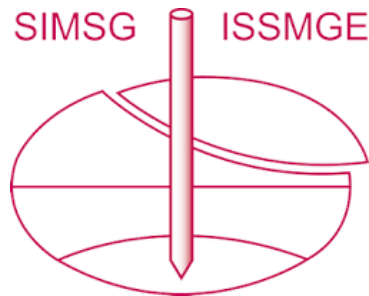


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## Proposed methods and considerations to allocate damages for deficient mechanically stabilized earth walls

Méthodes et considérations proposées pour attribuer des dommages et intérêts pour déficience de murs de soutènement en sol stabilisé mécaniquement.

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**ABSTRACT:** Mechanically stabilized earth (MSE) walls rarely fail catastrophically. Proper monitoring during and after construction would reduce MSE wall failures in the United States and around the world. When MSE structures require either early remediation or total replacement of the structure before the end of their service life, it is a complex issue to determine which party or parties are at fault and whether the issues related to the failure or forthcoming failure are a result of design defects, construction defects, or a combination of both. This paper provides a background on the essentials of the dispute resolution process that is typical for MSE structures and provides recommendations for considerations when determining the allocation of damages between design and construction defects. A case study is used to show some examples of how to use contract documents, field data and forensic investigation and analyses to help with the allocation process. Considering that most MSE wall failures are avoidable, incorporation of MSE walls into a Geotechnical Asset Management (GAM) plan is a potential path forward to be able to track performance of MSE structures and deploy low level maintenance needs before extreme repair or total replacement is required.

**RÉSUMÉ :** Les murs de soutènement en sol stabilisé mécaniquement (MSSM) échouent rarement de manière catastrophique. Une surveillance adéquate pendant et après la construction réduirait les défaillances des murs MSSM aux États-Unis et dans le monde entier. Lorsque les structures MSSM nécessitent soit un assainissement précoce, soit un remplacement total de la structure avant la fin de leur durée de vie utile, il s'agit d'une question complexe pour déterminer quelle(s) partie(s) est(sont) fautive(s) et si les questions liées à la défaillance ou à la défaillance à venir résultent de défauts de conception, de défauts de construction ou d'une combinaison des deux. Le présent document fournit un contexte sur les éléments essentiels du processus de règlement des différends qui est typique des structures MSSM et fournit des recommandations pour les considérations à prendre en compte lors de la détermination de la répartition des dommages et intérêts entre les défauts de conception et de construction. Une étude de cas est utilisée pour montrer un exemple de la façon d'utiliser les documents contractuels, les données sur le terrain et les enquêtes et analyses judiciaires pour faciliter le processus d'attribution. Étant donné que la plupart des défaillances de murs MSSM sont évitables, l'intégration des murs MSSM dans un plan de gestion des actifs géotechniques est une voie potentielle pour être en mesure de suivre le rendement des structures MSSM et de déployer des besoins d'entretien de bas niveau avant que des réparations extrêmes ou un remplacement total ne soient nécessaires.

**KEYWORDS:** MSE walls, construction dispute resolution, geotechnical asset management, construction defects, design defects

### 1 INTRODUCTION

Defective civil structure disputes are often complex matters. Through dispute resolution means, the mediation parties, arbitrators or a court jury and appointed judge will, to the best of their abilities, decide which party (or more likely which parties) are to blame. When civil structures require repair or replacement before the end of their service life, the ensuing costs can easily exceed tenfold that of the original construction cost to account for damage claims, investigation programs, physical repairs, attorney fees, etc.

#### 1.1 *Mechanically Stabilized Earth (MSE) walls and asset management*

MSE is a construction material made from soil that has been strengthened with reinforcement elements such as metal grids or strips, non-biodegradable fabrics (geotextiles), geogrids, and the like (Das, 2013). Their widespread use is attributed to a flexible system with an accepted and structured design methodology, and their ability to be constructed with common construction equipment, materials, and labor. Compared to other earth retention alternatives such as cast-in-place, sheet pile, soil-nail, etc., they offer the required support for a fraction of the cost.

