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Stabilization through improved drainage using stone mattresses

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ABSTRACT

Efficient and sustainable forest road construction is essential for the forestry industry, ensuring accessibility while minimizing environmental impacts. This study investigates the effectiveness of stone mattresses, also known as French mattresses, as a stabilization and drainage technique for forest roads in Sweden. A field trial was carried out on a forest road in Dalarna County, involving two nearby sections, Section 1 and Section 2, each approximately 200 meters in length. Each section was divided into two parts: one stabilized with stone mattresses and the other without, for comparison purposes. Stone mattresses, composed of coarse rock wrapped in geotextile, facilitate water drainage while enhancing road durability. Various tests, including lightweight deflectometer (LWD) measurements, profile surveys, material analysis, moisture assessments, and visual inspections, were performed before and after exposure to traffic and weather conditions. Results showed that road sections with stone mattresses exhibited improved bearing capacity, the rate of change in dynamic deformation modulus (Evd) was 12–23% higher than on unstable road surfaces. Additionally, these sections exhibited reduced rutting, indicating improved structural integrity and resilience. Further optimization of construction methods, as discussed in this study, could enhance efficiency, making the implementation of stone mattresses even more effective for stabilizing forest roads in challenging conditions.

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KEYWORDS

Bearing capacity; drainage; forest roads; light weight deflectometer (LWD); profile measurements; stone mattresses

Introduction

Efficient transport of raw materials is fundamental to the success of the forest industry, as it has a direct impact on productivity and economic viability (Derochers et al. 2025). Central to this transportation network are forest roads, which provide essential access for timber harvesting, wildfire suppression, and various forestry operations (Muneoka and Shirasawa 2024). The strategic development of forest road networks facilitates the sustainable extraction of forest resources, supports firefighting efforts, and enables recreational activities, thereby contributing to local economies and community well-being. In addition, well-planned forest roads contribute to biodiversity conservation by providing controlled access for monitoring and research, and by minimizing habitat fragmentation when well-designed.

The construction of forest roads typically follows a two-layer system, consisting of a base and a surface course. These layers must be able to withstand the heavy loads imposed by logging operations while remaining resilient to environmental stressors, particularly heavy rainfall. Achieving this balance requires efficient construction methods that prioritize the use of locally available materials, such as soil and stone (Pereira et al. 2018). However, forest road development is not only a matter of engineering, but also requires consideration of terrain characteristics, soil stability, hydrological impacts and ecological sensitivity. In addition, regional factors such as glacial history, geological composition, climate, and land tenure further shape forest road design, construction, and maintenance strategies (Lyons et al. 2022).

Improving the structural strength and load-bearing capacity of forest roads is essential to ensure their long-term functionality. Various stabilization techniques are used to improve road performance, particularly in difficult terrain. Soil stabilization, a widely used approach, involves the incorporation of stabilizing agents to improve physical and mechanical properties, including Atterberg limits, compaction, California Bearing Ratio (CBR) and swelling potential (Petry and Little 2002). Depending on the soil type and environmental conditions, stabilization can be achieved by mechanical or chemical means. Traditional chemical stabilizers such as cement, lime, fibers and fly ash are commonly used (Ouhadi and Goodarzi 2006), while non-traditional alternatives such as polymers, resins, enzymes, sulfonated oil and calcium chloride have also gained attention (Estabragh et al. 2010; Skorseth et al. 2015).

The need for effective stabilization strategies has become even more urgent due to the increasing frequency of extreme weather events associated with climate change. Research has shown that the performance of gravel roads is strongly influenced by heavy transportation and climate impacts, as further underlined in the study by Kuttah (2016) and Kuttah and Arvidsson (2017), where such roads were found to be particularly vulnerable to erosion and deformation under high loads. Heavy rainfall and flooding accelerate road degradation, leading to washouts, landslides and increased maintenance costs, all of which pose environmental risks (Leutenbauer and Schlenz 2013). In response, mechanical stabilization techniques, such as compaction, have been used to improve soil properties to increase bearing capacity and reduce

susceptibility to deformation (Pattison et al. 2010). Recent research has also explored sustainable alternatives such as bio-char, polyacrylamide and straw fiber composites for subgrade stabilization (Bouhicha et al. 2005; Aldaood et al. 2021; Hao et al. 2021). These environmentally friendly solutions have shown potential in improving the mechanical properties of forest road subgrade, particularly in cold regions. Similarly, the use of crushed stone for road bases and geosynthetics has proven effective in improving road durability while minimizing ecological disturbance (Starke and Geiger 2022).

Proper drainage is another critical aspect of forest road maintenance, as water infiltration into the road base can lead to saturation, structural instability and accelerated erosion. To mitigate these effects, innovative stabilization techniques have been introduced, including the use of stone mattresses, also known as French mattresses. These structures, consisting of clean, coarse stones wrapped in geotextile fabric, provide a dual benefit by stabilizing the road base while allowing water to flow freely. By preventing concentrated water flow that can cause gully erosion and pothole formation, French mattresses provide a practical and sustainable solution for maintaining road stability in wet or saturated conditions (Dirt and Gravel Road Studies 2022).

Ensuring proper maintenance of forest roads is essential to protect the initial investment in their construction (Fannin and Lorbach 2007; Begus and Pertlik 2017). Beyond economic considerations, well-maintained roads improve safety, operational efficiency, and environmental sustainability by minimizing soil erosion, sedimentation, and water quality degradation (Fannin and Lorbach 2007; Keramati et al. 2020). Previous studies have highlighted the environmental impacts of forest roads, including their role in sediment delivery to streams (Brown et al. 2015) and broader ecological disturbances (Boston 2016). These impacts are particularly pronounced in regions with unstable soils, steep slopes or high precipitation, highlighting the importance of stabilization measures (Boston 2016, Deljouei, 2018; Lugo and Gucinski 2000; Bao et al. 2024).

Neglecting routine maintenance can result in significant financial burdens, as deteriorating roads may require extensive rehabilitation rather than minor repairs. Implementing best management practices – including optimized drainage design, regular maintenance and the use of environmentally sustainable stabilization materials – is critical to mitigating these risks. Research has also explored the use of protective mats to maintain soil integrity on temporary forest roads, helping to minimize the environmental footprint of logging activities (Kunickaya et al. 2024). Among the various innovative stabilization techniques, this study examines the use of stone mattresses to stabilize forest roads in Sweden. Their ability to improve road durability while ensuring effective water management underlines their value as a sustainable solution in forest road construction.

Materials and methods

Location of tested road sections

The field trial was conducted on an existing forest road located approximately 2 km northeast of Grängesberg in Dalarna

County, Sweden. Two adjacent road sections, each around 200 meters long, were selected for the trial. Each section was divided into two parts: one featuring stone mattresses and the other without, for comparison purposes. The pilot road is owned by Kopparfors Skogar AB that manages approximately 283,000 hectares of forest land, primarily in central Sweden. The company's forest management strategy focuses on maintaining biodiversity, implementing nature conservation measures and promoting climate benefits through responsible forestry operations.

Characteristics of the materials in the road sections

The pilot road tested and the surrounding terrain has a high proportion of fine-grained, water-holding material. This has caused access problems with heavy transport in the past.

The availability of gravel at the site is good as there is a commercial quarry close to the road. Macadam in the 70–150 mm fraction was used in the mattresses. The macadam was covered with N1 class geotextile and a finer material in the 0–32 fraction on top.

The grain size distribution was determined according to SS-EN 933-1 2012. The material composition of the test sections is shown in Figures 1 and 2.

For the wearing and base course of section 1, Figure 1 shows that approximately 10% of the particles pass through a 0.063 mm sieve, 37% are finer than 2 mm and 100% pass through a 45 mm sieve. For the overall superstructure material of section 1, Figure 1 shows that approximately 25% of the particles pass through the 0.063 mm sieve, 67% are finer than 2 mm and 100% pass through the 125 mm sieve.

The analysis for the wearing and base course of section 2, see Figure 2, shows that 5% of the particles pass through the 0.063 mm sieve, 30% are finer than 2 mm and all 100% pass through the 63 mm sieve.

