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GUIDELINES AND LOGISTICAL MODEL FOR RECYCLED MATERIAL USE IN INFRA CONSTRUCTION

CIRCWASTE, SAMPAANALANLAHTI

LIFE15 IPE FI 004
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CONTENT

ABBREVIATIONS

EDS	Energy-dispersive x-ray spectroscopy
FTIA	Finnish Transportation Infrastructure Agency (Väylävirasto)
GGBS	Granulated blast furnace slag
UCS	Unconfined compression strength
XRD	X-ray diffraction spectroscopy

1. INTRODUCTION

This guideline is part of EU LIFE IP funded CIRCWASTE project (LIFE15 IPE FI 004) and sub-project C.10. Subproject C.10 is piloting smart material utilization in earth construction including testing and piloting of new type of binder materials in mass stabilization as well as effective utilization of recovered materials in earth construction. The binder materials consist of industrial waste material mixtures from various industries e.g. lime mud, green liquor dregs, fly ash and gypsum waste. Dredged sediments from the nearby fairway deepening as well as bottom ash, kaolin clay and C&D waste have been used as filling and embankment material in basin B. Stabilization field piloting has been carried out in basin B during 2017-2018 and the stabilization works were finished in spring 2020. The stabilized bay area will be used as an industrial storage area. The cover structures for storage area will be constructed during 2021-2022 and utilization of various recovered materials will be piloted during the construction. This guideline will be updated after the cover structure piloting is finished.

Sampaanala bay case is an excellent example of transition from linear production process towards circular model and higher utilization rates for industrial waste materials, which has potential for economical savings and significant reduction in CO_2 emissions compared to traditional methods. The purpose of this guideline is to compile the most necessary issues which need to be taken into account when recovered materials are used in earth construction. The guideline presents also the best practices learned during the Sampaanala bay piloting.

2. RECOVERED MATERIAL USE AS MASS STABILIZATION BINDER

Designing of stabilization works goes in certain phases: Research and designing phase, tendering phase and implementation. During the implementation an important aspect for stabilization is quality control for used industrial waste materials and quality control of stabilization works. The implementation of mass stabilization process has been previously guided in various works e.g. mass stabilization manual and in previous EU-funded project Absoils (LIFE09 ENV/FI/000575) deliverable "*International guidelines on the methods of converting surplus soft soils into useful earth construction materials and on how to use them in the construction of different applications*" (Ramboll Finland Oy, 2015; Forsman, et al., 2015). The main steps of stabilization process according to above mentioned guideline are shown in figure 1.

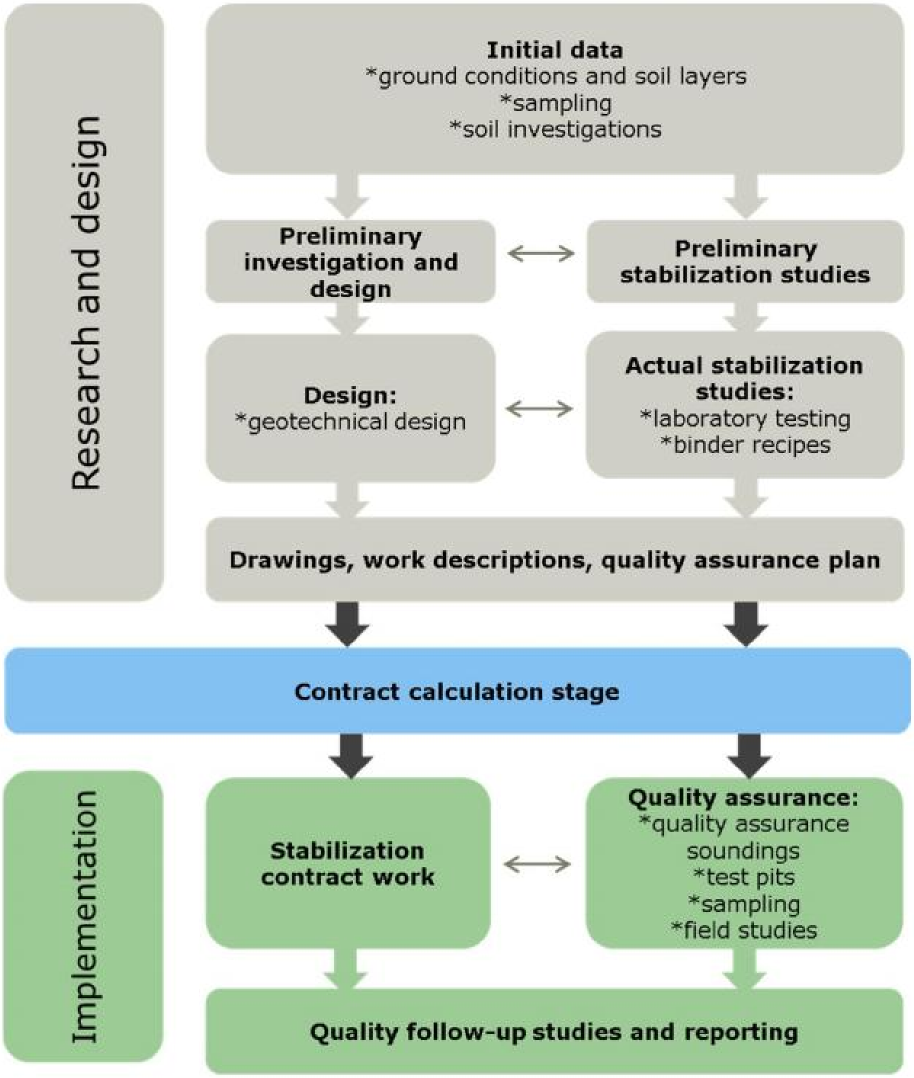

Figure 1. Main phases of mass stabilization project (Ramboll Finland Oy, 2015).

