Session 5.2 Room Fez 1
Infrastructure / Construction

Moderator : Mr. GUO Hui
Associate Researcher, CARS, China

ONCF UIC

Session 5.2
Infrastructure / Construction
Speaker Lists;

1	2	3	4	5	6	7
						
Mr.Domenico Caputo	Mr.BENARBIA ABDERRAHIM	Mr.WANG Shuguo	Mr.Candan Gokceoglu	Mr. Ümit Guney	Mr. Abdullah Çorak	Mr. Servet Karahan
Italy	Morocco	China	Turkey	Turkey	Turkey	Turkey

UIC HIGHSPEED Morocco 2023
HIGH-SPEED RAIL : THE RIGHT SPEED FOR OUR PLANET
Under the High Patronage of his Majesty King Mohammed VI

11TH WORLD CONGRESS OF HIGH-SPEED RAIL

Marrakech, 7-10 MARCH 2023

PYROCLASTIC SOILS TREATED WITH LIME

Domenico, Caputo
Letizia, Berardi
Stefano, Ciufegni,
Francesco, Sacchi
Roma, Italferr, Italy

Session2-5.2 Infrastructure / Construction

PREMISE

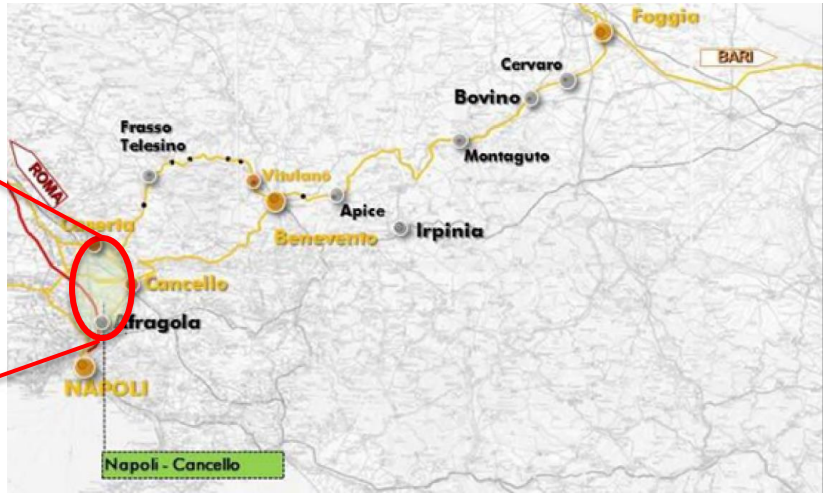
In the last years, the word “sustainability” has been more and more often associated to construction companies designing major works that require the use of natural non-renewable resources and material with elevated performance capacity. The lime stabilization technique represents a valid solution to satisfy requirements of earth with high geotechnical characteristics, with undeniable improvement effect on the territory impact and on the infrastructure cost. It should be supported, in any case, by a preliminary laboratory study.

In the next slides, with regard to the proposed case study of the railways embankment construction, the following aspects will be examined:

- ✓ Studies and laboratory results concerning the experimental determination of mixtures for the stabilization of soils with lime;
- ✓ Results of experimental test fields to validate results of laboratory studies;
- ✓ Conclusions.

Napoli-Cancello, first lot of the Napoli-Bari High-Speed railway line

The analized intervention concerns the construction of the embankments on the section Napoli-Cancello, first lot of the Napoli-Bari High-Speed railway line, for an overall length of 15.5 km of which 8 km are realized in embankment and 2.5 km in artificial tunnel.



Napoli-Cancello, first lot of the Napoli-Bari High-Speed railway line

The necessary soil volume for the construction of the embankments equals to roughly 1 milion of m3, whereas the soil coming from the artificial tunnel excavation is approximately 0.6 milion of m3. The study for the reuse of the excavation materials has been carried out during the design phase, detecting the presence of pyroclastic soil, non-plastic and with very variable Proctor optimal water content (16-40%); in addition, these materials were found totally amorphous. For these reasons, materials cannot be used like they are. In the perspective of pursuing targets of Sustainable Development, it has been then chosen that all the pyroclastic soils coming from the artificial tunnel excavation be used and treated with lime for the construction of the embankment.

Sample:	Depth (m)	W	Limits				Organic	ICL	Pumice
		(%)	WL	WP	Ic	CLASSIFICATION	(%)	(%)	(%)
PZ01 - TER 110	0,00 -3,50	27,99	N.D.	N.P.	-	A4	4,11	3,2	6,3
PZ02 - TER 111	0,00 -3,50	23,95	N.D.	N.P.	-	A4	3,89	3,0	3,02
PZ03 - TER 112	0,00 -3,50	27,28	N.D.	N.P.	-	A4	4,99	2,9	2,46
PZ04 - TER 113	0,00 -3,50	31,43	N.D.	N.P.	-	A4	4,62	2,6	2,56
SC01 - TER 114	0,00 -3,50	26,3	N.D.	N.P.	-	A4	3,48	3,0	2,8
SC02 - TER 115	0,00 -3,50	29,22	N.D.	N.P.	-	A4	4,92	4,0	3,3
PZi08 - TER 115bis	0,00 -3,50	18,76	N.D.	N.P.	-	A4	5,05	3,8	3,77
PZi08 - TER 116	0,00 -3,50	23,77	N.D.	N.P.	-	A2-4	4,07	3,0	1,92

Embankment Construction: Mixtures Study

Before the start of processing, the Mixtures Study has been performed in two Steps:

1. Laboratory Study
2. Check full-scale through the execution of field trials

For the laboratory study on the lime treatment of the representative sample, three different mixtures have been realized with increasing lime oxide content (3.5% - 4.0% - 4.5%).

The following laboratory tests were performed on these mixtures:

- Determination of Atterberg Limits;
- particle size analysis by wet with sieves and hydrometer;
- Content of organic substances;
- Initial consumption of lime;
- Test compaction AASHTO Modified;
- determination of the immediate bearing index (IPI);
- determination of CBR index at 7 (after immersion in water for last 4 days) and 28 days of curing (after immersion in water for last 4 days);
- uniaxial compressive strength after 7 of curing and 2 of immersion in water with different moisture contents (Wott, Wott + 3%, Wott-3%);
- uniaxial compressive strength after 7 and 28 days of curing with different moisture contents (Wott, Wott + 3%, Wott-3%);
- CD triaxial tests with Wott after 28 days of curing.

Embankment Construction: Laboratory Study

The samples were compacted and left to cure, after which they were submerged in water to check their integrity, that can be considered garanted if the material is provided with cementation. In the picture below is possible to see three distinctive specimens, with a different lime treatment ratio of respectively 3.5%, 4% and 4.5%, left to cure for 5 days after other 2 days of being completely submerged in water. No visible geometric softening or shape loss phenomena occurred, confirming the correct outcome of the pozzolanic reactions which are responsible for the cementation of given material.

Embankment Construction: Laboratory Study – Triaxial tests results

In the following table, there are the results of the CD triaxial tests after 28 days of curing:

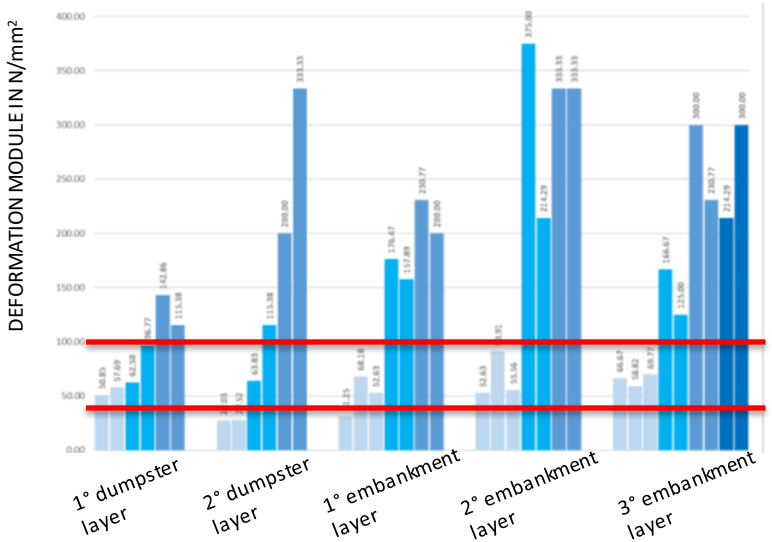
Samples	Peak Strength	
	C' (kPa)	Φ' (°)
3,5%_28days	291,3	44,6
4,0%_28days	361,3	41,6
4,5%_28days	433,9	49,6

The values of the shear strength of the lime stabilized pyroclastic soil are very high. The laboratory tests show how the mechanical response of the treated soil is like to that of a soft rock.

