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Finite Element Bus Rollover Test Verification

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Abstract – *This study is conducted to verify the rollover test of the finite element bus model. Verification is a process of determining that a computational model accurately represents the theoretical mathematical model and its solutions. In case of bus rollover simulation, the verification process is by looking into its energy balance, in which all energy associated with the bus rollover process must be equal and preserved before and after the rollover. Any energy imbalance indicates errors in the rollover process and must be rectified so that the errors remain in acceptable tolerance. The main energies involved in calculations are potential energy, kinetic energy, internal energy, contact energy, rigidwall energy, damping energy, hourglass energy, and total energy. The finite element bus model used is CONTRAST bus developed by CM/E Group, Politecnico di Milano. The rollover test standard used is UN R66, and the software used to set up and solve the simulation are LS-PrePost and LS-DYNA. Energy balance and energy ratio from the rollover simulation shows that the verification procedure is followed, results are within acceptable values, and the rollover test is verified.*

Keywords: finite element, bus model, rollover simulation, verification, energy balance

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1.0 INTRODUCTION

Severe bus rollover crashes usually resulting in a high number of casualties. One of the main reasons for this is the failure of bus structure when it collapses during the rollover crash. The structure collapses and intrudes into survivable space of the bus, and this causes the occupants trapped in the bus. The examples of such cases are shown in Figure 1. The bus structural deformation is worsening if it is affected by ageing effects (Abdul Hamid and Li, 2013).

(a) (b)

Figure 1: Examples of severe bus rollover crashes in Malaysia (Hamzah et al., 2012)

Because of this problem, standard bus rollover tests were made available around the world to define and describe the level of bus structural deformation and its intrusion level into the survivable space, so that its structural strength can be further improved to at least withstand its minimum survivable space.

The bus rollover test can be conducted in various ways, e.g. full body rollover test on a new bus, rollover test using bus body sections, body sections quasi-static loading test, or by quasi-static calculation. For full-body rollover, bus body sections rollover and quasi-static loading test, it can be done either by real test or visual test (UNECE, 2006). Visual test refers to computer simulation test using finite element (FE) software. For this test, the finite element model needs to be verified to ensure its results are accurate and close to the real test results. The purpose of this paper is to show how the process of FE bus model rollover test is verified, and how the results of the rollover should be within the acceptable range.

2.0 METHODOLOGY

2.1 Selection and Rollover of FE Bus Model

The finite element bus is modelled from a single deck high-floor, intercity CONTRAST bus assembled by VEST-BUSSCAR AS Company, which is the distributor for Iveco bus in Norway and Sweden (Revolvy, 2017). The bus model was developed by Pezzucchi (2016), and further improved and validated by Cortese and Gazzaniga (2014). LS-Prepost software was used to apply parameters in the bus model, e.g. material models, assignment of properties, element formulation, contact definition, initial conditions, and boundary conditions. The solver used to simulate the bus rollover is LS-DYNA. The rollover of the bus was setup according to UN R66 regulation (UNECE, 2006).

Figure 2 shows the snapshots of bus rollover simulation. Figure 1(a) shows the bus at its unstable condition (49^{o}) at t = 0.0 sec. The bus then slowly falls and hits the ground at t = 1.36 sec. The contours of effective plastic strain (unitless) can be seen at several locations of the structural points after the impact with the maximum value of 5.077 x10^3. The bus eventually at its rest position after t = 2.00 sec.

