Applied virtual (VT) technology on bus superstructure roll-over tests

VINCZE-PAP Sándor[1]**, CSISZÁR András**[2]

[1]JÁFI-AUTÓKUT Engineering Ltd., H-1115 Budapest, Csóka u. 7-13.,
email: vincze_pap@jafi-autokut.hu ; www.autokut.hu
[2]Meshining Engineering Ltd., H-9026 Győr, Ady E. u. 49.,
email: andras.csiszar@meshining.com ; www.meshining.com

Abstract. The crashworthiness of buses and coaches largely depends on the energy absorbing capability of the rectangular tubes not neglecting the importance of the new shape-design and the manufacturing technology. The vehicle industry, in the development process, expansively uses the virtual techniques. In spite of that the final qualification or approval procedure does not allow the usage of this kind of methods widely till now. (The European ECE R66 is the only vehicle regulation in the subject of passive safety due to the virtual methods.) For improving and checking the rollover safety, many Hungarian achievements can be found from the beginning. This paper tries to set up précised analysis of virtual procedure, detailed initial condition-system for rollover simulation and possible virtual methods are presented too.
The ECE R66 regards to the adequacy of bus superstructure strength and this regulation specially allows not only real roll-over test but the usage of different computer techniques, virtual technologies too.
The future trend in the vehicle regulations is to widen the possible applications of virtual (VT) technology and it is a very sensitive question both for test centres and approval authorities. There are many test centres and engineering offices in Europe which carry out computer control calculations on partials or full-scale bus structure for determining the bus roof strength conformity due to the official ECE 66.01 regulation. In spite of the excellent virtual techniques the test procedures are not adequately validated and controlled; the condition of VT procedures are not clarified.

Keywords: bus, ECE 66 Regulation, passive safety, roll-over, virtual technology, IMVITER project

1 Introduction

Virtual method are widely used in the vehicle development process, virtual methods for checking of regulated requirements mostly as partial, additional methods can be used. The vehicle regulations –tanks for the rare exception -, does not allow the thoroughly usage of virtual method. Using virtual tests we can make differences between the full and partial (hybrid) virtual tests. The second one is more frequently used. The main difference between two methods is the simplicity of system to be checked by full VT if the requirements allow to omit the validation tests at full virtual approach. ANNEX XVI of directive 2007/46/EC (framework for the approval of motor vehicles) and EU Regulation 371/2010 summarise the specific conditions required from virtual testing methods and regulatory acts for which virtual testing methods may be used by a manufacturer or a technical service. Sorrowfully passive safety or dynamic tests are lacking from these regulatory acts till now.

JÁFI-AUTÓKUT (Budapest) has participated in the IMVITER project (EU 7 Framework programme) which was finished last year. [1] Main objective of it was the implementation of virtual (VT) procedures in existing safety standards by consolidation of advanced VT technologies and looking for the improvement of homologation procedures as well as setting the base for improvement of integrative safety. (Some special modifications were proposed by IMVITER to the legislative text of Regulation 371/2010 worked out by detailed researches, e.g. scope extension of virtual testing methods with seat belt anchorages (ECE R14) and pedestrian protection (directive 2003/102/EC) too.)

1.1 Short history of development bus roof strength test method in Hungary

The first proposal for European regulation on the bus roof strength test was developed by Hungary at the beginning of 70's last century, and the official version of ECE Regulation No. 66 entered into force only in 1986 based on the mutual English-Hungarian proposal. [2] The regulated basic accident situation: the bus (with fixed half passenger weight) shall be rollover from 800 mm height onto concrete surface requiring a minimum residual (survival) space. For this requirement the maximum deformed shape and intrusion of structure shall be measured or calculated all the time of roll-over process. (Figure 1) Some modifications of Regulation have happened in 2005, but essentially it is not changed last quarter century. [4]

Extremely interesting thing is that it was the first and it is still the only dynamic vehicle regulation which allows calculation (computer) method in the approval procedure.


