“Subballast project” design of a new recycled crumb rubber bituminous layer in the railway track subgrade

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ABSTRACT. *Bituminous subballast rail track, compared to conventional granular subballast track not only reduces maintenance costs, but also increases subgrade bearing capacity and impermeability. Furthermore, bituminous products are likely to be mixed with recycled materials, which is useful to environment. Because of that, improved viscoelastic properties can be achieved as it is provided a better vibration reduction. In addition, the main problem of granular subballast as a track material is its low level of obtainment from quarry.*

“SUBBALLAST PROJECT” pretends to take advantage from bituminous material properties so that these kinds of products take part into the subgrade. Thus, two main premises have been set up. On the one hand, the features of this new solution have to improve or equalize granular subballast ones. On the other hand, the final investment has to be lower. In this way, another condition has been established. It is pretended to find the right bituminous dosage which is able to offer a similar structural behaviour as granular materials do.

Three different types of bituminous dosages have been taken into account, and their mechanical behaviour has been established. According to this research, asphalt with crumb rubber provides relevant advantages by the time the environment is respected as crumb rubber particles come from outdated car tires. In order to attain the correct bituminous layer thickness, a finite element model has been performed. Then a testing track is going to be built so that the solution is tested in a real situation.

At this point, some interesting additional conclusions have been reached. In terms of transport costs, it has been figured out that for medium distances from the quarry -45 km-, it is truly profitable to choose bituminous materials as the suited solution.

This project is being developed by several private and public companies. The consortium is consisted of OCIDE, Aglomerados Los Serranos, AMINSA, Intercontrol Levante, with two outsourced entities such as Universidad Politécnica de Valencia -UPV- and Ente Gestor de la Red de Transporte y de Puertos de la Generalitat -GTP-. It has been approved by "Centro para el Desarrollo Tecnológico Industrial" -CDTI-, with a budget of 4.2 million euros.

KEYWORDS: *subballast, subgrade bearing capacity, asphalt with crumb rubber, vibrations*

2. Background

2.1. High-speed rail

The development reached by today's society motivates the increasing demand of high mobility rates and environmental friendly transportation. In this context, the high-speed rail is suitable for both passenger and freight transport.

The growth experienced by the high-speed rail in recent years shows the determination of the authorities in giving a response to the demand. Moreover, technology and construction methods have significantly improved.

Nevertheless, since the high-speed rail has a promising future, the technology should get better. It is necessary to create more competent and effective constructive solutions whose aim is to improve the constructing and operating performance.

These yields are conditioned by the stringent requirements demanded to the rail infrastructure: withstanding high operating speed results in high dynamic loads per axle; ensuring adequate comfort levels to travelers involves performing the work of the railway in very good conditions; providing a high reliability in the service requires durability, structural stability and a low maintenance need, which is the main investment in the rail service.

Traditionally, the research has been focused on improving the rails (shape and quality of steel), the fasteners (strength, elasticity and durability) and the sleepers (strength and service life). However, new fields of action are being developed. They are related to elements of the track and the lower layers. In this context, the current project focuses on the subballast layer.

2.2. Subballast. Current situation

The subballast layer is commonly placed between the ballast and the platform, and it serves as a union between both of them. Usually it consists of gravel and/or well graded sand, which is a material suitable to carry out their functions within the track. These functions are:

- To distribute homogeneously the stresses transmitted to the platform, reducing them by increasing the area of distribution. This will avoid exceeding the bearing capacity of the lower layers.
- To evacuate rainwater towards transversal drainage elements.
- To separate physically the ballast and the platform, avoiding the contamination of the ballast by vertical migration of the material from lower layers, and protecting the platform against particle attrition and possible ballast water leaks.
- To keep the track geometry throughout service life.

Hence, the main functions of the subballast layer can be summarized as bearing capacity and impermeability. It must be noted that this layer is fundamental in ensuring a proper durability of both infrastructure and superstructure, influencing future maintenance needs.

Figure 1. *Granular subballast spread*

Although the granular material is mainly used for the subballast layer by almost all railway administrations, it presents a number of drawbacks that confirm the need to explore new solutions.

