Stabilization of Marginal Soil in New and Existing Right-Of-Way
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ABSTRACT
Mass stabilization involves mixing binding agents into marginal or contaminated soil to improve the subject material’s physical and/or chemical properties. Successfully applied in Scandinavia and other European countries, the technology is now being applied in the northern latitudes of the U.S. and Canada. These regions have significant areas of “peaty” soils that can complicate construction and maintenance of rail and structure foundations. Mass stabilization can be used to improve the bearing strength of these soft soils for subsequent construction of railroads, pipelines, roads, and buildings. In civil engineering, the technology is often used to improve the construction properties such as bearing strength, of a marginal soil. In environmental engineering, stabilization is remediation treatment technology that protects human health and the environment by immobilizing hazardous constituents within the treated material. The treatment is conducted while the subject material remains in-place (in situ). Mass Stabilization is often used to accomplish both civil and environmental purposes on the same project effectively addressing marginal soil while eliminating the expense of soil removal and replacement.

This paper presents the principles of mass stabilization technology, implementation in the field and recent completed railway projects.

The example projects will focus on improvement of marginal soil physical properties including application to treat peaty soil during construction of high-speed rail in Finland. Bench-scale studies and full scale implementation as well as soil construction properties before and after mass stabilization will be discussed. The paper and presentation will include information on the advantages of mixing methods and binding agent delivery systems.

INTRODUCTION
New or existing railroad right-of-ways may cross ground with low bearing capacity. Right of way subgrade undergo deflection (strain) as loads (stress) are applied (1). The amount of strain or deflection of the subgrade caused by loading of a train is proportional to the stiffness of the subgrade materials. Some soils, such as tamped ballast, are very stiff and resist loads well. Other soils such as soft clay, peat, or loose sand have low stiffness and undergo substantial movement under loads. It is very desirable to have the stiffest possible material in a track subgrade.

Stiff subgrade material limits deflection under load, reducing track roughness and occurrence of track defects. Mass stabilization is a geotechnical method that can be used to improve the bearing capacity or stiffness of soil in these right-of-way. Mass stabilization involves mixing binding agents into soil subject to treatment while the soil remains in-place or in situ. Variations in the design or areas subject to treatment can be used to address transmission of vibration to adjacent structures.
Mass stabilization can also address contaminated soil and may therefore be used to attain several goals in rail applications. In this environmental application the technology is known as solidification/stabilization (S/S). S/S protects human health and the environment by immobilizing hazardous constituents within the treated material.

Mass stabilization can be used on new right-of-ways allowing construction of rail onto areas of soft ground. Mass stabilization may also be used to improve existing rail systems where soft ground has become a problem.

Figures 2 and 3: Before (left) and After (right) Mass Stabilization treatment of peaty soil Kivikko, Helsinki, Finland (3)
PRINCIPLES OF MASS STABILIZATION

Properties of Mass Stabilized Soil

Mass stabilization is used to improve the construction properties of a marginal soil. Marginal soil includes, but is not limited to, peaty soil, or soil with high proportion of silt or clay. Mixing a cementitious binder into marginal soil creates a material similar to cement-modified soil. When accompanied with compaction at the time of construction and use of a higher addition rate of cement, the mixed material may become similar to soil cement. The goals of mass stabilization may include:

- Increase in the California Bearing Ratio (CBR).
- Increase in unconfined compressive strength (UCS).
- Reduction in plasticity characteristics as measured by Plasticity Index (PI). (applicable to clayey soil).
- Reduction in the amount of silt and clay size particles. (through agglomeration or cementation).
- Increase in shearing strength.
- Decrease in volume-change properties (applicable to expansive soils).
- Reduction in hydraulic conductivity.
- Reduction of pore water.

Goals for mass stabilization of contaminated soil may include reduction of the leachability of hazardous constituents, and reduction of hydraulic conductivity thus immobilizing hazardous constituents. An increase in strength usually is desired as well.

More information on the physical and engineering properties of treated soils, including cement modified soil and soil cement is available from a number of sources including publications from the Portland Cement Association, Deep Foundations Institute, and American Concrete Institute.

Binders

Mass stabilization involves mixing binder into soil subject to treatment. A variety of binders have been used including portland cement, fly ash, slag, kiln dusts, and lime. The most commonly used binding agent in mass stabilization is portland cement. Most people are familiar with portland cement as the gray powder that is mixed with sand, aggregate, and water to create concrete used in construction. Cement itself is used in mass stabilization. When mixed into soil cement-modified soil or soil cement is produced. Water may be added if the soil does not include sufficient water to hydrate the cement. Portland cement is a generic material manufactured to industry standards. Cement is a generic material manufactured to industry standards with global availability. The effects of
Portland cement additions to soil and the properties of these mixtures may be better understood than other binders. These factors make portland cement the most frequently used binder in mass stabilization.

