Earth Reinforcement Practice, Ochiai, Hayashi & Otani (eds) © *1992 Balkema, Rotterdam. ISBN 90 5410 093 1*

Twenty five years of corrosion control in Reinforced Earth structures

M.J. Bastick
La Terre Armée, France

J.-M. Jailloux
Terre Armée Internationale, France

ABSTRACT: Long term performance of civil engineering structures as well as their maintenance during their expected service life is a key element for the choice of a good and cost effective solution. Reinforced Earth behaviour is largely dependant on the durability of the reinforcing strips. Research programs conducted by the Reinforced Earth group are presented with their main results. Practical guidances to a conception of the Reinforced Earth structures leading to a long life expectancy are given along with the main lines of the effective maintenance program conceived with and presently used by the Ministry of Tranportation in France.

1 INTRODUCTION

During the past twenty-five years Reinforced Earth has been used extensively throughout the world. All but a few exceptions of these structures make use of galvanized steel strips for the reinforcement. The possible degradation of these strips through corrosion is a concern which has been assessed already in the early days of the technique and gave the impulse for a long and thorough in-house research program. Although many data and theoretical developments concerning corrosion are available, and although other civil engineering techniques such as steel culverts or sheet piles use steel in contact with soils it was found that research on the specific case of Reinforced Earth where the metal is completely buried in a selected fill needed more research. Design offices of the Reinforced Earth group specialised in the technique integrate the concern by using specific design details prone to increase the life span of the structures.

The purpose of this article is to present some of the results of the research done and show how it is integrated by our design offices into the conception and the maintenance of the nearly 20,000 Reinforced Earth structures erected in the world to which about 2,000 are added each year.

2 SUMMARY OF RESEARCH

Since 1970, Terre Armée Internationale has been pursuing its own programme of research aimed at confirming prior findings and carrying investigations further forward.

Three main lines of experimentation are being simultaneously pursued :

1. Box tests: a reference framework was provided by placing strip samples in boxes filled with selected soils which are kept in conditions identical to real backfills. Samples are removed and weighed at regular intervals.
2. Laboratory tests: the same soils, and many others, were placed together with strip samples in a total of 200 electro-chemical cells developed specifically for this study where periodic measurements are made of instantaneous currents of corrosion. Faraday's law is then applied to calculate the corresponding metal loss. Such measurements have been going on for more than twelve years, agreeing well with the reference test findings.
3. Full scale tests: a 6 meter high experimental wall was brought to failure to study the effect of corosion. Lengths of strip or durability samples are removed from structures currently in service and here, too, average loss of thickness is measured.

The results have been regularly published.

The main findings are :

1- the rate of corrosion depends mainly on the value of five parameters:

- water content; soil water contains the salts and constitutes the electrolyte;
- resistivity of soil, measured at saturation, gives a figure in relation with the total amount of salts present in the soil,
- pH, that governs the solubility of corrosion by-products and thus the build up of protective layers around the buried metal,
- chloride content, the most common aggressive salt, and
- sulphate content.

2- the behaviour law of corrosion of galvanized steel can be defined by the equation (I) $P = A T^n$, where P is the average thickness-loss of metal (zinc plus iron) for one side, A is a coefficient depending on the aggressivity of the soil, T is the time, and n is an exponent to be smaller than one. This means that the corrosion rate of galvanized steel in soil decreases with time This is due to the build-up of a protective layer made of corrosion by-products and particles of soil.

For the whole range of common soils, it is possible to establish an envelope curve of experimental curves and site investigation results (figure 1). This envelope is defined with A = 25 µm/year and n = 0.65.

Previous research as the one conducted by Romanoff, perfectly confirm these findings. The common soils, when used for out of water structures, comply with the following criteria:

Resistivity (Saturated state)	> 1000 Ω.cm
pH	between 5 and 10
Chlorides	< 200 mg/kg
Sulphates	< 1000 mg/kg

These limits are the most widely accepted specifications for Reinforced Earth structures construction. In France they have been defined in a standard document NF A 05-252 issued in July 1990. It presents also the required sacrificial thickness for usual service life to be deducted in the design from the actual reinforcing strip thickness.

