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Review Article

An investigation of high speed transport systems: Design and geodynamics

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ABSTRACT

High speed rail systems are an important transportation system that is desired to be developed in almost every country around the world. These systems made train transportation more attractive than conventional railways. Train speed is the most effective parameter that differs from each other when compared to traditional railways. This difference requires special designs in order to keep the vibration that will occur during movement in high speed systems within the limits that will not harm the substrate and the environment. Vibrations caused by high train speed are transferred from the rails to the sleeper and to the ballast system through the sleeper in common ballast systems, and can cause serious deformations in the rail system and the ground. These cases that pose a problematic in high speed rail systems need to be resolved. The geodynamics of these systems examine the vibration problems caused by motion caused by high-speed trains and the deformations caused by this vibration. It tries to ensure the conformity of the rail system to the continuous movement and the safety conditions of the system. The design of high-speed rail systems, which have many variables and unknowns compared to traditional railways, is the common work area of ground and railway engineering. In this article, the geodynamics of fast transportation systems, the main structures and design of these systems, and their operation methods are examined. At the same time, the ballasted and non-ballasted conditions of fast transport structures are also discussed in detail.

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INTRODUCTION

With the widespread use of high-speed trains and the increase in demand, it has been discovered that the vibrations in the railway system and the ground are caused by trains. The situation causing the vibration; thought to be caused by the contact between the wheels-the rail system at high speeds as shown in Figure 1 [1]. For this reason, countries that want to use high-speed railway transportation in recent years have taken steps to build new railway lines in a

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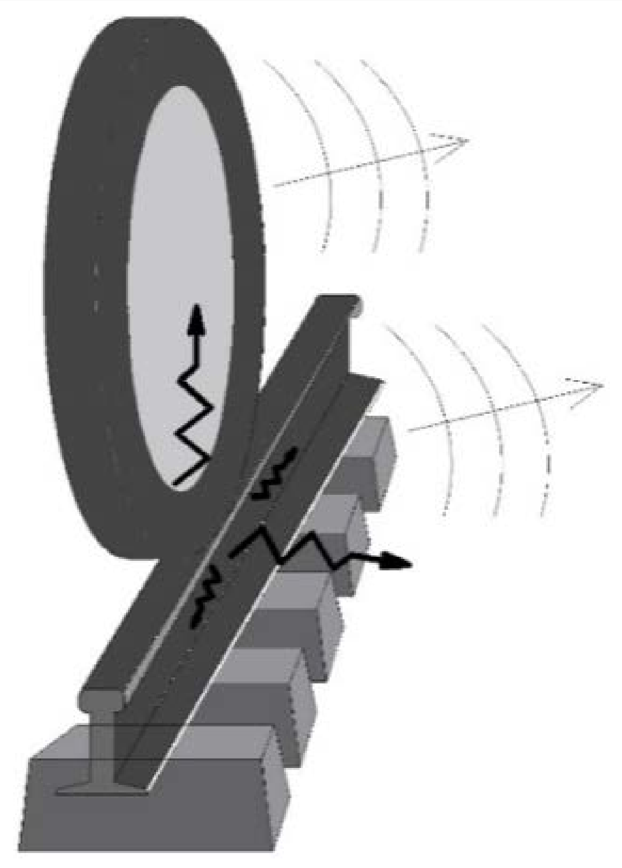

Figure 1. Transfer of dynamic effect caused by movement from wheels to railway system.

safe and economical way by removing these vibrations. In line with this increasing demand against the transportation system, this issue has started to be studied academically in order to solve the negativities of the system itself [2, 3].

It has been observed that the vibration caused by the movement of the train can damage both the railway design [4], the ground below and the structures around the transportation system. It has been observed that these dynamic effects, which are caused by the movement of high-speed trains transferred by the rail, cause discomfort not only to the buildings but also to the people as external effects. These disturbances can cause problems with the noise that occurs during the train passage or the continuous use of delicate materials in the buildings. All of these effects are shown in Figure 2. This damage, which is said to occur in the environment, may cause some architectural damage, although not largely structural damage. However, this is a sufficient reason to consider the issue [3, 5–8]. Speed is not the only parameter of high-speed trains, which seems to have some damages if they are not specially designed. At the same time, the increase in the load of the trains creates a problem in terms of the safety of the system, as a heavier load will be transmitted to the rails and substrates [7].