This chapter focuses more on specific issues which needs to be taken into account when utilizing industrial waste materials as binder materials in mass stabilization. The best practices learned during the Circwaste c.10 sub-project is also presented.

2.1 Material testing

In the development of industrial-waste-based binders for mass stabilization application both technical and environmental testing needs to be concerned as well as the cost effectiveness and practical implementation. Various industrial by-products such as fly ash, granulated blast furnace slag (GGBS), gypsum, lime waste has been tested for the binder material use together with commercial binders such as cement.

2.1.1 Technical properties

The material testing is essential part when implementing new type of binder materials in mass stabilization. The development includes the optimization of the binder composition. The functionality of the binder needs to be verified with unconfined compression strength tests (UCS) for stabilized soil samples case by case. The detailed stabilization laboratory testing is described in mass stabilization manual and in annex 1 of Finnish Transportation and Infrastructure Agency (FTIA) guideline design of deep stabilization (syvästabiloinnin suunnittelu 17/2018) which is available in Finnish (Forsman, et al., 2018).

The hydraulic strengthening is probably the most important property of the binders. Industrial-waste-based binders can for example try to imitate the properties and composition of cement and therefore the cement test methods can be applied in the preliminary testing phase. Hydraulic properties of novel industrial waste-material-based binders can be tested for example with chemical composition analysis (e.g. SEM/EDS or XRD), heat generation and compression strength after certain curing time (usually 28 days). The compression strength tests can be conducted to test specimen made from the binder (cement standards EN 196-1).

The physical properties, such as grain size and water content, of industrial waste materials used in binders have major effect on the utilization. The binder should be completely dry and fine grained so that it can be feeded in pressure feeder of mass stabilization equipment. The grain size of binder material can be modified for example by grinding. The grinding of certain industrial by-products e.g. fly ash increases the specific surface area of material and therefore it can also increase the reactivity of the binder.

After the composition and properties of industrial-waste-based binder has been adjusted to the wanted level, the functionality and suitable amount of the binder must be verified with by testing the unconfined compression strength of stabilized soil specimens (modified SFS 179-2 – CEN ISO/TS 17892-7:fi). For mass stabilization purpose the testing of properties of the binder itself is not enough and stabilization specimens must be tested case by case.

As the stabilized areas are usually relatively large and the soil quality varies it is important to consider the effect of variation soil properties (e.g. water content) on the area to the binder recipe. The soil samples used in preliminary laboratory testing should be representative for the whole contract area so that the final result for stabilization can be achieved despite the variation in soil properties. The binder composition or amount needs to be adjusted, if the UCS results does not meet the requirements given for the specific site. The adjustment of binder recipe can be done also during the stabilization based on quality control studies carried out during the stabilization works. Effective binder adjustment during the stabilization works, however, needs information from preliminary laboratory studies as the changes needs to be done quickly and there is no time to wait long curing times during the construction. Therefore, it is vital that the variation in soil properties in the site is known and the stabilization recipe has been tested in advance for different situations. It is also financially reasonable to adjust the binder recipe during the stabilization works if the soil properties vary a lot. As the binder cost plays major role in overall costs of the construction works in stabilization it is not reasonable to use excess amount of binder material.

The chemical composition can be modified by mixing or adding different waste fractions. The grain size and in some cases the reactivity of the binder can be modified by grinding. The UCS test specimen and UCS testing equipment is shown in the figure 2.

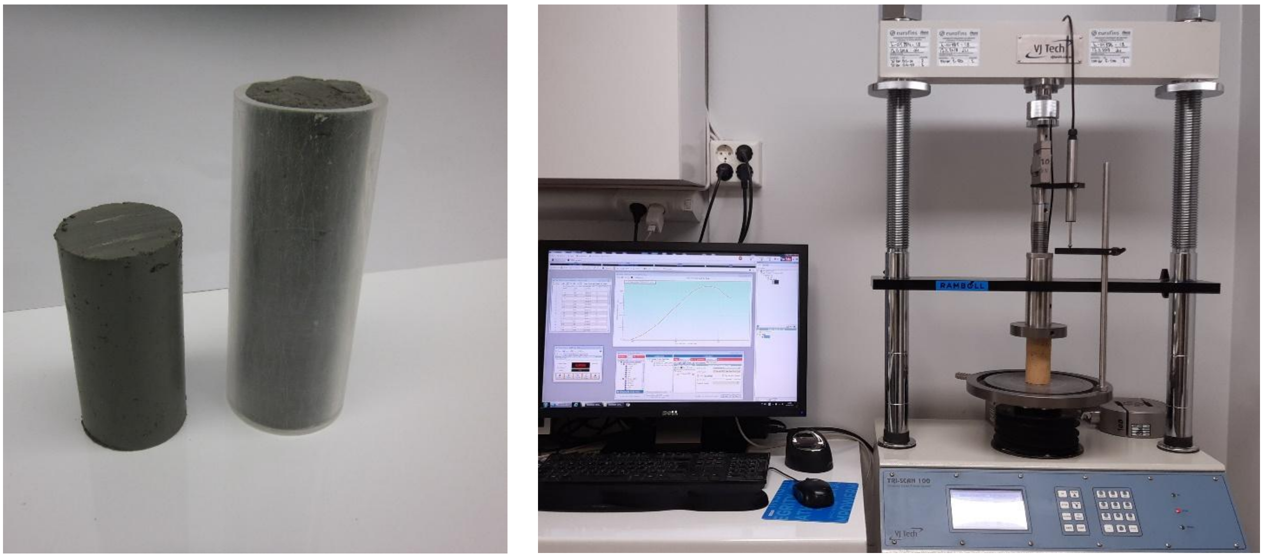

Figure 2. Stabilized test specimen (left) and UCS testing equipment (right)

