Investigation of Modern Technologies for Reducing Carbon Dioxide Emissions in Railway Networks

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Abstract: The revenues for railway infrastructure managers, are proportional to the volume of passenger and freight traffic, on the railway lines, supplemented by other revenues and subsidies. To maximize their revenues in a changing economic environment (where there is a tendency for the state to withdraw from funding), it is important to have and operate an infrastructure with sufficient capacity. In the event of inadequate track conditions, they will not only face a loss of revenue from network charges, but also additional penalty costs. One of the key elements in achieving stable, good track conditions, is to ensure that the substructure conditions, are adequate. In practice, the use of large-scale mechanized formation rehabilitation is becoming increasingly common, ensuring a sufficiently fast job and consistent quality. Another advantage of this technology is that it allows 100% of the logistical tasks of renewal, to be carried out on the railway track and reduces the amount of new raw materials to be installed. In this article, we present the application possibilities of large-scale mechanized formation rehabilitation and highlight the savings, in newly installed raw materials. The new materials have a high installed CO2 emission, thus, significantly increasing the ecological footprint of infrastructure development. The study aims to develop the methodology for reducing the ecological footprint, for the improvement of the railway network.

Keywords: Modern technologies; Railway network; Rehabilitation; CO_2 emission

1 Introduction

The rail network, much of which was built 100-120 years ago across Europe, needs to undergo major renewal and modernization every cycle, with ongoing maintenance. As the capacity of rail passenger and freight transport has developed, speeds and axle loads have increased dramatically [1-3]. Reinforcing and rebuilding the railway substructure involves high costs and traffic disruption using unconventional technologies [4] [5]. As early as in the second half of the 1970s, in Austria and Germany, the need arose for a new technology that would allow rapid reinforcement of the substructure under the existing tracks without demolishing them. The development of the technology for large-scale mechanized formation rehabilitation required not only innovation from a mechanical point of view but also new thinking in terms of track and geotechnical design and engineering control procedures. A prerequisite for the applicability of the machinery systems in Hungary was the introduction of technology-specific design and technical control procedures and their adaptation to domestic conditions. Over the last forty years or more, the mechanical and engineering background has been further improved and the emphasis on recycling processes has increased.

The mobility and successful economic activity of a country's population is fundamentally linked to the performance of its transport infrastructure, whether rail, road or waterway. The key aspect is the high technical standard and constant availability of the infrastructure. For rail traffic, this requirement means that the railway network must be designed to meet these demands. The requirements are essentially determined by the speed of trains and the axle load. Both train speeds and axle loads have increased over the last decades (due to the increase in the loads carried). In order to keep pace with this development, infrastructure facilities, such as the track system, need to be constantly upgraded and kept up to date with technical progress. This is the aim of the constantly revised general technical rules and the specific guidelines for the design of track systems issued by the infrastructure managers. In addition to the technical specifications and, in particular, the structural design specifications, the construction technologies used also play an important role in ensuring that the railway track meets the requirements in the long term.

Looking in detail at the possibilities for large-scale mechanized formation rehabilitation, the following conclusions can be drawn. By using large-scale mechanized formation rehabilitation technology, the track possession times can be minimized, thus minimizing the loss of revenue caused by train cancellations. By creating a uniform formation protective layer, the long-term stability of the track is ensured. The reuse and recycling processes that can be carried out on site (immediately on the track) during large-scale mechanized formation rehabilitation significantly reduce the amount of new material to be installed, thus, reducing transport, loading and disposal costs as well as CO_2 emissions.

Research questions and hypotheses:

- Explore the potential of the large-scale mechanized formation rehabilitation method. It is hypothesized that the application of this method will result in faster work, more uniform and better-quality track conditions at the end of the work process.
- The deterioration of the achieved track condition is significantly slower when using the large-scale mechanized formation rehabilitation technology than with conventional (earthmoving) formation rehabilitation technology and is therefore considered cost-effective.
- In addition to being cost-effective, it is also eco-efficient, as a significant amount of the track materials can be reused thanks to the recycling process. with effective reduction of CO_2 and the ecological footprint.

