# Effects of Ground Voltage or Stray Current on Infrastructure Caused by High Voltage Direct Current (HVDC) Transmission Lines



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**Background:** The requester asked for background information concerning the effects of ground voltage produced by a high voltage direct current transmission line and its potential effects on steel or iron products which are part of a state DOT's infrastructure. The requester was contacted by a property owner who is concerned about the proposed Grain Belt Express High Voltage Transmission line.

**Discussion:**

- The effect of stray current corrosion on underground infrastructure has been a concern for decades. As one example, a 1967 article warned about the "stray current corrosion of **underground metallic structures**" caused by HVDC transmission lines. [10]
- In the literature, most studies are concerned about potential damage to **pipeline structures**. Sometimes, the structures are referred to more generically. For example, the Corrosion Wiki from NACE International states that "stray currents which cause corrosion may originate from **direct-current distribution lines**, substations, or street railway systems, etc., and **flow into a pipe system or other steel structure**."
- The most recent reference related to the stray current corrosion of **bridge structural elements** was Caltrans' *Corrosion Guidelines* (see below).
- Based on information at the Grain Belt Express website, the company is considering a **monopole system**.
    - According to a 2010 NACE International paper, "monopolar systems use the earth or preferably sea water as the return circuit, whereas bipolar systems only use the earth or sea water during electrical upsets or faults." [8]
    - According to a 2008 Argonne National Laboratory study, "when the current return is through the ground … this return path presents a danger to **buried metal infrastructure** through electrocorrosion." [2]
- According to European sources, how DC stray current affects reinforced concrete varies. The most damaging effects are seen when the **rebar is already corroded.** [17]

I have excerpted professional opinions from the literature below as to whether and how stray current corrosion from HVDC transmission lines might affect underground structures.

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# Effects of Stray Current Corrosion on Infrastructure

## Caltrans

The 2012 edition of *Corrosion Guidelines* published by the California Department of Transportation addresses the effect of stray current corrosion as it applies to **bridge structures, long steel culverts and pipes.** [1]

- "Stray current corrosion (interference corrosion) is corrosion caused by **direct current** from an external source that travels through paths other than the intended circuit. Accelerated corrosion may result if the current is collected by a structure and leaves to enter the soil. Stray currents in bridge structure elements can be caused in two ways, either **through direct connection or through a soil gradient**."
- "**Direct connection involves attaching a pipeline, electric railway track, or high-voltage contact system to bridge structure elements.** Installation requires an approved insulator between the pipe or rail and the bridge element, and the high-voltage contact

system requires double insulation for safety. Since concrete is not an insulator, a failed insulator, even if connected only to the concrete, will cause corrosion in bridge structure elements."

- "Measures must be taken to mitigate possible stray current problems whenever they are anticipated or suspected."

## FHWA

### *Mechanically stabilized walls [14]*

"Stray currents may be an additional source of corrosion for [Mechanically Stabilized Earth Wall] MSE systems constructed adjacent to electrically powered rail systems or other sources of electrical power that may discharge current in the vicinity of these systems, such as existing utilities, cathodically protected radio stations, etc."

"In general, stray currents decrease in magnitude rapidly as they move away from the source and are believed not to be a factor 100 to 200 ft (30 to 60 m) away from the source. For structures constructed within these distances, AASHTO recommends that a corrosion expert evaluate the hazard and possible mitigating features on a project-specific basis. Furthermore, it is recommended that a long-term corrosion monitoring program be integrated into the design, if steel reinforcements are used."

### *Ground anchors [15]*

"Stray current corrosion occurs as pitting of prestressing steel when subject to prolonged exposure to stray electrical currents. Stray currents in the ground result from the discharge of direct electrical current from power sources such as electric rail systems, electrical transmission systems, and welding operations and is particularly damaging in the marine environment. Power sources beyond a distance of 30 to 60 m from a ground anchor are believed to not cause a significant amount of stray current corrosion (FHWA-SA-96-072, 1995). Protection of anchors from stray currents commonly involves complete electrical isolation of the prestressing steel from the ground environment with a nonconducting barrier such as plastic."

