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An experimental study of the corrosion of metal reinforcing elements in soil

Etude expérimentale de la corrosion des armatures métalliques dans les sols

RÉSUMÉ

Ce rapport décrit une étude effectuée au Transport et Road Research Laboratory sur le comportement à la corrosion d'une gamme de métaux pouvant servir d'éléments d'armature dans les structures en terre armée. On a placé des échantillons de cinq métaux différents dans des remblais et des fossés construits dans deux sols très dissemblables, sélection nés selon les critères existants pour déterminer l'agressivité du sol envers les métaux enterrés. Les sols choisis étaient une argile grasse (sol agressif) et un sable de granulométrie uniforme (sol non-agressif). Les métaux étudiés etaient deux types d'acier inoxydable (austénitique et ferritique), un acier doux galvanisé, un alliage d'aluminium et un acier doux recouvert d'aluminium.

Après une période d'exposition de deux ans, les premiers résultats de cette étude ont montré que les deux types d'acier inoxydable n'avaient pas été attaqués ni dans l'un ni dans l'autre type de sol. Les couches protectrices de zinc et d'aluminium sur les échantillons d'acier doux on subi une certaine perte et les résultats suggèrent que, admettant que la vitesse de la corrosion soit linéaire, ces couches seraient complètement détruites en moins de vingtans, ce qui est la durée de vie de projet utilisée en Angleterre pour les structures en terre armée. Quoique l'on n'observe qu'un faible degre de corrosion générale sur les échantillons d'alliage d'aluminium, la plupart des échantillons présentait des traces considérables de piquage.

En général, l'attaque de la corrosion sur tous les spécimens était semblable dans les deux types de sol, apparemment très différents et les résultats indiquent qu'il serait peut-être nécessaire d'évaluer l'agressivité du sol avec des techniques plus raffineés.

INTRODUCTION

The potential corrosion hazard of the buried metal reinforcing elements in reinforced earth structures is the subject of extensive research effort in progress at the Transport and Road Research Laboratory and the University of Manchester Institute of Science and Technology. A preliminary review(1) of the corrosion of metal buried in soil has highlighted the lack of factual data on this topic and has lead to the present experimental study. A range of potential types of metal reinforcing element were installed in two widely differing soils - classified as aggressive and non-agressive - to allow rates of corrosion of the different metal samples to be monitored in these extreme conditions.

MATERIALS EMPLOYED IN THE STUDY

Selection of soils

Two soils were selected such that, on the basis of the classification system for defining soil aggressivity (Table 1) proposed by the National Physical Laboratory (NPL) (2), one was classified as aggressive (heavy clay) and the other non-agressive (uniformly graded sand).

As shown in Table 1, the classification involves a measure of soil resistivity which indicates the possibility of oxidative corrosion. The determination of redox potential provides a means of assessing whether a soil is susceptible to the activity of sulphate reducing bacteria.

Selection of metals

The metals chosen for the study (Table 2) were considered to comply most closely with the requirements for the reinforcing elements in a reinforced earth structure - namely high tensile strength, reasonable corrosion resistance and relatively low cost.

As shown in Table 2, a coating rate of 610 gm/m^2 was employed for galvanising the mild steel. Normally a coating rate of 1000 gm/m^2 is required for reinforcing elements but it was considered that the lower rate would provide an adequate thickness for assessing the behaviour in view of the short duration of the study (approximately seven years).

TABLE 1

Properties of the soils selected for the study in relation to the NPL classification system

Soil Test \ Classification	Limits of aggressive soils	Properties of agressive soil selected (Heavy clay)	Limits of non-aggressive soils	Properties of non-aggressive soil selected (Uniformly graded sand)
Resistivity (ohm-cm)	< 2000	1156	> 2000	30400
Redox potential at pH = 7 (volts) (normal hydrogen electrode)	< 0.400 < 0.430 if clay	0.263	> 0.400 > 0.430 if clay	0.520
Boderline cases resolved by moisture content (per cent)	> 20	28.5	< 20	12.1