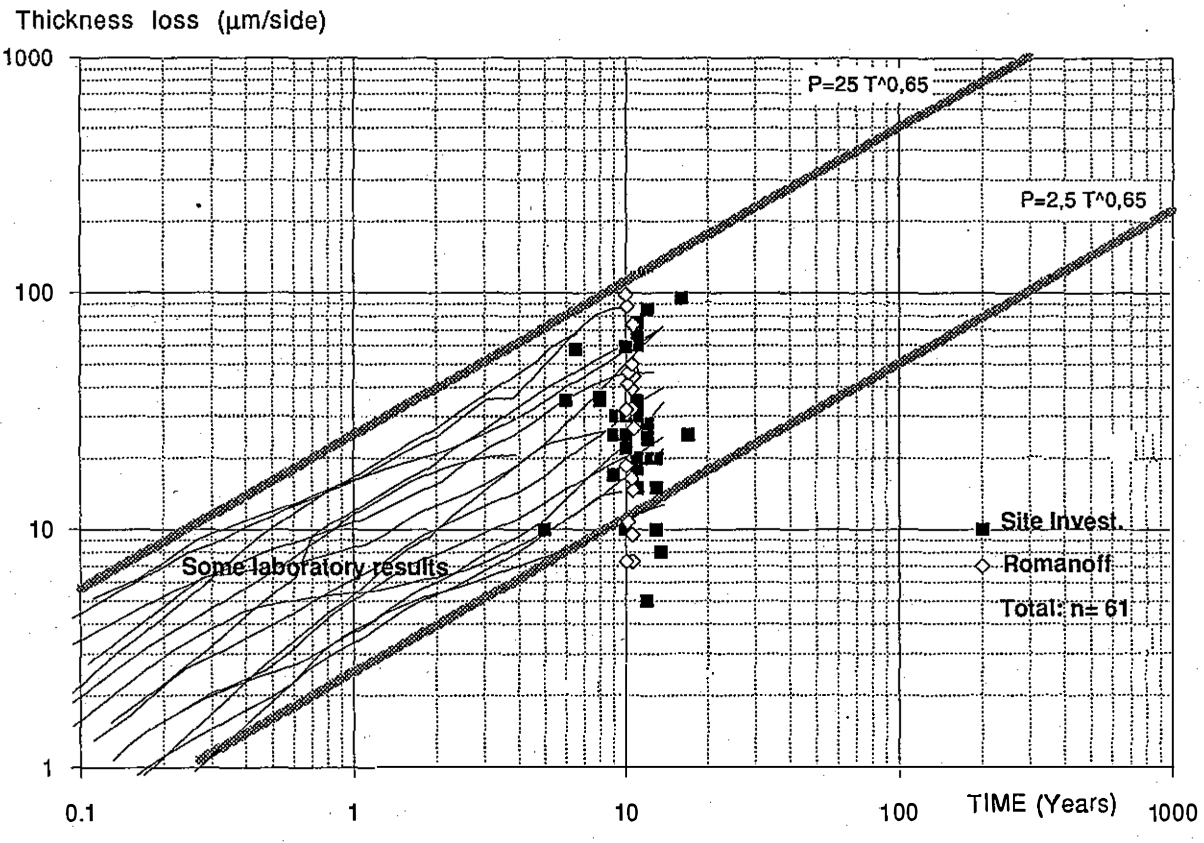

Fig. 1 Corrosion of galvanized steel in soils complying with standard. Summary of results

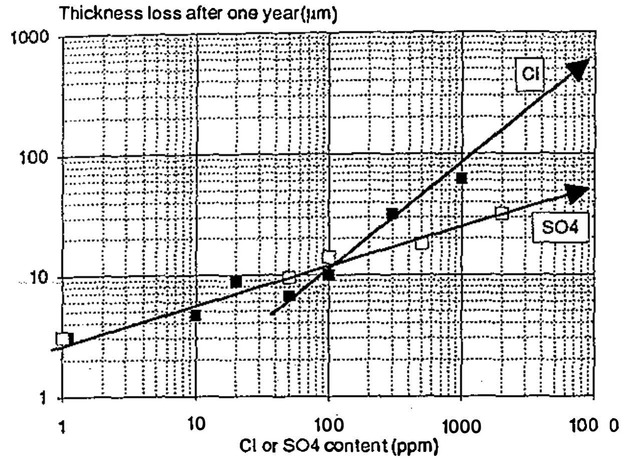

Fig.2 Effect of chloride and sulphate on corrosion of galvanized steel after 1 year.

Table 1: Comparison of thickness losses (µm).

Time (year)	Number of samples	Average loss per side (Zn+Fe)	
		Calculated	Actual
2	12	188	250
3	15	245	245
4	22	295	297
6	21	385	392
8		464	N.A.

