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STUDY ON DYNAMIC LOAD FACTOR FOR NARROW GAUGE RAILWAYS. APPLICATION ON VIETNAM'S NORTH – SOUTH LINE

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Abstract. In high-speed railways, dynamic load factor has been received many studies recently. This work aims to determine the dynamic load factors of the traditional railway (1000 mm gauge) of North-South railway line in Vietnam. The objective of this research is to determine the dynamic load factors of the track based on the D19E locomotive with an axle load of 13.5 tons, rail P43, and ballast track. Simulation and experimental methods are implemented in the research. The simulation method was performed by SIMPACK software. The experimental method was carried out on a section of the North - South railway line in Vietnam. Based on the obtained simulation results, the dynamic load factors are 1.046, 1.110, and 1.361 corresponding to the speeds V=15km/h, V=30km/h, and V=70km/h. According to the experiment results, the dynamic load factors are 1.113, 1.134, and 1.181 corresponding to the speeds V=15km/h, V=30km/h, and V=70km/h. The results will be a tool for the track design engineer to implement correct design activities, and the design process will be safe and economical. Additionally, the SIMPACK software can be used to determine the dynamic coefficient for railways instead of experimental methods.

Keywords: dynamic load factor, traditional, railway, ballast, 1000mm gauge.

1. INTRODUCTION

Dynamic Load Factor (DLF) is a coefficient that characterizes the increase in load acting on railway structures due to dynamic effects, compared with the corresponding static load. DLF is used in the calculation, design, inspection, and testing of railway structures. The dynamic load factor is determined based on the following formula:

$$\Phi=P_d/P_s \quad (1)$$

Where

P_d: Dynamic load

P_s: Static load

Many researchers around the world have conducted studies on dynamic load factors. The dynamic load factors for high-speed railways were introduced by Germany Railways, [1], the American Railway Engineering Association [2], Indian Railways [3], and China Railways [4]. The Washington Metropolitan Area Transit Authority recommended a dynamic load factor for transit trackwork [5]. In 2013, Van Dyk et al. researched on wheel impact load detectors [6]. Ding Youlian and Wang Gaoxin studied dynamic load factors for a high-speed railway truss arch bridge [7]. Vietnamese design standard, the dynamic load factor does not take the train operating speed [8]. In 2020, Tran Anh Dung et al. studied the dynamic load factors for urban railways [9]. Current studies have mainly been conducted for high-speed railways and urban railways, while there have been no studies addressing 1,000 mm gauge railways.

Many parameters affect the dynamic load factors of the track. Some of these parameters are based on vehicle, and track. In this article, the authors study the dynamic load factors depending on the train speed of a section of the North - South railway in Vietnam (1000 mm gauge). Locomotive load is considered in this study as more disadvantageous than car load. The D19E [10] locomotive is the most commonly used locomotive type currently on the North - South railway line. The track structure has ballast and 43kg/m rail [11] type.

2. SIMULATION STUDY TO DETERMINE DYNAMIC LOAD FACTORS

2.1. Models for Vehicle–Track Dynamic Simulation

SIMPACK software, developed by the German company INTEC, is a software package for dynamic analysis and simulation. MBS Modelling Elements used in the SIMPACK software. Multibody simulation (MBS) is a method of numerical simulation in which multibody systems are composed of various rigid or elastic bodies.

- The locomotive:

The locomotive is using 2 bogies with 3-axle each. Its axle load is 13.5 tons. The model of locomotive-D19E includes 9 parts: car body, front bogie, rear bogie, and 6 sets of wheel axles. Each part of the system has five degrees of freedom: bouncing, lateral, rolling, yawing, and pitching. So, each locomotive has 45 degrees of freedom as shown in Figure 1-Figure 3 [12] and Table 1 [13].

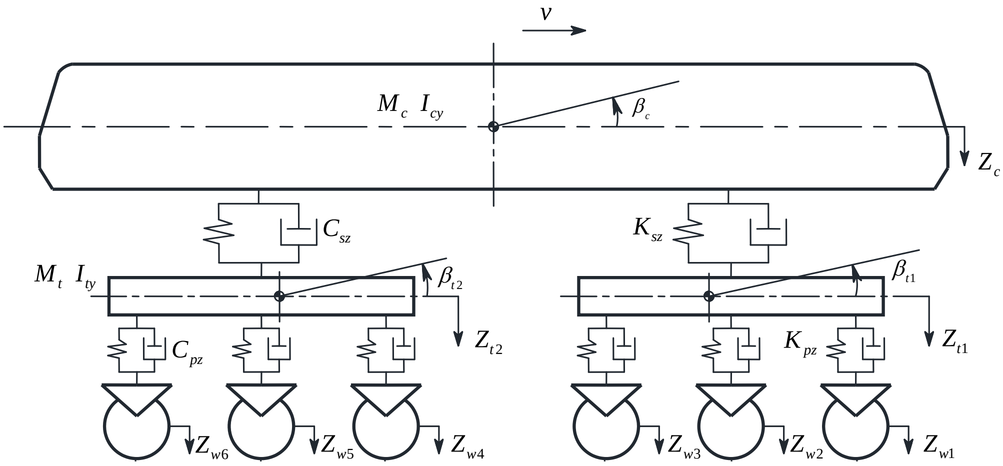

Figure 1. Dynamics model of the locomotive (lateral view).

