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LESSONS AND CONCLUSIONS- LEARNED FROM THE ANALYSIS OF BUS ROLLOVER ACCIDENTS

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ABSTRACT

A four years accident statistic is shown and analysed, including more than hundred bus rollover accidents. The number of fatalities and serious injured passengers proved that although this type of accident is rear, it is the most serious bus accident. Data can be found in this statistics about the small buses and double decker (high buses and coaches) too which are not covered yet by ECE Regulation 66. The different kind of rollover accidents (turn on side, roll dawn from the road into a ditch, falling into a precipice, combined rollover accident, etc.) may be studied. The standard accident – which is the basis of the approval test in an international regulation – is analysed on the basis of the accident statistics. The paper shows the development of the standard rollover test used in the ECE Regulation 66 (required strength of bus superstructure in rollover) and points out the problem of the "limited deformation". The limited deformation is an existing problem of the Regulation 66 created by the used standard rollover test. This paper and its discussion could contribute to the international work done for the development of Reg.66. The author is the chairman of the international expert group doing this job.

KEY WORDS:

Bus rollover, accident statistics, standard accident, geometrically limited deformation

1. SAFETY REGULATIONS

The simplified process of producing passive safety regulations for vehicles is the following:

- The public, the society recognises that a certain accident type (e.g. rollover) of a certain vehicle category (e.g. bus and coach) has an unacceptable high risk of mortality and injury and trough the media (press, radio, TV) requires an urgent solution. The common opinion is realistic and accepts that there is no way to protect the passengers when the bus rolls down into 100 m deep precipice, but there is a technically not well defined accident situation (or group of situations) in which the public needs the

protection. This is formulated in the concept of the "standard accident" which is the basis of a safety regulation.

- The responsible traffic authority (government, international body) recognizes the public demand and entrusts experts to work out requirements, test methods (regulation) applying of which the risk of mortality and injury may be drastically reduced. The experts are collecting information, studying accident statistics, analysing real accident situations, making measurements and tests and on the basis of these knowledge they define a standard accident situation together with belonging requirements and they describe a regulation
- The government puts into force – by low or by order –the new regulation and after that only those vehicles may participate in the traffic, which are approved according to this regulation.
- Further examination of (bus rollover) accidents helps both to the experts and to the public opinion to control the effectiveness of the new regulation. If the accident statistics proves the demanded reduction of the fatality and injury risk, no further action is needed. If the goal is not achieved, certain modification shall be made in the regulation, more severe requirements are needed, new standard rollover test shall be specified, etc.

2. EARLY STATISTICS ABOUT BUS ROLLOVER ACCIDENTS

After a very serious rollover accident – happened in 1973 – Hungary raised in ECE Geneva the problem of the required strength of bus superstructures in the case of rollover accidents. The born of an international regulation needed 12 years. The major problem was to find an appropriate standard rollover test, which is easy to perform, repeatable, which can separate the strong superstructure from the weak one, which leads to a higher level of passenger safety. [1]. In the mid of '70-s there was no experience and knowledge about the bus rollover accidents, therefore the first step was to collect some statistical data. One of the first rollover statistics came from Hungary [2] collecting 19 rollover accidents from 1973-76. At that time it was very difficult to get information about these accidents, they were not published in the media, the police handled these events as secrets. (The information were available only through friendly connections) The main categories of these rollover accidents can be seen in Table 1. These accidents "produced" altogether 10 fatalities, 37 serious and 55 light injuries. But it has to be mentioned that there was no injury data available about 5 accidents and in 5 buses there were only 2 or 3 people, together with the driven. Another interesting information that the speed of the bus was less than 10 km/h in 5 cases, no speed information in 3 cases and there were only 4 accidents where the speed exceeded the 40 km/h when the rollover process started. All of these buses were large (11 m long) vehicles, the superstructure collapsed totally in 8 accidents, strongly damaged in 3 accidents, no information about the damage in 3 cases.

Another collection was presented in UK [3] containing the description of 8 rollover accidents from 1976-77 (See also in Table 1.) Four superstructures completely collapsed, 2 of them seriously damaged. 50 persons were killed in these accidents and many of them injured. They reported 4 accidents in which passengers were ejected from the bus and then rolled on (killed) by the vehicle.(Altogether 8 fatalities on that way) Two buses belonged to the midi category (7-8 m long)

Table 1.