To define the framework of our research as precisely as possible, it is essential to review the relevant literature. Significant changes in recent decades, such as the development of motorization, changes in travel habits and transport needs, digitalization, sustainability, and environmental protection, are having an impact on which railways need to respond [6]. According to a German study, a 10% increase in railway services reduces carbon monoxide pollution by about 1% and nitrogen oxide pollution by 2%. The research also found that increasing railway services reduces car and motorcycle use. They concluded that the positive effects of pollution reduction through the expansion of railway services are worth significantly more than the budget funds spent on railway subsidies [7]. Results from a Chinese study also demonstrated that the introduction of high-speed railways was negatively correlated with metropolitan PM2.5 emissions and carbon dioxide emissions, suggesting a reduction in urban air pollutants and carbon dioxide emissions [8]. Other findings suggest that the establishment of high-speed rail networks can trigger green innovation, enhancing energy efficiency and thereby indirectly reducing carbon emissions [9]. A study in Serbia compared the impact of road and rail traffic on the soil by analyzing the presence of heavy metals in soil samples collected along a busy highway, local roads and an active railway line. Results showed that cars emitted higher amounts of heavy metals than trains [10].

Rail transport also has negative effects, as the most significant environmental problem it generates is low-frequency noise. The associations between noise exposure and hypertension risk are strongest at low frequencies [11].

2 Research Methodology

2.1 Comparison of Technologies

The workflows specific to conventional earthmoving and large machine technology are summarized in Table 1. In the current study, the authors investigate the properties of formation rehabilitation machines manufactured by Plasser & Theurer GmbH and operated by Eurailpool GmbH and Swietelsky AG.

Table 1

Comparison of technologies

Conventional earthmoving technology	Large machine technology
Preparatory work	
– Delivery of the protective layer to be installed to an intermediary depot. – Construction of access roads along the entire length of the line to be built. – Partial elimination of existing drainage system at the access roads.	– Delivery of the protective layer to be installed to an intermediary depot.
Work that can be carried out during track possessions	
– Dismantling and removal of track structure – Excavation and transport of track bed material to an intermediary depot – Cleaning of track bed material at the depot. – Transport of waste material to landfill – Excavation of material to prepare space for the protective layer and transport to landfill – Road transport and installation of the protective layer on the entire length of the track section – Road transport and installation of the crushed stone ballast on the entire length of the track section – Transport to site and construction of the track structure materials.	– Work carried out by the formation rehabilitation machine: • Excavation and cleaning of track bed material • Installation of re-usable ballast material. • Transfer of waste material to transport wagons • Excavation of material to prepare space for the protective layer and transfer to transport wagons • Supply of protective layer material by wagons. • Installation of a protective layer • Tamping of track • Transport of waste material to an intermediary depot by wagons. • Supply of track structure materials by wagons • Reconstruction the track structure. • Removal of dismantled track structure materials by wagons

Finishing work	
− Restoration of drainage systems. − Removal of the entire intermediary transport route − Restoration of the original environmental state	− Removal of intermediary depots − Restoration of the original state

In the case of maintenance or upgrading of existing railway tracks, the following factors are decisive for the choice of construction method and technology for the technical design of the structure:

- Local conditions/circumstances
- Time and operational requirements for construction
- Economy
- Security
- Environment protection and sustainability

Every designer and, ultimately, every client of construction services is confronted with the choice of the proper working method again and again. Starting from the 5 factors listed above, the detailed criteria in Table 2 should be considered when choosing the proper working method.

Table 2

Criteria for the choice of working method

Factor	Detailed criteria
Local conditions, circumstances	− Single or double track section, track spacing, possible obstacles − Length of the working area − Work area access (embankments, cuts) − Season, weather
Construction time and operational specifications	− Duration of execution (length of cut-offs) − Materials logistics on site
Economy	− Length of the working area − Material supply and waste disposal − Optimization of track possessions − Quality of work, careful use of materials
Security	− Safe construction work
Environment and sustainability	− Area occupied − Noise emissions, CO_2 emissions − Damage to fauna and flora − Recycling and reuse of materials

2.2 Evolution of Formation Rehabilitation Machines

Railway formation rehabilitation machines are integrated systems that can be divided into three main components. At the front of the machine is a section of equipment for transporting the excavated material, consisting of so-called MFS wagons (material conveyor and hopper units). These special wagons are equipped with conveyor belts, which, while continuously filling the last unit of the train, allow the transfer of the excavated old formation and ballast material to the first wagon and fill the set of MFS wagons from the front to the back. The next part is the working unit, which houses the excavation chains for extracting the old crushed stone, protective layer and formation material, depending on the type of machine: the cleaning, crushing and washing units, the spreader unit and compacting plate vibrators used for laying the new protective layer, and the crushed stone spreading unit. At the rear of the machine system are special container carrier wagons equipped with gantry cranes for the transport of the new materials to be installed.