Rollover slope test (Hungarian proposal) - 1975


Pendulum test - 1988

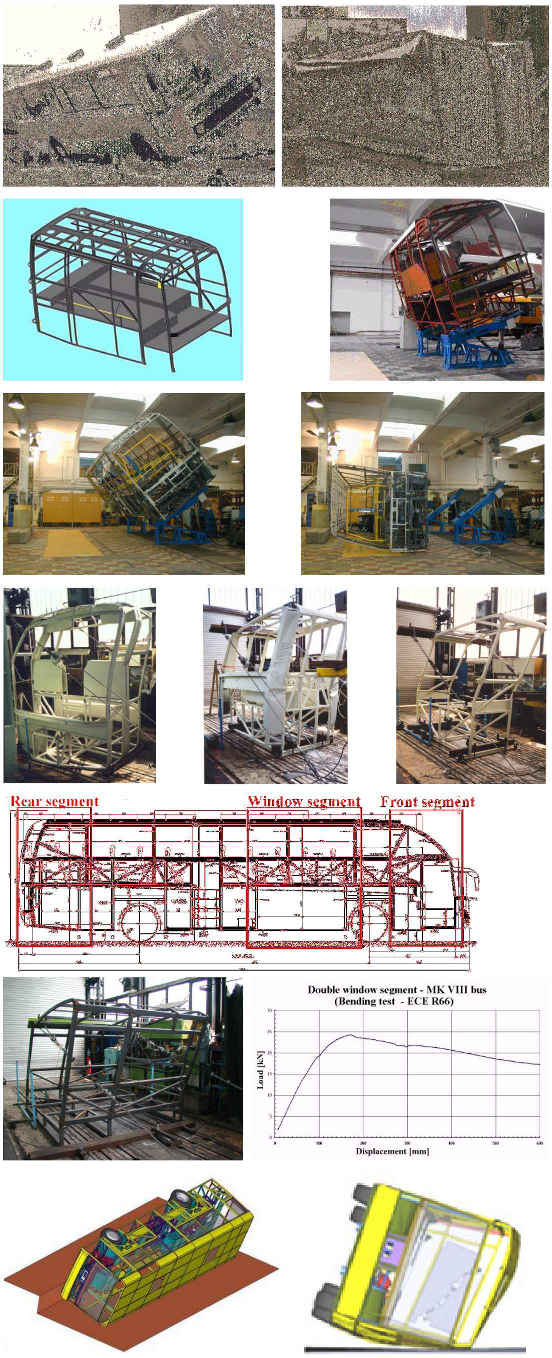

First regulated (ECE R66) rollover test on Ikarus 365 bus - 1986

Fig. 1 Earlier test versions from practice of AUTÓKUT Budapest

(Remark: the pendulum test on body sections as alternative method was allowed till 2005, although its inadequacy was already proved in 1993. [3])

2 Regulated test versions of roof strength tests

Fig. 2 summarises the basic and alternative, equivalent roof strength test methods can be carry out for proving the compliance with the requirement due to the ECE R66.01.



a. Rollover test on a complete vehicle as the basic approval method

(b1. Compressed structure)

b. Rollover test on body sections representing the complete vehicle

(b2. Original structure with essential and substitutive structural elements)

c. Quasi-static loading tests of body sections

d. Quasi-static calculations based on the results of component tests

e. Computer simulation - via dynamic calculations - of the basic rollover test on a complete vehicle

Fig. 2 Updated test methods by ECE 66.01 regulation

The first three versions (a-b-c) of bus roof strength test are based on laboratory structural tests without any worthwhile calculations. The last two versions (d-e) show possible applications of special calculations where whatever virtual method usage are considered. (The quasi-static calculation method which was applied at the AUTÓKUT first in 1990 can not be considered as a virtual method. The quasi-static calculation means a special iterative calculation in our application.)

For the better explanation of virtual technology and demands of computer simulation, let’s see the roll-over phases at complete roof strength test.

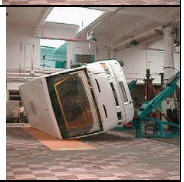
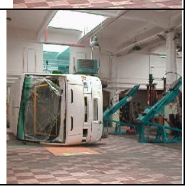
a	*Initial condition* (t_o=0) the bus stands on one-side wheels in instable condition	
b	*Rigid-type turning* ($0<t<t_1$) turning on the shoe-points of the wheels	
c	*Impact of cantrail* ($t=t_1$) movement of cantrail is stopped	
d	*First period of structural deformation* ($t_1<t< t_2$) plastic hinges are working	
e	(*Possible impact of waistrail* ($t = t_2$) depending on the superstructure rigidity)	
f	*Second period of structural deformation* ($t_2<t< t_3$) plastic hinges are further working	
g	*Maximum structural deformation* ($t = t_3$) sidewall deformation reaches the maximum value while the bus slides on the concrete surface	
h	*Structural deformation is over* (t_4) while the bus is moving	
i	*Ending position* ($t = t_5$) the bus lays on the concrete surface	

Fig. 3 Phases of a complete bus roll-over test

And a simple energy balance of the roll-over process:

$$\mathbf{E_p = W_{ph} + W_f + W_s + W_v}$$

Where:
$\mathbf{E_p}$ - initial potential energy at the instable position;
$\mathbf{W_{ph}}$ - absorbed energy by structural elastic and non-elastic deformation;
$\mathbf{W_f}$ - friction energy at the first period of structural deformation while the cantrail slides on the surface;
$\mathbf{W_s}$ - energy absorbed by the surface during the surface-touching of cantrail and waistrail;
$\mathbf{W_v}$ – rest (friction, surface absorbed energy, kinetic energy) after reaching the maximum deformation.

Together the phases of the roll-over process and this simplified formula of energy balance of the strength test due to basic, standard method we can clarify more clearly the requirements of VT technology.

