

Validation of longitudinal dynamics of Gatimaan Express model in Matlab/Simulink[®]

Prabin Kumar Jha* and Sadanand Sadashiv Gokhale

Mechanical-Mechatronics Engineering Department, The LNM Institute of Information Technology, Rupa Ki Nangal, Post-Sumel, via Jamdoli, Jaipur 302031, India

Received: 4 August 2017 / Accepted: 30 May 2018

Abstract. This paper presents a mathematical model of longitudinal dynamics of Gatimaan Express. It has one locomotive class WAP5, two generator vans, eight second class chair cars and two executive chair cars respectively. Forces associated with longitudinal dynamics of model are developed in Matlab/Simulink. Longitudinal and coupler forces as well longitudinal velocities are studied during the failure of coupler of 3rd (coach of middle train) second class chair. Validation of longitudinal velocity of the model is done by comparing simulated results with measured field data provided by Research Designs Standards Organization (RDSO), Lucknow, India.

Keywords: Longitudinal velocity / coupler force / longitudinal force / Matlab/Simulink[®]

1 Introduction

Increasing the potential demand of high-speed train around the world and problems associated with its dynamic stability, comfort and safety are reasons for researchers to study its dynamics. Longitudinal dynamics is a vital part of railway vehicle dynamics. It deals with coupler and braking dynamics which affect operational safety. During braking, a significant amount of compressive force developed in coupler between consecutive coaches. This may be due to coupler stiffness and the coupler gap. As a result, catastrophic train derailments can be occurred. In addition to this, a large amount of coupler rotation appears in curve track which alters the lateral force to wheelset and which may result in derailment.

Researches have been carried out to study longitudinal dynamics of train in normal and emergency braking. High-speed train running with non-inform velocities either accelerating to achieve maximum speed or decelerating during the switching of tracks or approaching to station, control in rail dynamics is still a challenge for researchers to study. Therefore various research have been accomplished to study the dynamic performance of braking dynamics as well as coupler dynamics.

Iryna et al. [1] developed a longitudinal dynamics model of train with automatic couplers to study the electrody-

amic braking forces in various track gradients. The model was evaluated in fully loaded and empty wagon conditions.

Oleksandr et al. [2] modeled a train to monitor its brake system. It was determined that the breakage line of train model could be made automatically. They studied the response of breakage by changing its pressure in mathematical model.

David et al. [3] developed a tool to calculate braking distances of various trains. The tool was written in C++ and fault tree analysis was implemented to verify model performance. The tool was used for commercial applications. So, precise mathematical model was made to avoid the error.

Marin et al. [4] measured the variations of the pressure in the brake cylinders of a vehicle, as a function of the input pressures. A mathematical model was established based on polynomial fit of measured data. It was observed that the model was more accurate to study its various performances of braking systems.

Camil et al. [5] simulated a train model of ten coaches to study the longitudinal dynamics and coupling dynamics at the time of braking operations. Compressive force at the coupler during emergency braking was determined.

Cantone et al. [6] developed a software, called TrainDy which is based on Matlab/Simulink and its results were verified and validated by the UIC (International Union of Railways) data. Software has two parts: pneumatic and dynamic. Pneumatic validation was done with experimental data from European Railways and Italian Railways and was found 10% error. Longitudinal forces and

* e-mail: pkjha@lnmiit.ac.in

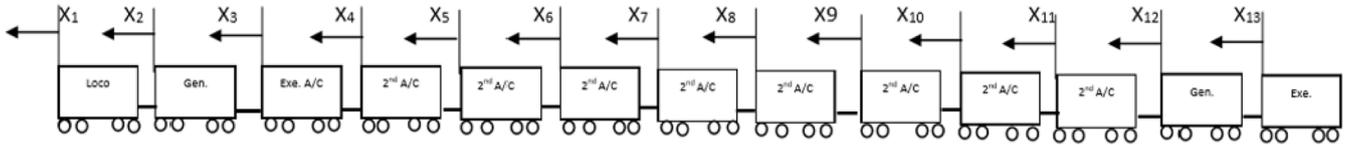


Fig. 1. Schematic picture of Gatimaan Express model.

the stopping distances in dynamic validation of software were performed with UIC field data and result was found satisfactory.

Lu et al. [7] modelled a pneumatic braking system of train and validated its results with experimental data and found a good match. They purposed to add quick release valve in the brake system to increase its air discharge. It was noted that rubber diaphragm characteristics in brake cylinder had a key factor for brake delay.

Sachin et al. [8] designed six compressed draft pads of draft gear in Finite Element Method to study the behaviour of defective draft pads on rail dynamics. They observed the performance of draft pad due to its crack location, crack width and crack aspect ratio.

Cole and Sun [9] modeled a train of 103 wagons and 3 locomotives connected through couplers and studied three different cases: autocouplers with standard draft gears, autocouplers with draft gears and wedge with unlocking features, and the traditional drawhook buffer system respectively. They found that autocoupler draft gear units had minimum fatigue damage.

Jeong et al. [10] performed the sensitivity analysis on their model and noticed that coupler dynamics had high potential for derailment on curve track.

Xu et al. [11] designed a model to analyze the coupler rotation behaviour on the train dynamics. It was a rubber draft gear model which had hysteresis characteristics, friction characteristics and alignment-control characteristics of the coupler knuckles and the coupler shoulder respectively. They noted that the rotational behaviour of coupler on the different types of track affects railway vehicle dynamics performance, especially during braking. The impact of middle coach couplers is a main cause for the same.

Tianwei et al. [12] studied a model of couplers with different rotation angles and found that large coupler rotation angle produced more longitudinal coupler compressive force than the coupler with small rotation angle.

Wei et al. [13] made a train with coupler system model to study its coupler jackknifing behaviour and further it was evaluated with the experiment data. Results indicated that a braking induced impact due to coupler behaviour has negative effects on the train dynamics.

Most of research works in this domain investigated the braking response in normal and emergency conditions as well as coupler forces and coupler rotations. To fill up the gap in the literature survey, it is important to validate the model and dynamic study of couplers at its failure conditions. This paper presents the validation of longitudinal dynamics of Gatimaan Express model with the measured field data provided by RDSO. Performance of longitudinal dynamics due to failure of draft gear and coupler is studied. Mathematical model of Gatimaan Express which has one Locomotive class

WAP5, two Generator Vans, two Executive Chair cars and eight Second Class Chair cars is made in Matlab/Simulink®.

The lateral and vertical dynamics of model has been validated by comparison of simulated lateral and vertical accelerations with the measured field data in [14].

2 Mathematical model of Gatimaan Express

A comprehensive study of longitudinal dynamics of Gatimaan Express model based on several forces is carried out. The validation of model is performed and the effects of couplers behavior are investigated. Moreover, actual distributed mass to each wagon and available input parameters is incorporated in longitudinal dynamics of model.

Look up table for dynamic braking is based on the actual data from the characteristics curve of locomotive [15]. A schematic diagram of a complete train model of Gatimaan Express is shown in Figure 1. Sequential order of coaches connections are same as in real one to understand system response closely. Quasi dynamic model based on following key assumptions is made [16].

- Lateral and vertical dynamics are not considered. As they were studied separately in [14]
- Each coach has a single degree of freedom
- Each coach is considered as a rigid body
- Coupler of each coach has same characteristics
- Point mass is considered for each coach

Governing equations of forces acting in longitudinal dynamics are expressed below.

2.1 Tractive effort

The force required to pull a train is called tractive effort. It is a force that can be applied before the wheels begin to slip and is determined by the weight on each wheel multiplied by adhesion of wheels on the rail. As speed of the train increases, adhesion decreases. The tractive effort is almost constant for a certain speeds and as it increases further, the current in the traction motor falls, and hence the tractive effort reduces. The throttle control has eight positions with an idle position. Each of the throttle positions is called a “notch”. For slowest speed, notch 1 is pressed and notch 8 is for highest speed. Notch in locomotive to control throttle is linearly proportional to motor current. The manufacturers characterize the measure tractive effort as a function of speed and the traction effort curve of Loco WAP 5 is

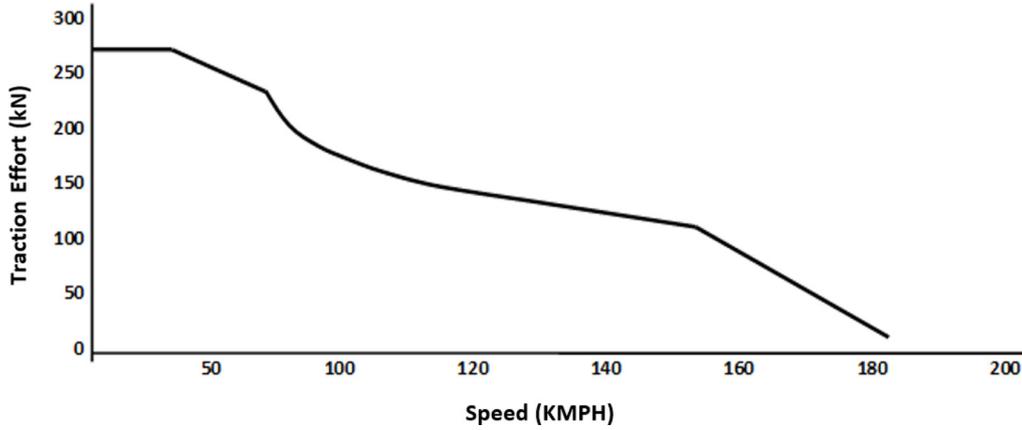


Fig. 2. Traction effort curve.

Table 1. Specification of Loco WAP5, [15].

Configuration: <i>BoBo</i>	Gauge: 1676 mm
Bogies: Flexi float	Length: 18162 mm
Wheel base: 1300 mm	Length: 18162 mm
Width: 3142 mm	Height: 4237 mm
Axle load: 19.2 ton	Loco weight: 78 ton
Electric system(s): 25 kva 50 Hz A/c	Current source: Pantograph
Traction motors: 4ABB Group 6FXA 7059	Gear ratio: 67: 35: 17
Train Bake: Air	

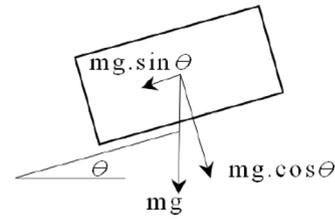


Fig. 3. Train model on hill track.

shown in Figure 2. Equation for modeling of tractive effort [17] is demonstrated as:

for $F_{t1} v < M^2/64P1_{max}$ do $F_{t1} = \frac{M}{8} T_{max} - k_1 v$,
else

$$F_{t1} = \frac{M^2/64P1_{max}}{v},$$

end for where, F_{t1} is the traction force,

$P1_{max}$ the maximum loco traction power,

T_{max} is the the maximum loco traction force,

k_1 is the torque reduction,

M is the number of throttle notch,

v is the velocity of train. The specification of Loco WAP 5 is enlisted in Table 1.