3 INFLUENCE OF CHLORIDE AND SULPHATE

It is interesting to know how the kinetics is governed beyond these limits, and particularly in soils containing large quantities of chlorides and sulphates.

Clean sand in which salts were added to obtain predetermined chloride or sulphate contents, was used to specifically study the influence of these parameters. The figure 2 shows the loss of thickness of galvanized steel obtained after one year (these will be in fact the different "A" inputs of the relation (I) above) for increasing amount of salt.

Below 100 ppm, chloride and sulphate contents display similar aggressiveness. For contents greater than 100 ppm, chloride proves to be more aggressive than sulphate. The apparent linear relationship (in the log scales) between salt content and corrosion can be translated in the following equations:

(II) $A_{Cl} = 0.21 [Cl^-]^{0.86}$

(III) $A_{SO4} = 2.74 [SO_4^{--}]^{0.32}$

Doubling the chloride and the sulphate increases corrosion by a factor of respectively 1.8 and 1.25. When a combination of both ion species occurs, we assume an additive effect, hence:

(IV) $A = A_{Cl} + A_{SO4}$ and finally

(V) $P = (0.21 [Cl^-]^{0.86} + 2.74 [SO_4^{--}]^{0.32}) T^{0.65}$

4 APPLICATION FOR PREDICTING CORROSION IN AGGRESSIVE SOILS

A structure, called Tweepad in South Africa, was built using a very aggressive backfill. After analysing numerous soil samples from the site, it turned out that the average chloride content was 1338 ppm and the average sulphate content was 584 ppm. Taking the effect of each anion we find that after one year the average loss of thickness (one side) would be around 100 µm due to the chlorides and around 20 µm due to the sulphates. The total being 120 µm after one year.

Hence for this "average" soil, the behaviour of galvanized steel would be expressed by:

$P = 120 * T^{0.65}$. The samples taken in the structure were accurately weighed after removing of all corrosion by-products. This allowed to estimate the average loss of thickness. Comparison of the actual values and the theoretical values is tabulated below in which the calculated and actual values are in a remarkable agreement.

Another set of results was provided by two other actual cases. One concerned retaining walls in Saverne, east of France, where soil was locally contaminated by de-icing salts entering the Reinforced Earth mass through defects in the drainage system.

The last case took place in Arabic peninsula where an abutment was backfilled with a soil containing too much salts. In both cases high corrosion rates induced by high chloride content was however found to be in accordance with estimates computed as described above.

The formula (V) is thus confirmed by these unintentional experiments. It is useful for estimating the rate of corrosion of galvanized steel in soils that contain more than 100 mg of chloride or sulphate per kg of soil, and for non-saturated conditions.

5 DESIGN DETAILS AND DURABILITY OF STRUCTURES

While the mechanical performances, the safety, and the behaviour of a Reinforced Earth structure is mainly assessed through computations during the design phase, long term performances are much more dependant on a judicious choice of construction details.

5.1 Backfill

Choice of backfill is essential and chemical criteria for use in Reinforced Earth have been detailed above. Long term behaviour of the structure is however dependant not only on the backfill characteristics at the time of erection but on its possible evolution in time. For this reason it is very important to ensure that no detrimental chemicals, such as water contaminated by de-icing salts, will permeate through the reinforced soil mass. This can be adequately achieved by a good drainage system and, if needed, the placement of an impervious membrane layer where de-icing salts infiltration is to be feared or expected.

5.2 Drainage

Water content was shown to accelerate corrosion. It is therefore very important to control the water flows and keep them out of the structures with a drainage system. Also, as it is the case for nearly all geotechnical structures or problems a good drainage is very often a highly desirable situation from the point of view of the structure stability.

5.3 Impervious membrane

All the Reinforced Earth structures located under a road in a cold climate surrounding where there is a risk of permeation of water contaminated with de-icing salts are protected against such an eventuality by an impervious membrane. This membrane is normally supplied by the Reinforced Earth company to ensure compliance with specifications. These specifications on mechanical and permeability characteristics were determined through a series of in situ tests where samples where put in place within different types of backfills, compacted, extracted and then tested for imperviousness. These test showed that a membrane alone could not resist puncture by coarse aggregates and led to the choice of a composite made out of a PVC membrane 1 millimeter thick (minimum) bonded to a puncture resistant non-woven geotextile.