2.1 Iterative calculation method based on laboratory segment bending tests

First a bit back to the simple iteration calculation method based on laboratory cross-segments' bending tests which was developed by AUTÓKUT in 1980 and published on ESV conference in 1998. It also uses computer simulation but is not possible to classify as virtual method. (Practically this method was suggested to substitute the pendulum test method.) The basic idea of this method is that the cross-sectional rings - except mainly the front and rear walls - can be modelled with perfect plane frames. These extended (mostly the front and rear) parts of coaches as extended sections can also be substituted with plane-frames at the rigidity centreline measuring or calculating the bending stiffness of the original extended cross-sectional units. Then geometrically all the substitutive plane-frames can be positioned into own centre plane of bending stiffness or CG and the calculation of complex bus deformation can be started. [4]

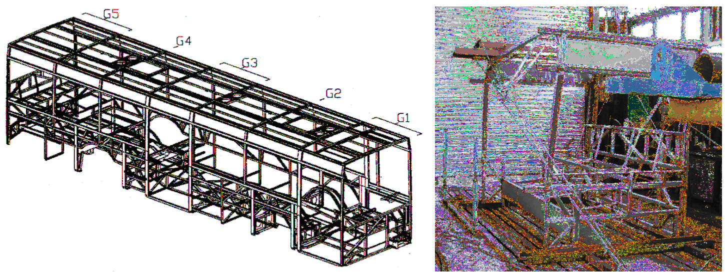


Fig. 4 NABI 700SE bus geometrical layout and dividing into five cross-segments; and the laboratory bending test on extended, bus manufacturer made, rearwall segment

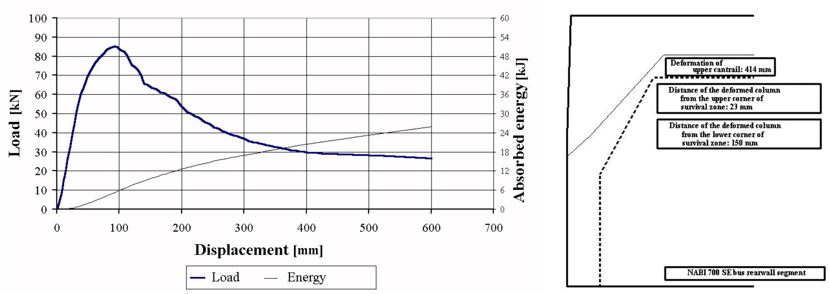


Fig. 5 Load-displacement diagram of rearwall segment bending test and the calculated maximum deformed shape of rearwall outline with consideration of plastic joints' places

The reference energy to be absorbed by the bus shall be calculated by the requirement of ECE R66.01. Our iteration method calculates the cantrails deformations using small time-steps considering the bus rotation around its rigidity point. Deformation displacements of 'k' pieces cross-sectional frames are modeled with 'k' pieces non-linear springs. At the example in **Fig. 3**, 'k'=5. The process of rollover shall be simulated as a behavior of non-linear elastic support and it is ended when the bus absorbed the prescribed reference energy. The whole procedure is described in paper [4].

This method is a so-called conservative approach. It is based on the proved facts that the dynamic deformation of a given structure is less than the static deformation of it in the case of same loading position and quantity of absorbed system energy. (Remark: at static loading the structure's deformation happens through equilibrated load-positions and all the measured and transmitted energy causes deformations in the given structure, in correct conditions. At dynamic loading the system energy is not transmitted fully to the given structure to be deformed. Starting with same initial transmitting energy the absorbed energy of the given structure and its deformation will be less than at static loading case.)
Final evaluation of this method uses couple hundred iteration steps in closed mathematical formulas but it can not be regarded as a virtual (VT) technology, because no any advanced computer aided engineering is needed in the procedure.

3 Conditions for rollover simulation

"A virtual testing method should provide for the same level of confidence in the results as a physical test. Therefore, it is appropriate to lay down relevant conditions to ensure that proper validation of the mathematical models is conducted." (R 371/2010)

Due to this guideline next Figure delineates the layout of the (hybrid) virtual method that can be used on regulated bus roof strength's tests due to our practice.

Big advantage of roof strength test by VT is that the checking can be carried out in the development process. For the Approval Authority satisfaction the test centre shall prove the adequacy of its method in four fields (Figure 6).

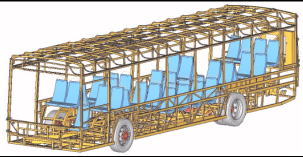
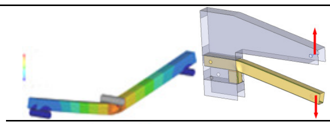
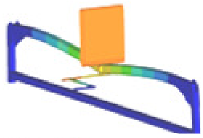
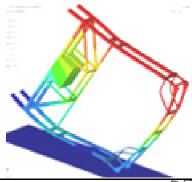
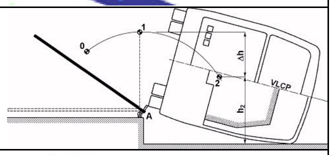
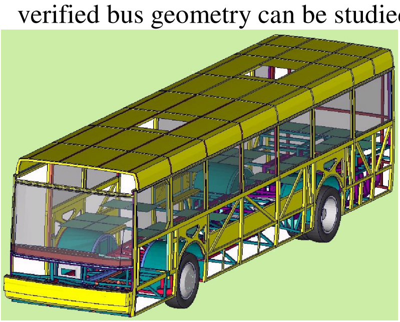
GEOMETRY		
BASIC MATERIAL PROPERTY		▪ *base $\sigma - \varepsilon$ curves* ▪ *strain rate model* ▪ *anizotropy model* ▪ *enhanced corner properties*
VALIDATION (PLASTIC JOINTS TESTS)	Static test	
	Dynamic test 1	
	Dynamic test 2 (Segment test)	
IMPACT CONDITIONS	Suspension Surface	
OUTPUT (Result)		

Fig. 6 Relevant parts of the virtual (VT) procedure on bus roof strength test

In the next subpoints we survey these fields through a real simulation.