TABLE 2

Metals selected for the study

Metal	Description	Proof stress (N/mm^2)
Stainless steel type 316 S 16, CR	Austenitic B.S. 1449: 1975	0.2% > 400
Stainless steel type 434 S 19	Ferritic B.S. 1449: 1975	0.2% > 250
Galvanised steel	Grade 43/25 steel. Hot dipped galvanised with a zinc coating > 610 gm/m^2 B.S . 729: 1971	0.2% > 245
Aluminium alloy	Grade NS8 in H2 condition B.S. 1470: 1972	0.2% > 235
Aluminium-coated steel	Grade CR4 steel coated with 99.7% pure aluminium. Coating rate 200-250 gm/m^2 (including both sides). B.S. 1449: Pt1:1972	0.5% > 140

Preparation of test specimens: A total of 500 specimens were prepared which corresponded to 100 specimens of each metal type. The dimensions of the specimens were approximately 200mm in length by 600mm wide with thicknesses of up to 3mm. The overall dimensions of the samples were determined to within 0.1mm and their weight established to within 0.01 gm (at least 0.01 per cent). Prior to weighing, two holes each of 2mm diameter were drilled in the specimens to provide a coding system for subsequent identification. The aluminium-coated steel samples were excluded from this method of identification as they were already protectively coated with aluminium which would have been damaged in the drilling operation. The method of identifying these specimens was based on their location at the time of recovery. The mild steel specimens to be zinc-coated were drilled prior to hot dip galvanising.

DETAILS OF THE TEST LOCATIONS AND EXPERIMENTAL PROCEDURES

Installation of specimens

To represent a reinforced earth structure, a 3m high embankment was constructed from the heavy (London) clay and the uniformly-graded sand as shown in Fig. 1.

To provide information on the influence of water-table fluctuations on corrosion rates, two pits were excavated below the natural ground surface and back-filled with the same two soils (Fig. 1).

During the filling operations in both the embankments and the pits, the soils were compacted in 125mm thick compacted layers by at least three passes of a vibro tamper according to the Department of Transport's specification for road and bridge works(3). The metal specimens were placed on compated layers at 500mm vertical intervals and arranged such that each vertical profile contained only the same type of metal. The horizontal spacing between vertical profiles was maintained at 400mm and to prevent interaction of the two different soil types, specimens were excluded from the central region of the embankment where the two soils abutted. (see Fig. 1 and Plate 1).

The installation of the specimens was completed in the Spring of 1976. It was proposed to remove profiles of five specimens of each metal type from each of the four locations to assess corrosion rates by weight loss and pitting at intervals over a period of about seven years.

