A Study in Practice: Evaluating the Life Expectancy of an MSE Wall with Steel Strip Reinforcement

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Abstract

In over 50 years since the invention of Reinforced Earth walls, structures have been designed to fulfill a variety of retaining solutions for infrastructure projects, as well as mining, marine, industrial, commercial and residential projects. Over the service life of these projects, owners may decide to change the scope of structures. These changes may include: design life extension, wall height increase and other alterations in geometry, changes in loading configuration, etc. To accommodate these modifications, structures must be assessed based on new scope, in addition to incorporating design changes.

This paper will present an inspection and evaluations program though a case study where specific assessment methods and techniques have been utilized to demonstrate whether Mechanically Stabilized Earth (MSE) walls can be stable for the required changes in scope. The assessment method includes visual inspections, strip sample extractions, and corrosion assessment. Since the service life of the structure is dependent on the strength of the soil reinforcements, by evaluating the strength of the test samples, the stability and remaining design life of structures at the current state can be determined. Following a similar method, the stability of a structure can be evaluated if loading conditions or geometry configurations need to be changed over the remining structure's design life.

1. Introduction

A Structure Asset Management (SAM) program has been implemented for Reinforced Earth walls, which offers the necessary techniques and data analyzing methods for evaluating a MSE Wall (i.e. the condition, maintenance needs, and performance of the structure). More specifically, the SAM program aims to evaluate the conditions of structures in service, assess the integrity and estimate the remaining design life of existing MSE walls, generate inspection practices, provide techniques and solutions for rehabilitation and/or re-design of the structure, as well as develop strategies and provisions for future inspections and maintenance management.

The assessment and evaluation program is carried out in different phases: visual inspection, extraction of reinforcing strips and backfill samples, testing of materials, analysis of corrosion of metal reinforcements embedded in backfill, evaluation of thickness and cross-sectional area loss, and the remaining tensile capacity of strip reinforcements, as well as provide comments and recommendations on the serviceability of the structure. A visual representation of the SAM program is shown in Figure 1.

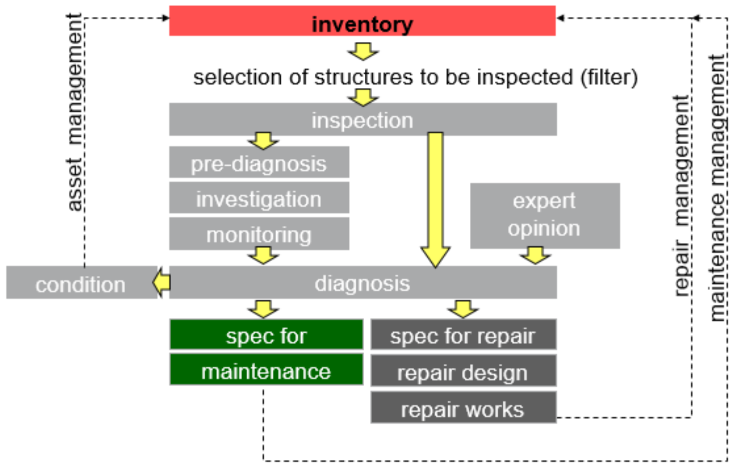

Figure 1 - SAM Program Flow Chart

2. Reinforced Earth Walls

The MSE Walls are coherent gravity retaining walls consisting of a composite material that is formed by the interaction between the backfill and reinforcing strips. In addition to the backfill and reinforcing strips, another major component of the wall is the facing (precast or wire mesh), which serves to protect from erosion of backfill and provide an aesthetic appearance.