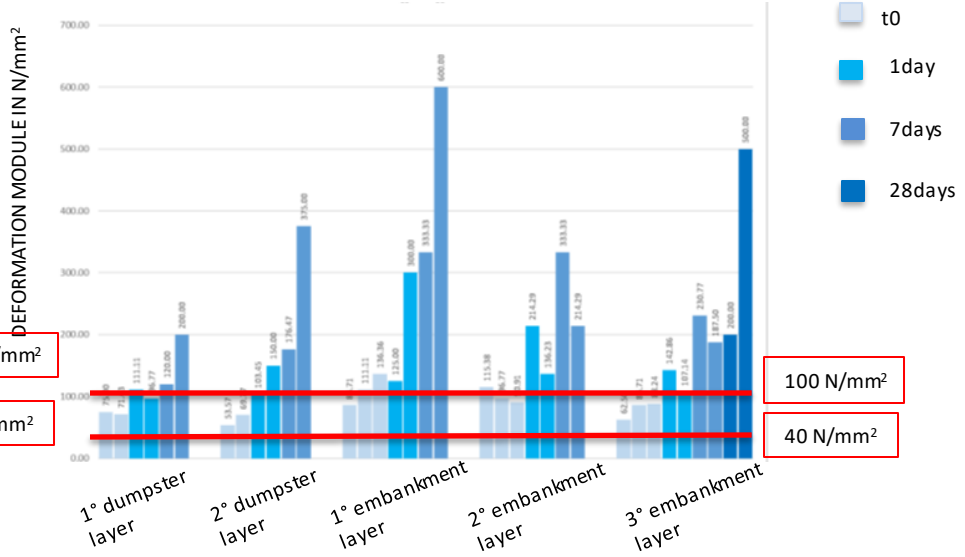
Embankment Construction: Field trials - Results

On the basis of the results of laboratory tests, 2 field trials were performed. The percentage of calcium oxide used were (% by weight): 3.0% - 3.5%
For the realization of the field trials, the same operations as provided for the subsequent construction of embankments were carried out:

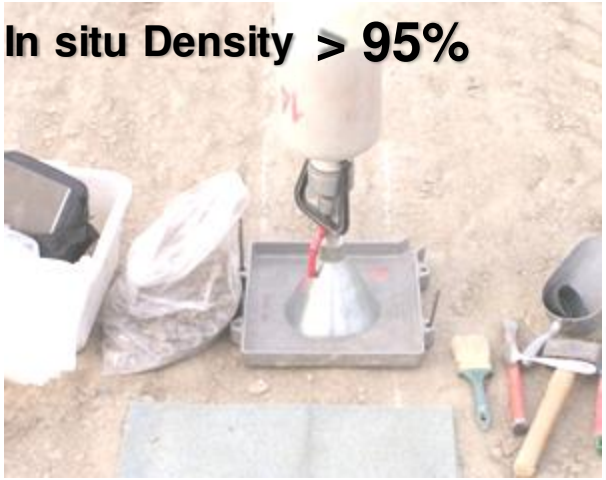
VALUE OF DEFORMATION MODULE (MD) - FIELD TEST 3% LIME MIXTURE 1 LOAD CYCLE

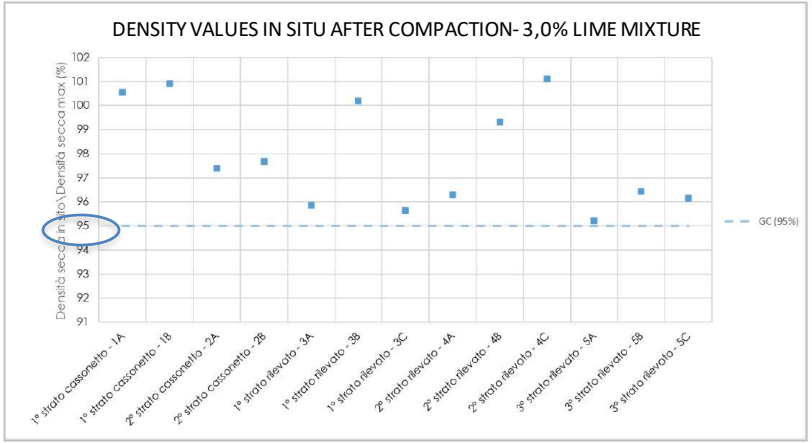


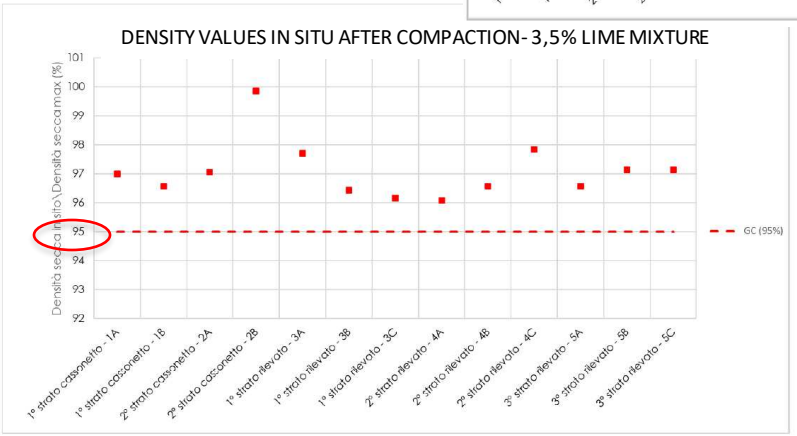
VALUE OF DEFORMATION MODULE (MD) - FIELD TEST 3,5% LIME MIXTURE 1 LOAD CYCLE



Field trials – Results – foundation and embankment body



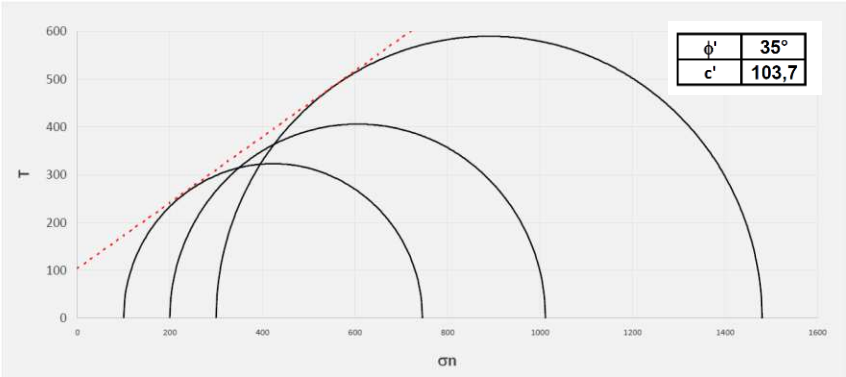




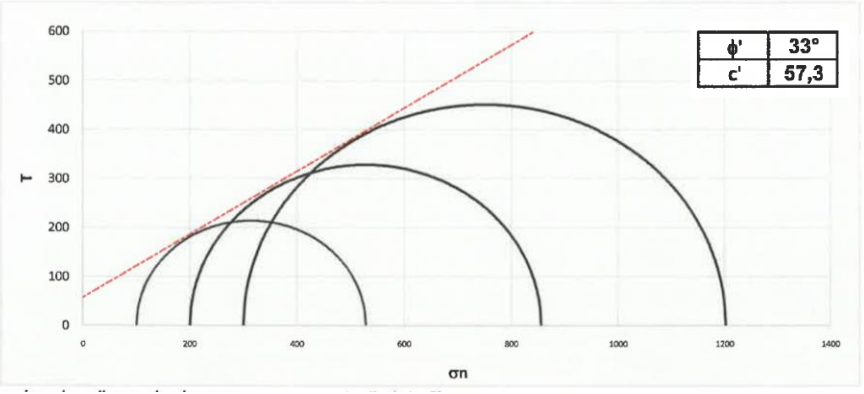
Field trials – Triaxial tests results

The consolidated drained triaxial tests performed on the samples taken from the test embankments, by core drilling, showed high values of shear strength parameters at 28 days of curing, due to the chemical and physical reactions induced by the addition of lime.

Mix 3% of lime



Mix 3% of lime submerged in water



Conclusions

The case history described shows the excellent mechanical performance obtained on lime-stabilized pyroclastic soil. The experimental approach allowed in the first instance to evaluate the feasibility of lime treatment, showing the crucial role of cementation in the mechanical behavior of the material.

The analysis of the results carried out during the execution of the test field has showed the efficient of the soil lime stabilization with a modest amount of calcium oxide (3%-3.5%).

Then it is possible to transform, what until yesterday was considered a “potential waste”, into a construction material for railways embankment.

At the end it is obtain considerable benefits both from an environmental and economic point of view for the construction of a nex high-speed railway line.

THANK YOU

✉ d.caputo@italferr.it

+39 3387316391

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Elaborate Materials from Renewable Resources for High Speed Train

Dr Abderrahim, BENARBIA
Head of Guercif Station, ONCF, Morocco
Session2-5.2 Infrastructure / Construction

ONCF UIC

Future of mobility is Electric, Circular and Digital … Morocco's context is friendly for the development of all of it