Despite the fact that MSE walls are the most popular type of fill earth retaining structure in the United States, and arguably around the world, little to no guidance, compared to other civil structures, is provided to owners and agencies for use in determining acceptable construction and performance

throughout the structure's life expectancy. Likewise, it is rare for MSE walls to be continuously evaluated on some regular cycle. For decades, bridges, pavements, and buildings have been the primary asset on the receiving end of available resources, leaving MSE walls in the hands of owners to deal with. When a problem is recognized, it is typically too late to avoid being faced with a major problem.

Historically MSE walls have been viewed as a maintenance-free asset (especially compared to bridges and pavements), but this is not necessarily correct. There is an increased awareness that all infrastructure features have a limited performance life.

#### 1.2 *MSE walls and dispute resolution*

It is common to see the words "designed by others" adjacent to the vertical line on a set of construction drawings; the line representing a retaining wall. An MSE wall is commonly built by a sub-contractor. The materials may have been procured by a separate entity other than the wall builder. The inspector may have been included under the general contract in the large scope of the project, under a unique contract specific to the MSE wall, or more commonly inspection for MSE walls is completely excluded (especially true in the private sector). Material and construction acceptance criteria and tolerances are often missing. Walls are sometimes installed by a team with minimum experience related to water, soil, and structure interaction.

All of this makes the dispute resolution process complicated. Although it is more common for MSE walls to fail primarily due to construction defects, design defects can also play an important

role. It is uncommon for MSE walls to fail rapidly in a catastrophic state, therefore routine inspection could help identify any percolating issues caused by design or construction defects, but again, this is typically excluded.

In a dispute resolution situation, the decision maker is faced with using all of the available information related to the MSE wall design, material procurement, construction practices, contractual responsibilities and the continued use of the wall system, to determine who is responsible. Often, allocation of damages between multiple parties is unavoidable due to the nature of how these structures are contracted and how these structures fail.

## 2 ALLOCATION OF DAMAGES

In some cases, it may be obvious whether the structure failed due to design or construction defects. Although in many other cases it can be quite challenging to track the project from design, through bidding, through construction and finally through its current day use and condition. When developing all the reasons related to premature failure or unacceptable performance it is imperative to address the following:

- What do we know and what don't we know (what information is missing) related to the defective structure(s)?
- Who were the project stakeholders? Document who was responsible for the design, construction, and quality assurance throughout the life of the project.
- Who owns the structure now and has it been used the way it was intended to be used?
- Was the failure or poor performance avoidable?
- Are there life safety concerns that require immediate repair, and if not, when does the structure require remediation?
- How should the structure be repaired or replaced?
- Who is responsible to pay for damages and when?

In evaluating the project, there are two primary parts of the study. The desktop study focuses on all the project documentation to date including contractual documents, project emails, field notes, photographs, etc. Secondly, the physical study encompasses new site visits, deploying investigation programs and other active methods to complete a forensic investigation (when permissible and funded) to further the knowledge and understanding of the project concerns that may have led to failure. The level of physical study most likely depends on the magnitude of the project at hand and the allowable resources, (time and money) for investigation. For example, if urgent remediation of the structure is required to mitigate concerns of life safety risk, or major transportation challenges, an in-depth investigation of the failed structure may not be possible. Usually a third-party consult or firm specializing in geotechnical engineering (or multiple firms) is retained under an independent contract to complete both the desktop and physical study.

Failure does not always have to be catastrophic (such as a wall blow out or collapse), and the term "failure" can be defined within the language found in the original contract documents, or "failure" may be defined by the parties involved in the dispute resolution.

### 2.1 Desktop study

Review of all contractual documents including plans and specifications, design calculations and reports, and field notes during construction, and project correspondences can be very time consuming. The investigators will also review the time relevant industry recognized standards of practice, although specific project specifications and contract documents take precedence over national standards.

The desktop study is essential in developing the history of the project and identifying which parties had which responsibilities, particularly useful for multi-year projects with different contracts, subcontracts, and agreements.

