Possible Applications of Modern Technologies to Reduce Disruption on the Railway Network

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The revenues of the railway infrastructure managers are proportional to the volume of the traffic on the railway lines, supplemented by other revenues and subsidies. To maximise 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 condition is to ensure that the formation conditions are adequate. In practice, the use of large-scale mechanised subgrade rehabilitation is becoming increasingly common, ensuring a sufficiently fast job and consistent quality. Another advantage of its technology is that it allows 100% of the logistical tasks of renewal to be carried out on the track and reduces the amount of new raw materials to be installed. In this article, we will present the application possibilities of large-scale mechanised subgrade rehabilitation and highlight the savings in newly installed raw materials. With this thought-provoking article, we aim to raise the interest of the professional audience to learn more about this technology.

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1 Introduction

The rail network, much of which was built 100-120 years ago across Europe, needs to undergo major renewal and modernisation every cycle, with ongoing maintenance. As rail passenger and freight capacity has developed, so has speed and axle load. Reinforcing and rebuilding the formation entails high costs and traffic disruption compared with conventional technologies. Already 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 formation under the existing tracks without demolishing them. The development of the technology for large-scale mechanical railway 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. Over the last forty years or more, the mechanical and engineering background has been further refined and the emphasis on recycling processes has increased. The use of this technology has both economic and environmental benefits. Lichtberger (2022) and Esveld (2014) have dealt with the general aspects of railway track maintenance in detail, while the basics of the life cycle engineering approach have been described by Gáspár et al. (2011).

2 The evolution of formation rehabilitation machines

Railway undercarriage rehabilitation chains are integrated structures that can be divided into three main sub-assemblies. At the front of the chain is a section of equipment for transporting the excavated material, known as the "excavator section". MFS wagons. These special wagons are equipped with conveyor belts which, while continuously filling the last unit of the assembly, allow the conveyor belts to transfer the excavated old fill and aggregate to the first wagon and fill the assembly from front to back. The next part is the working unit, which houses the scraper chains for extracting the old crushed stone, protective layer and filling material, the grating, crushing and washing units, depending on the type of machine, the spreader and compacting plate vibrators used for laying the new protective layer, and the crushed stone spreader unit. At the rear of the assembly are wagons equipped with gantry cranes consisting of so-called cushion wagons for the transport of the new materials to be installed.

Table 1: Main characteristics of formation rehabilitation machines

Year of production	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 UHM	yes	yes	yes

The machines listed in Table 1 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 crushed stone was crushed by the crushing equipment on the machine and mixed with the new protective layer material delivered to build the new protective layer. In the upgraded versions, the partial and then the complete recycling process is then carried out. The PM 1000 UHM is the most advanced of all. With its three scraper chains, it is able to separately extract the crushed stone to be recycled, which is then recycled as a sub-bed after screening, bouncing and washing. The second scraper chain lifts the mixed zone consisting of the old bedding and the old protective layer. Crushed stones with a grain size of more than 45 mm are fed into the first chain's crushed stone recycling process. Material with a grain size of less than 45 mm will form the basis for the additional intermediate and support layers under the new protective layer. A soil stabilising material, such as cement, can be added to this support layer.

Key benefits of the technology:

- high working speed, significantly less cutting time compared to earthmoving technology, no need to dismantle the track and all operations are carried out in the cutting zone,
- no damage to the top of 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.

However, it is also true that:

- the thickness of the protective/reinforcing layer to be installed is limited, soil replacement and classical soil stabilisation are not possible,
- additional measures in response to deficiencies discovered during construction can only be implemented to a very limited 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.

3 Nationalisation of design and technical control specifications

The formations of the sections to be rebuilt are often in a very poor condition and can only be made suitable for the required load-bearing capacity by the installation of an additional reinforcing layer. In Hungary, the design guidelines in Instruction D.11 are the standard for formation requirements. The renewal of the Instruction D.11 was very important for the introduction of large-scale formation rehabilitation in Hungary. The introduction of rapid and technology-specific design methods is essential for the optimal use of mechanical formation rehabilitation technology. The modernisation of field measurement methods in the design and quality control processes has resulted in a great deal of time savings.