3.1 Bus geometry

Almost independently from the FE code a good example for a general layout of verified bus geometry can be studied in the Figure 7.



NODE number: 75200
SHELL element number : 81380
SOLID element number: 2161
BAR/BEAM element number : 781
Property number: 102/ Material number: 102
SHELL element quality criteria (by PamCrash):
Warping = 10/ Aspect ratio = 4
Minimum quadrilateral internal angle = 40
Maximum quadrilateral internal angle = 140
Minimum triangle internal angle = 30
Maximum triangle internal angle = 100

Fig. 7 An example for set up of bus finite element structure

3.2 Material property

Vehicle collisions shall be considered as a highly dynamic deformation process, where structural steels deform under different strain rates. Therefore, an appropriate material model, which takes strain rate effects, anisotropy and enhanced corner properties into account, has to be chosen for a right numerical model.

The material law of mathematical model must contain:

a. Definition of base *s* - *e* curve of material
b. Strain Rate hardening effect
c. Sheet metal Anisotropy
d. Enhanced corner properties
(Our samples regard to the X2CrNi12 ferrite stainless steel.)

a. Base *s* - *e* curve of material

Stress-strain relationship for annealed and cold formed stainless steels is nonlinear. A typical stress-strain curve for stainless steel has no yield plateau as is the case for carbon steel. The stress-strain curve shows a material that behaves in an increasingly non-linear fashion and the overall ductility is generally very high. On the other hand, unlike carbon steel there are clear differences associated with the longitudinal tension and compression, as well as with transverse tension and compression.

For simulation purposes a full range stress strain relationship has been developed for X2CrNi12 ferritic stainless steel alloys which are valid over the full strain range. The expression is useful for the design and numerical modelling of stainless steel members and elements which reach stresses beyond the 0.2% proof stress in their ultimate limit state.

The stress-strain curve was chosen as a standard Ramberg-Osgood (Ramberg and Osgood, 1941) curve, which generally provides close approximations to measured stress-strain curves for stresses up to the 0.2% proof stress. In order to improve the accuracy of stress strain curve in the range from the 0.2% proof stress until to the ultimate tensile strength (σ_u), Rasmussen suggested an enhanced ***s* - *e*** expression.

KARA K03 *(Arcelor)* X2CrNi12 ferritic stainless steel's σ - ε curve according to Ramberg-Osgood ($\sigma<\sigma_{0.2}$) and Kim JR Rasmussen ($\sigma>\sigma_{0.2}$)													
	Strain (ε)	Stress (σ)	True Strain (ε)	True Stress (σ)		$R_{P0,2}$ (MPa)	R_m (MPa)	E_0 (Mpa)	$\sigma_{0,01}$	$\sigma_{0,2}$	σ_u	ε_u	n
	0,000000	0,0	0,000000	0,0				210000,0	250,0	320,0	486,4	0,34	12,1

b. Strain rate

The strain rate domain can be divided into three main different categories: Low strain rates form 10^{-5} to 10^{-1} s^{-1}, medium strain rates 10^{-1} to 10^{2} s^{-1}, high strain rates from 10^{2} to 10^{4} s^{-1}. Rates of strain from 10-1 to 10^{2} s^{-1} are characteristic of vehicle collisions. (Rollover test belongs to medium rate level.)

The relation between the dynamic stress σ and the strain rate $\varepsilon' = d\varepsilon / dt$ of a particular material is given by (*Cowper-Symonds*):

$\sigma = \sigma_o [1 + (\varepsilon' / D)^{1/q}]$, where ε' = strain rate (s^{-1}), D = constant (s^{-1}), q = constant, σ = dynamic stress (N/mm^2) at uniaxial rate ε' (s^{-1}).