Type of rollover	Hungary [2]	U.K. [3]	GRSA [4]	Hungary [5] [6]
On flat road, turn on side (1/4 rotation)	6	2	11	6
On flat road rolled on the roof (1/2 rotation)	2	3	6	5
Rolling down on a slope (3/4 – 1,5 rotation)	9	2	17	6
Rolling around falling down from overbridge	2	1	-	-
Severe or combined rollover accident	-	-	-	2
Altogether	19	8	33	19

On the basis of these accident statistics GRSA (the international working group in Geneva, which worked out the ECE Regulation 66) started to work and continued to collect accident statistics. During the period 1980-1988 altogether 33 rollover bus accidents have been reported in GRSA involving 8 countries as the scene of the accidents. [4] The distribution of the type of these accidents is also shown in Table 1. Their result was 93 fatalities and 206 injuries. This was the first statistics in which the high decker (HD) coaches appeared as victims of rollover: 6 HD coaches were reported turning on their side.

The brief results of another Hungarian rollover statistics [5] [6] is given in Table 1, too. These data were not published yet, these accidents resulted 13 fatalities, 205 injuries and there were no data about fatalities/injuries in 5 accidents.
Further interesting and useful statistical data are given about bus rollover accidents in reference [7] [8] [9].

3. UNUSUAL STATISTICS

It is very difficult to get technically informative accident statistics about bus rollovers. This type of accident is a rather rare one. There is no organization, institution which is interested in, which has the capability to collect and record these data. In the best case, the statistical yearbooks contains one column – among the road vehicles – for buses, giving the number of accidents (all together), the number of fatalities and injuries. But these information is almost nothing to understand deeply the types of this accident, their severity, to establish a good standard accident, etc. There are two possibilities to get more, deeper information, statistics:

a) A certain expert group in an institution (e.g. Cranfield CIC in U.K., AUTÓKUT in Hungary, HUK Verband in Germany etc.) builds up good personal and institutional connections to big bus operators, local polices and the experts are immediately informed about every bus accident they are interested in, so they can study the crashed bus on the scene and collect all the important data, they can take photos, etc. All the accident statistics mentioned before were based on this method.
b) A group of experts keep watch on the media (Radio, TV, newspapers, journals, etc.) which reports about the so cold "interesting", severe accidents. While a bus rollover is an interesting and severe accident, there are many reports in the media.

This new, unusual way is used in Hungary in the last 10 years, but really intensively in the last 4 years. Three statistics have been presented in GRSG [10] in Geneva (now this working group is working on the development of Reg.66.) These reports contain altogether 97 rollover accident around the whole world. Now in Annex 20 new rollover bus accidents collected in the last half a year. These information are not officially checked, neither technical nor medical examinations, investigations were made. The structural deformations were estimated about the pictures presented in the newspapers, or about the films shown on the TV. As it can be seen in Annex, the reports say only a few words about the accident, sometimes nothing about the bus type, no specific information about casualties. In spite of these insufficiencies, some interesting things, tendencies may be read out from the 117 rollover accidents. Table 2. gives a summary of the four statistics containing altogether 117 rollover accident. Table 2. needs some explanations which follows below (the referring numbers are used in Table 2. as well):

(1) countries may be involved as manufacturer, approval authority, operator or the scene of the accident.
(2) not too severe accident, but more than turning on side (1/4 rotation) roll down into a ditch, down on a slope (not more than 2 rotation) turned down from an overbridge of a highway
(3) more than two rotation, more than 8 m level difference in the rollover or falling dawn
(4) the combined accident means e.g. rollover after a serious frontal collision, rollover with fire, falling into water after rollover, etc.
(5) serious deformation means the damage of the survival space, (the collapse of the superstructure obviously belongs to this category).
(6) slight deformation means that the survival space very likely did not damage in the rollover accident.