Table 3
Main characteristics of formation rehabilitation machines

Year of manufac ture	Machine type	Installation of geosynthetics	Crushed stone regeneration	Protective layer material recycling
1980	PM 200-1 BR/C	yes	no	yes
1994	AHM-800-R	yes	no	yes
2000	RPM 2002	yes	in part	yes
2002	PM 200-2R	yes	yes	yes
2009	**PM 1000 URM**	**yes**	**yes**	**yes**

The machines listed in Table 3 represent the main steps in the evolution of the technology. Initially, the material for the old protective layer was delivered in its entirety, while the ballast material was crushed by the crushing equipment on the machine, and the new protective layer was built by mixing this material with newly delivered stone material. This solution is known as the AHM technology. In further developed versions, the partial and then the complete recycling process is carried out in the machine. The PM 1000 URM is the most advanced of all and will be the subject of the authors' further research.

2.3 Description of the Materials used in the Technology

When a railway track is upgraded, the top of the formation is usually reinforced. With the introduction of the large-scale mechanized formation rehabilitation technology, the role of the sand and gravel layer previously used in Hungary as a protective and reinforcing layer has been replaced by a more homogeneous mixture of a crushed stone supplementary layer, the granular mixture "CGM1" (or coarse-grain mixture "CGM1" [12]), the particle distribution of which is shown in Fig. 1.

The granular mixture "CGM1" has a relatively high fine content and is, therefore, nearly impermeable. The mix is very sensitive to exceeding the optimum water content during installation. The additional layer of crushed stone ensures that precipitation is kept away from the subsoil and also increases the bearing capacity of the substructure as a layered structure. The thickness of the additional layer is usually 40 cm.

The granular mixture "CGM1" is produced by mixing fractions of natural material with fractions of broken and round particles in such a way that the following conditions are met [13]:

- The percentage by weight of the crushed stone fraction is at least 30%
- The mixture must contain at least 30% round particles
- The granular mixture "CGM1" may be made up to 100% of a crushed stone fraction if the following requirements for compactness and load-bearing capacity can be demonstrably met after installation:
  - It's particle size distribution curve must fall within the limiting curves shown in Figure 1
  - It's inequality index must be C_u≥15 because this ensures that it does not disintegrate under dynamic loads
  - It's maximum particle diameter must be at least 32mm but >63mm
  - It's water permeability coefficient at T_{rp} = 100 % solidity must be k≤1×10–6 m/s
- The fine content of d≤0.063 mm must not exceed 7% by weight (with C_u≥15), as this ensures frost resistance
- The abrasion values for the Los Angeles and micro-Deval tests are also numerically specified

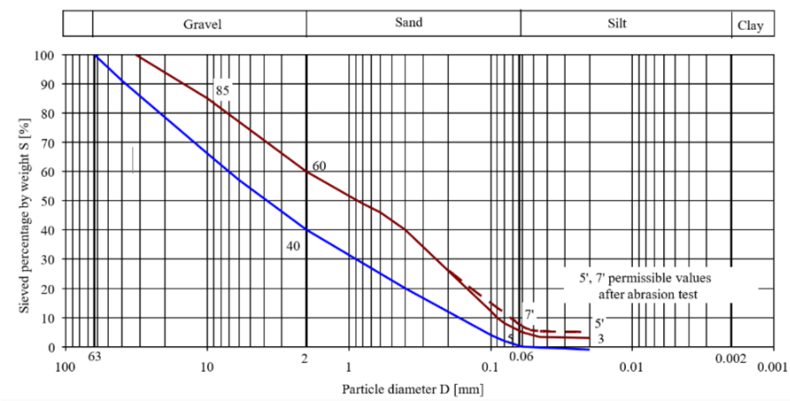

Figure 1

Limit curves of the granular mixture "CGM1" [13]

