Research Article

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Influence of suspension parameters on a tilt angle of passenger bus for the stability test

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ABSTRACT

Passenger bus stability testing is frequently conducted in accordance with a regulation standard of the Economic Commission for Europe of the United Nations. Specifically, this standard defines a test that requires the vehicle to be titled to either side at an angle of 28 degrees from the horizontal without overturning. Generally, the stability of a vehicle at this tilt angle is primarily affected by the height of the center of gravity as well as the suspension system. This paper explains a study of several parameters influencing the tilt angle stability test of the passenger bus to avoid bus accident caused by a rollover. The parameters consisted of the spring stiffness, damping coefficient, anti-roll bar stiffness including the static stability factor (SSF). The full factorial design of the experiment was used to analyze the results of the main effects on the tilt angle as evaluated by multibody dynamics simulation software. According to the results, the SSF of the passenger bus displayed higher sensitivity to the tilt angle than the suspension parameter at approximately 82%. The passenger bus with a low SSF tended toward rollover or low tilt stability more than one with a high SSF. For the suspension system, the anti-roll bar stiffness manifested a greater effect on the stability than the spring stiffness and damping coefficient, respectively. The results can be used to make design decisions and improve suspension parameters for improved vehicle stability.

Keywords**:** stability test; passenger bus; suspension system; tilt angle

1. INTRODUCTION

In Thailand, the Department of Land Transport (DLT) is the agency responsible for developing motor vehicle test standards for bus safety. In determination of the stability of a vehicle, they involke the tilt table test, in accordance with the standard regulations no107 of Economic Commission for Europe of the United Nations. The vehicles used for the carriage of passengers (classificatations of M_2 and M_3) must pass the safety test with a tilt angle of 28 degrees from the horizontal (United Nations Economic Commission for Europe, 2014). The stability testing is one of the regulational requirements regarding registration and certification for public buses controlled by government agencies. The DLT of Thailand has announced regulations for all buses which have height dimensions greater than 3.6 meters must pass a vehicle stability test with a tilt angle of over 30 degrees (Department of Land Transport, 2012) to be certified as a public bus. The vehicle stability testing which causes overturning must be conducted on an inclined floor with an increment application of the angle of 0.05 degrees per second. The maximum tilt angle of vehicle stability was

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determined from the point when the wheel on the opposite side starting lift from the tilt table, as shown in Figure 1. In the case of the passenger bus which has not passed the standard test with the tilt angle more than 30 degrees, then the bus manufacturers or owners cannot obtain registeraration and extension of the annual vehicle tax.

Figure 1 The typical passenger bus in tilt table test (Bingley, 2015)

According to the statistical report of the DLT (Safety Department of Land Transport, 2019), there are approximately 300 units of passenger buses classified into 4 standards which have height dimensions greater than 3.6 meters, and approximately 40.8% do not pass the tilt test as shown in Figure 2. Generally for legal registration and operation, all passenger buses involve obtaining passing results of all tests regarding regulation and certified by the DLT. Owing to the fact that bus superstructure development necessarily takes a long time as well as significant cost, the bus manufacturers often choose to design the height of the bus to be less than 3.6 meters to avoid the stability tilt test requirement. However, the height of the structure is not the only factor involved in causing a bus rollover. The suspension and subsystems were identified as relating to the stability of the vehicle such as anti-roll bars, leaf springs, coil springs, and damping (Dixon, 1999).

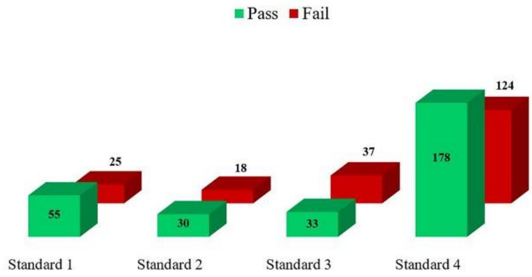


Figure 2 The statistics report on the stability tilt test in each passenger bus classification

For the bus suspension systems, the design components involved in the stability of the vehicles were considered the leaf springs, dampers, and anti-roll bar components. Normally, the shock absorber component has the main function to support the load included reducing the vibration of the vehicle for stability and safety. The components of the shock absorber consisted of leaf springs working with a damper to help act in absorbing noise and vibration. The anti-roll bars of vehicles are used to provide an increase of roll stiffness during cornering. Additionally, the static stability factor (SSF) which is related to the center of gravity position was also affecting vehicle stability (Hinch et al., 1992). For each vehicle type, it is recommended to design an appropriate SSF value. For example, the double-decker buses have suggested the magnitude of SSF in a range of 0.60 - 0.75 for appropriate stability.

