Safety Evaluation of Buildings in the Vicinity of Railway Tracks and Compliance with ISO14837-1

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Abstract

This paper presents a study of the harmful effects of ground borne vibration induced by high speed trains. A model has been designed using ANSYS software to evaluate and predict nearby building damage. A comparison has been conducted between predicted and real peak particle velocity inside the building.

To excite the structure model, sample inputs for peak particle velocity are chosen from recommendations by ISO14837-1 standard. Frequency analysis of the output data of the software and comparing such output with ISO14837-1 standard predicts some harmful effects such as plaster cracking of the building.

In order to reduce harmful effects, mechanical dampers were added to the structure model. Adding such dampers effectively reduced the level of vibrations and consequently reduces the harmful effects on the building model.

Keywords:

Train induced vibrations, wheel/rail contact, frequency analysis, structure safety

Introduction

Worldwide, population remorselessly increase urbanization increases. Land in cities formerly considered unsuitable for building on begins to reassessed. As structures are more frequently begin built above around close to railways so the problems of transmission of structure-borne sound and vibration in buildings emanating from railways, needs to be more closely considered. [1]

Train induced vibrations go through the buildings in two forms: vibration and noise. In this paper, we are going to analyse the effect of ground borne vibrations induced by train on nearby buildings. The noise effect is not of great importance in this paper.

These vibrations might have been the result of trains passing in an unbalanced way or the result of wheel/rail roughness contact surface. Train-induced ground borne vibrations transferred by the soil could have destructive effects in building structures. It can also cause irritation among residents and malfunctioning to sensitive equipment. In this paper, the main discussion is about the result of ground borne vibrations on nearby building structures. [2,3]

According to the importance of nearby structure safety, we are going to simulate the vibrations exactly. The simulation of soil, buildings and vibrations is based on the model made by the ANSYS software. In this software, the vibration as a force is a function of time. According to the related references, we try to analyse the software data for building damage. All these analyses are based on ISO 14837-1 standard.
After considering different softwares for modeling the problem, ANSYS was the best one which can simulate the problem as perfectly as possible.
Scandinavian countries, e.g. Sweden, are the following countries which have had considerable studies and researches in this field.

Definitions

Peak particle velocity: peak particle velocity is the basis of evaluating train-induced borne vibrations. This velocity is measurable and the unit of this variable is m/s or dB.

dB: the definition for this variable is:

$$dB = 20.\log\left(\frac{X}{X_0}\right) \quad (1)$$

X0: this quantity is not changing in the formula. In America, it is 10e-6 m/s and in other countries, the quantity is 10e-4 or 10e-8 or .5*10e-8. For example, in Sweden standard (SS 460 48 61 (1992)) the quantity for X0 is 10e-9 for velocity and 10e-6 for acceleration.
In this study, recent quantities for velocity and acceleration are for X0 10e-9 m/s for velocity and 10e-6 m/s^2 for acceleration.

ISO 14837-1
Mechanical vibration--Ground-borne noise and vibration arising from rail systems--
Part1: General guidance

In this standard, the harmful effect of train-induced ground borne vibrations on nearby buildings is completely discussed. In this standard, the evaluations for building damage are based on peak particle velocity (dB). The train-induced ground borne vibration could have transferred in two ways:

1. After working for a long time, unbalance occurs in all parts of the train. The unbalance causes vibrations and we are going to consider the effect of vibrations on wheel/rail contact.
2. According to the trains passing in a long time, inevitable roughness occurs and the main part of vibrations affecting on ground is related to this one.

Vibrations have different particle velocities, but peak particle velocity is important for us and is the base of calculation. We have a picture in part **e** of the Figure **2** in ISO14837-1 (Figure 1 in this paper) for vibrations discussion. Figure 1 shows the effect of vibrations. The horizontal axle is related to the frequency and the vertical axle is velocity (dB).
The maximum point in this Figure, is peak particle velocity. In this research, we use this Figure (1) for software calculations. According to the real quantities for peak particle velocity in wheel/rail contact surface and considering the standard (Figure2-e: Example insertion gain for track predicted by train/track model and Y: insertion gain for train/track relative to a reference define track, dB) Therefore we should drag up

the Figure in vertical axle in order to achieve the normal velocities for train. [4]