The part of the superstructure structure considered with the crushed stone ballast, which should be reused to the greatest extent possible as ballast or recycled as part of the supplementary protective layer during track renewal. The PM 1000 URM formation rehabilitation machine is mainly used for line modernization and renewal; it makes it possible to install the supplementary layer and to regenerate and reuse the old ballast material in one step. Table 4 summarizes the required quantity and CO_2 emissions of the granular mixture "CGM1" used for the supplementary layer to be installed in single and double-track cross-section design on the Hungarian railway lines relevant to the current research, based on calculations by Öko-Institut [14].

Table 4
Required quantity and CO_2 emissions of the crushed stone granular mixture supplementary layer in the case of track modernization and renewal

	Unit	Single-track	Double-track
Width of intervention	m	7.32	11.42
Volume of supplementary layer	m^3	3.20	4.99
Mass of supplementary layer (2.6 t/m^3)	kg	8320	12974
CO_2 emissions of supplementary layer (0.004 kg/kg)	kg CO_2/m	33.28	51.896

The crushed stone ballast material to be installed has a grain size of 31.5/63 mm; it is free of impurities. A sharp-edged crushed stone material is usually andesite or basalt in Hungary. Its quality testing is required by [15]. Table 5 shows the amount of ballast material required and its CO_2 emissions per running meter of track for single and double track with reinforced concrete sleepers.

Table 5
Required quantity and CO_2 emissions of ballast stone material for of track modernization and renewal

	Unit	Single-track	Double-track
Volume of ballast	m^3	2.17	4.30
Mass of ballast (1.65 t/m^3)	kg	3573	7099
CO_2 emissions of ballast (0.004 kg/kg)	kg CO_2/m	14.292	28.396

3 Results

3.1 Comparison of Technologies

In a complete analysis of the technical content of the work, for example, if the installation of load-bearing and protective layers under the crushed stone ballast is required, the differences between the conventional excavation method and the large-machine conveyor technology usually reveal the following economic and technical advantages of the conveyor method over the conventional method:

1. **Short construction time**

   The technology allows for an output of up to 1000 track meters per day, so the reconstruction work only takes a short time. The required track possession time of the section being worked on is reduced to a minimum.

2. **No need to use the adjacent track**

   On double or multi-track sections, the track(s) adjacent to the working track(s) is/are available to rail traffic without restriction. The capacity of the railway line is only slightly reduced.

3. **The adjacent track clearance zone remains intact**

   Track-side technology operates at a specified system width that precludes intrusion into the adjacent track clearance zone. Large-scale mechanized railway technology guarantees a very high level of traffic safety.

4. **High level of worker safety through the machine's warning system**

   Worker safety is paramount in any working method. Warning of rail traffic hazards is an essential element of safety at work. The machine's warning system, together with external warning systems, helps to ensure optimum protection for workers.

5. **All materials are transported in an environmentally friendly way, exclusively on the working track**

   Materials for track-bound construction techniques are transported in and out of the working track only. On multi-track sections, it is not necessary to use the adjacent track(s) under traffic. The adjacent track is thus fully and continuously available for traffic. There is no need for parallel construction access roads and no need for road vehicles to enter the track zone.

6. **Protection of the top of the formation and load-bearing layer**

   Conventional excavation methods also use the working area as a transport route. This can lead to excessive stress on the already weak existing subsoil. The inhomogeneity of the formation will require more stabilization measures at the level below the crushed stone ballast.

7. **Suitability for difficult track conditions (high embankments and long cuts, densely built-up urban areas)**

   In such topographical situations, the renewal of the railway track is not a problem either because all the material transport to and from the formation rehabilitation machine is done exclusively on the working track.

8. **Homogeneity of the installed layers, no overlapping of sections**

   Track-bound technologies are used to install the load-bearing and protective layer systems under the crushed stone ballast in a continuous manner so that no "gaps" (weak sections) are created due to interruptions in the construction.

9. **Installation of a complete load-bearing layer system in a single session**

   The structurally required load-bearing layer system (consisting of a mixture of granular sand and gravel and geotextile base and separation layers) is installed in one single operation, including the crushed stone sub-ballast above. The axial loading of the substructure materials by earthmoving machinery can be avoided, thus avoiding the resulting structural weakening.