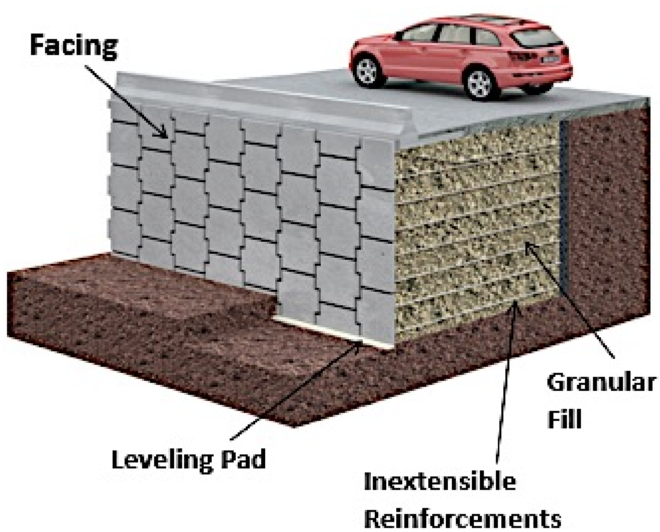

Figure 2 – MSE Wall Components

The design of a MSE Wall is dependent on modes of failure including:

- External – Base Sliding, Overturning, Bearing Capacity
- Internal – Tensile Over-Stress, Pull-out, Internal Sliding
- Global Stability
- Connection Failure (Facing)

The length and density of the reinforcing strips, along with the size of the Reinforced Earth mass and its mechanical properties are carefully engineered for each application, as these are major elements that affect the stability of MSE walls. The thickness of soil reinforcements accounts for the sacrificial thickness calculated based on AASHTO corrosion rates in non-aggressive granular backfill material for the service life of the structure. Any granular backfill that meets the criteria for mechanical and electrochemical properties specified in AASHTO is typically considered a non-aggressive material.

3. Methodology

The SAM Program is an investigation that consist of gathering field samples from site visits, assessing and analyzing those samples in laboratories, evaluating the results for remaining strength of reinforcement samples, and commenting on the remaining serviceability of the structure.

The first step is conducting a visual inspection of the wall. The condition of the concrete facing is inspected to determine if deterioration such as cracking, spalling, or chipping of panels has occurred. Other inspections include inspecting the drainage system, and recording where water stains and de-icing salts observed on the panel surface. This inspection is important to determine if precast panels are affected by freeze-thaw cycles, which can damage the facing. Moreover, any signs of settlement such as panel rotation and misalignment, joints width closing or opening, deterioration of the geotextile behind the panels (if there is any) are observed during the visual inspection. The examination through visual inspection can often be sufficient, especially for external stability conditions; however, the extraction and testing of a limited number of samples from the structure can confirm its current internal properties and assist in examining the actual condition of the structure components.

In the second step, steel reinforcement samples are extracted from various locations in the wall to verify the internal stability parameters and more specifically, the steel corrosion rates. Soil samples are recovered from the same sampling locations and tested for mechanical and electrochemical parameters. The location of extraction should be scattered all over the reinforced mass, however it is usually limited to accessibility and available extraction tools. Reinforcing strip samples are usually extracted from the face of the wall by coring through the facing, and sometimes from the top of the structure by controlled excavation. The number of samples extracted is formulated based on the size of the wall and sampling frequency throughout the service life of the structure. Some of the MSE walls are constructed with test samples embedded during construction. The number of the samples are usually specified in the project specifications, e.g. one (1) test strip for every 25m^2 of MSE wall area. The number and location of test samples are selected to be an appropriate representation of the project scope.

Before conducting any testing, the extracted strips are visually inspected for discoloration, rust, and pitting. All of these samples are measured to evaluate the galvanization and steel loss and some of them are tested to determine the remaining tensile strength. First, they are measured for overall thickness, zinc thickness, strip width, sample weight, and cross-sectional area. The zinc loss is measured by weighing samples before and after removal of zinc oxide. This procedure is carried out according to ASTM A90. Some of selected strip samples are also tested for tensile strength in accordance with ASTM A370 and ASTM E8. Additionally, soil samples are tested for organic content (ASTM D2974), chlorides content (AASHTO T291, ASTM D4327), water-soluble sulphides (AASHTO T290, ASTM D4327), electrical resistivity (AASHTO T288, ASTM G187), pH (AASHTO T289, ASTM D4972), and organic content (ASTM D2974).

The data from laboratory testing is used to assess the magnitude of corrosion of reinforcing strips, and also to verify the corrosion rates to be able to determine the remaining life of the structure. Comparing the testing results to its original design capacity can show corrosion behaviour of backfill in the years that the structure has been in service.

