating is non-conducting

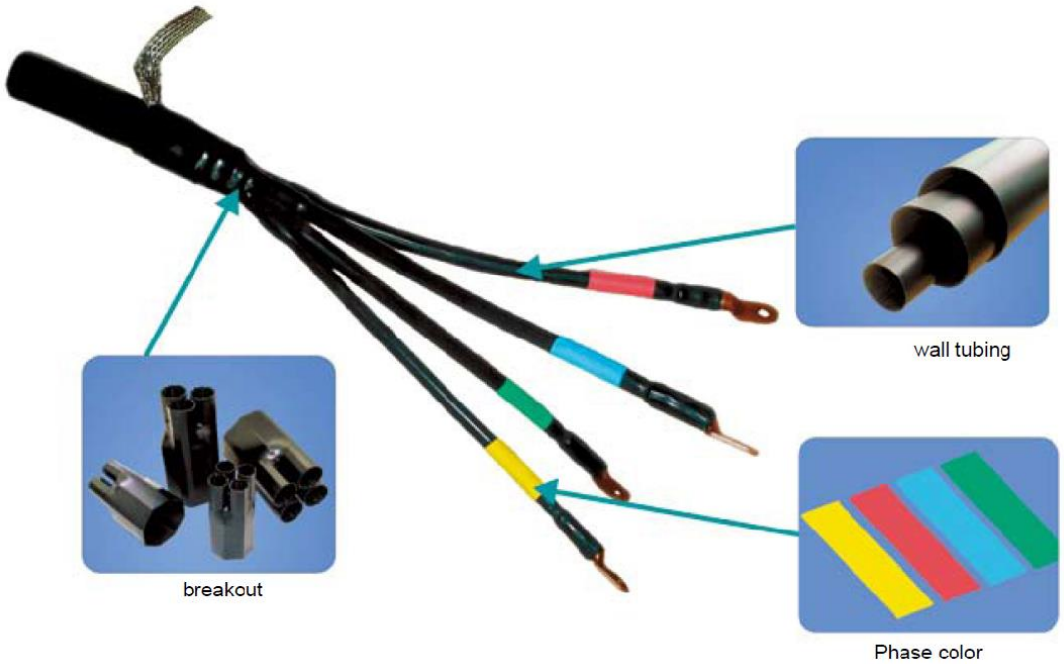
X

- The cable gland for aluminium armoured (AWA) single-core cables shall be made of non-ferrous material (brass) (to avoid overheating due to eddy current losses)

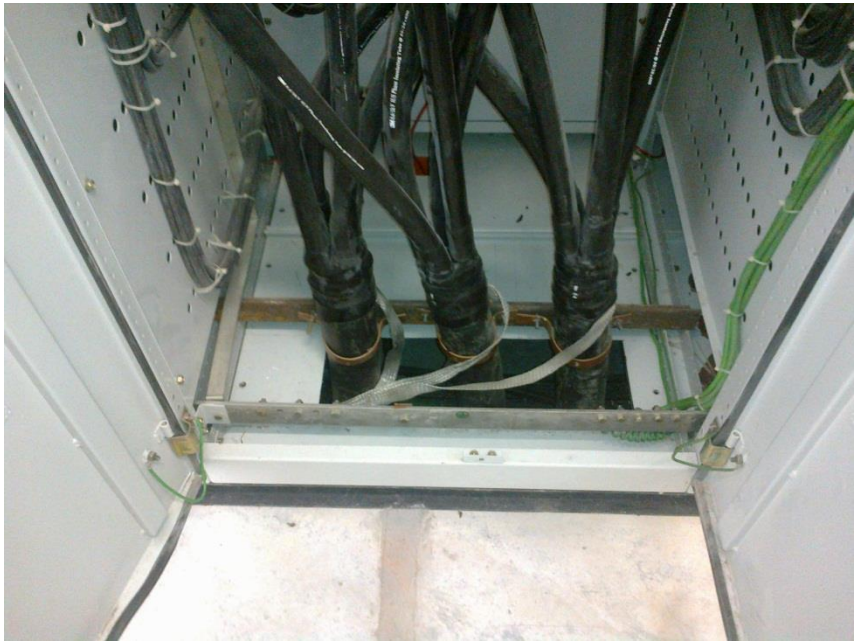
# Heat Shrink Cable Terminations

- Heat shrink cable terminations c/w braided protective conductor can be installed instead of cable glands



# Heat Shrink Cable Terminations

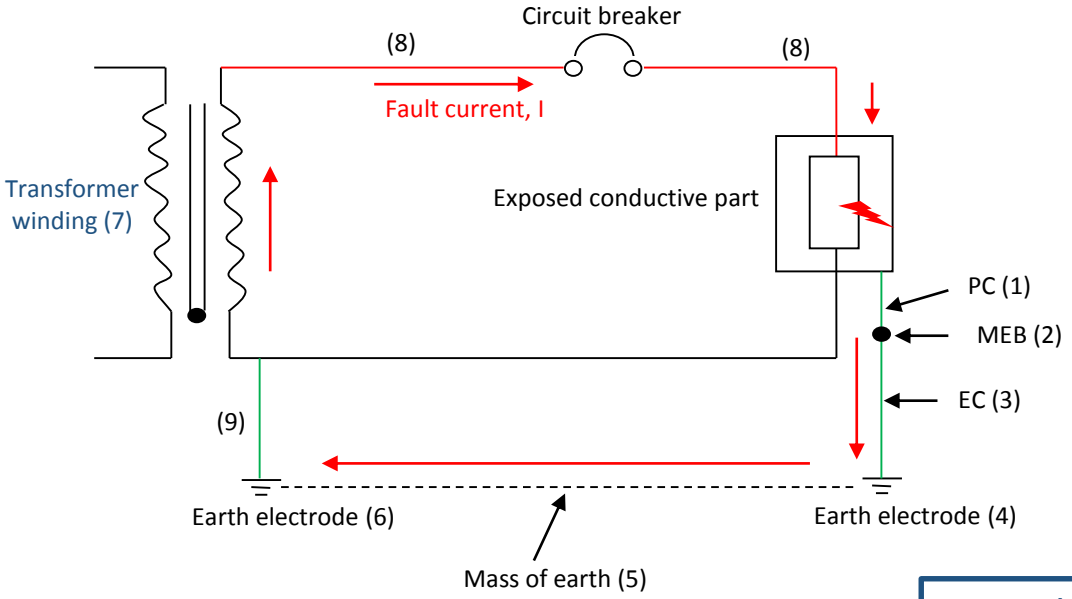



Recommended for cable ≥ 50 $mm^2$

- Solid earthing → earthing should present a low impedance path for short circuit current to return to the source of power (transformer), thus opening a fuse or tripping a circuit breaker (without installing protection relays or RCDs)