10. **Prevention of unevenness in the formation**

    The removal and transport of formation materials and the supply and installation of new load-bearing and protective layer materials will not result in loads that would cause further deformation and unevenness in the already weakened formation.

11. **Optimum wetting of the load-bearing and protective layers on the machine before compaction**

    To ensure that the load-bearing and protective layers are adequately compacted, it is necessary to set the optimum water content. If the materials to be installed are too dry, the machine can add the missing moisture before installation and compaction.

12. **No need to provide static protection/enclosure to the adjacent track**

    In contrast to conventional excavation methods, the conveyor belt technology does not require the construction of a static fence/railing to the adjacent track. The excavation only undercuts the adjacent track's load cone for a short enough time that no damage can occur to the adjacent track in service. The machine immediately fills the area to be covered with the material to be installed.

13. **Recycling of existing used crushed stone ballast with the help of the formation rehabilitation machine**

    The units of the formation rehabilitation machine process the crushed stone, pre-clean, break, grind and wash it, and then, after the load-bearing and protective layers have been installed, re-install it as a sub-bed in the track. Recovered materials that are not suitable for use as ballast material undergo a special processing operation inside the machine, after which they can be reused as load-bearing, protective or intermediate layers. The recycling of these materials in the formation improvement layers reduces the need for new materials and, thus, the amount of material to be extracted from the mines.

14. No need for road access to the work area

The construction of access roads is not necessary, due to the transport of materials on the working track. The lease or purchase of land for the construction of such temporary access roads is not necessary when using the track-bound method.

15. Reducing depot areas

The processing of existing used crushed stone within the formation rehabilitation machinery and the immediate reintegration of materials eliminates the need for temporary depots. Minor use of non-owned land

Since there is no need for construction access roads and depot areas, there is less need for the use of non-owned land compared to conventional excavation methods.

16. No need for fixed material processing facilities

Material processing within the formation rehabilitation machine eliminates the need for fixed material processing facilities and the associated logistics expenses.

17. Protection of fauna and flora, working within environmentally protected areas

Especially since there is no need for construction access roads and depot areas outside the track zone, and therefore, there is no need to use non-owned land, track-bound technology will noticeably spare the fauna and flora living in the vicinity of the track zone.

18. Significant reductions in pollution (by around 20-30%), lower carbon emissions, improved life cycle assessments, greener working

The frequent debates on global warming have recently led to a number of analyses of the environmental impact of different construction methods. In particular, results on formation rehabilitation technologies are now available.

3.2 Reuse and Recycling Process of the PM 1000 URM Machine

The machine uses three excavation chains to lift the crushed stone, the old protective layer and part of the top of the formation from under the track. The material extracted by the first and second excavation chains is recycled on-site.

The operations and recycling are carried out by the first excavation chain and its linked units. The recycling process starts with the extraction of the top layer of crushed stone. The stone is pre-cleaned by sieving, after which a finger screen cleans the crushed stone of any remaining fine particles and other impurities. Any metal parts that may have ended up in the ballast are removed from the crushed stone by a magnetic conveyor belt. In the next step, the ballast material is re-sharpened by bouncing in a screw crusher. The thus sharpened stone material is fed into the vibrating screen together with the undersized particles produced during the process. This sieves out the undersized particles, which are then spread on the side of the track in front of the second excavation chain. The crushed stone material, regenerated as described above, is then cleaned by washing equipment integrated into the assembly and reused as the sub-bed. The water used in the washing equipment is purified in the integrated cleaning device and reused in the washing process.

The work process is carried out by the second excavation chain and its linked units. The second excavation chain brings out the mixed zone consisting of the lower part of the old ballast and the old protective layer, as well as the smaller-grained crushed stone material recovered in the first excavation chain work process. The excavated material is also removed from this process by a magnetic conveyor belt to remove any metallic particles, and after screening, the crushed stone material with a grain size of more than 45 mm is sent to the crushed stone recycling process of the first excavation chain. The material with a particle size of less than 45 mm is used to build up a new layer of a so-called sub-bed, usually 15-20 cm thick, up to 5m wide, under the new aggregate layer, using a pulley spreader, which can be supplemented with a soil stabilizing material such as cement.