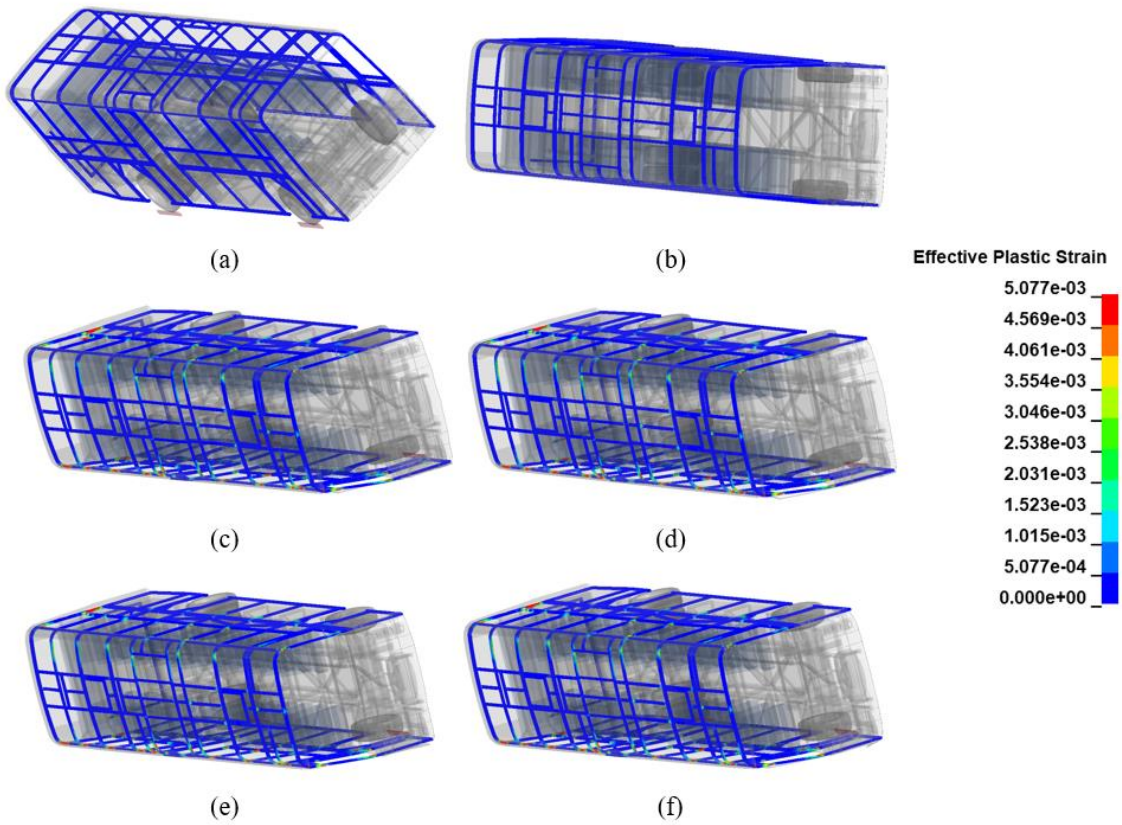

Figure 2: Snapshots of the bus rollover simulation in its original condition at
(a) t = 0.0 sec. (b) t = 1.2 sec. (c) t = 1.4 sec. (d) t = 1.6 sec. (e) t = 1.8 sec. (f) t = 2.0 sec

2.2 Verification by Energy Balance

Verification is the process of determining that a computational model accurately represents the theoretical mathematical model and its solution (Schwer, 2007). In case of bus rollover simulation, verification can be made by checking the quantity of energy balance, deformations, kinematics, kinetics and other quantities (Matolcsky and Molnar, 1999). Bojanowski (2009) introduced the procedure of bus rollover simulation, in which all energy components during the rollover should be conserved and all non-physical energy should be kept minimum. Bojanowski (2009) specifies the conservation of energy equation, in which

$$E_{LS\,total} = E_{kin} + E_{int} + E_{si} + E_{rw} + E_{damp} + E_{hg} = E_{kin}^0 + E_{int}^0 + W_{ext} \quad (1)$$

where

$E_{LS\,total}$ = LS-DYNA total energy,
E_{kin} = kinetic energy,
E_{int} = internal energy,
E_{si} = contact (sliding) energy,
E_{rw} = rigidwall (stonewall) energy,
E_{damp} = system damping energy,
E_{hg} = hourglass energy,
E_{kin}^0 = initial kinetic energy,
E_{int}^0 = initial internal energy,
W_{ext} = external work from applied loads.