4. EVALUATION OF THE NEW ROLLOVER STATISTICS

4.1. Rate of HD coaches in the rollover

The HD coaches became very popular in category 3 (long distance and tourist coaches) in the last decade. Their ratio in this category is increasing, mainly in the developed countries. Let us study what is their position in the rollover accidents. Table 2. shows that 53% of buses having rollover accident belongs to category 3. and to DD coaches (altogether 62 accidents) But HD and DD coaches are really tourist and long distance coaches independently from the fact that they are covered by two different general safety regulations (Reg.36. and Reg.107) Table 3. shows that 22 coaches were HD and DD among the rollover accidents (35% of the coaches) In 18 cases there was no information about the construction of the coach, so 3 or 4 of them might be as well HD or DD. It means that 40% or more is an acceptable estimation for the representation of the high coaches (HD and DD) in the rollover accident of the long distance and tourist coaches. In other words: they are over-represented in the rollover statistics compared to their rate in the total population of

long distance and tourist coaches around the world. Two important technical problem is connected to the HD coaches:

a) the dynamic lateral stability of these high vehicles is not sufficient, it should be increased and regulated
b) because of the geometrically limited structural deformation, the existing standard approval test is not appropriate for HD coaches to separate the weak superstructure from the strong one [11] [12]

Table 2.

Summary of four statistics

Summary of rollover statistics	Statistics I. 1990-1999	Statistics II 01.01.2000 01.03.2001	Statistics III 01.03.2001 31.07.2002	Statistics IV 01.08.2002 31.12.2002	Sum of I - IV
The number of accidents	23	23	51	20	117
The number of countries involved(1)	min.15	min.15	min.26	min.14	min.40
Total number of fatalities	238	254	519	170	1181
- serious injuries	103	107	94	56	360
- light injuries	122	123	170	47	462
- injuries without classification	197	122	189	160	668
- reported "many injuries"	2 times	1 time	6 times	1 time	10 times
Type of rollover accident (severity)					
- turned on side	4	2	5	5	15
- rollover from the road(2)	13	12	18	7	50
- serious rollover (3)	3	6	9	3	21
- combined accident with rollover(4)	3	3	19	5	30
Category of the bus rolled over					
- Category I. (city, suburban) (Reg.36)	2	2	2	-	6
- Category II (intercity, local) (Reg.36)	-	2	2	-	6
- Category III (tourist, long-distance)	18	10	20	9	57
- Small bus (Reg.52)	-	2	9	8	19
- Double decker (Reg.107)	2	2	1	-	5
- School bus	-	1	2	-	3
- Other (worker, pilgrim, etc.)	-	1	4	-	5
- unknown	1	3	9	3	16
Deformation of the superstructure					
- serious deformation(5)	4	5	6	9	24
- slight deformation(6)	5	5	11	7	28
- no information	14	13	34	4	65

4.2. Severity of different types of rollover accidents.

The number of the different kind of rollover accidents – based on their virtual severity – in the whole statistics is shown in Table 2. As we mentioned in chapter 1. the severity of the accident is an essential issue when determining the standard approval test, this expresses the demand of the public opinion: in which kind of accident situations should be the passengers protected, the survival possibility assured. It seems to be acceptable to say that the first two accident type, the "turn on side" and, "rollover from the road" accident categories (protected accidents) should be covered by the standard rollover test. 65 accidents (55% of the total) belong to these two categories. It must not be forgot that the severity of the reported accident could depend on the locality of the accident, e.g. a rollover of a minibus without fatalities is reported if it happened in Hungary, but it is not a news for the Hungarian media if it happened in Brasilia or China. This is proved by Table 4. The conclusion of this effect is that the more severe rollover accidents are over-represented in this accident statistics considering the whole world, or in other words the protected accident types cover at least 70-75% of the total bus rollover accidents around the world. Table 5. shows that the majority of the injuries are "produced" by these two accident types and their fatality rate is also exceeding the 30%.

Table 3.

Construction of coaches having rollover accident	Number	%
Traditional (total height 3-3,2 m)	17	27,5
Probably traditional	5	8,0
HD (total height more than 3,4 m)	17	27,5
DD (double decker coach)	5	8,0
No information about construction	18	29,0
Total:	62	100

Table 4.

	Turned on side	Rollover from the road	Combined rollover	Serious rollover	Total
Hungary	9 (26%)	21 (60%)	5 (14%)	-	35 (100%)
Europe (excl. H.)	6 (15%)	15 (37%)	10 (25%)	9 (29%)	40 (100%)
Other than Europe	1 (3%)	14 (33%)	15 (36%)	12 (28%)	42 (100%)
Total	16	50	30	21	117

Table 5.