Work carried out by the third excavation chain: the third excavation chain is used to form the bottom plane of the top of the formation. It excavates the rest of the subsoil at the intended level. The excavated material is not recycled but is transferred by conveyor belts to a unit of MFS 100 wagons in the front of the train, where it is transported away and deposited according to the direction of work or occasionally used as embankment material.

Key benefits of the technology:

- High working speed, significantly less track possession time compared to the conventional earthmoving technology, no need to dismantle the track and all operations are carried out in the working track zone
- No damage to the top of the formation (e.g., due to longitudinal material transport), as all material transport is by rail and is less sensitive to adverse weather conditions
- Homogeneous and durable installation quality, geotextile/geogrid can be laid by machine at the same time

But it is also true that:

- The thickness of the protective/reinforcing layer to be installed is limited; soil replacement and classical soil stabilization are not possible
- Additional measures in response to deficiencies discovered during construction can only be implemented to a minimal extent
- The control of construction quality (compactness, load capacity) is limited in space and time
- A very weak (E_2 < 5...10 MPa) top of formation is not suitable for this technology [16]

4 Discussion

In addition to designing the technical handover method and identifying the materials to be incorporated, the most suitable machines for the task were put into operation in Hungary. The RPM 2002-2 was the first machine type used for the rehabilitation of the railway formation of the Budapest-Biatorbágy, Kecskemét-Városföld and Sopron-Szentgotthárd lines. In 2011, the PM1000 URM, the most powerful state-of-the-art machine, was applied for the first time on the Tárnok-Székesfehérvár line. By 2016, a total of 217509 meters of track formation rehabilitation work had been completed using this technology, followed by several other projects, but the results of these projects are now part of a well-established technology and are not presented here. The formation rehabilitation works were, of course, carried out in one project with the superstructure replacement, mainly using the SMD-80 fast track renewal train, which has been in operation in Hungary since the mid-1990s. The main quantities of formation rehabilitation works carried out during the period of the KÖZOP (Transport Operative Program) projects are summarized line by line in Table 6.

Table 6
Large-scale mechanized formation rehabilitation work between 2009 and 2016 ("rm" is running meter)

Project name	Project period	Track length [rm]	Target price [days]
South shore of Lake Balaton I. Phase I.	2014-2015	26740	64
Gyoma-Békéscsaba (left track)	2013-2015	4556	11
Gyoma-Békéscsaba (right track)	2013-2015	4556	9
Nagyút-Mezőkeresztes	2014-2015	35604	53
Szajol-Püspökladány (left track)	2011-2015	56517	80
Szajol-Püspökladány (right track)	2011-2015	56517	93
Tárnok-Székesfehérvár (left track)	2011-2013	6600	10
Tárnok-Székesfehérvár (right track)	2011-2013	6600	10
Sopron-Szombathely-Szentgotthárd	2009-2011	25687	49

During the works, great emphasis was also placed on monitoring the completed installations during operation. Examining the operational properties of the completed track formations, it was found that under the soil characteristics of average Hungarian railway lines, the 40 cm thick, load-bearing layer of crushed gravel installed in an area with a design load capacity of 10-15 MPa distributes the vehicle load so well, that stresses on the lower plane of the layer, cause hardly any deformation [17].

In Hungary, the act on waste [18] was the first piece of legislation to set out specific requirements to reduce or eliminate the treatment of materials generated during construction and demolition works as waste. In terms of the requirements of the Waste Act, the technological process implemented by the PM1000 URM machine is fully compliant with the legal requirements.

The total amount of additional layers to be installed per running meter of cross-section in Figure 2 is approximately 3.2 m^3 (8.32 tons). The use of the formation rehabilitation machine results in the installation of approximately 0.8 m^3 (2.08 tons) of intermediate layer without leaving the work area. Up to 25% of the total cross-section is made from locally recycled material. Reclaimed crushed stone is being incorporated into the crushed stone ballast. From the 2.17 m^3 (3.58 tons) of ballast material per running meter of the track to be rehabilitated, up to 0.8 m^3 (1.32 tons) of reclaimed crushed stone can be recovered, depending on the condition of the ballast material of the track section to be rehabilitated, which represents 40% of the total ballast requirement.