The energy balance is perfect if the energy ratio is equal to 1 (LSTC, 2015).

$$e_{ratio} = \frac{E_{total}}{E^0_{total} + W_{ext}} \quad (2)$$

where

E^0_{total} = initial total energy

The acceptable value of the ratio is 1.00 +/- 0.07 (Pezzucchi, 2016). The discrepancies in the ratio are due to spurious energy produced in the system and simulation error.

3.0 RESULTS AND DISCUSSION

From GLSTAT ASCII file in LS-Prepost, the energy balance for the rollover simulation was extracted and is shown in Figure 3. Potential energy, E_{pot} and the real Total Energy, E_{total} were hand calculated and added in the figure in the dotted lines.

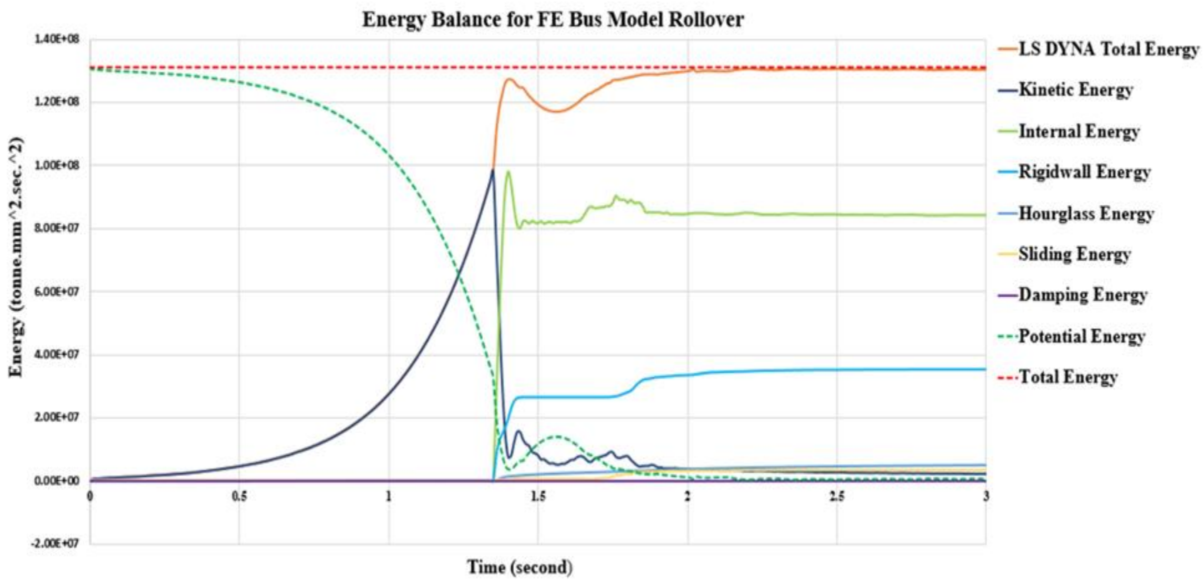

Figure 3: Energy balance for the rollover simulation of the CONTRAST bus

The summary of energies expected theoretical results, actual results and their level of tolerance are shown in Table 1. Note that the unit used for energy in Figure 2 is tonne.mm^2.sec.^{2} which is used in LS-Prepost. This is equivalent to the typical unit of kilojoule (kJ).

Before impact, E_{kin} exponentially increased until it reached its maximum value of 98.2 kJ during impact at t = 1.36 sec. It then suddenly decreased and stabilised at 3.1 kJ. After the impact, the kinetic energy transforms into several mechanical works like E_{int}, E_{si}, E_{rw}, and E_{hg}. These energies emerged but within their acceptable values, while E_{damp} remains zero throughout the simulation.

Potential energy, E_{pot}, is calculated using the typical equation of

$$E_P = Mg\Delta h \tag{3}$$

where

M = total mass of the bus

g = gravitational acceleration (constant)

Δh = vertical movement of the bus from the highest and unstable position of CG of the bus to its final location.

