Next-generation Anti-vibration Mats for Modern-day Track Designs

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Introduction
Track engineers often encounter conflicting demands when designing a track system: on the one hand seeking uncompromised track stability ensuring safety and comfort for the passengers and low maintenance cost for the track owner, on the other hand ensuring a track that is sufficiently soft – typically by means of the deliberate introduction of one or several types of resilient elements into the track structure – thereby ensuring that national standards are met with regard to ground-borne vibration levels, e.g. at nearby dwellings. Obviously, what is sought is a resilient element that not only lives up to the basic requirements of the national accreditation in question – for instance the well-known German Railways DB BN 918-071-1 norm – but surpasses these requirements and delivers sterling performance on aspects such as constant form stability, ultra-low sensitivity to environmental factors, extended fatigue resistance and fire safety. With a special view to such performance aspects, this paper takes an in-depth look at the most important features, advantages and benefits of the RockXolid and RockBallast product lines.

What is Stone Wool?
As a starting point for the discussions in the following, this chapter will provide for a quick look at stone wool as the core material as found in both the RockXolid product line and in the RockBallast product line. The creation of stone wool is a natural phenomenon of nature that may, under certain conditions, be observed after volcanic activity. Imitating the natural process is today done in highly sophisticated machinery using an elaborate production process that allows for a wide range of carefully engineered products. ROCKWOOL stone wool, as the basis for all RockDelta products, is made from diabase volcanic rock which is mixed with coke and lime and subsequently melted in large cupola furnaces at approx. 1500°C. The resulting melted mass is directed down onto a fast spinning wheel that whirs the melted stones mass into thin threads with an average diameter of 0,005 mm. A binding agent is added and – as one of the last stages of the “hot-end” production process – the desired density of the impregnated stone wool product is selected. This is being followed by the final production step where the stone wool is hardened in special furnaces, thereby curing the binding agent. The finished ROCKWOOL stone wool product is then ready for various “cold-end” tailoring processes, including a unique aging process that ensures outstanding long-term mechanical stability, whereby the product is turned into its designated RockXolid or RockBallast application.
Stone Wool as the Basis for an Elastomer Element: RockXolid and RockBallast Product Lines

Providing for decades of stable, predictable and highest vibration isolation, even in the most demanding applications, the RockDelta solution for vibration isolation of ballasted railway tracks is based on a sophisticated two-stage approach using high-efficiency RockBallast as the core element.

Fig (1). High-performance, dual density RockBallast solution with a Terram geotextile. Dual density – high density top layer and low density bottom layer design – ensures that static and dynamic loads from gravel, stones, soil and other covering materials do not result in deterioration of the stone wool fibre material thus helping to provide the exceptional long product life cycle, e.g. as documented by the Technical University of Denmark.

The solution consists of a unique dual-density sub-ballast mat with: (a) a low-damping, soft resilient layer; and (b) a force distributing high-density top layer. As the second element in the RockBallast solution, the sub-ballast mat fibers are being protected from potential impairment by the ballast stones with a first-rate Terram geotextile. The non-woven geotextile exhibits high puncture resistance, high tensile strength, superb filtering characteristics and excellent water flow capacity. At the same time, it deforms perfectly under the load exerted by the ballast, as well as making it particularly easy to replace the ballast as and when required.

The RockXolid solution consists of a full-contact, sheet-type resilient stone wool based support system that introduces a high-efficiency spring-damper element into the track structure, thereby decoupling the dynamic behavior of the concrete slab and the track system effectively from the ground.

Fig (2). With ultra-low sensitivity to environmental factors, e.g. water, frost and acid rain, RockXolid stone wool based anti-vibration mats exhibit outstanding efficiency and durability even after decades of operation under adverse climatic conditions. This has been verified, for instance, by an exhaustive Norwegian field study of the long-term functional performance of a track that had been vibration isolated in 1978 using stone wool based anti-vibration mats.

Armed with unique material characteristics, most of which will be examined in the following chapters, the RockXolid solution significantly aids the attenuation of ground-borne vibrations stemming from any type of floating slab track design.

Most Important Features, Advantages and Benefits of RockDelta Stone Wool

RockDelta resilient mats offer a highly efficient, durable and environmentally friendly solution to even the most demanding vibration problems encountered alongside rail and tram tracks. Some of the most important of these features, advantages and benefits are as follows:
Excellent dynamic properties with first-rate volume compressibility for track bed independent performance.