2.2 Curve resistance

The curve resistance is developed during wheel-rail interaction at curve track and depends upon the angle of attack. This resistance causes wear and tear on the rails and wheels. To reduce the friction, greasing on the rails is done. Cant deficiency, rail profile, rail lubrication and curve radius also affect the vehicle motion [18]. It is expressed as:

$$F_{c1} = \frac{6116}{R} \quad (1)$$

where, F_{c1} is the curve resistance and R is the radius of curvature.

2.3 Rolling resistance

It is the sum of the resistive forces that must be overcome by the tractive effort of the locomotive to move a railway vehicle on track. These forces include:

- the quality of track offers rolling friction between wheels and rail;
- bearing resistance varies with the weight on axle;
- train dynamic forces effect on the impact between the wheel flanges against the gauge side of the rail and wheel/rail treads;
- air resistance that varies directly with length and shape of the train and its cross-sectional area.

The rolling resistance of a train can be calculated by using an empirical expression given by Davis below [17]:

$$F_{dr} = \sum_{n=1}^{13} m(0.699 + 2.1510^{-02}v + 8.3510^{-05}v^2), \quad (2)$$

where, F_{dr} is the rolling resistance and m is mass of coach.

2.4 Gradient resistance

It is also called gravitational resistance. If a train goes down a hill or up a hill on the track, the weight of each car should be considered in calculations of forces. It gives additive or subtractive effort to the longitudinal dynamics of train.

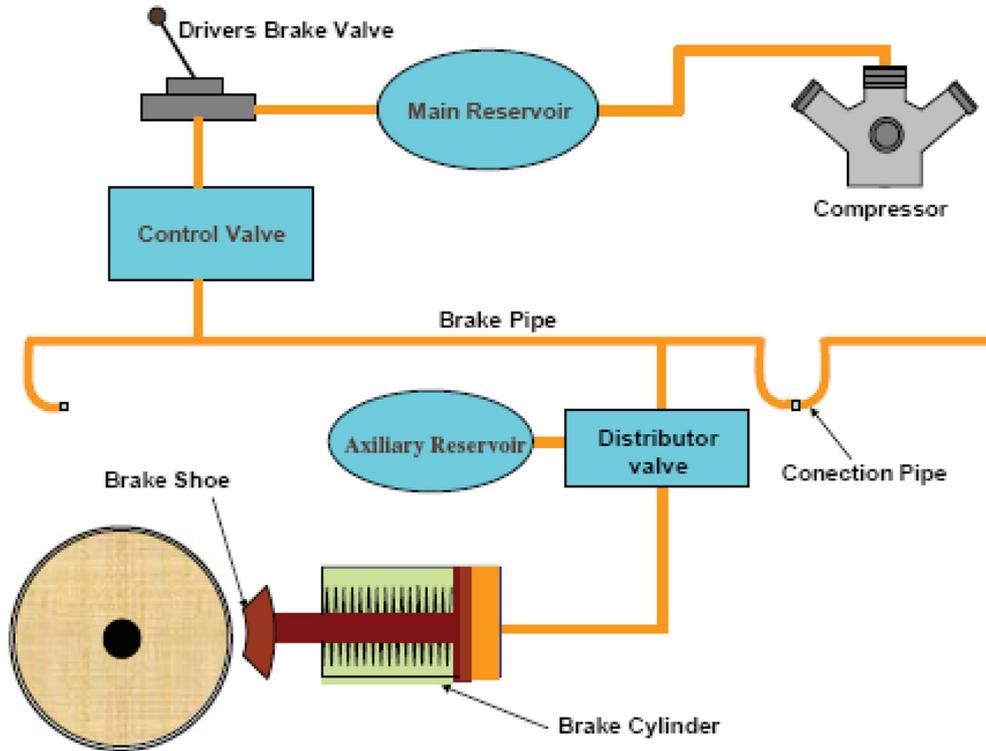


Fig. 4. Schematic layout of Pneumatic braking system.

Table 2. List of parameters assumed for simulation.

$m_{secondcl} = 50000 \text{ kg}$	$k_{e1} = 3600000 \text{ N/m}$	$k_{f1} = 2000000 \text{ N/m}$
$k_{e2} = 7200000 \text{ N/m}$	$k_{f2} = 3000000 \text{ N/m}$	$R = 3500 \text{ m}$
$\mu = 0.35$	$r_i = 2.48$	$N_i = 16$
$p_{br} = 3.8 \text{ bar}$	$A_{br} = 0.051 \text{ m}^2$	

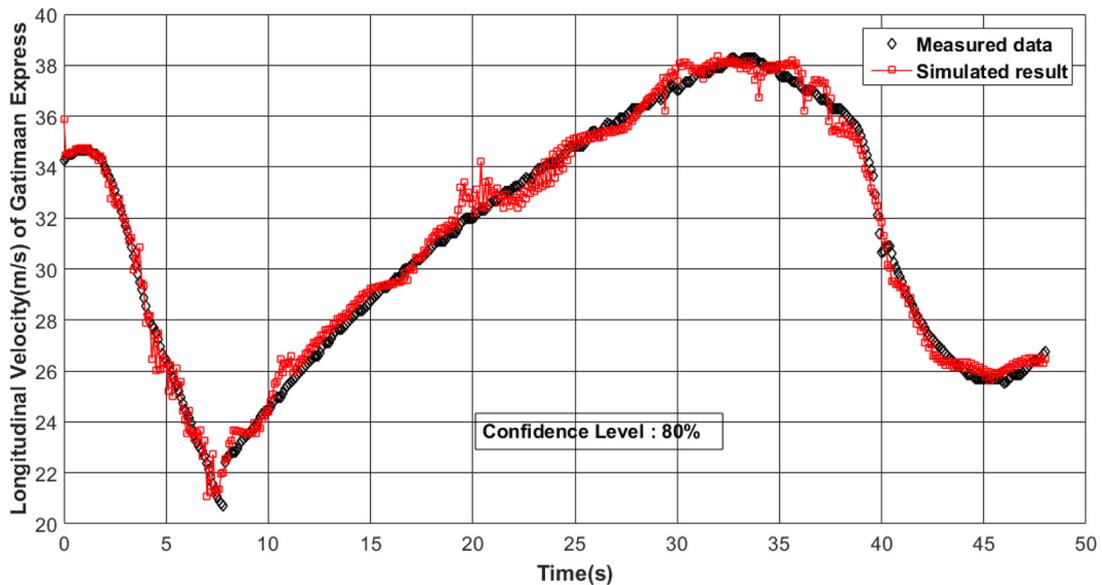


Fig. 5. Comparison of longitudinal velocities.

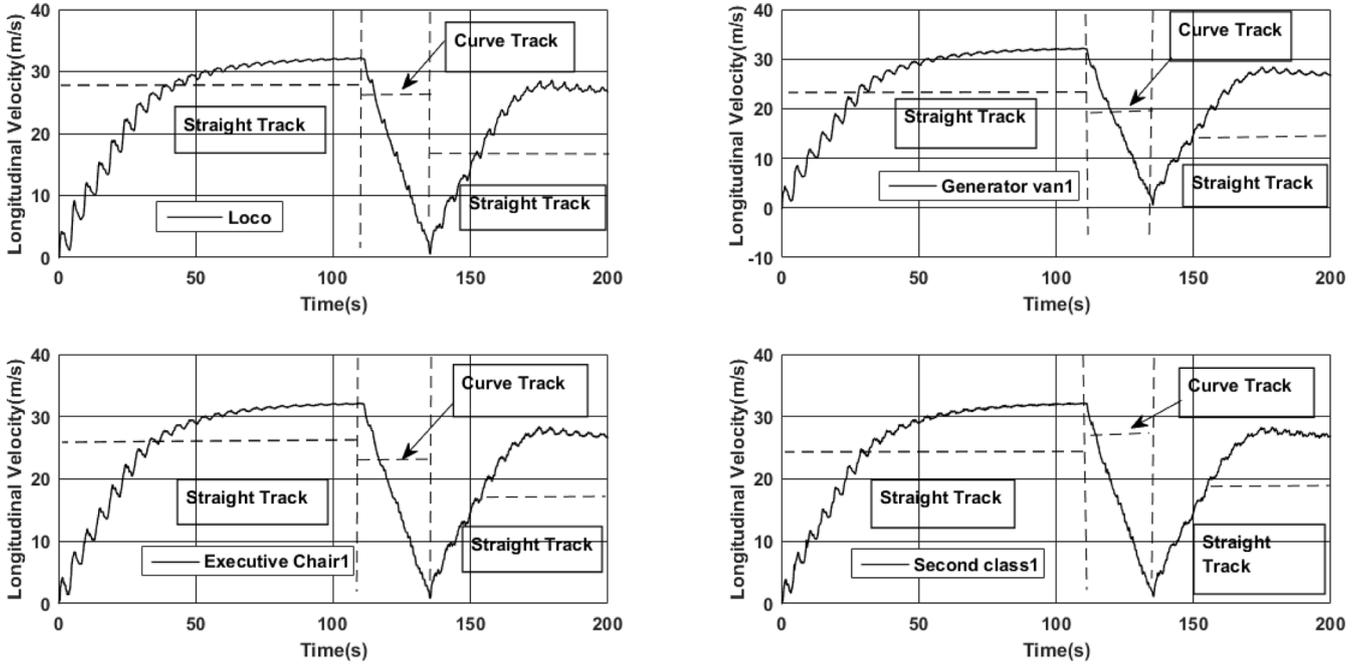


Fig. 6. Longitudinal velocities.

