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Copper-clad steel earthing materials • since 2009

Corrosion-Resistant Earthing Materials in China

From many options to one selection ladder: galvanised steel for low corrosivity, copper-clad steel for medium and high, copper for the worst soils – as fixed by DL/T 2650-2023

After widespread corrosion failure of galvanised-steel earthing grids, the Chinese power industry tried zinc-clad steel, stainless and stainless-clad steel, high-purity iron, copper, copper-clad steel, as well as nano-carbon-coated steel and graphite-based flexible electrodes. This report reviews that period of "a hundred flowers" and how three standards – DL/T 2094-2020, Q/GDW 12015-2020 and DL/T 2650-2023 – converged the choice into one ladder graded by soil corrosivity. Every clause is quoted with its reference.

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Summary

One ladder. Clause 5.1.1.5 of DL/T 2650-2023, the technical-supervision guide for earthing metals in power engineering, grades the choice of earthing metal into four steps by soil corrosivity. It is the Chinese power industry's final word on "which corrosion-resistant earthing material":

Negligible / low	Medium	High	Special-high / indoor & underground
hot-dip galvanised steel (zinc average ⩾ 85 μm, minimum ⩾ 70 μm)	hot-dip galvanised steel with cathodic protection, or copper-clad steel (copper ⩾ 0.60 mm)	copper, copper-clad steel (copper ⩾ 0.80 mm) or other material of equivalent corrosion resistance	copper preferred in coastal, reclaimed, chemical and saline areas with salt ⩾ 1.5 % (Q/GDW 12015); indoor and underground substations shall use pure copper

The logic of the ladder is "the cheapest material that meets the design life at each step": copper in low corrosivity is waste, galvanised steel in medium corrosivity does not last, 0.6 mm in high corrosivity is not enough, and in the worst soils even copper-clad steel is not safe. It rejects no material; it places each one where it creates value.

1 Where the problem began: corrosion failure of galvanised grids

The great majority of China's existing earthing grids are hot-dip galvanised flat and round steel. It is cheap, easy to weld, the same metal as towers and structures, and in low-corrosivity soil it works for decades. The trouble is in medium- and high-corrosivity soil: the zinc is only tens of micrometres thick, is consumed within a few years in saline, acidic or stray-current conditions, after which the steel thins at a few tenths of a millimetre a year; a down-lead rusted through at the soil line is the classic failure.

Annex E of DL/T 2650-2023 records a typical case, which serves as a footnote to this whole period: severe corrosion of the earthing flat steel of a 110 kV transmission line, one tower-leg down-lead rusted through at the soil line, and excavation showing corrosion of down-leads along the whole line. Findings: the base metal was a conforming Q235B; the zinc layer was only 2.3–13.2 μm, from a cold (electro-) galvanising process; the soil had Cl^- 3930 mg/kg, sulphate 1320 mg/kg, resistivity 2.3 Ω · m, pH 8.57 – graded "high" corrosivity. The guide's conclusion and recommendation:

> E.5.1 Main cause: the material was not selected with regard to the soil corrosivity class and the project conditions, so that galvanised down-leads could not reach the design life in high-corrosivity soil; secondary cause: the galvanised parts were cold-galvanised with a low coating thickness …
> E.5.2 Recommendation: in the next major overhaul, replace the earthing material of the lines in this area with copper, or with copper-clad steel having a coating thickness greater than 0.8 mm.
>
> — DL/T 2650-2023 Annex E (informative), Typical failure analysis of earthing metallic materials

The case shows two things: the root cause of failure was "not selecting by soil corrosivity class", not galvanised steel as such; and the direction of repair was copper or copper-clad steel above 0.8 mm.

2 A hundred flowers: the industry's answers

Under the pressure of galvanised-steel failures, the first fifteen years of this century saw a wide range of corrosion-resistant earthing materials on the Chinese market, each with its standard, its makers and its pilot projects:

Material	Principle and selling point	Standard	Problems exposed in practice
Zinc-clad steel	steel core with ⩾ 1 mm zinc, sacrificial protection, same metal as galvanised grids	DL/T 1457	zinc consumed fast; high corrosivity needs 3–5 mm (DL/T 2650 Table 2); cracks at bends
Stainless / stainless-clad steel	austenitic stainless or stainless-clad core, passive film	DL/T 248, DL/T 1667	pitting in chlorides; both anti-corrosion standards advise against coastal and saline soils; low conductivity
High-purity iron	fewer impurities, slower corrosion	—	appears only as a high-corrosivity option in DL/T 2094; little application
Copper	corrosion-resistant, conductive, exothermic welding mature	DL/T 1342	expensive, theft, galvanic effect on steel structures to be assessed
Copper-clad steel	steel carries the load, copper protects and conducts, about one fifth of the copper of solid copper	DL/T 1312, Q/GDW 10466	early 0.25 mm plated product fell short of design life in medium and high corrosivity (see our report TR-01)