Table 1: Summary of energies obtained during the FE bus rollover simulation

Type of energy	*Expected theoretical results (kJ)*	*Expected % of $E_{LS\ total}$*	*Actual results (kJ)*	*Actual % of $E_{LS\ total}$*	*Tolerance*
$E_{LS\ total}$ (at t = 3.0 sec.)	-	-	131.0	100	-
E_{kin} (max. at point of impact when t = 1.36 sec.)	-	-	98.2	75.0	acceptable
E_{kin} (at t = 3.0 sec.)	-	-	3.1	2.4	acceptable
E_{int} (at t = 3.0 sec.)	-	-	84.2	64.3	acceptable
E_{si} (at t = 3.0 sec.)	-	-	3.3	2.5	acceptable
E_{rw} (at t = 3.0 sec.)	32.75	25	35.5	27.1	acceptable
E_{damp} (throughout simulation)	0.0	0.0	0.0	0.0	acceptable
E_{hg} (at t = 3.0 sec)	< 6.55	< 5	4.9	3.7	acceptable
E_{pot} (at t = 0.0 sec)	-	-	131.0	100.0	acceptable
E_{total} (throughout simulation)			131.0	100.0	acceptable

At the highest, unstable position of CG, E_{pot} is 131 kJ (at t = 0.0 sec.). The value decreases until the point of impact, where the value stabilises and reaches its zero level. By adding E_{pot} and $E_{LS\ total}$, the real Total Energy, E_{total} is obtained. E_{total} is maintained throughout the simulation, which is 131 kJ. This shows the total energy is conserved before, during and after the bus impact. The energy ratio obtained from the simulation is shown in Figure 4. The ratio is in between 0.95 and 1.06, which is within the acceptable range for further analysis.

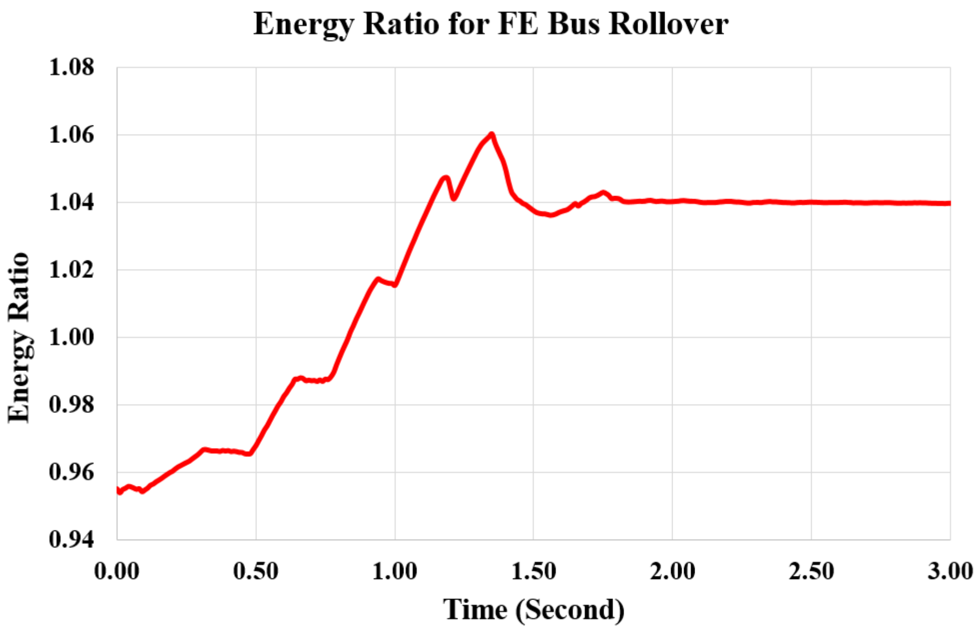

Figure 4: Energy ratio for the FE bus rollover simulation

4.0 CONCLUSION

From the results of energy balance, it can be seen that the energy components throughout the simulation of CONTRAST bus rollover, together with its energy ratio, are within the acceptable range. Hence, it is concluded that the bus rollover is verified. It can be used as a baseline for further analysis.

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