Injury levels in accidents belonging to "turn on side" and "rollover from the road" (totally 63 accidents)	Number of persons	% of the total, given in Table 2.	Number per accident
Fatalities	351	30 %	5,7
Serious injuries	218	60 %	3,5
Light injuries	310	67%	5,0
Injuries without classification	297	44%	4,8
Statement "more fatalities and injuries"	5 times	50%	-

Some words about the virtual severity of the accident type, "Turn on side" accident seems to be the less severe rollover accident. Two comments to this statement:

Fig.1. Turn on side, where the rotation is stopped by a tree

a) What accident situation will result "turn on side" rollover accident? It depends mainly on the circumstances and not on the construction of the vehicle. Many rollover accident start on the following way: the bus slips on the road, the one side wheels are stopped (blocked) by the soft, deep soil of the roadside (or by the curb stone) and the lateral accelerations rotates the bus around the blocked wheels. The further motion depends on the circumstances. Fig.1. shows a situation, when a tree or another example: the shape of the ditch and the soft deep snow (Fig.2.) prevented the further rotation,

Fig.2. Turn on side in a snowy ditch.

b) Very typical "turn on side" accident may be ended by a very severe situation. Three similar accident were analysed, which started on the same way: driving with high speed, after a sudden steering the bus turned on its side crosswise on the road and slipped away, finally
   - slipped into a ditch and the superstructure collapsed, 20 fatalities [12]
   - slipped away and rolled down on the slope of the elevated road and the superstructure collapsed, 46 fatalities [7]
   - slipped away and hit the steel side rail of the road which cut and pressed the superstructure, 20 fatalities [13]

All of these three vehicle were HD coaches to which the existing Reg.66. does not provide a good standard approval test. General argument is for maintaining the existing approval test: in the real accident situations the HD coaches turn only to their side and they do not need strengthened superstructure. Counter evidences are given with the examples above.

4.3. The control of the standard rollover approval test.

It is difficult to control whether the decided and used standard approval test is adequate to separate the strong superstructure from the weak one, to meet the demand of the public, to assure the required safety for the passenger. A slow feedback can be found from the accident statistics, from the analysis of rollover accidents. Fig.3. shows the results of two rollover accidents happened to the same bus type: "a" rolled down from a road having a slope with a tangent 4/6, "b" rolled over on a flat road. It is obvious that the superstructure is weak, can not assure a survival space for the passengers. Different kind of standard rollover tests showed the same result [1] After reinforcing the superstructure, all the different standard rollover tests gave positive result.Fig.4. shows the final position of a reinforced bus in a rollover accident, Fig.5/a shows also this reinforced type, while Fig.5/b gives another example with an approved vehicle rolled down on the same slope of the road which destroyed the weak superstructure.

Fig.3. The results of real rollover accidents with weak superstructure

Fig.4. Rollover accident with reinforced superstructure

Fig.5.Strong superstructure assures the survival space

This new rollover statistics does not give direct information about the approval of the buses regarding Reg.66. But indirectly Table 6. gives an interesting comparison. At it was defined above, "protected rollover accident" covers those accidents in which the passengers should be protected, the survival space shall be maintained. Among the 117 rollover accidents there are 49 in which we have information about the behaviour of the superstructure: 26 accidents did not cause damage in the survival space and in 23 accidents the survival space was harmed, including the total collapse, too. The casualties belonging to these two groups are significantly different. The fatality rate is 16 times, the serious injury rate 3 times higher when the survival space was damaged. From this recognition it comes the clear goal of the international regulation: in the protected accidents the survival space shall be maintained. It is interesting to mention on the basis of Table 6. that the number of the light injuries are not closely related to the type or category of the accident. It may be assumed that this type of injuries are caused mainly by the inside collision of the passengers when they are leaving their seats, seating position during the rollover process. The main tool to reduce this kind of injuries could be the use of seat belts. (It has to be emphasized that the seat belt can reduce the number of fatalities and serious injuries, too.)

Table 6.

