Externalities of Soil Stabilization in the Construction of Main Transportation Infrastructures. The Case of the High Speed Railway in North Italy: Economical and Environmental Benefits

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Abstract: The technique of soil stabilization is usually adopted with the purpose of rendering plastic soils coherent to the standards and requirements of engineering projects. The environmental benefits of soil stabilization versus the use of traditional natural material from quarries are generally underestimated. The case study of one significant section of the Italian High Speed Railway is presented here. This section is a part of the line from Milan to Venice. The volume of material that is needed for the development of embankments amounts to about 3 million m^3 and 1.5 millions m^3 of aggregates are needed for concrete. At the same time the construction of foundations produces about 1 million m^3 of soil: 350,000 m^3 from foundations, 400,000 m^3 from diaphragms and drilled piles and 70,000 m^3 from helicoidal piles. The need to manage such a significant volume of soil suggests the need for the consideration of recycling the clay soil after lime stabilization. The technical compatibility is here verified. The total costs of all the actions derived from the Environmental Impact Assessment for environment protection is less than 8% of the savings produced by the stabilization of soil. It finally demonstrates that the question of non-renewable resource management, such as soil, is strategic also under an environmental protection perspective.

1. INTRODUCTION

Air pollution, noise and vibrations, impacts on ecological balances or sometimes on flora and fauna, risk of water contamination, electromagnetic induction are considered the main environmental questions related to the construction and operation of transport systems. Scientific and professional communities all over the world are involved in the study of these questions engaging human and financial resources. In the last decade the know-how in this field has increased and the knowledge widely disseminated [1]. However there are issues related to the construction of infrastructures that are often neglected in terms of environmental assessment. Sometimes they have implications to the environment that are much more relevant in addition to traditional questions such as noise or air pollution. This is the case in the use of alternative materials, stabilization of soil and recycling, which is the topic of this paper.

The technique of soil stabilization is usually adopted with the purpose of rendering plastic soils coherent to the standards and requirements of engineering projects. The issue is always considered under a construction perspective and environmental benefits are often neglected.

These techniques have a long history. It was used in ancient Mesopotamia and Egypt, and Greeks and Romans later used soil and lime mixes to increase the stability of roads [2].

The first application on a significant scale was carried out in 1924 in the United States for short sections of federal motorways [3]. The first standards for soil stabilization using lime are relatively recent [4].

In the thirties the use of lime for stabilization of plastic soils increased greatly, especially in the USA, but the most important diffusion of the technique was during and immediately after the second world war, in consequence of the enormous increase in the number of motor vehicles.

More recently lime stabilization for the development of roads and railways has become a widely used technique in industrialized countries, from North America [5-8], to Australia [9] and in many European countries [10] and, surprisingly, in a few of developing countries (i.e. in Giordania [11]; in Ghana [12, 13]; in India [14, 15]; in Turkey [16]).

The excellent results of stabilization in many constructions [17, 18] and the promising frontiers for new applications, pressed researchers and engineers to write manuals and handbooks [19- 22] and to develop standard operating procedures [23] and quality controls [24] (see Table **1** for the standards).

Adding lime to clay soils has an immediate binding effect induced by the cation exchange between the metallic ions from the surface of clay particles and the calcium ions of lime. These ions saturate the electrical poles of water molecules that are around the clay particles and these particles are attracted closer to each other. This attraction makes the clay particles form flocks. The flocks change the grading of soil from ultra-fine micrometric particles to millimetre size particles that consequently change their mechanical properties. This process is immediate and occurs in the presence of a low percentage of lime (generally from 1 to maximum 3% by weight) and is commonly referred as lime fixation or soil modification [25].

When the percentage of added lime is higher (generally from 3 to 8%) chemical reactions occur: alumina-silicates

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Table 1. ASTM and AASHTO Standards for Lime Stabilization

For the Materials	
ASTM C977	Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization
AASHTO M216	Lime for Soil Stabilization
ASTM C593	Standard Specification for Fly Ash and Other Pozzolans for Use With Lime (applies to soil stabilization and building lime)
ASTM C618	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete
ASTM D5050	Guide for Commercial Use of Lime Kiln Dusts and Portland Cement Kiln Dusts
For the Tests	
ASTM D6276	Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization
ASTM D3155	Standard Test Method for Lime Content of Uncured Soil-Lime Mixtures
ASTM D5102	Test for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures
ASTM D 698	Test Methods for Laboratory Compaction of Soil Using Standard Effort
ASTM D 1557	Test Methods for Laboratory Compaction of Soil Using Modified Effort
AASHTO T 99	Standard Proctor Test
AASHTO T 180	Modified Compaction Test
AASHTO T 294	Conventional Resilient Moduli Test
ASTM D4318-00	Test Methods for Liquid Limit, Plastic Limit, & Plasticity Index of Soils
ASTM D3551	Lab Preparation of Soil-Lime Mixtures Using a Mechanical Mixer
ASTM D3668	Test Method for Bearing Ratio of Laboratory Compacted Soil-Lime Mixtures
ASTM D3877	Standard Test Methods for 1-Dimensional Expansion, Shrinkage, & Uplift Pressure of Soil-Lime Mixtures
ASTM D5093	Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring (can be used for soil-lime mixtures)
ASTM D6236	Standard Guide for Coring and Logging Cement- or Lime-Stabilized Soil
Moreover	
ASTM E1266	Standard Practice for Processing Mixtures of Lime, Fly Ash, and Heavy Metal Wastes in Structural Fills and Other Construction Applications

precipitate as hydrated cementitious in an alkaline environment produced by lime.