The desktop study is likely to be the place where design defects are discovered. Related to MSE walls, the design defects commonly observed are:

- Mixing and misapplication of design standards
- Improper Pullout Resistance Factor (F\*)
- Absent considerations for special features (impact barriers, drop inlets, culverts, signposts)
- Not analyzing splayed reinforcements
- Inaccurate method used to calculate tributary area (of soil supported by reinforcement)
- Not analyzing overall or compound stability
- Ignoring surcharge loads
- Inadequate consideration for deterioration (corrosion potential)
- Evaluation of lateral stress behind bridge abutments
- Incorrect soil unit weight and strength values (as recommended in geotechnical report)
- Use of inappropriate remediation measures and associated designs (soil nails and ground anchors)
- No design on record

(DiMaggio, MacMillan 2018)

Careful review of all documentation during construction, such as daily reports, photographs, internal and external communications, in-situ testing, and as-built surveys is used to identify design or construction defects. For example, a change of condition which was noted in a field inspection log but never brought to the attention of the engineer of record. This could be a weaker soil layer, an obstruction such as a buried pipe affecting compaction of backfill material, different backfill material, etc. Each example (and others) can have an impact on satisfactory performance, especially with time. An advantage of using MSE walls is that they are flexible systems which can work around complex skews, above and below ground obstructions, and different soil types, but these special conditions need to be designed for. MSE walls can handle the introduction of water, when accounted for and when the drainage is designed properly. Communication channels between the wall builder and designer needs to be clear relating to any change of condition encountered.

Contract documents for MSE walls rarely specify inspection. Even when inspection is addressed, it is addressed globally with other project features (such as asphalt compaction) and again, the other project features tend to get most of an inspector's site time.

### 2.2 Physical study

Following or in conjunction with the desktop study, a comprehensive field study is often required. The physical study for MSE walls aims to identify material specification conformance, any change of condition (for example the presence of groundwater or different soil types), and to collect data for back analysis (soil properties, degradation of reinforcement strength, unanticipated surcharge loading etc.)

The physical study may be a one-time occurrence, such as a site visit by selected parties involved and industry experts or may be more elaborate, such as an investigative program that may include additional geotechnical testing and laboratory analyses, repetitive condition assessments, structure forensic evaluations and more. The physical study may have short-term and long-term monitoring components, to track conditions such as the presence of groundwater, wall rotation and settlement.

### 3 A CASE STUDY: THE COLONY AT WHITE PINE CANYON

The Colony at White Pine Canyon (The Colony) is a residential development located in Park City, UT at the Canyons ski resort. The construction was divided into multiple phases based on the overall development plan.

Due to the mountainous terrain, hundreds of grade separation, earth-retaining structures were required in the form of walls, bridge abutments and ski crossovers. The primary retaining wall system used metallic reinforcements for internal stability, and gabion type baskets at the wall face for the desired aesthetics. These walls had an intended service life of 75 years. Figure 1 shows a typical structure at the Colony project.



Figure 1: Typical MSE structure (bridge abutment) at the Colony Project.

#### 3.1 Project background

The Colony project team consisted of a developer, designer(s), geotechnical engineer (testing), wall contractor, general earthwork contractor and a Homeowner Association (HOA). During some phases of the project, other sub-contractors were involved for various needs.

Within the first year following the phase one of construction, several of the walls exhibited signs of distress. Most notably the distress was collapsed face wire, bulging, voids, pavement cracking, guardrail movement, settlement, and overturning of some walls.

It was clear that further investigation was needed to evaluate the level of distress and related action plan. Specifically, one focus of the study was to address whether the walls that were not displaying excessive deformation were structurally sound. An extensive investigation plan was implemented. As the investigation plan was set in motion, ongoing signs of distress occurred. A visual monitoring program for each structure was deployed.

Five years following initial construction, partial and full remediation of some walls was underway. During the initial remedial work, internal degradation of the steel reinforcements was noted, completely corroded in some areas, which added a level of concern as to the stability of all the MSE walls throughout the project. Now, the project team was faced with a multifaceted state of wall distress – both internal and external components were experiencing unacceptable performance in the form of internal steel degradation and external deformations. A complimentary invasive investigation of the material and soil in the reinforced backfill of the walls was launched.