The modification of soil or sediment before stabilization is notable method to decrease the dry binder need especially in cases when the water content of soil or sediment is very high. Moist binder material or other additives, such as gypsum, piled fly ash or additional fine-grained soil, can be mixed to sediment before mass stabilization to improve its strengthening properties and lower the need of dry binder, which can provide remarkably savings in binder costs. In Sampaanala bay, additional dredged sediment was added to the basin to raise the sediment level. Piled fly ash was mixed to sediment with excavator before actual mass stabilization. The suitable amount of additives needs to be always tested in laboratory in advance.

2.1.2 Environmental eligibility

Environmental eligibility testing is essential to carry out for industrial-waste-based binders. The leachability and elemental analysis testing can be carried out for the binder material. The same test methods can be applied for binder materials which are used for waste materials in general. Most commonly used leaching tests for waste materials are 1- and 2 batch leaching tests (SFS-EN 12457-2 and 3) or up-flow percolation test (CEN/TS 14405). The percolation test might in some cases be unsuitable for hydraulic binder material as the water permeability of hardened binder might be too low. The waste landfill criteria have been used in many cases for general evaluation of the suitability of the industrial-waste-based binders.

The solubility testing of binder material alone is not appropriate indicator for stabilized soil, as the soil stabilization reduces the leachability of various hazardous elements. Therefore, the testing of stabilized soil gives more accurate overview of the real leachability of components. One major problem for environmental eligibility testing of stabilized soil is the lack of uniform criteria and test methods. Batch leaching tests have also been used for stabilized soil, but more reliable results can be achieved with surface leaching (diffusion) test (figure 3). Test can be carried out for example according to CEN/TS 16637-2 or Dutch standard EA NEN 7375:2004.

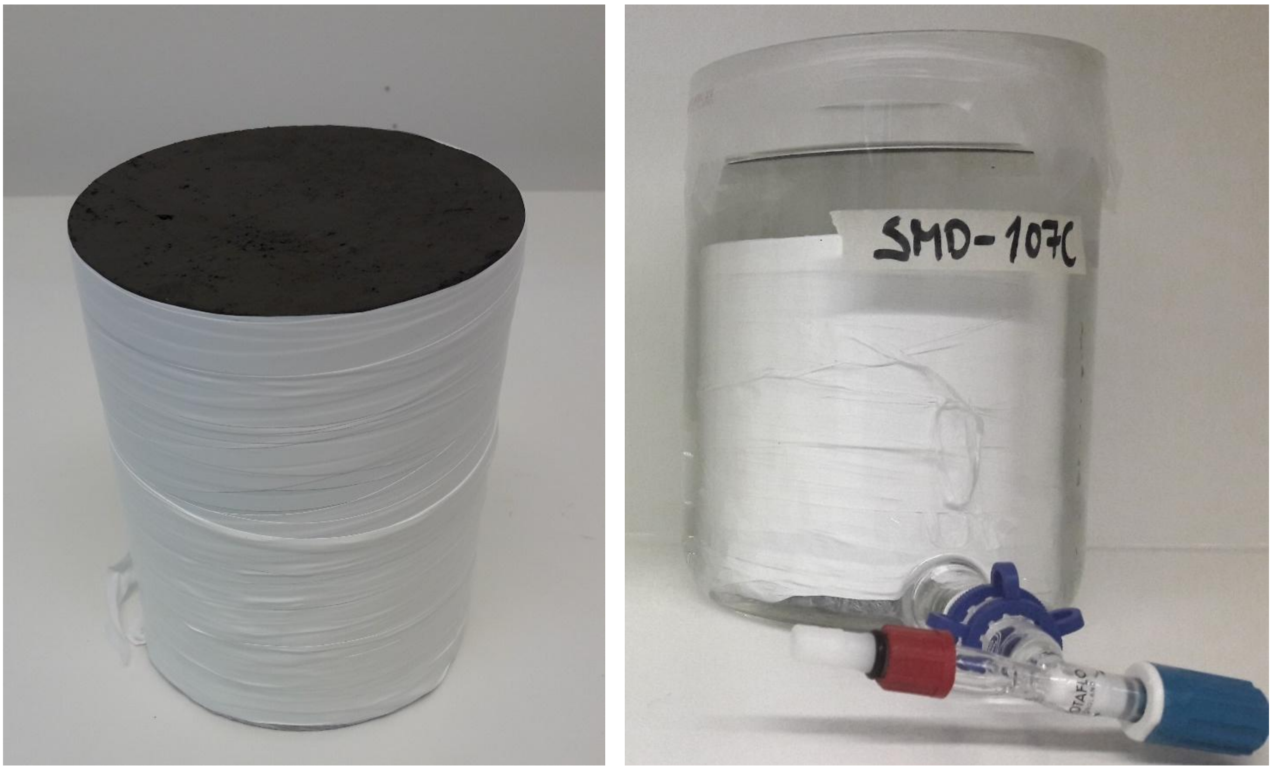

Figure 3. Prepared stabilized test specimen (left) and submerged stabilized test specimen (right) during sur face leaching test.