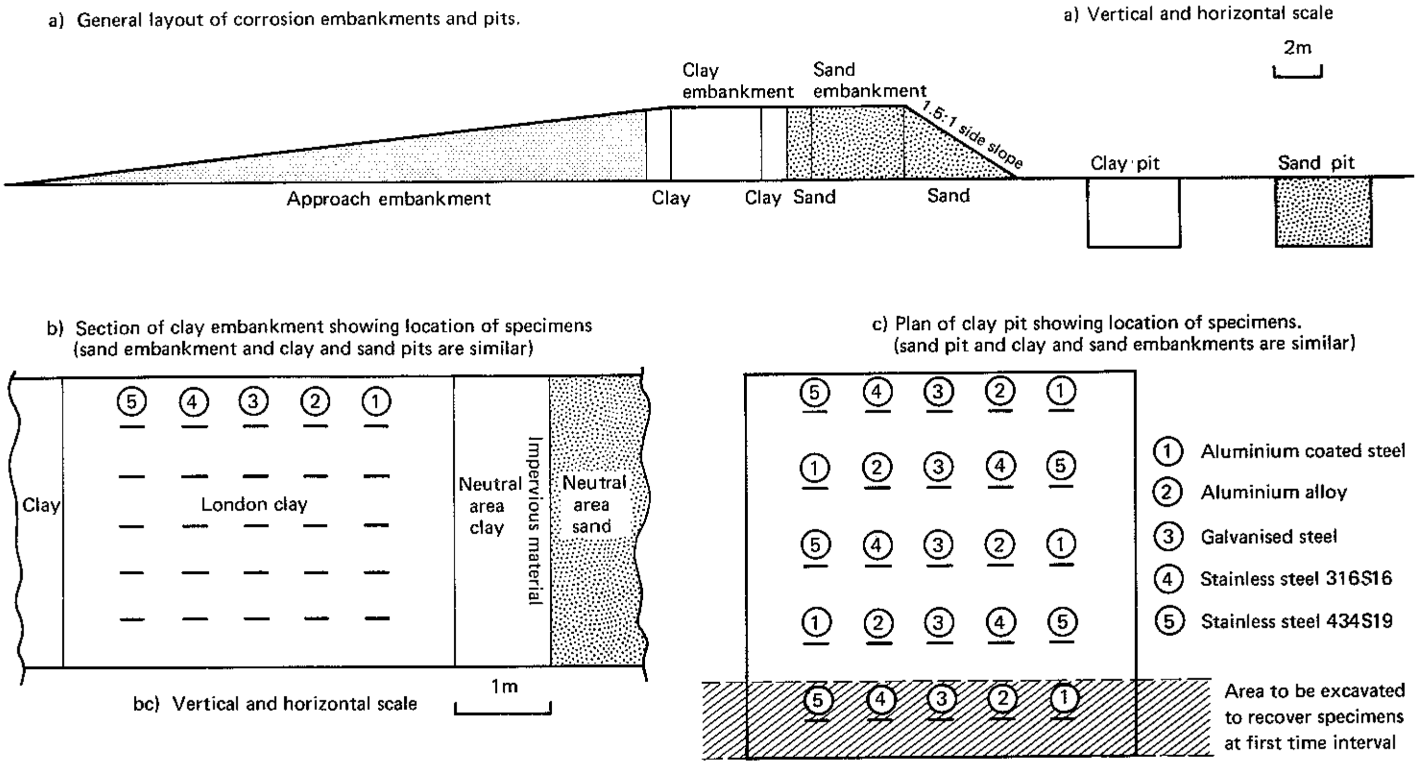

FIGURE 1. LAYOUT OF CLAY AND SAND EMBANKMENTS AND PITS SHOWING LOCATION OF CORROSION SPECIMENS.