- Circuit breaker/fuse should operate in the event of a fault from phase to earth. The speed of operation of the protection is extremely important and will depend on the impedance of the earth fault loop path (Zs).The value of Zs should be as low as possible to allow enough fault current to flow to operate the circuit breaker as quickly as possible.

## The earth fault loop path (TT system)




Starting at the fault, the path comprises:

(1) Protective conductor (PC)
(2) Main earthing bar (MEB)
(3) Earth conductor (EC)
(4) Installation earth electrode
(5) Return path (earth)
(6) Earthed neutral of the supply transformer
(7) Transformer winding
(8) Phase conductor from the transformer to the fault
(9) Transformer N-E conductor

Therefore, we have:

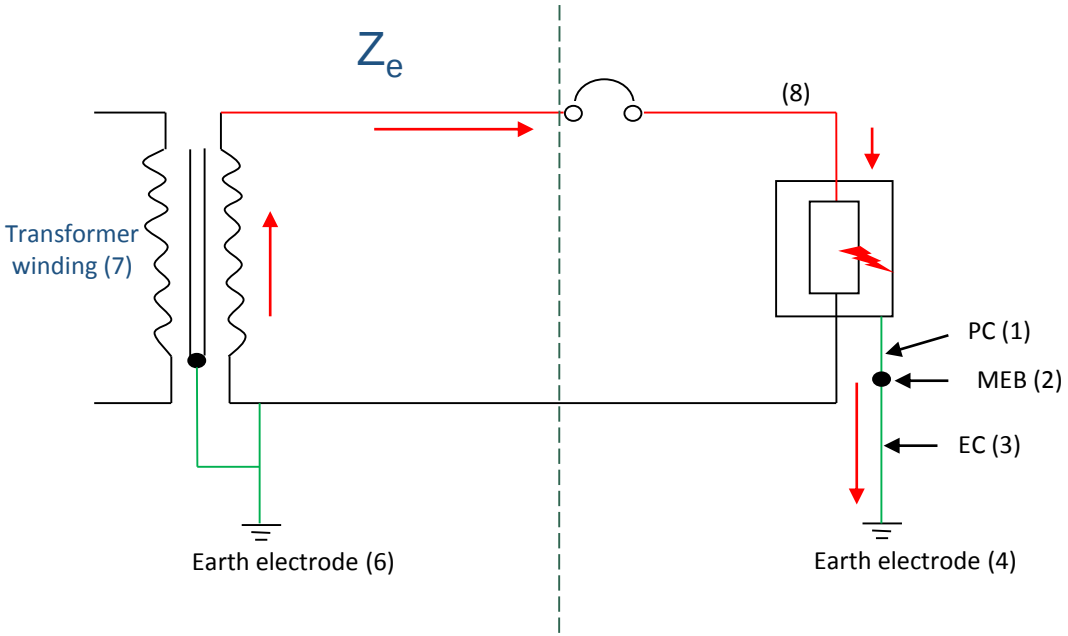
$Zs = Ze + R1 + R2 + R3 + R4$

Where Ze is the loop impedance external (from TNB) to the installation, R1 is the resistance of the phase conductor, R2 is the resistance of the PC, R3 is the resistance of the EC and R4 is the resistance of the installation/consumer earth electrode resistance.

Example:

Circuit breaker ($I_n$) = 200 A
Neglecting the impedance of (1), (3), (8) & (9)
(4) = 1 Ω
(6) = 1 Ω
(7) = 4.75 % Ω

Calculate the fault current, $I_f$. So the circuit breaker tripped?