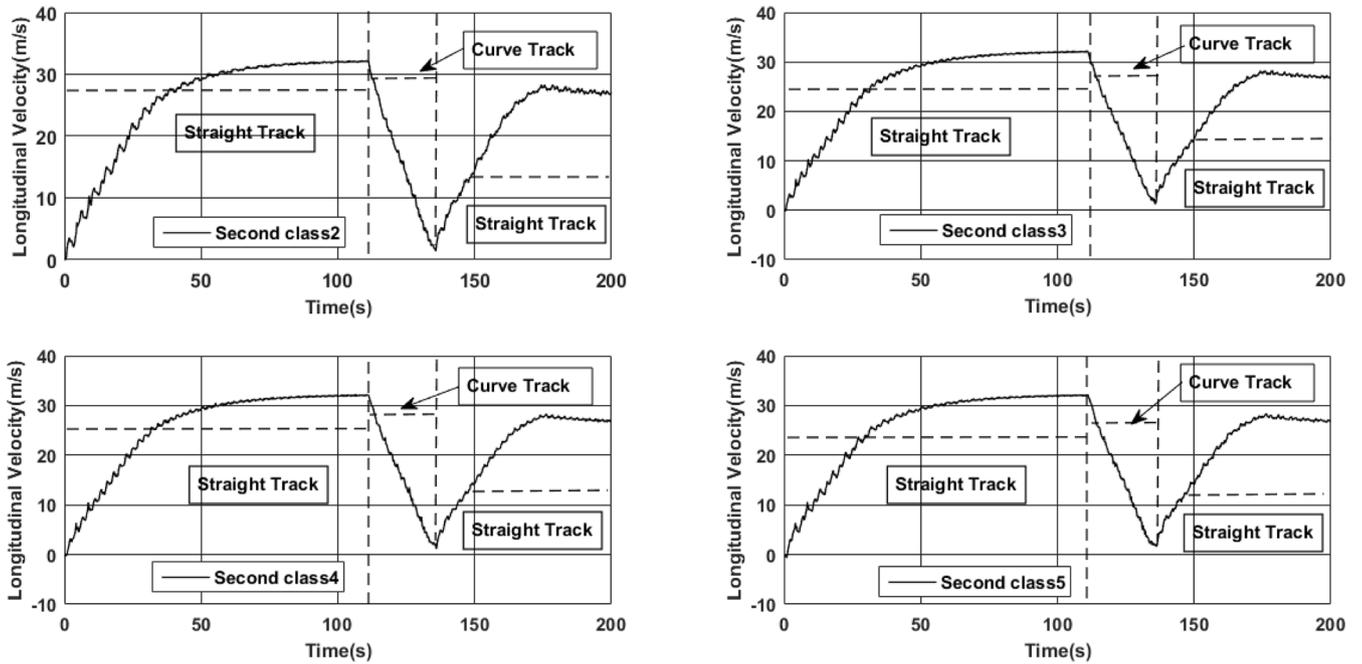


Fig. 7. Longitudinal velocities.

The downhill has negative grade resistance whereas uphill has positive grade as shown in Figure 3 and is formulated as

$$F_g = \sum_{n=1}^{13} mg \sin \theta, \quad (3)$$

where, F_g is the gradient resistance and θ is the angle of inclination.

2.5 Coupler force

Compressive and tensile forces are produced at buffer and coupler while the train runs and depends on relative displacements and velocities of consecutive coaches. LHB coach has center buffer coupler (CBC), which can be opened manually but closed automatically during the coupling of coaches. It is AAH type coupler, which automatically locks when fully mated. LHB coaches have

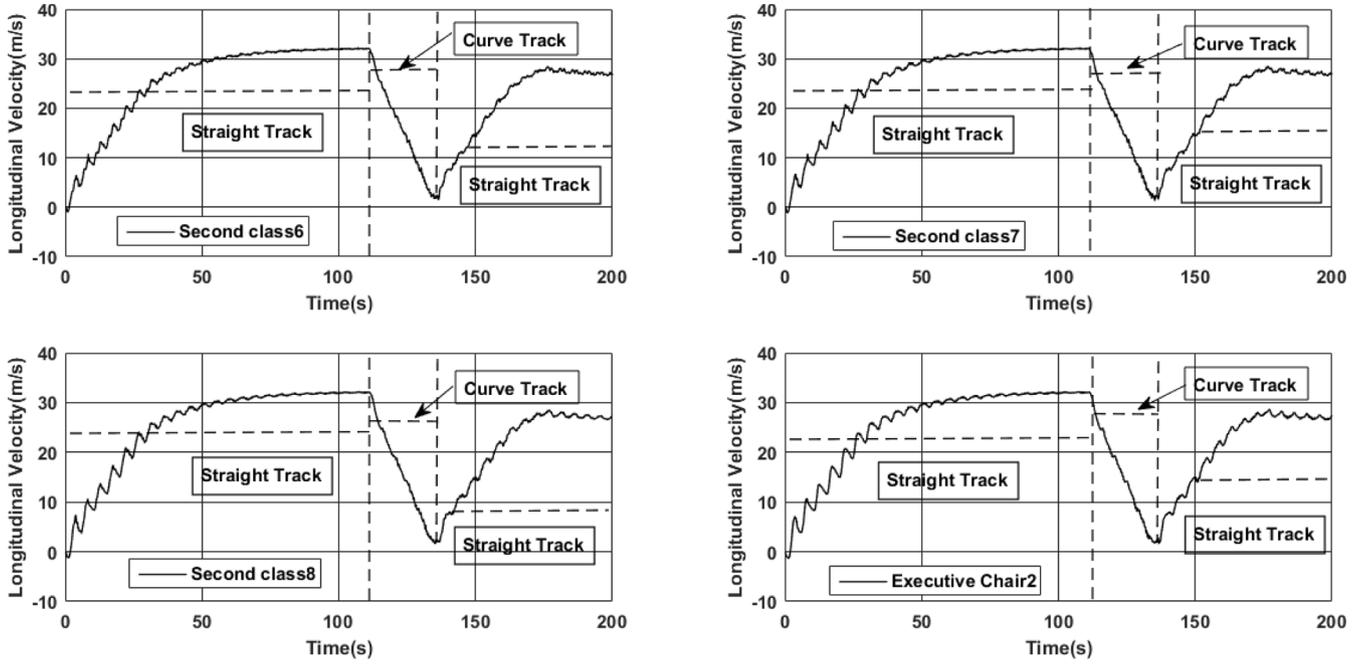


Fig. 8. Longitudinal velocities.

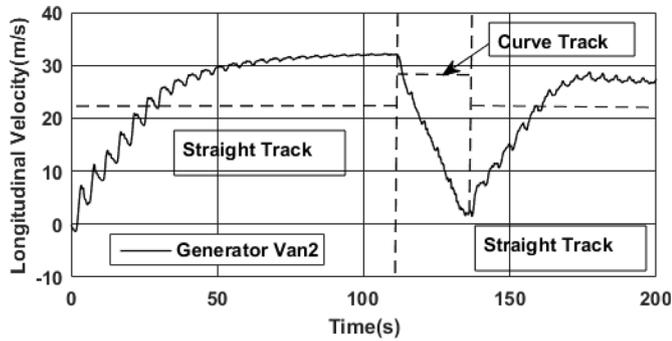


Fig. 9. Longitudinal velocities.

been provided with tight lock a CBC instead of screw coupling. Equation for coupler force is given below:

$$F_1 = \begin{cases} k_{e1}x + k_{f1}|x| \tanh(u_1\dot{x}), & \text{if } x < 0, \\ 0, & \text{if } x = 0, \\ k_{e2}x + k_{f2}|x| \tanh(u_1\dot{x}), & \text{if } x > 0 \end{cases}$$

where,

F_1 is coupler force,

k_{e1} is stiffness of buffer,

k_{f1} is friction force constant of buffer,

k_{e2} is stiffness of coupler,

k_{f1} is friction force constant of coupler,

x is the relative displacement of two adjacent coaches,

\dot{x} is the relative velocity of two adjacent coaches.

2.6 Brake force

Gatimaan Express has a pneumatic braking system. The system mainly consists of braking cylinder, auxiliary reservoir, distributor, compressor, main reservoir, brake valves, cocks

with hose, command reservoir. Simple layout of pneumatic braking is shown in Figure 4. From the compressor, pressured air is fed into braking cylinder through brake pipe. Further, it provides air to trailing coaches passing through cocks and coupled hoses. The distributor is connected to brake pipe. The function of distributor is to monitor the difference between the constant pressure of the command reservoir and the reference signal of brake. If the pressure of the brake pipe is lower than the command reservoir pressure, the distributor maintains the pressure of the braking cylinder. The pressured air is supplied to distributor by the auxiliary reservoir through brake pipe. In case of the braking cylinder pressure crosses the desired level, the cylinder pressure port is exposed to the atmosphere, operated by distributor. The driver's brake valve controls the reference pressure signal of brake cylinder. At the time of shorter brake release phase, an auxiliary pressurized pipe is directly connected to the auxiliary reservoir [19,20].

Equation for the braking system is given below:

$$F_{bk} = p_{bk}\mu_{bk}r_iA_{bk}\nu_{bkr}N_i, \quad (4)$$

where, F_{bk} is brake force,

p_{bk} is relative instantaneous in air cylinder pressure,

μ_{bk} is the friction coefficient of brake pad,

r_i is rigging ratio,

A_{bk} is effective brake cylinder area,

ν_{bkr} is dynamics efficiency of rigging ratio,

N_i is number of pad.

Input parameters are enlisted in Table 2.

Now combining all these forces to develop longitudinal dynamics model of Gatimaan Express, we have

For locomotive WAP5,

$$m_t\ddot{x}_l = F_{tl} - F_{cl} - F_{bkl} - F_{gl} - F_{drag} - F_{l1}, \quad (5)$$

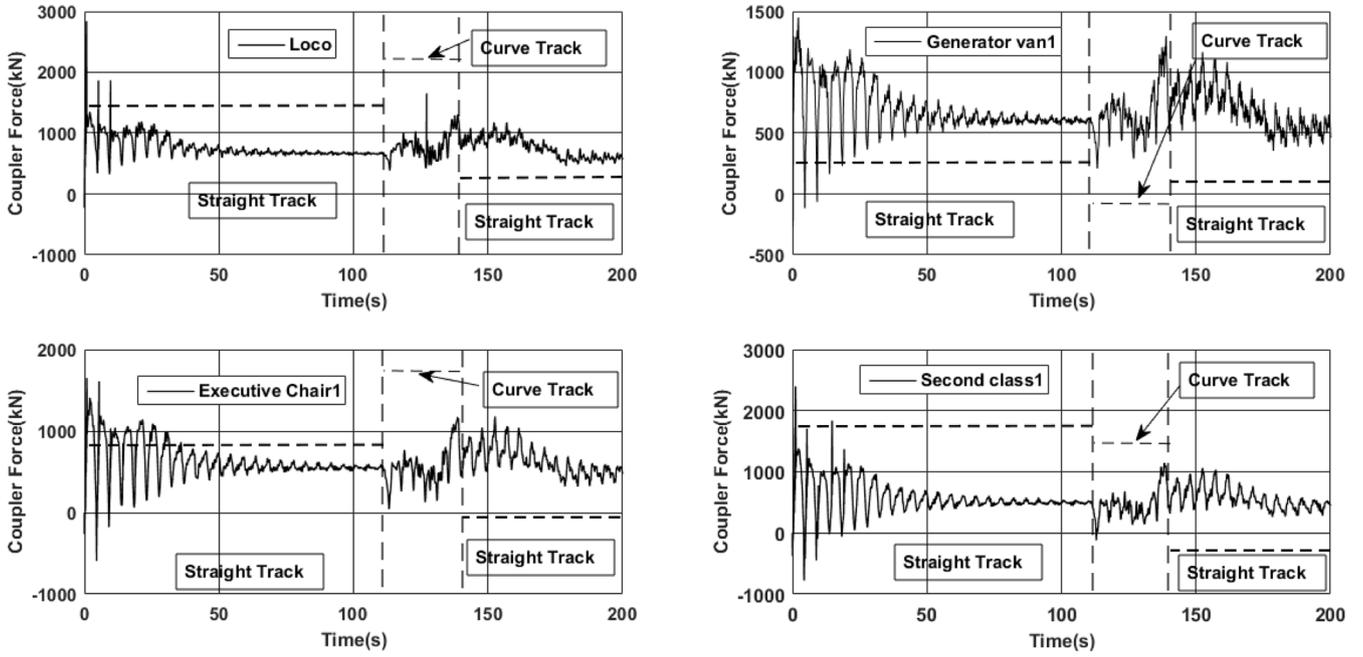


Fig. 10. Coupler force (kN).