2.2 Design

The designing of subgrade reinforcement with mass stabilization needs to be designed case by case. Suitability of mass stabilization technique for various applications are described in mass stabilization manual (Forsman, et al., 2015). More detailed designing guide for deep stabilization applications can be found from FTIA guideline design of deep stabilization (Syvästabiloinnin suunnittelu 17/2018) (Forsman, et al., 2018). Existing structures, e.g. pile foundations in the project area, are important factor to consider when planning mass stabilization. Important issue to consider in the designing of mass stabilization is the overall cost effectiveness of construction. The binder costs cover usually over 50 percent of the overall costs of stabilization works. The binder cost can be lowered by replacing commercial binders with cheaper alternatives (industrial wastes) or by enhancing the soil properties (e.g. water content) by mixing or adding some surplus material before stabilization. In Sampaanala bay both of these measures were used: dredged sediment was deposited to bay before stabilization and additional piled fly ash was premixed to sediment with excavator before mass stabilization. In addition, commercial cement binder was replaced with industrial waste materials, mostly with dry fly ash from the power plant just next to the site. The surplus soils, such as silt or clay, are especially in Finland deposited and not used. Such material could also have been used instead of dredged sediment in Sampaanala bay. Additional quality control for soil properties needs to be considered, if the additional soil or sediment is mixed in large quantities before stabilization, as this changes the index properties of soil which effects on the binder recipe for stabilization.

In Sampaanala bay the mass stabilization works were carried out in several phases. The main reason for the phased construction was availability of fly ash which was used as a major replacement of cement in binder. The storage hall was filled with fly ash and the stabilization work was continued after the storage was full. When all the fly ash was consumed, the stabilization works paused and the storage was filled again. The availability and logistics of suitable industrial-waste-based binders needs to be considered in large scale mass stabilization projects as they might be limiting factor especially if the schedule for construction is tight. The best practices for the logistics in Sampaanala bay case are further described in section 4.1.

The existing structures and other possible obstacles need to be considered when mass stabilization is designed. For example, Sampaanala bay had a lot of sunken logs due to recent industrial activities in the bay. The logs and other obstacles such as rocks needs to be mapped in advance and removed or take into account in the stabilization works. The deep stabilization equipment, such as mass stabilization mixing head, can break if it hits the rocks or other large objects. Existing structures and foundations should also be considered in stabilization. In Sampaanala bay for example there was old conveyor passing through the stabilized area founded on steel piles. Due to this the nearby area of the conveyor was left unstabilized so that the foundations would not be effected.

The designing of mass stabilization with waste-based binders is carried out similarly compared to traditional mass stabilization. The major exception which needs to be considered in design phase with waste-based binders compared to traditional mass stabilization is possible environmental permitting. The use of waste-based materials in earth construction has variable legislation in different countries and always the local effective legislation needs to be considered.

The waste materials produced in industrial processes, for example fly ash, are considered as waste and the utilization follow waste legislation. The industrial waste can also be considered as a by-product if the material if the further use of material is guaranteed and it can be utilized without remarkable modification (European Commission, 2008; European Commission, 2007). The waste material must be evaluated and approved as by-product. In Finland various industrial wastes, such as many iron and steel industry slags, have received by-product status. The status is applied e.g. in environmental permit of the production plant and it is granted by local environmental authority. By-products does not anymore fall under the scope of waste legislation. It is also possible to apply end of waste status for waste-based products according to Waste Framework Directive 208/98/EC. However, by-products and materials which fulfills the end of waste criteria need to meet the requirements (product legislation, chemical legislation etc.) given for the application (European Commission, 2008).

In Sampaanala bay piloting the industrial-waste-based binders were utilized in mass stabilization according to environmental permit which was applied for the area. The need for environmental permit needs to be considered in advance in design phase of the project if the waste-based binders are to be used in mass stabilization. The required leaching tests or other environmental eligibility testing should be designed to carry at the same time with technical testing. The laboratory testing for mass stabilization takes usually 2-3 months in minimum and even longer if the testing is carried out in several phases. The environmental permitting on the other hand can take for instance in Finland from three month up to couple of years.

2.3 Construction

The mass stabilization with dry industrial-waste-based binders does not differ from the use of commercial binder materials e.g. cement. The grain size of waste-based binders might have effect on operation of pressure feeder. The suitable grain size of binder material needs to be verified from the mass stabilization equipment manufacturer. The chemical composition of binder can also have effect on the equipment and in some cases, it can cause corrosion or wearing of the equipment. This needs to be also considered and verified from the equipment manufacturer.

The condition of the stabilized area needs to be examined before mass stabilization works. Big obstacles like rocks, tree stumps, logs, etc. can cause damage to mass stabilization equipment and they need to be clear out from the construction area before mass stabilization. In Sampaanala bay the constructed area was cleared from sunken logs with excavator before the stabilization works (figure 4).