In this case the soil chemically changes its own properties and the process is properly referred to as stabilization. Stabilizing the soil increases mechanical properties not only in the force of grading changes but also for pozzolanic binding reactions that contribute to develop strength gradually over a long period of time [26].

Basically all types of clays react with lime, but the reactions can be different in kinetics or effectiveness depending on mineral composition. Clay soils with monmorillonite react significantly with lime and the cation exchange is relevant. Kaolinitic clays are less sensitive to lime [27].

The evidence from the literature demonstrate that from a mechanical point of view the properties of plastic clay soils after stabilization with lime in adequate percentages are coherent to required standards for unbound layers (subgrade and subbase) of roads and railway constructions.

More in depth, the effect of stabilization is quantified by a significant increase in the Atterberg Plastic Limit and by a relevant reduction of plasticity (Plastic Index). CBR values increase with aging, from 4 to 10 times the original value after 2 hours and over 100 times for the long term. The mechanical behaviour stress-strain changes from viscous-plasticity towards elasticity. For long periods of time, the modulus of elasticity increases up to 10 times the value of the modulus of the original clay soil. The effect of stabilization is evident also in the standard compaction test (Proctor test). The maximum value of dry densities decreases and simultaneously the value of optimum moisture content for compaction increases [28].

All these considerations demonstrate the relevant benefits of stabilization under a structural and mechanical perspective [29-31], but significant benefits have to be underlined under an environmental protection perspective and many times also under a financial one.

The specific objectives of this work are to validate the applicability of soft soil stabilization to High Speed Railway development and to assess the environmental positive impacts of the soil reuse. The soil stabilization in High Speed Railway construction has been rarely used but the environ-

mental benefits have never been quantified. This work gives a first useful methodological contribution through the presentation of a very important study case at the national and European level.

The case of Italy is anomalous because soil stabilization is currently not diffused as expected. Strong pressure for the use of stabilized soils came up in Italy at the end of nineties for the development of a High Speed Railway in the North of the country from Milan to Bologna. Here only clay soils are available on site. Without extensive stabilization an enormous amount of clay soils extracted from cuts, foundations, piles, and plinths should have been disposed as waste and, at the same time, volumes of adequate material should have been extracted from natural sites and transported to the yards.

2. LIME STABILIZATION OF CLAY SOILS

Stabilization of clay soils implies not only environmental benefits such as the saving of significant amounts of non-renewable resources, but sometimes relevant benefits from a financial point of view, if compared to the traditional approach using natural materials extracted from quarries. The financial advantages from stabilization are difficult to be calculated because they depend on many factors such as the distances of quarries, the characteristics of materials, the structure and logistics of yards, the available machines, and the cost of waste disposal. Considering all of these uncertainties, any generalization evaluating costs and benefits is completely unreliable. The assessments have to be developed case by case. Here, some considerations that can be assumed to be objective and commonly found in the technical literature are briefly summarized.

The construction of embankments using natural soil extracted from quarries without stabilization typically is developed in the following phases: acquisition of material, transport and dumping, arrangement of soil in layers of adequate thickness using a bulldozer or grader, compaction with vibrator steamroller.

If there is no limitation with the material supply, the volume of embankment that can be constructed in one day by a work team can be over $2000m^3$. The costs are for 90% of material acquiring and transport and for 10% of the work of the team. A portion of the 90% accounts for the transport from the quarry to the yard, and moreover the associated environmental (air and noise pollution) and societal costs (quality of life deterioration) should not be neglected.

The construction of an embankment using lime stabilized soil typically is developed in the following phases: excavation and short transport of soil inside the yard to the construction site, arrangement of soil in layers of adequate thickness using a bulldozer or grader, milling using a pulvimixer, lime mixing, levelling of the layer and compaction. The volume of the embankment that can be constructed in one day by a work team can be about $3000m^3$, but it depends on the soil characteristics, the weather, and the capacity of recycling machines. The costs are 40% for material, 40% for the machines and 20% for the work of the team.

In general, extrapolating from previous experiences and on the basis of consolidated know-how, when the balance between excavated and filling volume produces a significant soil surplus, the option of lime stabilization has to be considered in order to save 30% of financial costs in respect to traditional construction methods.

3. ENVIRONMENTAL ASPECTS

The environmental benefits of soil stabilization versus the use of traditional natural material from quarries are generally underestimated. Especially if it happens in countries where natural materials are relatively abundant and where the cost of waste disposal is low. The main environmental benefits concern: the saving of natural resources and the preservation of the landscape by quarry prevention, decreasing the production of solid waste and consumption of area for disposal, the heavy reduction of air pollution and noise as a consequence of the reduction of material transport.