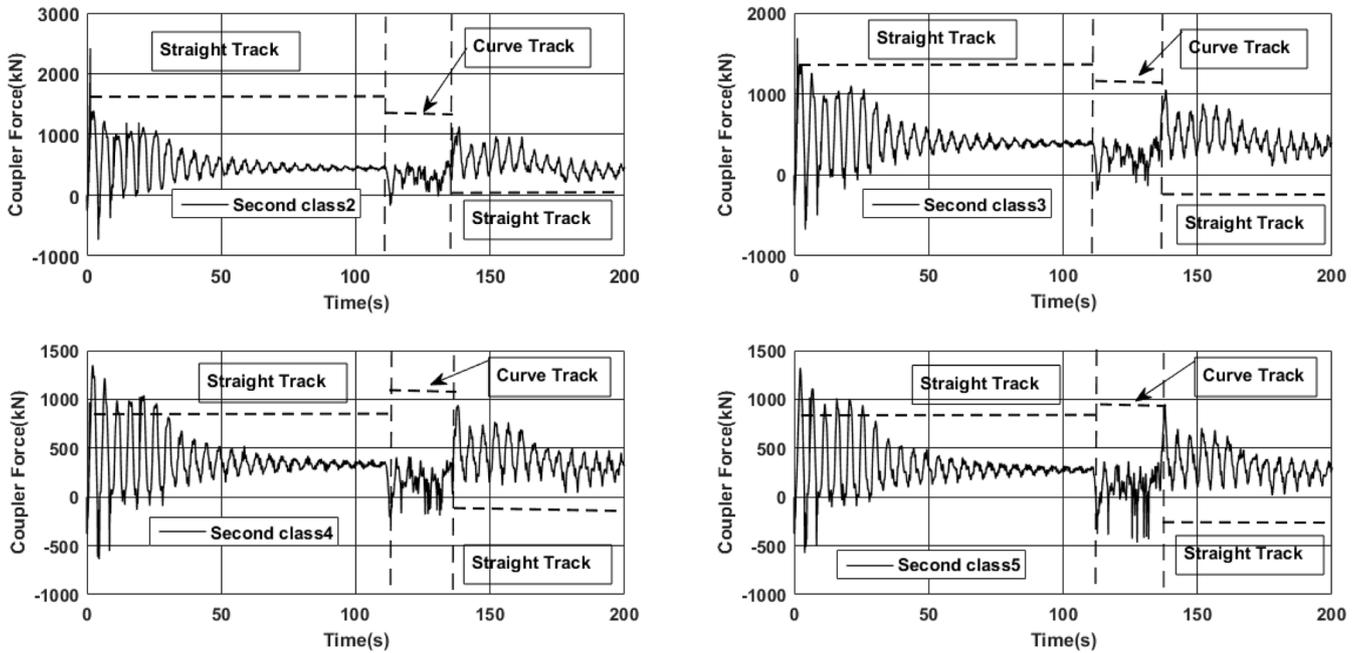


Fig. 11. Coupler force (kN)

For k th coach,

$$m_k \ddot{x}_k = -F_{ck} - F_{bkk} - F_{gk} - F_{1k} + F_{1k-1}, \quad (6)$$

For last coach,

$$m_k \ddot{x}_{ls} = -F_{cls} - F_{bkl s} - F_{gls} - F_{1k-1}, \quad (7)$$

3 Development of Gatimaan Express model in Matlab/Simulink[®] and discussion

Presented equations of longitudinal dynamics of Gatimaan Express model are expressed in Matlab/Simulink[®] with its version of R2015b applying Runge Kutta ode45 order solver and time step of 0.001s with the relative and

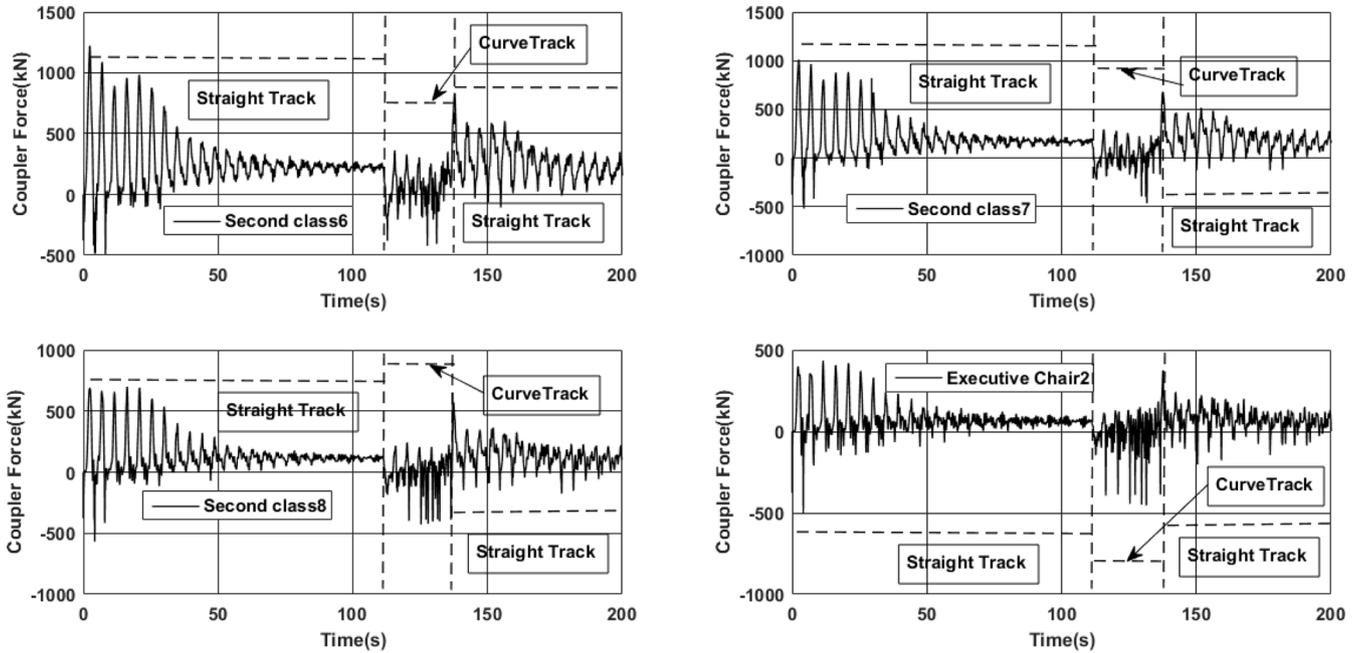


Fig. 12. Coupler force (kN).

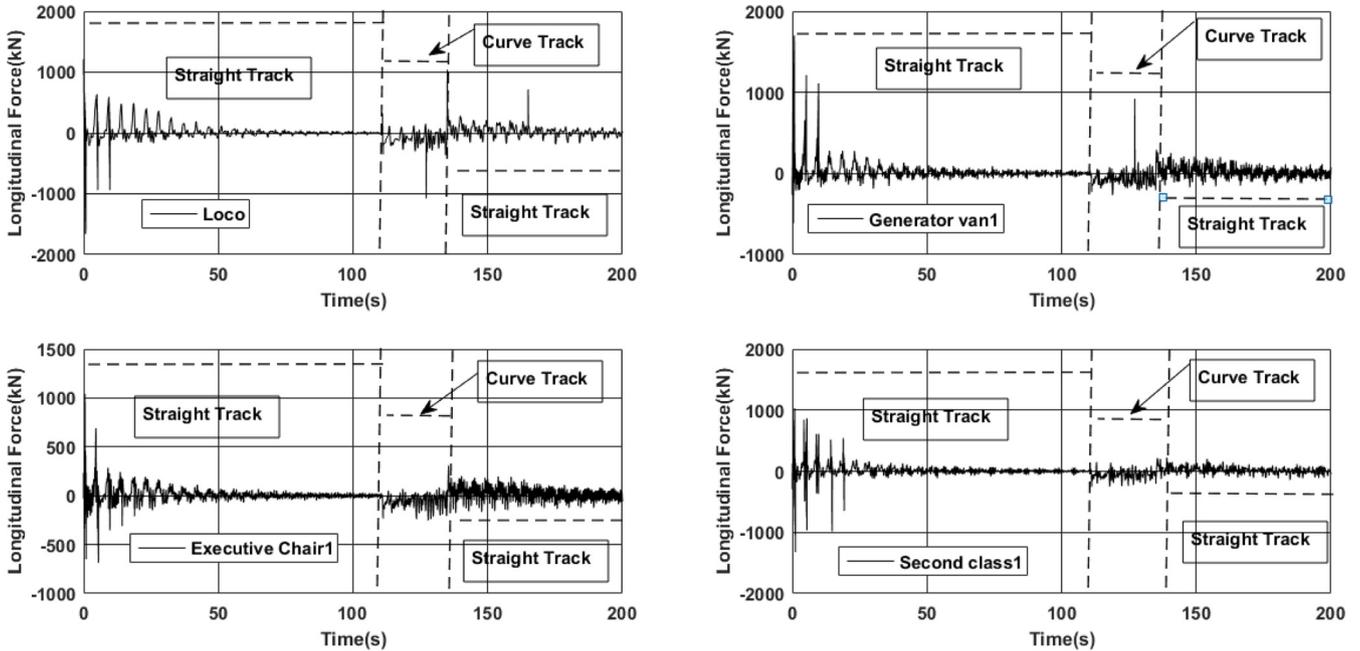


Fig. 13. Longitudinal force (kN).

absolute tolerances $1e-03$. The track curve from Agra Cantonment to Palwal is incorporated in the model, provided by Track Machines and Monitoring Department (TMMD) RDSO. The major input parameter values are taken from [15] and different research papers. Simulated longitudinal velocity of Locomotive of Gatimaan Express is compared with its measured field data during test run is shown in Figure 5. It is shown that there is a good match

between simulated samples and the measured data. There are small difference between the simulated and measured velocities of about 1.5 m/s at 20, 30 and 36 s which can be due to damping of the model.