In the actual test, the bus manufacturer would not be able to predict that passenger buses will pass the standard tilt tests due to the height of the center gravity position not being determined in the design process. The SSF parameters, consequently, could not be easily analyzed in practice. There was only the suspension parameter that could be evaluated in the preliminary design process. However, if one were able to know the factors that affect the design for adjustments to the suspension system they could be tailored to be suitable in vehicle stability. These would be able to improve the suspension parameters of the passenger bus such for it to be suitable and reduce trial and error before the actual tilt test.

Therefore, the objective of this study was to evaluate the influences of suspension parameters on the tilt angle test of the passenger bus. The suspension parameters evaluated consisted of the spring stiffness, damping coefficient, and anti-roll bar stiffness of the double-decker bus, which were analyzed as well as the value of SSF. Using multibody dynamics analysis, a total of sixteen design of experiments with full factorial was performed to determine the tile angle with MSC ADAM/Car software. Consequently, the main effect of the suspension parameter was obtained from the Pareto Chart. The results of this study could lead to an improved suitable design of the suspension parameter to include reducing time for trial and errors before the standard tilt test of the passenger bus.

2. MATERIALS AND METHODS

2.1 Materials

An analysis of multibody dynamics is generally used to model the dynamic behavior of interconnected rigid or flexible bodies, each of which may undergo large translational and rotational displacements (Michael and Damian, 2004). The results of dynamic behavior obtained from the equilibrium of applied forces included the change of momentum. In this study, the three-dimensional model of passenger buses included the simulation of a tilt table test that was performed using multibody dynamics software (MSC ADAM/Car) as shown in Figure 3. The parameters of the SSF and suspension system consisted of spring stiffness, damping coefficient, and anti-roll bar stiffness with the various sub-systems of bus models were evaluated in a total of 16 design scenarios to analyze in the tilt table test module.

From the previous study (Sert and Boyraz, 2017), the results of comparison accuracy on behavior the rollover of the actual test and using the MSC ADAM/Car software on tilt table test analysis, the result of the tilt table angle was 26.2 degrees, while the roll angle of the actual vehicle test was 31.6 degrees that measured from the first wheel that was lifted off the surface of the actual test. However, the simulation result of the roll angle using MSC ADAM/Car revealed 28.25 degrees. Therefore, it can be noticed that the results of the roll angle from the virtual vehicles body analysis displayed close correlation to the actual test.

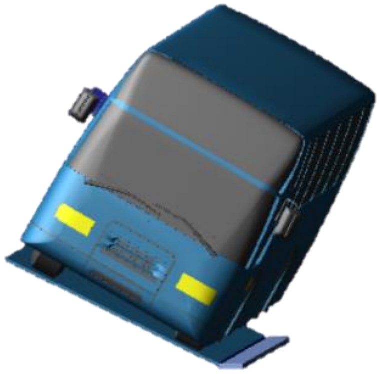


Figure 3 Tilt table test on MSC ADAM/Car software

The rollover of the vehicle causes a lot of danger and damage to both life and resources. If the bus manufacturer is able to predict the trends of behavior towards rollover, it will reduce accidents caused by the rollover. The parameter used to analyze the rollover resistance is SSF (Heydinger et al., 1999) that calculated as followed equation (1):

$$SSF = \frac{b}{2h} \tag{1}$$

where b represents the width of the vehicle which is determined from the distance between the center of the vehicle, and h represents the center of gravity height of the vehicle to the tilt table. Theoretically, the bus structure with a lower SSF was at more risk for the rollover than the one with a higher SSF. The typical of SSF value in each vehicle type is shown in Table 1 (Andrzej, 2015).

There are many important factors for the design and improvement of the SSF of vehicles to avoid rollover as much as possible. For example, the emplacement of equipment that affected the total weight of the vehicle and/or the center of gravity including the suspension system affecting the center of gravity's height. Table 2 shows the detail of the subsystem parameters consisting of mass and the center of gravity position used to analyze in MSC ADAM/ Car software.