The decade-long investigation to determine the extent of the design and construction defects was exhaustive and ultimately consisted of approximately:

- 275 vertical borings with continuous sampling
- 3,500 electrochemical tests
- 11 wall deconstructions (for investigation)
- 4,000 wire diameter measurements of extracted metallic grid
- 8 horizontal mining studies
- 16 surface inclinometers

- Hundreds of visual wall audits of multiple structures over multiple years
- Thousands of linear polarization readings over multiple years

To the author's knowledge, this is the largest set of data correlating corrosion of buried bare steel to soil resistivity to date.

Dozens of industry experts, attorneys, owner's representatives, contractors, subcontractors, material vendors, and designers were involved in dispute resolution that spanned almost two decades. Intermountain GeoEnvironmental Services, Inc. (IGES), Geocomp Corporation, and The Collin Group, among others, were independently hired as experts in the investigation of the construction and design defects for the walls at The Colony.

#### 3.2 Design and construction defects

The findings from the complex desktop study of the design and contractual requirements, as well as over a decade of physical study through structure monitoring and investigation presented evidence that both design defects and construction defects contributed to premature failure of the wall systems. The premature failure was attributed to the following primary defects:

- Neglecting to oversize the reinforcing steel or galvanize or epoxy coat (*design defect*)
- Inadequate compaction of the reinforced backfill and face rock (*construction defect*)
- Out of specification backfill, including oversized material (*construction defect*)
- Out of specification reinforcement including shortened mats, improper wire size, lack of mechanical connections (*construction defect*)

Ultimately, an important assumption for MSE walls to achieve full-service life for permanent structures (in this case 75 years) depends on the creation of a non-aggressive corrosion environment during construction within and immediately adjacent to the reinforced volume of soil. Uniformly and densely compacted reinforcement backfill is imperative to the validity of the assumed "uniform corrosion" model and is directly tied to adequate performance.

It was clear that bare steel should not have been used and was not appropriately oversized for use in a corrosive environment. However, the driver for most of the early remediation was due to poor construction practices for the MSE walls which do not produce a homogenous reinforced zone. This allowed for both water and air to accelerate the corrosion potential creating severe pitting corrosion and reinforcement area loss.

#### 3.3 Dispute Resolution

The design and construction dispute resolution process for this project spanned approximately a decade due to the complex nature of the problem at hand. Towards the end of the long dispute resolution process, the allocation of damages between design and construction defects was explored using the Delphi Principle. (Note: The dispute was settled in mediation, so these allocation percentages were not used, but the methodology is illustrative.)

The Delphi Principle is internationally recognized as a reliable predictive modeling tool to use collective and consensus "expert" opinion to solve complex technical matters to arrive at quantitative results where factual data may be limited and where the contribution of multiple variables collectively contribute to a specific outcome.

The team revisited the years of project study and findings and developed a method to determine a system to allocate responsibility of structure failure between the design and construction defects.

### 3.3.1 Construction versus design defects

The impact of construction defects occurs almost immediately, and then levels out. These defects can be identified by the human eye (bulging panels, voids, pavement cracking); and are obvious and aesthetically unappealing.

The impact of design defects (in this case mostly related to the accelerated corrosion of the steel reinforcements) are harder to identify from visual inspection of the walls, however, during invasive wall take downs it was easy to see the degrading internal network of reinforcing elements. Typically, internal wire loss severe enough to threaten structural integrity would only occur over many years. This is due to conservatism in the design methodology which allow for some reduction of wire loss without a negative impact to performance. However, for this project wire loss rates were accelerated in early years, due to the nonhomogeneous environment created by the construction deficiencies.

The early serviceability indicators were caused by poor construction. Effects of corrosion of the metallic reinforcements would not have caused the noted distress such as overturning, rotation, severe compression, settlement, and pavement cracking until later in the wall life.