The effects of this vibration that develops due to dynamic motion are considered under two different disciplines. The effects of vibration in the structures close to the railway system and the negativities caused by the movement in the environment concern the employees and the noise parameter is generally emphasized. The second issue is to examine the deformations and displacements that may occur in the railway system. An effective dynamic motion can cause serious damage to railway components [2]. Increasing needs and demands require faster rail transport. For this reason, new railways should be built in this direction, and lines designed for conventional railways should be arranged if they are used for high-speed trains. The vibration and dynamic effects that cause these problems should be resolved, and their effects on railway components should be eliminated. With the repetitive movement of high-speed trains, stress-induced deformations will also accumulate (Fig. 3) in the ground beneath the railway components, which will cause displacements. Another issue that needs to be improved is how the ground layer under high speed systems will be exposed and how it will behave [5, 9]. For this reason, determining or predicting these damages before the design will make the design more secure. The design and construction of rail systems can result in much higher than the projected cost from project planning to completion. This increase is observed especially in high speed rail systems. One of the reasons is to try to get away from the vibration effect. It is also important to estimate the vibration levels in order to reduce the construction cost [10]. With advancing science and technology, new methods are being developed to predict vibrations of concern. Studying this complex movement in advance for an area to be designed increases the safety of the design to be made. In this way, it can be ensured that dynamic effects and deformations caused by vibration can be kept under control [7].

Train Speed and Rayleigh Speed

The amount of vibration caused by trains in motion; it is controlled by the interaction between the speed of the train and the ground wave velocity [11]. The vibration problem caused by high-speed trains has become a problem to be solved with the increase in use of these trains. The solution to this problem is to predict the vibration that will occur in the design area. The running speed of trains can reach levels that exceed the speed of the Rayleigh wave on the ground. The solution to this problem is to keep the controllable train speed at a certain level [12, 13]. If this control is not achieved, it may cause undesirable effects such as road and infrastructure damage, passenger discomfort and noise to the environment [14]. In Figure 4, the activation of the said vibration is realized.