1

The ambitious development of Renewable Energy already reached Railways

The first Noor solar power plant in Ouarzazate

The wind farm in Tangier

Alboraq is electric by design and 100% green since 2022

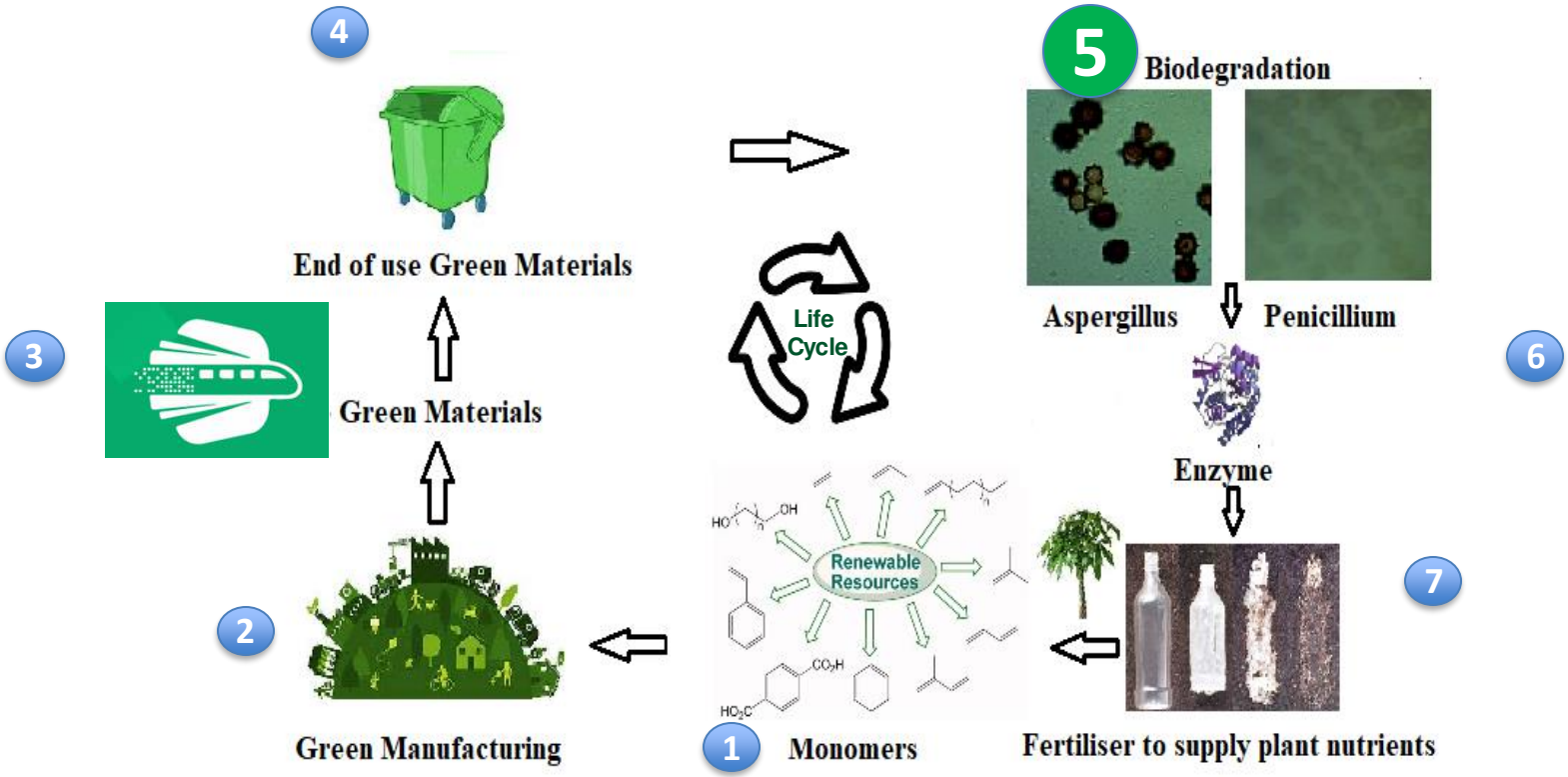
2

Awareness related to fossil derivative materials started early in our daily lifes but …

In 2010, the law 22.10 forbid the use of plastic bags and orient towards biodegradable material instead

How can we improve **Circularity and Environment** impact of most **materials used in HST manufacturing ?**

We are looking for **Renewable Resources** materials with **similar or better mechanical, chemical and Biodegradation properties and performance**



Case Study – POLYCAPROLACTONE (PCL) : the "reference" material

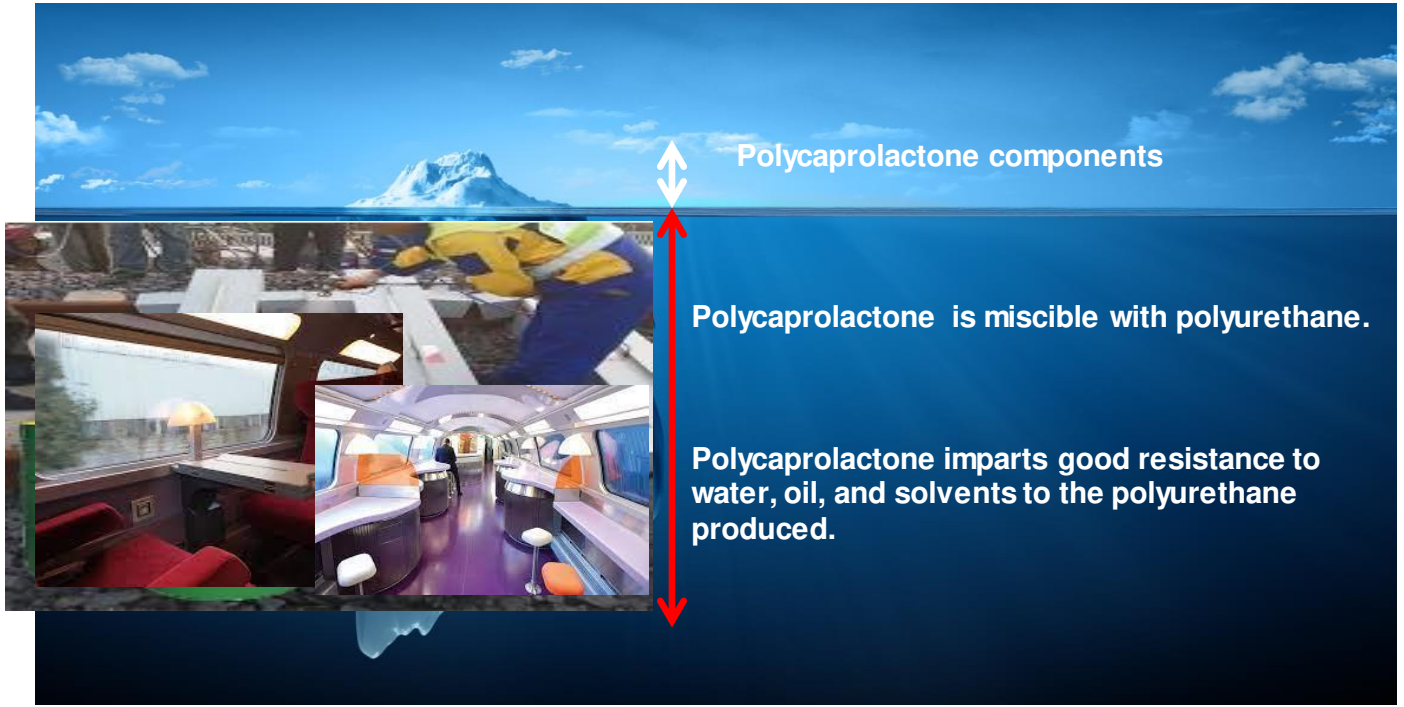
The aim of the present work is to elaborate a composite from renewables resources having the same or better properties

Polycaprolactone is biodegradable polymer material from **fossil**, non toxic, semi-crystalline, hydrophobic with a relatively polar ester group and five non-polarmethylene groups in its repeating unit.

It has gained much attention as **ideal material** for applications in various fields like agriculture, medicine, pharmacy, packaging and also in construction and railway industry as **polycaprolactone material or mixture as polyurethane**.

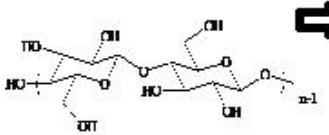
POLYCAPROLACTONE

The aim of the present work is to elaborate a composite from renewables resources having the same or better properties than PCL



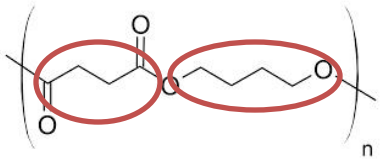
Case Study – POLYBUTYLENE SUCCINATE (PBS): the substitution material

The aim of the present work is to elaborate a composite from renewables resources having the same or better properties

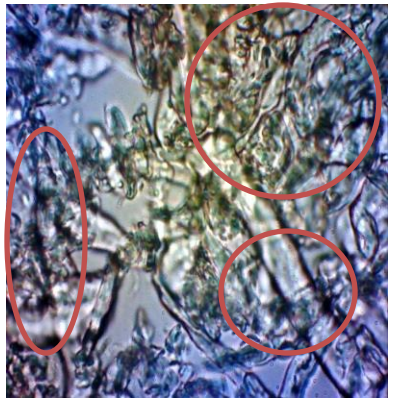


Cellulose

Polybutylene succinate



Acid succinic Butandiol



Microscope observations:

Blend of cellulose (80%) with PBS (20%)

Elaboration of Substitution Materials to PCL from a Renewable Resources based on PBS showed promising results

While

Blend (Cellulose / PBS)

- From **renewable resources**
- Affordable cost

and

Polycaprolactone (PCL)

- From **fossil**
- Expensive

Both are

Hydrophobic
Resistance to oil
Resistance to solvent

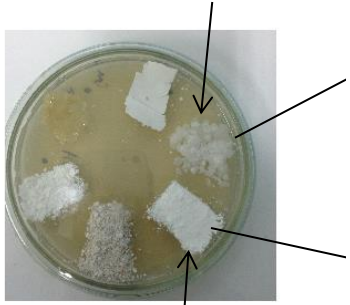
Furthermore,

- the study of the **thermal degradation kinetics** concluded that the average of activation energy of polycaprolactone and blend (cellulose (80%)/PBS (20%)) are the same, which is a useful information for optimizing processing and use conditions of the material.
- The **biodegradation properties** are also **in favor of PBS** and (Cellulose/PBS) blend …

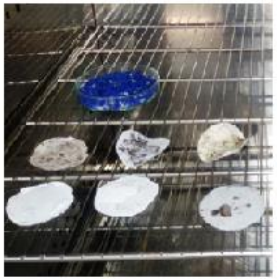
Biodegradation Cellulose vs PCL: It was noted that Cellulose shows a high biodegradation phenomenon compared to PCL

The invasion of micro-organisms in a Petri dish is carried out according to the ASTM G 21-90 and ASTM G 22-76 standards. The study of biodegradation by contamination, inoculation by drop of lixiviate from discharge Ouida. Morocco

Conclusion ?