### 3.3.2 Physical Study

Numerous accounts of visual distress were noted in very early investigations in the first five years following original wall construction. The MSE structures supporting the infrastructure for this community are the primary emergency access road from the winding hillside properties, down to the base of the town. Any structure which was exhibiting very poor performance was immediately scheduled for remediation. For other structures, while the investigation was carried out, observations and investigations were performed for over a decade. This investigation stage included multiple wall deconstructions and invasive studies, extensive visual wall audits were conducted at each structure at approximately 8, 10, 12, 13, 14 and 15-years post construction. This allowed the project team to piece together the timeline of the wall distresses over time. These distresses could be in some instances tied to change of contractors or change of material specifications.

During the wall audits, the walls were visually evaluated, and their condition documented. Serviceability indicators were documented such as face bulging, drainage protection, condition of face rock (tightness), face wire condition (broken, corroded), wall batter (overhanging), and surface pavement cracking. In some instances, verticality of the wall face was measured. The condition was described and assigned a condition level rating by the criteria in Table 1.

Table 1. Example condition level assessment matrix.

Condition Level	Description	Serviceability Indicators
1	Excellent	No face bulging, tight face stone, good drainage protection, < 10% degradable face rock
2	Satisfactory	Some face bulging, tight face stone, no drainage problems
3	Poor	Face bulging, broken wire, face rock degradation, poor drainage, moderate corrosion of wire at face
4	Terrible	Either overhanging sections, or pavement cracking, drainage problems, or severe corrosion of wire at face.

### 3.3.3 Applying study to allocation of damages

Most serviceability indicators which are visually observed early in a wall's life are direct indications of construction defects. Although it is known that internal corrosion of the reinforcements may have been (and likely was) occurring since the initial construction of the wall, that level of corrosion would

not have caused the noted serviceability issues (such as overturning, rotation, severe compression, settlement and pavement cracking).

The observed conditions and condition level assignments were reviewed for the visual wall audits conducted at 8-, 10- and 12-years post construction to arrive at an assignment of construction and design allocation. Based on a study of these walls, and knowledge about how walls deform and show signs of distress, it was suggested that the unfavorable performance in the first ten years of a wall's life on this project was a direct result of poor construction, and accordingly, the premature failure of these walls would be attributed solely to construction defects.

Opposingly, for walls which were noted to be in excellent condition in the 8-12 years following construction, it was suggested that the design defects were the sole culprit (i.e. they did not have poor construction practices). This was confirmed through the slew of visual inspections and by evaluating the resistivity of the soil (collected in the vertical borings and horizontal mining). As construction practices were refined as the phased development progressed, the desired homogenous environment in the reinforced zone was created (by using in specification materials allowing for proper compaction). When this occurs, although the metallic reinforcements would still have some level of degradation it would be much less detrimental, and it would also be closer to uniform (now the uniform corrosion model applies). There were other minor modifications made that also impacted favorable performance.

For the remaining walls which fell in the "Satisfactory" category, engineering judgement, as well as other project knowledge (such as how material specifications or compaction methods changed with time), were used to allocate the cause of premature failure between design and construction. Table 2 was developed for allocation of defects (design vs. construction):

Table 2. Proposed allocation of damages for the MSE structures at The Colony.

Observed Condition Level	Allocation %		Engineering Judgement Basis
	Construction	Design	
1 (Excellent)	0%	100%	N/A
2 (Satisfactory)	0%	100%	Minor or infrequent serviceability indicators
	50%	50%	Moderate serviceability indicators
	100%	0%	Severe or frequent serviceability indicators
3-4 (Poor-Terrible)	100%	0%	N/A

In categorizing the walls, the visual wall audit reports were examined beyond the numerical rating and assignments. The wall audits include verbal condition assessment statements regarding wall performance as well as photographs for each year they were evaluated. Additional field data was reviewed which included observations of intrusive wall investigations from IGES and Geocomp reports. The purpose of reviewing this data was to determine if there were any telltale signs of construction defects. Additional project reports completed to date also included information relative to the resistivity of the reinforced backfill at each wall location.