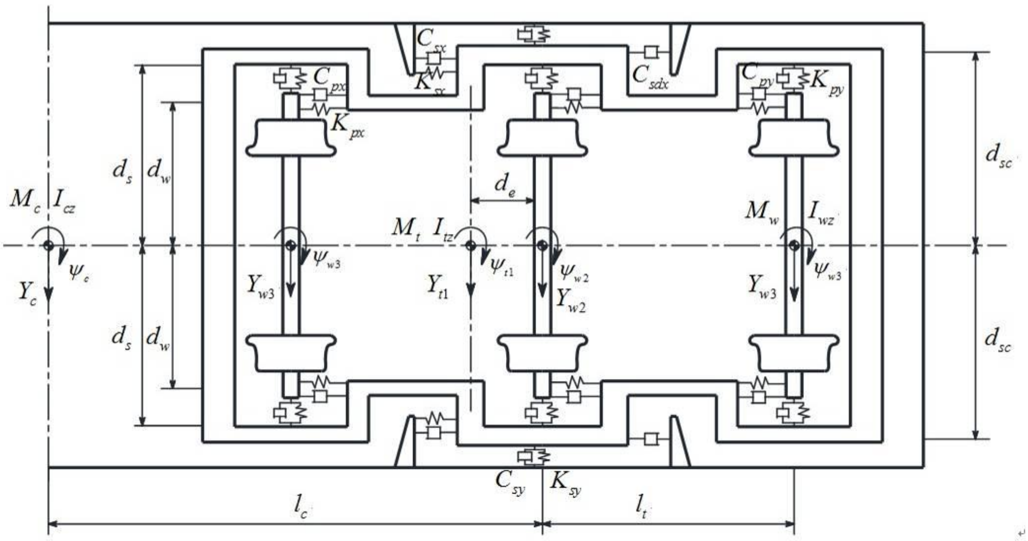

Figure 2. Dynamics model of the locomotive (top view).

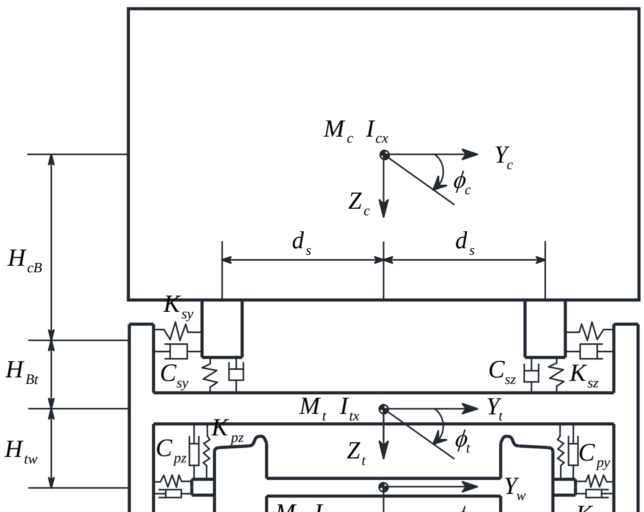

Figure 3. Dynamics model of the locomotive (end view).

The specifications of the locomotive-D19E were modeled in software such as Table 1:

Table 1. The specifications of the D19E locomotive.

No.	Technical parameters	Symbols, units	Values
1	Mass of locomotive body	M_c [ton]	48.766
2	Mass of frame	M_t [ton]	3.277
3	Mass of wheel set	M_w [ton]	1.730
4	The car body around the X axes' rotational inertia;	I_{cx} [ton.m^2]	55.024
5	The car body around the Y axes' rotational inertia;	I_{cy} [ton.m^2]	989.178
6	The car body around the Z axes' rotational inertia;	I_{cz} [ton.m^2]	993.404
7	The bogie around the X axes' rotational inertia;	I_{tx} [ton.m^2]	2.0
8	The bogie around the Y axes' rotational inertia;	I_{ty} [ton.m^2]	12.743
9	The bogie around the Z axes' rotational inertia;	I_{tz} [ton.m^2]	10.6
10	The wheel set around the X axes' rotational inertia	I_{wx} [ton.m^2]	0.952
11	The wheel set around the Y axes' rotational inertia	I_{wy} [ton.m^2]	0.110
12	The wheel set around the Z axes' rotational inertia	I_{wz} [ton.m^2]	1.142
13	The distance between two bogie centre plates	2L [mm]	8,100
14	The distance between two wheel axes	L_t [mm]	2,200
15	The lateral distance between two axle box springs	$2d_w$ [mm]	1,680
16	The lateral distance between two air springs	$2d_s$ [mm]	1,680
17	Diameter of wheel	D [mm]	1,000
18	Distance between two wheel rollers	2S [mm]	1,070
19	Longitudinal stiffness of one side of the air spring	K_{sx} [MN/m]	0.1682
20	Lateral stiffness of one side of the air spring	K_{sy} [MN/m]	0.1682
21	The vertical stiffness of one side of the air spring	K_{sz} [MN/m]	0.5065
22	Longitudinal stiffness of an axle box	K_{px} [MN/m]	43.0
23	Lateral stiffness of an axle box	K_{py} [MN/m]	22.0
24	Vertical stiffness of an axle box	K_{pz} [MN/m]	56.0
25	Lateral damping coefficient of air springs	C_{sy} [kN.s/m]	60.0

No.	Technical parameters	Symbols, units	Values
26	Vertical damping coefficient of air springs	C_{sz} [kN.s/m]	0.10
27	Vertical damping coefficient of axle box springs	C_{pz} [kN.s/m]	60.0
28	Coefficient of snake movement resistance by shock absorber damping	Csdx[kN.s/m]	600.0

- Wheel and rail profiles:

Defining wheel and rail profiles: 2-D plots of the profiles of the wheels and rails were generated. In this study, the structure and technical parameters of the wheel rolling surface of the D19E locomotive (Figure 4) [10], and rail P43 [11] are used (Figure 5).