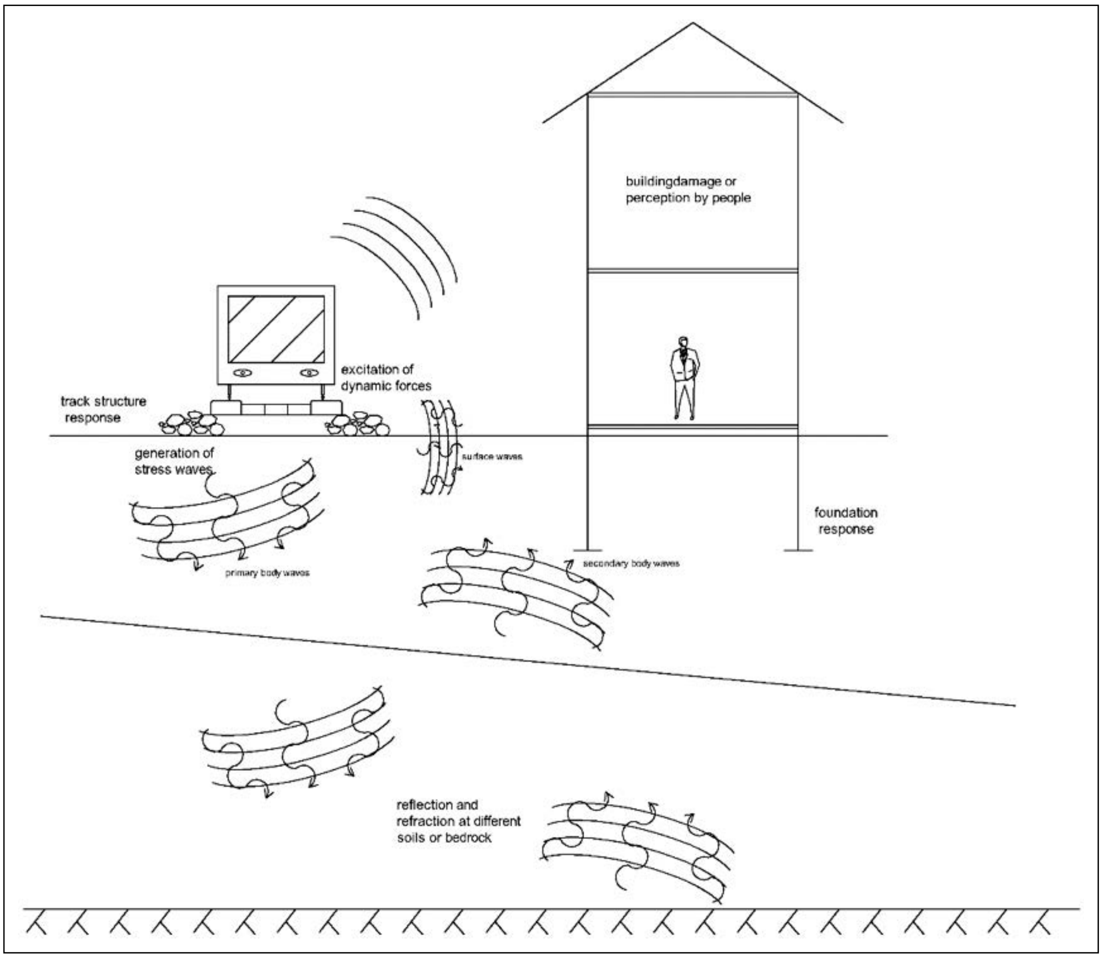

Figure 2. Effects of vibration during train passage.

Ballasted - Ballastless Runways and Comparison

In railway systems, the increase in the speeds and the loads carried by the trains required all the system components carrying these trains to be in the best possible way. In general, the arrangement in the railway system is in the form of rail-sleeper-ballast. If there is a ballast layer, the crushed stones that make up this layer try to absorb the vibrations that will occur with the movement of the train. The hardness ratio of the ballast controls the amount of damping. Although the initial construction cost of the ballastless railway is high, it is seen that it is increasingly preferred due to the advantages it provides after operation [14–16]. Especially under the presence of high speed trains, there is a lot of maintenance and repair costs in traditional ballast systems.

The introduction of trains moving with high operating speed offered the ballastless track model as a useful option against ballasted systems. In the ongoing ballast systems, the ballast structure carries the rail-traverse system that is exposed to the movement of the train. In ballastless systems, reinforced concrete plates act as a ballast layer against the static and dynamic forces caused by the movement of the train. Ballastless systems are a preferred method, especially in railways where high-speed trains will be transported, since they have high strength and relatively lower maintenance costs compared to ballast systems. In these systems, the counterpart of the ballast layer is concrete slabs [17, 18]. A ballast-free high-speed rail structure usually consists of the rail system and the underlying ground substrate. When compared to ballasted layers and ballastless plates, although systems without

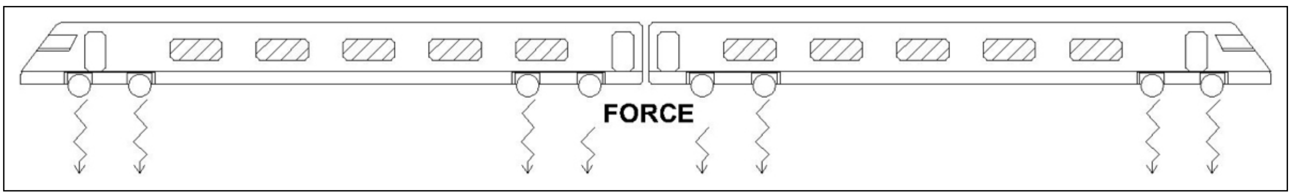

Figure 3. Speed and load transferred from train to railway system.

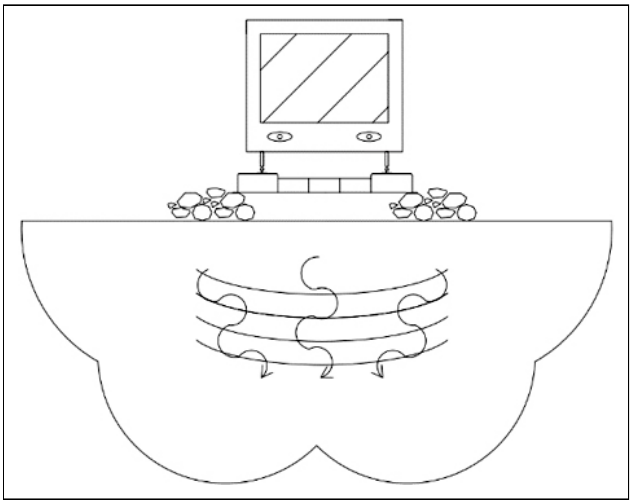

Figure 4. Train-rail, railway-ground interactions.

ballasts are more costly during construction, they become a highly preferable application due to their lower cost in terms of use and the services to be applied afterwards [18].