The main problem is the lack of quarries able to provide a suitable granular material for the subballast layer. This involves high transportation costs from the quarry to the construction site. In addition, quarrying implies a negative environmental effect. Thus, the large amount of railways to be constructed in the coming years forces to question the supply capacity.

Furthermore, a high thickness of the granular subballast layer is required to achieve the appropriate bearing capacity, which results in a high amount of material and an increase of the transportation costs, see figure 1.

Likewise, the waterproof capability is specified by the Spanish regulations, which defines a vertical permeability coefficient of the subballast (K). The permeability of the subballast layer, compacted to 100 % as compared to the modified Proctor, must be less than 10^{-6} m/s. This low permeability could be achieved through the presence of fine aggregates in the granular material. However, the fine aggregate is limited by structural requirements, which makes it complicated to reach the mandatory impermeability. Moreover, the granular material is vulnerable to water saturation and vibration.

All the mentioned problems justify the present research project, whose purpose is highly innovative.

2.3. Need of the project “SUBBALLAST”

Then, it is evident the interest of studying an alternative to the granular subballast, searching a solution that replaces or enhances the current track railway design. This new solution should guarantee the required bearing capacity and impermeability, achieving at least an equivalent structural behavior to the conventional subballast track. Also, it would be desirable to reduce the costs and to be environmentally friendly.

In this context, the project is undertaken by the consortium formed by OCIDE, Aglomerados Los Serranos, AMINSA and Intercontrol Levante, along with the UPV and GTP, as subcontracted entities. The project is titled as “SUBBALLAST: Design of alternatives with new materials as a subballast layer for railway tracks”.

3. Objective

The objectives of the project are clear and specific, summarized in the next two points:

- To study, design and validate a new configuration of the material used as subballast to improve the existing specifications of the granular subballast.
- To reduce both economic and environmental costs associated with the exploitation of the few quarries granular subballast comes from.

4. Solution

The first stage in a research process implies a thorough investigation of the state of the art. In this case, the conventional subballast mainly used has been characterized. It has been confirmed the existence of abundant technical regulations (both national and international), which deal with the requirements of that granular material of conventional subballast has to achieve. Also, the main functions of the subballast layer and the problems related to the current solution have been studied.

Proceeding with the characterization, a numerical model has been developed in order to determine the structural behavior of a track with the current configuration of granular subballast. The mathematical modeling was carried out by the finite element method, FEM, which takes advantage of the computing power nowadays available and which has a wide experience on its application in railway framework. In this regard, to elaborate the model, the recommendations defined at [1] and [2] have been applied. To calibrate and validate the model it has been used real data taken on a stretch track between “Las Palmas de Castellón” and “Oropesa del Mar”.

The reason why the FEM has been used is that it permits to reduce real experiences in prototypes or test beds, reducing costs and providing the opportunity to compare easily different design alternatives in order to achieve the optimal solution. The schematic process taken for the study is showed in figure 2.

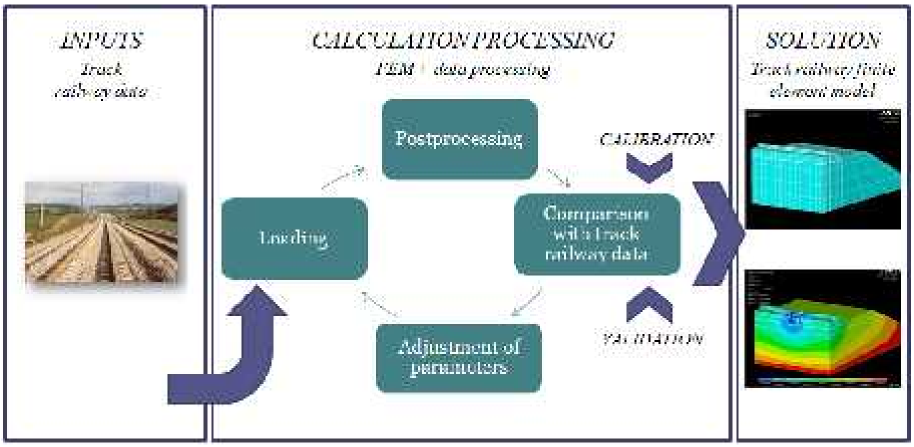

Figure 2. Stages to obtain a numerical track model

At this stage, the characterization of the behavior of the current granular subballast layer is known, and a strong and validated model to face the innovative stage of SUBBALLAST project is elaborated.