Figure 4. Removal of logs from the basin before mass stabilization carried out by excavator with attached rake head

As mentioned, the dry binder material can be feeded with mass stabilization equipment. However, the moist binder materials like gypsum waste or piled fly ash cannot be feeded with pressure feeder. The moist binders need to be mixed manually to the sediment. The moist binders are spread on top of the stabilization block and premixed with excavator to the sediment (figure 5). Further mixing is carried out by mass stabilization head during the mass stabilization, when the dry binder is mixed to the sediment.

Figure 5. Spreading and premixing of gypsum waste to sediment with excavator.

Typically, the binder amounts which are feeded with mass stabilization equipment varies from 50-200 kg/m^3. The feeding of high amounts, from 250 to 350 kg/m3, of binder was also tested during piloting in Sampaanala bay with two different methods:

- 100 kg/m^3 of the dry binder was spread on top of the stabilization block and premixed with excavator. Rest of the binder (250 kg/m^3) was added with mass stabilization equipment. The premixing some of the binder was done to speed up the mixing.
- All 350 kg/m^3 binder was added with mass stabilization equipment.

The used binder material in this test was fly ash from nearby power plant. Both tested methods worked on the field. More homogeneous result was obtained by feeding of high amount (350 kg/m^3) of fly ash with mass stabilization equipment (figure 6). However, the time consumed for stabilization was higher (around 2,5h per block) than usually (around 1,5h per block) with this method.

Figure 6. Mass stabilization with high (350 kg/m^3) binder amounts

2.4 Quality assurance

Quality assurance (materials, technical quality, environmental quality) needs to be done before the actual stabilization work, during the stabilization work and after the stabilization work. Quality assurance is linked to the sampling and to the technical tests at the site and in the laboratory. It is also good to keep in mind that additional quality control and binder recipe verification needs to be done, if the soil properties are changed by mixing additional soil, sediment or other additives (such as piled fly ash) which changes the original soil properties.

It is recommended to take samples (à ~2 kg) from all the used binders every now and then for archiving purposes. If any troubles or surprises occurs these samples can be investigated if needed. Working methods such as mixing time and efficiency needs to be observed continuously.

Documentation is very important part of quality assurance. Documentation is needed for example from the binder producers, stabilization contractor (used amount of the binders/each block, amount of stabilized mass, mixing time, dates and times when each block has been stabilized, weather conditions, any troubles or malfunctions, behavior of the binders etc.) and from the quality controller (ocular observations, measurement readings, other test results etc.).

2.4.1 Technical quality

Before the stabilization and before any moist binder added there must be taken “0-samples” from the basic mass to be stabilized. Samples need to be taken from different depths and water content must be determined immediately to guide the stabilization work (if the water content differs much from the assumed). Later also the ignition loss and the density of the sample needs to be determined in the laboratory. These results (together with the water content) makes reading of the other technical results easier afterwards, if needed.

In the mass stabilization pilots the technical quality of the stabilized mass is checked right after the stabilization and control-investigations continue in different ways during the strengthening phase. The methods are same as in the actual production stabilization, but they need to be made more often in the pilots.

Right after the stabilization, when the binder feeding and the mixing is done, samples are taken from the stabilized mass (different depths) with the help of an excavator (figure 7). It is recommended to take 1-liter archive sample and make some compacted samples in cylinder shaped form for different test purposes that are made later in laboratory.

Figure 7. Sampling for technical testing during stabilization works.

The size of the cylinder for 1-axial compression strength test piece is *Φ* 42 mm, *h* 120 mm and for water permeability test piece *Φ* 102 mm, *h* 120 m. Normal storage temperature for specimens is +20 °C for the first two days and after that +8 °C until the specimen is tested. Vertical load is not used during curing time. After storage a test piece is removed from the form and the ends of the test piece are flattened (figure 8).

Figure 8. Making of test specimens (left) and after curing time compression strength test specimen is removed from the form, ends are flattened, and specimen is ready to be tested (right).

1-axial unconfined compression strength (UCS) is a standard test where a cylindrical test piece is subjected to a steadily increasing axial load until failure occurs. The axial load is the only force or stress applied. The rate of the load is 1 mm/min for stabilised sediment test pieces. The test is performed after certain curing time of test specimens. Usually the curing time is 7, 28, 90 and/or 180 days.

Water permeability of test pieces/materials is tested in "flexible wall permeability test with constant pressure". A test piece inside a rubber membrane will be subject to a 3-dimensional pressure in a test cell. Water will be conducted through the test piece from a front container to a back container, and the water level differences of the containers will be measured. Water flows upward inside the test piece, when there is higher pressure in the front water container than in the back container. The water permeability factor is calculated with a simple formula using data and dimensions from the test and test piece.

In the following days after stabilization the beginning of the strengthening phase at the stabilized area is tested with a field inspection vane borer (figure 9). The vane borer is driven down into the stabilized mass to the desired depth, measuring instrument is placed on the top of the rods and measurement of shear strength is taken by slowly turning the extension rods until shear is obtained. Measurements are recommended to be done depth of every 1 m. Measuring the shear strength gives important information of the strengthening and helps to estimate when it is safe to go on top of the mass with an excavator and continue working and stabilizing masses in the near area. Amount and time of the measurements depends on how the strength develops in the stabilized mass. If demanded level of the starting phase strength (usually ~20 kPa) is not achieved, there must be done more measurements later on. If the demanded level of the starting strengthening phase is achieved no more measurements need to be done. Field inspection vane borer is intended to measure shear strengths under 100 kPa.