In case of X2CrNi12 ferrite stainless steel the different strain rate curves are as follows:

KARA K03 *(Arcelor)* X2CrNi12 ferritic Stainless Steel's strain rate curves (σ - ε) by Cowper-Symonds										
True Strain (ε)	$\varepsilon' = 0$ 1/s True Stress (σ) (Pa)	$\varepsilon' = 0,1$ 1/s True Stress (σ) (Pa)	$\varepsilon' = 1,0$ 1/s True Stress (σ) (Pa)	$\varepsilon' = 10,0$ 1/s True Stress (σ) (Pa)	$\varepsilon' = 15,0$ 1/s True Stress (σ) (Pa)	$\varepsilon' = 20,0$ 1/s True Stress (σ) (Pa)	$\varepsilon' = 30,0$ 1/s True Stress (σ) (Pa)	$\varepsilon' = 40,0$ 1/s True Stress (σ) (Pa)		ε' (1/s)
0,000000	250300000,0	293591620,7	318295829,5	357097406,8	365934760,5	372644992,0	382768889,2	390455997,3		0,1

c. Anisotropy

Another material characteristic considered was the anisotropy. The basic isotropic nonlinear plastic hardening model was modified to include the material anisotropy caused by cold-rolling of metal sheets. For cold-rolled sheets, the principal axes lie in the direction of rolling, the σ_{11} is the stress in the direction of rolling, σ_{22} is transverse to the direction of rolling and σ_{33} is normal (or through-thickness) anisotropy. The anisotropy was incorporated in the initial yield surface according to the Hill criteria described by:

$$f(\sigma) = \left[\frac{(G+H)\sigma_{11}^{\ 2} + (F+H)\sigma_{22}^{\ 2} - 2H\sigma_{11}\sigma_{22} + 2N\sigma_{12}^{\ 2}}{2} \right]^{1/2}$$

Anisotropic Yield function with Lankford's coefficients:

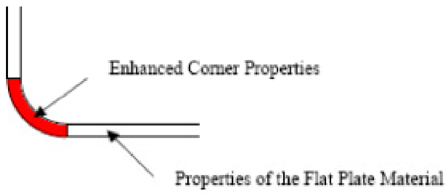
$$f(\sigma) = \left[\frac{P\sigma_{11}^{\ 2} + R\sigma_{22}^{\ 2} + PR(\sigma_{11} - \sigma_{22})^2 + (2Q+1)(P+R)\sigma_{12}^{\ 2}}{P(R+1)} \right]^{1/2}$$

In case of X2CrNi12 ferrite stainless steel the Hill's coefficients and Lankford's coefficients are as follows:

Hill's anisotropic coefficients (*F, G, H, N*) of KARA K03 (Arcelor) X2CrNi12 ferritic Stainless (*calculated Lankford coefficients*)												
F Hill coefficient	***G*** Hill coefficient	***H*** Hill coefficient	***N*** Hill coefficient	***H*** H=1-G Check!	***P*** or r_{90} Lankford coefficient	***Q*** or r_{45} Lankford coefficient	***R*** or r_0 Lankford coefficient		R_{11} anisotropic stress ratio	R_{22} anisotropic stress ratio	R_{33} anisotropic stress ratio	R_{12} anisotropic stress ratio
0,41	0,54	0,46	1,24	0,46	1,12	0,81	0,87		1,00	1,15	1,10	1,10

d. Enhanced Corner Properties (anisotropic nonlinear plastic hardening model)

As the bus roof and upper body consists of ferrite stainless steel tubes which have been produced by cold work and welding the anisotropic nonlinear plastic hardening model was modified to include the enhanced corner properties, which were applied strictly to the corner geometry of the section. Enhanced corner properties were calculated according to the AS/NZS 4673 (2001) model for predicting corner strength, where *r* is the centreline corner radius, *t* is the section thickness, $\sigma^0_{0,2}$ is the flat sheet yield strength, $\sigma^C_{0,2}$ is the enhanced corner yield strength and σ^0_U is the flat sheet ultimate strength.



$$\sigma^C_{0,2} = \frac{B_C \sigma^O_{0,2}}{(ri/t)^m}$$

$$Bc = 1{,}486 \frac{\sigma^O_u}{\sigma^O_{0,2}} - 0{,}210\left(\frac{\sigma^O_u}{\sigma^O_{0,2}}\right)^2 - 0{,}128$$

$$m = 0{,}123 \frac{\sigma^O_u}{\sigma^O_{0,2}} - 0{,}068$$

In case of X2CrNi12 ferritic stainless steel the enhanced corner properties are as follows:

Enhanced corner properties of KARA K03 (*Arcelor*) X2CrNi12 ferritic Stainless Steel at corners												
r_i (mm)	t (mm)	E_0 (Mpa)	$\sigma_{0,01}$	$\sigma_{0,2}$	σ_u	ε_u	*n*	*e*	$E_{0,2}$	*m*	$\varepsilon_{0,2}$	B_C
3,0	3,0	210000,0	250,0	320,0	486,4	0,34	12,1	0,0015	12405,7	3,3	0,0035	1,65

3.3 Model validation (plastic joints tests)

After the verification of bus geometry and the set up basic properties of materials special validation tests shall be carried out for final adjusting and giving proof of acceptability of applied material properties. As the Figure 6 shows static or different kind of dynamic validation tests can be carried out depending on the required accuracy of approximation.