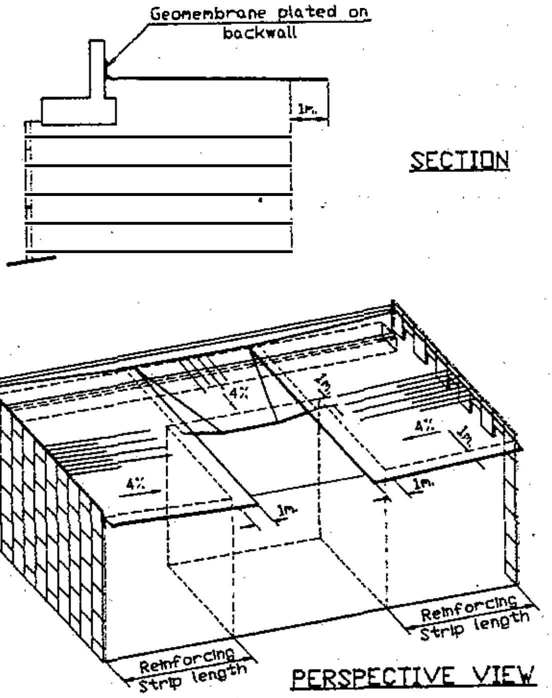

Fig. 3 Waterproofing of a Reinforced Earth abutment and return walls

The placement of this membrane should be studied carefully so that water collected is effectively led away from the Reinforced Earth mass. Figure 3 shows typical solutions for usual structures.

5.4 Case of stray currents

Reinforced Earth has been widely used for structures adjacent or above railway lines. Most railway systems make use of electric power, the current being fed to the engine either through an overhead catenary line or through a third rail and returning to the power station through the rails. In most cases the insulation between rails and soil is not perfect and part of the current travels through the ground in form of stray currents. When such stray current goes through a steel member, rapid corrosion will appear at the point where it leaves the metal. In case of Reinforced Earth structures located near a railway line, such corrosion can be avoided

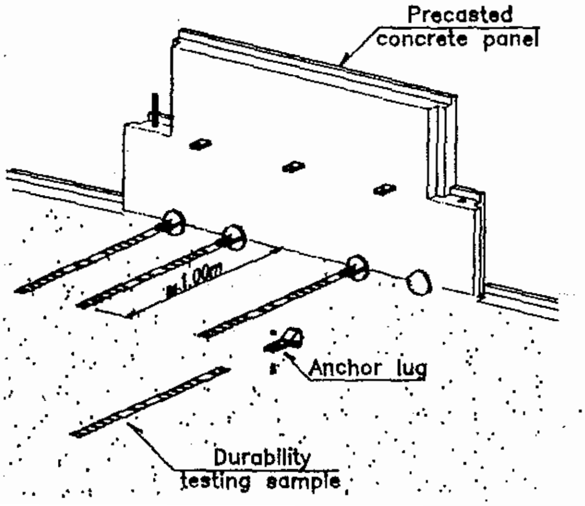

Fig. 4 Installation of durability testing samples

by simple yet effective design dispositions. Resistivity of the Reinforced Earth backfill in dry conditions is generally much larger than the one of the surrounding soils which will tend to attract the current. Hence it is very important to prevent water to enter the reinforced mass as this would lower the fill resistivity. Strips are very often perpendicular to the main direction of the stray currents and always very short in relation with their total path. It is important to keep it that way and especially to avoid any contact between strips. In some cases insulation membranes can be placed to cut any potential stray current path and keep it out of the reinforced mass.

6 STRUCTURE MAINTENANCE AND FOLLOW-UP

The durability of a Reinforced Earth structure can benefit from a good maintenance program. For this reason maintenance procedures have been written jointly by the Reinforced Earth company and the French administration. Similar guides are available in other countries.

6.1 Description of durability samples

Special facing elements incorporating durability samples are provided in each structure at the design stage. In the most common case of a vertical concrete facing the elements are shown in figure 4. The durability samples are made out of a standard reinforcing strip taken from the stock of finish product which will be used for the structure. The strip is then cut in one meter pieces. One of these pieces will be used to make a full set of tests to precisely identify the characteristics of the strip (and of the durability sample) in its original state. If the strip piece is galvanized, thickness of zinc coating is measured by dissolution and in all cases a tensile rupture test is performed. A minimum of two such panels or eight durability samples is installed in each structure, their number being increased for large structures. Care is taken in the design phase to position these samples in the most unfavourable location i.e. below a low point of the road vertical alignment or where incoming water or deficient drainage is to be feared.