Table 1 The typical static stability factor values of vehicle type

Vehicle type	Static stability factor (SSF)
Car	1.3-1.45
Van	1.10-1.25
Sport utility vehicle	1.05-1.20
Truck, pickup truck	1.10-1.25
Double-decker bus	0.60-0.75

Table 2 The detail of subsystems used in the study

Subsystem	Mass [kg]	CG		
		X [mm]	Y [mm]	Z [mm]
Front ARB	4.09	2815.57	1060.05	543.92
Steering	44.41	1836.77	449.06	1372.03
Front suspension	43.60	2488.74	1060.05	356.81
Powertrain	304	6368.50	1060.05	359.37
Chassis frame	10,000	5000	1060.05	1457.29
Rear suspension	431	7749.95	1059.21	508.75

2.2 Methods

All parameters obtained from the bus manufacturer (Scania Siam Co., Ltd.) are shown in Table 3. The suspension parameters of the passenger bus, presented in a range of maximum and minimum value, consisted of the spring stiffness, damping coefficient, and the anti-roll bar stiffness, respectively as well as the SSF value. A full factorial design of the experiment consisted of all possible combinations of two-levels with the maximum and minimum valus for all factors those were performed. A total of sixteen design scenarios were created and used for the analysis of the maximum tilt angle of stability test.

Table 3 Parameters used in this study

Parameters	Values
Spring stiffness* [N/mm]	240 to 260
Damping coefficient* [N/ms^{-1}]	6,935.8 to 13,872.0
Anti-roll bar stiffness* [N·mm/deg]	78,200 to 7,980,000
SSF	0.60 to 0.75

*Source: Data from Siam Scania Co., Ltd.

3. RESULTS AND DISCUSSION

Table 4 shows the results of the maximum tilt angle in each case with the maximum and minimum values of the 4 parameters, denoted by +1 and -1, respectively. Using 2^k full factorial design, a total number of 16 design scenarios were obtained. It can be observed in the case of using the high SSF values in all 8 cases (as a case of 9 to case 16). The maximum tilt angle was the tendency to be quite high. The tilt angle of the body structure which has the highest value in the case of 12 was 39.55 degrees.

Table 4 The results of maximum tilt angle in each design scenario

Case	Spring	Damp	anti-roll bar	SSF	Maximum tilt angle (degree)
1	−1	−1	−1	−1	34.28
2	+1	−1	−1	−1	34.15
3	−1	+1	−1	−1	33.22
4	+1	+1	−1	−1	33.75
5	−1	−1	+1	−1	33.19
6	+1	−1	+1	−1	31.96
7	−1	+1	+1	−1	32.20
8	+1	+1	+1	−1	32.47
9	−1	−1	−1	+1	38.52
10	+1	−1	−1	+1	38.06
11	−1	+1	−1	1	38.94
12	+1	+1	−1	+1	39.55
13	−1	−1	+1	+1	38.28
14	+1	−1	+1	+1	37.67
15	−1	+1	+1	+1	37.86
16	+1	+1	+1	+1	38.16

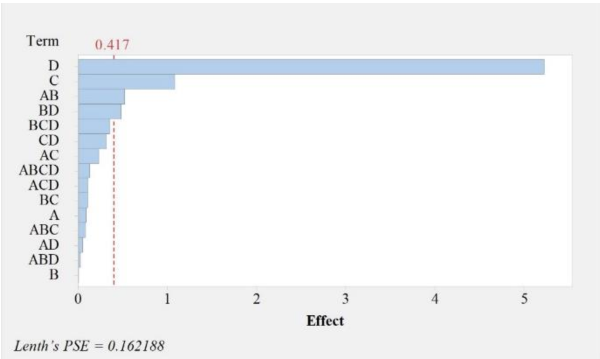
In experiments that use a low SSF value, there was a tendency of the maximum tilt angle to be low in all 8 cases (as a case of 1 to case 8) when compared to the case that uses the highest SSF. Therefore, the lowest value of the experiment of tilt the body structure in the case of 6 was 31.96 degrees. From these results, it can be drawn that the SSF is the most influential parameter on the tilt angle.

Figure 4 shows the results of the Pareto chart of all parameters affecting the tilt angle consisting of the spring stiffness, damping coefficient, anti-roll bar stiffness, and SSF, represented by A, B, C, and D, respectively. The critical line was created to determine the parameters with the significance level of 0.05. Figure 4(a) displays the four bars followed by D, C, AB, and BD which beyond the critical line of 0.417, which revealed a significant effect on the tilt angle. However, there is no significant probability value (*P*-value) at the first factorial design, as shown in Table 5. Therefore, it could not be determined that the main factors affected the tilt angle.