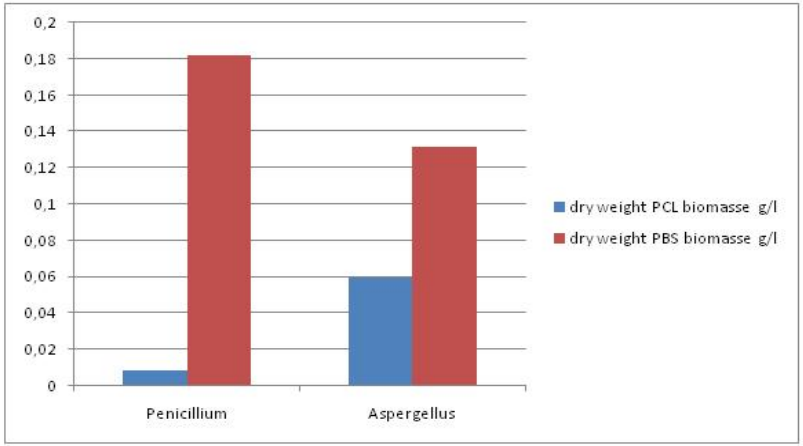


Biodegradation PBS vs PCL : Experience results show that PBS has higher biodegradation performance compared to PCL



Sample	T_0 *	T_1 *	dry weight (g/l)
Blend (asp)	0,1950	0,3268	0,1318
Blend (pcni)	0,1962	0,3784	0,1822
Capro(asp)	0,1997	0,2594	0,0597
Capro(pcni)	0,1963	0,2048	0,0085

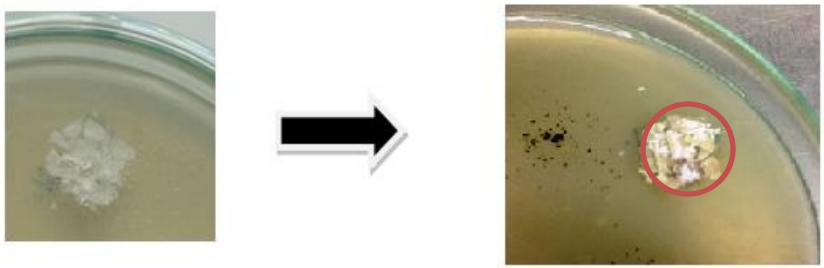
T_0: Dry filter weight before dried,
T_1: Weight of the filter + weight of the biomass after dried at 100 ° C



According to the Dry/Wet Weight Measurement Procedures, we noted that biodegradation increases in case of PBS and were clearly noted in case of Penicillium sp S1.

Biodegradation of the blend (Cellulose and PBS) occurred only by inoculation

- The invasion of microorganisms in a Petri dish is carried out according to the ASTM G 21-90 and ASTM G 22-76 standards. The study of biodegradation by contamination, inoculation by drop of lixiviate from discharge Oujda, morocco.
- We observed that **the biodegradation phenomenon occurred only by inoculation**



Conclusion & Perspective for the future

The **new material obtained** via mixing **natural polymers** (cellulose (80%) + PBS (20%)), is a material having **ecofriendly attributes** and minimizing the generation of pollution while keeping **similar properties with PCL.**

Application of this study results in **Railway industry** should be very promising and would help **improving recyclability and recoverability efficiency**.

Revision of standards such as **UIC leaflet 345** "Environmental Specifications for New Rolling Stock" and **End-of-Life rolling stock (ELRS)** works handled by **UNIFE** should support such research work and orientation

Natural polymer based on PBS should be explored as **serious substitutes to PCL / Polyurethan materials used on HST trains equipment (interiors, etc …)**

Renewable materials towards a better use of our planet ressources

THANK YOU

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Cutting-edge Theory and Scientific Problem of High-speed Railway Engineering – Track System and Operation & Maintenance Mechanism

Shuguo, Wang
China Academy of Railway Sciences, China
Session 5.2, Infrastructure / Construction

ONCF UIC

0 Introduction

- Track structure state directly affects train operation
- Ballast track: France, Spain, et al. Ballastless track: China, Germany, Japan
- Ballast: deterioration, maintenance, Ballast splash
- Ballastless : noise and vibration, temperature, coupling with substructure
- Key factors: Design theory, health monitoring and assessment, long-term service performance

China's high-speed railway mileage

Typical ballastless track

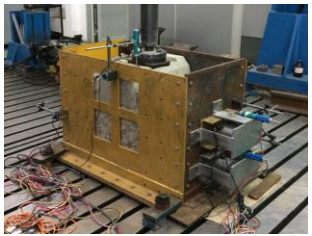
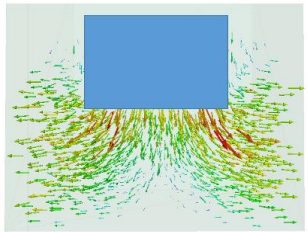
Typical ballast track

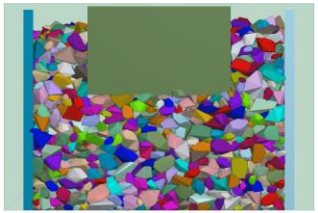
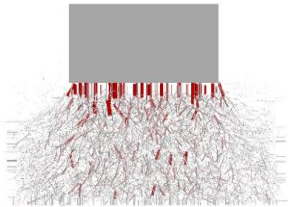
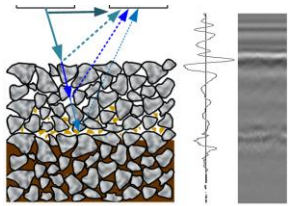
Damage and maintenance

1 Research status and development trend

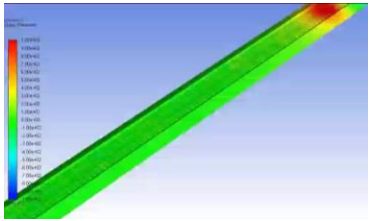
1.1 Ballast track structure

- ❖ Mechanical characteristics and deterioration mechanism of ballast bed
  - ➢ Experimental study: Triaxial, ballast-sleeper box
  - ➢ Theoretical study: Discrete element simulation

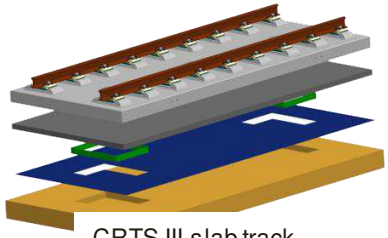
- ❖ Splash of ballast and its prevention in high-speed railway
  - ➢ Dynamic aerodynamic analysis model of linear porous media
  - ➢ Comparison between China and Europe

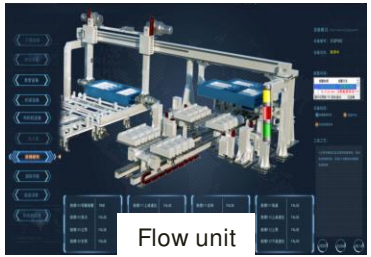


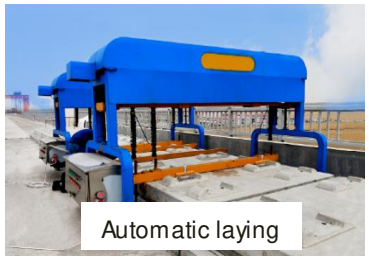
1 Research status and development trend

1.2 Ballastless track structure

- Structural design: CRTS series
- Intelligent manufacturing
- Adaptability of ballastless track on long-span bridge
- Damage mechanism
- Rapid repair technology


CRTS III slab track


Flow unit


Automatic laying


Ballastless track on bridge


Mortar damage


crack


Arch deformation


Before

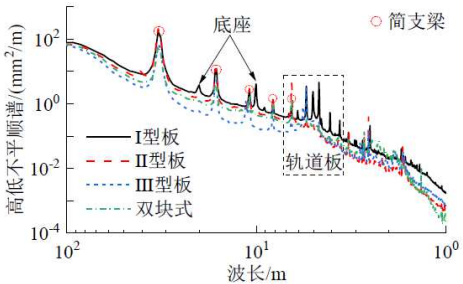

After

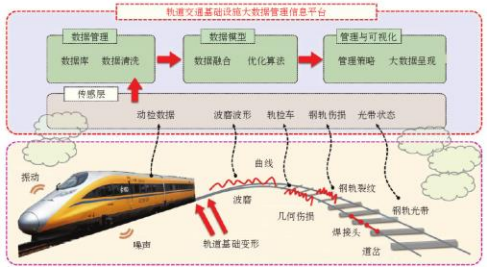

Gap filling

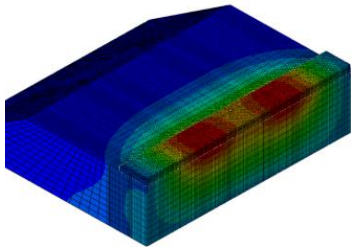
1 Research status and development trend

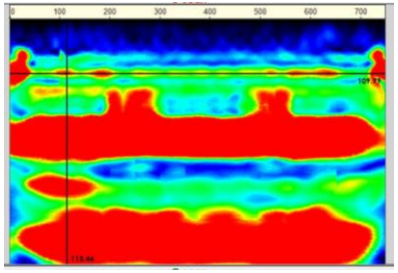
1.3 Health monitoring and management

- Tack inspection car
- Track detection technology, real-time monitoring
- Health assessment
- Maintenance management