- Low dynamic-to-static stiffness ratio for minimised conflict between rail deflection and degree of vibration isolation.
- High shear modulus even in adverse climatic conditions helping to ensure constant geometry in complex track sections, e.g. curves.
- Unique long-term fatigue resistance and form stability ensuring known and constant track geometry.
- Temperature independent functional performance for perfect vibration isolation during any climate or season.
- Virtually no sensitivity to the presence of water helping to safeguard performance, e.g. during periods of flooding or excessive precipitation.
- Decreases the risk of sub-grade failures, e.g. “mud pumping”, thereby helping to minimise track maintenance costs.
- Unaffected by the exposure to sunlight and ultraviolet rays for worry-free storage and transportation in any climate.
- Very high degree of resistance to chemical, biological and environmental factors for best confidence in the track design.
- Fire and smoke safe mats for additional protection in tunnels, e.g. during construction work.
- Excellent thermal insulation to help protect against frost heave thereby increasing structural support with challenging frost heave susceptible tracks.
- Fast, easy and handy installation to minimise cost and maximise worker’s safety.
- Environmentally friendly and 100% recyclable solution in pact with EU “green” policy guidelines.
- Long-term practical experience in adverse climates demonstrating real-life durability and real-life performance.

In the following, these selected features, advantages and benefits will be examined in more detail.

**Excellent Dynamic Properties with First-rate Volume Compressibility**

A material’s suitability as a resilient component in track anti-vibration applications is governed by many factors.

Fig (3). A material’s suitability as a resilient component in anti-vibration rail track installations is governed by many different factors. In confined space applications, the material’s ability to absorb loads with no significant change in its elastic properties is important. This ability is described via the bulk elastic (volume compressibility) properties of the material. These determine how much the material compresses under an external load. RockDelta resilient mats possess a uniquely high degree of volume compressibility, which means that the material has a Poisson’s Ratio of almost zero.

Firstly, the material obviously needs to have a suitable load-deflection curve with a wide operating range and the ability to achieve a working point on the load-deflection curve that provides for ample dynamic range in which the material may provide for resilient support.
Fig (4). Since neither grooves nor “artificial” cavities are needed with RockDelta resilient mats to create a high degree of volume compressibility, the track formation needs no special levelling preparation to achieve a specified level of Insertion Loss. This has been schematically shown on the above figure as two different sub-grade scenarios with resiliently supported tracks: the bottom part shows a perfectly plane sub-grade scenario while the top part shows a sub-par scenario with respect to the Leveling of the sub-grade. However, supposing an otherwise similar track substructure design with the same (uniform) load distribution in both scenarios, the Insertion Loss that can be obtained from the two scenarios will not differ with RockDelta resilient mats.

Secondly, in many applications the material’s ability to absorb loads without a significant change to its elastic properties is almost equally important. This ability is often described as the bulk elastic (volume compressibility) properties, which determines how much the material will compress under a given amount of an external load (pressure). RockDelta resilient mats posses a uniquely high degree of volume compressibility, which means that the material has a Poisson’s Ratio of virtually zero. This unique property indicates that a RockDelta track antivibration solution will be independent on the actual track bed footprint dimensions. The material inherently posses the voids needed to absorb the compression of the material. For a resiliently supported floating slab track this provides for an important advantage since the stiffness of RockXolid resilient mats will not vary as a function of the track bed width. Furthermore, since neither grooves nor “artificial” cavities are needed with RockDelta resilient mats to obtain a high degree of volume compressibility, the track formation needs no special leveling preparation to achieve a specified level of Insertion Loss.

Low Dynamic-to-Static Stiffness Ratio for Minimised Conflict between Rail Deflection and Vibration Isolation

Resilient mats are often rated by their static stiffness measured according to a defined measurement procedure and test setup, e.g. as found in the German Railways norm DB BN 918 071-1. The static stiffness of a mat relates to the elastic rail deflection1 of a stopped train. However, equally important is the dynamic stiffness at predefined frequencies and predefined preloads, measured, as is the case for the static stiffness, according to a defined measurement procedure and test setup, e.g. as found in the German Railways norm DB BN 918 071-1. The dynamic stiffness at low frequencies relates to the elastic rail deflection of a moving train whereas the dynamic stiffness at medium and high frequencies generally relates to the mat’s vibration isolation capacities.