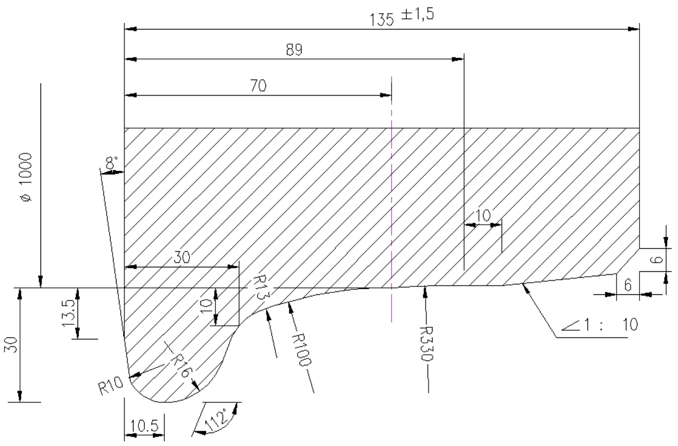

Figure 4. Technical parameters of the wheel rolling surface.

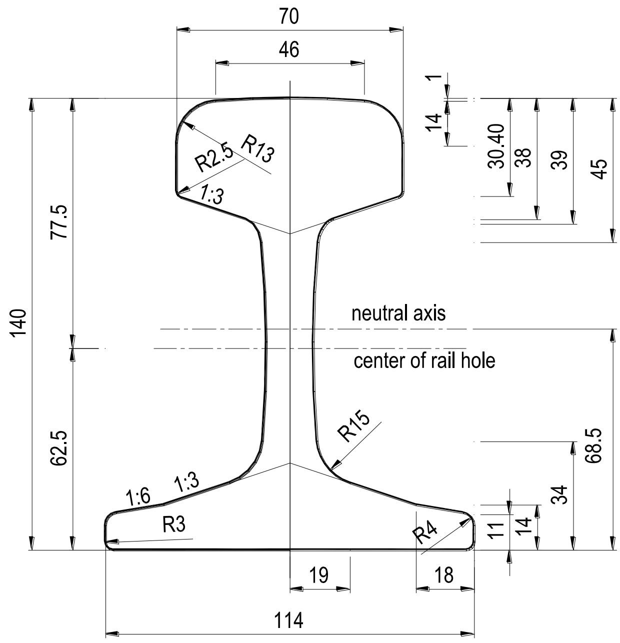

Figure 5. Profile of rail 43kg/m.

- Track:

Generate 2-D plots of the track and display the 3-D track representation. The ballasted track model is used in the following conditions: Rails are continuous beams on elastic supports, in each of the discrete sleeper fulcrums of primitives, each supporting unit with double quality, and three layers of spring damping vibration (Figure 6-Figure 7).

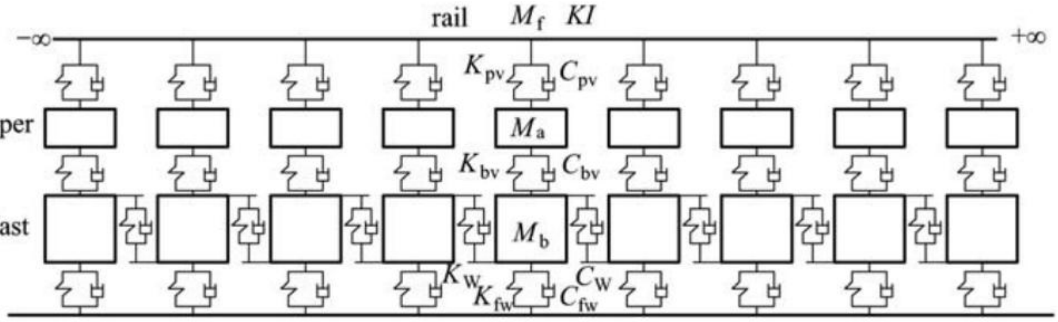

Figure 6. Dynamics model for ballasted track structure (lateral view).

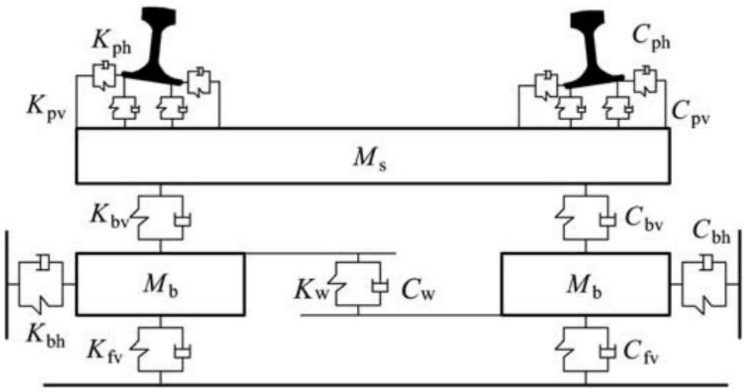

Figure 7. Dynamics model for ballasted track structure (side view).

Based on the technical specifications of the track structure and locomotive, we use SIMPACK software [14] to simulate as shown in Figure 8 to Figure 11.