Further, Gatimaan Express model is simulated on straight and curve tracks for 200 s. Longitudinal velocities of each coach, second class car, executive class car and generator van of Gatimaan express model are shown in

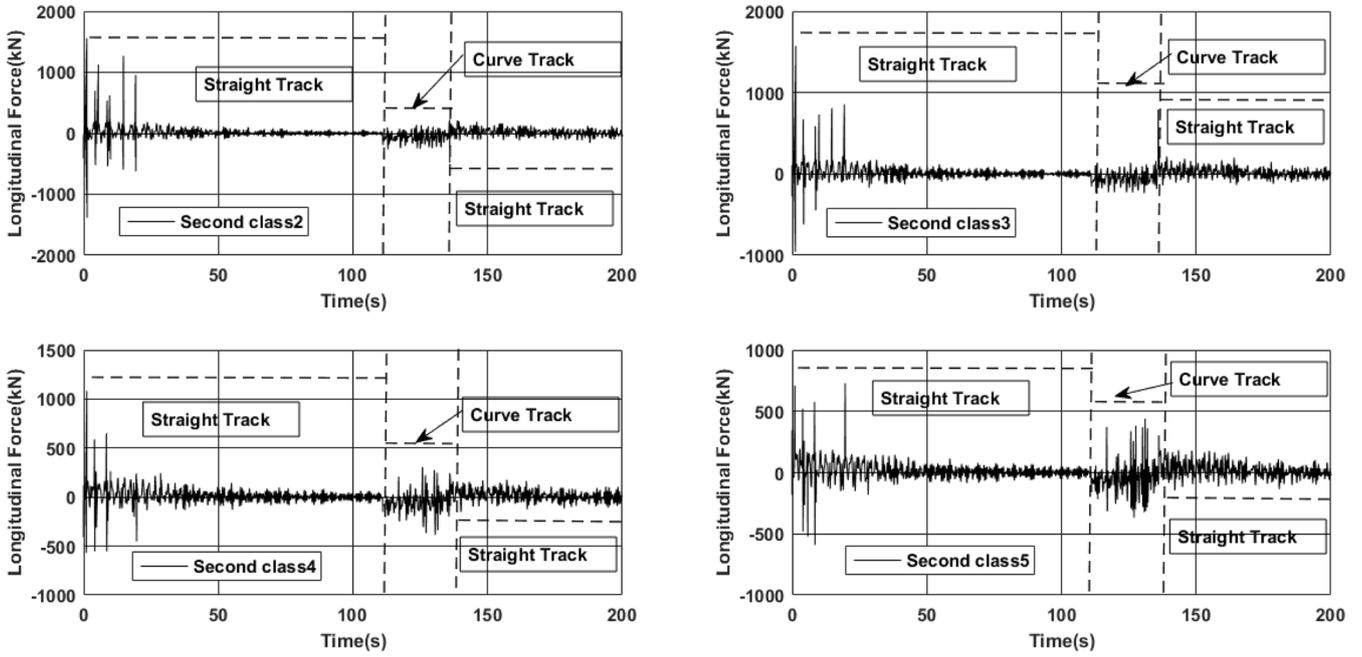


Fig. 14. Longitudinal Force(kN).

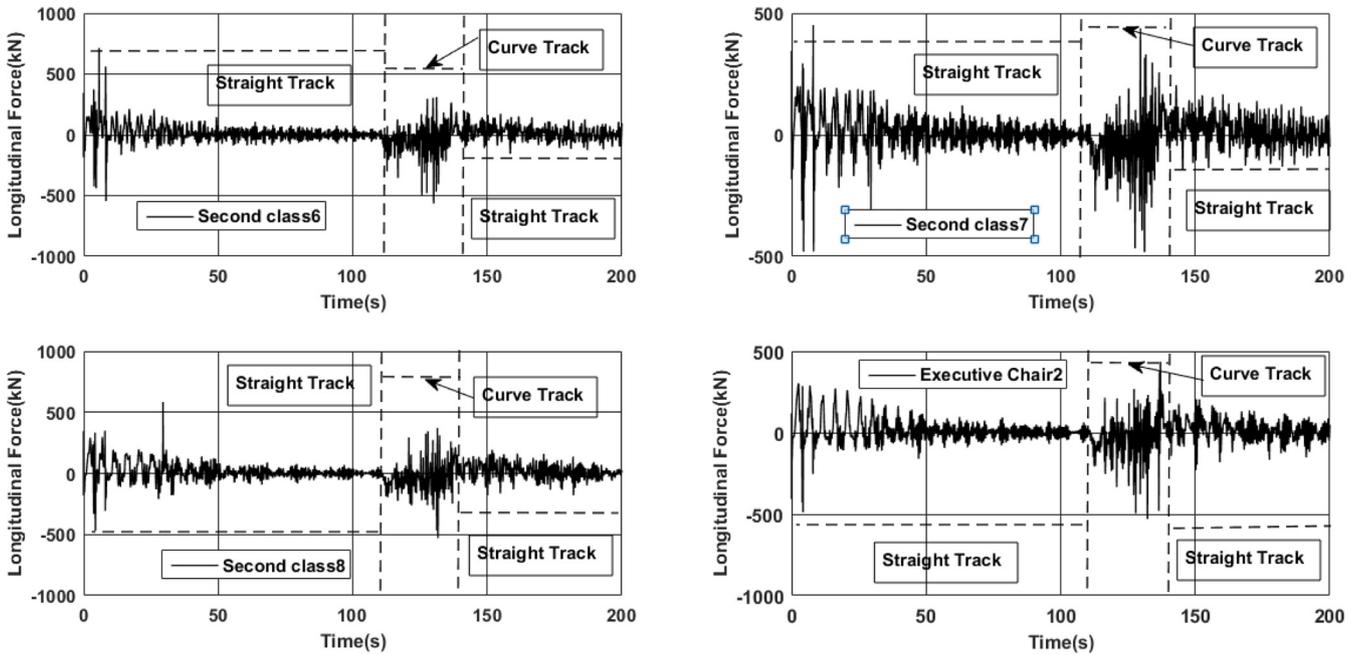


Fig. 15. Longitudinal force(kN).

Figures 6–9. It is observed that each coach has almost the same response. Coupler and longitudinal forces of complete train model are shown in Figures 10–16.

It can be noted that the behavior of these forces on straight and curve tracks are different. There are compression and tension of forces on the curve track whereas on straight track, they become saturated after certain interval of simulation. Another remarkable point is that simulated velocities of each coach from 111 to 165 s are similar with measured data.

Simulation is performed based on the assumption that coupler with buffer of 3rd second class chair car fails due to fatigue load, its stiffness and constant friction force reduce to zero.

Equating coupler force zero,

$$k_{e2}x + k_{f2}|x|\tanh(u_1\dot{x}) = 0, \tag{8}$$

$$x(k_{e2} + k_{f2}\tanh(u_1\dot{x})) = 0, \tag{9}$$

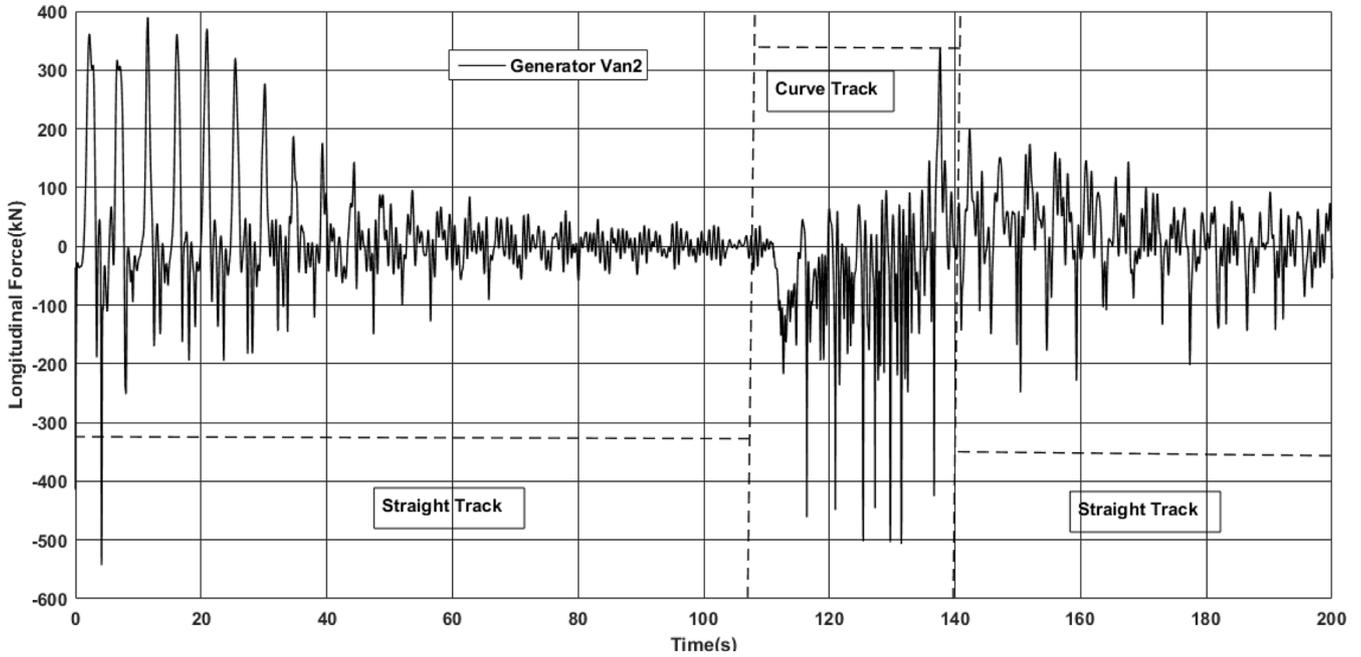


Fig. 16. Longitudinal force (kN).