This implies of course that a resilient mat exhibiting a high static stiffness combined with a low...
dynamic stiffness (at medium and high frequencies) is beneficial since such a mat will help to minimize the potential conflict between maximum allowable elastic rail deflection and necessary (minimum) level of vibration isolation. All RockDelta resilient mats exhibit a low dynamic-to-static stiffness ratio with a typical value of 1.3:1(2).

**High Shear Modulus Even in Adverse Climatic Conditions**

From material sciences, the Shear Modulus or Modulus of Rigidity, denoted by G, is defined as the ratio of shear stress to the shear strain and is in many ballasted track applications an important material constant that helps to define the chosen track design’s ability to sustain horizontal loads for instance occurring while the rolling stock is braking or negotiating curves.

Fig (5). The Shear Modulus (G-Modulus) is defined as the ratio of shear stress to the shear strain and is in many ballasted track applications an important material constant that helps to define the track design’s ability to sustain horizontal loads for instance occurring when passing rolling stock is braking or negotiating curves.

RockDelta resilient mats are characterised by their low G-Modulus values even under adverse climatic conditions thereby helping to safeguard against track degradation phenomena developing over time (e.g. top variation, versine, cant, twist and sub-grade failure).

The well-known German Railways norm DB BN 918 071-1 for ballast mat approval accordingly has a clause dealing with how precisely to quantify the G-module value at high and low temperatures as well as in a dry and wet conditions. Looking at the test report from the Technical University of Munich (TUM), where RockBallast 3515 has been tested according to DB BN 918 071-1, the result of the G-module measurement is stated as follows:

…the value for the G-module is at all times to be found between 1.51 N/mm² (Room temperature, dry) and 3.05 N/mm² (-25°C,wet condition). This more than fulfils the requirements of the DB TL 918 071-1 where a minimum G-module value of 0.55 (summer/winter and wet/dry) is stipulated …

It should be noted that the measurement setup for a determination of the G-module is very important when it comes to the usefulness and accuracy of the value produced. The measurement setup used at TUM is according to DB BN 918 071-1 and is constructed with flat and parallel steel plates. The G-module measurements are conducted under a low static pressure of 0.0125 N/mm² thereby helping to ensure conservative G-module values.

**Unique Long-term Fatigue Resistance and Form Stability**

RockDelta stone wool based resilient mats exhibit outstanding efficiency and durability even after decades of freight line operation. Exhaustive laboratory tests at The Danish Technical University have confirmed the outstanding durability of RockDelta stone wool fibers – under very high mechanical stress levels and over extraordinarily long periods of time. A large-scale laboratory based fatigue life test has demonstrated that RockDelta resilient mats exhibit virtually unchanged dynamic stiffness, according to both ISO 10846-2 and German Railways norm DB BN 918071-1, after being exposed to an amazing 100 million repeated load cycles at a single frequency sinusoidal load fluctuating between 15 and up to 40 kN/m². The conclusion of this fatigue life test was clear and unambiguous: Displaying the stiffness of the test specimen as function of the number of load cycles at selected frequencies, the resulting Dynamic Transfer Stiffness curves and Low Frequency Dynamic Bed
Modulus curves demonstrated stiffness and form changes that were within the uncertainty of the measurement.

**Temperature Independent Functional Performance**

RockDelta resilient mats provide for high-performance track vibration isolation independent of the ambient temperature.

To corroborate this, a test was carried out at the Technical University of Munich where samples of RockDelta resilient mats were subjected to large sub-zero temperature variations – at the same time measuring the Low Frequency Dynamic Bed Modulus according to German Railways norm DB BN 918 071-1 clause 2.7.2.2 at predefined temperatures from -25°C to +25°C. It was concluded that the vibration mitigation performance of RockDelta resilient mats retained their functional performance regardless of the ambient temperature levels with stiffness changes less than 8%.