In the Hungarian design practice, geotechnical design using CPT sounding data was introduced in the context of the design of large-scale formation rehabilitation works, which does not exclude the traditional large live cutting operations with relatively long train-free times, but instead this much faster method can be used.

The main features of the applicability of CPT probing are:

- A complete picture of the formation layers down to a depth of 2 m,
- non-destructive testing, without introducing local track defects,
- continuous load line,
- a quick, efficient survey method,
- the measurement frequency can be easily compressed,

- requires little live work and can only be carried out during the cutting season.

Prior to the introduction of the test method, hundreds of measurements were made using CPT probing and conventional sectioning in the same cross-section and the results were presented in a design review. The results spoke for themselves, and it is now used as an accepted method. The next element of the practical implementation was the search for a fractured aggregate supplementary layer material with a suitable grain size distribution and rock physics. A trial mix of mines in Hungary with suitable rock physics properties was used to produce a mix with the designation SZK1, which was suitable in all respects. In addition to the technical criteria, the logistical transport and production capacity aspects were also important.

4 Experience gained in construction work

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 formation of the Budapest - Biatorbágy, Kecskemét - Városföld and Sopron - Szentgotthárd lines. In 2011, the PM1000 URM, the most powerful state-of-the-art machine chain, was used for the first time on the Tárnok - Székesfehérvár line. Figure 1 shows the machine chain at work.

Figure 1: PM 1000 UHM during the installation of the additional layer
Source: photo by Róbert Horváth

Using this technology, a total of 217,509 metres of track rehabilitation work was completed in 2016, the main quantities of which are summarised by line in Table 2.

Table 2: Large mechanical formation rehabilitation works between 2009 and 2016

Project name	Project period	Track length [vfm]	Target price [days]
South shore of Lake Balaton I. Phase I	2014-2015	26,740	64
Gyoma-Békéscsaba (left track)	2013-2015	4,556	11
Gyoma-Békéscsaba (right track)	2013-2015	4,556	9
Nagyút-Mezőkeresztes	2014-2015	35,604	53
Szajol-Püspökladány (left track)	2011-2015	56,517	80
Szajol-Püspökladány (right track)	2011-2015	56,517	93
Tárnok-Székesfehérvár (left track)	2011-2013	6,600	10
Tárnok-Székesfehérvár (right track)	2011-2013	6,600	10
Sopron-Szombathely-Szentgotthárd	2009-2011	25,687	49

During the works, great emphasis was also placed on monitoring the completed installations during operation. By testing the in-service properties of the completed formations using subsidence gauges installed at the top and bottom of the additional layer, it was found that, under the soil characteristics of average Hungarian railway lines, the 40 cm thick crushed stone protection layer installed over an area with a design load of 10-15 MPa distributes the vehicle load so well that stresses on the lower plane of the layer hardly cause any deformation. One of the characteristics of the material is observed in the installation of dolomite rubble pavements from mines in Hungary. For the installation of a fracture-crushed material corresponding to the SZK1 boundary curve, its water content must be kept at an optimum level of between 5 % and 7 %. The levelling beam of the formation rehabilitation machine chain spreads the material evenly according to the required profile, and the layer is then compacted using high-power vibroplates. A geotextile is placed between the top of earthwork and the additional layer to act as a separator, while a geogrid is placed in the crushed stone layer. The geogrid is placed either directly on the geotextile or in the overlying granular layer up to a height of 5-25 cm. Immediate measurements in a uniformly distributed SZK1 granular supplementary layer installed by vibratory compaction give significantly lower bearing capacity values than measurements after (1 week) pore water pressure has been released due to increased pore water pressure. After the pore water pressure is released, the bearing capacity of the additional layer is correspondingly developed. In all projects, back measurements were taken at the time of installation and at 1 week of age. It was found that, at installation, the protective layer could meet the design load capacity, which in this case was E_{vd} = 45 MPa i.e. E_2 = 90 MPa, when the top plane of the additional layer had a load capacity of E_{vd} = ~35 MPa.