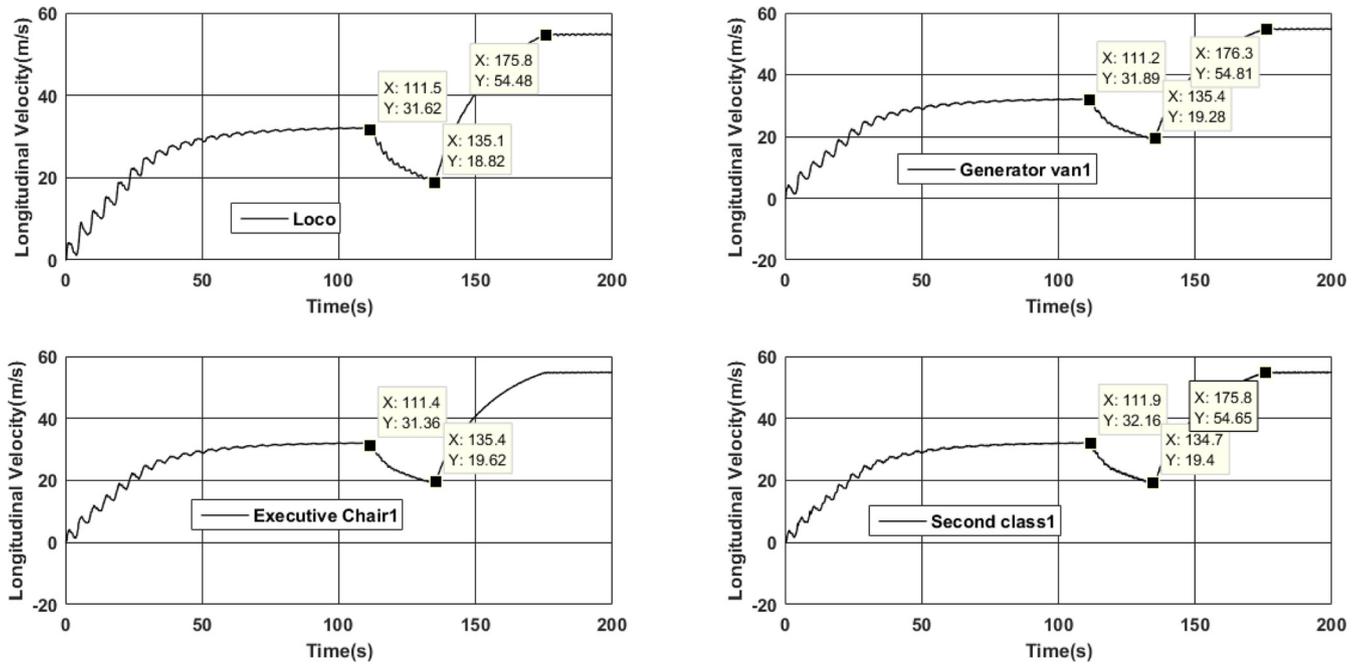


Fig. 17. Longitudinal velocities.

$$x = 0, \tag{10}$$

$$k_{e2} + k_{f2} \tanh(u_1 \dot{x}) = 0, \tag{11}$$

$$\dot{x} = \frac{\tanh^{-1} \frac{-k_{e2}}{k_{f2}}}{u_1} \tag{12}$$

$$x = \frac{\tanh^{-1} \frac{-k_{e2}}{k_{f2}}}{u_1} * t + c, \tag{13}$$

Longitudinal velocities of locomotive, generator van1, executive chair car1, second chair car1, second chair car2, second chair car3 are shown in Figures 17 and 18. Coupler of 3rd second chair car failed at 111 s of simulation and is found about 19 m/s velocities on curve track at about 135 s where as in normal running condition at same time, velocities are about 3 m/s. Velocities of train increased about 6 times rapidly due to coupler failure which may lead to derailment. On straight track at about 176 s of simulation, velocities are 55 m/s where as in normal condition, at about same

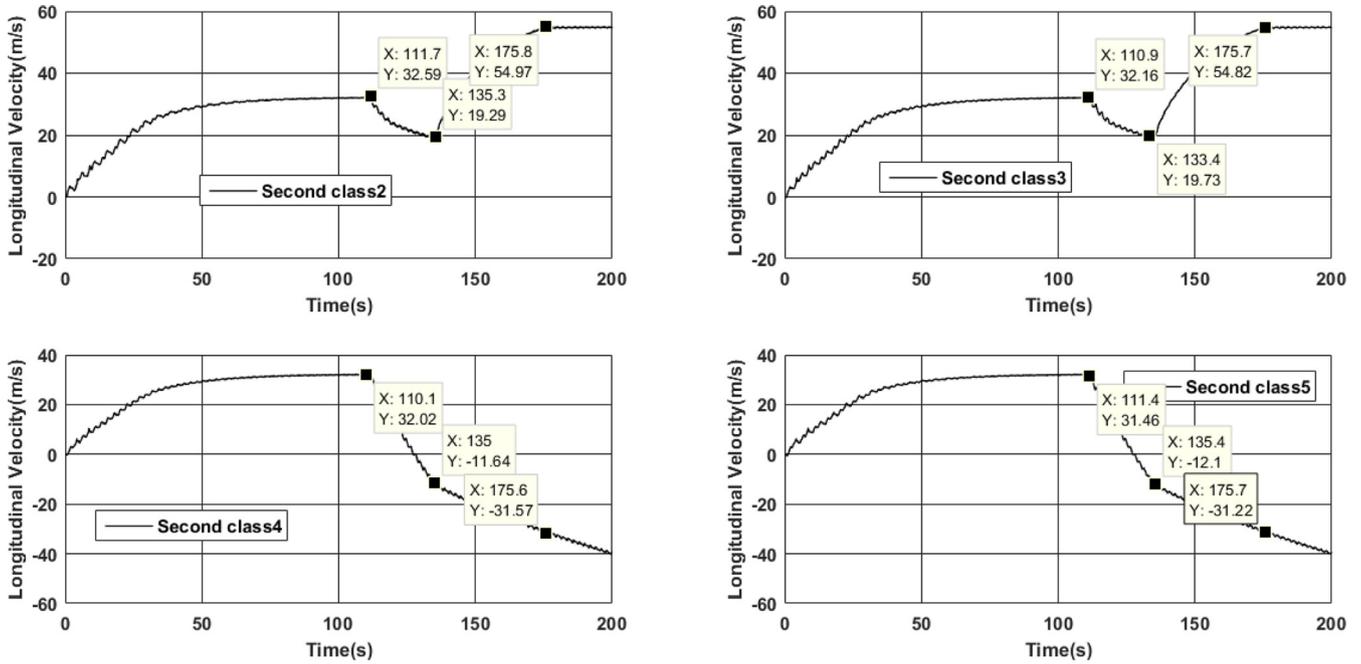


Fig. 18. Longitudinal velocities.

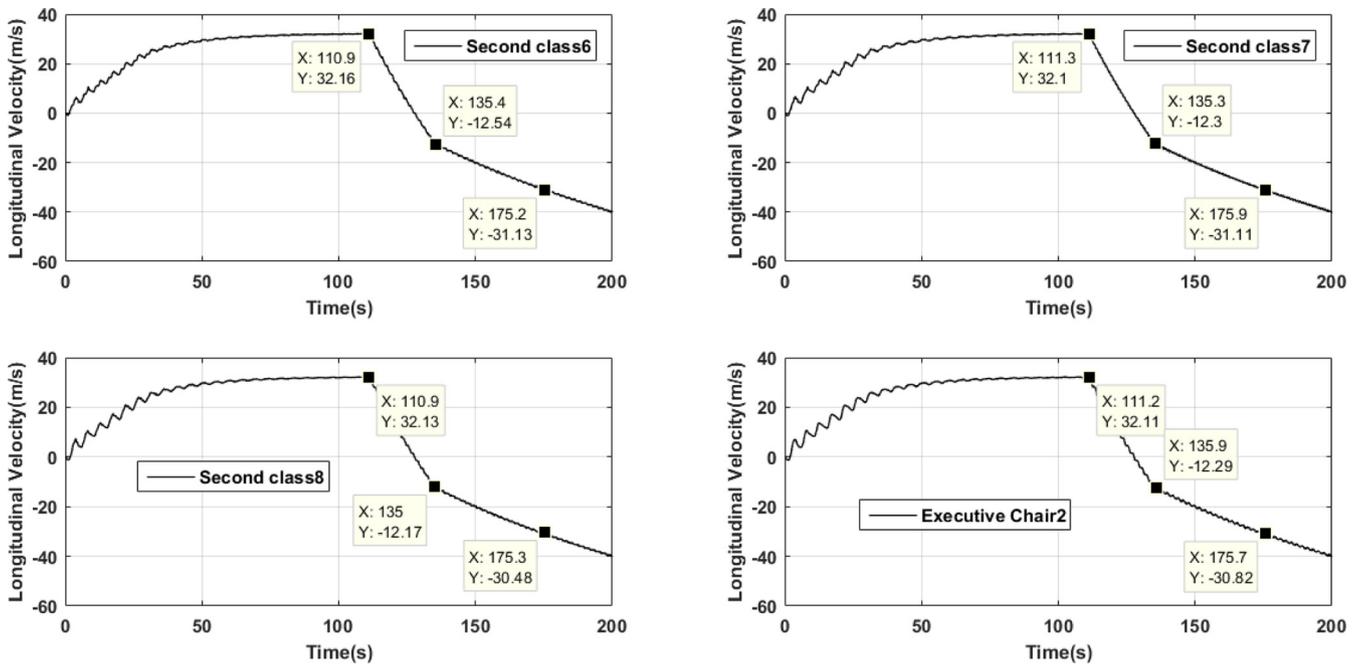


Fig. 19. Longitudinal velocities.

the time velocities are 28 m/s. It means in both tracks due to coupler failure, the accelerations of Gatimaan Express model is increased and if driver applies emergency brake, it may be chance of derailment. Decoupled coaches have negative velocities after 111 s as the pulling force through the coupler of two consecutive coaches is lost. There are increasing in negative velocities of second chair car 4 and 5, 6, 7, 8, executive

char 2 and generator van2 as shown in Figures 18–20 respectively. Dynamic responses of coupler forces are shown in Figures 21–23. It is noticed that compressive coupler forces at its failure condition are more than at normal condition.

Longitudinal forces of model are presented in Figures 24–27 respectively. It can be observed the behavior of these forces are more critical than in normal case.