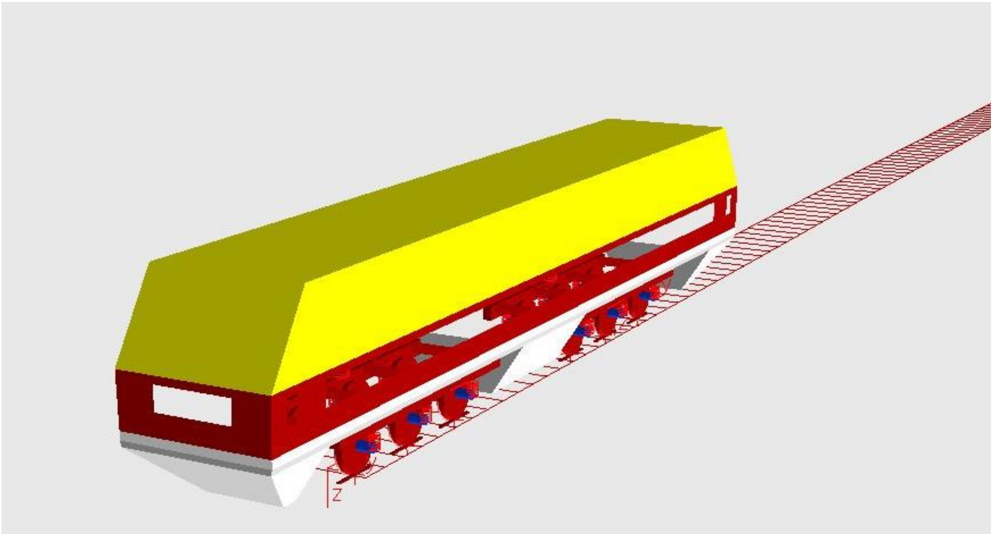

Figure 8. Locomotive model.

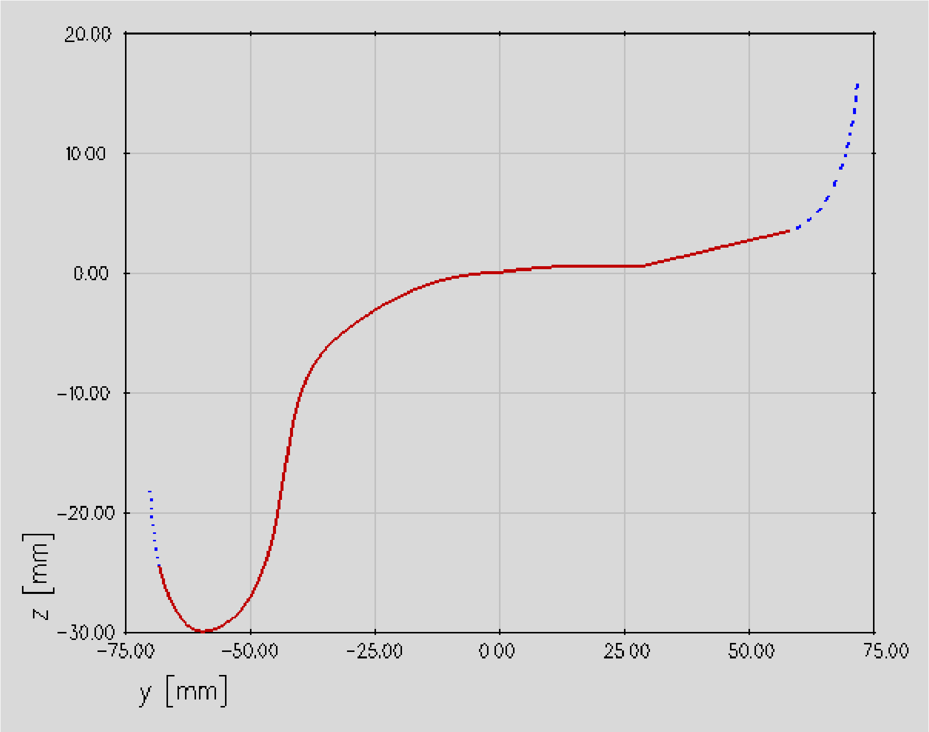

Figure 9. Wheel rolling surface model.

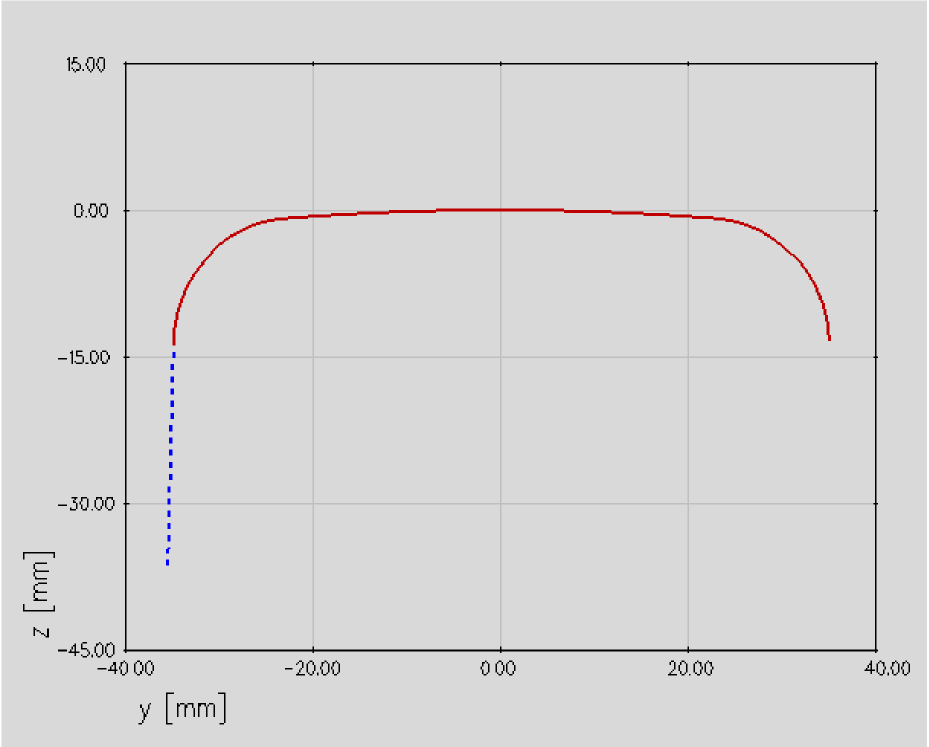

Figure 10. Rail model.

