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The monitoring of soil reinforcements' durability: Thoughts about experience and needs

Pierre Segrestin
Terre Armée Internationale, France

ABSTRACT: Galvanized steel strips have been monitored in many real structures for 20 years, positively confirming the safety of the design procedures. This paper explains why the same requirements should also apply to steel bar mats and geosynthetics. The other topics discussed relate to the carefulness which is required when using some extrapolation methods, the relevance of creep rupture strength with regard to the allowable tensile load and why this sends back to the definition of factors of safety.

1. SUMMARY

This panelist's report is essentially about the monitoring and the prediction of the long-term performance of soil reinforcements. It is primarily based on the experience and the practice of the Terre Armee Internationale (TAI) Group of Companies and on its ongoing research.

In the first section, we will summarize how the TAI Group validates laboratory studies in the field, that is, we will present the current practice concerning the field monitoring of steel strip reinforcements. This will lead us to discuss the need for similar product-specific field testing, especially for steel grids and geosynthetic reinforcements.

In the second section, we will discuss a couple of issues regarding the validation of extrapolation theories, as well as the need for testing the characteristics of the reinforcing products which are actually relevant for design.

2. FIELD MONITORING OF GALVANIZED STEEL STRIPS

We will first describe the procedure which is used to monitor the long-term behaviour of galvanized steel strips in actual structures, and then summarize the main findings after more than 20 years of extensive experimentation.

2.1 *Monitoring procedure*

2.1.1 Purpose

The monitoring procedure consists of installing strip coupons in walls and extracting them periodically. This is at least advised for major structures and is now specified in several countries. The extraction of the coupons is usually scheduled to take place through the facing after 10, 30, 50 and 70 years.

The main purpose is to give the owner the option of making sure that everything is evolving more slowly than what was assumed for design. Should anything abnormal be revealed, enough time would be available to carry out further investigations and to decide about appropriate corrective measures. Moreover, the installation and retrieval of such strip coupons gives an opportunity to augment the data base and to further validate the theory.

2.1.2 Installation

The strip coupons are of the same type as the reinforcing strips used in the structure. Five coupons, each one metre long, are cut from the same strip, with four installed in the wall. The fifth one is used for future reference, and its breaking load and the thickness of the zinc coating are measured at the time of construction.

All strips coupons are identified, weighed and labeled before they are placed in the backfill of the

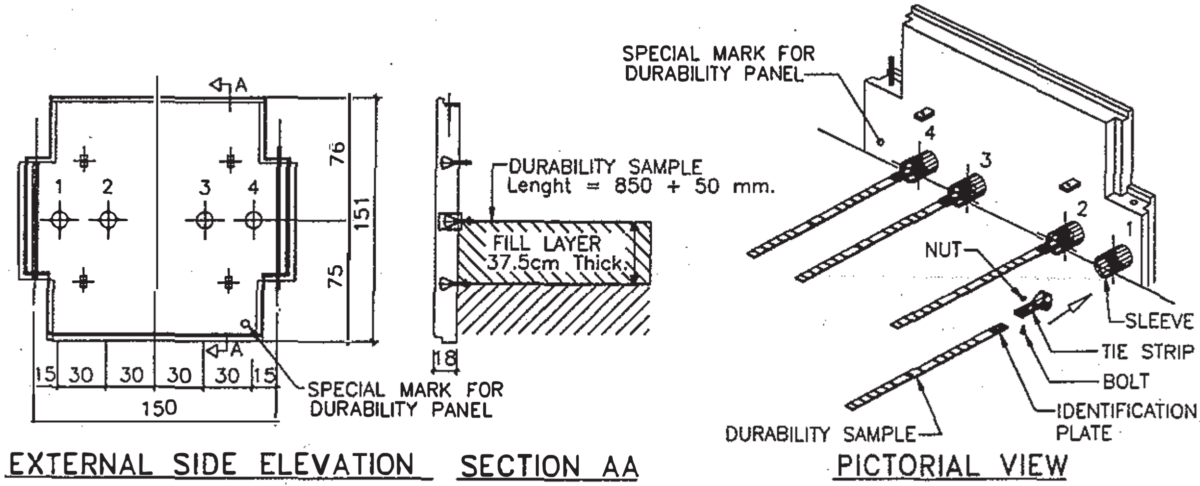

Figure 1: Installation of durability samples

Reinforced Earth structure, at the same time as the normal strips. They are equipped with tie-strips meant for future extraction and are placed perpendicular to the facing, behind sleeves made in special panels (Figure 1). These panels, located in different zones of the wall, have a discreet mark in one of their corners.