### *Tunnels [16]*

Corrosion is associated with steel products embedded in the concrete and otherwise used in tunnel applications. Ground water, ground chemicals, leaks, vehicular exhaust, dissimilar metals, deicing chemicals, wash water, detergents, iron eating bacteria and stray currents are all sources of corrosion in metals.

Increased concrete cover over reinforcing steel is an effective means of protecting reinforcing steel from corrosion. Increasing the concrete cover, however will also increase the thickness of the lining. The increased thickness will result in a larger excavation which will increase the overall cost of the tunnel. The use of increased concrete cover should be evaluated in terms of the overall cost of the tunnel compared to the benefit derived.

## NACE International

NACE International has tasked its Technical Committee on Reinforced Concrete: Stray-Current-Induced Corrosion (TG 356) with writing "a standard practice on detection and mitigation of DC and AC stray-current-induced corrosion of **reinforced and prestressed concrete structures**." [18] The standard was sent to NACE in 2014 for balloting.

## Other

### *Reinforced concrete [17]*

A technical handbook published in Europe on the corrosion of steel in concrete concludes that DC stray current causes the most damage in reinforced concrete when rebar has already been corroded (see excerpt below).

> Stray current can also flow through reinforced or prestressed concrete and produce an alteration of the potential distribution inside the concrete, which can influence corrosion of embedded steel [2, 3]. Several types of structures may be subjected to stray current, such as bridges and tunnels of railway networks or structures located in the neighborhood of railways. Here, the concrete, like the soil surrounding buried structures, is the electrolyte and the reinforcing bars or prestressing tendons can pick up the stray current. Laboratory studies have shown that stray DC current rarely has corrosive consequences on steel in concrete, in contrast to their effect on metallic structures in the soil [2–7]. In fact, passive steel in alkaline and chloride-free concrete has a high intrinsic resistance to stray current. Nevertheless, under particular circumstances corrosion can be induced on the passive reinforcement, especially if chlorides contaminate the concrete, even at levels in themselves too low to initiate pitting corrosion. A few cases have been documented [8, 9].
>
> **9.1 DC Stray Current**
>
> Consequences of DC stray current in reinforced concrete vary, depending on the properties of the concrete (alkaline, carbonated or contaminated by chlorides), the duration of the current circulation and the current density. It is therefore necessary to distinguish concrete structures noncontaminated by chlorides and noncarbonated from those contaminated by chlorides in quantities insufficient to initiate corrosion and, finally, from those that already have corroding rebars due to chlorides or carbonation.

Chapter 9.1 of the handbook discusses in **greater technical detail how DC stray current corrodes reinforced concrete**. One of the reference sources cited in this section is a 2010 NACE International paper Stray-Current-Induced Corrosion in Reinforced and Prestressed Structures. It is not available through interlibrary loan but is available for purchase from NACE.

## U.S. General Accounting Office (GAO)

A 2008 GAO report addressed right-of-way issues associated with HVDC transmission lines. The authors identified a risk "associated with siting HVDC electric transmission lines along active transportation ROW … Stray current could interfere with railroad signaling systems and highway traffic operations, and accelerate pipeline corrosion, resulting in accidents." [4]

## Effects of Stray Current Corrosion on Pipelines

### Argonne National Laboratory

**Argonne National Laboratory** is a non-profit science and engineering research laboratory operated by the University of Chicago for the Department of Energy. A 2008 technical memorandum discussed the design, construction, and operation of long-distance high-voltage electricity transmission technologies. See relevant excerpts below from page 54. [2]