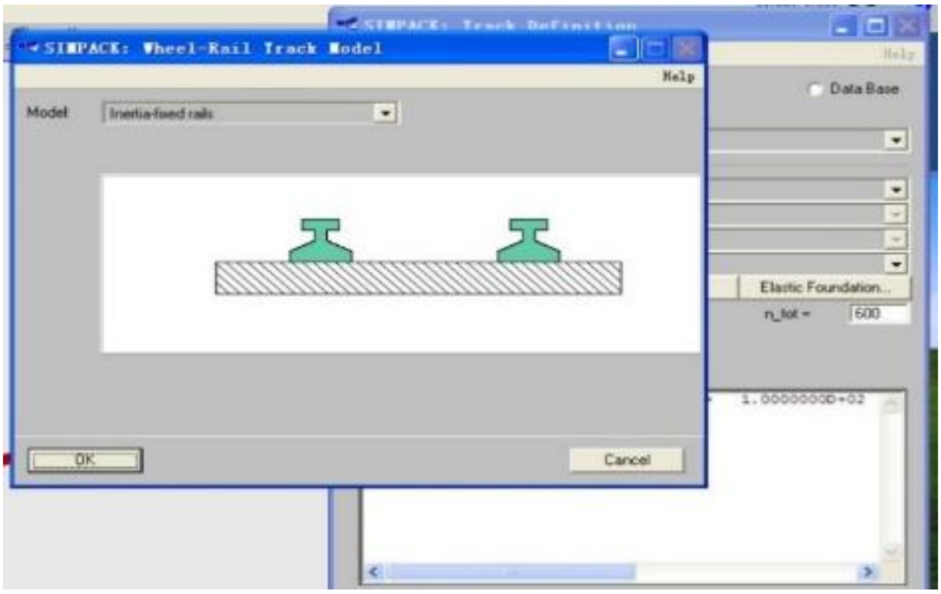

Figure 11. Track structure model.

2.2. Results

Dynamic load of the wheels acting on the rails when simulating the D19E locomotive on the North - South railway line moves on the rails at a speed of V=15 km/h at Km 17+500 as shown in Figure 12. The largest value of dynamic load acting on the left rail is 69,276.1 N. The largest value of dynamic load acting on the right rail is 68,524.8 N.

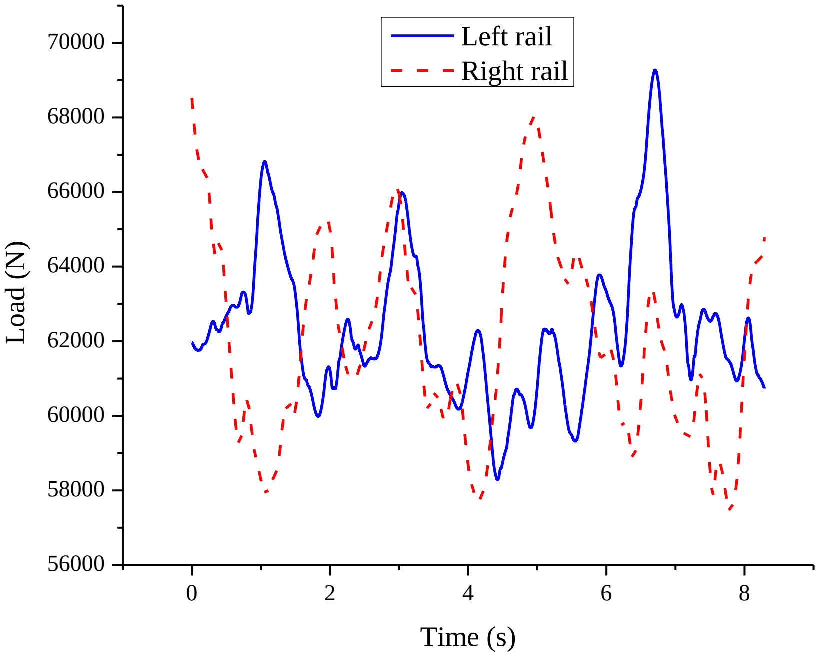

Figure 12. Dynamic load of locomotive at speed V=15 km/h.

Dynamic load of the wheels acting on the rails when simulating the D19E locomotive on the North - South railway line moves on the rails at a speed of V=30 km/h at Km 21+500 as shown in Figure 13. The largest value of dynamic load acting on the left rail is 73,526.9 N. The largest value of dynamic load acting on the right rail is 69,369.2 N.