Other binders may be considered for use in mass stabilization. These binders include fly ash, lime, bottom ash, slag, cement kiln dust, and lime kiln dust. Fly ash used in construction is usually classified according to the pozzolanic and cementitious properties of the fly ash. ASTM Class C fly ash has pozzolanic and cementitious properties. Class F fly ash has pozzolanic properties. A pozzolan is a material that becomes cementitious when reacted with calcium hydroxide. Other classes of fly ash may not exhibit these properties and may be used as inert “fillers” in mass stabilization. Lime may be used as lime or hydrated lime or as lime kiln dust—a byproduct of lime production. Ground granulated blast furnace slag, also called slag cement, has cementitious properties in mass stabilization.

The determination of what binder or combination of binders to use is based on attainment of performance standards, binder availability, and cost.

**Bench-scale Mix Design**

Projects usually include some level of laboratory-scale mix design. Several or more addition rates of a binder or combination of binders are mixed with representative samples of the soil subject to treatment. Mixing is usually done by bench-sized power mixers such as KitchenAid® or Hobart® stand mixers. Powered stand mixers impart significant mixing energy and shear to speed the work and assure thorough mixing. Thoroughness of mixing is important for reproducibility and comparison. Mixed samples are cured and then tested to determine if the desired engineering/physical properties (above) are achieved.
A matrix from successful mix designs is compiled. The matrix often includes the relative costs of the binder(s) used in the successful mixes. Cement addition rates may range from 100 pounds per cubic yard (lb/cy) to 350 lb/cy. Fine-tuning the mix design is important from a cost perspective. Fifty to 70% of the cost of a full scale mass stabilization project is the cost of the binder(s) used. There is a real incentive for selection of the least expensive mix design and efficient use of the binder(s) that meets the desired project performance standards.

FULL-SCALE MIXING

Mixing Equipment

Mass stabilization at full scale has been done with a variety of mixing equipment. These include deep soil mixing augers, high pressure jets, pulver mixers or road reclaimers, power mixer attachments to excavators and bare excavator buckets. Commonly used are the augers, excavators, and excavator attachments.

Soil mixing augers are efficient for mixing depths greater than 25 feet. These augers are up to 12 feet in diameter and are supported by a crane. An auxiliary turntable is mounted on the crane providing the power to turn the auger. The auger has a hollow stem and the auger flights have jets which inject the binder into the treatment area as the auger rotates through the soil.

![Figure 9 (left): 12-foot auger for deep mixing.](image)
![Figure 10 (right): Crane and turntable used in auger mixing.](image)

Excavators with attachments are efficient for mixing depths less than 25 feet. Power mixers are attachments to an excavator. Power mixers resemble a very powerful rototiller on a 20-foot stem. The power mixers are powered by the hydraulic system of the excavator. The mixing head of the power mixer imparts the mixing shear necessary to thoroughly mix the binding agent into the subject soil. A nozzle located between the mixing drums is used to inject binder(s) at the point of mixing.

Excavator-based power mixing appears to be particularly well suited for railway work since: (a) the attached mixing head can reach the required depths of treatment, (b) excavators are commonly available, (c) excavators are easily truck or rail transported to the jobsite- even high rail equipped excavators are now available, (d) the range of motion of an excavator’s arm reduces the amount of time lost in moving the mixing equipment in order to treat an area and (e) the attached power mixer imparts the mixing shear needed for thorough mixing and efficient use of binder(s).
Some projects utilize two or more geotechnical methods for improving the bearing capacity of subgrade. An example is the use of a combination of geogrids, compacted material, columns, and mass stabilized soil for new right of way suitable for high speed rail through marginal soil areas. The mass stabilized section is created first to act as a construction mat supporting the heavy equipment needed for the installation of columns or piles. The mass stabilized section remains as a component of the finished subgrade, bridging the columns, and supporting compacted material above.
Stabilization of subgrade or embankments in right-of-way can be done on existing railways. Areas of soft subgrade can be “spot” treated. Significant lengths of embankment can be treated. The mobility of excavator-based mixing equipment is an advantage. High rail-equipped excavators can be mobilized to treat remote locations.

Figure 14: “Spot” Treatment on Both Sides of an Existing Railway.

Binder Injection “Wet” vs “Dry”

Mixing binder into marginal soil while the soil remains in place (insitu) requires some method of introducing the binder into the subject soil. Binders are introduced either wet or dry. In “wet mixing” the binder is mixed with water prior to introduction. Using portland cement as an example, the cement is mixed with enough water to produce a pump-able grout. This grout is then injected and mixed into the soil by augers, power mixer, or other mixing equipment. An excess amount of water is used to produce a pump-able cement grout. “Excess” because in order to make a pump-able grout a water to cement ratio (w/c) of greater than 1 is needed. Portland cement chemically requires only a little less than half its weight in water to fully hydrate- a w/c ratio of a little less than 0.50. (3) Highest strengths are achieved at w/c ratios closest to 0.5. While the excess of water in a pump-able grout (w/c >1) may lubricate the mixing, more grout and corresponding cement (and cost) may be needed to achieve the desired strength properties of the treated soil.