When designing a MSE wall, a sacrificial thickness (corrosion allowance) is calculated according to relevant codes (e.g. European Code NF P 94-270, AASHTO, CSA, etc.). Same method of analysis can be utilized to calculate the loss of thickness from when the wall construction completed till the time sample is extracted; and consequently, calculate the remaining tensile strength of the strips. The calculated results are compared to measured loss of galvanization/steel and tested tensile strength to determine the reliability of the calculations and to provide proper comments on corrosivity of the backfill.

If it is determined that the MSE structure has reached the end of its service life and cannot provide the necessary strength to support the loading, proper solutions can be offered to keep the wall in service, e.g. soil-nailing.

4. Case Study

Reinforced Earth Company (RECo) was retained to perform an investigation to evaluate the integrity of a MSE wall, located in Ottawa that was built in 1984 and designed to be in service for 75 years. The structure supports a bus lane with a traffic barrier over the facing and consisted of a maximum height of 11.6m. The soil reinforcement consisted of two types of ribbed steel strips (i.e. 40 mm x 5 mm and 60 mm x 5 mm), and a granular backfill material was used in the reinforced zone. The scope of this project included a visual inspection and an assessment of existing conditions based on field data gathered and extracted samples from about 32 years after the structure was built. The scope of work also included analysis on the remaining strength of the structure, and determining if the lifespan of the structure could be extended by another 10 years. Additionally, the internal stability of the structure was checked for the future LRT project, with 1m raised profile and new coping detail.

4.1. Visual Inspection

This structure has been visited and inspected several times after its construction in 1984. During visual inspections, some deterioration on facing panels as well as efflorescence in the joints from de-icing salt was observed; however, there was no sign of significant structural issues (e.g. bulging, sliding). Water stains on the panels were also observed, indicating improper drainage on top of the wall. Presence of the water and salts and the effect of ‘freeze/thaw’ cycles can be the cause of the damage to the pre-cast concrete panels.

4.2. Sample Extraction

For further investigations, a total of 33 test samples in two sets were extracted from a depth of 1 m below the pavement at top of the wall with controlled excavation, and some samples taken from lower portions of the wall. Backfill samples were also collected from the extraction locations for electrochemical testing. The strip samples exhibited a range of corrosion damage in the form of pitting and rust spots at the edges of the strip. The strips that were extracted from the bottom sections of the wall presented less and relatively uniform corrosion.

4.3. Zinc Thickness Measurements

All steel strip samples extracted were examined for zinc loss. Remaining zinc thickness was measured in different section of each test strip. Elcometer 456 was used for zinc thickness measurements. The results indicate that zinc was found in all sections however it varies significantly along each sample.

The visual observation of the strips also confirmed the presence of local pitting; however, the result from total thickness and the remaining zinc measurements on the strips showed that the corrosion rate was not as high as considered in the design.

4.4. Electrochemical Testing on Backfill

The soil samples collected from top of the wall were tested for chlorides and water-soluble sulfates content, electrical resistivity, and pH values. The test results showed that most of the soil samples did not comply with current AASHTO specifications for electrical resistivity and chloride content. Assuming that the backfill used at the time of construction met with the specifications, it is speculated that the high values for electrochemical content were a result of the presence of de-icing salts at the top layers of the MSE wall.

4.5. Cross-section Examination

The strip cross section is measured after zinc removal. The remaining cross section area of 44% of the samples after 32 years is greater than the original nominal size of the strips.

Steel galvanization is 87µm in accordance with CSA G164 (Table 1 – P.19) and the corrosion allowance is calculated based on AASHTO corrosion rates as follows:

- Galvanization loss = 15 µm/year for the first 2 years, 4 µm/year for subsequent years
- Carbon steel loss = 12 µm/year after zinc depletion

Theoretically, the amount of zinc on a hot-dip galvanized steel strips lasts about 15 years. Consequently, the corrosion allowance of the strips after 32 years in service is calculated to be 0.378 mm. However, in the original design, the sacrificial thickness was calculated based on corrosion rates similar to European Code NFP 94270. Accordingly, the expected loss of thickness after 32 years is 0.525 mm in dry conditions.