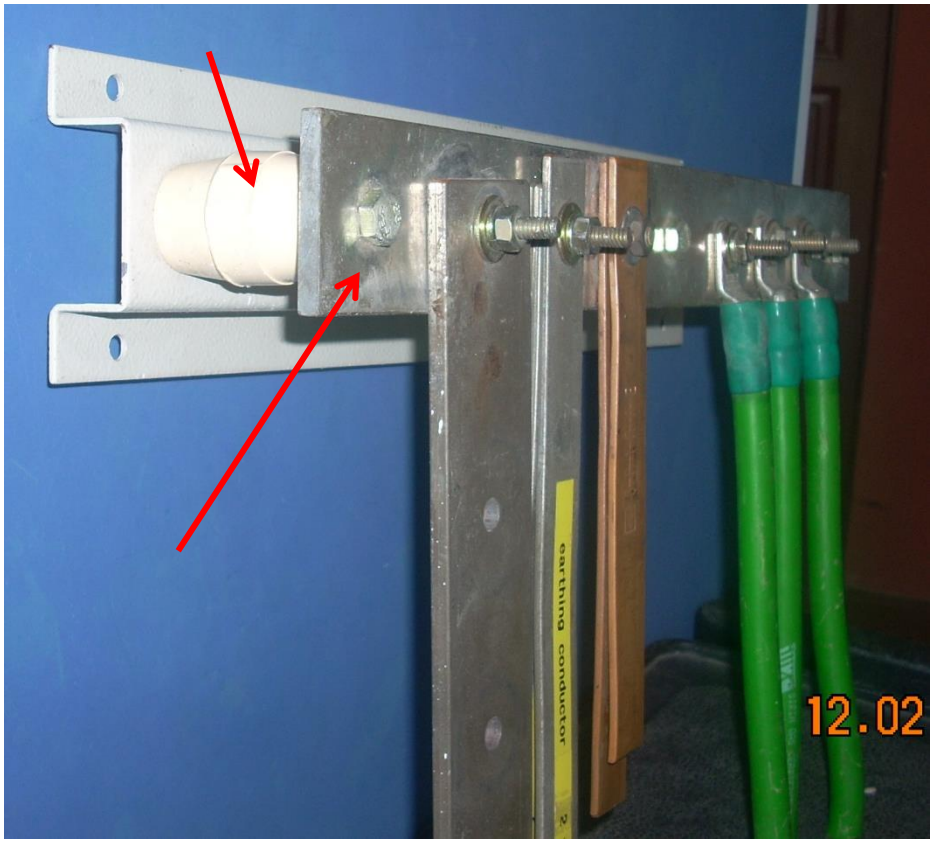

Prospective Earth Fault Current (PEFC) or Prospective Short Circuit Current (PSCC) determined by dividing measured mains voltage by measured loop (L-E) resistance or line (L-N) resistance, respectively

Three methods available to get the value of $Z_e$:

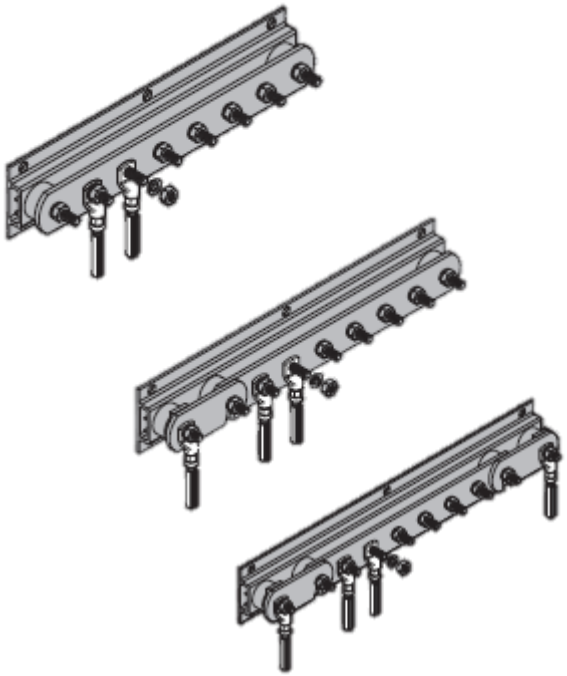
1. Determine it from details (if available) of the TNB transformer, the main distribution cable (provided by TNB).
2. Measure it from the supply intake position of an adjacent building having service cable of similar size and length to that proposed.
3. Use maximum likely values issued by the supply authority (in Malaysia, TNB do not provide the Ze value).

- MEB mounted on porcelain insulators shall be provided external to the switchboard on the wall near to the switchboard as indicated in the drawings

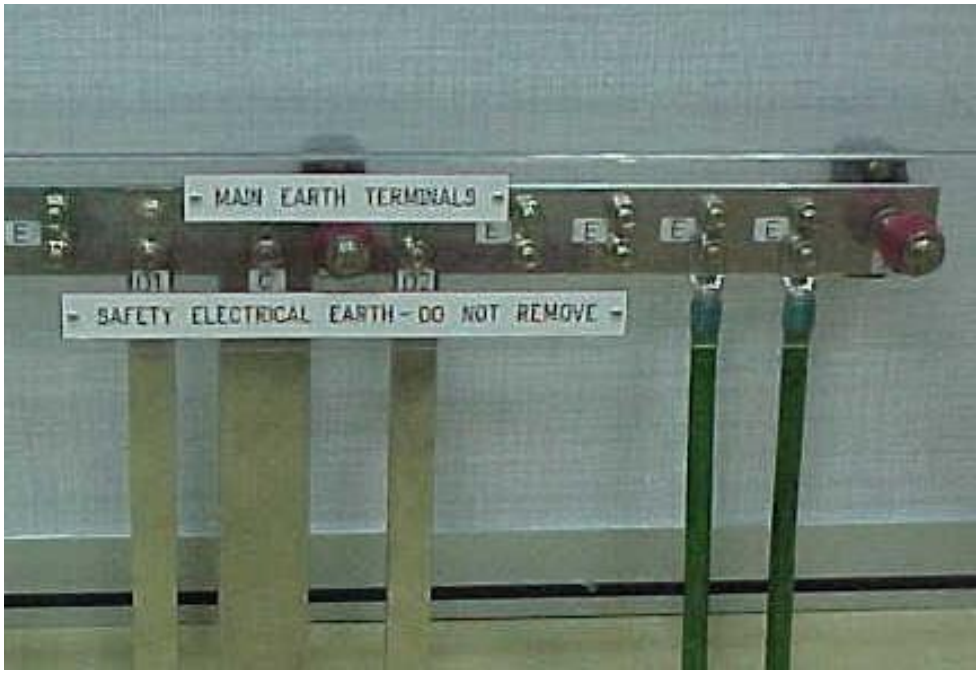
- MEB shall be of tinned copper bar of dimension as in Table 14A with respect to the PEFC



- MEB shall be of sufficient length to accommodate termination for all PCs, ECs and main equipotential bonding conductors, LPS bonding conductor and generator installation bonding conductor.



- Permanent label marked with words ‘Main Earthing Bar - Safety Electrical Connections - Do Not Remove’ shall be installed near to the MEB



- Two sets of ECs of copper tape dimension as in Table 14A shall be provided to connect the MEB to two different earth electrodes [3].