Figure 2 also shows that for the overall superstructure material for section 2, approximately 22% pass through the 0.063 mm sieve, 55% are finer than 2 mm and all 100% pass through the 63 mm sieve.

Design and construction process for the road sections with and without stone mattresses

The size and spacing of the stone mattresses can be adjusted based on the amount of water to be drained and the specific site conditions. As previously mentioned, the construction process involves excavating trenches across the road, lining them with geotextile, filling them with macadam, and then covering the macadam with another layer of geotextile and a finer material on top. In this experiment, the mattresses were built with a width of 1.5–2 meters. The spacing between them varied, with approximately 40 meters between mattresses in section 1 and 25 meters in section 2 (see Figure 3). In total, three stone mattresses were installed along the northern drainage section (section 1) and four along the southern drainage section (section 2).

The construction was performed using a 17-ton wheeled excavator for excavation and macadam placement, along with

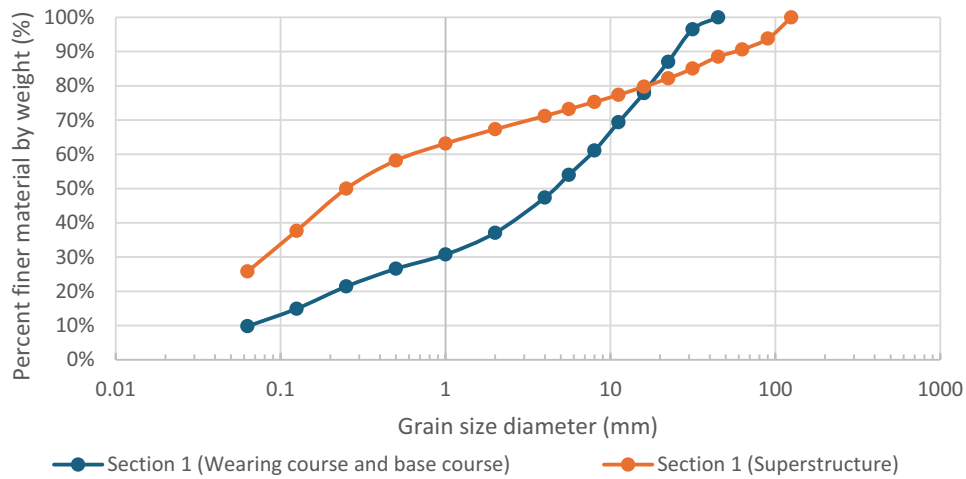


Figure 1. Grain size distribution of wear and base layers and superstructure material for section 1.

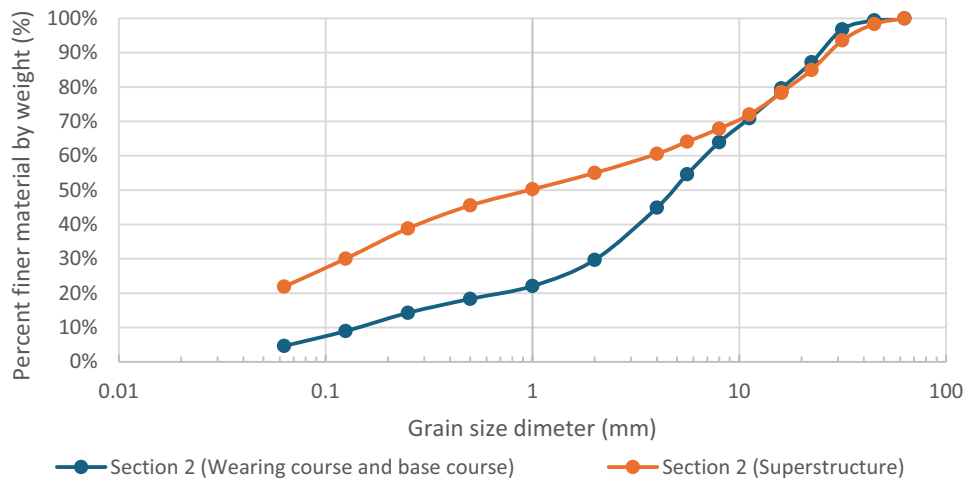


Figure 2. Grain size distribution of the wear and base layers and superstructure material for section 2.

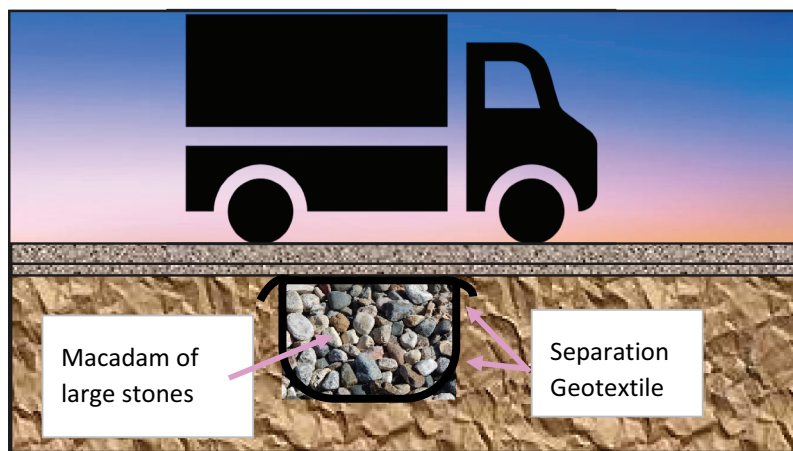


Figure 3. Forest road construction with stone mattresses.

a soil vibrator for compacting the material. Additionally, a gravel truck was used to transport the gravel to the site, while a loader assisted in loading the material into the trenches.

The process began with the excavator digging a trench across the road, extending from one inner slope to the

other. The trench, approximately 1.5–2 meters wide, was sectioned at the bottom for stability. It was then lined with geotextile (soil fabric class N1), with an extra piece set aside for later use on the upper part of the stone mattress.



Figure 4. Field construction of stone mattresses. Photo: Johan Persson, Kopparfors.

Next, the trench was filled with macadam in the 70–150 mm fraction, which was transported from a nearby quarry. The excavator lifted the material from the truck into the trench, and when only a small amount remained, it was tipped onto the ground while the truck returned for a new load. Once all the macadam was in place, it was compacted using a soil vibrator. After compaction, the upper layer was covered with the previously set-aside geotextile, followed by a layer of finer material in the 0–32 mm fraction, which was also compacted with the vibrator.

Finally, after the stone mattresses were completed, both the improved and reference sections were finished with a thin layer of 0–32 mm gravel, ensuring a uniform surface (see Figure 4).

Potential for efficiency improvements during construction

Several potential improvements were identified to streamline the construction of stone mattresses. By adjusting the way the work is done, it is possible to reduce resource consumption and save more time.

The trial used a wheeled excavator, which was considered less suitable for the job. It is recommended that a tracked excavator be used instead, as it is considered to be better adapted to the work and can be moved more easily past the trench for the stone mattresses, even after the road has been excavated, thus achieving greater efficiency. It is also proposed to use a larger excavator, as this would allow the excavation to be carried out more efficiently by reducing the excavation time and handling larger volumes of material. It is also believed that the work could be streamlined by removing the gravel material before excavation begins, potentially saving time by avoiding waiting times for both the excavator and the gravel truck. However, this means that the exact amount of material required for each stone mattress must be determined – a challenge given the varying terrain and conditions. If an inaccurate amount of material is delivered, inefficiencies can result, with too little material stopping work and, if the road is impassable, making completion more difficult; and if too much material is hauled out, there is a risk that excess material or waste will incur handling costs if left unused in the forest. Therefore, a more accurate estimate of material consumption is considered essential for the effective use of this method. Another improvement is the possibility of rationalizing the use of ground staff, who in the trial were responsible for laying the geotextile and handling the soil vibrator. Instead, it is proposed to roll out the geotextile using a device or holder on the excavator, thereby eliminating the need for additional personnel for this step. It is also considered possible to rationalize the need for packing with a soil vibrator by allowing the material to pack itself, with one option being for this work to be carried out by the excavator operator, provided that the efficiency of the excavation is not compromised. By reducing the over-capacity of personnel, cost reductions can potentially be achieved. In conclusion, there are good opportunities to rationalize the use of stone mattresses; by adapting the choice of machinery, improving the logistics of material handling and reducing the need for manpower, the work can be carried out both more quickly and more cost-effectively.