Sixteen durability samples, behind four special panels, are usually placed in a same structure, and their locations in the wall are recorded.

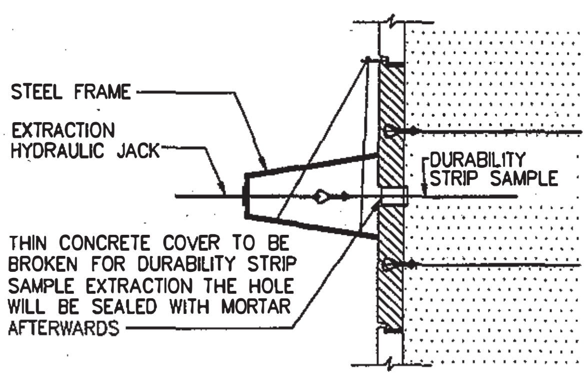

Figure 2: Extraction device

2.1.3 Retrieval

At the time of retrieval, the strip coupons are pulled-out through the facing (after breaking the concrete plug) with the help of a light extraction device placed against the panel (Figure 2). Usually four coupons are retrieved from a particular structure on the same date, one from each zone where test samples are located.

A sample of backfill is also taken in the vicinity of each test sample extracted. Care is taken to ensure that it is representative of the core of the backfill. A determination of its electro-chemical characteristics (pH, resistivity, chloride and sulfate content) is made, using appropriate testing procedure.

2.1.4 Analysis

Once extracted, the durability test samples are the subject, in the laboratory, of:

- a visual examination before and after the removal of the corrosion by-products
- the measurement of the loss of weight, equivalent to an average loss of metal thickness (zinc and steel)
- the measurement of the tensile strength. Since the initial resistance is known, the loss of resistance can be determined and correlated with the loss of steel thickness.

All manipulations, including the way the samples must be brushed, cleaned of corrosion by-products, rinsed etc... and the ways the measurements must be made and the results recorded, are described in a detailed manual.

2.2 *Findings*

Such samples have now been extracted from more than 100 walls, built with moderately aggressive backfills complying with the standards. Two thirds of these walls are 10 to 22 years old.