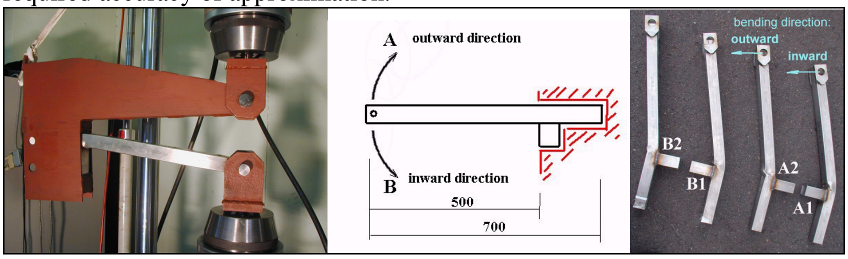


Fig. 8 Laboratory static bending test arrangement of welded joints; Inward and outward direction functions are differing with 4-5% which divergence shall be considered FEM calculations (direction is related to the real roll-over test for right and left side of the coach!); deformed shapes of empty (A) and resin-filled tubes (60/40x1,5 mm)

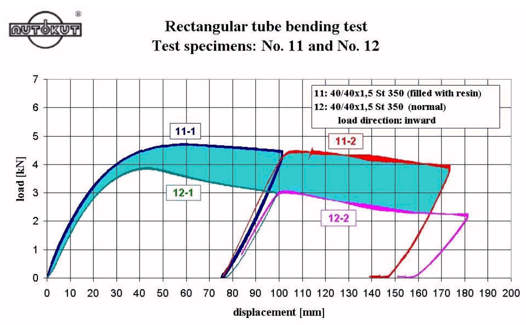


Fig. 9 Empty and resin-filled 40/40x1,5 mm St 350 tubes' bending tests; the measured bending force is bigger with 20% and the absorbed energy is also bigger with 30% than the standard empty tubes' values;

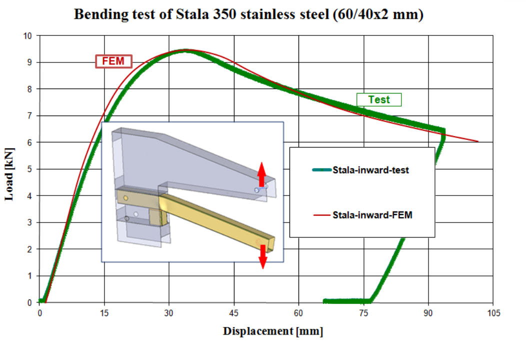


Fig. 10 The measured and simulated load-displacement functions for bending of welded joint

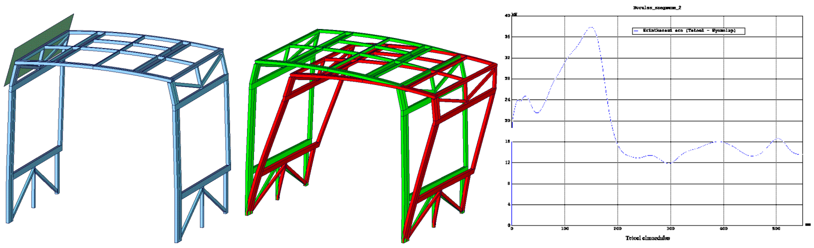


Fig. 11 The calculated load-displacement diagram by simulation of static bending test of window-frame segment and

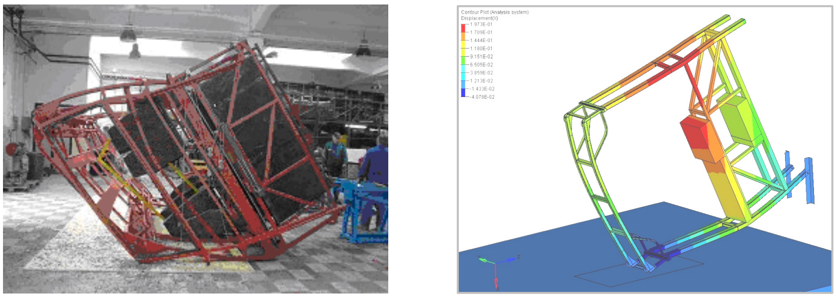
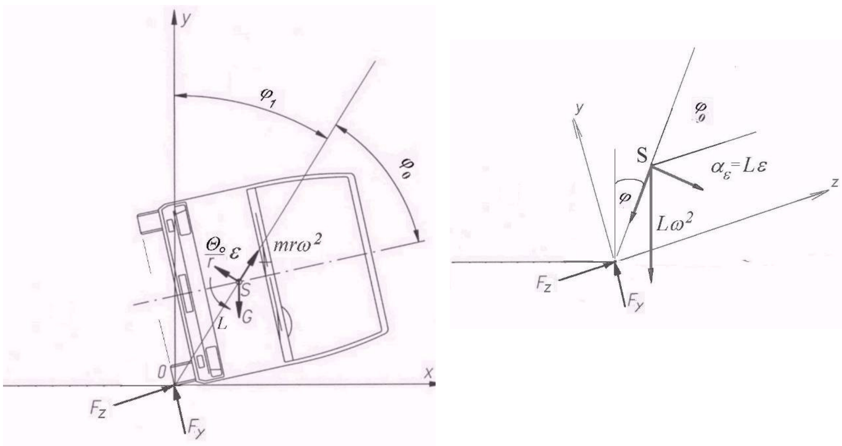
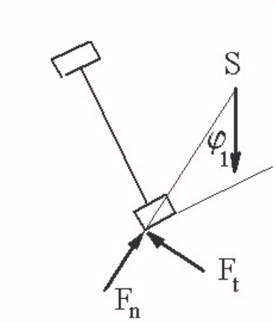