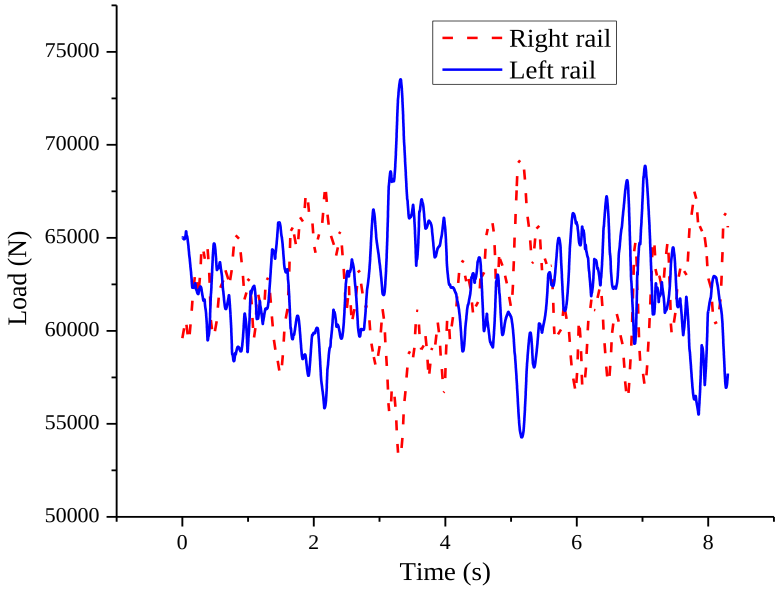

Figure 13. Dynamic load of locomotive at speed V=30 km/h.

Dynamic load of the wheels acting on the rails when simulating the D19E locomotive on the North - South railway line moves on the rails at a speed of V=70 km/h at Km 25+500 as shown in Figure 14. The largest value of dynamic load acting on the left rail is 90,1465.4 N. The largest value of dynamic load acting on the right rail is 83,107.5 N.

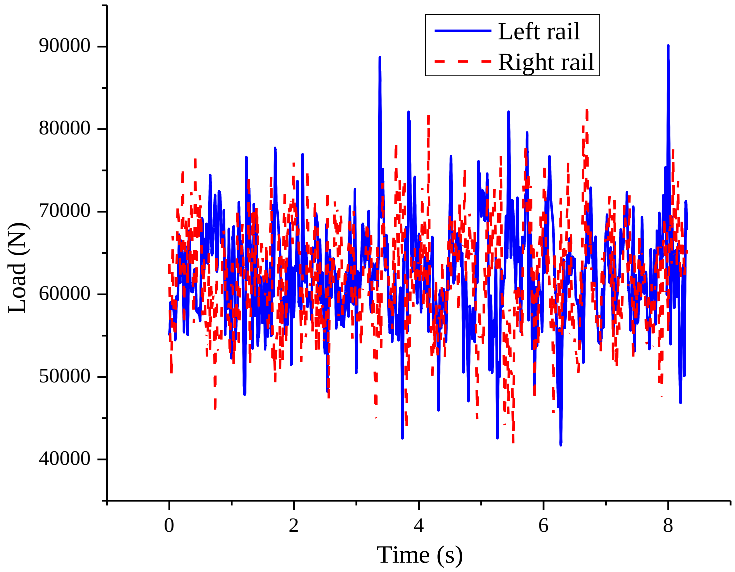

Figure 14. Dynamic load of locomotive at speed V=70 km/h.

Dynamic load factor of D19E locomotive on the North - South railway line using simulation method such as Table 2.

Table 2. Dynamic load factors according to the simulation method.

No.	Speed (km/h)	Dynamic load factor Φ	
		Left rail	Right rail
1	15	1.046	1.035
2	30	1.110	1.048
3	70	1.361	1.255

3. EXPERIMENT STUDY TO DETERMINE DYNAMIC LOAD FACTORS

3.1. Testing Equipment

Displacement measuring equipment are Linear Variable Differential Transformers (LVDT) (Figure 15). This electronic measurement method includes linear conversion equipment. LVDT is equipment based on the principle of electrical-mechanical conversion. It converts displacement signals into volt signals according to a certain ratio. LVDT connects to a data logger and the computer allows automatic recording of displacement values. Linear variable differential transformers are used to measure rail displacement when a load is applied.

a) LVDT

b) Data logger

Figure 15. Linear Variable Differential Transformers.

3.2. Testing Load

Field test surveys were done with the D19E locomotive load (Figure 16). The locomotive includes 2 bogies. Each bogie has 3 axles. The axle load is 13.5 tons/axle. The load arrangement diagram is shown in Figure 17.

Figure 16. D19E locomotive.

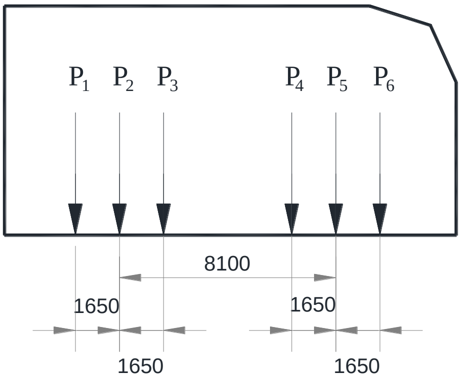

Figure 17. The load arrangement diagram for locomotive D19E (Dimensions in the drawing is in mm).

3.3. Testing Arrangement

The study's experimental setups all had similar setups and measurement equipment. The rail displacement is measured using Linear Variable Differential Transformers (LVDT), designed to measure small displacements (±0.5 mm) and read and write data frequencies from 1Hz to 1000 Hz. Using displacement measuring equipment attached to the rail between the two sleepers (Figure 18-Figure 19).

Figure 18. Arrangement Linear Variable Differential Transformers.