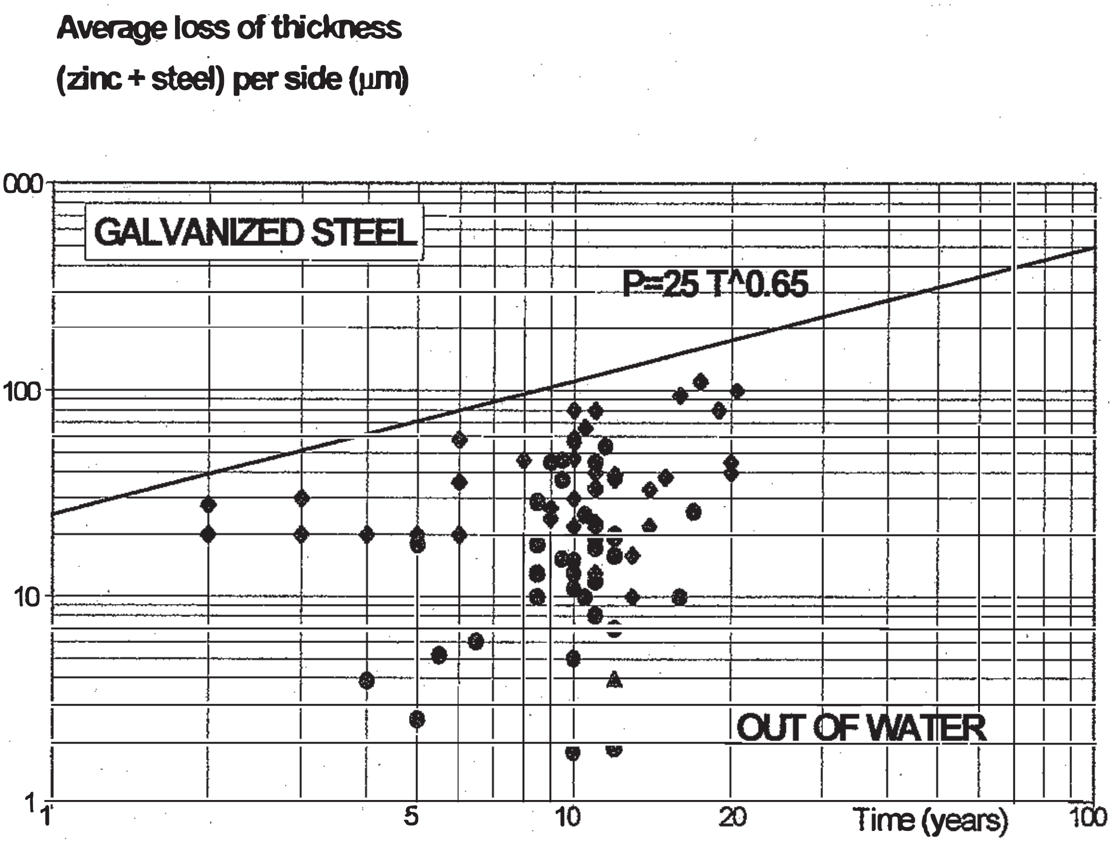

Figure 3: Results of monitoring of galvanized steel strips in actual structures

2.2.1 Loss of thickness

As the graph shows (Figure 3), in all cases the loss of thickness, represented by the dots, is well below the theoretical loss. The actual rate of corrosion is often 5 to 10 times slower.

The straight line envelope (plotted on a log-log scale) was drawn to enclose all results obtained in the laboratory, over 20 years, both from test boxes and from over 200 corrosion cells (these based on electro-chemistry techniques). The envelope, and the results shown here, represent only data obtained in soils for which the electro-chemical characteristics meet the current specifications for fill materials used in dry-land structures.

2.2.2 Loss of strength

For the coupons where steel is most corroded, the relative loss of tensile strength is found to be less than 1.7 times the relative loss of steel weight, again below the current assumptions for design.

3. FIELD MONITORING OF STEEL BAR MATS

3.1 *A product-specific issue*

We think that there is a need for collecting the same kind of information for other types of reinforcements, first for galvanized steel grids or welded bar mats made of small round bars.

It must be acknowledged that the correlation between the relative loss of strength and the relative loss of weight and, subsequently, the sacrificial thicknesses used for design, were specifically developed for flat thin strips, based on the research conducted by Terre Armee Internationale. This correlation does not apply in like manner to the round bars which are used in the mats and grids later introduced by other wall suppliers.

3.2 *The effect of local pitting*

An analysis specific to bar mats still needs to be developed. It should primarily address the question of superficial pitting. The fact is that the loss of strength is affected by local pitting, although pitting is much smaller with galvanized steel than it is with black steel.

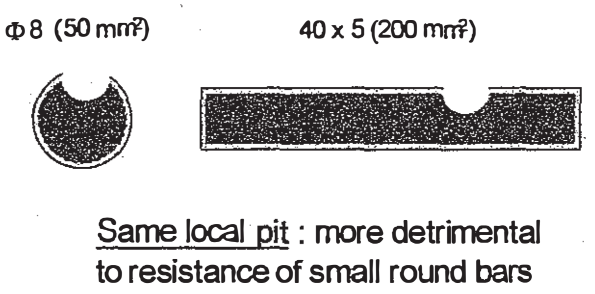

Figure 4: Effect of superficial pitting on the resistance of small round bars

Figure 4 clearly shows why the tensile strength of a small round bar such as those currently used in bar mat reinforcements, possibly 4 times smaller than a current flat strip, can be more significantly affected by a given local pit. Even if the loss of average thickness is likely to be about the same, the tensile strength of bar mats and grids made of small bars, about 8 or 10 mm in diameter, is expected to decrease more quickly than the resistance of strips about 5mm thick. This should logically result in larger sacrificial thicknesses for design for these grids.