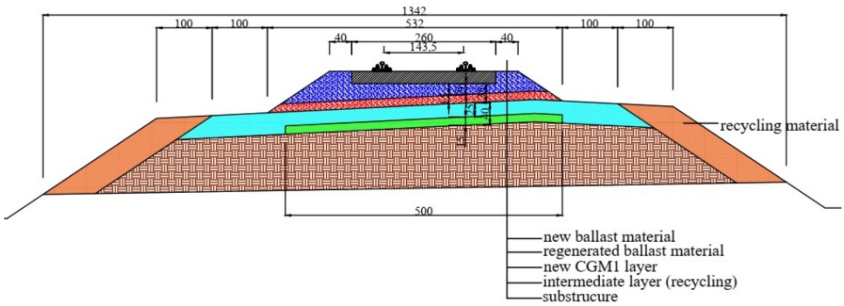

Figure 2

Possible track cross-section created by the formation rehabilitation machine (source: own design, every dimension in the figure is in cm unit)

Materials that are no longer suitable as load-bearing layers and are not incorporated during ballast regeneration are not necessarily landfilled as waste. If embankment widening is required to create a new railway track, it may be used as embankment material or, if the track environment permits, as additional formation shoulder on site. The machinery has a so-called mobile recycling license in Hungary, which allows the classification of the materials generated during the recycling process as material products (e.g., soil and stones EWC 17-05-04). The savings in CO_2 emissions on transport as a result of materials recovered and installed on-site by the formation rehabilitation machine are shown in Table 7.

Table 7
Savings in CO_2 emissions on transport as a result of materials recovered and installed on-site by the formation rehabilitation machine g CO_2 /rm ("rm" means running meter)

Name and quantity of material [t]	**Road transport 34-40 t semi-trailer truck at 100 km distance emissions g CO_2 /rm**	**Rail transport at 100 km distance emissions g CO_2 /rm**
Crushed stone; 1.32	11.22	3.6315
Granular mixture “CGM1”; 2.08	17.16	5.5536

By using the reclaimed interlayer and crushed stone material on-site during the recycling process, in addition to saving on transport and landfill costs, the CO_2 emissions of the construction process are reduced. A semi-trailer truck with a load of 34-40 t produces 82.5 g CO_2 /tkm, while rail transport produces 26.7g CO_2 /tkm. It is easy to see that in the case of large-scale mechanized formation rehabilitation using the recycling process, by reducing the amount of material to be supplied alone, a reduction of up to 17.16 kg CO_2 for granular mixture "CGM1". In contrast, for crushed stone material, a reduction of up to 11.22 kg CO_2 can be achieved as opposed to road transport, which represents a significant environmental benefit for each kilometer of track renewed. The 217509 m of renovated track described in Table 6, calculated with the more favorable rail transport, results in a saving of 0.79 t of CO_2 emissions for crushed stone and 1.208 t for granular mixture "CGM1" [19] [20]. The reductions in CO_2 emission from the new material savings per running meter must be calculated which can be achieved by using large-scale mechanized formation rehabilitation technology. The material savings of 2.08 t of granular mixture "CGM1" per running meter of the track will reduce the total emissions of the installation by 8.32 kg of CO_2, while the savings of 1.32 t of ballast stones will reduce the total emissions of the installation by 5.28 kg of CO_2. Over the project period presented, this represents a saving of 1809.65 t CO_2 for granular mixture "CGM1" and 1148.45 t CO_2 for ballast stone. In total, the application of on-site reuse and recycling technology has reduced CO_2 emissions by approximately 2960.1t in the course of track rehabilitation work carried out with formation rehabilitation machines between 2009 and 2016.

Conclusions

The presented, large-scale, mechanized, formation rehabilitation technology, requires a sufficient load-bearing capacity of earthwork, without which, it’s application is not possible. A preliminary estimation of the quantity of secondary raw materials (recycling) is always necessary since the quantity of primary raw material required to carry out the work, can be effectively reduced but not completely replaced, so, the quantity of the supply must be known, in order to carry out the work successfully.

Acknowledgment

The authors thank Mag. phil. Zs. Mondok for translating the article.

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