6.2 Monitoring of structures

Like any other type of civil engineering structure Reinforced Earth structures should be visited regularly and maintained. Programs should emphasise the regular maintenance of the drainage system. Corrosion is monitored through the durability sample described above. A first sample (or series of sample when the structure includes more than eight) is retrieved after 10 years and other samples are normally retrieved every 15 years.

6.3 Analysis of results

When each sample is taken out of the structure it is brushed clean and weighted. The remaining zinc metal is dissolved in a solution of hydrochloric acid and antimony chloride. The weight of the sample after dissolution and drying compared with its weight before dissolution and the weight which was recorded when the sample was placed in the Reinforced Earth mass permit the computation of the loss of zinc, the loss of base steel, and the global loss of thickness. The loss of thickness is then plotted on a graph such as the one represented figure 5 where lines represent the expected loss of thickness versus time in a Log-Log scale.

Three cases may arise depending on the position of the representative point of the loss of thickness of the considered sample.

It may fall in:

- the region located below the lower line (Zone I). In this case corrosion is slower than

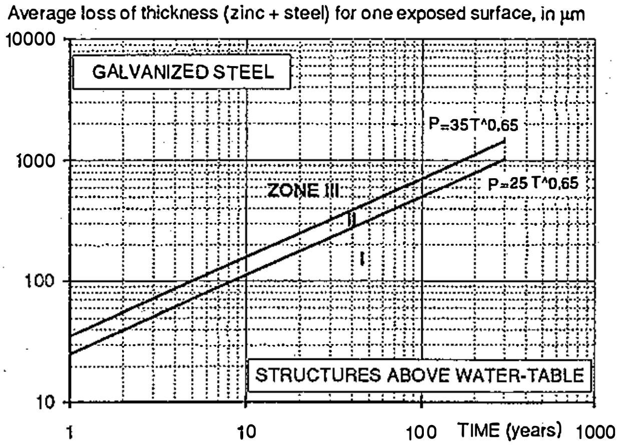

Fig. 5 SETRA chart for durability control

expected probably because the backfill was within the specifications. The better the fill (lower resistivity, lower chloride and sulphate content) and the dryer, the better will be the durability of the structure and the lower the representative point. In such a case the next sample should not be retrieved to soon (not before 15 years) and the service life of the structure may eventually be increased,

- the region located between the two lines (Zone II). In such a case the corrosion is slightly less or at most equal to what was expected. The next sample should be retrieved 15 years later,
- the uncommon event of a representative point located above the upper line (Zone III) is an indication that corrosion is progressing in the structure at a faster pace than anticipated. In such a case other samples will be retrieved earlier than usual (less than 15 years), a specific study may be necessary and remedial action should be taken.

6.4 Remedial actions

The repair of a Reinforced Earth structure suffering from corrosion may be done easily with soil nailing. It would however be a severe mistake to think readily of repairs when a durability sample shows a corrosion rate higher than expected. Indeed this increased corrosion rate is very likely to be linked either to bad drainage (in which case the rate should be close to the one in fresh water conditions) or to an income of de-icing salts. In both cases a repair of the drainage system (culvert, channels, pipes) or the addition of an impervious geomembrane is very likely to solve the problem for a minimal cost. Provided the correction has been efficient, water content of the soil will drop and so will the corrosion rate.

7 CONCLUSIONS

Extensive research programs spanning over a period of more than fifteen years contributed largely to our understanding of the long term behaviour of galvanized steel in buried condition. The controlling parameters are now well known and long term performance of Reinforced Earth structures using galvanized steel strips can be assessed with a very high standard of confidence.

Although the phenomenons involved, the corresponding research and the governing laws may be quite complex, we insisted on the fact that the adoption of appropriate specific design details is essential to the long term behaviour of the structures. Monitoring and maintenance programmes are not difficult to implement since corrosion test samples are systematically incorporated to the structures. Yet they may trigger simple remedial actions (mainly on the drainage system) which, for a very minimal cost, proved to be very effective.

REFERENCES

Darbin M., Jailloux J-M., Montuelle J. 1988. Durability of Reinforced Earth.structures : the results of a long-term study conducted on galvanized steel *Proc. Instn Civ. Engrs*, Part 1, 84, Oct., 1029-1057

Jailloux J-M. 1989. Durability of materials in soil reinforcement applications. *Proc. 9th European Congress on Corrosion: TR-086.* Utrecht