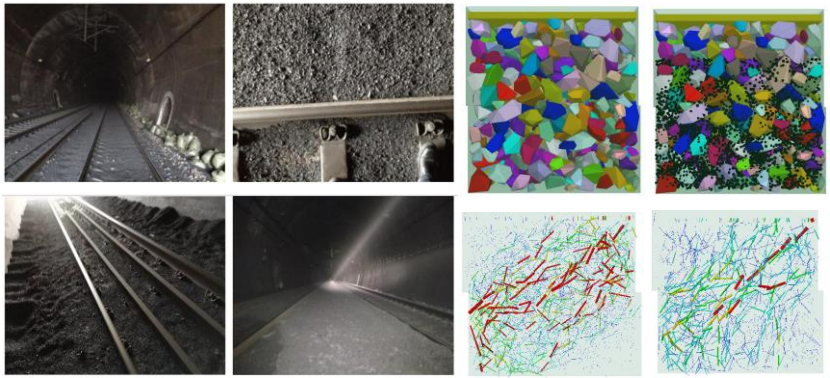




2 Existing problems

2.1 Ballasted track structure of high-speed railway

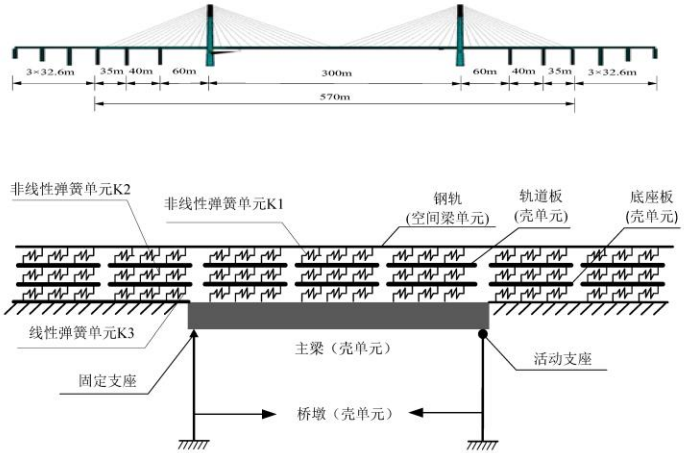
- Accurate simulation of ballast particles and the mechanical state
- Evolution law of track bed deterioration under complex environment
- Influence mechanism of tamping maintenance on the state of granular ballast bed
- Mechanism and prevention of ballast splash

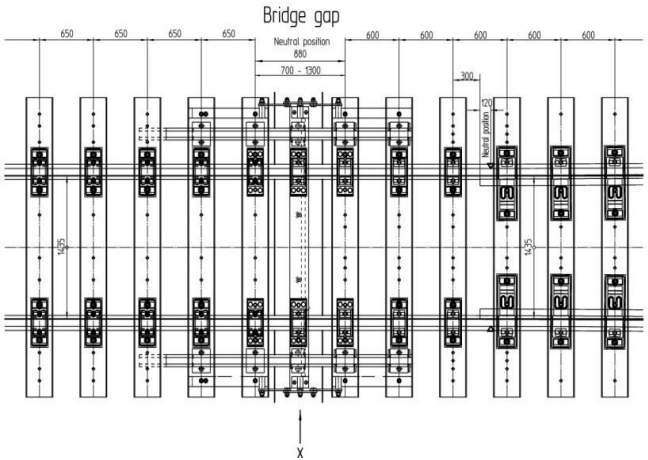


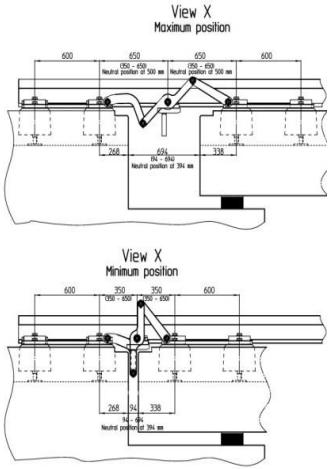
2 Existing problems

2.2 Ballastless track structure of high-speed railway

- The mutual adaptation between ballastless track and super long span bridge;
- Running safety of high speed vehicles on super long span bridge and maintenance method of ballastless track geometry;
- Update technology of ballastless track and its reliability test and evaluation.





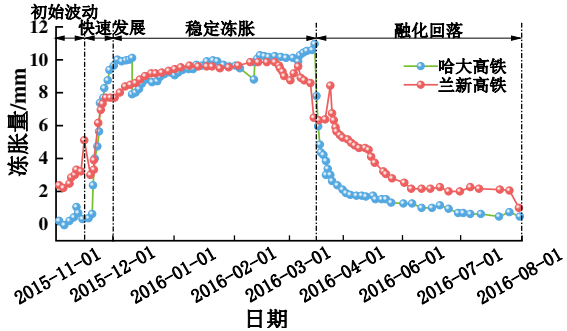


2 Existing problems

2.3 The service status, safety monitoring and health management of high speed railway

- Reasonable disease diagnosis and safety assessment methods for high-speed railway track structures；
- Equipment and method to monitor the crack and fracture of switch rail in real time；
- The evolution law of service performance of high-speed railway ballastless track under disease repair conditions is unknown；
- Unclear identification of disease characteristic parameters in multi-layer composite structures under high-speed railway tracks；
- Reasonable high-speed long rail track locking rail temperature detection method and on-line detection equipment.

Nondestructive testing of rail



Service performance deterioration

locking rail temperature detection

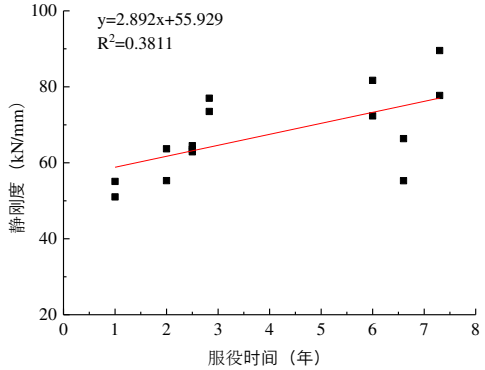
3 Research direction and suggestion

3.1 Study on the mechanism and prevention measures of ballast splash under the action of high-speed train

- Formation mechanism of ballast splash under the coupling action of multiple stress field and factors;
- Treatment measures to prevent ballast splashing and the optimization of track structure design parameters;

3.2 Evolution mechanism and law of track stiffness in special section of high-speed railway

- Reasonable matching principle of track stiffness in special section of high-speed railway;
- Dynamic evolution law of track stiffness in special section of high-speed railway under long-term operation conditions and its influence mechanism on the dynamic characteristics of track structure ;



Changes of track stiffness

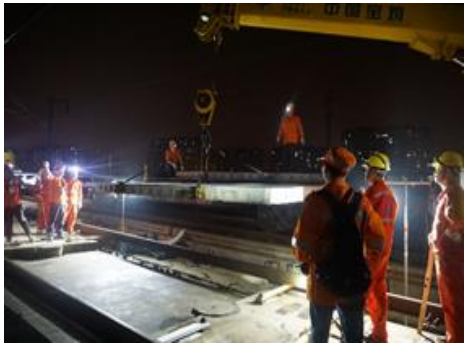
3 Research direction and suggestion

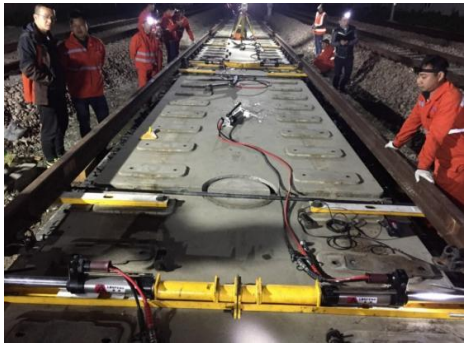
3.3 Research on disease perception theory and state control method of multi-layer composite structure under rail of high-speed railway

- Intelligent evaluation method of under-rail structure state and the state repair index system;
- Research and development of precise guidance rapid repair technology for typical diseases;
- Construction of modern inspection and repair theory for damage and disease of high-speed railway track structure

3.4 Evolution and evaluation of service performance of high-speed railway ballastless track under disease repair conditions

- Evolution law of service performance of ballastless track after disease repair;
- Monitoring, identification technology and early warning mechanism of track structure damage and abnormal state;

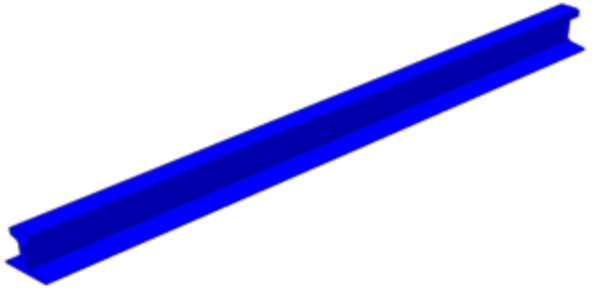




3 Research direction and suggestion

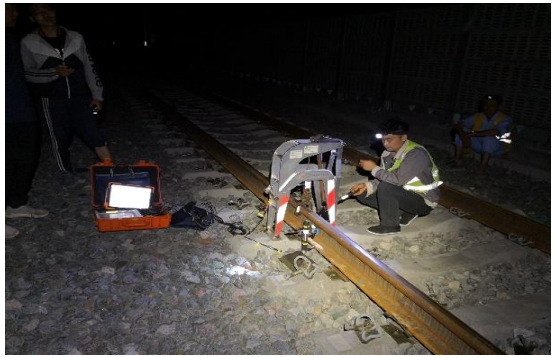
3.5 Theoretical research and system implementation of guided wave application in rail nondestructive testing