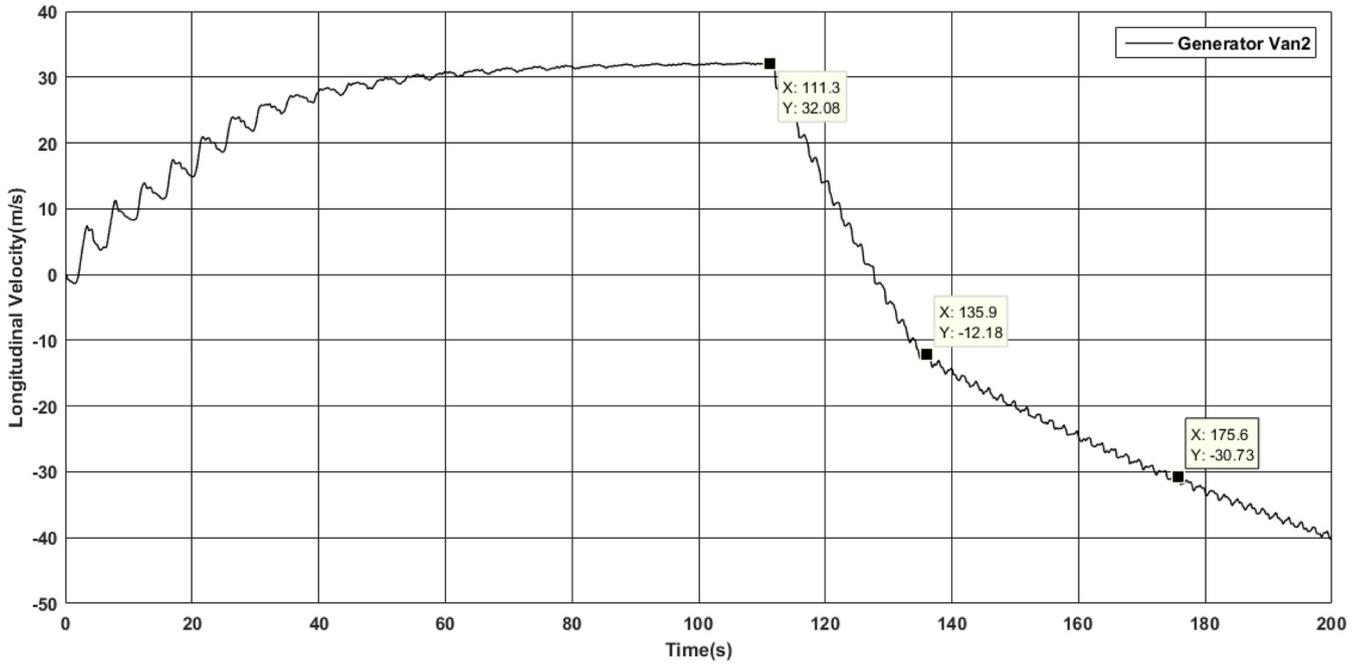


Fig. 20. Longitudinal velocities.

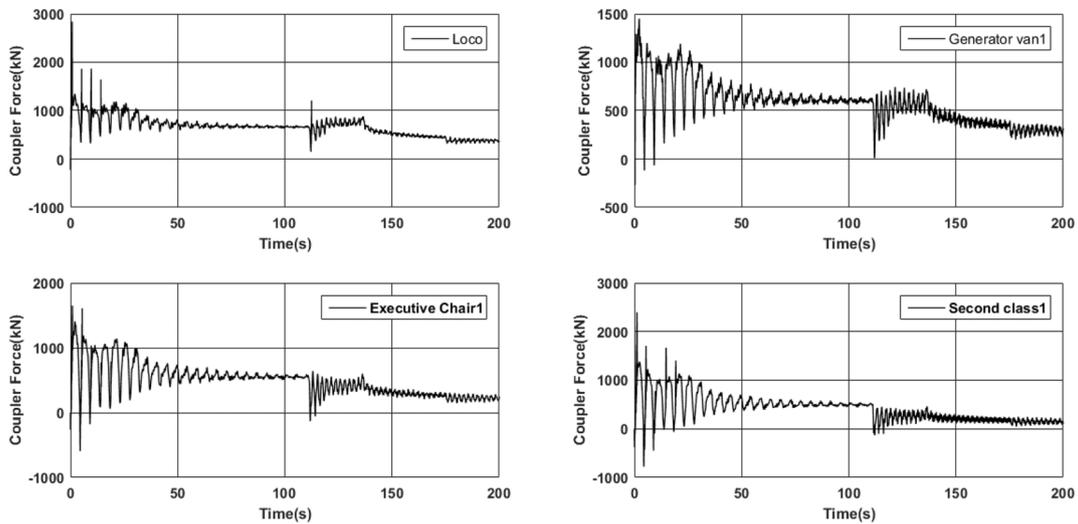


Fig. 21. Coupler force (kN).

4 Conclusion and remarks

Longitudinal dynamics of complete Gatimaan express model is developed in Matlab/Simulink[®] successfully. The actual mass is given to each coach of the model and simulated longitudinal velocity of locomotive is compared with measured data and is found a good match with 85% confidence level.

Longitudinal dynamics of Gatimaan express in case of 3rd second class chair car coupler failure is studied and probable derailment behavior is analyzed. The model can be implemented to examine the track dynamics, emergency

stopping distance and emergency braking response. Dynamic behavior of model due to failure of different coaches are also studied which are not presented in this paper. They have same kind of performances.

Lateral and vertical dynamics can be added to the study complete dynamics of Gatimaan Express model. Model with different coupler characteristics can be performed.

The longitudinal railway vehicle dynamics simulator can be made for education and research purposes. The performance of train dynamics on the different tracks with this model can be studied. The braking performance of the rail dynamics can be evaluated. The drag force at higher speed can be studied.

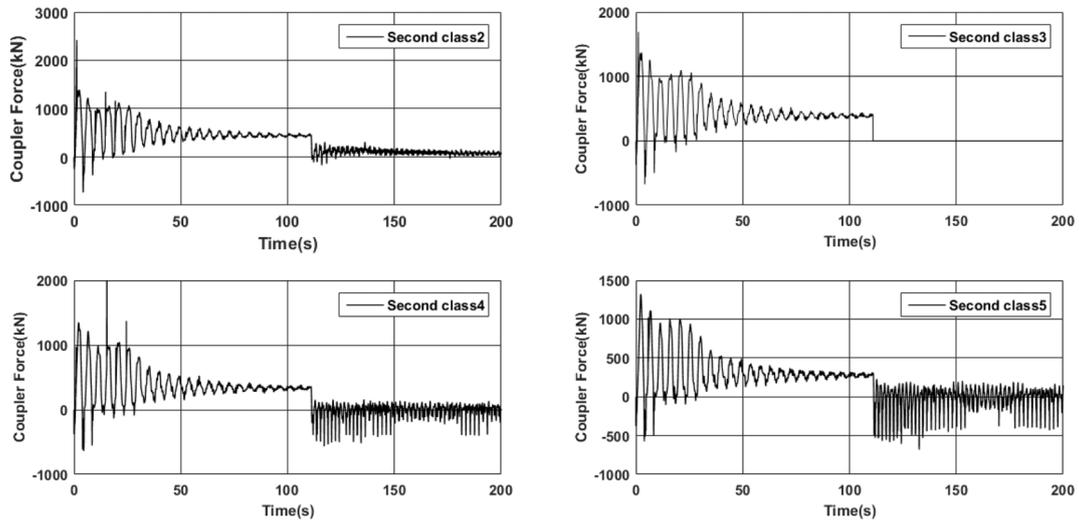


Fig. 22. Coupler force (kN).

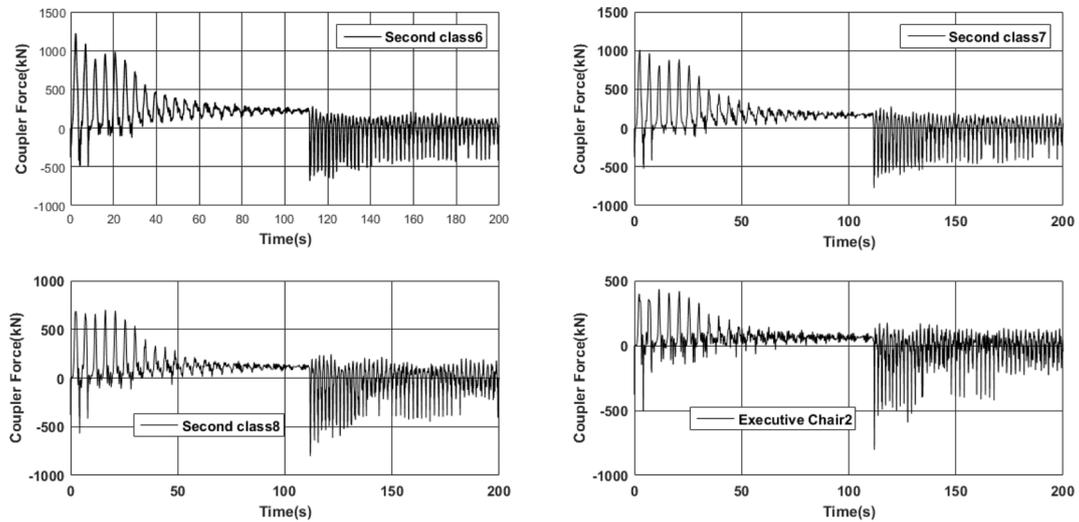


Fig. 23. Coupler force (kN).

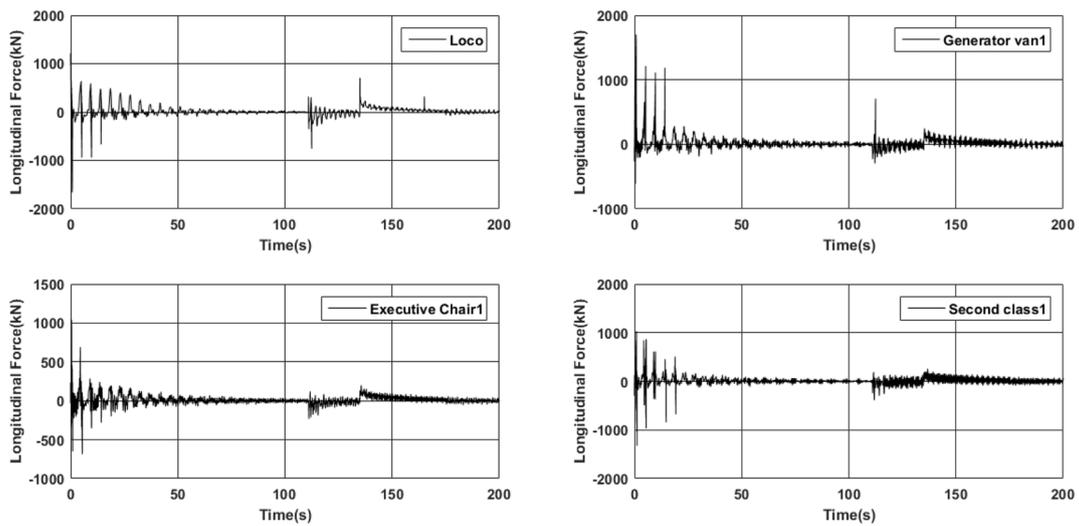


Fig. 24. Longitudinal force (kN).