“Soft” (marginal) areas of soil are often the result of excessive water in the soil. Mass stabilization is very often used to “dry” soil to improve its engineering properties. Dry mixing may be appropriate in areas where there is sufficient water already present in the soil to hydrate the cement. Dry mixing uses pneumatic Pressure Feeders to feed the binder to the augers, power mixers, or mixing equipment. Dry mixing is often more cost effective compared to wet mixing. Utilizing the existing water within the soil may result in a water cement ratio closer to 0.5. Higher strengths can be attained with lower addition rates of cement. Note that over 50% of the cost of a mass stabilization project is the cost of the binder.

Locating, Controlling, Recording for QA/QC

Mass stabilization is used to improve infrastructure. The engineering properties of mass stabilized areas are important for the support of buildings, highways, roads, and rail systems. Efficient insitu mixing and meeting performance standards requires monitoring of the actual location, depth, binder addition, and thoroughness of mixing. The advent of GPS equipped mixing equipment, computer monitored binder feed and metering devices, and
computer recording of these conditions has made this job easier. Automated data recording is used in quality control and quality assurance documentation.

Figure 15: Schematic of GPS and mixing data recording system mounted on Power Mixer and Pressure Feeder. Illustration includes excavator operator’s display guiding operator- green completed “blocks” and red not-yet-completed “blocks” and graphic of data reports.

EXAMPLE PROJECTS

High Speed Rail Peräseinäjoki, Finland (3)

Pilot testing of mass stabilization methods was conducted in order to design/improve a right-of-way for high speed operations. Improvements to grade support to facilitate high speed passenger trains at speeds of 120 mph (200 km/h) and freight trains with speeds up to 60 mph (100 km/h) with rail axle weights of 56,000 lb (250 kN).

The right-of-way goes through an area of peat and silt. This area was comprised of 15-foot (5-meter) deep layer of peat, underlain by 6 to 15 feet (2 to 5 meter) of silt, underlain by a moraine.
Figure 16: Confinement of embankment between mass stabilized areas.

The mass stabilized area along side of the railroad embankment essentially creates confinement of the railroad embankment from the peat soil on either side. This confinement may improve the bearing capacity of the embankment. A Power Mixer attachment to an excavator and dry binder Pressure Feeder was used to treat the peaty soil insitu. Sulfate-resistant portland cement was used as a binder. The binder addition rate was 170 lb/cy of soil (100 kilograms per cubic meter (kg/m³)). Shear strength of 5 psi (40 kPa) was achieved ensuring embankment stability and zero settlement of the rail under the anticipated loads of high speed passenger trains and freight trains.

Foundation for the High Speed Rail in Luhdanoja, Finland (3)

Portions of 40 mile (63 km) new high speed rail line cross areas of peaty soil. Design anticipated maximum speeds attaining 140 mph (220 km/h). Passing over soft ground mass stabilization was used to create 15-foot (5-meter) thick pads or working platforms for pile driving equipment. A Power Mixer Feeder attachment to an excavator and dry binder Pressure Feeder was used to treat the peaty soil insitu. Ordinary portland cement was used as the binder at an addition rate of 340 lb/cy (200 kg/m³). This addition rate easily created a working platform strong enough to support the 50 metric ton pile driving equipment. Piers were driven through the stabilized soil and underlying peaty and clayey soil onto competent supportive layers beneath.

Figure 17: Mass Stabilization creating working platforms for pile driving equipment at Luhdanoja, Finland
Mass Stabilization Elements to Dampen Train Induced Vibration at Koria, Elimaki, Finland

A column-stabilized wall along the railroad right-of-way was used to dampen vibration from the operating line to an adjacent residence. The “wall” also served to confine material within the embankment providing additional stability to the right-of-way.

Embankment Stabilization Near Nokia, Finland

In 2014, an embankment bordered by a freshwater lake was stabilized to permit heavier and more frequent freight service on a railway near Nokia Finland. A section of an embankment 500 ft (150 m) long by 30 ft (10 m) wide immediately adjacent to a lake was stabilized to a depth of 23 ft (7m). A Power Mixer and Pressure Feeder were used within the limited work space confined between the lake and the rail bed. The project was conducted in February’s -4°F (-20°C) temperature.
Figure 19 (top): Existing railway near Nokia, Finland

Figure 20 (middle): Embankment and confined work area between lake and rails

Figure 21 (bottom): Mass stabilization with Power Mixer and Pressure Feeder
REFERENCES


2. Mikko Leppänen of Ramboll Finland OY


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Mass Stabilization

• Geotechnical and/or environmental remediation technique
• Mixing binder(s) into soil/sediment while material remains in-place (insitu).
• Improve physical and chemical properties of the subject material.