- The possibility of guided wave crack detection and monitoring should be verified;
- The rail nondestructive testing system and software and hardware system based on guided wave principle should be developed;



3.6 Research on theoretical method and key detection technology on locking temperature of seamless rail

- Research and development of online, full coverage, accurate seamless line temperature stress detection equipment;
- The scientific system and application scheme of ' key detection technology on locking temperature of seamless rail' are constructed;



THANK YOU

Shuguo Wang
+86 13911230376
zzddxx4473@sina.com

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Marrakech, 7-10 MARCH 2023

A Ground Improvement Application For A Railway Bridge Approach Embankments (Turkey)

Candan Gokceoglu
Prof. Dr.,Hacettepe University, Department of Geological Engineering, Turkey
Session2-5.2 Infrastructure / Construction

ONCF UIC

Project and Problem Description

- ✓ Ankara-Sivas High-Speed Railway Project is planned to be a part of an arterial railroad that will cross Turkey from west to east. Along the route, the railway passes through the cities of Ankara, Kirikkale, Yozgat, and Sivas with a total length of 400 km (Figure 1).
- ✓ Along the route in the study area, there are numerous rigid structures such as bridges, subways and elastic structures such as embankments in short intervals.
- ✓ Deformations and settlement problems were seen on the track between KM: 84+100 - 85+300 soon after the railway was taken into service.
- ✓ In this study, a ground improvement application to cope with the settlement problem of an in-service railway embankment was investigated as a case study.

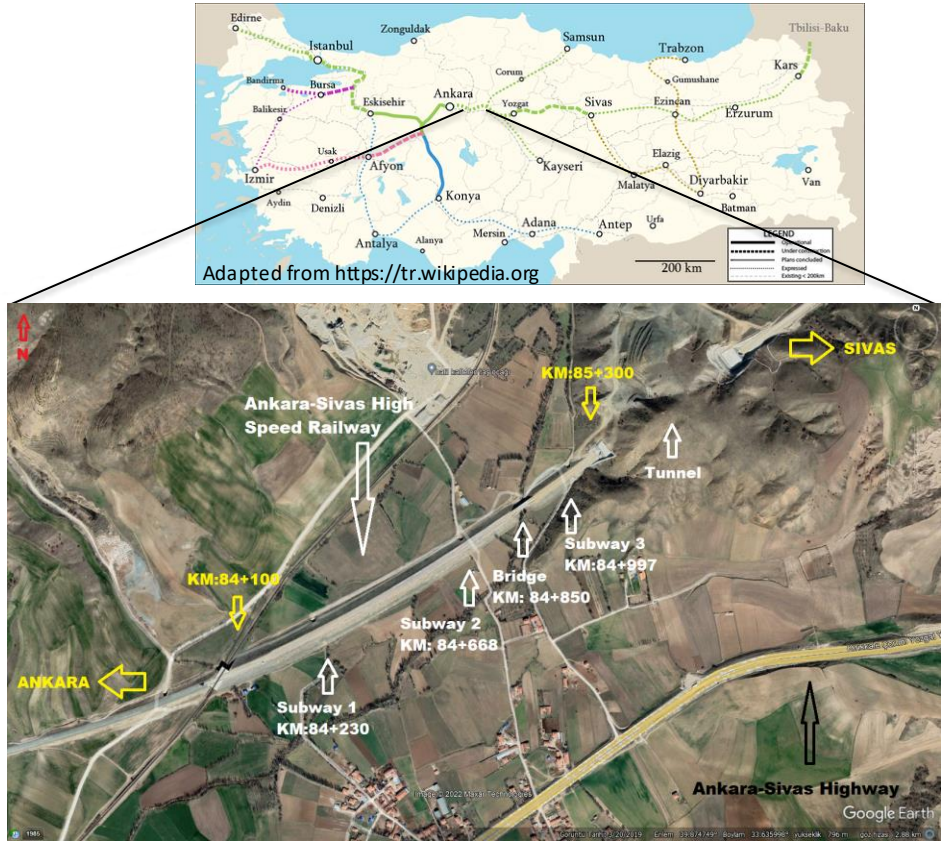


Figure 1. Location map of study area

Project and Problem Description

- ✓ Geophysical surveys were conducted along the route (MASW and SRT Methods) for the upper rail elevation readings in October 2021.
- ✓ Up to 7 cm settlements were observed on bridge approach embankments having a maximum elevation of 13-14m. Cracks were observed on the asphalt pavement of bridge (Allowable vertical deflections for high-speed railways are restricted by ± 5 cm).
- ✓ 7 cm vertical deflections were seen with naked eye on track (Figure 2).
- ✓ The abrupt changes arising from different types of construction and fluctuating groundwater levels in the study area were infered as the probable reasons for the deflections in short intervals (Figure 3).

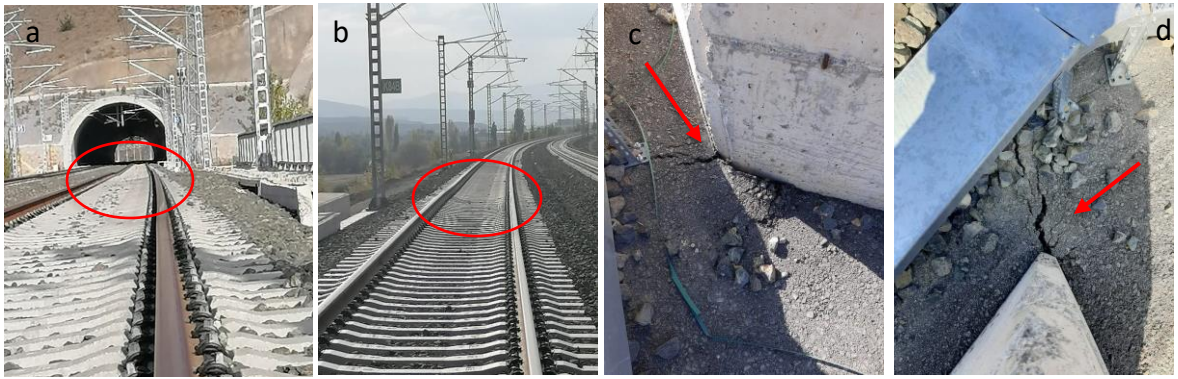


Figure 2. (a,b) Deformations observed on the railway bridge entrance due to settlement problem, (c,d) Cracks on the asphalt pavement

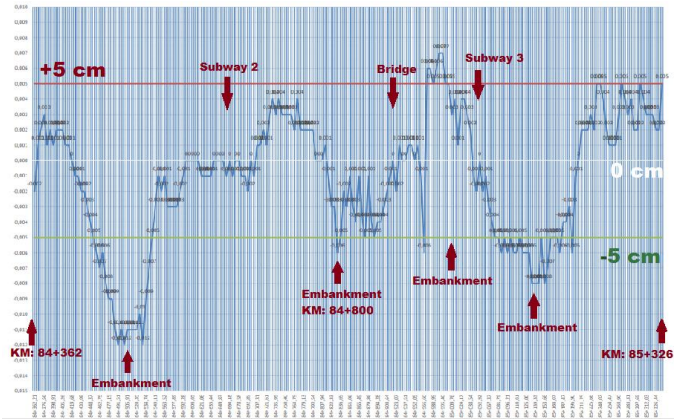


Figure 3. Total deflections in study area

Geological Profile of Study Area

- ✓ The geological setting around the study area consists of Miocene-Pliocene fluvial and Quaternary aged alluvium (Qal) along old stream deposits.
- ✓ 6 boreholes with a total depth of 92.5 m.
- ✓ The geological units include mainly low SPT-N values in clayey, muddy layers.
- ✓ GWL varies between the depths of 14.3 m and 18.0 m.