Material	Principle and selling point	Standard	Problems exposed in practice
Nano-carbon-coated steel	a nano-carbon anti-corrosion coating applied to a steel electrode to isolate it from the soil	falls under DL/T 2094 clause 5.4, "Anti-corrosion coating protection": the coating must meet national or industry coating standards, the coated electrode must itself still meet the earthing-material standard, and over-protection must be avoided when combined with cathodic protection (5.4.1–5.4.4)	once the coating is damaged in transport, installation or bending the damaged spot is bare steel; protection depends on coating integrity, and unlike a metallic layer it cannot be gauged on site for acceptance; by industry feedback it is used mainly within the Sinopec system, has not spread to other sectors and has had frequent quality problems

Material	Principle and selling point	Standard	Problems exposed in practice
Graphite-based flexible electrode (graphite rope: copper core, graphite sheath)	non-metallic sheath does not corrode; flexible, easy to lay around tower footings	industry standard "Technical conditions for graphite-based flexible earthing electrodes for transmission-line towers"	application limited to transmission-line tower earthing: lines tolerate a certain lightning trip-out rate and tower footing resistance is far less strictly required than a substation grid; not used in substations, rail or chemical projects where earth resistance and thermal stability are hard requirements. Outside the scope of DL/T 2650

The mark of this period: every material could show a successful pilot and every one had its failures, and a designer facing a dozen choices had no single yardstick tied to site conditions. What the standards did next was to supply that yardstick.

3 Convergence: three steps to one ladder

3.1 Step one: DL/T 2094-2020 lists the options by corrosivity class

Clause 5.2.1 of DL/T 2094-2020 *Technical specification for corrosion protection of AC power engineering earthing* was the first to tie material selection to soil corrosivity class and to set a minimum coating thickness for each material:

> 5.2.1 Earthing metals may be plain carbon steel, hot-dip galvanised steel, high-purity iron, zinc-clad steel, copper-clad steel, copper or stainless steel.
> 5.2.1.1 Negligible corrosivity: plain carbon steel or hot-dip galvanised steel.
> 5.2.1.2 Low corrosivity: hot-dip galvanised, zinc-clad or copper-clad steel … copper layer of copper-clad steel greater than 0.25 mm.
> 5.2.1.3 Medium corrosivity: hot-dip galvanised steel preferred; galvanised steel with cathodic protection, copper-clad steel or zinc-clad steel permitted. Zinc layer of zinc-clad steel not less than 1.0 mm; copper layer of copper-clad steel greater than 0.6 mm …
> 5.2.1.4 High corrosivity: hot-dip galvanised steel with cathodic protection preferred; high-purity iron, zinc-clad steel,

> copper, copper-clad steel, stainless steel or stainless-clad steel permitted. Stainless steel and stainless-clad steel are not recommended in coastal and saline soils with high chloride. Copper layer of copper-clad steel greater than 0.8 mm …
>
> — DL/T 2094-2020 clause 5.2.1

This edition still carries the marks of the "hundred flowers": in medium and high corrosivity galvanised steel with cathodic protection is still "preferred", and high-purity iron, zinc-clad and stainless steel remain on the list. But the three key numbers are already there: 0.25 / 0.6 / 0.8 mm.

3.2 Step two: Q/GDW 12015-2020 narrows the options and names the important sites

State Grid's corporate standard Q/GDW 12015-2020 *Technical specification for corrosion protection of power engineering earthing materials*, issued the same year, has a selection clause (5.2.2) of the same structure as DL/T 2094 but tightened in three places: negligible corrosivity is simply "galvanised steel preferred"; in medium corrosivity copper and copper-clad steel are listed as regular options alongside galvanised steel, which must "increase the design section according to local corrosion data", with cathodic protection only "after full justification"; and in high corrosivity high-purity iron and zinc-clad steel disappear from the list. Two targeted rules were added:

- Clause 4.8: in medium- and high-corrosivity areas, plants and substations of 330 kV and above, fully indoor substations, hub substations of 220 kV and above, urban substations of 66 kV and above and compact substations, and in high and special-high corrosivity areas 110 kV plants and substations, "should use copper, copper-clad steel with a copper layer of at least 0.8 mm, or other equivalent anti-corrosion measures".
- Clause 5.2.2.5: in coastal, reclaimed, chemical and saline areas with salt content ⩾ 1.5 %, substation earthing should use copper; clause 5.2.2.6: where pH ⩽ 4.5, the copper layer of copper-clad steel should be ⩾ 1.0 mm.