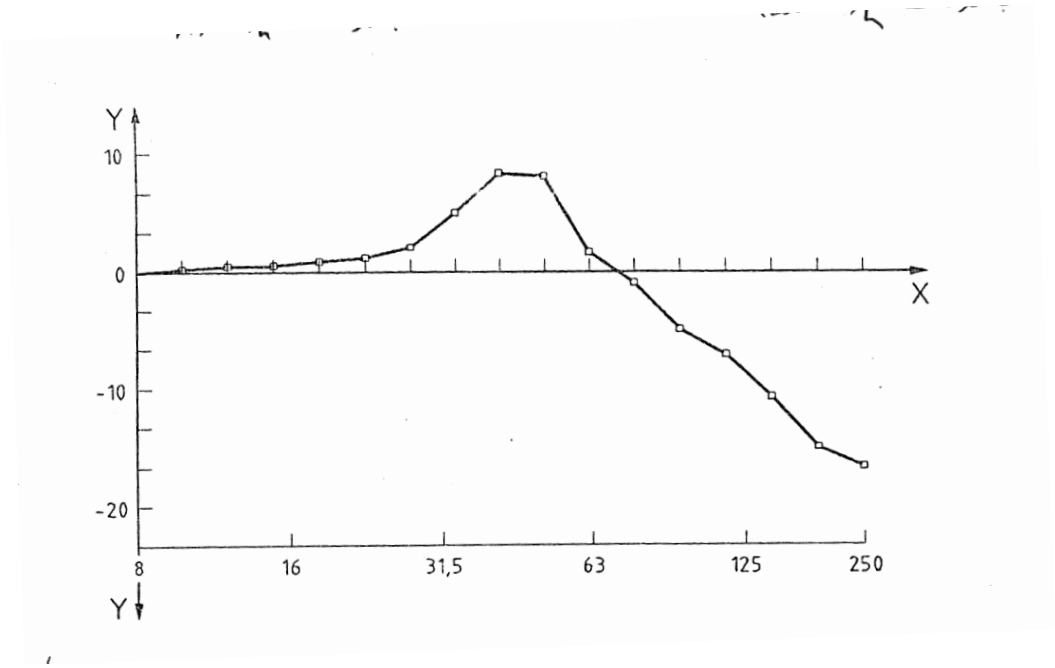


Figure1)

X: frequency, HZ (e.g.one-third-octave mid frequency)

Y: insertion gain for train/track relative to a reference define track , dB

Example insertion gain for track predicted by train/track model

In this standard, nearby building damage risk and related discussions are of great importance.

For example, in one part of this standard we have: "Typically, dominant frequencies are less than 100 Hz because they represent the response of building elements. The frequency range relevant to the evaluation of the risk of vibration-induced damage on building structures is 1 Hz to 500 Hz, although high strains associated with higher risk of damage are associated with low frequencies. Most building damage from man-made sources occurs in the frequency range 1 Hz to 100 Hz."

Therefore, in this research the frequency domain for vibration is 1 Hz to 100 Hz. This is an appropriate range for evaluating building damage and peak particle velocity.

A proposed safe level for "serious" structural damage is very high: 50 mm/s peak particle velocity. Nevertheless, much lower levels may be relevant for damage to old and historic buildings(as low as 2 mm/s), and for more "minor" damage in ordinary building ("fine plaster cracking and reopening of old cracks") [5]

Some examination performed and presented in papers

A long number of examinations have been done all over the world. The particle velocity and acceleration are measured in different distances of the rail and nearby buildings.

A comparison between old and new rail systems

Some examinations have been performed by ORE D 151 Committee. One of them is mentioned and analyzed in this part of paper. [6]

In the following picture, acceleration in the first floor of a building is showed. The velocity of train is 60km/h. Three different condition of wheel have been analyzed:

wheels with new profile, wheels which have been in service for 150000 km, and old wheels which have been is service for more than 150000km.slope is occurred in these wheels because of wheels roughness. Emergency brake could be one of reasons in this case.

Attending to the picture, peak particle acceleration resulting to building damage in frequency range of 1HZ to 100HZ for old rail system is approximately 20% more than the new rail system. But according to reference quantity for acceleration in this search and according to calculation based on Figure 2, we can conclude that peak particle acceleration and peak particle velocity affecting on building damage in frequency range of 1HZ to 100HZ for old system is about 10% more than the new system. Therefore, old peak particle velocity (dB) dividing to the new one is 1.1.