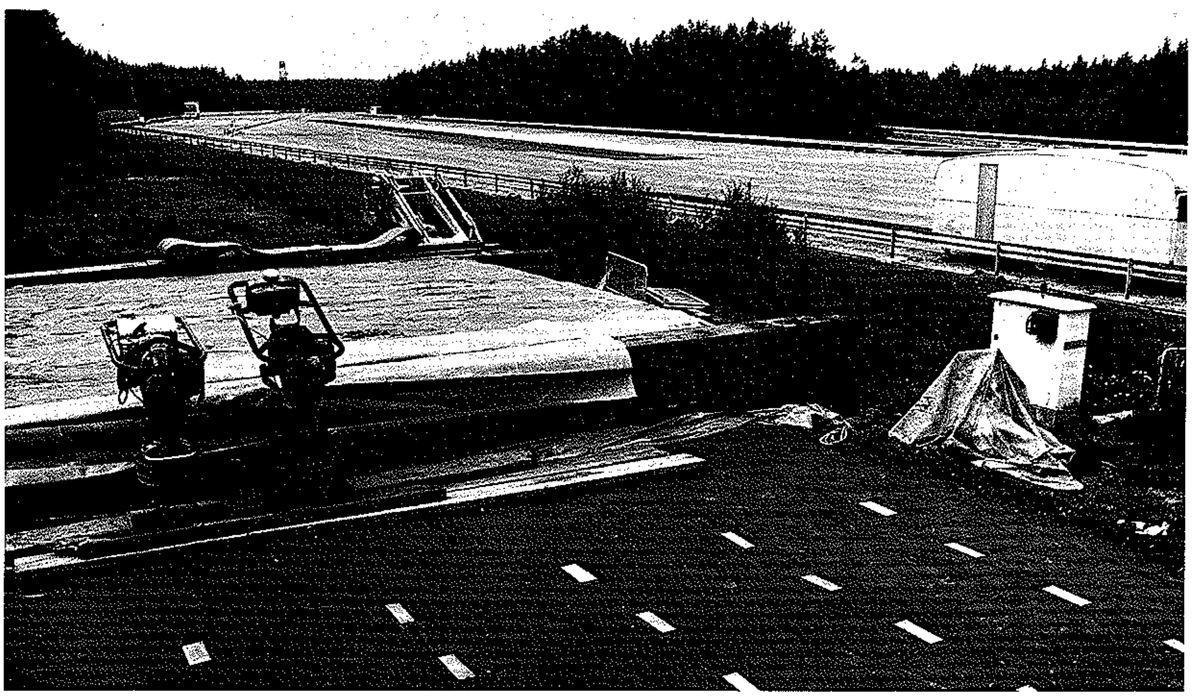

PLATE 1. LAYOUT OF SPECIMENS IN THE CLAY EMBANKMENT ALSO SHOWING THE COMPLETED SAND EMBANKMENT AND THE COMPACTION PLANT USED.

Recovery of specimens and reinstatement of trenches

The first profiles of specimens were recovered in the Spring of 1978 from the plan area shown hatched in Fig. 1 following an exposure period of about two years. After removal of the specimens, the excavated trenches were reinstated employing the same filling and compaction procedures used originally. As the stainless steel specimens had not corroded these were reinstalled in their original positions to provide additional long-term measurements of corrosion rates. To provide an indication of the corrosion resistance of mild steel, commonly employed in reinforced earth applications as the substrate material, additional samples were prepared from mild steel and installed in the reinstated trenches. A further advantage of studying the corrosion of mild steel directly, as opposed to protectively-coated mild steel eg galvanised steel, is that extensive data has been accumulated on the corrosion of this material buried in soil. These data may provide a method of calibrating the results from the present study such that longer term extrapolations may be possible. The mild steel used to prepare samples was a grade 43/25 steel (BS 1449: Pt 1: 1972) which was the base steel selected for the galvanised steel samples.

Inclusion of electrical - resistance probes. Additional to the original study, a number of electrical-resistance probes (4) were installed at each location. The probes were prepared from stainless steel, mild steel, zinc and aluminium alloy to correspond to the metal types being investigated in the main study. The object of these probes is to assess the reliability of remote monitoring of corrosion rates by comparison with the rates obtained from the buried metal specimens. A disadvantage of the resistance probes is that although they measure total metal loss, they cannot separate pitting corrosion from general corrosion.

PRELIMINARY RESULTS

A general assessment of corrosion rates following an exposure period of about two years is given in Table 3.

After a relatively short exposure time of two years the results given in Table 3 are unlikely to provide very reliable predictions of long-term corrosion rates based on extrapolations and it is not possible to reach any firm conclusions on the basis of the results obtained from the study. However, as there was no significant difference in the rates of corrosion in two apparently very different soils, the results indicate that more refined techniques may be required for assessing soil aggressiveness. A further point of interest from the study relates to the similarity between the corrosion rates in the same soil in both the embankment and below natural ground situations. This result suggests that assessments of corrosion rates made in the natural ground at source during the planning stage of a reinforced earth structure may provide a reasonable guide to performance in the completed structure.

In considering the actual performance of the various metals, both types of stainless steel showed negligible weight losses on all the specimens and no indication of any pitting attack. The aluminium alloy specimens gave low general corrosion rates on all specimens although there was evidence of extensive pitting corrosion attack on most of the specimens.