5 Environmental assessment of large-scale mechanical formation rehabilitation

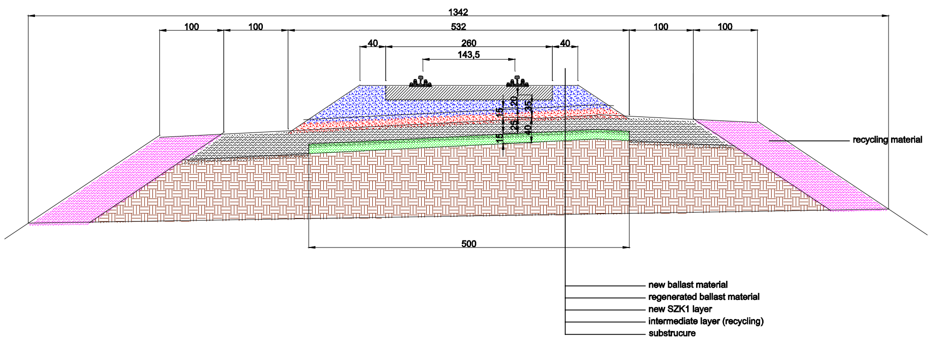

Figure 2: Possible cross-section of the track cross-section during the rehabilitation of the formation with a machine chain
Source: author's own illustration, dimensions in cm!

In Hungary, Act CLXXXV of 2012 on Waste 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. The PM1000 URM machine line is fully compliant with the requirements of the Waste Act. The total amount of additional layer to be installed per linear metre during the construction of the cross-section as shown in Figure 2 is approximately 3.2 m^3 . During the application of the formation rehabilitation machine chain, approximately 0.8 m^3 of intermediate layer is installed without leaving the work area. Up to 25% of the total cross-section volume is made from locally recycled material, with material savings of around €23/metre at current Hungarian prices. Reclaimed crushed stone will also be incorporated into the crushed stone bedding as described in Chapter 2. Depending on the condition of the ballast material of the track section to be rehabilitated, up to 0.8 m^3 of reclaimed crushed stone can be recovered from 2.1 m^3 of ballast material per linear metre, which is 40% of the total ballast requirement, with material savings of €31/metre at current Hungarian prices. By using the technology, the in-situ incorporation of waste material results in significant savings, which translated into business terms, provides a significant competitive advantage for contractors, and reduces the cost of the project for the client.

Materials that are no longer suitable as load-bearing plywood and are not incorporated during bedding regeneration are not necessarily landfilled as waste. If embankment widening is required to create a new railway track, it may be used as fill material or, if the trackbed environment allows, as replacement embankment on site. The machinery chain in Hungary has a new Mobile Use Permit, which allows the classification of the materials generated during the recycling process by product (e.g. soil and stones EWC 17-05-04). By using the reclaimed interlayer and crushed stone material on site during the recycling process not only saves on transport and landfill costs, but also reduces material costs by up to €54 per metre and reduces CO2 emissions from the construction process. The fundamentals of ecological economics have been previously discussed in detail by Major et al. (2023a and 2023b). It is easy to see that large-scale formation rehabilitation using the recycling process can achieve significant environmental benefits for each kilometre of track reclaimed simply by reducing the amount of material that has to be supplied. The correct choice of the reconditioning strategy also has a decisive influence on the lifetime of the structure, the analysis of which and its impact on the ecological footprint has been discussed in detail by Eisinger et al. (2022).

6 Conclusions

In this article we summarised the experiences of the rehabilitation works carried out on the Hungarian railway network between 2009 and 2016 with the use of a large machine track rehabilitation machine chain. We briefly presented the essential elements and machines of the technology, and described the design and control aspects introduced during its application in Hungary. We pointed out the benefits of the recycling process carried out by the machinery chain and the CO_2 emission reductions achieved by its use. The technology presented is a typical example of technology development that achieves increased eco-efficiency as a result of economic improvements made in the interests of the company. In fact, the economic benefits are accompanied by a reduction in emissions. As a further direction of our initiated research, we intend to investigate further options, both from the technological (Koch et al., 2023) and raw material side (Gáspár (ed.), 2005), to increase the capacity of the railway network with the lowest possible environmental impact. This complex approach will require a specific data analysis method, an example of which can be found in Kocsis (2014).

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