Using these observations along with construction records and contract documents, the experts and attorneys were able to propose an allocation of design and construction defects for each structure.

## 4 APPLICATION OF METHOD

The extensive investigation on The Colony project was required due to the premature failure of the wall systems caused by accelerated corrosion, poor compaction and out of specification materials. Unique to this project, most of these structures supported the only true emergency exit for the residents. Most troubled structures will not have such a lengthy investigation with thousands of data points, pictures, and documentation to work with.

However, one way to use this method in a proactive format, would be to include some baseline wall audit protocol for MSE structures in agency or owner asset management plans. After all, MSE structures are major civil assets, just as a bridges, pavements and buildings are.

On top of providing third party inspection during wall construction, in most cases, evaluating wall performance on some routine basis will allow for the owner to pick up on signs of poor performance before there is a catastrophic failure and life safety concerns. If an unfavorable set of indicators (linked to poor performance) is noted during either a single inspection or a trend is noticed from multiple inspections, the owner can be ready to implement an action plan to either further investigate or correct the noted condition. Figure 2 shows a simple flow chart for MSE asset management that leads to action steps.

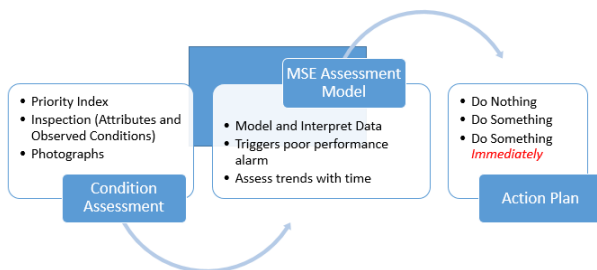


Figure 2: Flow chart for asset management of MSE walls

Some example actions tied to poor MSE performance are noted below and are generally listed in an order of least intrusive to most intrusive:

- Increase inspection frequency or level of inspection.
- Establish safety provisions around the structure (on top, beneath).
- Maintenance and preservation activities (clean out drains, seal pavement and surface drainage joints, resurface pavements).
- Develop and deploy an instrumentation and monitoring program.
- Plan and deploy an invasive or non-destructive testing program.
- Close roadway, lanes, bridge for life safety preservation.
- Select, design and deploy stabilization treatments (e.g. surface, subsurface drainage, berms, soil nailing, partial reconstruction).

An asset management program is only as valuable as the user makes it. Ongoing inspections should allow for time-sensitive correction actions. Ideally, the database should be updated regularly, and the data include recommended potential corrective actions based on noted conditions of wall performance.

Regardless of the approach that is developed to care for the MSE structures, it should use a model that is capable of both identifying new issues (from a condition assessment) as well as identifying emerging trends over time (from continued inspection). A qualitative and quantitative rating system tied to a set of threshold values and descriptors can be used to develop and deploy the appropriate required action or maintenance plan before collapse.

## 5 CONCLUSIONS

MSE walls are not commonly treated the same as other major civil assets such as bridges, pavements, and buildings. Due to this, setting and enforcing tolerance and acceptance thresholds as well as deployment of programs focused on the long-term evaluation and preservation of these structures is usually overlooked.

With this oversight, coupled with other design and construction deficiencies, MSE walls do fail. Most of these failures are avoidable and incorporation of MSE walls into GAM plans would be a great first step in mitigating major failures of these structures.

From the case study presented at The Colony project, there is clear correlation between severe poor performance indicators in the early life of the wall systems tied to construction defects. Since there is inherently conservatism in engineering design methodology, typically these errors would only manifest into poor performance much later in a structure's life. For other projects, with their individual components and constraints, the type of failure mechanism and careful study of the project is required for individual allocation of damages between construction and design defects.

Construction defects coupled with design defects can make a difficult position for the decision maker to allocate shares of responsibility during dispute resolution. Careful study of the project coupled with a solid understanding of how and why these structures fail sheds light onto the situation. Increased inspection, both during construction and routinely should help to decrease the number of failures in the MSE industry.

## 6 ACKNOWLEDGEMENTS

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