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PLEASE CITE THE PUBLISHED VERSION

https://issuu.com/railpro/docs/may_2016_issue

PUBLISHER

Rail Professional Ltd.

VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

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Krylov, Victor V.. 2017. "A Sensitive Area: Victor Krylov Looks at Ground Vibration Boom - the Phenomenon to Be Reckoned with When Developing HS2 High-speed Lines". figshare. <https://hdl.handle.net/2134/26127>.

Ground vibration boom - the phenomenon to be reckoned with when developing HS2 high-speed lines

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Development of high-speed railways brings into consideration new environmental problems that were unknown for conventional trains travelling at lower speeds. One of the most serious problems associated with high train speeds is a dramatic increase in the level of railway-generated ground vibrations that can occur when the train speed exceeds the velocity of Rayleigh surface waves in the supporting ground. This phenomenon has been first predicted theoretically more than 20 years ago (Krylov, 1994), and it is currently known as 'ground vibration boom', because it is similar to the well-known phenomenon of 'sonic boom' from supersonic aircraft that occurs when the speed of aircraft exceeds the velocity of sound in air.

There are currently many speculations surrounding this phenomenon and circulating within the communities that may be affected by the construction of HS2 railway lines. Sometimes it is even considered as a reason to abandon the development of high-speed railways altogether. Is this phenomenon really so dangerous? To understand the situation better, it is useful to look back at the developments of supersonic jet aircraft in the 1940s. Initial concerns about aircraft possible destruction when passing through the sound barrier turned out to be exaggerated. However, the sonic boom phenomenon, that can be perceived by observers on the ground as a very loud bang, did happen, and it still remains the main environmental obstacle that affected and continues to affect the developments of passenger supersonic aircraft, like Concorde. Because of the sonic boom, Concorde flights were banned over continents, and only trans-Atlantic flight were permitted. Such restrictions made Concorde commercially vulnerable, which led to eventual termination of its services.

Can a similar destiny await high-speed trains because of the ground vibration boom? I do not think so. The essential difference between sonic boom and ground vibration boom is in the fact that, whereas sound velocity in air is roughly the same in all locations above the earth surface, the Rayleigh wave velocity in the ground is different in different locations, depending on local geological properties of the ground. In some locations, where the ground is soft and marshy, the Rayleigh wave velocity can be very low, so that it can be exceeded by high train speeds. And it is such 'sensitive' locations that may represent the risks of occurrence of ground vibration boom from operating high-speed trains. Some preliminary estimates show that the proposed HS2 high-speed routes connecting London with Northern England via Birmingham at speeds up to 400 km/h may give a possibility of ground vibration boom to occur in some sensitive locations. Therefore, there is no point to ban high speed trains over the entire country because of the ground vibration boom. As a rule, train speeds even as high as 400 km/h are still lower than Rayleigh wave velocities in the ground in the majority of locations. However, in sensitive locations characterised by low Rayleigh wave velocities the phenomenon of ground vibration boom will represent a serious environmental hazard to be reckoned with.

Note that, in addition to the above-mentioned ground vibration boom, which is caused by train-generated Rayleigh waves propagating away from a railway track, another type of elastic waves, namely the so-called 'bow waves' propagating in the system track/ballast can be also generated by high-speed trains if their speeds exceed the track critical velocity. The latter is indirectly related to Rayleigh wave velocity in the ground and is usually higher than Rayleigh wave velocity by 10-20%. This means that for train speeds larger than track critical velocity the ground vibration boom and the bow wave phenomenon will take place simultaneously. They should not be confused though. Unlike ground vibration boom, the bow wave phenomenon does not directly affect local residents and buildings as it is confined to the track. However, the associated vertical dynamic displacements of the track may exceed static displacements by 2-3 times, which may adversely affect the train stability and even cause train derailment.

It is clear from the above that the proposed HS2 routes should be thoroughly investigated on Rayleigh wave velocities that should be measured in all locations along the routes before any construction works have started. Such investigations would reveal sensitive locations, with low values of Rayleigh wave velocity, where the occurrence of ground vibration boom and of the closely related bow wave effect is likely. After that, the decisions should be made on how to mitigate the ground vibration boom problem in the identified sensitive locations. The easiest way is to reduce train speeds at sensitive locations. However, this may not be desirable for operational reasons. Therefore, other possibilities can be considered, such as stiffening of the supporting ground by inserting piles or using traditional means of ground vibration screening, such as open and in-filled trenches or embedded rigid barriers.