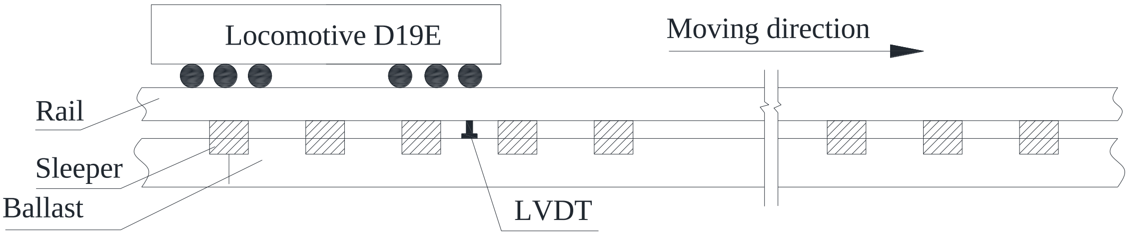

Figure 19. Diagram of arrangement Linear Variable Differential Transformers.

Implementing displacement measurements at 3 different locations with speeds V=15km/h, V=30km/h, and V=70km/h of the D19E locomotive moving on a railway section of the North - South railway line.

Figure 20. Measurement at location 1 (V=15km/h).

Figure 21. Measurement at location 2 (V=30km/h).

Figure 22. Measurement at location 3 (V=70km/h).

3.4. Results

Figure 23 shows the graph of displacement over time of the rail under the effect of dynamic load of the train when the train moves at a speed of V = 15 km/h.

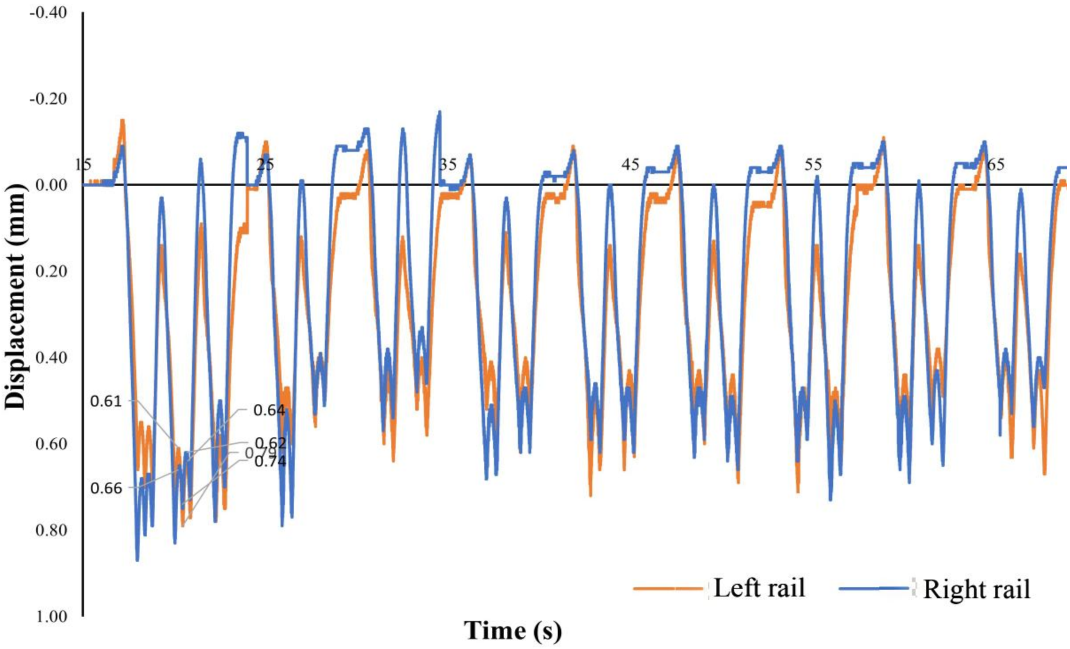

Figure 23. Dynamic displacement over time when D19E locomotive moves with speed V = 15 km/h.

Table 3. Dynamic load factor at speed V = 15 km/h.

Measurement location	Z_{max} (mm)	Z_{min} (mm)	Dynamic load factor Φ
Left rail	0.79	0.63	1.113
Right rail	0.74	0.64	1.072

Figure 24 shows the graph of displacement over time of the rail under the effect of dynamic load of the train when the train moves at a speed of V = 30 km/h.

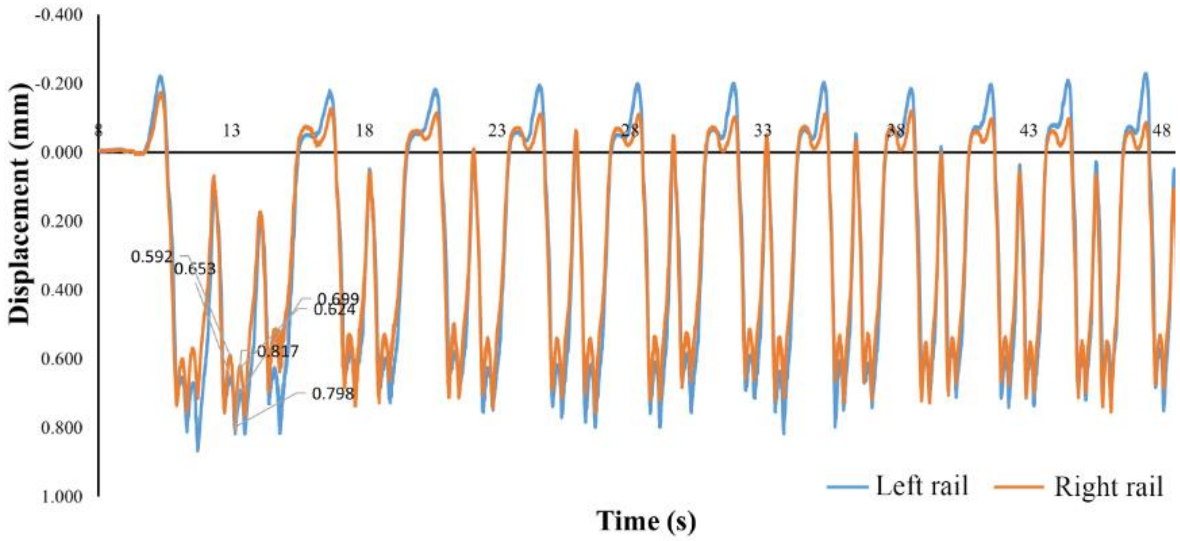

Figure 24. Dynamic displacement over time when D19E locomotive moves with speed V = 30 km/h.