The issue is already roughed-out, although only from a theoretical point of view, in a paper titled "Durability of galvanized steel reinforcements as a function of their shape," prepared for the Kyushu'96 Symposium by A. Smith, J.-M. Jailloux and P. Segrestin (page 151).

3.3 *The need for experimental data*

There is a clear need for more studies, which should be backed up by actual data, obtained from the monitoring of samples of grids and mats retrieved from a large enough number of existing structures.

4. FIELD MONITORING OF GEOSYNTHETIC REINFORCEMENTS

4.1 *Reasons for the monitoring*

We believe that the same policy of installing test samples in most structures should also apply to geosynthetic reinforcements, at least for structures designed for a service life in excess of 25 years. The main reason would again be to give the owner a possibility of controlling the condition of his wall.

There are important additional reasons to install test samples.

- For one, samples would permit the progressive obtaining of confirmation that the various reduction factors used in the design are still valid and conservative in the actual environment. In addition, sampling could give some insight into the question of the potential synergy among the main causes of loss of strength: construction damage, creep and environmental aging.

- Contrary to what is done with the steel coupons, however, the first retrieval of geosynthetic samples should take place right after the construction, so that the effects of the construction damages can be immediately assessed.

4.2 *Recommended procedure*

The European Standards Organization (CEN, Technical Committee 189, WG 5) is presently working on a series of standards dealing with the durability of geotextiles and geotextile-related products. It will include a standard about the "installation, on-site retrieval and laboratoy testing of samples," which will specify how such a procedure should be implemented and how the monitoring and the analysis should be conducted.

5. CAREFULNESS REQUIRED WITH EXTRAPOLATIONS

This new section will be about the limitations of the knowledge concerning the extrapolation theories dealing with chemical degradation. For this discussion, we will refer to the TAI Group's research regarding polyester-based reinforcements.

5.1 *Summary of TAI's research programme*

Our research programme about the hydrolysis of polyester is a long-term one, divided into three phases. The first phase, conducted at 95°C in 27 different media, aimed at identifying the most aggressive environments. The second phase, at 80°C, aimed at differentiating the performances of various fibers.

The third phase is now underway and it will last until about year 2010! It is much slower, since it is conducted at 50° and 23°C. This time, the main purpose is to analyze the kinetics of hydrolysis in neutral and aggressive environments by correlating the results obtained at the 4 different temperatures.

5.2 *Third phase: early findings*

No definite conclusions can be drawn yet, after only two years of the third phase, but very alkaline environments (pH = 13) confirm to be extremely aggressive, with 40% loss at 23°C.

More important with regard to our discussion, however, it appears that, at least in a very alkaline environment, the Arrhenius equation which is usually applied in order to extrapolate the results obtained at elevated temperatures does not work very well. For the results to fit, the activation energy would have to be reduced from about 25,000 cal/mole to 15,000 cal/mole below the glass transition temperature (65° C). This is explained in more details by J.M. Jailloux and P. Anderson in a paper titled "Long term testing of polyester yarn and product at 50° C and 23° C in different environments," Kyushu'96, page 45.

This might be an example of the carefulness which is required before conducting such extrapolations over either large ranges of temperatures or from only one year (or 10^4 hours) to 100 years!

6. SELECTION OF RELEVANT PARAMETERS

6.1 *Example of creep*

This last section is about the need for identifying the parameters which are actually relevant to the design, the ones for which testing methods are actually necessary. The effect of creep is one of the most critical examples.

6.2 *Irrelevance of creep strain*

It should be noted that some guidelines still define the allowable tensile strength of extensible soil reinforcements which are subject to creep, by referring to a given limit strain, for example 10% or 5% (Figure 5). This could be relevant to a serviceability criteria, but it is not relevant to an ultimate limit state criteria.