Figure 9. Field inspection vane borer set (top left), vane borer driven down into the stabilized mass to the desired depth (top right) and measuring the shear strength of stabilized mass at the Sampaanala bay (bottom left & right).

Long-term strength development in the stabilized mass needs to be measured with a geodrilling machine. Usually the shear strength is measured 28 and/or 90 days after the stabilization to see what is the “final” (most of the strengthening has happened) level of the achieved strength.

2.4.2 Environmental monitoring for mass stabilized soil

There are several ways to carry out environmental monitoring in mass stabilization sites. Tests can be done directly to the stabilized soil with different leaching tests. In this case, the test specimens are made from the stabilized soils in the construction site and the specimens are usually let cure for certain period of time before leaching tests. After curing time, the test specimens can be tested with batch leaching test or surface leaching tests. In Sampaanala bay case, surface leaching tests were used for environmental quality assurance. In figure 10 is showed sampling and making of test specimens for eligibility testing in Sampaanala bay. The detailed results from the environmental eligibility testing is shown in the “Environmental eligibility report” of the C.10 subproject.

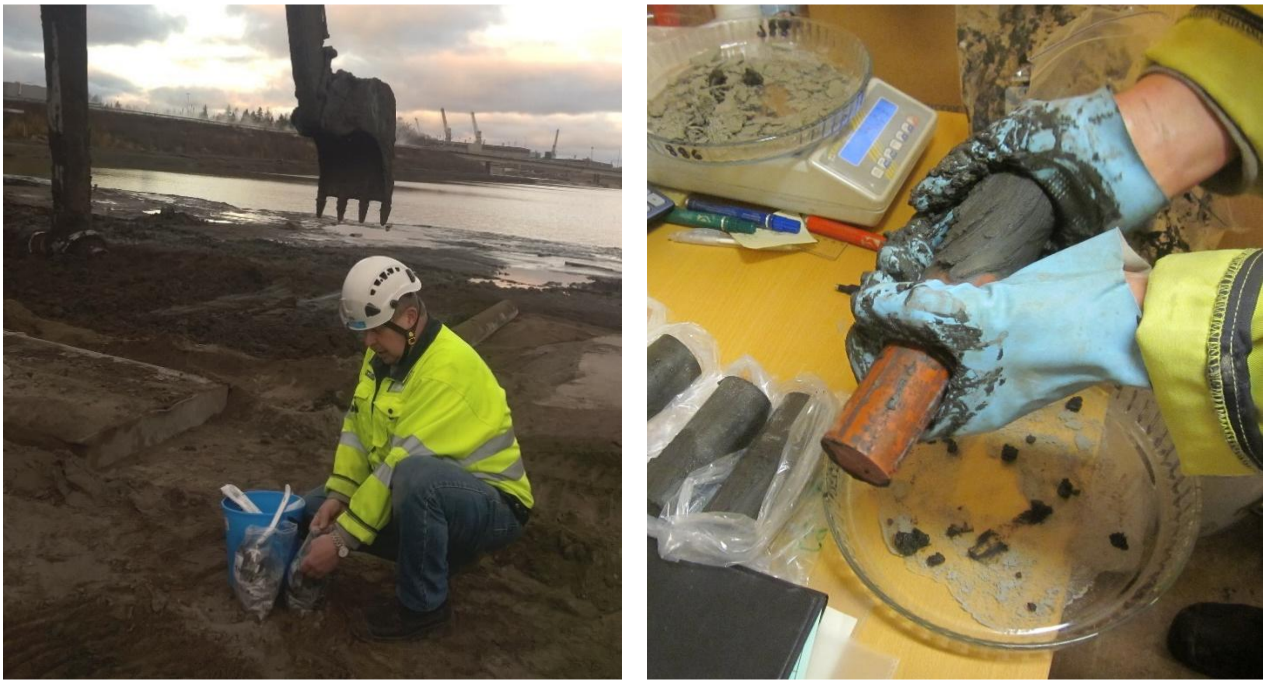

Figure 10. Sampling for environmental eligibility testing during stabilization works (left) and making of test specimens (right).

Indirect methods used for environmental monitoring of stabilized soil can include monitoring of seepage water from the stabilized areas. In some cases, lysimeters are used for environmental monitoring of stabilized soils. The lysimeter testing however can be challenging for the mass stabilized soils, if the water permeability of the soil is very low and the generated amount of seepage water in lysimeters remains low which may cause unreliable test results.

The selection of environmental monitoring method for each site should be designed case by case. Usually the local environmental authorities may suggest some environmental monitoring method for the site which is determined in the environmental permit of the site, where industrial wastes are used in the earth construction. For example, the environmental permit for construction of Sampaanala bay includes the follow up of stabilized soil leaching properties with surface leaching test.

3. RECOVERED MATERIAL USE IN BASE COURSE

To be updated after piloting is done

3.1 Material testing

3.2 Design

3.3 Construction

3.4 Quality assurance

4. LOGISTICAL MODEL FOR RECOVERED MATERIALS

The designing of logistics is essential part of the utilization of industrial waste materials in earth construction applications. The utilized material volumes are typically high in construction and therefore the optimization of transportation distances and intermediate storing has major effect on the material costs and emissions. As the industrial waste materials are typically formed irregularly, the availability, storing and scheduling of such materials needs to be considered and ensured well in advance. Certain materials such as fly ash is typically generated during winter season when the electricity and heating need is higher. The utilization of fly ashes, however, is usually carried out during the summer season. The properties of utilized waste materials vary a lot and the quality control for all waste material is important in every step from production to utilization.