**Table 14A: Dimensions of SEB, PC, MEB and EC**

| | | SEB/MEB | | | PC | EC |
|---|---|---|---|---|---|---|
| | PEFC for 1s (kA) | $S=\frac{\sqrt{I^2 t}}{k}$ ($mm^2$) | Nearest cross-sectional area ($mm^2$) | Standard copper bar size (mm x mm) | No x Copper bar/tape size | No x Copper tape size |
| 1 | 10 | 62.9 | 75 | 25 x 3 | 1 no – 1 x 25mm x 3mm | 2 sets of 1 x 25mm x 3mm |
| 2 | 15 | 94.3 | 150 | 25 x 6 | 1 no – 1 x 25mm x 6mm (bar) or 2 nos – 1 x 25mm x 3mm (tape) | 2 sets of 1 x 25mm x 3mm |
| 3 | 20 | 125.8 | 150 | 25 x 6 | 1 no – 1 x 25mm x 6mm (bar) or 2 nos – 1 x 25mm x 3mm (tape) | 2 sets of 1 x 25mm x 3mm |
| 4 | 25 | 157.2 | 150 | 25 x 6 | 1 no – 1 x 25mm x 6mm (bar) or 2 nos – 1 x 25mm x 3mm (tape) | 2 sets of 1 x 25mm x 3mm |
| 5 | 30 | 188.7 | 180 | 30 x 6 | 1 no – 1 x 30mm x 6mm (bar) or 4 nos – 1 x 25mm x 3mm (tape) | 2 sets of 2 x 25mm x 3mm |
| 6 | 40 | 251.6 | 240 | 40 x 6 | 1 no – 1 x 40mm x 6mm (bar) or 4 nos – 1 x 25mm x 3mm (tape) | 2 sets of 2 x 25mm x 3mm |
| 7 | 50 | 314.5 | 300 | 50 x 6 | 1 no – 1 x 50mm x 6mm (bar) or 4 nos – 1 x 25mm x 3mm (tape) | 2 sets of 2 x 25mm x 3mm |

- The ECs shall be buried in the ground at a depth of not less than 600mm below finished ground level [3].

- PC between SEB and MEB shall be linked by copper tape of same cross sectional area as the MEB

**Table 14A: Dimensions of SEB, PC, MEB and EC**

| | | SEB/MEB | | | PC | EC |
|---|---|---|---|---|---|---|
| | PEFC for 1s<br>(kA) | $S=\frac{\sqrt{I^2 t}}{k}$<br>($mm^2$) | Nearest cross-sectional area<br>($mm^2$) | Standard copper bar size<br>(mm x mm) | No x Copper bar/tape size | No x Copper tape size |
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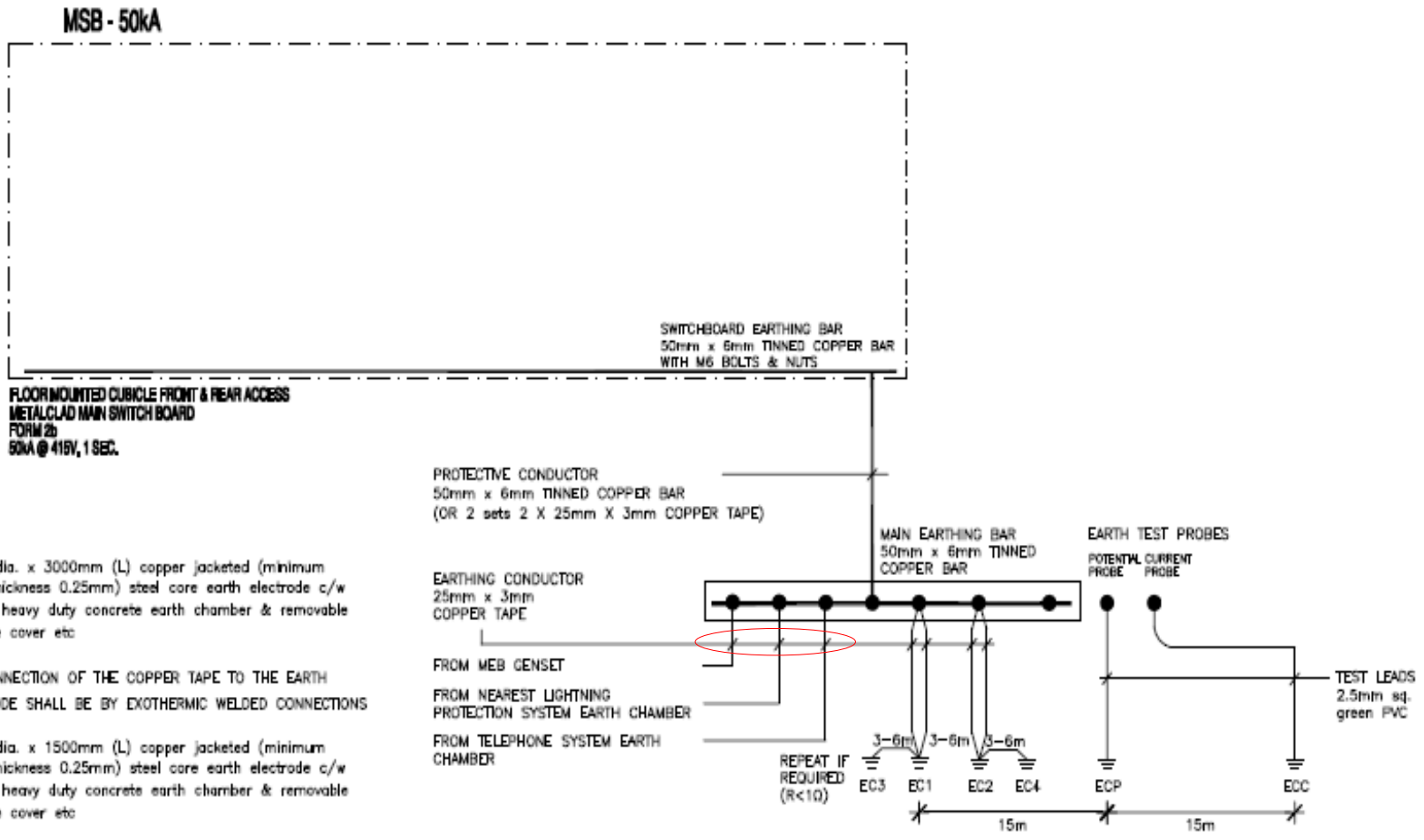
| 7 | 50 | 314.5 | 300 | 50 x 6 | 1 no – 1 x 50mm x 6mm (bar)<br>or<br>4 nos – 1 x 25mm x 3mm (tape) | 2 sets of 2 x 25mm x 3mm |