Considered accidents	Number of events	Casualty per accident			
		fatality	Serious injury	Light injury	Injury without classification
All rollover accidents (117 events)	117	10,1	3,0	3,9	5,7
Protected rollover accidents (65 events)	65	5,7	3,5	5,0	4,8
Survival space unharmed (26 events)	26	0,8	18	4,8	1,7
Survival space damaged (23 events)	23	13,2	5,6	4,9	7,6

4.4. Ejection of passengers

The attention was called in the very beginning to the fact that the ejection could be very dangerous situation for the passengers in a rollover accident. [2] This new type of accident statistics showed and analysed here is not detailed enough to get reliable information about this problem. But it has to be mentioned that there were 6 reports in which the ejection of the passengers were mentioned. It proves that this is an existing problem.

4.5. World wide bus rollover situation

It is very difficult to get a valid picture about the worldwide situation of the bus rollover accidents. This new method collets worldwide statistics but as it was pointed out in connection with Table 4. this statistics is projected by the Hungarian media (It means that from the far countries only the very serious accidents are reported) Table 7. gives the yearly distribution of the accidents. It is interesting to mention that the real collection of the data started in 1999 but this was not a complete year. The intensity of the collection was increased during the years. The small buses, mini buses were out of interest before 2001. The number of the registered buses in Hungary is around 19 thousand. This fleet produces 10 rollover accidents per year as an average. (Independently from the casualties) The complete European bus fleet could be in the range of 500-550 units. Using the Hungarian proportion the expected number of bus rollover accidents in Europe could be in the range of 250-270/year. It is interesting to mention that in Spain 33 rollover accidents were reported [7] between 1984-88 and 20 in the years 1991-92 [8] This figures involves only the tourist coach accidents in which passengers died. (At least one)

Table 8.

	1990-1998	1999	2000	2001	2002	Total
Hungary	4	2	4	13	12	35
Europe (excl. H.)	13	8	7	6	8	40
Other than Europe	4	7	7	12	14	42
Total	21	17	18	31	34	117

5. CONCLUSION

Introducing a new method of collecting statistics about bus rollover accidents, on the basis of 117 accidents some interesting information, evidences and tendencies could be recognized:

- The high vehicles (HD and DD coaches) are over represented in the rollover statistics, compared to their rate in the bus population (they need special attention in respect of lateral stability and strength of superstructure)
- The severity of an accident type depends on the circumstances of the individual accidents, the “turn on side” accident could be more severe than another accident type having higher virtual severity
- The small buses, minibuses are also endangered by the rollover accident. Until now they were out of interest, therefore further investigation is needed to study the strength of their superstructure.
- The public demand may be formulated: the buses and coaches have to assure the survival space in the case of “turn on side” and “rollover from the road” type accidents. This two accident types covers around 70% of the total number of rollover accidents.
- If the survival space is assured in an rollover accident, the rate of fatality is reduced by 90-95% and the rate of serious injury by 60-65%.

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Bus rollover accidents collected between 01.08.2002 – 31.12.2002

	Date City (district) Country	Bus type Category Operator	Circumstances of rollover	Fatalities and injuries	Damage of superstructure
1.	07.08.2002 Tampico Mexico	local operator	Because of the high speed the bus could not take the curve, rolled over	8 fatalities 13 injuries	
2.	10.08.2002 Haragaulsk Georgia	local operator	In a hilly district two buses – a small and a large one – collided and the large bus with 15passengers on board rolled down into a precipice	7 fatalities 9 injuries	
3.	15.08.2002 Poland	Minibus local operator	Minibus collided with a truck on a slippery road and after that rolled over. All the passengers and the driver died.	9 fatalities	
4.	27.08.2002 Budapest Hungary	Mercedes Minibus Local operator	The ambulance car (minibus) was hit by a car and turned on its side. 3 person on board, only the driver was injured	1 injury	The windscreen and the driver seat out, but no serious damage, the survival space was unharmed
5.	13.08.2001 Kagenfurt Austria	HD tourist coach Italian operator	30 Italian pilgrims on board, the bus crashed the part of a tunnel and rolled over	10 serious injuries 20 light injuries	The superstructure damaged, the survival space probably harmed. The seats torn up.
6.	05.09.2002 Eger Hungary	IKARUS classic Category III 12m VOLÁN-AGRIA	The bus was passing a truck which pushed it down from the road. The bus rolled down into a 0,5 m deep ditch and laid on its side	3 serious injuries 6 light injuries	No serious damage on the superstructure
7.	11.09.2002 Belényes România	Ford Transit Minibus Local operator	17 people on board. The bus drifted out from the road in an “S” curve, hit a pole and rolled into a 90 m deep precipice. Those passengers survived who were ejected after the first collisions.	8 fatalities 9 serious injuries	The superstructure completely damaged
8	13.09.2002 Main USA	Minibus	15 people on the board. The minibus hit the guard of a wooden bridge (100 km/h) and rolled down into a river. One person survived, breaking out rear window and climbing out.	14 fatalities	
9.	13.09.2002 Szolnok Hungary	VW Transporter Minibus Local operator	The empty minibus had a frontal collision with a truck, after that rolled down into a 0,8-1 m deep ditch, stopping on its roof.	1 light injury	The front wall and the roof seriously damaged
10.	11.09.2002 Sárvár Hungary	Ford Transit Minibus	5 passengers on board. The minibus was hit by a car, after that it turned on its side and slipped into a 1 m deep ditch	No injury	Only slight structural damage
11.	11.09.2002		The bus left the road in a	21 fatalities	The superstructure col-