Right-Of-Way Soil Stress and Strain

• When load (stress) is applied, movement (strain) of soil will occur.
• Stiffness = Stress / Strain
• Subgrade stiffness is desired

Strain of Soil in Right Of Way

• Settlement
  – Total – seldom an issue
  – Differential - settlement over short distance, change in rail geometry
• Slope Stability
  – Slides

Improvement Physical Properties

• Increase California Bearing Ratio (CBR)
• Increase Unconfined Compressive Strength (UCS)
• Reduction in Plasticity, measured by PI
• Reduction in amount of silt & clay particles by agglomeration or cementation
• Increase Shear Strength
• Decrease in volume change properties (expansive soils)
• Reduction in hydraulic conductivity

Railway & Right-Of-Way Applications

• Protects human health and the environment by immobilizing hazardous constituents
• 2nd most frequently applied technology for Superfund site source control remedies
• Insitu application permits re-use of contaminated properties e.g. Brownfields

Environmental Remediation Applications
Results

BEFORE

AFTER

Binding Agents

Portland cement
Cement kiln dust
Fly ash e.g. Class F and C (pozzolanic fly ashes)
Lime e.g. quicklime, hydrated lime
Lime kiln dust
Slag

Influence of Water/Cement Ratio

• Strength of hydrated cement mixtures is highly influenced by water/cement ratio
• Stoichiometric W/C is around 0.4
  – Lower w/c result un-hydrated cement- wasted cement
  – Higher w/c results lower strengths- more cement req’d
• Water of convenience
• Soils with greater than 30% water maybe better “dry mixed”

Laboratory Formulation

Cost and Efficient Use of Binder Matters

• Most of the cost in a mass stabilization project comes from the binder, which can represent about **50-70 % of the total project cost.** Cement 100-350 lb/cy
• Efficiencies are improved by:
  • Controlled Water/Cement ratio
  • Thoroughness of mixing- mixing shear
  • Accurate metering
  • Accurate location

Physical Tests
Example Mixing Methods

• >25 feet Below Ground Level
  – Augers
• <25 feet Below Ground Level
  – Excavator buckets
  – Excavator attachments - Power Mixers

Auger Mixing

Power Mixer and Pressure Feeder

Excavator-Based

Thoroughness of Mixing = Efficiencies

MIXING ENERGY and SHEAR

SPOON FOLDING ACTION

Efficient Use of Binders Matters

Most of the cost in a mass stabilization project comes from the binder, which represents about 50-70 % of the total project cost. Efficiencies (Cost Savings) are improved by:

• Thorough mixing (mixing shear & energy) resulting in intimate contact of binder and subject material.
• Introduction of binder at mixing point.
• Locating and metering of binder to avoid under-dose and overdose.
• Use of dry binders in wet materials to conserve drying capacity of binders.
Mass stabilization can also be used in combination with deeper soil mixing or even other ground improvement methods. The top part of the soil layer is mass stabilized while deeper soil layers are reinforced by deep soil mixing, concrete columns, stone columns, etc.

New Railway: Combined Technologies

Rail Embankment Stabilization Nokia Finland

Railroad embankment support, Nokia Finland

- Stabilize embankment for heavier/more frequent freight traffic.
- Section of embankment 500 ft long, 30 ft wide, 23 ft deep (150X10X7 m)
- Confined work space
- February 2014 in -4°F (-20°C)

- Soft peat area was hardened by mass stabilization to carry heavy piling (50 metric ton) machines
- 1000 ft (300 m) X 130 ft (40 m)
- Up to 16 ft (5 m) deep
- 70,000 cy (50,000 m³)
- Mix design 340 lb/cy (200 kg/m³)

Existing Railway: Improving Areas Two Sides

Subgrade Stabilization New High Speed Rail Luhdanoja, Finland

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Project to support railway embankment so that the trains maximum speed can be increased. Personal trains to 200 km/h and cargo trains to 100 km/h.

- Depth max. 15 ft (5 m)
- Width 10 ft (3 m)
- Length 1000 ft (300 m)

Project for one complete ALLU stabilization system.

Location and modeling of vibration dampening effects of column stabilized wall along rail Koria, Elimäki, Finland

Widening existing road, Florida USA

- Project to widen existing road from two lane to four lane. New road will used for possibly evacuation.

- Environmental:
  - High water level
  - Soil rich of peat and vegetation

- Site facts:
  - Length 9 miles (14.4 km)
  - Width 4 ft to 60 ft (1.2…20 m)
  - Depth max. 12 ft (4 m)

Project for one complete ALLU stabilization system.

Questions - Contact

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