- "When 'metallic return,' that is, a separate conductor not used to carry power, is used, HVDC power transmission does not produce ground currents or any attendant concerns."
- "When the current return is through the **ground**, however, the current path between grounding installations of HVDC converter substations lies through the whole thickness of the Earth, while environmental impacts are limited to the moderate area near grounding installations. If, however, there is an available buried conductor, such as a pipeline, current will return through this conductor. **This return path presents a danger to buried metal infrastructure through electrocorrosion. The degree of corrosion depends on the quality of electrical insulation and the effectiveness of the means of electrical corrosion control used with the metal infrastructure present, as well as on the amount of current passing through the object.**"
- "Cathodic protection of **buried pipelines or other underground metal objects near the grounding installation** might be needed to prevent rapid corrosion of this infrastructure."

### ASM

**ASM International**, formerly known as the American Society for Metals, is a professional organization for materials engineers. Their multi-volume *ASM Handbook* is considered a comprehensive and definitive series of reference books with data on various metals. The information excerpted below is from Volume 13C on Corrosion: Environments and Industries. [7]

- "Corrosion of underground pipelines can be accelerated by stray dc flowing in the soil near the pipeline. Sources of direct electrical current include foreign pipelines that are not properly bonded to the pipeline and ground currents from dc sources. Electrified railroads, mining operations, and other similar industries that utilize large amounts of dc sometimes allow a significant portion of current to use a ground path return to their power sources. These currents often utilize pipelines in close proximity as a part of the return path. This 'stray' current can be picked up by the pipeline and discharged back into the soil at some distance down the pipeline close to the current return. Current pickup on the pipe is the same process as cathodic protection, which tends to mitigate corrosion. The process of discharge of a dc off the pipe and through the soil accelerates corrosion of the pipe wall at the discharge point, causing stray current corrosion. The morphology of stray current corrosion tends to be very localized at holidays (defects or holes) in the pipeline coating. Rates of attack can be very high, resulting in rapid perforation of a pipeline."

## ASTM

**ASTM International**, formerly known as the American Society for Testing and Materials, is a technical standards organization. Chapter 5 of their *Manual of Industrial Corrosion Standards and Control* addresses stray current. See relevant excerpts below. [6]

- "No matter what the source of the stray direct current may be, there is no damage, normally, where the current is picked up from the earth by the pipeline, but where this same current is discharged back to earth to continue its journey to its source, corrosion attack does occur."
- "Direct-current transmission lines (known as HVDC systems) involve an additional source of possible stray current corrosion on pipeline systems. Under present concepts, HVDC systems involve transmission of bulk electric power between terminals which may be several hundred miles apart. At each of the terminals there is a high-capacity grounding electrode through which unbalanced system current can flow to or from the earth. Under conditions of unbalance on the HVDC lines, the magnitude of this unbalance current can be quite great, and it will be flowing, as stray current, through the earth along the possibly several-hundred-mile-long path between terminals. The worst condition develops during operation of the HVDC system under emergency conditions with one overhead conductor completely inoperative; full load current then flows through the earth path and through the remaining overhead conductor. Pipeline systems in the vicinity of the terminals will be subject to possible stray current pickup or discharge, depending on the nature of the HVDC transmission line unbalance condition. With improperly designed terminal equipment, or for pipeline systems located too close to HVDC system terminals, pipeline corrosion can be severe. Although the use of HVDC electric transmission systems is presently quite limited, the concept involved is getting greater acceptance with time, and interference from this type of system may ultimately become more prevalent."
- "Installation of HVDC terminal grounds should be located a sufficient distance from the nearest pipeline systems to minimize the amount of stray-current pickup by the pipelines, assuming that the terminal ground is properly designed."