Fig. 12 laboratory and virtual roll-over test on bus segment

3.4 Impact conditions

Here two essential parameters shall be considered:
a. Suspension simulation: rigid (or independent)
b. Influence of friction half-cone angle of tyre





$$\varepsilon = \frac{mg\sin\varphi_1}{\Theta_0} = \frac{F_t}{\Theta_s}$$

$$\boxed{F_t = \frac{\Theta_s}{\Theta_0} mg\sin\varphi_1}$$

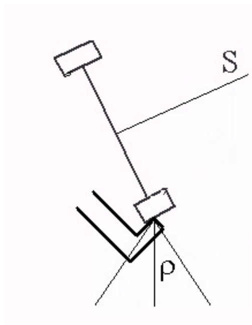


Fig. 11 Clarifying the effect on tyre by the rollover equipment

φ_1 **-** border-angle of tyre backsliding

Condition of backsliding: $\dfrac{|F_z|}{|F_y|}$ > tg ρ (ρ half-cone angle of friction)

c. Importance of surface quality (ECE R66 does not clarify this!)
Our laboratory's surface friction, μ= 0,33 (suggested: 0,3-0,45)

Elasticity (E): 12 –(cca. 16)- 24 kN/mm^2.

3.5 Results

Carrying out the virtual test the Figure 13 shows the calculated maximum deformations of front and rear parts of superstructure.

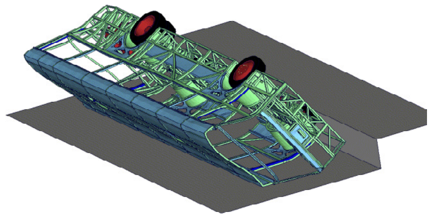


Fig. 12 Using validated test material cards the complete virtual rollover simulation can be carried out

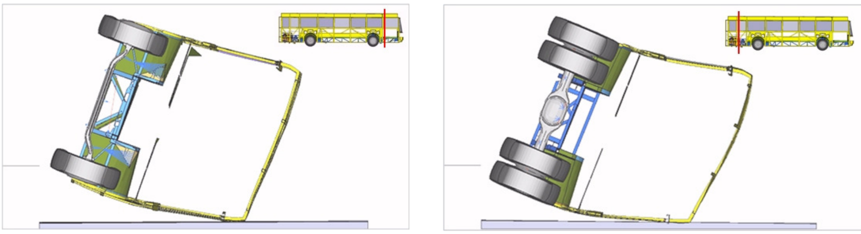


Fig. 13 Maximum deformations of front and rear parts of bus

The simulation was carried in three mass versions of this 42 seated bus. (Without passenger mass, with half 37,5 kg passenger mass and with 75 kg passenger mass.)

The table below shows the result summary of the bus roll-over simulation.

		Result Summary of BUS Roll over calculations										
		TOTAL ENERGY (Nm)	INTERNAL ENERGY (BUS absorbing +External work) at 250 ms (Nm)	Energy absorbing by GROUND at 250ms (Nm)	KINETIC ENERGY (Remaining) at 250ms (Nm)	Energy Ratio (GROUND/Internal) at 250ms (%)	GROUND Ratio (Stiff/Soft)	Total Displacement (Roof edge front) (mm)		Total Displacement (Roof edge back) (mm)	Ground sliding (Roof edge font) (mm)	Ground sliding (Roof edge font) (mm)
m_{dummy} 0,0 kg	STIFF Ground (E=24 KN/mm^2) Friction (μ=0,35)	78475,1	57745,1	2013,9	29843,2	3,61	1,25	200,0	at 80 ms	240,0	155,9	216,5
	SOFT Ground (E=12 KN/mm^2) Friction (μ=0,55)	78475,1	63351,0	2509,4	15170,8	4,12		206,0		256,0	143,5	146,4
m_{dummy} 37,5 kg	STIFF Ground (E=24 KN/mm^2) Friction (μ=0,35)	88328,8	68822,9	2603,1	31071,9	3,93	1,14	225,0	at 95 ms	273,0	173,3	226,0
	SOFT Ground (E=12 KN/mm^2) Friction (μ=0,55)	88328,8	78636,8	2965,6	14859,4	3,92		233,0		300,0	108,5	150,0
m_{dummy} 75,0 kg	STIFF Ground (E=24 KN/mm^2) Friction (μ=0,35)	98248,0	83468,2	2920,5	31974,0	3,63	1,16	250,0	at 120 ms	313,0	187,0	330,0
	SOFT Ground (E=12 KN/mm^2) Friction (μ=0,55)	98248,0	92442,0	3375,0	16748,8	3,79		260,0		362,0	90,0	213,0

4 Summary

As an assessment can be stated that before the virtual testing is carried out, the vehicle model shall be subjected to and pass the verification process (phase 1). Then the vehicle model has to be validated, i.e. the results compared to the results of a corresponding real test (phase 2). Once the vehicle model has been validated, it can be used later as a reference for type approval extension process of modified vehicles (phase 3) [1].