Traffic simulation

Once the stone mattresses had been laid, a traffic simulation was carried out to assess how the test sections would react to heavy traffic. The traffic simulation was carried out using a gravel lorry (truck) with a trailer attached, where both the lorry and the trailer had three axles with double suspension. The payload of the truck was 13.5 tons, and the payload of the trailer was 15.5 tons. The total weight of the vehicle without load was 20 tons, so the total weight during the simulation was 49 tons.

The traffic simulation was carried out by driving the vehicle over the test tracks a total of 60 times. On the day of the simulation, the weather was dry and good. The road was in good condition both before the simulation began and after the 60 passes had been made, and no visible effects on the road were observed, either on the drainage sections or on the reference sections.

Field test methodology and measurement setup

Several tests were conducted, including lightweight deflectometer (LWD) measurements, profiling surveys, moisture content assessments, and visual inspections. The LWD measurements were performed to continuously monitor road surface deformations under load, providing a more detailed understanding of the road's bearing capacity under real traffic conditions. The deformations measured with the LWD were used to calculate the dynamic (elastic) deformation modulus (Evd) using the built-in equation in the LWD device (Kuttah 2023).

In addition to LWD measurement points, three profiling locations were selected within each road section to document changes in surface deformations. More details on the methodologies used to measure cross-sectional profiles of gravel roads can be found in Kuttah and Waldemarson (2024).

The tested road sections followed a similar measurement layout, with multiple locations designated for LWD and profile measurements in each section. This arrangement provided a comprehensive overview of the technical performance of the road sections (see [Figures 5 and 6](#)). The numbered circles indicate LWD measurement points, while the yellow lines mark the locations of profile and rut measurements. However, during the final measurements, the LWD test points were slightly adjusted by approximately 30 cm to prevent any potential post-compaction effects that could occur if measurements were taken at the exact same locations as before. The dashed blue line shows the centerline of the road. A total of 46 LWD measurements were carried out, together with 12 profile measurements and several moisture determinations points adjacent to the LWD locations. A visual inspection was also carried out in conjunction with the final survey.

Results

Post-construction measurements before and after traffic and weather exposure

To assess the condition of the road sections, the research team carried out a series of measurements. These were carried out both immediately after construction and after the road sections had been exposed to traffic and weather. The aim was to collect data and evaluate the condition of the roads and the characteristics of the different sections. The measurements included light drop weight (LWD) tests, profile measurements, moisture ratio measurements and visual inspections of both the road sections and the surrounding terrain.

The initial measurements on the test sections were taken shortly after the roads were completed, see [Figure 7](#). The final measurements were taken after more than a year, when the road sections had been exposed to weather and traffic loads for several months, as well as a the traffic simulation. The initial and final measurements serve as reference points to assess road performance and identify any problems before and after the road sections were affected by external factors. The results of the initial and final tests are presented in the following section.

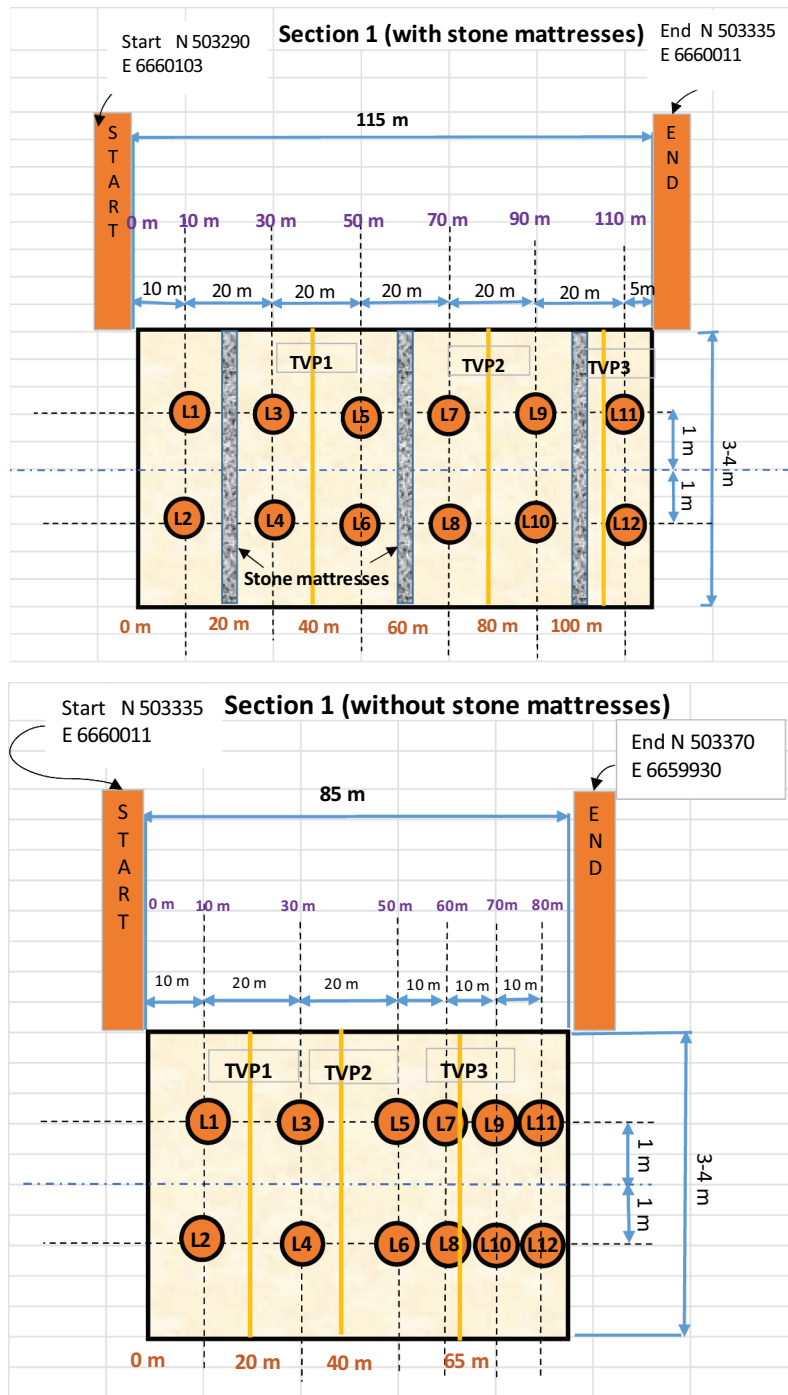


Figure 5. Test points and measurement layout for the two tested parts of section 1 with and without the drainage system (stone mattresses).

Lightweight and moisture ratio measurements for the sections

Figures 8 and 9 show the initial and final measurements of the dynamic deformation modulus (Evd) obtained using LWD for road sections 1 and 2 with and without stone mattresses. The dotted lines with corresponding Evd values represent the average Evd (MPa) for each section and measurement occasion.

The LWD test results for the sections with stone mattresses showed an improvement in bearing capacity compared to the

traditional design without stone mattresses. For section 1 with stone mattresses, the percentage change in average Evd (MPa) between the initial and final measurements was approximately 11%. However, for section 1 without stone mattresses, the same calculation showed a change of approximately -1%. This indicates that the dynamic deformation modulus (Evd) was 12% higher on stabilized road surfaces compared to unstabilized ones, based on the difference between initial and final measurements. This improvement was observed despite the relatively large distance of about 40 meters between each stone mattress.