Table 4. Dynamic load factor at speed V = 30 km/h.

Measurement location	Z_{max} (mm)	Z_{min} (mm)	Dynamic load factor Φ
Left rail	0.798	0.61	1.134
Right rail	0.817	0.68	1.092

Figure 25 shows the graph of displacement over time of the rail under the effect of dynamic load of the train when the train moves at a speed of V = 70 km/h.

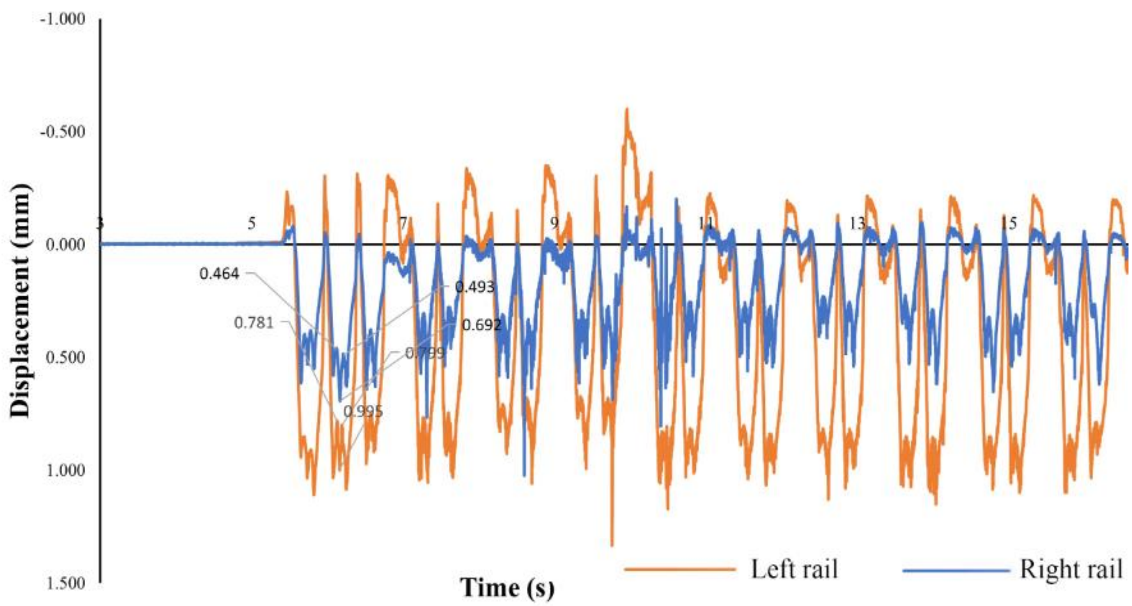

Figure 25. Dynamic displacement over time when D19E locomotive moves with speed V = 70 km/h.

Table 5. Dynamic load factor at speed V = 70 km/h.

Measurement location	Z_{max} (mm)	Z_{min} (mm)	Dynamic load factor Φ
Left rail	0.692	0.48	1.181

Right rail	0.995	0.79	1.115

Table 6. Dynamic load factors according to the experiment method.

No.	**Speed (km/h)**	**Dynamic load factor Φ**	
		Left rail	**Right rail**
1	15	1.113	1.072
2	30	1.134	1.092
3	70	1.181	1.115

Table 7. Comparison of dynamic load factors.

No.	**Speed (km/h)**	**Location**	**Dynamic load factor Φ**	
			Simulation result	**Experiment result**
1	15	Left rail	1.046	1.113
		Right rail	1.035	1.072
2	30	Left rail	1.110	1.134
		Right rail	1.048	1.092
3	70	Left rail	1.361	1.181
		Right rail	1.255	1.115

Compare the dynamic load factor results of this study with South African Railways for narrow gauge [15] railways such as in Table 8. The study's dynamic load factor results are consistent with the results of the South African railways.

Table 8. Comparison of dynamic load factors for South African Railways.

No.	**Speed (km/h)**	**Dynamic load factor Φ**		
		South African Railways	**Present study (Vietnam)**	
			Simulation	**Experiment**
1	15	1.074	1.046	1.113
2	30	1.148	1.110	1.134
3	70	1.344	1.361	1.181

4. CONCLUSION

Using simulation research and field experiments for a section of the North - South railway, the article has built a dynamic model of the interaction between the train and the track structure of the North - South railway line. Applying 3D simulation models of train dynamics and railway structures using SIMPACK software in a unified whole to determine dynamic load factors. In addition, the dynamic coefficient is determined by the experimental measurement method. The results of calculating the dynamic load factors by simulation method are consistent with the experimental measurement results. This result is the basis for determining dynamic load factors in the process of calculating superstructures on traditional railways (1000mm gauge). From the research results, it can be observed that the computational model developed in SIMPACK can be used directly to determine the dynamic load factor.

The next research direction is to study the dynamic load factor for other gauges such as 1435mm gauge railways and dual gauge railways.

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