These preliminary results indicated that the strength of aluminium alloy reinforcing elements was significantly reduced and may not therefore survive the required design life of 120 years when using these soils as fill materials. The galvanised steel specimens showed no indication of pitting corrosion attack although significant general corrosion had occurred. A coating rate of 1000 gm/m^2 for galvanising steel would represent a zinc thickness of about 140mm x 10^{-3}. Assuming the present average rate of general corrosion continues, all the protective coating will be destroyed after about 35 years in these soils. It would be expected, however, that corrosion rates would decrease with increasing exposure time. Moreover, it is also usual practice to include an allowance for corrosion losses in the substrate mild steel. See, for example, the Department of Transport's technical guide to reinforced earth design and construction (5). Thus the reinforcing elements should retain an adequate reserve of strength throughout the design life.

Surprisingly, more general corrosion had occurred in the sand fills than in the clay with the aluminium-coated steel specimens. Some slight pitting attack was evident on some of the samples from all four locations. On the basis of an average rate of general corrosion, the aluminium coating thickness of about 40mm x 10^{-3} will be destroyed after about 14 years in these soils assuming a linear extrapolation of present corrosion rates. However, as with the galvanised steel, it would be expected that corrosion rates would decrease with increasing exposure time.

CONCLUSIONS

In relation to the required life of 120 years for reinforcing elements, the exposure time of only two years is very limited. However, the following preliminary conclusions were made to provide an early indication of possible problems that may arise in assessing the aggressiveness of soils in reinforced earth applications.

1. There were no significant differences in the performance of the specimens in the two, apparently very different, soils. This suggests that existing criteria for determining soil aggressiveness may be inadequate for this purpose and will require refinement.

2. The rates of corrosion were not influenced by the location of the specimens within the structure or by fluctuations in the level of the water table.

3. Corrosion rates in the same soil in both the embankment and below natural ground situations were very similar and suggest that assessments of corrosion performance made in the natural ground at source during the planning state of a reinforced earth structure may provide a reasonable guide to performance in the completed structure.

4. Both types of stainless steel showed negligible weight losses and no indication of any pitting attack on all the specimens in the two soil types.

5. Although the aluminium alloy specimens gave low general corrosion rates there was evidence of extensive pitting attack on most of the samples. The preliminary results indicate that the strength of aluminium alloy reinforcing elements may be significantly reduced within the 120 year period required for the design life of reinforced earth structure.

6. If corrosion continues at its present rate the protective coatings of zinc and aluminium on mild steel reinforcing elements will be destroyed well within 120 years in these soils. However, it would be expected that corrosion rates would decrease with increasing exposure time and the corrosion allowance on the substrate mild steel may provide sufficient reserve of strength over the remaining period after the coatings are destroyed.

ACKNOWLEDGEMENTS

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TABLE 3

Average general corrosion rates and assessment of pitting corrosion

Reinforcing element metal	Average general corrosion rate (mm x 10^{-3} per year)				Pitting corrosion
	Sand embankment	Sand pit	Clay embankment	Clay pit	All sites
Galvansied steel	3.9	2.2	5.6	4.0	Nil
Stainless steel 316S16	0.0	0.0	0.0	0.0	Nil
Stainless steel 434S19	0.0	0.0	0.0	0.0	Nil
Aluminium alloy	0.2	0.3	0.8	0.2	Extensive
Aluminium-coated steel	4.4	4.0	1.3	1.9	slight

REFERENCES

1. KING, R A. A review of soil corrosiveness with particular reference to reinforced earth. Department of the Environment, TRRL Supplementary Report 316, Crowthorne 1977 (Transport and Road Research Laboratory).

2. BOOTH, G H, A W COOPER, P M COOPER and D S WAKERLEY. Criteria of soil aggressiveness towards buried metals. I Experimental methods, II Assessment of various soils, III Verification of predicted behaviour of selected soils, Br. Corros. Jrnl. 2 May 1967, 104-118.

3. DEPARTMENT OF TRANSPORT. Specification for road and bridge works. London, 1976 (HM Stationery Office).

4. MORBE, K. Corrosion tests by electrical resistance methods. Chemische Technik. 21 155 March 1969.

5. Department of Transport, Technical Memorandum (Bridges) BE 3/78, Reinforced earth retaining walls and bridge abutments for embankments, 1978.