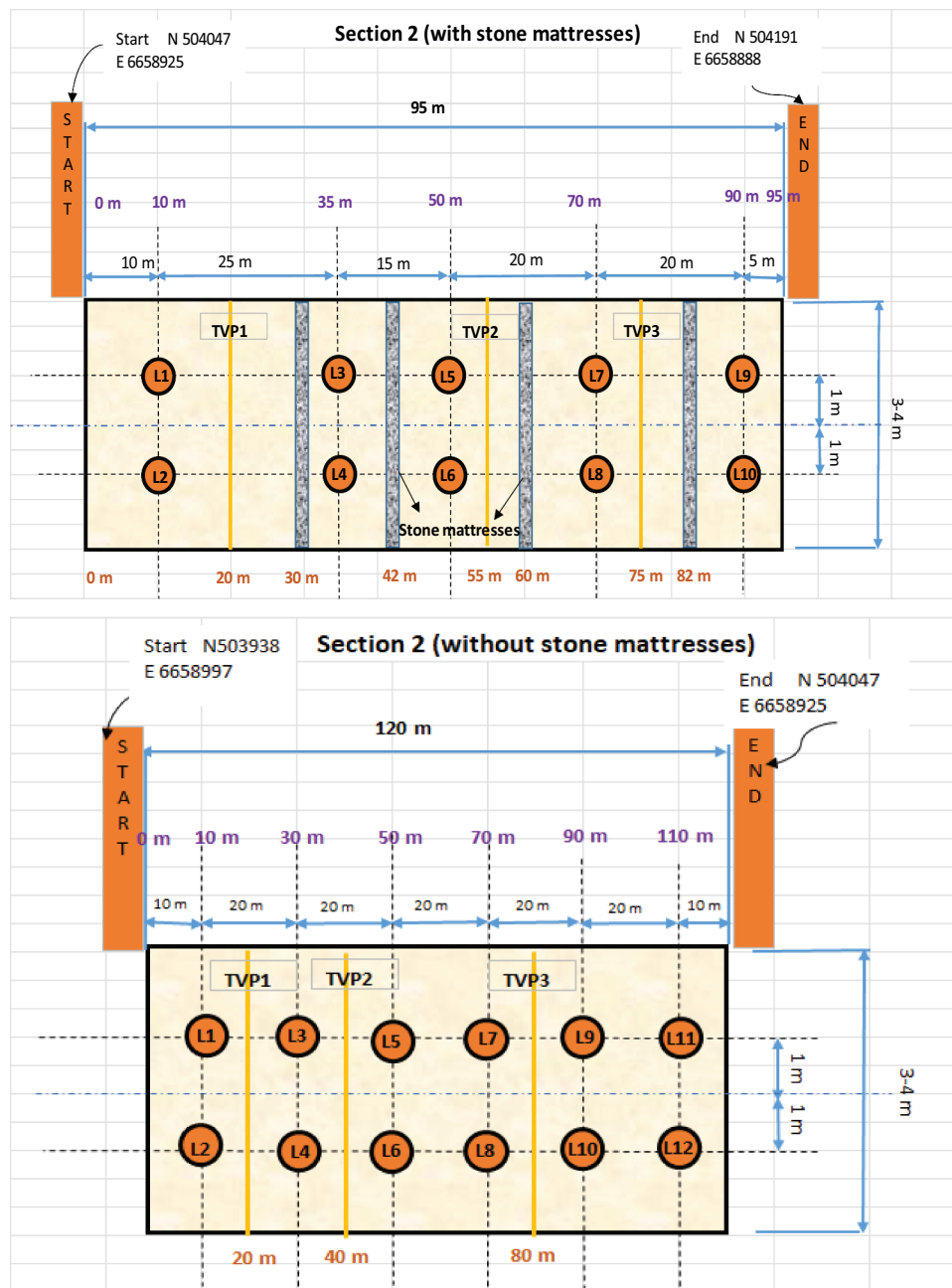


Figure 6. Test points and measurement layout for the two tested parts of section 2 with and without the drainage system (stone mattresses).

For section 2, the percentage change in average E_{vd} (MPa) between the initial and final measurements was approximately 37%, whereas for section 1 without stone mattresses, the change was approximately 14%. This means that the dynamic deformation modulus (E_{vd}) was 23% higher on stabilized road surfaces compared to unstabilized ones, based on the difference between initial and final measurements. This greater improvement can be attributed to the denser placement of the stone mattresses, which were spaced 25 meters apart. The water content measured alongside the LWD readings showed a significant increase, with final measurements being two to three times higher than the initial readings across all sections (i.e. section 1 with and without stone mattresses and section 2 with and without stone mattresses), primarily due to the rainy period during the final

measurements. While there was a notable variation between the initial and final measurements, the differences between the sections within each measurement occasion were relatively small. In section 1 with stone mattresses, the moisture content increased from 2.3% initially to 4.9% in the final measurements, while in section 1 without stone mattresses, it rose from 2.8% to 5.2%. Similarly, for section 2 with stone mattresses, the moisture content increased from 2.0% to 5.9%, whereas in section 2 without stone mattresses, it rose from 1.8% to 6.1%. These results demonstrate that although there is a significant difference in overall moisture levels between the initial and final measurements, the variation in moisture content between stabilized and unstabilized sections within the same measurement period is minimal.



Figure 7. The post-construction measurements before and after traffic and weather impacts of the road sections. Photos: Andreas Waldemarson, VTI.

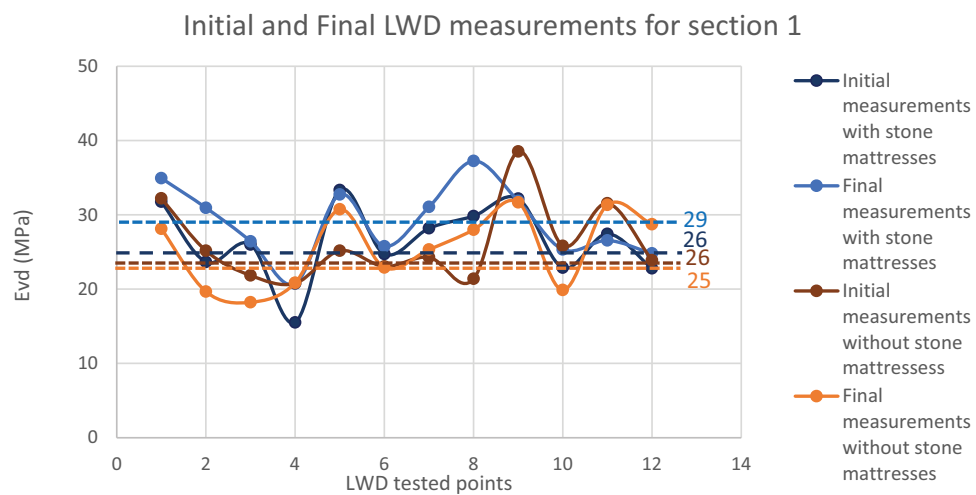


Figure 8. The Evd values from the initial and final LWD measurements for the tested road section 1.

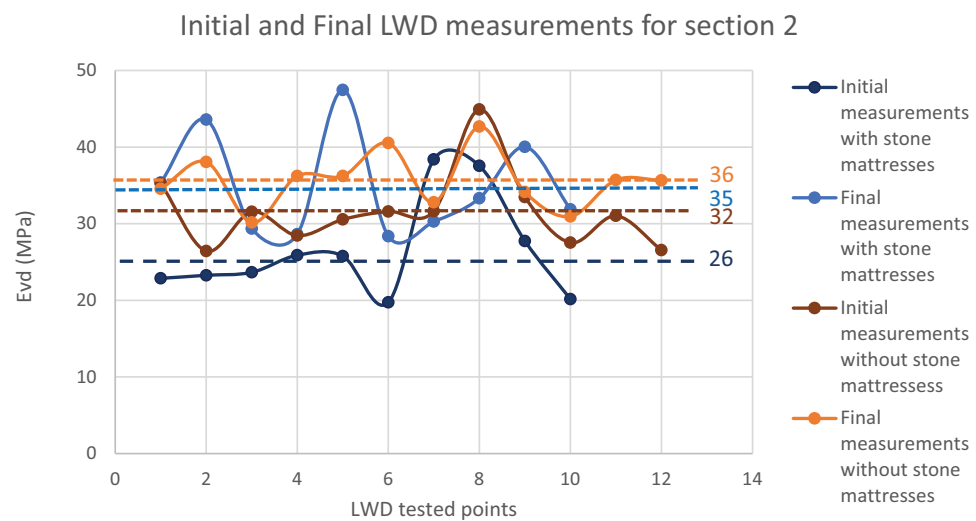


Figure 9. The Evd values from the initial and final LWD measurements for the tested road section 2.