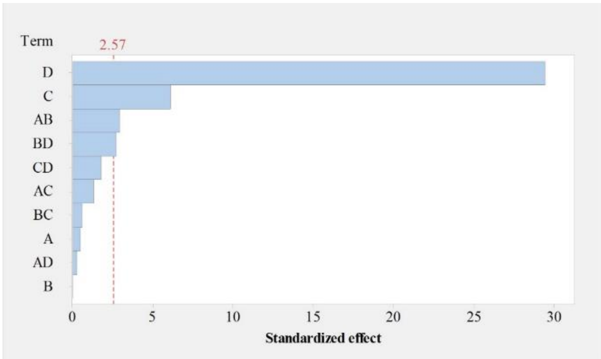
The elimination of the high order terms such as ABCD, ABD, ABC, ACD, and BCD was performed to evaluate the main parameter as shown in Figure 4 (b). In this step, the results of the parameters beyond the critical line of 2.57 consisted of D, C, AB, and BD with a significance level of 0.05. These results revealed the *P*-value of the main effect, however, there is a non-significant confidence interval of 95%, as shown in Table 5. The elimination of interaction terms between A and B such as AB, BD, AC, BC, and AD was performed due to A and B displayed the *P*-value higher than the others, as shown in Table 5 at the second factorial design.

Figure 4(c) shows the results of the final factorial design to evaluate the main parameters affected to the tilt angle of vehicle stability. The results in the term of D and C exhibited beyond the critical line, while the term of the CD displayed below the critical line, as shown in the Pareto chart. Therefore, the SSF value and the anti-roll bar stiffness were considered as significant effect parameters to the tilt angle with *P*-value <0.05, as shown in Table 5 at third factorial design.

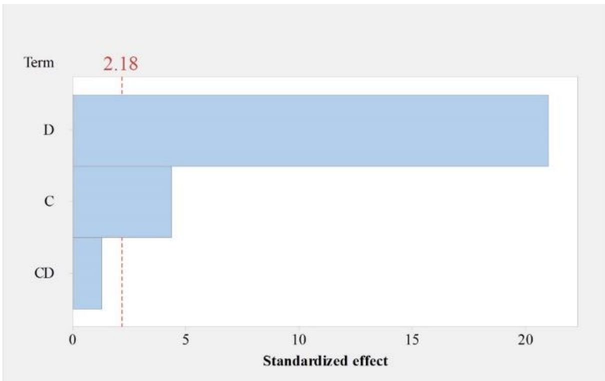
Figure 5 displayed the results of each parameter related to the maximum tilt angle. It can be noticed that the SSF value displayed quite a strong relational effect to the tilt angle of bus stability. The bus with low SSF value tended to exhibit the increased rollover or low tilt stability than a bus with high SSF. In addition, the increase of stiffness of the anti-roll bar tended to decrease bus stability or the ability of a high tilt angle. Therefore, the anti-roll bar stiffness was the main parameter in the suspension system of bus design besides the value of SSF. Figure 6 shows the percentage results of the main parameters that affected the tilt angle of the passenger bus. It could be revealed that the magnitude of the SSF of bus displayed high sensitivity to the tilt angle than suspension parameters with a percentage of 81.58% while the damping coefficient of 0.06% showed the least sensitivity parameter. The effect of the relationship between the tilt angle and the variable values could be implied to manipulate the suspension parameters of the passenger bus.



(a)



(b)



(c)

Figure 4 The Pareto chart of the all parameters; α = 0.05, A = spring stiffness, B = damping coefficient C = anti-roll bar stiffness, D = SSF

Table 5 *P*-values analysis of each parameter

Factorial design	*p*-value			
	Spring stiffness	**Damping coefficient**	**Anti-roll bar stiffness**	**SSF**
1	*	*	*	*
2	0.632	0.983	0.002	0.000
3	-	-	0.001	0.000