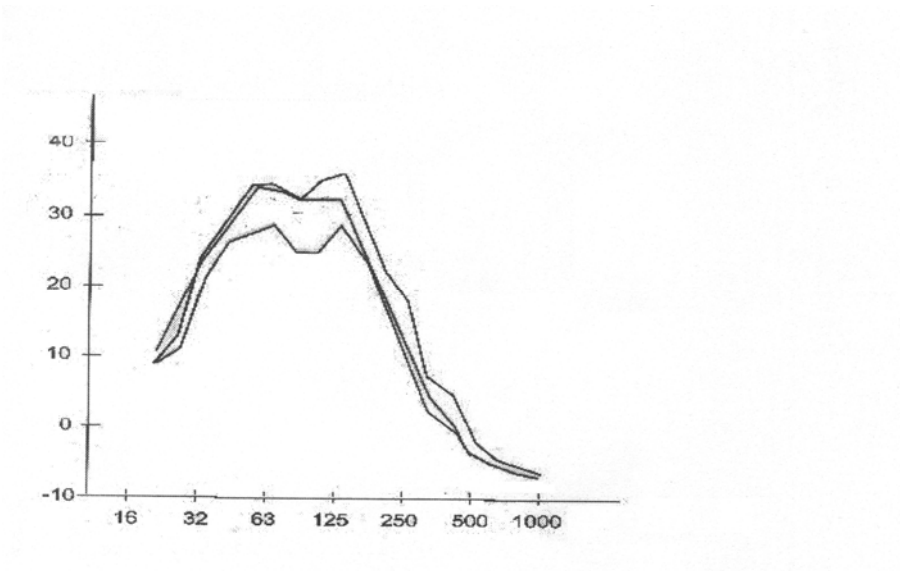


Figure 2) vibration measurement in a building nearby subway
X: frequency, HZ
Y: peak particle acceleration, dB
Highest curve: wheels with new profile
Middle curve: wheels which have been in service for 150000 km
Lowest curve: old wheels which have been is service for more than 150000km

Comparison between numerical calculations and examinations

According to numerical method for defining the peak particle velocity and comparing the results with measured quantities, the following figure is presented: [7]

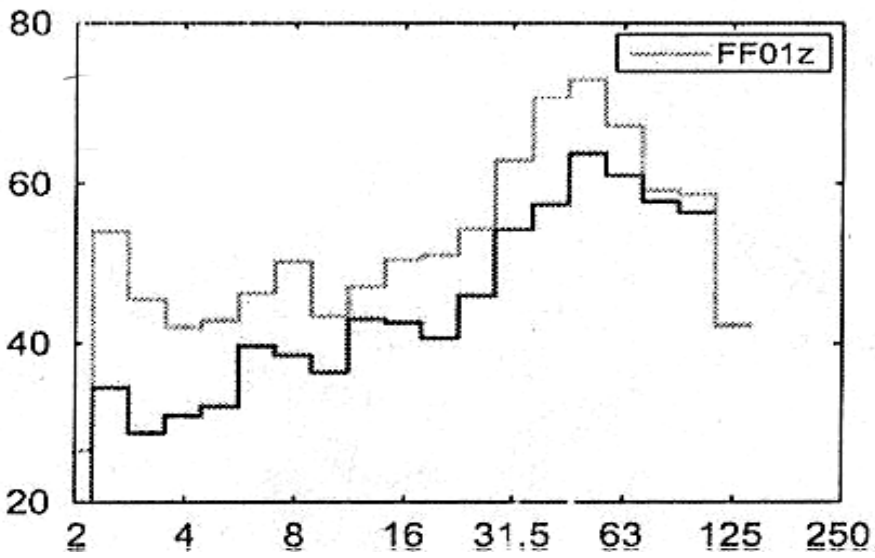


Figure3) Experimental (gray line) and computed (black line) one-third octave band RMS spectra of the vertical velocity in nearby soil during the passage of a test train at a speed of 47.6km/h.

Comparing calculation results with real quantities shown in Figure 3, the proportion of real quantity to calculated quantity is 1.15. But according to reference quantity for velocity in this research and considering the calculations in Figure 3, actual peak particle velocity (dB) dividing to the computed value in the range of 1 to 100 HZ is 1.11.