3.3 Step three: DL/T 2650-2023 settles it

DL/T 2650-2023 is a technical-supervision guide: it no longer discusses "what may be used" but prescribes the yardstick utilities apply in design review, construction supervision and operation. Clause 4.3 defines the scope of supervision as "bare carbon steel, hot-dip galvanised steel, zinc-clad steel, copper, copper-clad steel, stainless steel, stainless-clad steel and their connectors" – non-metallic electrodes are not among them. Clause 5.1.1.5 gives the final ladder (see Summary), and three tables fix the minimum thickness of every clad material by corrosivity class:

Soil corrosivity class	Hot-dip galvanised steel, zinc	Zinc-clad steel, zinc, mm (down-lead & horizontal / vertical)	Copper-clad steel, copper, mm	Stainless-clad steel, cladding, mm
Negligible, low	average ⩾ 85 µm, minimum ⩾ 70 µm (5.1.3.3)	1 / 3	0.25	0.50
Medium		3 / 3	0.60	0.50
High		3 / 5	0.80	0.70

Sources: DL/T 2650-2023 Table 2 (zinc-clad steel), Table 4 (copper-clad steel), Table 5 (stainless-clad steel); all are minima at any measuring point.

The guide also writes in rules previously scattered across the other standards: earthing materials for long-term use shall not be bare carbon steel, and aluminium conductors shall not be used (5.1.1.4); indoor and underground substations shall use pure copper (5.1.1.7); one material should be used within one area, copper and copper-clad steel may share an area, and substitute materials in retrofit work must be assessed for galvanic corrosion in advance (5.1.1.2); in high corrosivity, besides material selection, larger sections, thicker coatings and cathodic protection are to be considered together (5.1.1.6).

3.4 The three ladders side by side

Corrosivity	DL/T 2094-2020 (2020)	Q/GDW 12015-2020 (2020)	DL/T 2650-2023 (2023, supervision)
Negligible	carbon steel / galvanised steel	galvanised steel preferred	galvanised steel preferred
Low	galvanised / zinc-clad / copper-clad > 0.25	galvanised / copper-clad	
Medium	galvanised preferred; galvanised + CP / copper-clad > 0.6 / zinc-clad permitted	galvanised (larger section) / copper / copper-clad ⩾ 0.6 / zinc-clad	galvanised + CP, or copper-clad ⩾ 0.60
High	galvanised + CP preferred; high-purity iron / zinc-clad / copper / copper-clad > 0.8 / stainless (not coastal)	galvanised (larger section) / copper / copper-clad ⩾ 0.8 / stainless (not coastal)	copper, copper-clad ⩾ 0.80 or equivalent
Special-high / indoor	copper and copper-clad not recommended at pH ⩽ 4.5	copper at salt ⩾ 1.5 %; copper-clad ⩾ 1.0 at pH ⩽ 4.5; important sites copper or copper-clad ⩾ 0.8	indoor and underground substations: pure copper

Within three years the options narrowed from seven or eight to three main materials – galvanised steel, copper-clad steel and copper – with cathodic protection reduced to a supporting measure and zinc-clad and stainless-clad steel kept as conditional alternatives. That is the "convergence" of this report's title.

4 Why the ladder took this shape

- **Lowest cost that meets the full life at each step.** In low corrosivity galvanised steel already lasts 30 years, and copper-clad steel is extra money; in medium corrosivity galvanised steel falls short while 0.6 mm copper-clad steel loses 0.21 mm in 30 years at 0.007 mm/a and keeps a margin; in high corrosivity 0.8 mm loses 0.36 mm at 0.012 mm/a and still keeps a margin; at salt ⩾ 1.5 % or extreme pH even copper-clad steel is not safe, so copper.
- **Verifiability.** The materials left on the ladder all have site-measurable criteria: zinc and copper layers can be gauged on the spot, the bond can be hammer- or bend-tested on site (DL/T 2650 Annex B), coating quality can be checked by a site high-current test (Annex C). The materials that were narrowed out mostly lacked such site criteria.
- **Material consistency.** Existing grids are galvanised steel; extensions in low corrosivity use the same metal, avoiding galvanic corrosion at copper-to-galvanised joints; copper and copper-clad steel both present a copper surface and may share an area (5.1.1.2).
- **Institutionalised failure analysis.** Clause 4.4 requires that "the cause of earthing material failure shall be established, and general and family defects summarised"; Annex E is the model. The ladder was derived backwards from failure cases, not picked from material brochures.