In case of transition between two systems on the same line, care should be taken that there is no noticeable difference in comfort between systems without ballast and systems with ballast [16, 19]. Although a large number of valid studies have been done in ballast systems, which is a traditional method, there are few studies on the presence and performance of ballastless structures, especially in high speed systems. Detailed studies are needed to reveal clear information about the performance, durability and long-term performance of ballast-free systems under repeated loads [18]. In Figure 2, a traditional ballast railway structure is given with a model.

Ballasted flooring shown in Figure 5 has been used around the world for a long time due to its low cost and easy maintenance. Compared to the ballasted system, in ballastless flooring, the rails are fixed on the concrete slab with the support of a fixing system and concrete is poured into the floor to support the concrete slab. In this way, the load acting on the track through the train is evenly distributed with the concrete slab and the concrete base. Compared to ballasted floors, it can be thought that the concrete slab here serves as a ballast layer. In addition, the contact stress caused by the train load on the subfloor is well dispersed over the concrete base, thus ensuring the protection of the substrate and prolonging its efficient service life [9]. For systems with and without ballast, the ground stresses will not decrease at the same rate as the depth increases. Even for the same track type, there are many factors that change the coefficient of reduction, such as the characteristics of the ground beneath the track system, the train operating speed and the track system components. Ballast grains in a ballasted railway line can be damaged and deformed due to the effects of load and speed during the movement of the train. Such a movement may cause permanent damage to the rail system and the ground, especially if it is repeated cyclically. This is not the case for ballastless systems, but these points should be taken into consideration, since the stresses may increase especially at the edges and corners of concrete structures replacing plate-shaped ballasts [18].

Mach Effect

During the movement of high-speed trains over soft ground, their speed can reach a critical speed. This causes the line structure to resonate with the ground. This event,

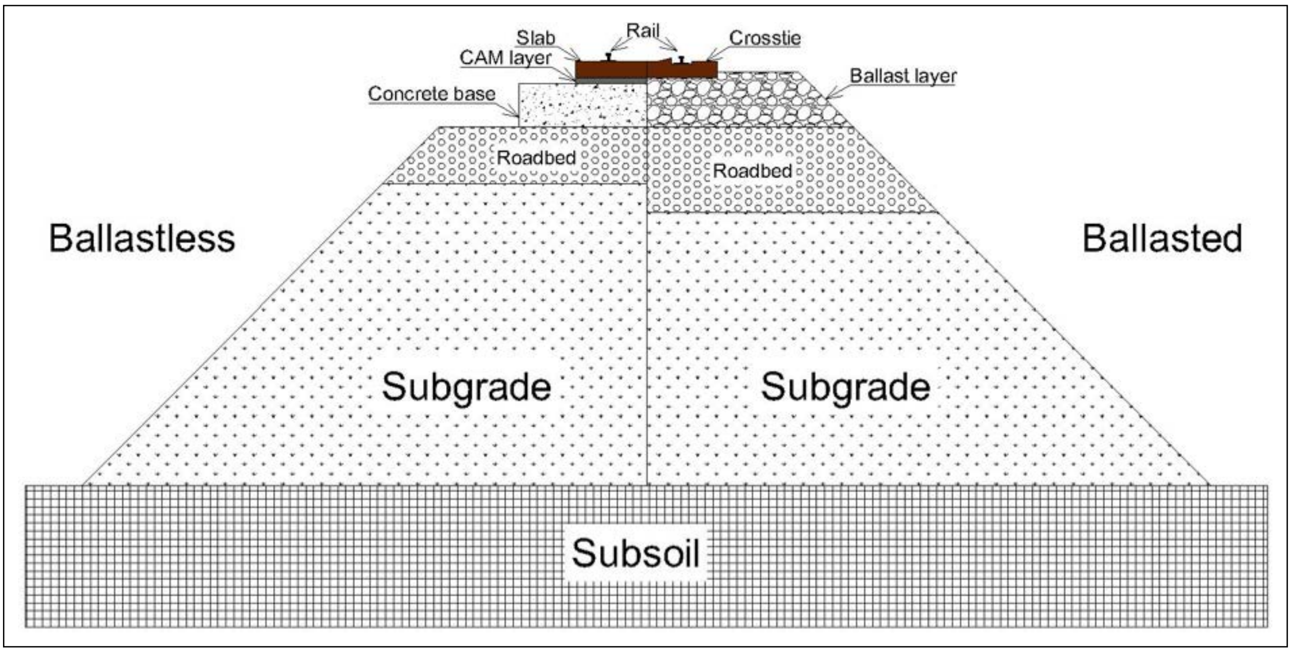

Figure 5. Ballastless and Ballasted High Speed Railway Line.

which causes the vibration of the substrate, is defined as the mach effect. In the studies carried out, it has been observed that mach effect occurs in systems where high speed trains operate on soft ground. It has been observed that the dynamic load imposed on the system and ground by high-speed trains is almost several times greater than the effects caused by low speed [9].