Generally these benefits are not quantified in feasibility studies nor in the Environmental Impact Assessment.

The relevance of positive environmental impacts can be evaluated through a comparison among all impacts. Of course such a comparison is possible only if the impacts were measured homogeneously. Approximately the cost of impact mitigation is here assumed as a measure of the impact itself. Under this hypothesis all impacts can be assumed under a homogeneous measurement.

For example the average level of noise before the construction of a railway is N_a [dBA]; as the trains operate the level of noise is N_b [dBA]. To reduce noise from N_b to N_a noise protection systems (barriers, windows isolation, trees, artificial hills...) are needed. The total cost for the system for the abatement of noise for N_b-N_a [dBA] is assumed as the magnitude of the noise impact. This evaluation is not difficult and it can be carried out using simulation models to predict the noise level and to design the protection system.

Analogously the magnitude of air pollution, waste production, natural resources consumption, or tree cutting, or other generic impacts can be evaluated as standard cost. If the full reduction of the impact to "ex ante" conditions is not possible, the cost of mitigation to the minimum reasonably acceptable value can be assumed.

Under this approach it is possible to evaluate the approximated relevance of environmental impacts using an objective and repeatable method.

4. CASE STUDY

The case study of one significant section of the Italian High Speed Railway is presented here. This section is a part of the line from Milan to Venice.

Problems with construction material provisioning are relevant in the stretch of railway around the city of Modena. Here the projected route develops for about 40 km on two tracks on new compacted embankments, and for 8 km of an additional track on existing embankments. Moreover an interconnected system to the old railways and a few viaducts for the HS railway complete the works for about 22 km of viaducts, for the so called Modena Viaducts System (Fig. **1**). This system lays on clay soils with high plasticity and with a very low value of CBR.
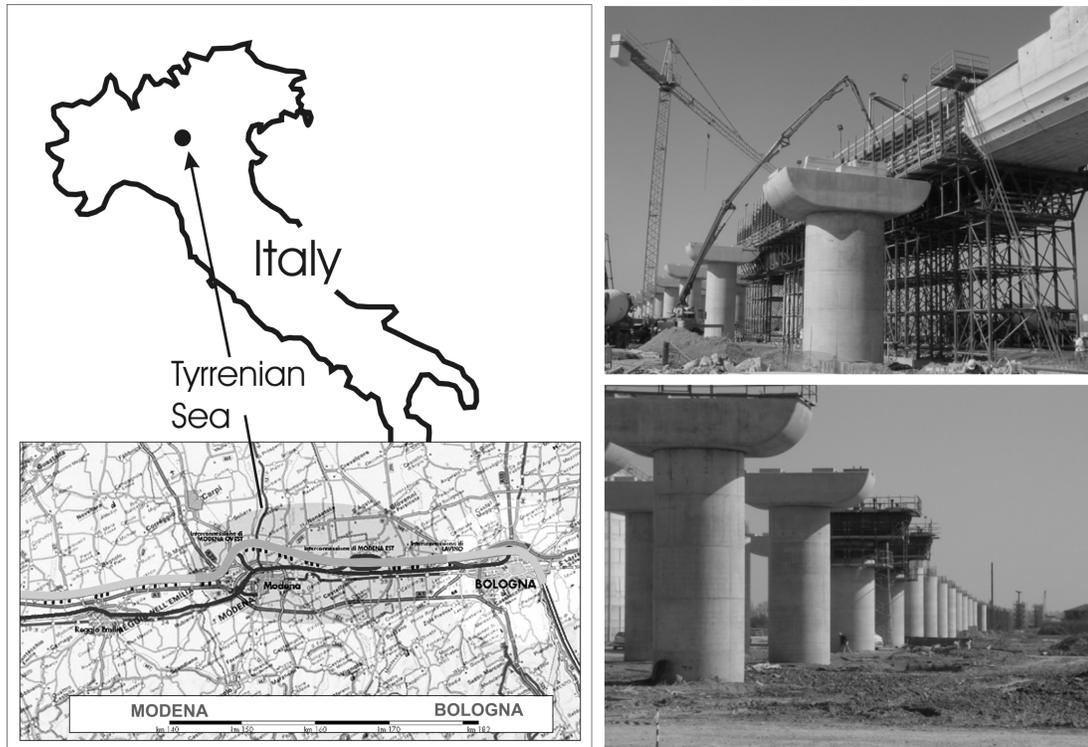
Fig. (1). Modena Viaduct System.

These viaducts have to be founded on drilled piles with a diameter of 1500 mm, between 35 and 50 m deep. The piles are alternated to rectangular diaphragms and over the piles plinths of about 300m^3 (for each track) are constructed as foundations for the railway structure.

The development of piles and plinths implies the extraction of a consistent volume of clay soil that is not adequate as is for construction applications, and in compliance Italian law, it has to be disposed as waste.