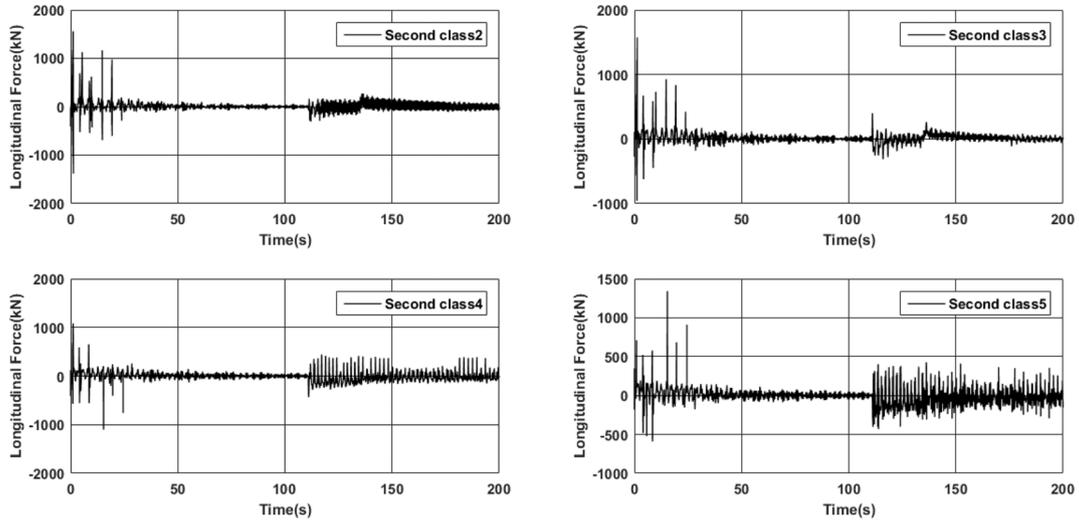


Fig. 25. Longitudinal force (kN).

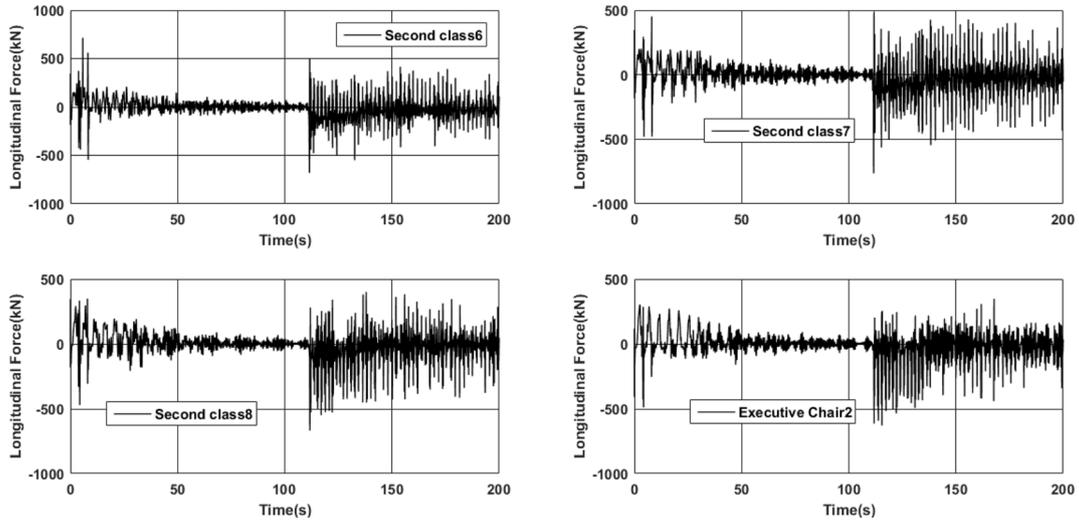


Fig. 26. Longitudinal force (kN).

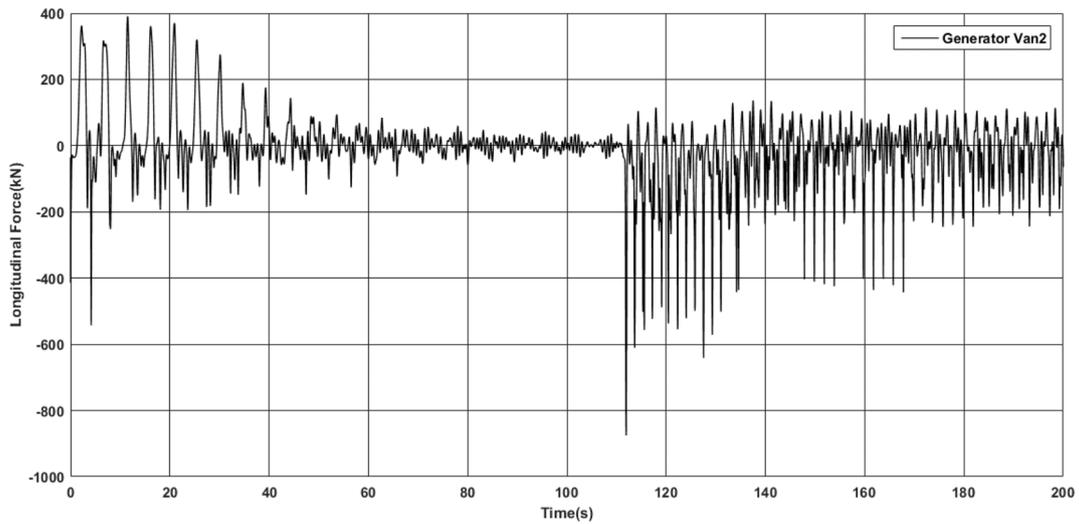


Fig. 27. Longitudinal force (kN).

Nomenclature

A_{bk}	Effective brake cylinder area [m ²]
F_{t1}	Tractive force [N]
F_c	Curve resistance [N/kg]
F_{dr}	Rolling resistance [N]
F_{gr}	Gradient resistance [N]
F_1	Coupler force [N]
F_{bk}	Brake Force [N]
k_1	Torque reduction [Ns/m]
k_{e1}	Stiffness of buffer [N/m]
k_{e2}	Stiffness of coupler [N/m]
k_{f1}	Friction force constant of buffer [N/m]
k_{f2}	Friction force constant of coupler [N/m]
N_i	Number of brake pad
M	Number of throttle notch
m	Mass of coach [kg]
$P1_{max}$	Maximum locomotive traction power [W]
p_{bk}	Relative instantaneous in air cylinder pressure [bar]
$T1_{max}$	Maximum locomotive traction force [N]
r_i	Rigging ratio
R	Radius of Curvature of track [m]
x	Relative displacement of two adjacent coaches [m]
\dot{x}	Relative velocity of two adjacent coaches [m/s]
μ_{bk}	Friction coefficient of brake pad
v_{bk}	Dynamic efficiency of rigging ratio
θ	Inclination of track [degree]

References

- [1] A.S.V. Iryn, A. Zavlatny, Determination of longitudinal forces in the cars automatic couplers at train electrodynamic braking, 9th International Scientific Conference Transbalities, 3, pp. 415–421, 2016
- [2] B.M. OleksandrMokin, Y. Lobatiuk, Simulation model for the monitoring system of air brake of the train and determining the place of breakage, Int. J. Traffic Transp. Eng. 4 (2014) 184–188
- [3] D.H. David Barney, G. Nikandros, Calculating train braking distance, 6th Australian Workshop on Safety Critical Systems and Software (SCS'01), 3 pp. 1–7, 2001
- [4] R.V. MarinM, Generalized model of the pressure evolution within the braking system of a vehicle, Int. J. Eng. 1 (2013) 1–6
- [5] C. CRĂCIUN, T. MAZILU, Simulation of the longitudinal dynamics forces developed in the body of passenger trains, Int. J. Eng. 3 (2014) 1–8
- [6] L. Cantone, T. Durand, Longitudinal forces evaluation of sncf trains, 9th World Congress on Railway Research, 3 pp. 1–12, 2011
- [7] X.B. LuYi, G. Bin, Dynamic modeling and experimental verification of bus pneumatic brake system, J. Open Mech. Eng. J. 9 (2015) 52–57
- [8] S.C.S. Sachin, S. Harak, S.P. Harsha, Dynamic analysis of draft gear and draft pad of freight wagon due to localized defects using fem, Int. J. Acoust. Vib. 21 (2015) 281–291
- [9] C. Cole, Y.Q. Sun, Simulated comparisons of wagon coupler systems in heavy haul trains, J. Rail Rapid Transit. 220 (2006) 247–256
- [10] O.O.D.Y. Jeong, M.L. Lyons, A. Perlman, Equations of motion for train derailment dynamics, ASME Rail Transp. Division Fall Tech. Conf. 38 (2007) 265–280
- [11] W.M.Q. Xu, Z.Q.S. Luo, Coupler rotation behavior and its effect on heavy haul trains, J. Vehicle Mech. Mobility 51 (2013) 1818–1838
- [12] W.D. QuTianwei, Ma. Weihua, L. Shihui1, Influence of coupler and buffer on dynamics performance of heavy haul locomotive, J. Open Mech. Eng. 5 (2015) 1033–1038
- [13] J.Z. LaiWe, Q. Wang, Investigation of in-train stability and safety assessment for rail vehicles during braking, J. Open Mech. Eng. 30 (2016) 1505–1525
- [14] P.K. Jha, S. Gokhale, Modeling and validation of gatimaan express with matlab/simulink, Int. J. Transport Dev. Integration, 162 (2016) 381–396
- [15] RDSO, Maintenance manual for bg coaches of lhb design, in Research Designs Standards Organization, pp.11–44, Ministry of Railways, 2012
- [16] V. Garg, R.V. Dukkupati, Dynamics of Railway Vehicle System, Academic Press Canada, Ontario, 1984
- [17] S. Maksym, C. Colin, Q.S. Yan, M. Mitchell, S. Valentyn, M. Tim, Design and Simulation of Rail Vehicles, CRC Press, Boca Raton, 2014
- [18] S. Iwnicki, Handbook of Railway Vehicle Dynamics, CRC Press, Boca Raton, 2006
- [19] A. Nasr, S. Mohammadi, The effects of train brake delay time on in-train forces, Proc IMechE, Part F: J Rail Rapid Transit, 224 (2010) 1033–1038
- [20] B. Allota, L. Banchi, L. Pugi, M. Malvezzi, P. Presciani, A parametric library for the simulation of a union internationale des chemins de fer (uic) pneumatic braking system, Proc IMechE, Part F: J Rail Rapid Transit, 218, 2003

Cite this article as: P.K. Jha, S.S. Gokhale, Validation of longitudinal dynamics of Gatimaan Express model in Matlab/Simulink[®], Mechanics & Industry 19, 307 (2018)