Modelling

High-speed railway systems have sharp limits on their design and more qualified modeling is required due to vibration caused by motion. Experimental modeling of ongoing railway systems is not sufficient for high speed rail [9]. Results obtained from the studies conducted; The two-dimensional designs give information about the effects of the vibration caused by the movement of the train on the structure of the railway and the ground, but three-dimensional modeling is needed to express the problem more clearly and to present the effective solution [7]. It is unfortunately difficult to determine every parameter clearly and accurately during modeling. It is difficult to characterize especially the ballast structure of the railway elements [3]. In case the train operating speed exceeds the Rayleigh wave speed of the ground, the critical speed obtained by simple calculations used for robust ballast structures against vibrations is accepted. Because the hardness of ballast and ground structures will be less compared to the rail system. However, there are questions regarding the use of similar critical speed calculations for systems without ballasts. In this system, concrete slabs replacing the ballast layer are more rigid than the floor layer [17]. The accuracy of the models and calculations created is generally limited by the complex properties of the soil materials. Investigating the geodynamics of high speed rail systems also reveals the characteristics of the dynamic responses of the substrate [9].

In 2,5 area solutions, it is advantageous for modeling systems without ballasts as the geometry does not change much in the direction of train movement. The assumptions accepted by the method allow the problem to be studied in 2 dimensions. This is useful because it is completed in a shorter time than a 3D model analysis [20]. When three-dimensional analyzes are compared with 2,5-area solutions, the equations used can include discontinuities in the ground, voids or different structures underground, and situations in the rail system. However, as can be understood from the fact that three-dimensional analyzes contain too many parameters, they are more complex and long studies. The active use of two-dimensional analyzes continues, as they respond to certain problems [7, 19].

DISCUSSION

The use of high speed rail systems is increasing. However, this increase in train speeds causes undesirable situations in terms of both the railway structure and the ground. The most obvious problem is dynamic vibrations that occur in the presence of critical velocity. If train speed and ground wave velocity match each other, the amplitudes overlap and the system is under the influence of very large vibrations. In determining the critical speed, the rail system on the railway and the structure of the ground are taken into account. This problem can affect the safety of the train and it is strong enough to deform the ground. Dynamic vibration-induced stresses occurring in the ground increase with increasing train operating speed. While vertical stresses are effective at low train operating speeds, they start to increase in horizontal stresses as they approach critical speed conditions. As the train speed increases, the dynamic magnification that occurs is further increased and the loads on the rail system increase. As long as critical speed-related problems are not resolved, maintenance and repair costs increase and there is concern over the security of the system [9, 21, 22].

CONCLUSIONS

In this article, attention is drawn to the geodynamics of rail systems and the importance of system-induced vibration. Rail system lines are intended to be designed to reveal higher speeds, heavier transportation and more, and they are tried to be brought to these levels in those that are currently used. Cities and the population here are growing steadily and rapidly, and this increase brings requirements that must be met for efficient and virtually vibration-free rail transport. These desired conditions prepare the ground for extra geodynamic problems that need to be solved. Some of these problems have been solved thanks to the studies carried out on them. Solvable problems can be presented in 3 items. These are: critical speed, durability of the rail system and propagation of increased vibration. In the study, the need to give importance to the geodynamic situation and vibration is explained. Ballasted and non-ballasted systems are emphasized, and the response of these systems in the presence of high speed rail has been studied in detail. The points to be considered when emphasizing the effects to control the dynamic state of the rail system and the ground, to prevent excessive deterioration of the railway system and to prevent vibration in the buildings if there is social life around. At the beginning of the design process, it is necessary to provide sufficient information about the existing ground to take action against all these problems. When necessary information is provided in terms of soil, if needed, soil improvement methods can be evaluated [5] and whatever is suitable for the site and need can be done.

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