There are various factors that may affect the corrosion rate acceleration including an aggressive backfill, which is defined by its original electrochemical properties, or an external corrosive environment such as presence of de-icing salt, sea water, etc. The average of remaining zinc thickness measured in the extracted samples was more than expected. In addition, from the 33 extracted strip samples that were tested, only one (1) exceeded corrosion results from the calculated corrosion loss of 0.378 mm (AASHTO & CSA G164-M92) or 0.525 mm (NFP 94270); however, the non-uniform corrosion and local pitting observed on some samples, especially those extracted from the top of the wall, is an indication of the corrosive material being unevenly introduced into the backfill over time. Therefore, while the existing corrosive material will continue to remain in place, it was noted that no more de-icing material will be introduced to the backfill in the future LRT project.

4.6. Tensile Strength Testing

In addition to the measurements for loss of galvanization and cross-sectional area, some of the reinforcing strips samples were tested for tensile strength capacity in accordance with ASTM A370 and ASTM E8. The steel grade used for this project is ASTM A36, with a minimum yield strength of f_y= 250 MPa. Based on the test results from the mill certificates for the strips supplied for this structure, the actual design Yield Strength, f_y (MPa) ranged from f_y = 297 MPa to 320 MPa, which is higher than the specified grade considered in the initial design calculations.

It was noted that 50% of the tested samples exhibited a tensile strength of the “first year” design strength or better. Based on the tensile test results, the strength of all strips exceeds the estimated strength by approximately 12% to 15%. This can be partly due to the fact that the actual yield strength of steel exceeded the design yield strength, and also because the design cross section was smaller than the actual supplied reinforcing strips.

4.7. Assessment

The wall stability had to be assessed based on new specifications, in addition to incorporating design loading and geometry changes. The observations and test results on all the extracted samples served as the basis for evaluating the expansion of the scope of work and, more specifically, for determining if the lifespan of the structure supporting a new loading configuration, whose altered geometry would consist of an elevated profile, and new coping configurations, could be extended by another 52 years from the time of sample extraction.

To determine if the lifespan of the structure could be extended with the new configurations, the most conservative scenario was considered. The assumptions for checking the structure stability was based on the worst strip condition (i.e. highest loss in cross-sectional area and lowest tested tensile strength). The result for the stability analysis of the structure, based on a limited number of samples extracted and tested, showed that the factors of safety at the end of the new service life were met.

In addition, in the process of changing the existing wall application, the traffic crash barrier was replaced with a fence on top of the wall facing. As a result, the stability of the top panels required additional strips at the top row of reinforcements. Therefore, the top layer of reinforcement was exposed and additional reinforcements were installed.

Other remedial works were also recommended and implemented, such as installation of proper drainage for collecting runoff water to protect panels from further deterioration; and patching of deteriorated panels or replacement of severely damaged panels.

As recommended in the SAM program, this structure will be visually inspected every 2 years. Often a visual examination of facing material is sufficient but extracting and testing of a few samples can confirm its properties and examine the condition of reinforcing strips in the future. The detailed inspections with probing and steel strip sampling can be undertaken during the periodic inspections every 5 to 10 years. The frequency of probing may change depend on the wall performance.

5. Conclusion

The Structure Asset Management (SAM) program for MSE walls offers the necessary techniques and data tools for assessment of a MSE wall. The program includes variety of services such as evaluation of a MSE structure in service, estimating the remaining design life of a MSE wall, providing solutions for rehabilitation and/or re-design of the structure, as well as generating inspection practices and developing strategies and provisions for future maintenance management. MSE walls with strip reinforcements present an advantage because this type of reinforcements can be extracted for assessment without affecting the overall stability of the structure.

Utilizing this methodology, the presented case study showed an existing MSE wall assessed and analyzed for a new loading and geometry configuration for an extended the service life. The laboratory testing and analysis on the extracted samples for loss in cross-sectional area and tensile capacity showed some differences in remaining strength, but were reasonably similar and in both cases, it generally demonstrated that it is greater than the designed values. This confirms the level of confidence and factors of safety used for the design of the MSE walls.

6. Acknowledgment

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