In this case there are simultaneously a relevant need for adequate soil for construction of embankments and an enormous volume of soil to be disposed. The management of material becomes the most important activity for containing the environmental impact both as waste production and disposal, both as natural non-renewable resources (soil) consumption. Moreover it has to be underlined that adequate natural soil is not available next to the yard (Po River Valley) and transport from Apennines or Alps, which is a distance over 50 km, is needed.

The volume of material that is needed for the development of embankments amounts to about 3 million m^3 and 1.5 millions m^3 of aggregates are needed for concrete. At the same time the construction of foundations produces about 1 million m^3 of soil: 350,000 m^3 from foundations, 400,000 m^3 from diaphragms and drilled piles and 70,000 m^3 from helicoidal piles.

The need to manage such a significant volume of soil suggests the need for the consideration of recycling the clay soil after lime stabilization. The impact of possible recycling is important both under an environmental perspective and

from an economical point of view. Of course the technical compatibility has to be verified.

4.1. Soils Extracted Along the Route

The soils extracted from excavation for the development of plinths, piles and foundations are basically homogeneous and highly plastic. Along the 40km of the projected route 127 cores have been drilled and the samples have been tested in the laboratory. The soils are classified as A6 and A7-6 under AASHTO classification. About the 90% of material passes at 75 μm grading analysis. Atterberg Plastic Limit (PL) is approximately 10-15 % in the first 20 km of the route, is about 15-20 % in the following 10 km, and in the last part of the route PL increases to 20-25%. The average values of the mean geotechnical characteristics of samples are summarized in Table **2**.

Such natural materials are obviously not adequate for embankments construction, but simultaneously they are generally good for lime stabilization.

A little part of the materials extracted from drilled piles had local intrusion of sand and gravel that discouraged recycling after stabilization, considering that lime mixing could be ineffective. These materials have been reused for secondary roads and ramps for the yards.

4.2. Preliminary Tests

According to the literature, a three percent compositions of lime have been assumed to stabilize the soil: 2%, 2.5% and 3%. The effect of lime mixing on Atterberg limits is to increase the liquid and plastic limits (LL and PL). PL increases from 21 % to 30% and LL from 44 to 48-50%. The

Table 2. Geotechnical Characteristics of Soil

Variable	Average Value
Liquid Limit (%)	44
Index of Plasticity (%)	23.5
USCS classification	CL
Nitrate (%)	0.03
Initial Lime Content (%)	2
w_{opt} (%)	17.3
$\gamma_{d,max}$ (kN/m^3)	16.64
Immediate Bearing Index (%)	10
CBR (%)	3
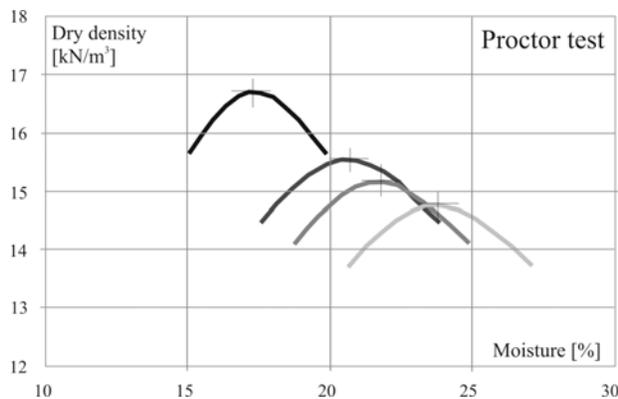
Fig. (2). Dry density after stabilization.

Plasticity Index (IP=LL-PL) decreases to 18% from 24%. Compaction test (Proctor), bearing tests (CBR and immediate bearing index) and vertical compression tests were carried out. The results demonstrate that the mechanical properties of the stabilized soil increase over the expectations, especially for 3% lime. In particular Fig. (**2**) shows that dry density decreases if the lime increases from 16.6 kN/m^3 for the natural soil to 14.8 kN/m^3 by adding 3% lime. The optimum value of the compaction moisture increases from 17% to 24%.

Fig. (**3**) shows the increase in the immediate bearing index when lime is added as a function of water content. The effect of stabilization is low at short time durations because the pozzolanic reactions are in progress; this is why the immediate bearing index increases to about 25% while CBR after 28 days aging increases from 3% (natural material) to almost 70%.

Vertical compression tests demonstrated that compressive strength increases after 28 days of aging around 900kPa. Fig. (**4**) shows that a three percentage composition of lime has a similar effect for the long term, and compressive strength increases approximately from 350-400 kPa after three days to 880-940 kPa after 28 days.
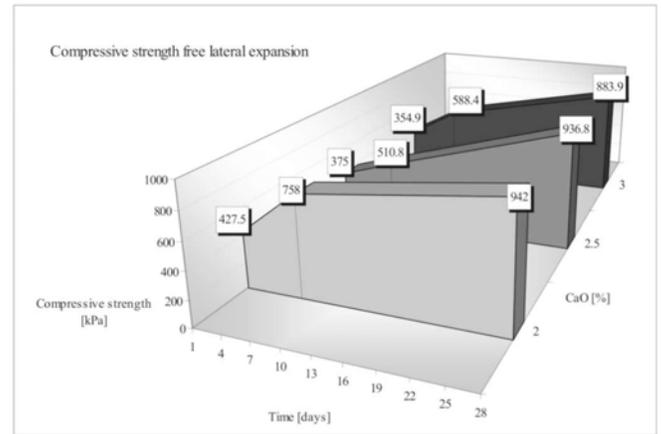
Fig. (4). Long term effects of stabilization: compressive strength.