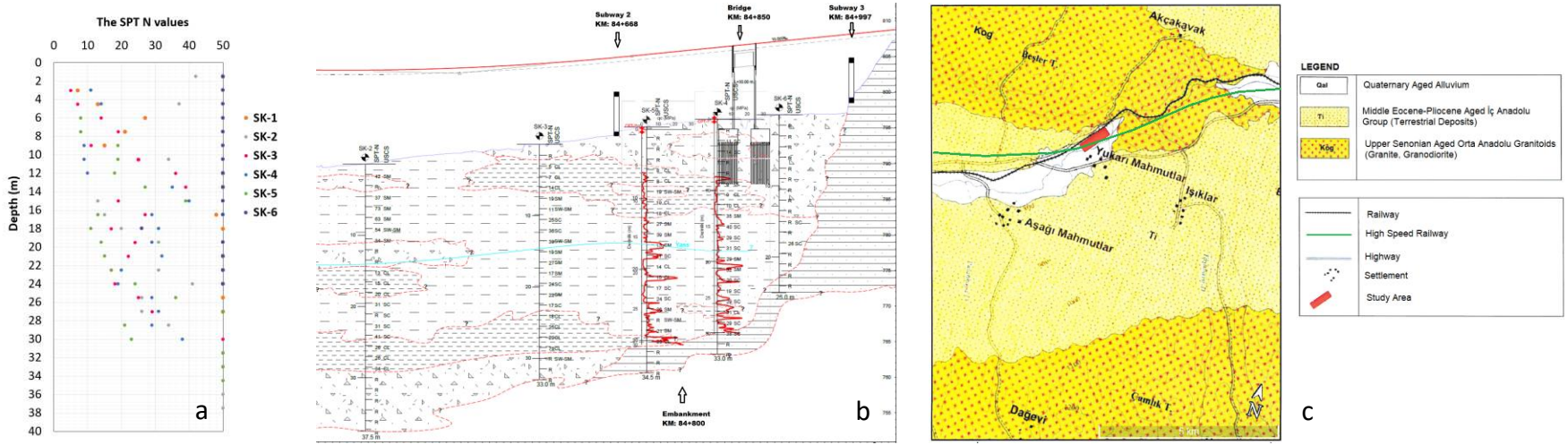


Figure 4. (a) The SPT-N values of the boreholes (b) Geological profile of study area, (c) Geological map of study area

Generalized Soil Parameters

- ✓ The undrained shear strength parameter used in the short-term analysis of clay units is calculated by the correlation based on the plasticity index, cu, and SPT-N values (Stroud, 1974).
- ✓ The effective internal friction angle (Φ) of clay layers is assumed to be 0 as the sample is fully saturated in undrained condition.
- ✓ In the long-term analysis of clay units, the correlation between the Angle of Effective Shearing Resistance and the Plasticity Index (Terzaghi, 1996) was used to determine Φ.

Figure 5. SK-4 Borehole core data

Table 1. Generalized soil parameters for Km :84+800 according to SK-4

Soil Formation	Depth (m)	Short-term			Long-term		
		γ (kN/m³)	c_u (kN/m²)	Φ (°)	γ (kN/m³)	c (kN/m²)	Φ (°)
Embankment Filling	-	20	5	35	20	5	35
Clay-1	0-5	18	60	0	18	3	32
Gravel	5-8	20	1	35	20	1	35
Clay-2	8-13	18	50	0	18	3	29
Sand	13-15	18	1	32	18	1	32
Clay-3	15-19	18	160	0	18	8	31
Sand	19-22	18	1	32	18	1	32
Clay-4	22-30	18	140	0	18	7	29
Gravel	30-40	20	1	35	20	1	35

Settlement Problem and Its Assessment

- ✓ Maximum settlement amount in the embankment subgrade are calculated as consolidation settlement under the expected soil conditions of the time-dependent settlement problem.
- ✓ m_v and c_v values required for consolidation settlement calculations were determined by the correlations given in Figure 6.
- ✓ Consolidation settlements calculations were done by Settle 3D software to define the settlements occurred before the ground improvement application and to identify the critical sections (Figure 7).

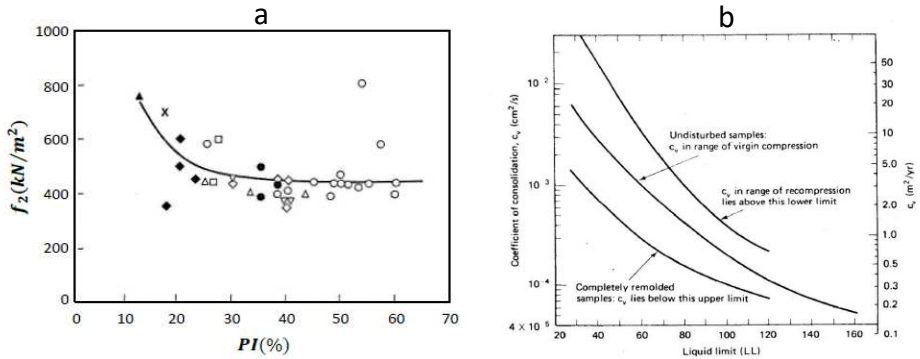


Figure 6. (a) Relation between N60, PI and undrained shear strength (Stroud, 1974), (b) Consolidation coefficient (cv), and liquid limit (LL) relationship (US Navy, 1971)

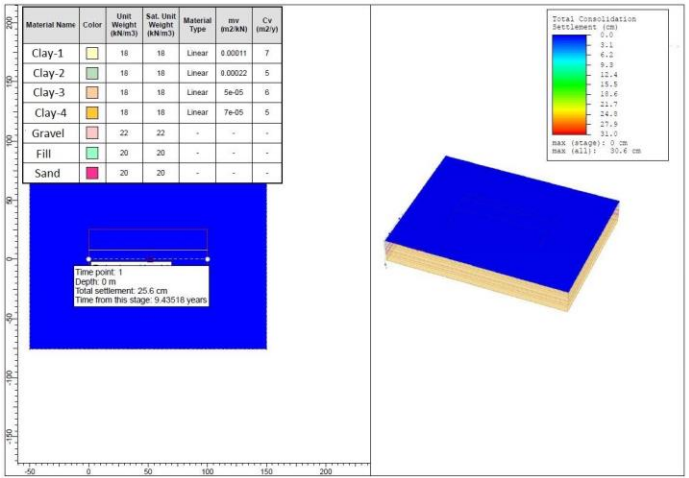


Figure 7. Consolidation settlements at KM:84+800 upon Settle 3D analyses results

Settlement Problem and Its Assessment

- ✓ According to the settlement analyses, the remaining settlement amounts for the sections KM:84+560, KM:84+700 and KM:84+800 are 37.20 cm, 31.30 cm, and 30.60 cm respectively.
- ✓ The time required for the settlement to degrade to allowable limits are calculated as 8.43, 8.60, and 9.44 years respectively for abovementioned sections. Since the embankments were constructed 7,5 years before, the remaining settlement is still above the allowable specification criteria.
- ✓ Therefore, a ground improvement methodology was required in the soft clay layer of railway embankments for the obtained critical sections.

Table 2. Consolidation settlements of critical sections calculated by Settle 3D Software

Section	Borehole No	Soil Unit	Depth (m)	m_v (m^2/kN)	c_v (m^2/year)	Consolidation Settlement (cm)	Time of Consolidation (year)	Elapsed Time (year)	Conclusion / Evaluation
Km:84+180	SK-1	Clay-1	3.00-5.00	0.00021	4.00	17.60	1.44	7.50	elapsed time > consolidation time Ground improvement is not required.
		Clay-2	5.00-8.00	0.00010	4.00				
Km:84+320	SK-2	Clay-1	15.00-18.00	0.00011	4.00	16.90	3.06	7.50	elapsed time > consolidation time Ground improvement is not required.
		Clay-2	18.00-24.00	0.00005	4.00				
		Clay-3	24.00-29.00	0.00007	4.00				
Km:84+560	SK-3	Clay-1	3.00-6.00	0.0003	4.00	37.20	8.43	7.50	elapsed time < consolidation time **Ground improvement is required.**
		Clay-2	6.00-10.50	0.0001	4.00				
		Clay-3	10.50-13.00	0.00004	9.00				
		Clay-4	20.00-30.00	0.0001	5.00				
Km:84+700	SK-5	Clay-1	5.00-8.00	0.00021	4.00	31.30	8.60	7.50	elapsed time < consolidation time **Ground improvement is required.**
		Clay-2	8.00-13.00	0.00011	4.00				
		Clay-3	18.00-24.00	0.00012	4.00				
		Clay-4	30.00-32.00	0.00009	4.00				
Km:84+800	SK-4	Clay-1	3.00-5.00	0.00011	7.00	30.60	9.44	7.50	elapsed time < consolidation time **Ground improvement is required.**
		Clay-2	8.00-13.00	0.00022	5.00				
		Clay-3	15.00-19.00	0.00005	6.00				
		Clay-4	22.00-30.00	0.00007	5.00				

* In the consolidation settlement calculations for the railway embankments, the upper limit of settlement is restricted by 5 cm (TCDD, 2020).

Ground Improvement Methodology for Settlement Problem

- ✓ In order to keep the consolidation settlements in allowable limits for the critical sections, a ground improvement method with inclined deep soil mixing (DSM) applications was designed (Figure 8.(a)). The consolidation settlement of the embankments after ground improvement by DSM columns was calculated by Settle 3D software.
- ✓ The composite modulus of elasticity of improved soil (Mcomp) of DSM is calculated according to the DSM pattern.
- ✓ According to Settle 3D analyses, settlements in the improved ground were within the desired limits for the critical sections.