# Dimensions

Assuming the PEFC = PSCC

- 50 kA PEFC for 1s duration
- 25 kA PEFC for 1s duration

# Standard Title Block



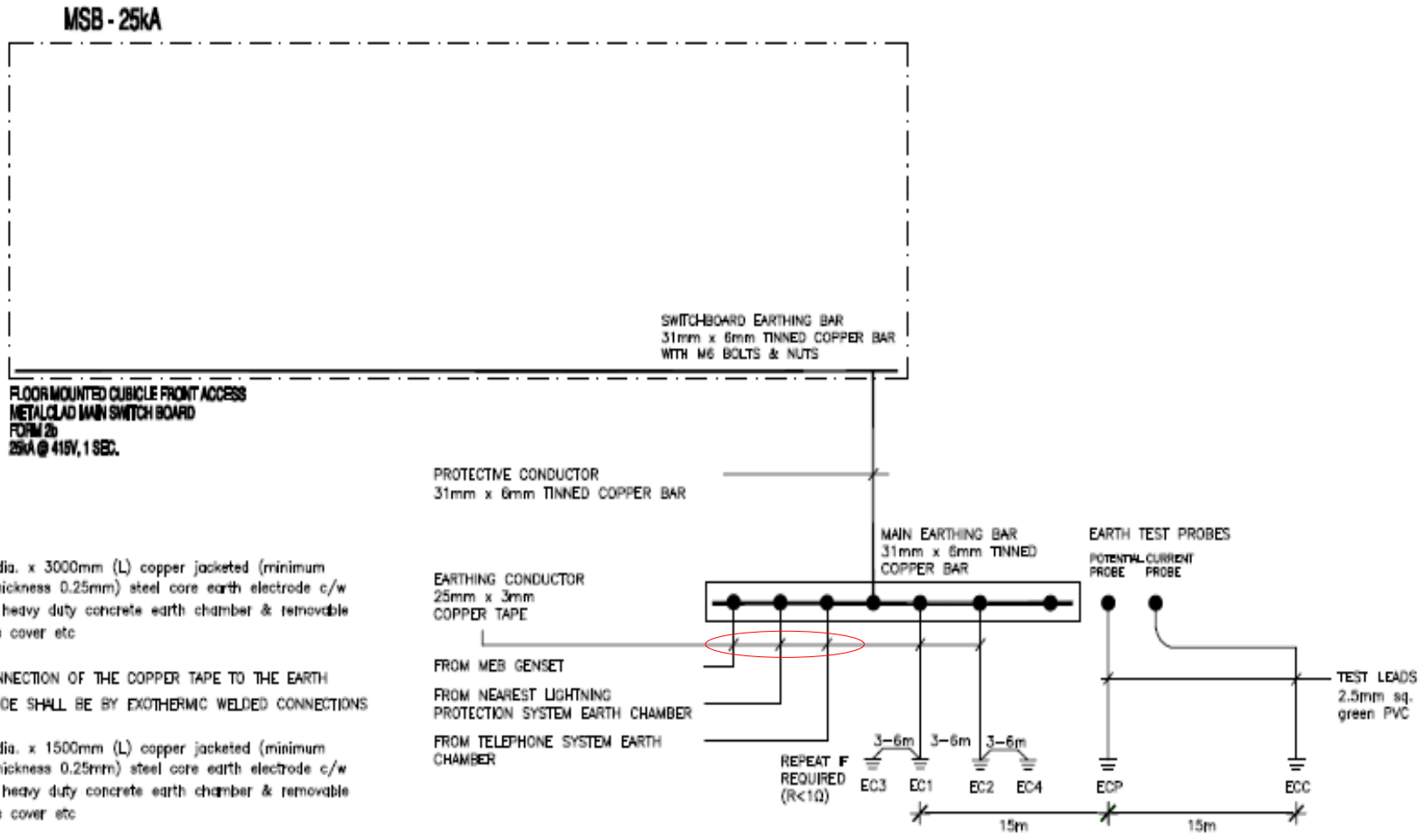

NOTE :

1. 16mm dia. x 3000mm (L) copper jacketed (minimum radial thickness 0.25mm) steel core earth electrode c/w precast heavy duty concrete earth chamber & removable concrete cover etc
   NOTE :
   THE CONNECTION OF THE COPPER TAPE TO THE EARTH ELECTRODE SHALL BE BY EXOTHERMIC WELDED CONNECTIONS

2. 16mm dia. x 1500mm (L) copper jacketed (minimum radial thickness 0.25mm) steel core earth electrode c/w precast heavy duty concrete earth chamber & removable concrete cover etc
   NOTE :
   THE CONNECTION OF THE CABLE TO THE EARTH ELECTRODE SHALL BE BY CLAMP

3. Earth test probes shall be installed if there is sufficient ground on site

# Standard Title Block




NOTE :