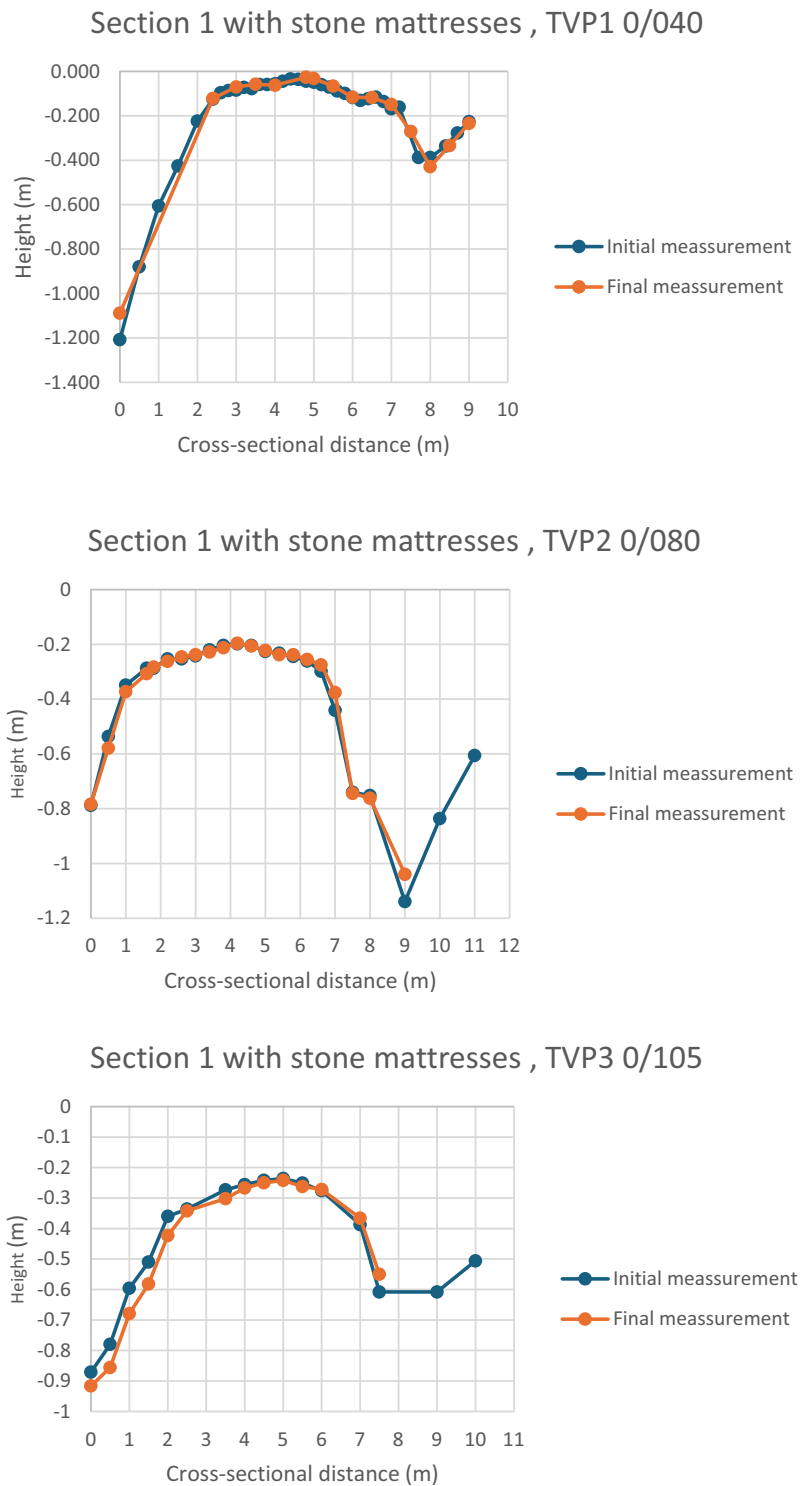


Figure 10. Initial and final profile measurements for road section 1 with stone mattresses.

This suggests that if the water content had been as low as during the initial measurements, it is likely that even higher Evd values would have been recorded during the final measurements. This would have resulted in even greater improvements in load bearing capacity, further highlighting the benefits of using the stone mattresses in both sections.

Profile measurements for the road sections

Profile measurements were taken on road sections 1 and 2 both before and after exposure to traffic and weather, allowing a comparative analysis of changes over time, see Figures 10–13.

The measurements show variations in height, cross-sectional shape and material distribution over different parts of the road. These data, shown in Figures 10–13,

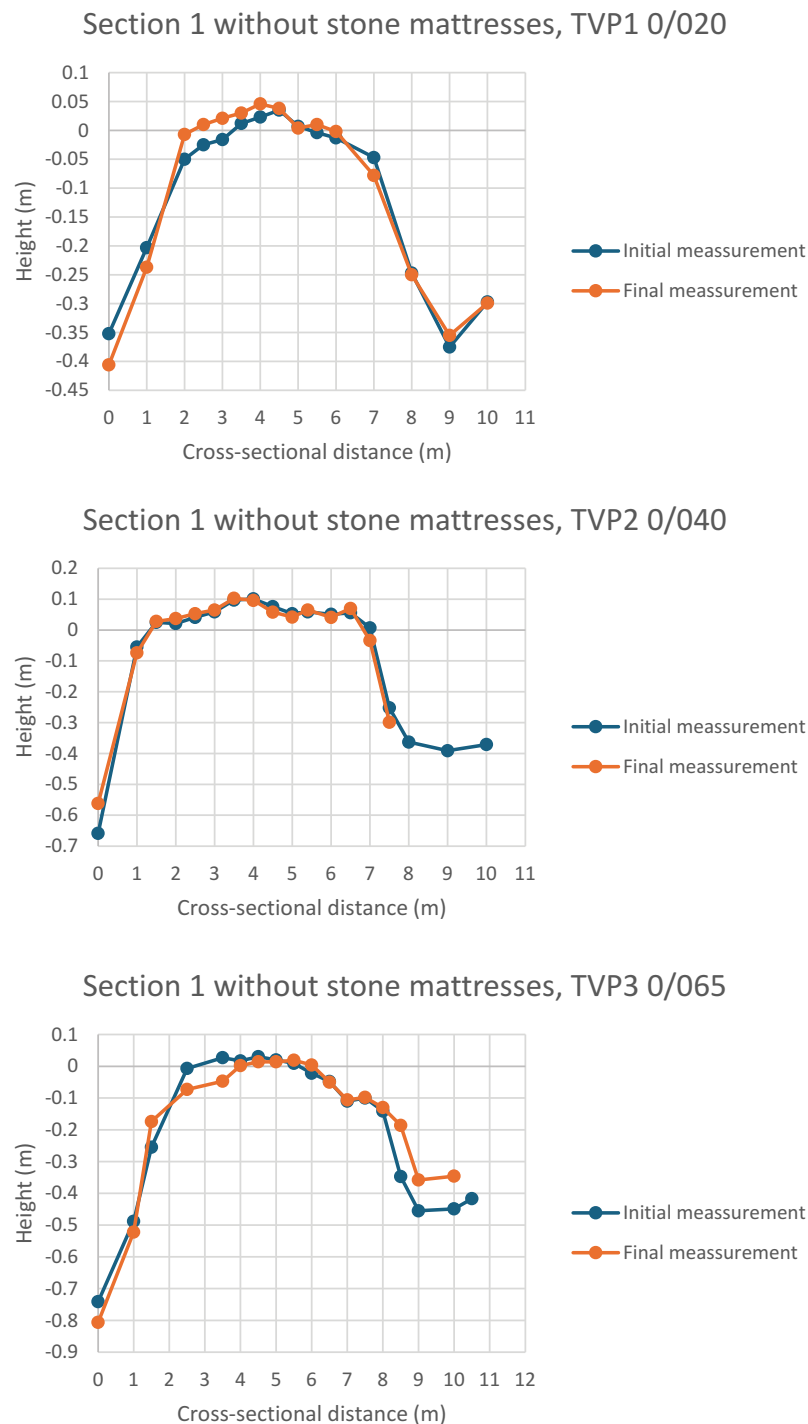


Figure 11. Initial and final profile measurements for road section 1 without stone mattresses.

highlight potential problems such as uneven wear, rutting or material displacement, which are crucial in assessing road performance and determining the need for maintenance or improvement measures.