As a starting point in finding the optimal alternative, the study of the state of the art in other countries with a longstanding railway tradition has led to propose a solution based on bituminous subballast which meets the requirements of bearing capacity and impermeability. Also, the use of bituminous mixtures adds new advantages like the improvement of the geometric stability and the reduction of maintenance works, the decreasing amount of aggregates due to the thinner thickness and as a result a bigger working margin for auto maximum height sign in tunnels (see figure 3), mitigation of vibrations due to its rheological behavior and the possibility to include in its composition reused materials.

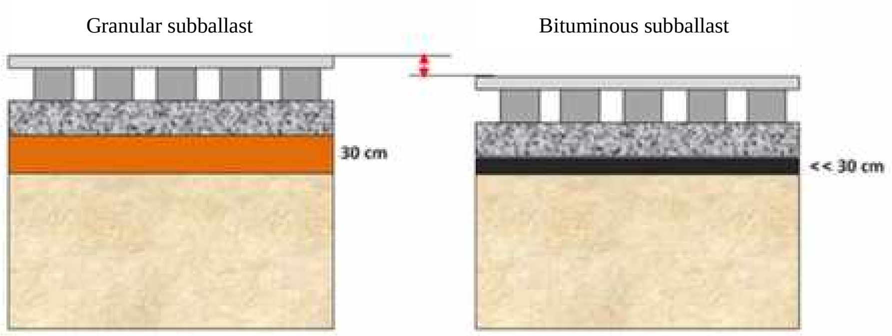

Figure 3. Thickness reduction due to higher bearing capacity of bituminous subballast layer

Once decided the bituminous composition of the new subballast layer, three possible alternatives have been suggested:

- Bituminous subballast consisting of a conventional mixture with crumb rubber from outdated car tires. It boosts the recycling of difficult elimination wastes and it also produces a mitigation effect of railway vibrations.
- Bituminous two-layered subballast consisting of a mix of high module and a layer of conventional mix. It implies a higher reduction of the thickness, due to the increasing of the bearing capacity.
- Bituminous subballast consisting of a semi warm mix layer. Its peculiar making and execution permits to reduce CO_2 emissions.

Next, in order to consider the appropriate inputs of the three alternatives in the mathematical model, a material supplies and testing campaign has been performed to define the compositions and to characterize the behavior parameters.

After the characterization of the materials which are susceptible to be used, its parameters are introduced in the model in order to calculate the optimal thickness of each alternative. The criterion used to size them is that the solution must present the same stresses, strains and vertical track stiffness as the granular subballast. The process consists of, in each case, proposing several thicknesses, carrying out a structural analysis and choose, as the optimal solution, the thickness which leads to the same stress-strain state as the obtained for granular subballast with the same forces. Therefore, once the sizing is done, each alternative is defined, in terms of both quality and quantity of materials needed.