1. 16mm dia. x 3000mm (L) copper jacketed (minimum radial thickness 0.25mm) steel core earth electrode c/w precast heavy duty concrete earth chamber & removable concrete cover etc
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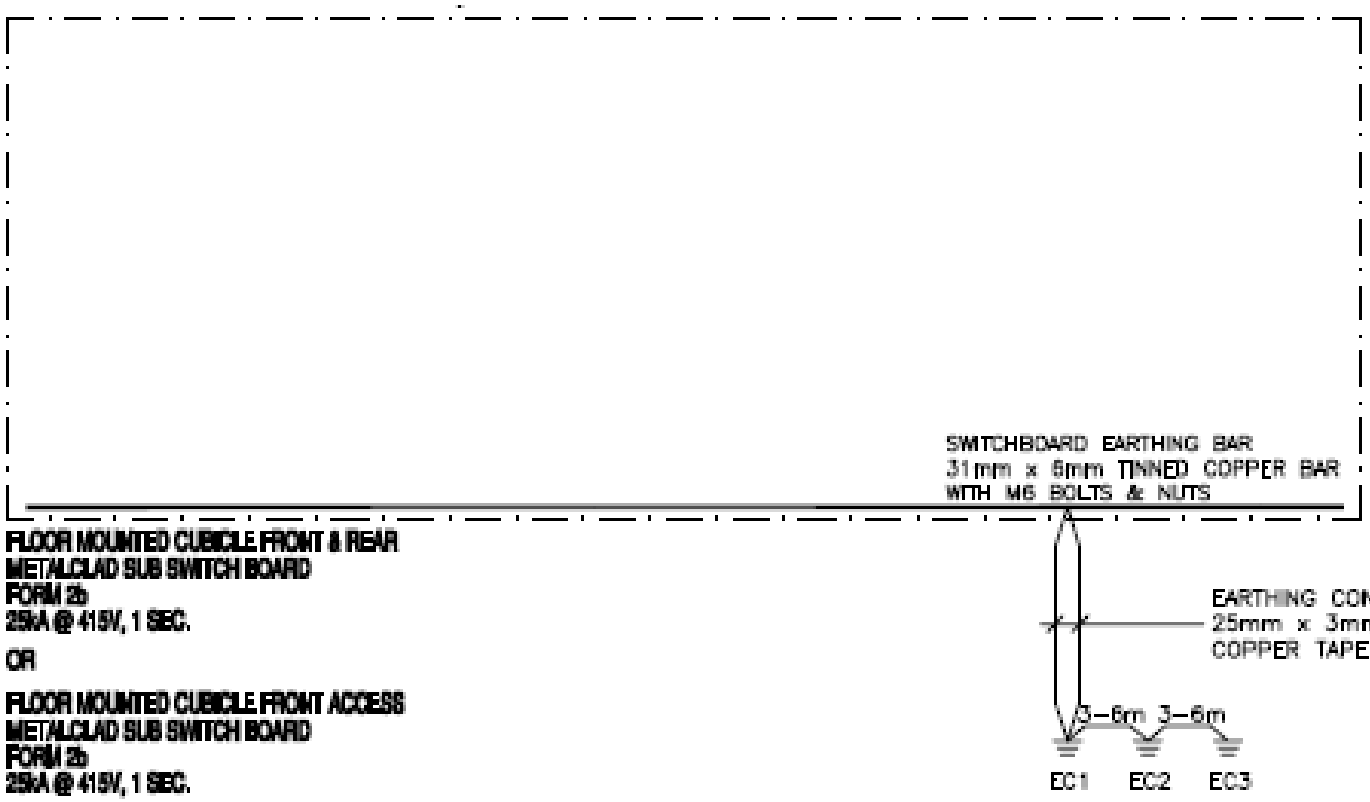



16mm dia. x 3000mm (L) copper jacketed (minimum radial thickness 0.25mm) steel core earth electrode c/w precast heavy duty concrete earth chamber & removable concrete cover etc

NOTE :

THE CONNECTION OF THE COPPER TAPE TO THE EARTH ELECTRODE SHALL BE BY EXOTHERMIC WELDED CONNECTIONS

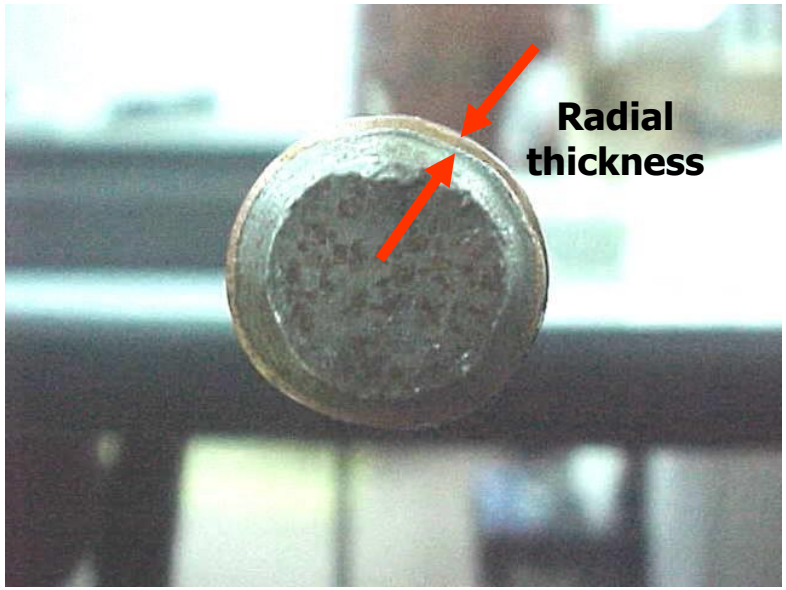
# Summary

Method of calculation the csa of the CPC, SEB, PC, MEB and EC

| Conductor | Formula/Table |
|---|---|
| CPC | $S = \frac{\sqrt{I^2 t}}{k}$ or Table 54.3 |
| SEB | $S = \frac{\sqrt{I^2 t}}{k}$ |
| PC | $S = \frac{\sqrt{I^2 t}}{k}$ |
| MEB | $S = \frac{\sqrt{I^2 t}}{k}$ |
| EC for 'RCCB Earth' | ($S = \frac{\sqrt{I^2 t}}{k}$ or Table 54.3) and Table 54.2 |
| EC for solid earthing | $S = \frac{\sqrt{I^2 t}}{k}$ |
| Bonding conductors | Clause 544 |