Modeling process

The conceptual model is a building situated between two rails presumable speed for train in 574.8 km/h .This is the highest train speed with wheel/rail contact experienced in the world until 2007.

We are going to analyse the effect of train-induced vibration on building structures. Finally, a damper is used to reduce the vibration destructive effects.

Software input

Software input should be train-induced vibrations. We use the Figure in the picture 2-e (ISO 14837-1) as the primitive Figure. In this Figure, variations of frequency are shown as an example function of frequency. The vibrations are related to the wheel/rail contact surface, as it is explained previously. The numbers in vertical axle should be added with a fixed number so that we could achieve to the data for going through the software

Peak particle velocity is the basis for analysing the train-induced vibration on nearby buildings. Therefore for defining real Figure in wheel/rail contact software, we need the real quantity for peak particle velocity in different train speeds. According to the examinations performed in London, peak particle velocity as a function of train speed in the wheel/rail contact software is shown in Figure 4: [8]

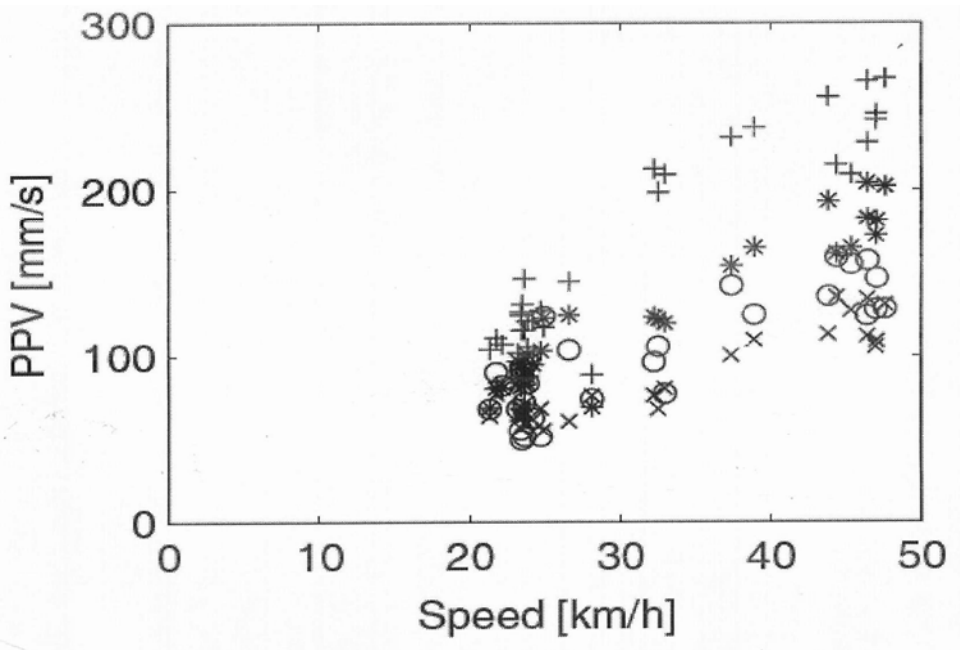


Figure 4) peak particle velocity–speed of a train generated by vibrations in wheel/rail contact surface.

Maximum points in Figure 4 are defined in the term of a mathematical equation that could be seen in Figure 5.
According to the new Figure, peak particle velocity for train passing with a speed of 547.8km/h is 1273.175 mm/s. the velocity is defined in the wheel/rail contact surface.