**Virtually no Sensitivity to the Presence of Water**

As many resilient materials are sensitive to water, both short-term and long-term, one of the most important potential threats to the prescribed level of Insertion Loss is probably the presence of accumulated, undrained water in the track bed. RockDelta resilient mats are characterised by being virtually insensitive (stiffness and damping) to submersion in water. To help demonstrate this important feature of RockDelta resilient mats, and to help contrast the results with other non-stone wool based resilient mats, an elaborate ISO 10846-2 based test scheme was devised and later carried out at Ingemansson Technology in Gothenburg, Sweden. The test consisted of three separate tests runs with the following test specimens; (1) RockXolid 50 specimen; (2) medium soft PUR based specimen, and; (3) soft PUR based specimen. After full submersion in pH neutral water for 0 (dry condition), 2, 12 and 24 hours respectively, each specimen was carefully tested. At each of the time intervals stated, the specimen was taken from the water basin, excess water was wiped off and the specimen tested according to ISO 10846-2. The results for the RockXolid 50 specimen showed surprisingly little influence from water. In fact, the difference between the stiffness curves for 0 (dry) and 24 (wet) hours were hardly noticeable (3). Contrasting this result, the Dynamic Transfer Stiffness measurements based upon the two PUR based specimens seemed to show strong influence from the following factors; time duration of immersion in pH neutral water, and; (2) material density. With a difference of up to more than 30% between the 0 (dry) and 24 (wet) hour curves, the soft PUR based specimen exhibited what can probably best be described as very strong influence from the presence of water.

**Helps Avoid Sub-grade Failure and Minimise Sub-grade Maintenance**

It is well-known that ballast degrades progressively under cyclic loading and causes deviation of track alignment and vertical profile from the original design geometry. Ballast degradation is influenced by several factors including the amplitude and number of load cycles, gradation of aggregates, track confining pressure, angularity and strength of individual grains.
Several types of sub-grade and track substructure failures may be prevented by the use of a sub-ballast layer, e.g. a composite geogrid-geotextile working in conjunction with a resilient mat. The build-up of water, e.g. stemming from precipitation or from mud pumping, in the track substructure (e.g. water filled ballast “pockets” in old tracks) is often a considerable factor when bearing capacity loss of the sub-grade occurs. Picture courtesy of Terram Ltd.

Based on extensive research, e.g. at the University of Wollongong, Australia (4), it has been found that the use of composite geosynthetics at the bottom of a ballast layer is highly desirable to serve the functions of both drainage and separation of ballast from the subgrade. Results from large-scale triaxial testing indicate, amongst other things, that bonded, or composite, geogrids-geotextiles help decrease differential settlements of tracks, ballast degradation and lateral movement, and the risk of mud pumping. In fact, various types of sub-grade failures and other track substructure failures may be prevented, or the risk of them occurring minimised, by the use of an appropriate subballast layer, e.g. a composite geogrid-geotextile working in conjunction with a resilient mat. To that end, some of the specific and important functions of subballast should be noted:

- Sub-ballast prevents the intermixing of ballast and subgrade soil i.e. it provides a separator function.
- Sub-ballast prevents subgrade attrition by the ballast particularly on hard subgrades, e.g. bridge decks.
- Sub-ballast acts as a water control filter for rain and ground water flow.
- Sub-ballast provides energy absorption from passing trains to prevent shock waves at track joints traveling downwards and possibly damage the sub-grade.
- Sub-ballast helps decrease the pressure on the sub-grade thereby helping to avoid subgrade failure.

Through consultations with RockDelta, Terram has developed a line of non-hydrophobic as well as hydrophobic composite geotextiles. These drainage enhancing highstrength composite geotextiles, forming an integral part of every RockBallast solution, are comprised of the following layers:

- Top separator/filter layer - thermally bonded, PP/PE based
- Core layer – an extruded drainage enhancing grid, HDPE based
- Bottom separator/filter layer - thermally bonded, PP/PE based

Working in conjunction with the RockDelta resilient mats, this purpose-made, high-grade line of composite Terram geogrid-geotextiles provide for a durable layer of sub-ballast and thus enables a
high performance track substructure with increased overall functional performance not least related to tracks in adverse climates and tracks that are prone to the build-up of water.

**Unaffected by Exposure to Sunlight and Ultraviolet Rays**

It is well-known that many resilient mat materials are prone to changes in key material characteristics when stored improperly, e.g. storage and transportation hardening (known to occur in some types of rubber as spontaneous cross-linking or as problems with stacking), low temperature crystallisation and – not least – exposure to sunlight. Although some of these effects may be reversible to a certain degree, e.g. via controlled conditioning in a hot room, the problems associated with storage and transportation will often manifest themselves only after installation in the track substructure thereby rendering a remedy both time consuming and expensive.

Stone wool based RockDelta resilient mats are characterised by their lack of sensitivity to temperature-related transportation and storage problems and by their lack of sensitivity to the exposure to sunlight and ultraviolet light. The latter point may become important, e.g. when mats are pending installation at the building site.