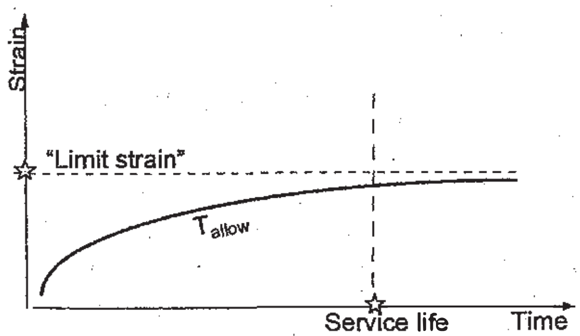

Figure 5: Allowable tensile load defined as a function of a limit strain

6.3 *The real issue: creep rupture strength*

With regard to ultimate limit state criteria, the question is, by definition: "Is the reinforcement susceptible to breaking before the end of the service life?" and the answer should be no. Then, rupture is the issue, and "creep rupture strength" is the only relevant creep criterion.

6.4 *The meaning of the "overall factor of safety"*

The remainder of this section is primarily directed at the people who are not too familiar with the use of "load factors" as partial factors of safety, but are used to "working stress" types of calculations (as it is generally the case in the USA). They should first recognize that there is no fundamental difference between these "load factors" and what they use to call the "overall factor of safety". It is important to understand, however, the real meaning of these factors, when considering the possibility of a rupture before the end of the service life.

The overall factor of safety is meant to cover all the uncertainties in the calculated tensile loads, such as: uncertainties in weights, surcharges, fill properties, potential for local overstresses, and inaccuracy of the calculation model. Its value is usually around 1.5 in all major Codes, independent of the type of reinforcing material. This factor means that there is a minor possibility, or a tiny probability which is accepted in advance, that the nearly constant tensile load could be actually 1.5 times larger than what is normally calculated. Even in this case, which is not totally excluded, the reinforcement must not break prematurely (Figure 6).

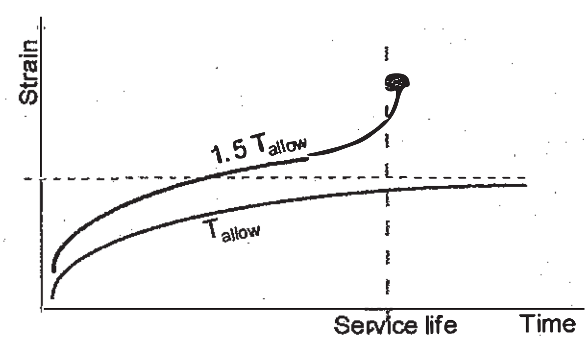

Figure 6: Creep rupture under factored load.

This is why one must assess the creep rupture strength of the reinforcement at the end of the service life and use it for the definition of the allowable tensile load.

No matter how the strength of the reinforcement evolves in the course of its life, even if this reinforcement still retains a significant residual strength a little before it finally breaks, what counts is that it does not break before the end of the service life, even if its load is 1.5 times larger than calculated.

Time to creep rupture is clearly what needs to be measured, over the longest possible period of time, in other words under the smallest possible loads, so that extrapolations remain reasonable. Of course it is desirable that creep rupture strength be measured in conditions which are representative of the confined three dimensional environment of a reinforcement in a real structure.

The question of creep rupture and more generally of the fundamental meanings of safety factors and reduction factors is thoroughly discussed in a paper titled "The need for standard factors of safety in the determination of allowable tensile loads," by P.L. Anderson, M.S. Boyd, P. Segrestin and K. Worrall (Kyushu'96, page 297). The whole issue can be summarized (or at least illustrated) as shown on figure 7. The graph explains how the reduction factors corresponding to installation damage, creep and environmental aging should be first applied. It shows how the factor of safety FS_l covering the uncertainties in loads, and the factor of safety FS_m accounting for the uncertainities in long-term tensile strength and extrapolations, should be then ideally introduced.