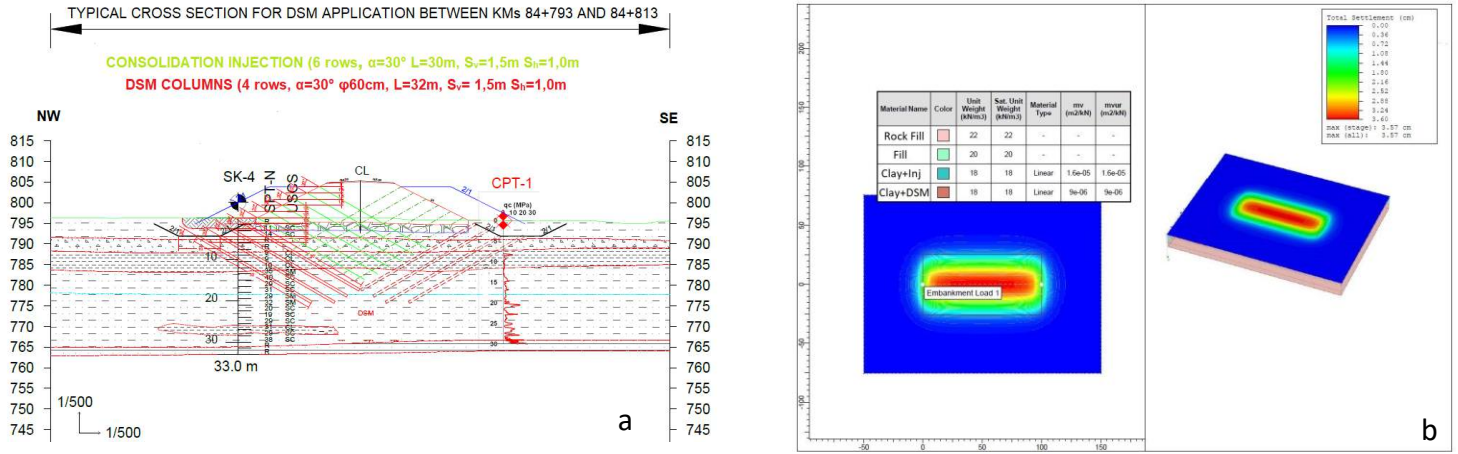


Figure 8. (a) Cross section of ground improvement application (b) Settle 3D analyses results of section Km :84+800 after ground improvement

Application of Deep Soil Mixing Columns

Design of Deep Soil Mixing (DSM)

- ✓ Diameter of 0.6 m, 3 to 4 rows in cross-section
- ✓ 1.5 m apart vertically, 1 m apart horizontally, L=32 m
- ✓ Application angle of 30°
- ✓ Water-cement mixture ratio = 0.8 to 1.0
- ✓ The rotary rotation rate = 80 rpm
- ✓ Water-cement mixture injection pressure = 60-100 bar

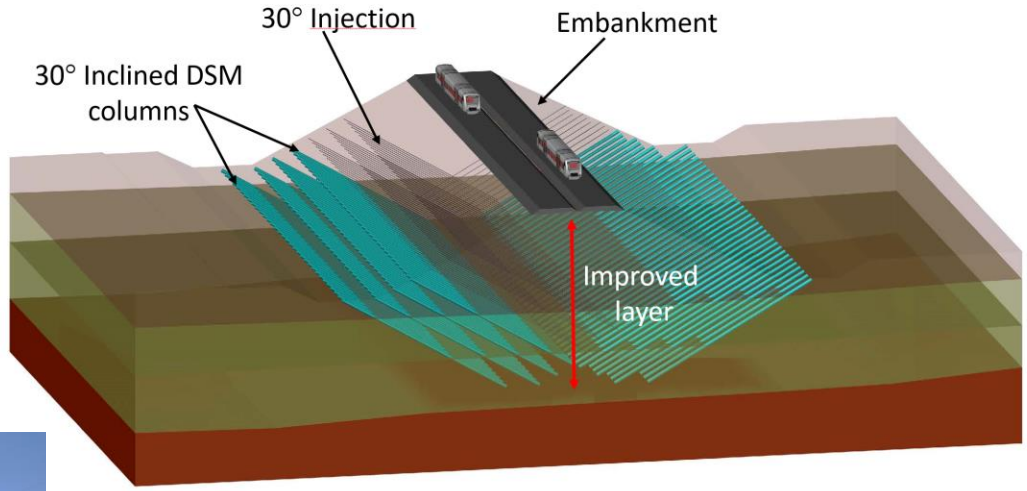
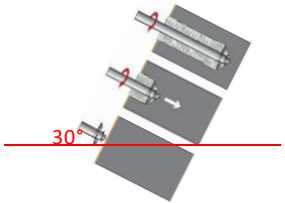


Figure 9. 30° Inclined DSM application design under the railway embankment

a b

Figure 10. (a,b) Application of inclined DSM columns on Ankara-Sivas Railway Line (Iksa Eng. Company, 2022)

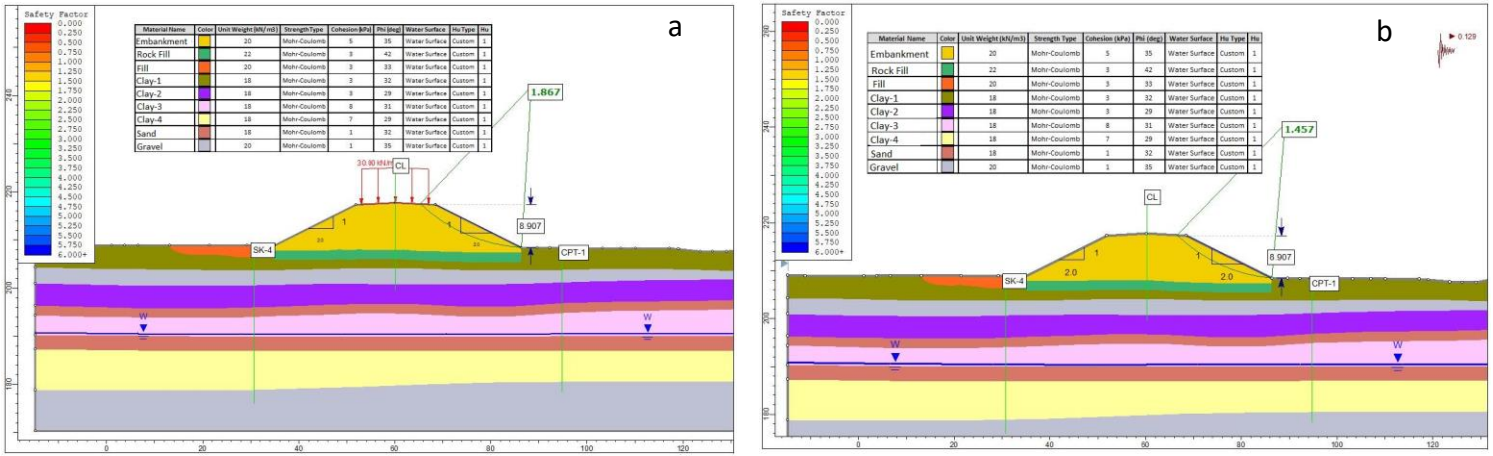
- ✓ The DSM columns are designed to be 30 degrees from horizontal to reach the deepest point of soft clay units for better improvement against settlement.



The deep mixing method was carried out in accordance with FHWA-HRT-13-046 (2013)*

Stability Assessment

- ✓ Slope stability analyses were performed by using Slide2 Limit Equilibrium Analysis (LEA) software for critical sections,
- ✓ The analyses were performed for short-term and long-term conditions in static and dynamic states,
- ✓ The superstructure load applied on the system is q = 30.0 kPa.
- ✓ The horizontal earthquake acceleration was used as kh = 0.129 g, according to the Earthquake Hazard Map of Turkey published by the Turkish Disaster and Emergency Management Authority (AFAD).
- ✓ The calculated safety coefficients were within the allowable limits (TCDD, 2020).



Figures 11. Stability analysis of section KM:84+800 in long-term (a) static state (b) dynamic state

Results

- This study investigated and presented the settlement problem on Ankara-Sivas High-Speed Railway embankments as a case study.
- Deep soil mixing methodology was chosen to solve the settlement problem on account of time, economy and ease of application for an in service railway. The application of DSM columns is designed to be 30 degrees horizontal to achieve the best results in clay layers.
- Consolidation settlement analyses done for unimproved and improved clay layers and it was concluded that settlement amounts remained in allowable limits for the improved ground with DSM columns.
- Stability analyses were done by Rocscience Slide software. In consideration of calculations, it was concluded that the railway embankments are stable and seismically safe after ground improvement by DSM columns.
- The DSM columns' construction was completed successfully as of December 2022. Deformations measured on track after the DSM application were within the allowable limits (i.e. below 1 cm).

THANK YOU

Co-authors of Article:
Candan GOKCEOGLU, Hacettepe University, Department of Geological Engineering, Ankara, Turkey
Ahmet SIRIN, General Directorate of Turkish State Railways (TCDD), Ankara, Turkey
Elif ATAR, General Directorate of Turkish State Railways (TCDD), Ankara, Turkey
Asli CAN, Iksa Engineering Company, Ankara, Turkey
Emre TURK, Akademi Zemin Company, Ankara, Turkey
Suat GULLU, General Directorate of Turkish State Railways (TCDD), Ankara, Turkey
Servet KARAHAN, General Directorate of Turkish State Railways (TCDD), Ankara, Turkey

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Marrakech, 7-10 MARCH 2023

Ankara Sivas Railway – Elmadağ Kırıkkale Section, Construction of T-15 Tunnel Under High Groundwater Pressure by NATM Method

Ümit Güney[3], Ahmet Şirin[1], Suat Güllü[1], Hüseyin Çelik[1], Servet Karahan[1], Candan Gökçeoğlu[2]
1, General Directorate of State Railways of the Republic of Turkey /ANKARA
2, Hacettepe University, Faculty of Engineering, Department of Geological Engineering /ANKARA
3, TCDD Teknik Company /ANKARA

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Marrakech, 7-10 MARCH 2023

SUSTAINABILITY ACTIVITIES OF HALKALI-KAPIKULE RAPID LINE CONSTRUCTION PROJECT

Abdullah ÇORAK
Deputy Head of Department, TCDD, Türkiye
Session2-5.2 Infrastructure / Construction

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