Exhibit F - UTCRS

UTC Project Information	
Project Title	Bumps in High Speed Rails: What is Tolerable?
University	Texas A&M University (TAMU)
Principal Investigator	Jean-Louis Briaud, Ph.D., Civil Engineering (PI)
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Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $40,000
Total Project Cost	$40,000
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	May 2016 – December 2017
Brief Description of Research Project	California is planning a high speed train (HST) to link Los Angeles, San Francisco, and Sacramento. Texas is planning a high speed train to link Houston to Dallas. In both cases, the embankments and bridges over which the train will travel are likely to develop bumps arising from subgrade soil movements. What is a tolerable bump for a train travelling at 400 km/hr.? That is the question. This project advances knowledge in this area and provides guidance as to what bump is tolerable at what speed. This project is building upon previous studies of bumps at the end of railway bridges, but extends the work to much higher speeds associated with high speed trains.
Describe Implementation of Research Outcomes (or why not implemented) Place Any Photos Here	There are different sources resulting in various types of track irregularities such as the non-homogenous properties of the ballast and subgrade soil, rail defects, joints, welds and transition zones near bridges and tunnels. In this research, the train/track interaction problem particularly at the bridge/embankment transition zone is of primary concern. Indeed a major source of track bumps is the transition zone between compacted soil embankments and bridge abutments resting on deep foundations. This irregularity is due to the

difference in stiffness between the two rolling surfaces (Davis and Plotkin, 2009) that leads to a dynamic oscillation of the train wheels, and to a cyclic variation of the contact force between the wheels and the rail. This dynamic effect can result in accelerating deterioration of the track near bridges. The problem of irregularities along railway tracks is a concern for both freight and public transportation. The main problem associated with freight tracks is the maintenance cost to repair the irregularities generated along the railway lines due to high impact load especially at the transition zones. On the other hand, for the passengers, the main concern is the train body acceleration which can affect the quality of the ride.

In this study, both the train/track interaction forces and the train body acceleration criteria were considered to define the allowable irregularity size at a wide range of train speeds [18 ≤ VT ≤720 (km/h)]. In the present research study, the influence of different parameters is studied such as train speeds, different irregularities types (Table 1), a wide range of irregularity sizes (Table 2), and the subgrade modulus.

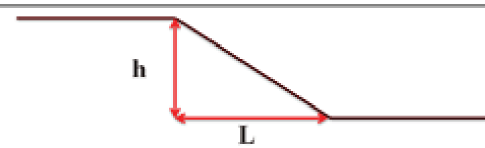
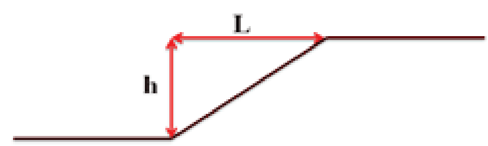
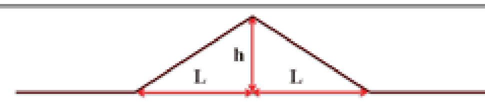
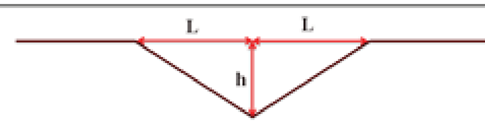
Irregularity type	Variables
Drop	
Rise	
Bump	
Dip	

Table 1: Irregularity Profile

L,m	h,mm	S=L/h
6	60	100
	30	200
	15	400
	7.5	800
	3.75	1600
12	120	100
	60	200
	30	400
	15	800
	7.5	1600

Table 2: Irregularity Size

All these parameters play important roles in defining the size of the tolerable irregularity; they were investigated through an extensive parametric study. A well-developed 4-D FEM in LS-DYNA including coupled train/track/soil model was first verified and then used to investigate the impact of different types of irregularity along HSRs (Figure 1). The problem of stiffness transition between a track on top of the embankment and a track on top of the bridge abutment (non-faulted track) was first addressed in the case of a non-faulted track. Then, the case of various types of irregularities in a faulted track along HSRs was then studied. To assess the allowable irregularity size, two criteria were considered: the allowable wheel/rail force, and the allowable train body acceleration (Table 3). The allowable values for these criteria are defined as those which keep the passenger safe and comfortable and decrease the maintenance cost and the required frequency of repair. The final results are presented in the form of applicable guideline charts which consider different influence factors including the subsoil modulus, the train speed, irregularity types, and irregularity sizes.