The three profiles in Figure 10 for section 1 with stone mattresses show that no significant rutting has occurred in the wheel paths on this section.

In contrast, for section 1 without stone mattresses, Figure 11 shows that there is some noticeable rutting in the wheel paths for profiles 1 and 2, while no noticeable rutting is observed in the wheel paths for profile 3.

The three profiles in Figure 12 for section 2 with stone mattresses show that no noticeable rutting has occurred in the wheel paths on this section.

Figure 13 shows some noticeable rutting in the wheel paths for profile 1, while there is no noticeable rutting in the wheel paths for profiles 2 and 3 on section 2, without stone mattresses.

In summary, the tests showed no significant rutting on the drained sections with stone mattresses. However, the measurements on the reference section without stone mattresses showed some noticeable rutting.

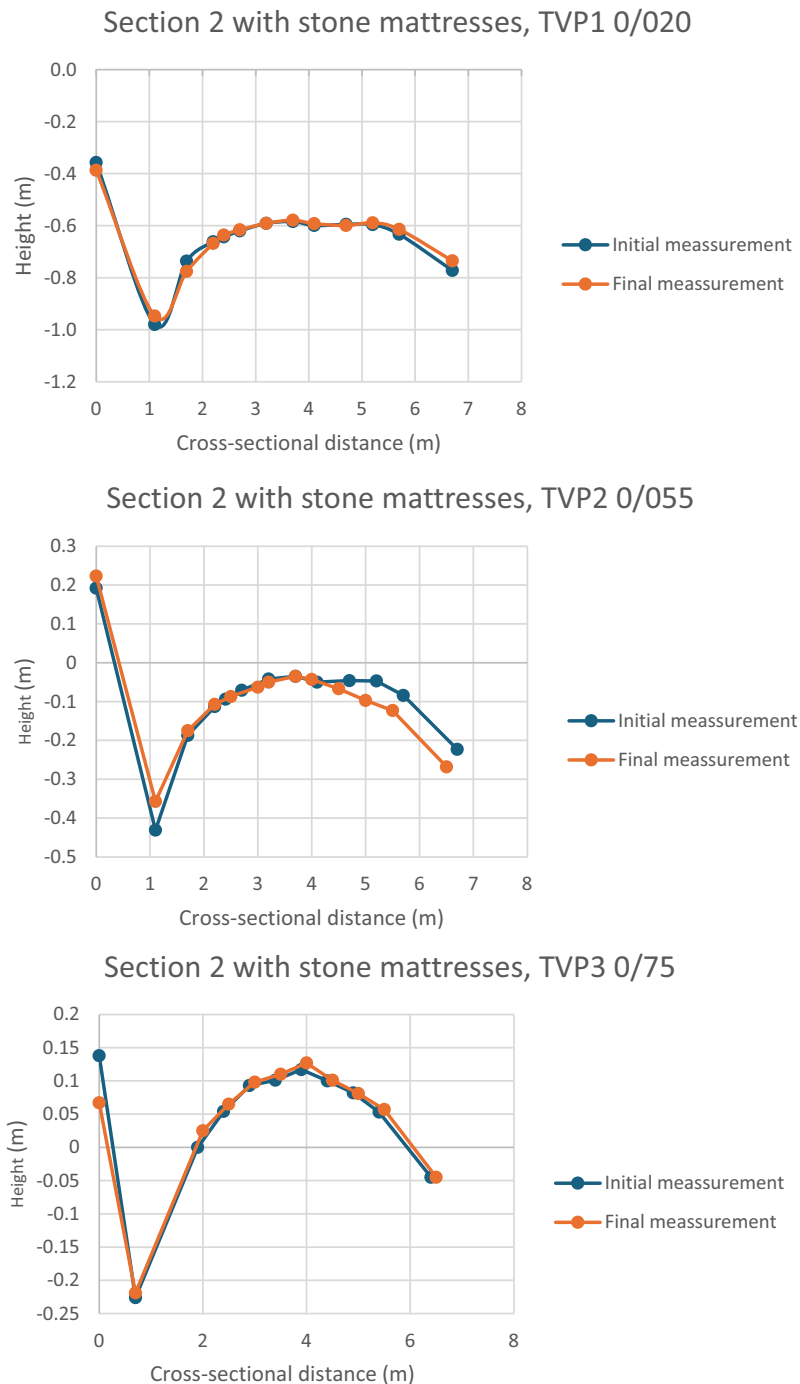


Figure 12. Initial and final profile measurements for road section 2 with stone mattresses.

Visual inspection for the sections

Visual inspection was carried out during the final measurements in variable weather conditions, with daytime temperatures ranging between 20 and 25 degrees F. The assessment of the road condition showed that the rain had made the road relatively wet, but the surface was dry at the time of the assessment. On section 1 there was standing water in the ditches but no erosion was noted.

There were no potholes on section 1, which was surfaced with stone mattresses. There were visual signs of rutting in the wheel paths. The loose gravel was pressed

into the road, which clearly showed where the traffic had gone, although the ruts were not very deep. As for the dust, it was difficult to judge due to the dampness of the road surface, but the loose stones were dry. There was a lot of loose gravel all over the road surface, particularly at the edges of the road, as clearly shown in the photographs, see Figure 14.

No ruts or potholes were observed in section 1 without the stone mattress. In the case of rutting, the loose material was seen at the edges of the road, making the ruts appear larger. Dusting was again difficult to assess due to the dampness of the surface, but the loose stones were dry.