4.1 Transportation

The recovered materials can be transported with typical transportation vehicles such as earth moving trucks, tanker trucks, ships etc. In Finland the transportation is carried out mostly with trucks because the cost-effective material transportation distances are typically short for recovered materials. The recovered materials are usually utilized as close as possible to the location where materials are formed to minimize transportation expenses. The recovered materials are used to replace natural aggregates in earth construction applications, and they are competing with them for price and material properties. Therefore, all additional loading, unloading, treatment or transportation needs to be minimized to minimize the overall material costs.

The sediments from the Rauma fairway deepening were transported to Sampaanala bay with dumper. Dry binder materials like cement and fly ash were delivered with tanker trucks to the site. The dry fly ash from the nearby power plant was transferred pneumatically to storage tent where it was loaded to tanker truck. All other utilized recovered materials like crushed concrete, bricks, kaolin clay and bottom ash were transported with earth moving trucks. Some suitable transportation methods for different materials are listed in table 1.

Table 1. Possible transportation methods for various waste materials

Transportation method	Material
Earth moving truck or dumper (no cover)	Crushed concrete and bricks, green liquor dregs, kaolin clay, surplus soils and sediments
Earth moving truck (covered) or trailer truck	Moisturized fly ash, bottom ash
Tanker truck	dry fly ash or other dry industrial-waste-based binder materials
Cargo trains (railway)	High voluminous materials can be transported via railways for large construction sites, if the distances are long. Train cars are suitable for both dry and moist material transportation. The limitation for railway transportation is the availability of railway connections between site and material producer as well as the overall cost-effectiveness of material utilization.

4.2 Storage

The storage requirements vary depending on the waste material as the storing can effect on the material quality and properties. Many of the recovered materials can be stored outdoors like natural aggregates without any special arrangements. Storage of some materials, especially fly ash, needs to be considered more in detail depending on the end use of the material. The material quality assurance is also important factor to consider when designing the storage of different materials as the quality (e.g. water content) can vary during the storage time. The storage methods and some estimation about the technical storage time of various recovered materials are listed in table 2.

Table 2. Storage methods for various industrial waste materials

Storage method	Material	Technical storage time
Storage piles without covering	Crushed concrete and bricks, bottom ash, green liquor dregs, kaolin clay, gypsum waste and fly ash	Long, no technical restriction, except fly ash which loses its reactivity if it is stored without covering.
Covered storage piles	Fly ash (moisturized)	Moisturized fly ash loses most of its reactivity in about 1-2 weeks depending on the amount of water added. Lost reactivity can be compensated with cement addition.
Lightweight Tarpaulin storage hall	Fly ash (dry)	Case-specific storage time depending air moisture contact, usually many months, even year.
Storage silos	Fly ash (dry), industrial-waste-based binder (dry)	Case-specific storage time depending air moisture contact, usually many months or even years.

In Sampaanala bay, the dry fly ash generated in the nearby Rauman Biovoima power plant was pneumatically transferred and stored in the tarpaulin light weight storage hall. The loading from the storage was carried out with screw conveyer (figure 11). The end use of the fly ash was binder material in mass stabilization. The ash could be collected around 1-3 months at the time in the tarpaulin storage hall. When the storage was full, the mass stabilization was continued until all the stored fly ash has been consumed. When all fly ash was consumed the mass stabilization was paused, and the storage hall was filled again. In general, material quality control, adequate storing capacity and ensuring of necessary material availability are key factors to be considered when designing the storing of industrial by-products.

Figure 11. Tarpaulin lightweight hall can be used for dry storage of fly ash from the power plant. Dry ash is stored in hall, loaded to tank truck and transported to stabilization site.

4.3 Material treatment and mixing

Some of the industrial waste materials e.g. fly ash can be utilized in mass stabilization without further treatment as the grain size and other physical properties are suitable for pressure feeder used in mass stabilization. Some of the piloted waste-based-mixtures however needed some additional mixing and milling before use. The compatibility of the waste-based binder mixtures for pressure feeder equipment needs to be considered beforehand while the binder material grain size or corrosivity or wearing properties might be unsuitable for pressure feeder.

In Sampaanala bay the fly ash was transported from the storage to the construction site with tanker truck (figure 12). The industrial-waste-based binder mixtures were mixed and milled for suitable particle size on production facility and transported to construction site in tanker truck. The industrial-waste-based binder mixtures used in the piloting were mixed to cement in the site by blowing them from different storage tanks several times before mass stabilization. The different mixing methods for high volume of binder materials during mass stabilization are further described in the chapter 2.3.

Figure 12. Dry binders were mixed on site by blowing them in different tanks several times before the mass stabilization. Two different binder mixtures (e.g. fly ash and cement) can be fed at the same time to the excavator with mass stabilization equipment.