	South Africa	Local operator	hilly district and rolled down into a precipice. Many people were ejected from the bus and compressed	52 injuries	lapsed, the bus was totally damaged
12.	28.07.1998 Nápoly Italy	Category III. HD Hungarian operator	46 passengers on board. The bus left the line of the highway, the driver made a quick steering correction, the bus turned on its side and slide away around 35 m	38 injuries, many of them seriously	The survival space was not damaged, slight deformations on the superstructure
13.	31.10.2002 Johanesburg South Africa	Category III 11 m N Local operator	The bus slipped on the wet road rolled over, stopped on its roof, on flat ground. 44 German, Canadian and English tourists on board	10 fatalities 12 seriously injured	The superstructure collapsed, no residual space. Seats were deformed and broken by the roof 4 PH deformation mechanism
14	16.11.2002 London U.K.	Plaxton- Volvo B10-H Category III. HD UK operator	43 passengers and 2 drivers on the board. The bust left the highway and veered off onto hard-shoulder and down the inclined embankment and rolled to its left side and slid down, 3 persons were ejected and killed by the bodywork.	6 fatalities 5 serious injuries	No major deformation of the superstructure
15.	05.12.2002 Sárkeresztes Hungary	Kässbohrer Category III 12 m N German operator	Speeding (120 km/h) on wet road the bus slipped, hit a truck and rolled into a ditch (1 m deep) and stopped on its side. The driver died.	2 fatalities 5 serious injuries 2 light injuries	Drivers compartment disappeared, the superstructure slightly deformed, survival space was not harmed
16.	06.12.2002 Szentendre Hungary	Minibus Local operator	The minibus (ambulance car) hit a car, spun around and turned on its side	2 serious injuries	Large scale deformation on the front wall, no significant deformation on the superstructure
17.	20.12.2002 Cairo Egypt	Small bus Local operator	The bus slipped on the wet road and rolled down from an overbridge	17 fatalities 17 injuries	The superstructure collapsed
18.	02.06.2002 Brisbane Australia	Category III. HD Local operator	On a wet road the bus slipped on the road, the wheels were blocked by the deep, muddy soil, the bus rolled down from the road on a slope and slopped on its roof. (44 persons on board)	2 fatalities 1serious injury 17 light injuries	The superstructure got severe deformation the survival space was harmed
19.	19.08.1992 Torreblance Spain	Category III. 12 m HD	The bus turned on its side on the road, slid away, collided with the metal safety rail and rolled down on a slope. After ½ rotation it stopped on its roof.	46 fatalities 9 serious injuries 1 light injury	The superstructure completely collapsed the roof came to the waistrail
20.	06.09.1992	Kässbohrer Category III 12 m HD German operator	The bus (53 passengers on board) having a speed 60 km/h collided with a car, on an overbridge, turned on its left side, slipped away and hit the breast rail by its rear part.	20 fatalities 30 injuries	The rear left side of the superstructure was cut and pressed by the breast rail