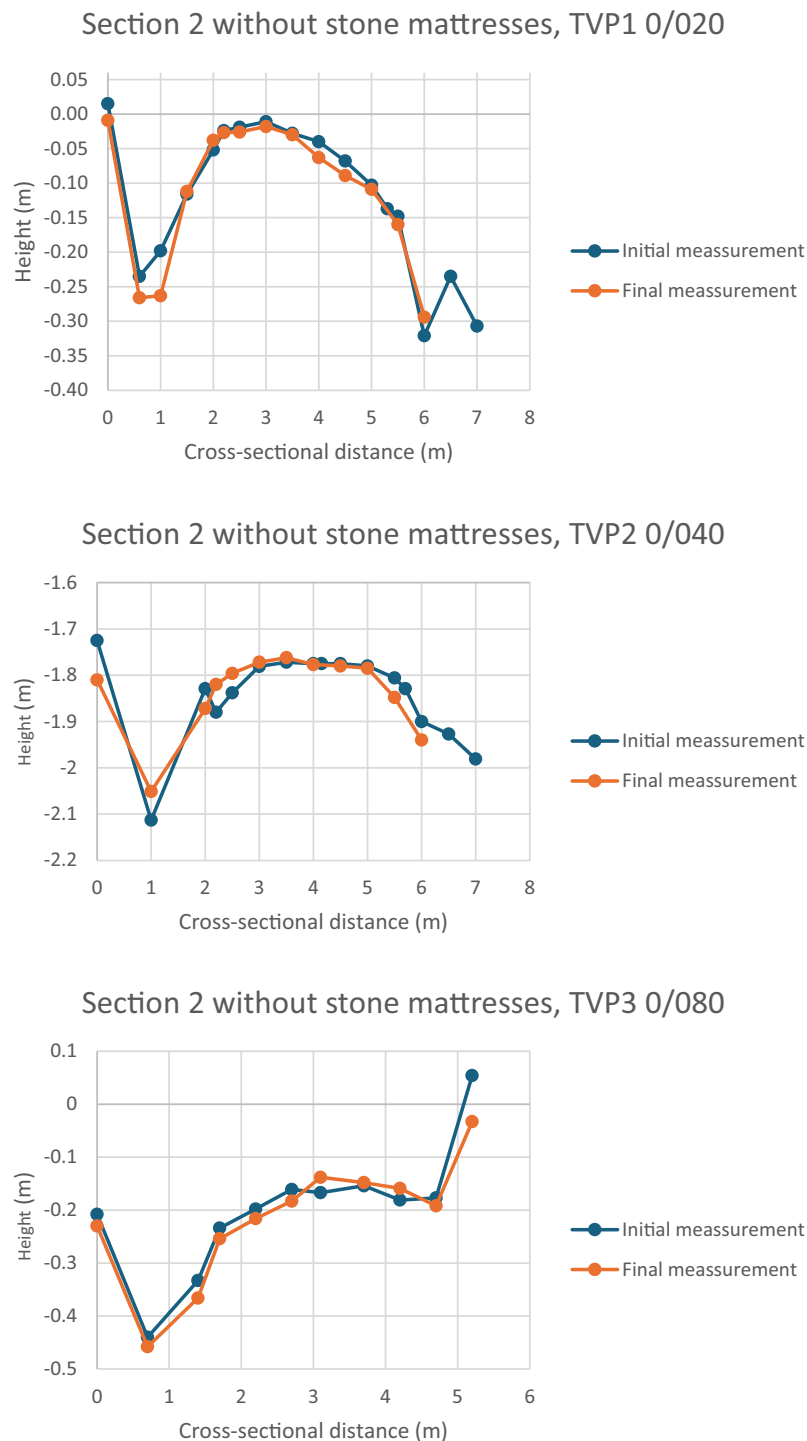


Figure 13. Initial and final profile measurements for road section 2 without stone mattresses.

Loose gravel was observed along both the section 1 road edges and the centerline, with the gravel being more compacted within the wheel tracks. The old markings from the initial measurements (over a year ago) were still visible despite the loose gravel, see [Figure 15](#).

For section 2 with the drainage system, it was noted that the centerline of the road had more loose gravel, which was observed when moisture samples were taken. No rutting was noted and there were no potholes. Where there were ruts, there was

a buildup of loose material at the edges of the road, which made the ruts appear larger.

There was more gravel at the edge of the section 2 road than on section 1, and it could be seen with the naked eye that the ruts were slightly larger here. Dust was again difficult to judge in section 2, with a wet surface and dry loose stones. There was loose gravel both at the edges and in the center of the road, and the loose gravel was more compressed in the ruts.



Figure 14. Visual inspection of section 1 (with stone mattresses) in Grängesberg. Photos: Andreas Waldemarson, VTI.

The old markings from the initial measurements were still there despite the loose gravel. This section was narrower and had some grass in the middle of the road, see [Figure 16](#).

In section 2, without the stone mattresses, the centerline of the road was once again found to contain more loose gravel.

No rutting was noted, and no potholes were found. Where there were ruts, the loose material tended to collect at the edges of the road, making the ruts appear larger. Dusting was difficult to assess with a wet surface and dry loose stones. There was loose gravel both at the edges and in the centerline of the road, and the loose gravel was more compressed in the ruts. The old markings from the initial measurements were still visible despite the loose gravel and this section was narrower with some grass along the centerline of the road, see [Figure 17](#).

Discussion

The drainage technique evaluated in this study is the stone mattress, also known as the French mattress. This technique consists of layers of clean, coarse rock wrapped in geotextile fabric, allowing water to pass freely through the road base while maintaining structural stability (Dirt and

Gravel Road Studies 2022). Effective water management is a critical challenge in forest road construction, particularly in areas prone to soil saturation and instability. By maintaining natural hydrological flows and preventing gully erosion, French mattresses offer a sustainable alternative to conventional drainage systems (Bloser et al. 2013; Dirt and Gravel Road Studies 2022).

This study specifically investigates the use of stone mattresses as a stabilization technique for forest roads. Building on previous research demonstrating their effectiveness in maintaining road performance under challenging conditions, the study aims to demonstrate their role in improving road durability while mitigating environmental impacts. By incorporating this innovative approach into forest road design, the findings contribute to the advancement of sustainable infrastructure solutions.

Overall, the implementation of advanced maintenance strategies such as stone mattresses supports the long-term sustainability of forest roads. Ensuring that roads remain in good condition not only reduces operating costs but also minimizes environmental disturbance and secures the infrastructure necessary for safe and efficient forest operations.



Figure 15. Visual inspection of section 1 (without stone mattresses) in Grängesberg. Photos: Andreas Waldemarson, VTI.

The test results for the stone mattresses showed an improvement in bearing capacity (modulus of elasticity) compared to the reference sections. On test section 1, with a distance of 40 meters between the stone mattresses, the bearing capacity increased by approximately 12% compared to the reference section without stone mattresses. On section 2, where the distance between the stone mattresses was 25 meters, the bearing capacity of the drained section increased by 23% compared to the undrained section.

It can almost be concluded that doubling the number of stone mattresses per unit length can result in approximately twice the percentage increase in E_{vd}.

Profile measurements were carried out on sections 1 and 2 before and after traffic and weather exposure to

analyze changes over time. The results show that no significant rutting occurred on the sections with stone mattresses and drainage, whereas some rutting was observed on the reference sections without stone mattresses, particularly in the wheel paths. This indicates that stone mattresses improve road performance and reduce the risk of rutting.

During the visual inspection, no rutting or potholes were observed on section 1 with the drainage system, but there were some traces of traffic with loose gravel pushed into the road. Similar conditions were observed in reference section 1, with loose material accumulating at the edges and ruts appearing larger.

On section 2 with the drainage system, there was more loose gravel in the center and the ruts were slightly larger,



Figure 16. Visual inspection of section 2 (with stone mattresses) in Grängesberg. Photos: Andreas Waldemarson, VTI.

with more gravel at the edges. On reference section 2, similar loose material was noted in the center and at the edges, and the ruts appeared larger. No ruts or potholes were observed in either section.

According to Kuttah et al. (2025), the cost analysis revealed that stabilizing section 1 using stone mattresses amounted to approximately SEK 231 per meter (for a 4-meter-wide road), compared to about SEK 35 per meter without stone mattresses. Similarly, stabilizing section 2 with stone mattresses cost around SEK 351 per meter, while the cost without stone mattresses remained approximately SEK 35 per meter

Conclusions

The construction and implementation of stone mattresses proved both practical and effective. The process was straightforward, taking approximately 1.5 hours per mattress, and there were no major complications during construction. Field testing showed that stone mattresses significantly improved the road's bearing capacity, with greater frequency of installation (every 25 meters)

leading to greater stiffness increases, up to 23%, compared to unstabilized reference sections.

Profile measurements and visual inspections further confirmed the positive impact of stone mattresses, showing reduced rutting and improved surface stability in treated sections over time. These findings suggest that stone mattresses enhance not only the bearing capacity, but also the durability and resilience of the road structure when exposed to traffic and weather. Therefore, stone mattresses are a promising solution for strengthening unpaved roads, particularly in areas susceptible to drainage and stability issues.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Figure 17. Visual inspection of section 2 (without stone mattresses) in Grängesberg. Photos: Andreas Waldemarson, VTI.