Preliminary tests supported the choice for the best percentage of lime. The value of 3% was adopted for the site tests on a real scale because all samples of stabilized soils with 3% lime had mechanical characteristics significantly higher than the standard requirements for High Speed Railway construction.

4.3. Site Tests on Real Scale

Starting from the outcomes of the preliminary tests a wide experimental campaign was carried out in order to assess: the best technology and the best methodology to compact stabilized soil, the reliability of laboratory results with respect to real scale construction. Four fields were prepared

Fig. (3). Immediate bearing index after stabilization.

Table 3. The Site Tests

Site	Objectives of the Tests	Site Dimensions	Evidences
Site A	Identification of the best % of lime	60 x 10 m	Best lime content = 3%
	Validation of different compaction methods		Compaction method C1 = 1 Cycle static steamroller + 1 Cycle vibrating steamroller + 4 Cycles static steamroller
	Identification of the best depth for lime stabilization		Best depth for soil stabilization and compaction = 0.30 m
Site B	Validation of stabilization and compaction treatment using an geo-synthetic over or under the natural soil level	50 x 18 m	The mechanical tests accord to the requirements for High Speed Railway
Site C	Validation of different compaction methods	30 x 220 m	The results confirm the best compaction method is C1
	Identification of the best method for lateral slopes construction and compaction		The construction and compaction slopes of embankments are identified and tested
	Validation on real scale of the treatment		The real scale outcomes confirm the laboratory scale outcomes and accord to the requirements
Site D	Feasibility study of polymeric materials for stabilization of soil from pile excavation	30 x 60 m	No reliable results

Fig. (5). Test field.

for tests. The dimensions, the specific objective of each field, the origin of the stabilized soil and the expected application are described in Table **3**.

The site tests confirmed the promising evidence obtained from laboratory tests.

In fact, according to the laboratory test, the optimal percentage of lime for the best mechanical properties of the stabilized mixes is 3%. Three different compaction procedures have been tested: (C1) one cycle with a static steamroller (18,500 kg), on`e cycle with a vibrating steamroller and four cycles with a static roller (Fig. **5**); (C2) four cycles with a
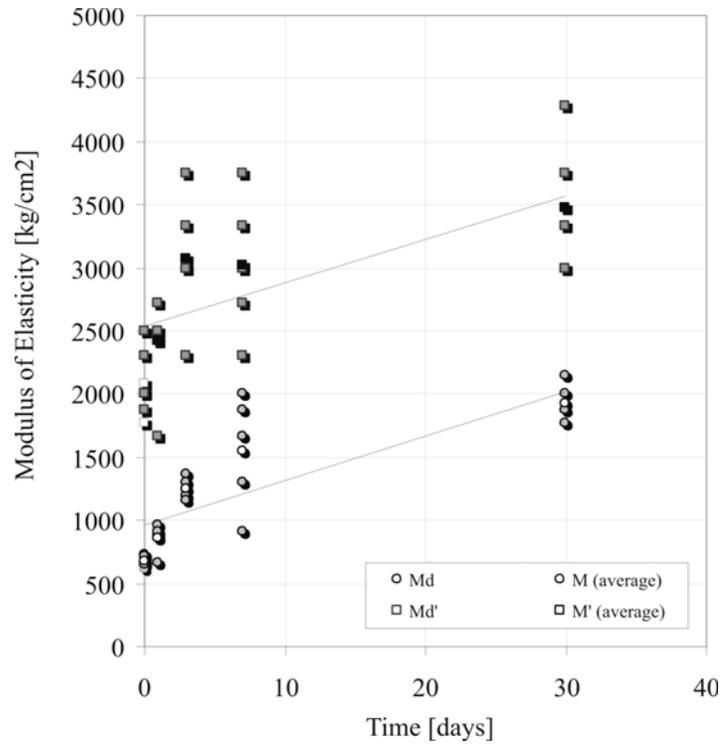
Fig. (6). Modulus of elasticity in two consecutive tests after compaction.
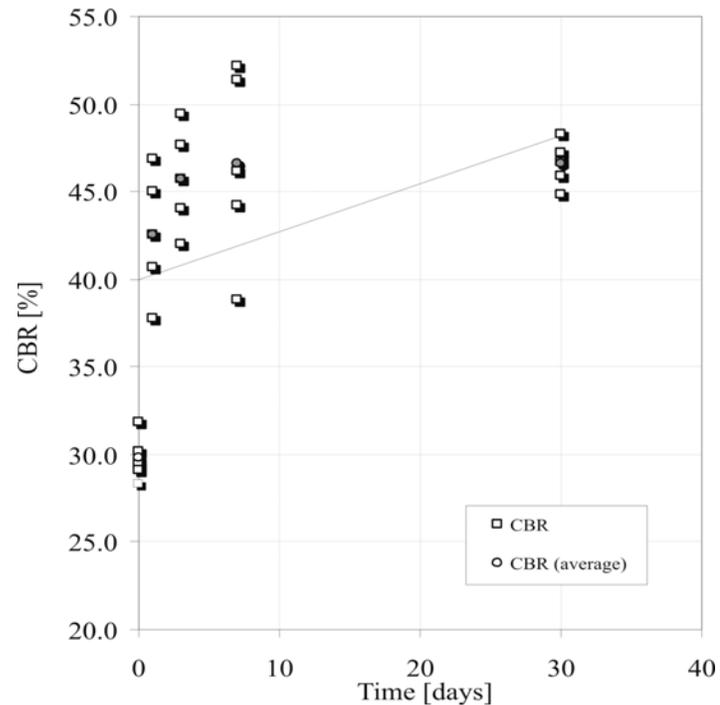
Fig. (7). CBR increasing after aging.