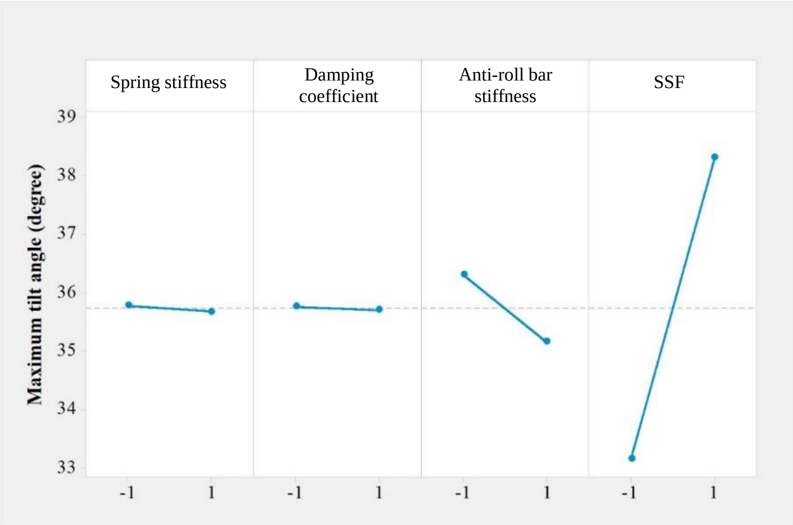


Figure 5 The relationship of parameter affected to the tilt angle

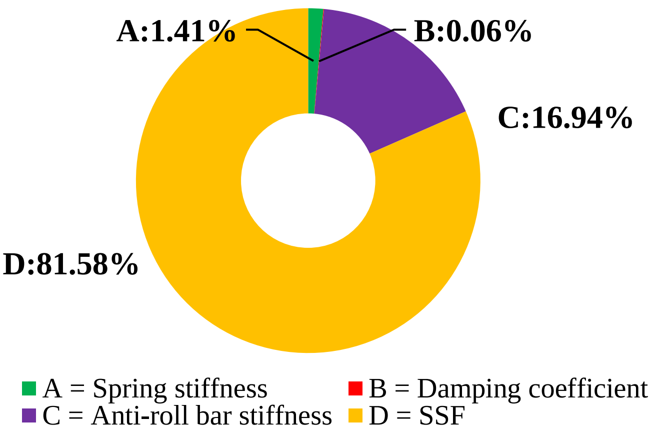


Figure 6 The percentage of the main parameters affected to the tilt angle

4. CONCLUSION

The effects of the suspension parameters (i.e., spring stiffness, damping coefficient, anti-roll bar stiffness, and SSF) on the tilt angle test in which the stability of the passenger bus was presented. The design of the experiment based on the full factorial method was used to analyze the main effects on the tilt angle. The results of the Pareto chart revealed that the static stability factor exhibited the highest sensitivity to the tilt angle with approximately 82%. For the suspension system of a passenger buses, the anti-roll bar or torsion stiffness was the main effect to tilt angle with approximate 17%, followed by spring stiffness and damping coefficient as 1.4% and 0.06%, respectively. In this study, it can be concluded that the suspension system of the passenger bus, especially in the anti-roll bar component, affected the tilt angle test.

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REFERENCES

Andrzej, R. (2015). Investigation of the influence of the centre of gravity position on the course of vehicle rollover. In *Proceeding of 24th International Technical Conference on the Enhanced Safety of Vehicles (ESV)*, Gothenburg, Sweden.

Bingley, H. (2015). *London transport RM1039 on the tilt test at Aldenham works 70's*. [Online URL: https://www.flickriver.com/groups/1921981@N24/pool/random/] accessed on February 20, 2020.

Department of Land Transport. (2012). *The regulation of stability test of the bus on 29 June 2012*. [Online URL:https://www.dlt.go.th/ minisite/m_upload/editor-pic/nakhonphanom/files/00000239(1)(1).pdf] accessed on October 18, 2019.

Dixon, J. C. (1999) *Tires, Suspension, and Handling*, 2nd, Cambridge University Press: UK, pp. 181-182.

Heydinger, G. J., Bixel, R. A., Garrott, W. R., Pyne, M., Hove, J. G., and Guenther, D. A. (1999). Measured vehicle inertial parameters-NHTSA's data through November 1998. *SAE Technical Paper*, 1999-01-1336.

Hinch, J., Shadle, S., and Klein, T., (1992). NHTSA's rollover rulemaking program - Results of testing and analysis. *SAE Technical Paper*, 920581.

Michael, B., and Damian, H. (2004). Introduction. In *The Multibody Systems Approach to Vehicle Dynamics*, 1st, New York: Butterworth Heinemann Ltd., pp.14-20.

Safety Department of Land Transport. (2019). *The results of the stability test bus in 2019 report*, Department of Land Transport, Bangkok.

Sert, E., and Boyraz, P. (2017). Optimization of suspension system and sensitivity analysis for improvement of stability in a midsize heavy vehicle. *Engineering Science and Technology, an International Journal*, 20(3), 997-1012.

United Nations Economic Commission for Europe. (2014). Requirements to be met by all vehicle. In *Uniform provisions concerning the approval of category M2 or M3 vehicles with regard to their general construction, Regulation NO.107*, pp. 32-69. [https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2015/R107r6e_01.pdf] accessed on September 7, 2019.