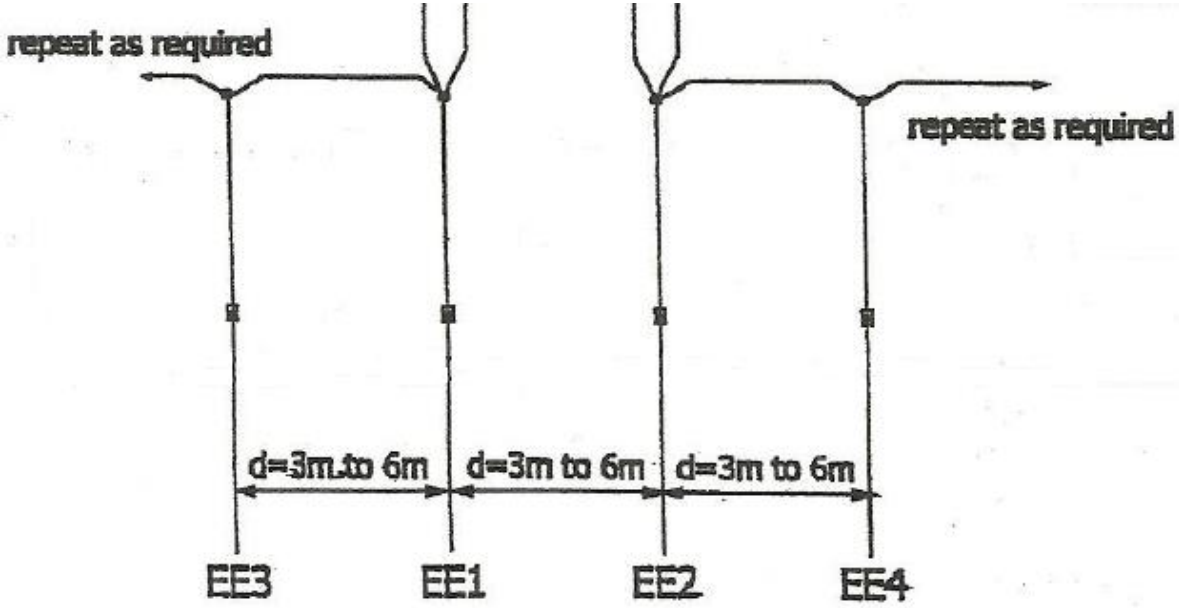
- Earth electrodes shall be of copper-jacketed steel core rods with 16mm nominal diameter and supplied in 1500mm length and shall have provision for screw coupling with another standard length.

- The copper jacket of 99.9 % pure electrolytic copper shall be of minimum radial thickness 0.25mm and shall be molecularly bonded to the steel core to ensure that the copper jacket and steel core are non separable.




- Each earth electrode shall be driven 3000mm in depth

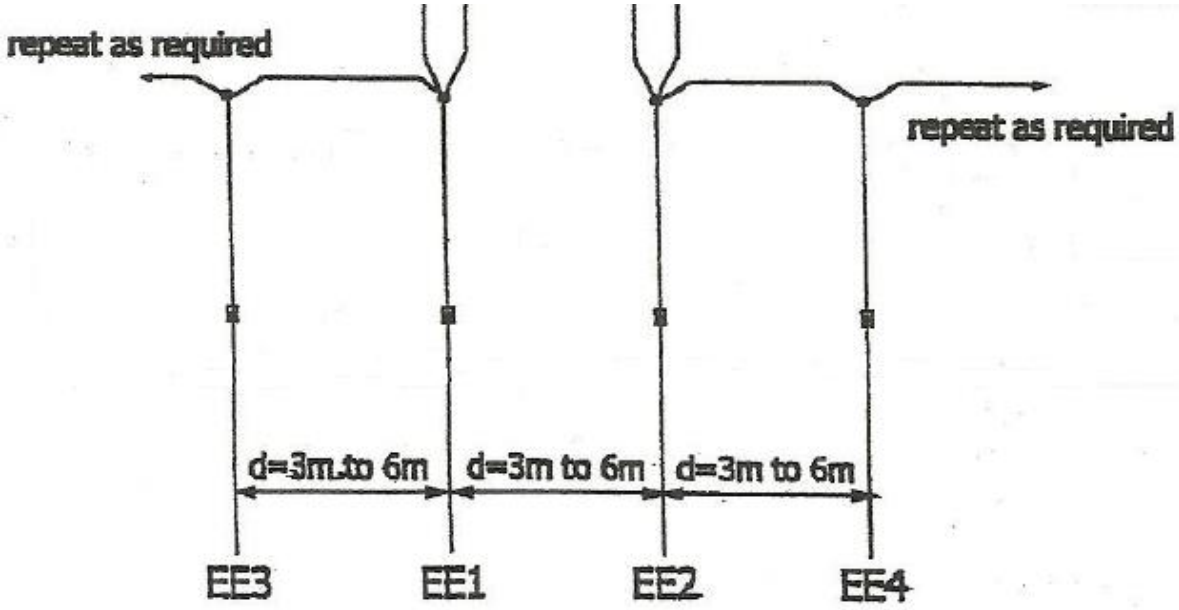
- Mutual separation between two earth electrodes shall be more than, but less than twice, the driven depth of the earth electrode.