vibrator plugged steamroller, one cycle with a grader and one cycle with a static roller; (C3) four cycles with a vibrator plugged steamroller and one cycle with a static roller. The procedures C2 and C3 are usually more effective with plastic soils rather than procedure C1, but in this case with lime stabilized soil, the mechanical properties of mix changes from plastic to elastic such that the best compaction proce-dure is unexpectedly, C1. The maximum thickness of the

layer to reach adequate mechanical characteristics is 30cm. For thicker layers the stabilization does not produce such good results.

The Modulus of elasticity measured in two consecutive tests on site increases after compaction and 30 days of aging to 1,500 kg/cm^2 for the first test and for the second test to 3,000 kg/cm^2 (Fig. **6**). These values of the modulus are much
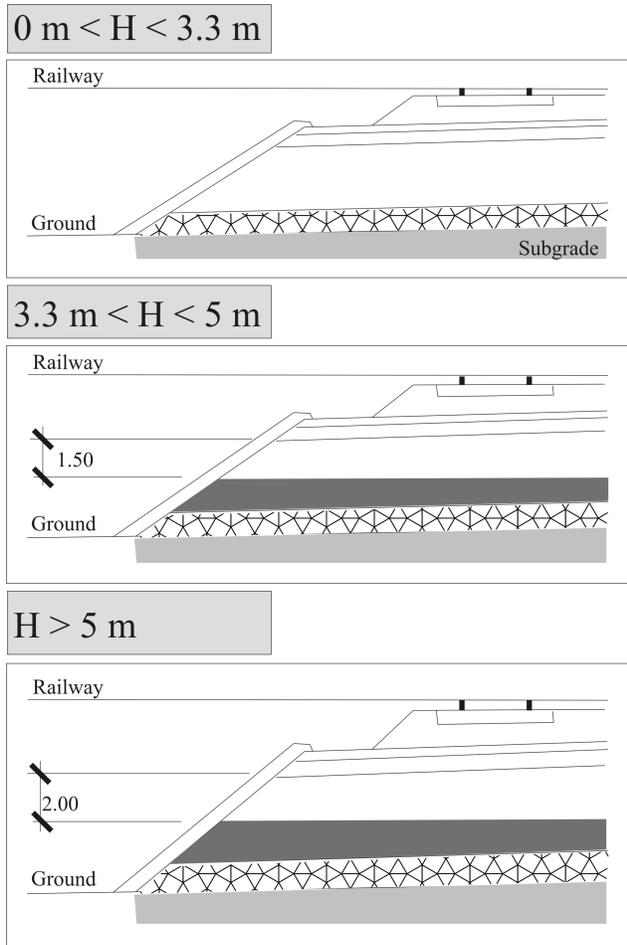
Fig. (8). Stabilized soil for railway embankment construction according to Italian regulations.

higher than the requirements for soil to be used for embankments of the Italian High Speed Railway.

Analogously the values of CBR obtained from the experimental fields increase from 30% after construction to 47% after 30 days of aging (Fig. **7**). The CBR of the original, not stabilized soil is 3%.

4.4. Construction Options

The results of tests demonstrated that the soil after correct stabilization using lime at adequate percentages is suitable for the construction of embankments. The current Italian technical regulation for High Speed railway development does not make possible the use of stabilized soils for the construction of the entire embankment. Stabilized soil can be used (only from 1998) only for the lower layer as in Fig. (**8**). The regulation does not take into account the mechanical performances of stabilized soils.