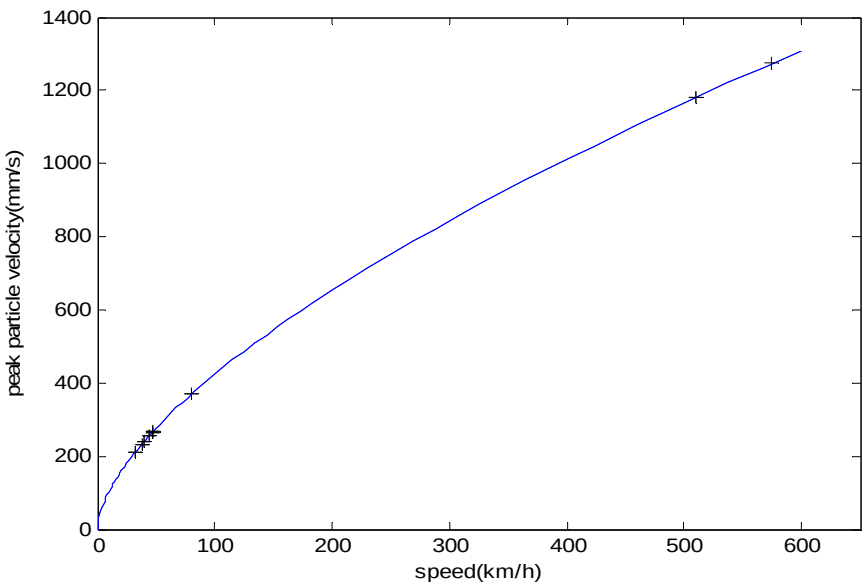


Figure 5) the suitable mathematical equation for figure 4 is: y=16.2863*x^(2/3)+11.5963*x^(2/5)

According to these descriptions, the primitive figure was changed to the Figure for particle velocity as a function of frequency. Using IFFT (inverse fast fourier

transform) we could achieve velocity-time figure based on a velocity-frequency figure.
Then we differentiated the last Figure and acceleration-time curve in Figure 6 was presented. The Figure 6 is like y= sin (wt).

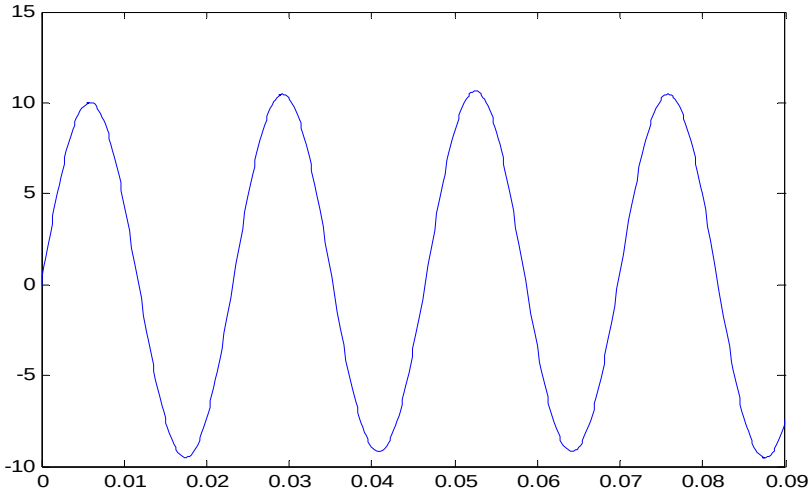


Figure 6) acceleration-time curve generated by vibrations in wheel/rail contact surface.

The train mass is 8*10e+5 kg. Considering the formula (2) we could achieve force-time figure based on Acceleration-Time figure.

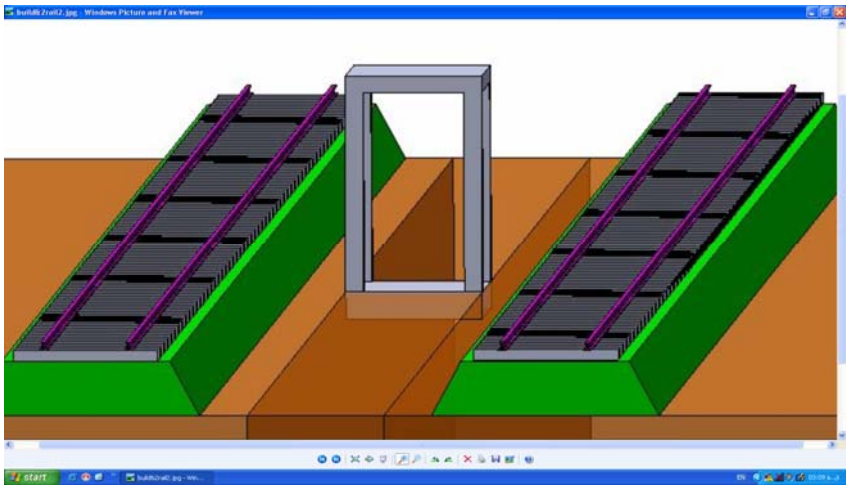
F= ma (2)