**Very High Degree of Resistance to Chemical, Biological and Environmental Factors**

Acid rain is probably one of the most common environmental conditions experienced by a track. This environmental condition relates not only to above-ground, open-air tracks but potentially also to underground tracks for instance due to flooding. It should accordingly be noted that RockDelta resilient mats exhibit outstanding resistance to acid rain and ion-exchanged water. One method that demonstrates this important feature is a laboratory test where specimens are immersed into an artificial acid rain liquid. Bottles with these test specimens are then left at room temperature and after 1, 2, 4, 7, 24, 48, 73 and 144 hours respectively, the pH value is measured. During this test, the degree of material dissolution is measured as well. In such a test the following important phenomena can be noted; (1) RockDelta stone wool fibres exhibit a chemical selfprotection mechanism by which the pH development stabilizes at a value close to pH neutral, and; (2) the infinitesimal dissolution stabilises at approximately 1 ppm (6). Obviously, RockDelta resilient mats are resistant to all naturally occurring soil alkalis and acids. As RockDelta resilient mats are inorganic and chemically inert, they neither contain nourishment for animals and nor do they sustain the growth of biological material, e.g. such as bacteria and fungi.

**Fire and Smoke Safe Mats for Additional Protection in Tunnels**

Within rail based transport, fire and smoke safety are vitally important topics with potentially far reaching consequences related not least to tunnel tracks, e.g. during construction work. Accordingly, for every building component in the tunnel structure, accurate knowledge of the components´ resistance to fire and reaction to fire is of high importance. RockDelta resilient mats exhibit inherent and unique fire and smoke safety features (7) as evidenced by the fact that RockDelta stone wool based resilient mats fall into Euroclass A2 (s1, d0) according to the new CEN fire safety standard. With minimum smoke generation (s1) and no flaming droplets (d0), RockDelta stone wool - inherently withstanding more than 10000°C - thus helps to ensure an effective fire and smoke safety with enhanced protection against loss of life, structural damage and financial losses.
Fig (8). RockDelta stone wool means advanced fire protection. RockDelta stone wool is made from diabase rock and therefore can not burn. RockDelta stone wool inherently resists temperatures higher than 1000°C.

**Excellent Thermal Insulation to Help Protect Against Frost Heave**

The outstanding thermal insulation capacities of RockDelta stone wool means that the potential phenomenon of frost heave associated with ballasted tracks in cold climates may be significantly suppressed. During winter time frost heave can cause significant vertical differential displacements and when the ice melts during spring thaw an excess of water remains in the track formation which causes softening. During the period of such thaw softening, severe plastic deformation can occur with resulting loss of track geometry and damage to the track components.

Fig (9). A schematic view of frost heave in a frost susceptible soil. The freezing of the ground and growth of ice lenses in the soil causes the ground surface to heave. As a result the formation level is lifted and damaged. During spring thaw the foundation soil is softened as the ice melts thus greatly weakening the structural support for the track. Good drainage combined with a RockDelta resilient sub-ballast layer helps guarding against the forming of ice lenses.

Picture courtesy of Terram Ltd.

Frost heave occurs when soil expands and contracts due to freezing and thawing. Certain soil particles have a high affinity for liquid water. As the liquid water around them freezes, these soils draw in liquid water from the unfrozen soils around them. If the air temperature is below freezing but relatively stable, the heat of fusion from the water that freezes can cause the temperature gradient in the soil to remain constant. The soil at the point where freezing is occurring continues to draw in liquid water from the soils below it, which then freezes and builds up into an “ice lens”. Three conditions are therefore needed for frost heaving to occur;

- freezing temperatures in the soil
- sufficient supply of water
- frost susceptible soil that has:
  o ability to conduct water
  o high affinity for water
  o pore spaces filled with water

Good drainage helps to limit the source of water and insulation of the frost susceptible soil by a sufficiently thick layer of non-frost susceptible soil (or sub-ballast layer) will help prevent freezing temperature. With an unrivalled level of thermal insulation capacity and the drainage enhancing...
capacity of the integral Terram geosynthetic a RockBallast based sub-ballast layer is perfectly suited to help guard against the forming of ice lenses.

**Fast, Easy and Safe Installation to Minimise Cost and Maximise Worker’s Safety**
RockDelta resilient mats come on one-way pallets – in convenient ready-to-install sizes for easy and swift positioning in the track bed.