To make a reasonable comparison in terms of the benefits of using stabilized soils for railway development, three possible options have been considered (Fig. **9**): (1) construction of embankments with natural adequate soil extracted from quarries, (2) construction of embankments partially using stabilized soil in accordance with Italian regulations, (3) construction of embankments using only stabilized soil that
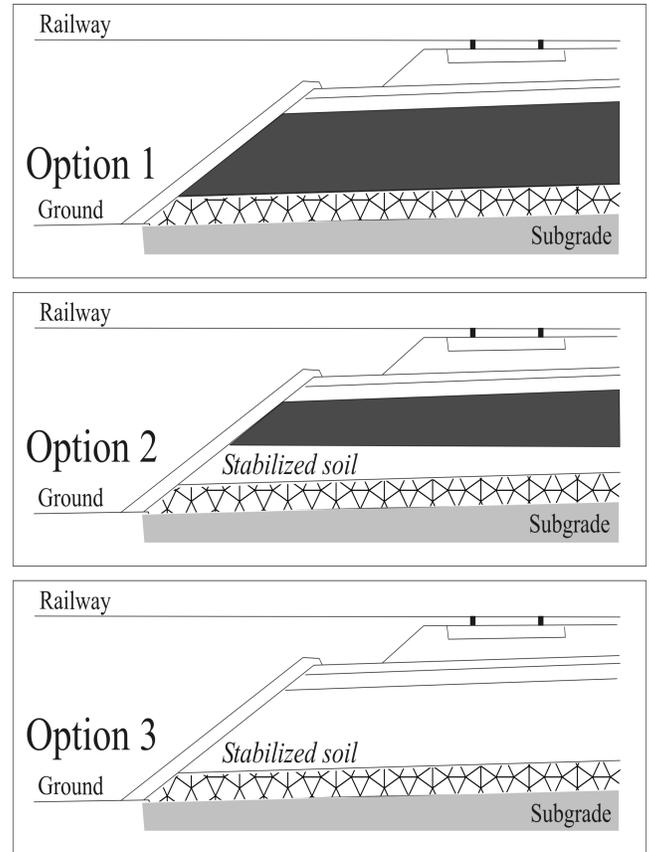
Fig. (9). Schemes of the three considered options.

is adequate from a mechanical point of view as demonstrated by laboratory and real scale tests. The environmental and financial impacts of these three options will be synthetically discussed.

5. FINANCIAL AND ENVIRONMENTAL ASSESSMENT: DISCUSSION

The costs of construction of this section of railway in the three mentioned options have been evaluated as follows. Table **4** shows the volume of different materials that should be used under the three options.

Assuming the average costs of providing material and transport, considering the different costs of construction and compaction using different techniques and the cost of waste management and disposal, the total costs are compared in Table **5**.

The available quarries have been identified at a maximum distance of 50km from the construction site. According to the real available volume to be extracted, these quarries have been selected in three categories to account different transportation costs: quarries A are maximum 15 km far from the work site, quarries B from 15 to 30 km and quarries C more than 30 km (see Table **5**).

The cost of construction in the second case is more than 30% lower and in the third case it is about 70% lower. Of

Table 4. Volume of Materials According to Different Options

Volumes [m³]		Material Provisioning				Material Storage		
		Adequate to the Requirement	Excellent Material	Adequate for Stabilization Process		Non Adequate to the Requirement	Non Adequate to Stabilization	Vegetal Soil
Option 1								
USE	Bottom of excavation	15.905	222.667			238.572		
	Embankment foundation		400.442					471.826
	Embankment development		1.290.944					
		On site	Quarry	On site	Excavation	Waste disposal	Waste disposal	On site re-use
Option 2								
USE	Bottom of excavation	15.905	18.131	220.441			18.131	
	Embankment foundation				400.442			471.826
	Embankment development		853.187		838.200			
		On site	Quarry	On site	Excavation	Waste disposal	Waste disposal	On site re-use
Option 3								
USE	Bottom of excavation	15.905	18.131	220.441			18.131	
	Embankment foundation				400.442			471.826
	Embankment development				1.290.944			
		On site	Quarry	On site	Excavation	Waste disposal	Waste disposal	On site re-use
		Origin of material				Material destination		

course this evaluation is a first approximation; however it is evidence that recycling after stabilization has a relevant positive impact on financial cost (Fig. **10**).

According to the methodology mentioned in section 3 the magnitude of these environmental impacts has been evaluated as the amount of savings from the reduction of waste disposal and recycling of materials.

The Environmental Impact Assessment does not consider soil stabilization as environmental impact mitigation and demonstrates that the most relevant impact is noise pollution, and secondly interferences with surface and ground water. But the costs for noise mitigation are much higher rather than costs for the reduction of all the other environmental impacts (excluding soil disposal and natural material consumption).

Actions and interventions for noise abatement for national regulation standards has been developed, according to the outcomes of simulation software (MITHRA) for noise prediction. The estimated costs for the implementation of such a project are about 500,000 €.