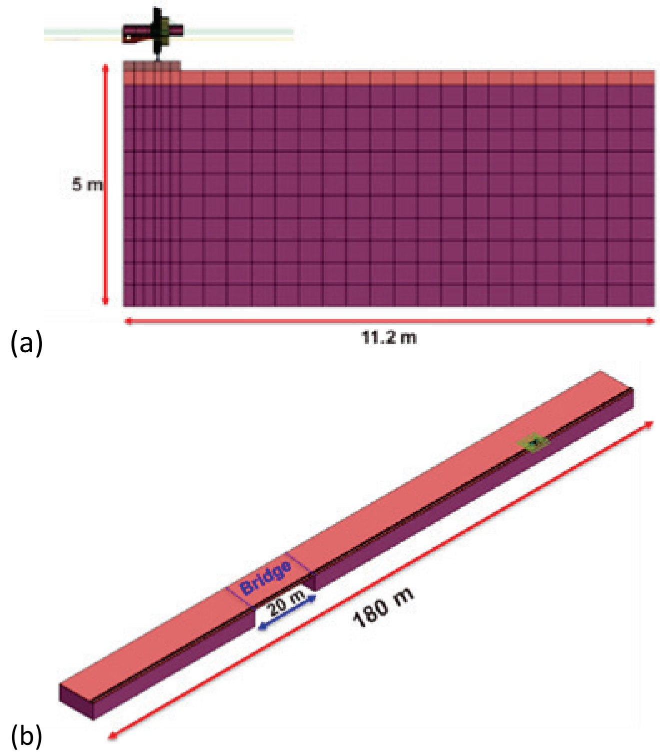


Figure 1: FEM mesh (a) Cross section, (b) 3D view

Parameter	Value	Reference
DAF*	1.50	Plotkin and Davis, 2008
DAF	2.00	Banimahd, 2008
DAF	2.50	Majka, 2009 (based on EN1991-2 Recommendation)
DAF	1.50	AS 1085.14
a_{max}** (g***)	0.10	Eurocode (European Committee for Standardization, 1995)
a_{max} (g)	0.12	Zhai et al., 2001
a_{max} (g)	0.20	Mao, 2004 (based on Chinese railway practice)
a_{max} (g)	0.05	SNCF, 1990 (the national railway of France)

* DAF: Dynamic Amplification Factor
** a_{max}: Maximum Permissible Vertical Train Body Acceleration
*** g = 9.81 m/s^2

Table 3: Threshold limit values

The final report including all these applicable guideline charts are presented in the form of one chapter of the PhD dissertation. Figure 2 shows one example of these guideline charts. In that figure, the Dynamic Amplification Factor (DAF) is defined as the ratio of the maximum dynamic rail/wheel reaction force to the static load on the wheel. Figure 2 indicates that for a constant irregularity type and size, the maximum train body acceleration and the DAF increase as the train speed increases. When train enters the range of high-speed, both the force and the DAF increase and become much worse than in the lower range of train speed. Indeed, the higher the train speed is, the larger the vibration experienced.

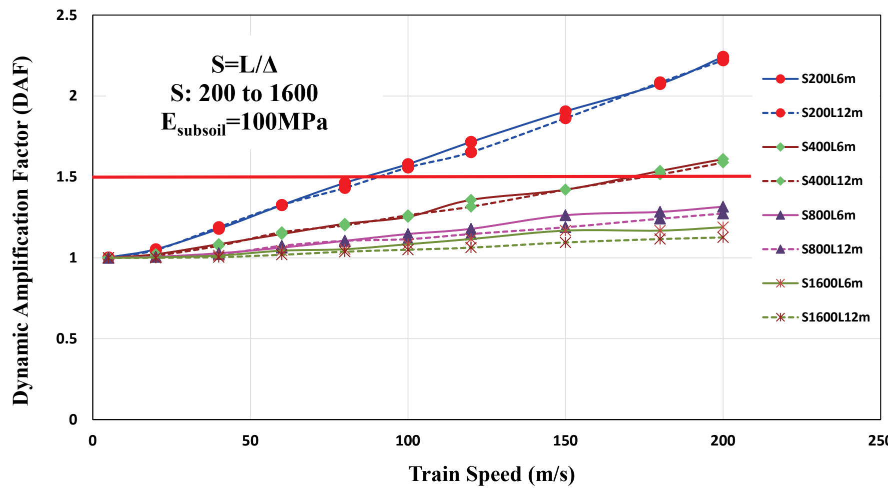


Figure 2: Effect of train speed, bump size and bump length on DAF

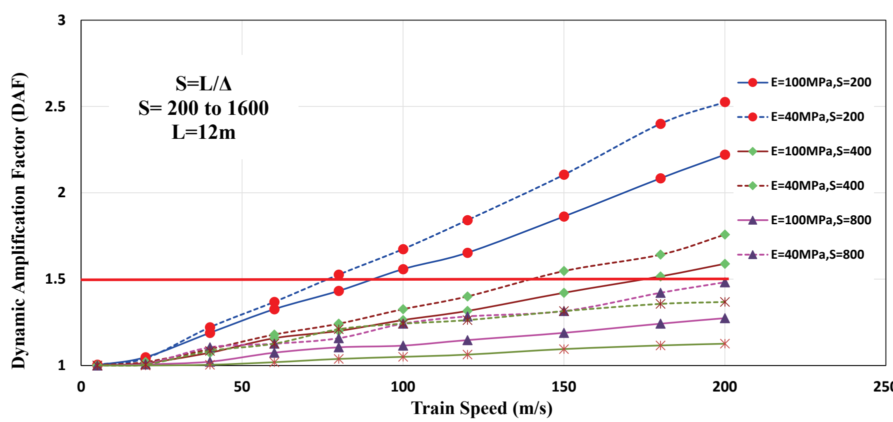


Figure 3: Effect of Soil Young Modulus on DAF

As an additional parameter, the modulus of the soil under the compacted embankment was varied within a reasonable range

	during the parametric study. The results show that the DAF decreases as the modulus increases (Figure 3). The reason is postulated as follows. If the soil is more compressible, the settlement of the track in the embankment zone is larger and thus a bigger "bump" is created when the train transitions onto the bridge.
Impacts/Benefits of Implementation (actual, not anticipated)	The work performed for this project contributed significantly to a doctoral dissertation titled: ▪ Tafti, S. R., "High Speed Train Geotechnics: Numerical and Experimental Simulation of Some Embankment Problems," Doctoral Dissertation, Zachry Department of Civil Engineering, Texas A&M University, December 2017.
Web Links • Reports • Project Website	http://www.utrgv.edu/railwaysafety/research/infrastructure/bumps-in-high-speed-rails/index.htm