- Earth electrodes shall not be installed close to a metallic fence unless the metallic fence is separately earthed

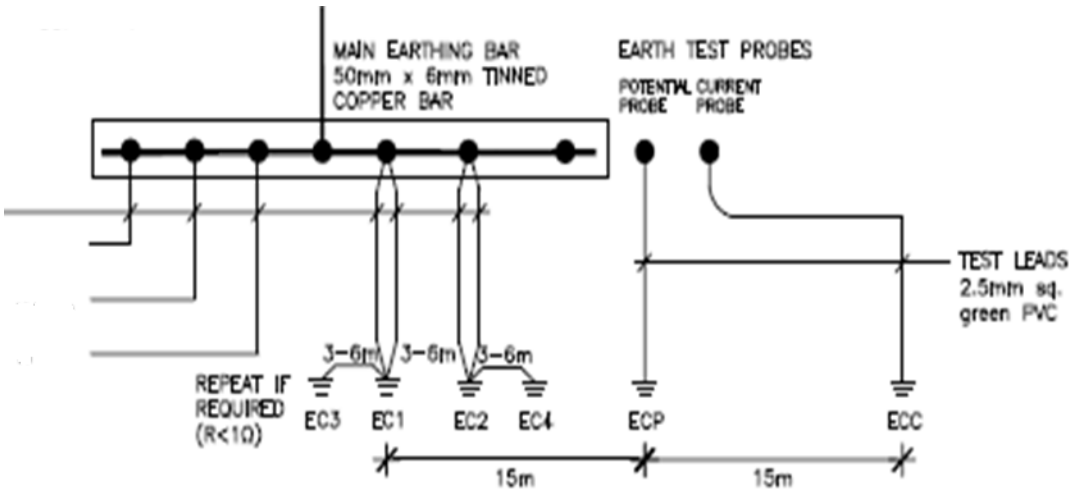
- The fence shall be separated from the electrical earthing system by at least 2000mm.

- Interconnection between different earth electrodes shall be by means of 25mm x 3mm annealed copper tape.

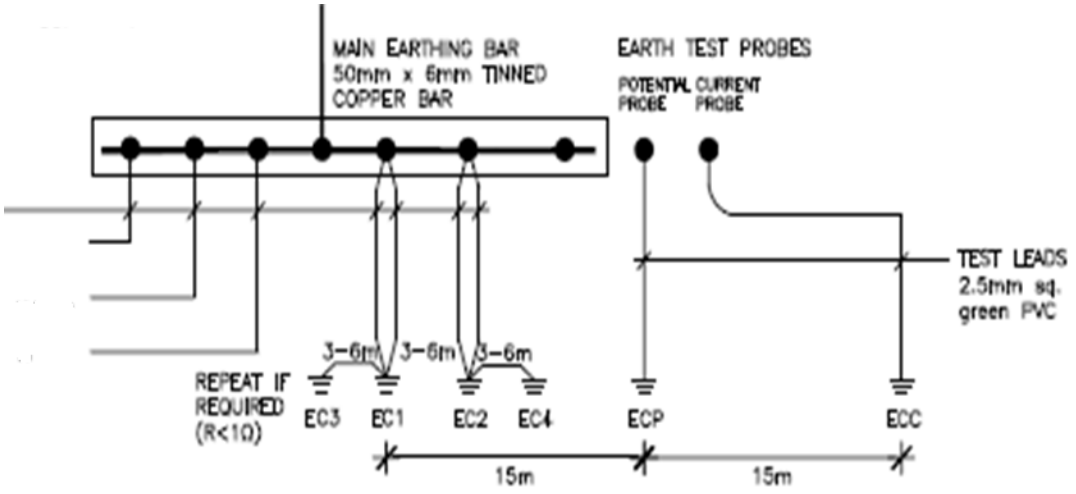


- Where the location of the installation is such that it is not possible in practice to provide the two auxiliary earth electrodes for the test (potential and current test probes), the P and C shall be installed.

- The P and C test probes shall be one length of 1500mm in depth.



- The current test probe shall be placed 30m from the first earth electrodes with potential test probe midway between.
- Test leads of 2.5 sq. mm PVC insulated cable connecting test earth electrodes shall be terminated independently on the porcelain insulators next to the MEB.



- The test leads shall be protected by means of non metallic conduit and buried in the ground at a depth of not less than 600mm below finished ground level.

- Termination shall be identified with permanent labels durably and legibly marked with words ‘Potential Earth Test Probe - Do Not Remove’ and ‘Current Earth Test Probe - Do Not Remove’

- Similar labels of not less than 4.75mm high shall be permanently fixed in a visible position at earth electrodes.


SAFETY ELECTRICAL
CONNECTION
DO NOT REMOVE
NIGLON BS 951.1999


SAFETY ELECTRICAL
CONNECTION
DO NOT REMOVE
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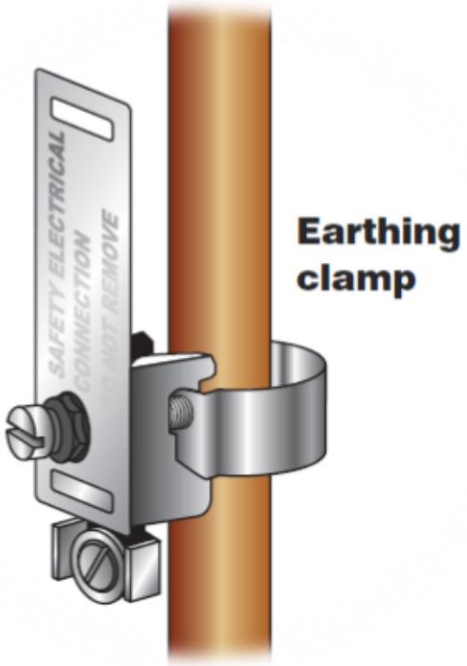
Earthing
clamp

# Residual Current Operated Circuit Breaker (RCCB)

$R_A \leq V_s / I_{\Delta n}$

| $I_{\Delta n}$ , mA (Residual Operating Current) | $R_A$ , Ω (Resistance of earth electrode + earthing conductor resistance) |
|---|---|
| **10** | **5000** |
| **30** | **1666** |
| **100** | **500** |
| **200** | **250** |
| **300** | **166** |

**Maximum values for $R_A$ corresponding to $I_{\Delta n}$ for RCCB protected circuits.**

***Note: It is recommended that earth electrode resistance should never be greater than 200 Ω***

# References


[1] **MS IEC 60364-5-54:** Earthing Arrangements, Protective Conductors & Protective Bonding Conductors

[2] **Brian Scaddan**, *"Explained and Illustrated",* Eighth Edition 2008, Elsevier Ltd.

[3] **BS 7430:** Code of practice for protective earthing of electrical installations

# Thank You

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