References

- Aldaoood A, Khalil A, Bouasker M, Al-Mukhtar M. 2021. Experimental study on the mechanical behavior of cemented soil reinforced with straw fiber. *Geotech Geol Eng.* 39(4):2985–3001. doi: [10.1007/s10706-020-01673-z](https://doi.org/10.1007/s10706-020-01673-z).
- Bao W, Zhang W, Dong J, Yang X, Xia S, Chen H. 2024. Impact of road corridors on soil properties and plant communities in high-elevation fragile ecosystems. *Eur J For Res.* 143(6):1717–1730. doi: [10.1007/s10342-024-01720-x](https://doi.org/10.1007/s10342-024-01720-x).
- Begus J, Pertlik E. 2017. Guide for planning, construction and maintenance of forest roads. place unknown: food and Agriculture Organization of the United Nations. 64; [accessed 2022 Apr 19]. <https://openknowledge.fao.org/server/api/core/bitstreams/bea6e023-b9e7-4e99-95a4-67ecc40f281c/content>.
- Bloser S, Creamer D, Napper C, Scheetz B, Ziegler T. 2013. Environmentally sensitive road maintenance practices for dirt and gravel roads. https://www.waterboards.ca.gov/rwqcb9/water_issues/programs/stormwater/docs/wqip/2013-0001/J_References/J117.pdf.
- Boston K. 2016. The potential effects of forest roads on the environment and mitigating their impacts. *Curr For Rep.* 2(4):215–222. doi: [10.1007/s40725-016-0044-x](https://doi.org/10.1007/s40725-016-0044-x).
- Bouhicha M, Aouissi F, Kenai S. 2005. Performance of composite soil reinforced with barley straw. *Cem Concr Compos.* 27(5):617–621. doi: [10.1016/j.cemconcomp.2004.09.013](https://doi.org/10.1016/j.cemconcomp.2004.09.013).
- Brown KR, McGuire KJ, Aust MW, Hession WC, Dolloff CA. 2015. The effect of increasing gravel cover on forest roads for reduced sediment delivery to stream crossings. *Hydrol Process.* 29(6):1129–1140. doi: [10.1002/hyp.10232](https://doi.org/10.1002/hyp.10232).
- Deljouei A, Sadeghi SMM, Abdi E, Bernhardt-Römermann M, Pascoe E, Marcantonio M. 2018. The impact of road disturbance on vegetation and soil properties in a beech stand, hyrcanian forest. *Eur J For Res.* 137(6):759–770. doi: [10.1007/s10342-018-1138-8](https://doi.org/10.1007/s10342-018-1138-8).
- Derochers J, Conrad JL, Bolding MC, Smidt M, Da Silva B. 2025. Trucks-to-trucks: a comparison of the raw forest products transportation industry and other forms of commercial trucking in the US south. *Int J For Eng.* 36(2):1–11. doi: [10.1080/14942119.2024.2448936](https://doi.org/10.1080/14942119.2024.2448936).
- Dirt and Gravel Road Studies. 2022. Worksite in focus - center for dirt and gravel road Studies. <https://dirtandgravel.psu.edu/general-resources/road-work/worksite-focus/>.
- Estabragh AR, Beytollahpour I, Javadi AA. 2010. Effect of resin on the strength of soil-cement mixture. *J Mater Civ Eng.* 23(7):969–976. doi: [10.1061/\(ASCE\)MT.1943-5533.0000252](https://doi.org/10.1061/(ASCE)MT.1943-5533.0000252).
- Fannin RJ, Lorbach J. 2007. Guide to forest road engineering in mountainous terrain. FAO.
- Hao J, Huang J, Yao J, Zhang Z, Zhang H. 2021. Unconfined compression strength and mesostructure of reinforced soil with wheat straw. *Bull Eng Geol Environ.* 80(12):9173–9183. doi: [10.1007/s10064-021-02473-2](https://doi.org/10.1007/s10064-021-02473-2).
- Keramati A, Lu P, Sobhani A, Haji Esmaeili SA. 2020. Impact of forest road maintenance policies on log transportation cost, routing, and carbon-emission trade-offs: Oregon case study. *J Transp Eng Part A Syst.* 146(5):04020028. doi: [10.1061/JTEPBS.0000335](https://doi.org/10.1061/JTEPBS.0000335).
- Kunickaya O, Novgorodov D, Druzyanova V, Levushkin D, Tikhonov E, Perfiliev P, Kleveko V. 2024. Protective role of mats in maintaining soil

- integrity on temporary forest roads: an in-depth analysis of their application. *Forest Sci Technol.* 20(2):105–113. https://www.tandfonline.com/doi/pdf/10.1080/21580103.2024.2307008?utm_source=chatgpt.com.
- Kuttah D. 2016. The performance of a trial gravel road under accelerated pavement testing. *Transp Geotech.* 9:161–174. doi: [10.1016/j.trgeo.2016.09.001](https://doi.org/10.1016/j.trgeo.2016.09.001).
- Kuttah D. 2023. Assessing the interactions among factors affecting the light-weight deflectometer measurements. *Bull Eng Geol Environ.* 82(6):238. doi: [10.1007/s10064-023-03231-2](https://doi.org/10.1007/s10064-023-03231-2).
- Kuttah D, Arvidsson H. 2017. Effect of groundwater table rising on the performance of a Swedish-designed gravel road. *Transp Geotech.* 11:82–96. doi: [10.1016/j.trgeo.2017.05.001](https://doi.org/10.1016/j.trgeo.2017.05.001).
- Kuttah D, Waldemarson A. 2024. Next generation gravel road profiling – the potential of advanced UAV drone in comparison with road surface tester and rotary laser levels. *Transp Eng.* 27:100260. doi: [10.1016/j.treng.2024.100260](https://doi.org/10.1016/j.treng.2024.100260).
- Kuttah D, Lindström D, Bergqvist M, Hindrikes M, Johansson T, Persson J, Olsson N. 2025. Solutions for faster development of forest roads in Sweden. *VTI report 1228*. Sweden: In Swedish. <https://www.diva-portal.org/smash/get/diva2:1932964/FULLTEXT02.pdf>.
- Leutenbauer M, Schlenz S. 2013. Neue Techniken beim Wegebau im Flysch. *LWF aktuell* 95, S. 42–45. https://www.lwf.bayern.de/mam/cms04/forsttechnik-holz/dateien/a95_neue_techniken_beim_wegebau_im_flysch_bf_gesch.pdf.
- Lugo AE, Gucinski H. 2000. Function, effects, and management of forest roads. *For Ecol Manage.* 133(3):249–262. doi: [10.1016/S0378-1127\(99\)00237-6](https://doi.org/10.1016/S0378-1127(99)00237-6).
- Lyons CK, Borz SA, Harvey C, Ramantswana M, Sakai H, Visser R. 2022. Forest roads: regional perspectives from around the world. *Int J For Eng.* 34(2):190–203. doi: [10.1080/14942119.2022.2160916](https://doi.org/10.1080/14942119.2022.2160916).
- Muneoka H, Shirasawa H. 2024. Bayesian inference of forest road failure frequency depending on rainfall intensity for every prefecture in Japan. *Int J For Eng.* 36(1):89–102. doi: [10.1080/14942119.2024.2414596](https://doi.org/10.1080/14942119.2024.2414596).
- Ouhadi VR, Goodarzi AR. 2006. Assessment of the stability of a dispersive soil treated by alum. *Eng Geol.* 85(1–2):91–101. <https://www.sciencedirect.com/science/article/pii/S0013795206000718>. (open in a new window).
- Pattison J, Boston K, Pyles M. 2010. Development of a correlation model between a 20-kg Clegg hammer and field CBR for measuring subgrade strength in forest roads in Western Oregon. *Int J For Eng.* 21(1):12–19. doi: [10.1080/14942119.2010.10702586](https://doi.org/10.1080/14942119.2010.10702586).
- Pereira RS, Emmert F, Miguel EP, Gatto A. 2018. Soil stabilization with lime for the construction of forest roads. *Floresta e Ambient.* 25(2):1–8. doi: [10.1590/2179-8087.007715](https://doi.org/10.1590/2179-8087.007715). (open in a new window).
- Petry TM, Little DN. 2002. Review of stabilization of clays and expansive soils in pavements and lightly loaded structures—history, practice, and future. *J Mater Civ Eng.* 14(6):447–460. [http://ascelibrary.org/doi/\(open in a new window\) 10.1061/\(ASCE\)0899-1561\(2002\)14:6\(447\)](http://ascelibrary.org/doi/(open%20in%20a%20new%20window)%2010.1061/(ASCE)0899-1561(2002)14:6(447).). (open in a new window).
- Skorseth K, Reid R, Heiberger K. 2015. Gravel roads- construction and maintenance guide. USA: U.S. Department of Transportation, Federal Highway Administration. <https://www.fhwa.dot.gov/construction/pubs/ots15002.pdf>.
- SS-EN 933-1. 2012. Tests for geometrical properties of aggregates - part 1: determination of particle size distribution - sieving method. Stockholm: SIS, Swedish Institute for Standards.
- Starke M, Geiger C. 2022. Machine vision based waterlogged area detection for gravel road condition monitoring. *Int J For Eng.* 33(3):243–249. doi: [10.1080/14942119.2022.2064654](https://doi.org/10.1080/14942119.2022.2064654).