## NACE International

**NACE International**, also known as the Corrosion Society and formerly known as the National Association of Corrosion Engineers, is a professional organization for corrosion control professionals. Their website maintains a Corrosion Wiki (see excerpts for stray current corrosion below). [3]

- "Stray currents which cause corrosion may originate from **direct-current distribution lines**, substations, or street railway systems, etc., and flow into a pipe system or other steel structure. Alternating currents very rarely cause corrosion. The corrosion resulting from stray currents (external sources) is similar to that from galvanic cells (which generate their own current) but different remedial measures may be indicated. In the electrolyte and at the metal-electrolyte interfaces, chemical and electrical reactions occur and are the same as those in the galvanic cell; specifically, the corroding metal is again considered to be the anode from which current leaves to flow to the cathode. **Soil and water characteristics affect the corrosion rate** in the same manner as with galvanic-type corrosion."
- "However, **stray current strengths** may be **much higher** than those produced by galvanic cells and, as a consequence, **corrosion may be much more rapid**. Another

difference between galvanic-type currents and stray currents is that the latter are more likely to operate over long distances since the anode and cathode are more likely to be remotely separated from one another. Seeking the path of least resistance, the stray current from a foreign installation **may travel along a pipeline causing severe corrosion where it leaves the line**. Knowing when stray currents are present becomes highly important when remedial measures are undertaken since a simple sacrificial anode system is likely to be ineffectual in preventing corrosion under such circumstances."

## ORNL

**Oak Ridge National Laboratory** is science and technology laboratory managed by UT-Battelle, LLC for the U.S. Department of Energy. In 1997, they published a technical report on the siting and design of HVDC power transmission electrodes. See relevant excerpts below. [9]

- "HVDC transmission lines injecting current into the soil through their ground electrode(s) are a source of stray current interference. Any buried electrically conducted structure can be affected by stray current with the current entering and exiting at one or more locations. Typical structures which may be affected are Telecommunication and CATV cables; Coaxial and fiber optic cables; Concentric cable neutrals; Structure reinforcing bars; Metallic support hardware; Grounding systems; Power system tower footings; Water, sewer, or communication systems; and Buried pipelines."
- "HVDC transmission lines are a cause of ground current injection when operated in the monopolar or unbalanced bipolar modes. Monopolar mode transmission lines inject the total load current into the ground electrode one hundred per cent of the time … Disruptive effects to equipments are generally proportional to the instantaneous injected current. However, corrosion effects are proportional to the time integration of the injected current. For example, corrosion of a steel structure progresses at the rate of 20 pounds metal loss per amp-year of interference current leaving the structure, i.e., one amp of current for ten years is equivalent to ten amps of current for one year."
- "The spatial electric field developed as a result of the flow of current into the system electrodes, and therefore, into the earth is an important factor in determining the disruptive and corrosive effects to an object or structure attributable to the collocated dc transmission line. The extent of such effects is dependent upon the magnitude and direction of the electric field at the location of each collocated buried facility. Affected facilities and systems can include telecommunication and CATV cable, electric power transmission facilities such as cables, tower footings, and transformers, buried pipelines, and railroad tracks and signaling and communication systems."

## Other

### *Academic Articles*

- A 1999 article in an environmental studies journal discusses the pollution effects of stray current corrosion. The author states that "minimizing the hazardous interaction of stray currents connected with the functioning of a monopolar HVDC power line is based on application of earth (marine) electrodes of possibly low resistance. For the above reason they have large dimensions and they are located in an environment of low resistance. Bipolar systems should be used in such a way so that leakage of equalizing currents to the ground does not occur." [5]

- A 2003 conference paper advises that "if there are pipelines or other underground metal objects near the grounding installation, it is recommended that additional cathodic protection of such objects be provided to allow prevent rapid corrosion." [13]

### *Standards*

- There is a **British standard** related to this topic - Protection against corrosion by stray current from direct current systems (BS EN 50162:2004) The standard "specifies the general principles to be adopted to minimize the effects of stray current corrosion caused by direct-current (d.c.) on buried or immersed metal structures." [*Note: Full-text not available without purchasing or obtaining through interlibrary loan*]. [12]

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