Moreover numerous actions have been planned as a result of the Environmental Impact Assessment to mitigate interferences with the natural surface hydraulic network. The following main actions are part of the environmental project: (1) ponds for pollutants entrapment and river protection dur-

Table 5. Comparison of Construction Costs

		Costs
Option 1	Excellent material from quarries A	€ 15.494.721
	Excellent material from quarries B	€ 2.734.363
	Excellent material from quarries C	€ 3.645.817
	Waste disposal	€ 596.430
	Total	**€ 22.471.331**
Option 2	Excellent material from quarries A	€ 7.053.528
	Excellent material from quarries B	€ 1.244.740
	Excellent material from quarries C	€ 1.659.654
	Stabilization of soil (on site)	€ 859.718
	Stabilization of soil (from excavation)	€ 4.107.179
	Waste disposal	€ 45.329
	Total	**€ 14.970.148**
Option 3	Excellent material from quarries A	€ 146.779
	Excellent material from quarries B	€ 25.902
	Excellent material from quarries C	€ 34.536
	Stabilization of soil (on site)	€ 859.718
	Stabilization of soil (from excavation)	€ 8.287.794
	Waste disposal	€ 45.329
	Total	**€ 9.400.058**

ing construction, (2) river banks protection and stabilization through ecological works, (3) avoiding bridge piles into riverbeds, (4) hydraulic isolation of yards and construction sites to avoid any eventual rain or runoff contamination, (5) waste water treatment before discharging. The protection of ground water is an important part of the environmental project considering that the piezometric level is approximately only a few centimetres deep, and no soil buffer or isolation exists. The main actions to mitigate impacts on ground water are (1) the construction of drainage systems to reduce the risk of polluted water infiltration, (2) permanent or temporary paving of work sites and roads where the risk of accidental pollutant discharge is not negligible.

Other minor local actions have been planned to reduce or eliminate environmental impacts to flora and fauna. The total costs for water protection and ecological impacts mitigations are about 200,000 €.

It means that the total costs of all the actions derived from the Environmental Impact Assessment for environment protection is less than 1,000,000 €. This is only about 8% of the savings produced by the stabilization of soil from option 1 to option 3. In fact in the case of option 1 (no stabilization) the construction cost is 22,471,331 € and in the case of op-

tion 3 (maximum stabilization of soil) it is 9,400,058 €, which yields and estimated saving of 13,071,273 €.

6. CONCLUSION

The construction of the High Speed Railway and the consequent operations of the HS Train have relevant impacts on the environment. The traditional approach of the Environmental Impact Assessment is effective noise and vibration mitigation, water protection, flora, fauna and ecological systems preservation. However, the question of non-renewable resource management, such as soil, is underestimated. Soil that is used for construction purposes has to have adequate mechanical characteristics. In certain geographical regions the traditional abundance of such resources from quarries and strong lobbies of waste and material natural management discouraged the use of alternative materials or recycling. These are the main reasons why this issue is usually underestimated in the Assessments. The case study of the High Speed Railway in North Italy, one of the most important national projects for transportation infrastructure in the last 20 years, demonstrates that the costs for environmental systems protection are much lower than the saving induced by soil stabilization and recycling. In conclusion it is not ac-
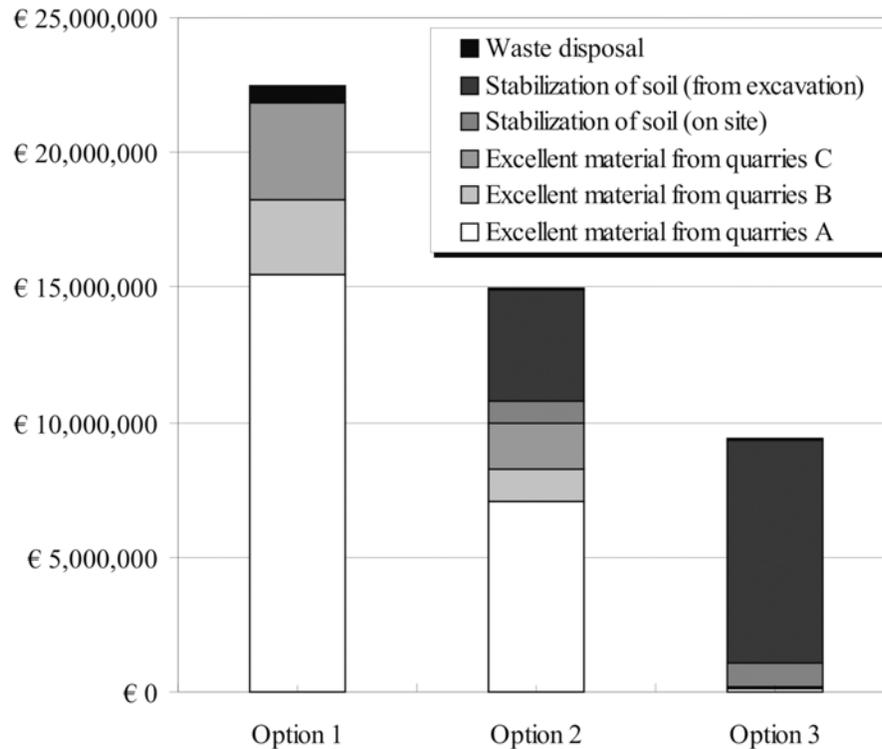
Fig. (10). Construction costs option 1, 2 and 3.

ceptable that such issues are neglected under an environmental assessment and considered only as an eventual strategy for monetary savings.

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