Fig (10). RockDelta resilient mats are easy, safe and swift to position in the track bed. Accordingly, installed mats per working man hour can reach beyond 30 to 40 m² per hour. Intricate track bed curves are easily negotiated with RockDelta resilient mats owing to the light weight and easy handling of the mats.

Under optimum conditions, installed mats per working man hour can even reach beyond 30 to 40 m² per hour. Importantly, not only straight track sections but also track curves are easily negotiated with RockDelta mats owing to the light-weight and easy handling of the mats (compare for instance to large, heavy and generally unhandy rolls). Track bed obstacles are easily negotiated. Even complex shaped track bed obstacles are easily negotiated with easy-to-cut and easy-to-carry RockDelta resilient mats. Likewise, even complex track bed geometries with variations in all three degrees of freedom (e.g. track curves) are easy to negotiate owing to the convenience of working with light-weight, mat based resilient elements.

Fig (11). Even complex shaped track bed obstacles, e.g. drainage channels and concrete anchors, are easily negotiated with easy-to-cut and easy-to-carry RockDelta resilient mats. Likewise, even complex track bed geometries, e.g. track curves, with variations in all three degrees of freedom, are equally easy to negotiate owing to the convenience of working with light weight, mat based resilient elements.

**Environmentally Friendly and 100% Recyclable**
Environmental responsibility is of vital importance to RockDelta. As part of the Rockwool Group, RockDelta follows the stringent, award winning, group environment policy that includes environmental analysis of all projects involving new production equipment or new products, an elaborate environmental management system and audits at the plants to assist the environmental work...
Long-term Practical Experiences in Adverse Climates
As early as 1978, the Norwegian National Railways (NSB) decided to install anti-vibration mats based on stone wool in a section of a tunnel track in the capital city of Oslo, located beneath the cathedral. In 1996, as part of a investigation to determine the best possible method for vibration isolation for the planned Gardermobanan line NSB decided to conduct extensive research into the real-world, longterm performance characteristics of RockDelta resilient mats (8).

The exhaustive test results showed that the mats had retained their functional performance over the full period of 18 years. On-site measurements were used to provide for an assessment of the degree of vibration isolation. It was concluded that the stone wool based mats gave significant isolation against structure-borne vibrations in the order of 8 to 12 dB in the important frequency range from approximately 30 to 125 Hz. The mats were in outstanding condition. As expected, signs of neither fungi nor bacteria could be found. The NSB noted several important issues pertaining to the use of stone wool based anti-vibration mats: (1) the maintenance requirements for the isolated Oslo Cathedral tunnel track section, when compared to other non-isolated tracks, had shown no need for special maintenance care; (2) no “setting” of the ballast could be found, and finally; (3) maintenance during the 18 years period was three times of ballast tamping – same three times as it had been for the non-isolated track sections.

Conclusion
It has been demonstrated that RockDelta stone wool based resilient mats exhibit important features, advantages and benefits perfectly suited for modern-day resiliently supported track designs. This includes: excellent dynamic properties, high volume compressibility, low dynamic-to-static stiffness ratio and a high shear modulus even when operating in adverse climatic conditions. Furthermore, and owing to the inorganic and chemically inert nature of RockDelta stone wool, resilient mats from the RockBallast and RockXolid product lines – environmentally friendly and 100% recyclable – exhibit unique long-term fatigue resistance, climate independent functional performance and a very high degree of resistance to all naturally occurring chemical, biological and environmental factors, including exposure to sunlight. Long-term practical experiences have demonstrated real-life durability and performance in adverse climates. It has also been discussed how fast, easy and handy installation helps to minimize cost and maximise worker’s safety. Finally, it has been discussed how a sub-ballast layer of RockDelta resilient mats working in conjunction with a Terram high-grade drainage-enhancing composite geosynthetic may help to prevent various types of sub-grade and track substructure failures.

References
(1). Unlike track degradation phenomena developing over time (e.g. top variation, versine, cant, twist and sub-grade failure) – elastic rail deflection in this context relates to a momentary change in rail level depression when a train wheel set passes over. This results in a deflection of the rails and, as a corollary, mechanical stress in the rails. The level of depression is, amongst other things, related to the static and (low frequency) dynamic stiffness of the resilient mats.


(5). In chemistry ion-exchange resins are known to catalyze organic reactions hence the general insensitivity of RockDelta stone wool to such resins helps to demonstrate the materials nonorganic nature.