4.4 Quality control

Quality control in all phases of material logistics and construction is essential when utilizing wastes in earth construction applications. The need for quality control varies between materials as some materials are more sensitive for properties shifting than others. In general, quality control should be done for recovered materials in following stages to ensure proper quality during the logistical chain:

- Quality control done by material producer
- Quality control during storage
- (Quality control after material treatment/handling, if it is carried out)
- Quality control of earth construction works

For example, fly ash properties may vary a lot in power plant depending on the fuel composition used in the boiler. In Finland, the environmental quality monitoring of generated waste, such as fly ash, is required to carry out continuously in power plants according to the environmental permit of the plant. If the fly ash is utilized in earth construction applications, it is also necessary to monitor the water content of fly ash during the storage. The requirements for water content depend on the end application. If the fly ash is used as a binder material it should be completely dry. If the fly ash is used as a massive layer structure or additional aggregate in mass stabilization, it is commonly stored slightly moisturized ($w \approx 15\text{-}20\%$) to prevent it from dusting.

After the storing fly ash can be treated of mixed together with other components or water depending on the end application. For binder material use fly ash is usually mixed with other components such as cement or lime and in some cases the mixture can be further milled before use. The proper grain size and homogeneity of the binder material is essential in mass stabilization. After the mass stabilization, the stabilized soil/sediment quality is verified with suitable test methods described in chapter 2.4.1.

If the fly ash is used for massive layer structure, the water content is adjusted near the optimum water content before the material is compacted. The adjustment of right water content before compaction is essential in order to obtain adequate bearing capacity for the structure. The quality control, such as bearing capacity testing or density measurement, is carried out for massive fly ash structures. The quality assurance of fly ash during each earth construction project step is summarized in the figure 13.

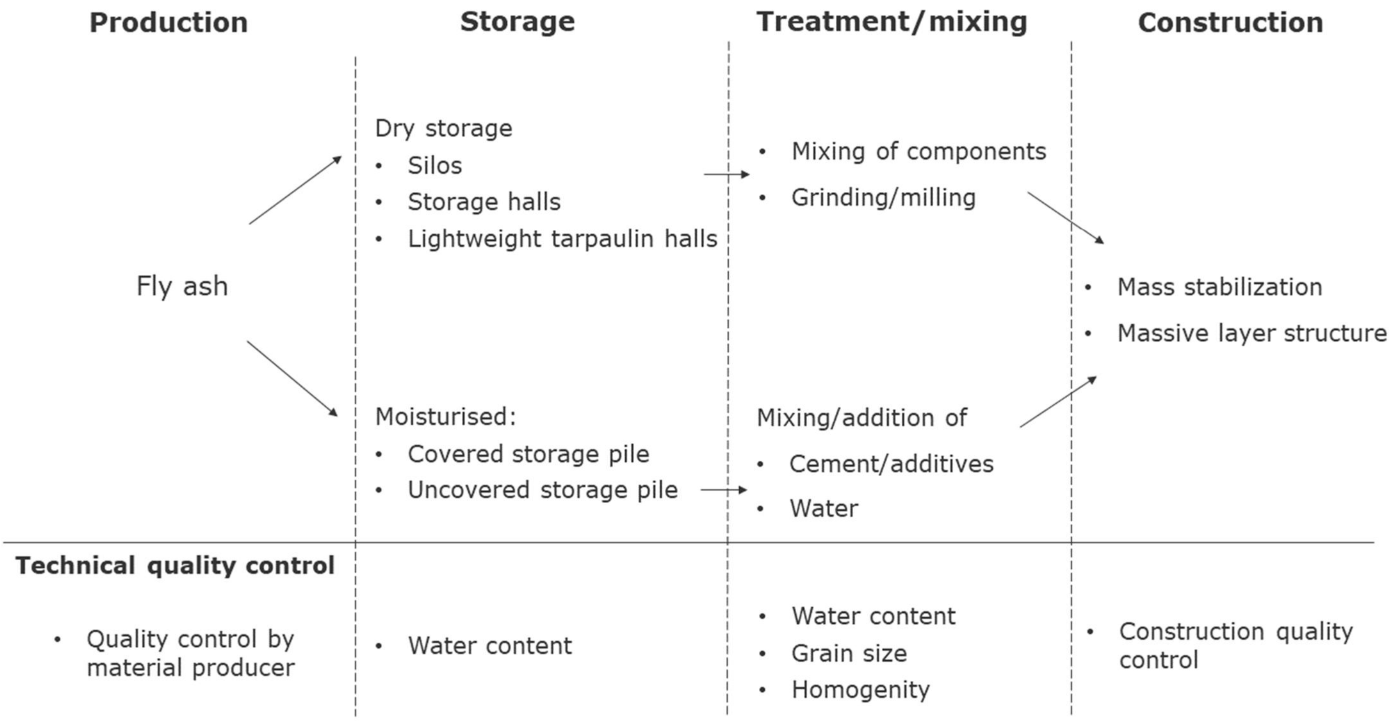

Figure 13. Brief summary of fly ash technical quality assurance during each phase in construction project

5. REFERENCES

European Commission, 2007. *Communication from the Commission to the council and the European parliament on the Interpretative Vommunication on waste and by-products.* Brussels: European Commission.

European Commission, 2008. *Directive 2008/98/EC on waste and repealing certain directives.* Brussels: European Comission.

Forsman, J., Jyrävä, H., Lahtinen, P. N. T. & Hyvönen, I., 2015. *Mass stabilization manual,* s.l.: Ramboll Finalnd Oy.

Forsman, J. et al., 2018. *Syvästabiloinnin suunnittelu,* Helsinki: Liikennevirasto.

Ramboll Finland Oy, 2015. *International guidelines on the methods of converting surplus soft soils into useful earth construction materials and how to use them in the construction of different applications,* s.l.: Absoils LIFE09 ENV/FI/575.