7. CONCLUSIONS

Monitoring the long-term behavior of soil reinforcements in actual structures and actual environments is a necessity. This is currently done for galvanized steel strips and it confirms the validity of the theory and of the design procedures. The monitoring needs to be implemented on an ordered basis for the other types of reinforcements: steel grids and geosynthetics. This should progressively help to improve our knowledge regarding issues such as the durability of small round bars, the synergy among construction damage, environmental aging and creep, and the validity of some extrapolations.

It is also necessary to state which mechanical characteristics, such as creep rupture strength, are actually relevant to the design and, therefore, need to be measured. Such clarification will eventually eliminate the confusion about the issue of safety factors.

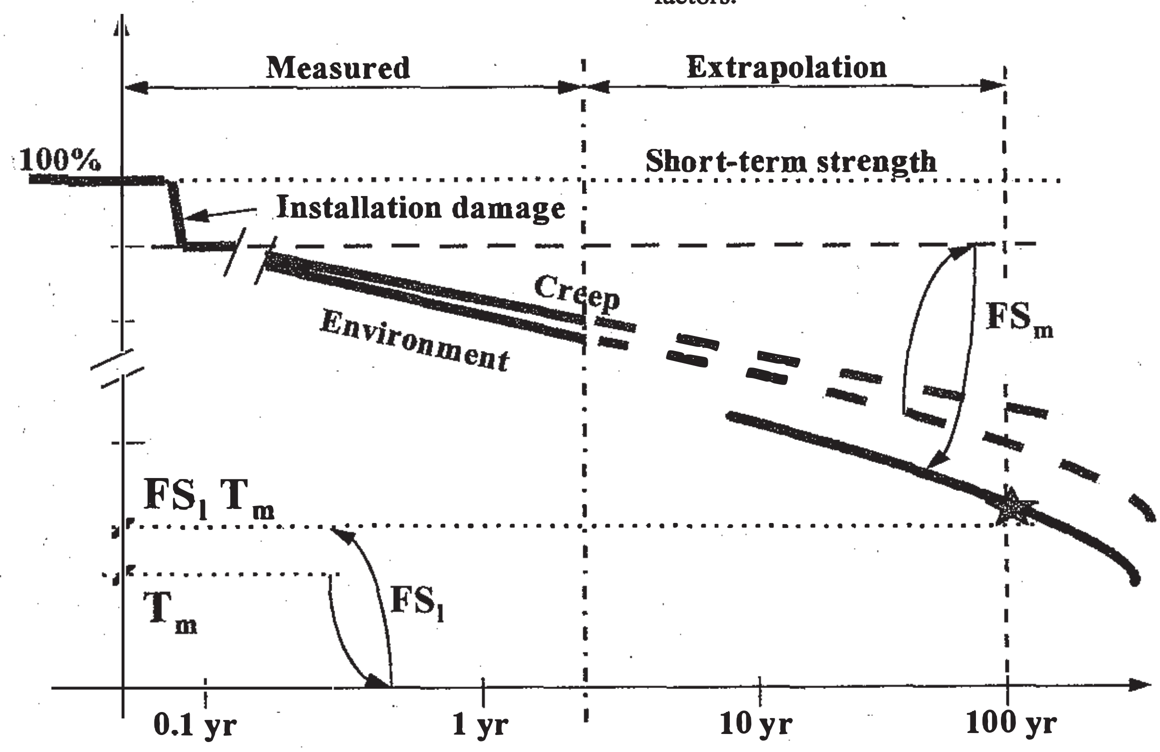

Figure 7: Allowable tensile load; applying reduction factors and safety factors

REFERENCES

Smith, A.; Jailloux, J.-M.; Segrestin, P.: Durability of galvanized steel reinforcements as a function of their shape. *Earth Reinforcement practice.* Fukuoka 1996.

Jailloux, J.-M.; Anderson, P.: Long-term testing of polyester yarn and product at 50°C and 23°C in different environments. *Earth Reinforcement practice.* Fukuoka 1996.

Anderson, P.; Boyd, M.; Segrestin, P.; Worrall, K.: The need for standard safety factors in the determination of allowable tensile loads. *Earth Reinforcement practice.* Fukuoka 1996.