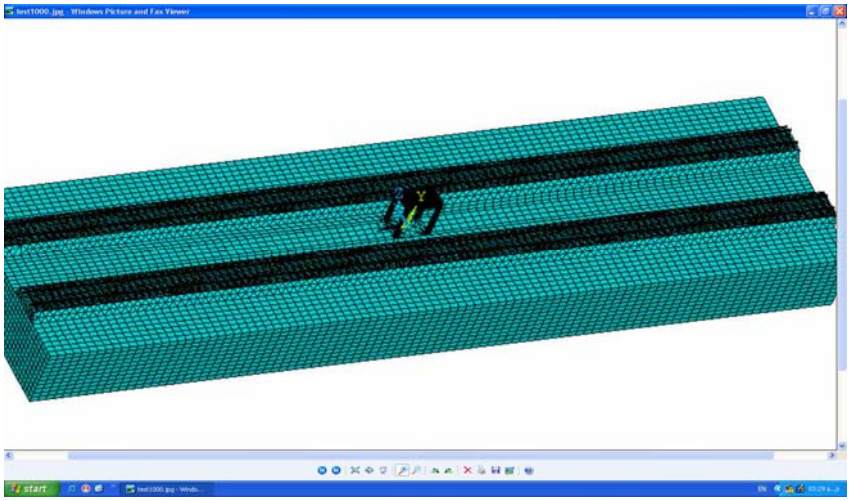
In ANSYS software, for loads in the form of y=sin (wt), harmonic analyze is used. Software inputs are frequency and maximum quantity for load. In this part frequency is 349HZ and maximum force is 7.936e+6N. The force was put constantly in nodes defined for rails in the model.

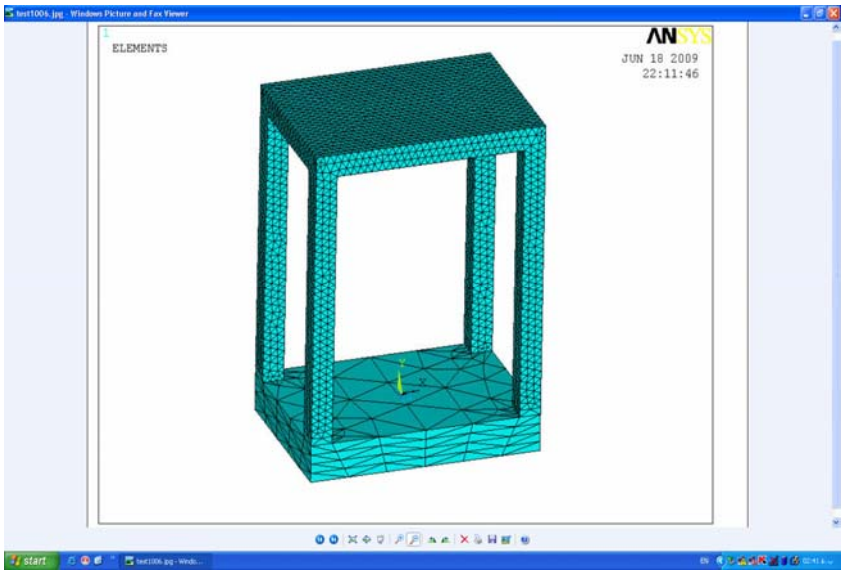
Analysing software model

According to the calculations related to maximum displacement for building in software output and considering factors for approaching calculations results to real quantities, peak particle velocity in building is 1.8mm/s.
Modeling the damper under building with special properties according to BSW Company (placed in Germany), peak particle velocity is 0.368mm/s.

Some picture of software model







Discussion

Frequency analysis

According to ISO 14837-1, peak particle velocity in frequency range of 1HZ to 100 HZ is the basis for nearby building damage.

As the input and output Figures in software are the same, peak particle velocity coming out from software output is the basis for building damage consideration.

Peak particle velocity limit for building damage is 2 mm/s as we discussed previously.

Peak particle velocity in the building without damper is 1.8 mm/s, therefore some harmful effects are probable. The probability of harmful effects is approximately (1.8/2=0.9) 90% such as plaster cracking and reopening of old cracks in the building. If the building is old and historic, building damage is more probable.

Conclusion

Structure safety is lower than the situation in which no train is near the building.In real situation, destructive effects are more than the model we made in ANSYS software. Therefore, building damages are more serious in real condition comparing to software condition, so that this paper predicts some harmful effects such as plaster cracking of the building.

Using damper layer under the building, hazards will completely disappear.

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