Phase 1: Mathematical Model Development and Verification
Starting from real vehicle drawings and bill of materials, the numerical F.E. model of such a product has to be generated according to the following steps, by the car manufacturer:

a) Discretization of the relevant vehicle geometries and components, i.e. the subsystems, joints + close environment of vehicle body structure, leading to the vehicle F.E. mesh.
b) F.E. modelling of material cards and joints, involved in the vehicle subsystem, having the appropriate level of complexity in terms of material and joint model, to validate with real test results in next phase (see Phase 2).
c) F.E. vehicle model assembly, with a validated procedure for simulating the joints involved in the real subsystem.

Phase 2: Model Validation
The bus manufacturer shall validate the vehicle model according to the procedure described in this paragraph, starting from the Verified model**.** The first step will be to validate the material cards and joint models to be used for virtual type approval procedure:

a) Generation of Material Cards: a battery of real tests must be conducted in order to compare with the material virtual test results. Both test (Real and Virtual) must also take into account the uncertainties. If the correlation criteria are fulfilled, this result shall be documented into a validation report, If not, the vehicle model has to be improved and the numerical simulations corresponding to the described validation steps repeated. After Approval Authority has verified that the quality and accuracy criteria are respected, the material cards become **Validated Material Cards** which can be used also later for other Virtual Type Approval Procedures.
b) Joint Models: a battery of real tests must be conducted in order to compare with the joint simulation test results. Both test (Real and Virtual) must also take into account the uncertainties. If the correlation criteria are fulfilled, this result shall be documented into a validation report. If not, the vehicle model has to be improved and the numerical simulations corresponding to the described validation steps repeated. After Approval Authority has verified that the quality and accuracy criteria are respected, the joint models become **Validated Joint Models** which can be used also later for other for Virtual Type Approval Procedure.

VT can be connected and permitted to many vehicle regulations which require significantly different test methods. Therefore, a general procedure can not be established, several different procedures are needed according to the technical content of the individual Regulations. (It should be noted that the existing Regulations are simpler as the real conditions, e.g. in many cases a static load is prescribed instead of the dynamic service loads or impacts in an accident.)
Some additional remarks for VT application:

a) In case of **small changes** to this vehicle type the model building and verification phase will be simple in a similar way as described above. The former validated model can be used without any new validation.
b) In case of more **significant changes** in the vehicle design (e.g. from line-welds to spot-welds) a subsystem real test and validation of the concerned subsystem model could be necessary, but there is no reason to repeated RT of the whole vehicle. The decision will show to the middle column and welded joints or modified sheet structure elements will be tested in electro-hydraulic test machines with moderate cost. FE model of these part systems will be developed and validated also quicker and at lower costs than in case of a full system model.

c) New validation could be necessary also if the simulation technique (software, model building method, elastic/plastic material model, iteration method, etc.) changes. The details of these changes should be worked out in cooperation with the concerned participants. Agreement of Approval Authority is enough once depending on the chosen direction of procedure.

References

[1] www.imviter.com (EU 7 Framework programme)

[2] ECE R 66.01 (TECHNICAL PRESCRIPTIONS CONCERNING THE APPROVAL OF LARGE PASSENGER VEHICLES WITH REGARD TO THE STRENGTH OF THEIR SUPERSTRUCTURE) http://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/r066r1e.pdf

[3] *S. Vincze-Pap:* **Realized Superstructure-Strength Methods on Buses, Criticism of ECE 66 Regulation** (The Third International Conference on Safety and the Environment in the 21st Century Nov. 7-10, 1994, Tel-Aviv, pp. 169-178

[4] *S. Vincze-Pap:* **European Test Methods for Superstructures of Buses and Coaches Related to ECE R66** *(THE APPLIED HUNGARIAN CALCULATION METHOD)* (16th International Conference on the Enhanced Safety Vehicles Conference, June 4-8 1998, Windsor, Canada), DOT HS 808 759, No. 98-S4-P-19, pp. 927-931. http://www-nrd.nhtsa.dot.gov/pdf/Esv/esv16/98S4P18.PDF

[5] *S. Vincze-Pap*, *A. Csiszár*: **Real and simulated crashworthiness tests on buses**, 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Paper No.: 05-0233, DOT HS 809 825, Washington, D.C. June 6-9, 2005 http://www-nrd.nhtsa.dot.gov/pdf/esv/esv19/05-0233-W.pdf

[5] *Vincze-Pap S*: **Autóbuszok passzív biztonsága** -Természet Világa - 2006 februári szám, Budapest, http://www.termeszetvilaga.hu/szamok/tv2006/tv0602/passz.html

[6] Matolcsy M.: **Crashworthiness of bus structures and rollover protection. Crashworthiness of Transportation Systems**: Structural Impact and Occupant Protection. 1997. Cluwer Academic Publisher. p. 321-360.