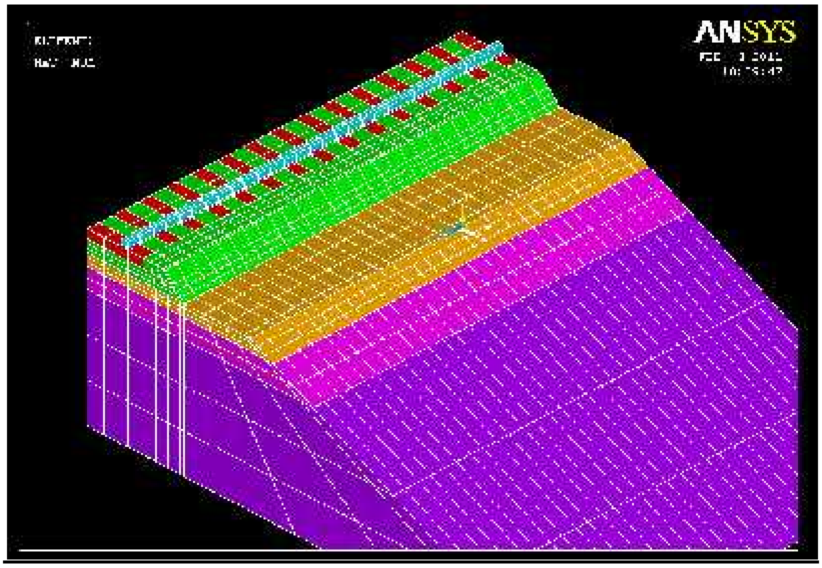

Figure 4. One of the used numerical models

With all the available data, it is possible to carry out a multi-criteria analysis to choose the best alternative. In practical terms, it has been done an evaluation using the PRES Method, which has assessed all the relevant aspects as the different costs (production, transportation, execution and maintenance), structural behavior, environmental impact and CO_2 global emissions. In this analysis, besides the three alternatives, it has been included the granular subballast solution.

According to multi-criteria analysis, the best solution is the alternative which consists of a conventional bituminous mixture with crumb rubber from outdated car tires. The use in its composition of this problematical waste permits to reduce its environmental impact and also produces a vibration mitigation effect. In addition to these characteristics which are peculiar to it, it presents the common advantages of a bituminous subbalast layer.

Furthermore, as a complement of this multi-criteria assessment which justifies theoretically the solution, a test bed (see figure 5) has been executed where it has been done full scale physical testing: statics to evaluate the stress transmissions and dynamics to study the vibration mitigation. First of all, the three bituminous alternatives have been compared, obtaining similar values of stresses, validating the results of the numerical analysis. The solution with crumb rubber from used tires has also been stated as the more efficient alternative in reducing accelerations caused by trains and it has been confirmed as the optimal solution. In order to guarantee this improvement, a real stretch track of granular subballast has also been tested. The comparison of the results has concluded that the new bituminous subballast reduces the vibrations by about 30% in terms of amplitude.

Figure 5. Full scale test bed

Finally, an economic study has been performed in order to compare the execution costs of granular subballast and bituminous subballast. As the bituminous material is more expensive than the aggregates but a lower quantity of it is required, it has been concluded that the comparison depends on a limit distance: it has been proved that for distances lower than a limit distance, the granular subballast is cheaper than bituminous one. But for distances higher than this limit distance, transportation costs of aggregates produce that the cheapest solution is the bituminous subballast. Specifically, the limit distance has been set between 40 and 45 km from the construction site to the quarry.

Therefore, a possible alternative to substitute the traditional granular subballast has been obtained. This new solution consists of a bituminous layer composed by a conventional mixture improved with crumb rubber from outdated car tires.

5. Conclusions

The "SUBBALLAST" project has been presented in this document. A new rail track configuration made of a bituminous subballast with crumb rubber has been proved to be advantageous compared to the conventional granular subballast layer. Throughout the research the following conclusions have been reached:

- The subballast layer must provide bearing capacity and impermeability. It is extremely hard to find suitable quarries that are able to supply the optimum materials for the layer. Therefore, both transportation costs and environmental impact increase. Besides, the future of the source is uncertain.
- Bituminous alternatives have been proposed to replace the conventional granular subballast. Additionally, they contribute to the stability of the track

and to reduce both the thickness of the layer and the vibrations. Moreover, it is possible the reuse of waste.

- The finite element method has been presented as a useful tool able to simulate the behavior of the rail track. It is powerful and reliable and it allows to know the response of a system without physical experimentation, which is more expensive.
- Three bituminous subballast layers have been proposed. The materials have been tested in a laboratory in order to obtain their mechanical properties. Then, finite element models have been created to size the thickness of the layers. The thickness in each bituminous subballast layer has been established so that the stress-strain state is similar to the granular subballast model.
- A multicriteria analysis has shown that the bituminous subballast with crumb rubber alternative is the best solution. This one has some advantages over the other bituminous alternatives, such as the reusing of a problematic waste and a higher vibration reduction (fact that has been proven in a full scale test). Furthermore, the solution turns out to be economically viable and reduce the environmental costs of quarrying.
- The “SUBBALLAST” project defines the quality control campaign that should be carried out over the spread and compacted layer. Also, the execution process will be determined, taking into account the possibility of using conventional roadway machinery, thus improving the performance during the building.

Therefore, the advantages of the “SUBBALLAST” project have been defined. An innovative solution to a real problem has been proposed, which has significant environmental benefits.

6. Bibliography

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