5 Each material's place

Material	Place on the ladder	Conditions of use (key points from the standards)
Hot-dip galvanised steel	first choice in negligible and low corrosivity; in medium, with cathodic protection or a larger section	zinc average ⩾ 85 µm, minimum ⩾ 70 µm; cold galvanising not acceptable (Annex E case); minimum sizes round Ø 8 / Ø 10, flat 48 mm² × 4 mm (Table 1)
Copper-clad steel	main material for medium and high corrosivity; may share an area with copper	copper 0.60 / 0.80 mm minimum at any point; one class up or ⩾ 1.0 mm where pH < 4.5; horizontal conductor annealed per DL/T 1312 / Q/GDW 10466; scratched lengths not to be used

Material	Place on the ladder	Conditions of use (key points from the standards)
Copper	parallel option in high corrosivity; the only option in special-high corrosivity and in indoor and underground substations	minimum sizes rod Ø 8 / Ø 15, flat 50 mm² × 2 mm, strand 50 mm² (Table 3); galvanic effect on steel structures, cables and pipes to be assessed
Zinc-clad steel	conditional alternative in medium corrosivity	zinc ⩾ 1.0 mm, rising to 3 / 5 mm with corrosivity per Table 2; no cracking at bends
Stainless / stainless-clad steel	conditional alternative in high corrosivity	cladding 0.50 / 0.70 mm (Table 5); not recommended in chloride-rich coastal and saline soils (DL/T 2094 5.2.1.4); austenitic stainless with Mn ⩽ 2 %
Bare carbon steel, aluminium	retired	not for long-term use; aluminium not permitted (5.1.1.4); carbon-steel down-leads for temporary earthing only (5.1.2.2)
Nano-carbon-coated steel	an anti-corrosion coating measure, not a material step of its own	managed under DL/T 2094 clause 5.4: coating to standard, base material to standard, no over-protection with CP; in practice confined to one sector
Graphite-based flexible electrode	transmission-line towers only	used for tower earthing under its own industry standard; not for substations, rail or chemical projects

6 What this means for a project abroad

Overseas projects face the same choice China faced ten years ago: galvanised steel is cheap but fails in corrosive soil, copper is reliable but expensive and stolen, and every "new material" has its story. The road China travelled with three standards can be borrowed directly:

1. **Grade the soil corrosivity.** From resistivity, pH, chloride, sulphate and salt content together (China uses the multi-factor rating of DL/T 1554; the Annex E case gives a typical set of "high corrosivity" values for comparison).
2. **Select by the ladder.** Low corrosivity: galvanised steel is enough – we will say so, even where it means not buying from us; medium: copper-clad steel ⩾ 0.60 mm; high: copper-clad steel ⩾ 0.80 mm or copper; salt ⩾ 1.5 %, indoor or underground: copper.
3. **Write verifiable criteria into the specification.** "Minimum coating or copper thickness at any measuring point", annealed temper, number of bends, bond test method; check on delivery with a gauge and a hammer rather than relying on the supplier's report.
4. **Keep materials consistent within an area.** Assess galvanic corrosion where new meets old; copper and copper-clad steel may be mixed.

7 Our position

Our company makes only copper-clad steel, but we advise along the whole ladder rather than for our own product alone: in low-corrosivity soil we recommend hot-dip galvanised steel; in special-high corrosivity and in indoor and underground substations we recommend copper; for horizontal conductor in medium- and high-corrosivity soil we supply and recommend 0.6 / 0.8 mm continuous-cast, annealed copper-clad steel, type-tested to the full DL/T 1312-2023 programme, with copper not below nominal at any point, hammer-testable and gaugeable on site. The free assessment states which step of the ladder a project falls on, why, and what to choose if it is not copper-clad steel.

References

1. DL/T 2650-2023, Technical supervision guide for grounding metallic materials in power engineering, National Energy Administration, issued 2023-10-11, in force 2024-04-11 (first edition).
2. DL/T 2094-2020, Technical specification for corrosion protection of AC power engineering earthing, National Energy Administration.
3. Q/GDW 12015-2020, Technical specification for corrosion protection of power engineering earthing materials, State Grid Corporation of China, issued and in force 2020-11-27.
4. DL/T 1312-2023 and Q/GDW 10466-2021, Technical conditions / specifications for copper-clad steel in power engineering earthing.
5. DL/T 1457 (zinc-clad steel); DL/T 248 and DL/T 1667 (stainless-clad earthing devices); DL/T 1554 (soil corrosivity assessment of earthing grids); DL/T 2049 (material selection guide for earthing installations).

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