VIRTUAL TESTING ACCORDING TO ECE R66 AS A TOOL FOR ESTIMATING PASSENGER COMPARTMENT SAFETY ON A SNOW GROOMER VEHICLE

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Abstract: *The concept of virtual testing is generally used method for understanding the structures behavior during loading. It can be used as accurate replacement of real tests only if they are correctly modeled and verified. The regulation UNECE R66 is uniform technical prescription concerning the approval of large passenger vehicles with regard to the strength of their super structure. The rollover test is the basic approval test, but virtual tests can be the adequate testing methods of the physical test. The verified computer simulation according to the regulation can be equivalent approval method. There is a need that snow groomer vehicle sometimes accommodates larger number of people (for sport, work or rescue missions). Because of the terrain those vehicles have to pass, there is significant danger of rollover. So far, there are no regulations for testing of such a superstructure. This paper describes the effort and results in the use of virtual testing according to ECE R66 as a tool for estimating the safety of passengers inside such a vehicle. A computer simulation of a rollover test of the snow groomer vehicle was made. The virtual test was conducted according to the ECE R66 which allows this kind of testing. By following the standard guidelines for computer simulation of a rollover test the vehicle superstructure was analyzed. Series of virtual test were carried for meeting the standard requirements and the customer needs. The final snow groomer superstructure had to undertake serious reinforcement considering the passengers surviving area.*

Keywords: SNOW GROOMER, PASSENGER COMPARTMENT, VIRTUAL TESTING

1. Introduction

Snow groomer vehicles are powered by tracks, equipped with front mounted blades and snow cutter at the back. Their main application is maintaining ski slopes during winter time. They can handle very steep slopes as a result of their low centre of gravity, large width and large contact area. Snow groomer can be used to transport employees at the skiing centers, rescuing injured skiers or touristic sightseeing. Some of these activities can be replaced by cable cars. But the only mean of transport for carrying enthusiastic skiers up the hills for off-track skiing is the snow groomer. For that reason one running snow groomer was adopted for passenger transport, Figure 1. The vehicle had to be equipped with passenger cabin for transporting maximum 12 people. Because of no passenger compartment safety regulation for this kind of specialized vehicles, one existing regulation for large passenger transport was used. The worst scenario that can arise during transportation on the mountain hills is the case when the vehicle rolls over one of its sides. For that reason ECE R66 regulation rollover test of large passenger vehicles was preformed. The initial compartment design was provided and virtual simulations were conducted according to the regulation.

Fig. 1 *Snow groomer Piston Bully 200 with the model of the passenger cabin*

2. Challenges of use ECE R66 as a virtual testing procedure

The large passenger vehicles should have superstructure that will ensure maximum safety of passengers during rollover. Or in other words after a rollover the surviving area should be provided. According to the regulation no part of the vehicle which is outside of the passenger surviving area or the residual space should intrude during the test. Parts that are already in that space can remain there. The residual space is continuous in the passenger, crew and the driver compartment between the furthermost and the front plane in the vehicle. It is defined as a vertical plane moving trough the length of the vehicle limited with straight lines. The boundary lines of the vertical plane are trough the Sr points on both sides of the vehicle. The Sr points are positioned on the seat-back on each passenger seat, 500 mm above the floor under the seat and 150mm from the inside surface of the side wall, as presented on Figure 2 [1].

The rollover test is an approval test for strength of the large passenger vehicle superstructure. It is a lateral tilting test with the following basic characteristics. The complete vehicle is standing on a tilting platform with a blocked suspension. It is slowly tilted to its unstable equilibrium position with the axis of rotation that runs trough the wheel-ground contact points. The vehicle overturns into a ditch with depth of 800mm, Figure 3. For equivalent approval test one of the following stated approval tests can be carried out: rollover test on a body section, quasi-static loading test on a body section, quasi-static calculations based on the results of component tests and computer simulation via dynamic calculations [2]. The basic challenge is to fully represent the tested vehicle behavior. Virtual testing is more economical compared to the real crash tests and as well time consuming procedure for evaluating different behaviors. A lot of parameters can influence the simulation output, especially in the case of impact analysis. Impact or the impulse is a sudden increase in force compared to the static, quasi static or dynamic analysis. This sudden change of structure behavior can lead to numerical instabilities of the solver in the virtual environment.

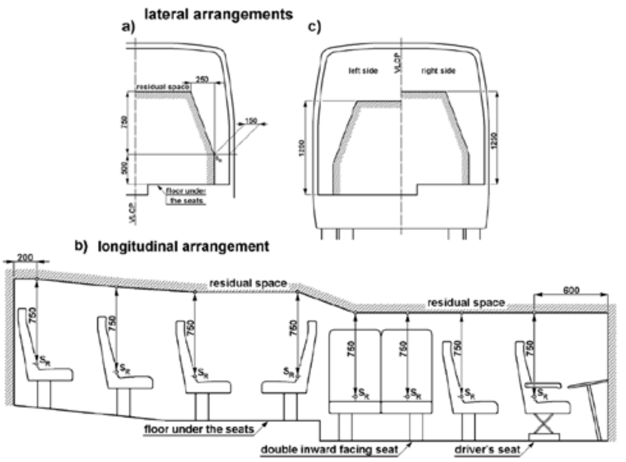

Fig. 2 *Specification of the residual space - passenger surviving area (source: E/ECE/324; E/ECE/TRANS/505; Rev.1/Add.65/Rev.1; Regulation No.66, page 14, 22 February 2006)*

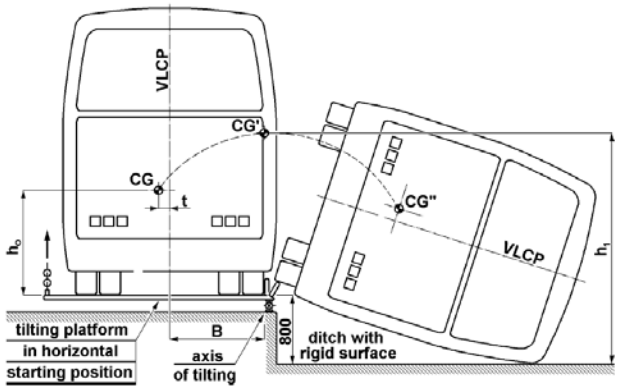

Fig. 3 *Specification of the vehicle rollover test (source: E/ECE/324; E/ECE/TRANS/505; Rev.1/Add.65/Rev.1; Regulation No.66, page 15, 22 February 2006)*

3. FEM model

The snow groomer passenger compartment is a cabin for 10-12 people together with a space for baggage. Passengers are seating backwards to the vehicle driving direction and the baggage area is on the side of the driver seating position. For bringing the model behavior more realistic and on the other side lowering the simulation time some adjustments had to be done:

- the show groomer is modeled with shell elements as hollow block. The block mass is defined as the vehicle total weight and it is achieved using element mass. Also it is rigid and no deformation on the snow groomer can occur, and it is also rigidly connected to the passenger compartment. The dimensions on the block are the outer dimension of the snow groomer, Figure 4.

- for accurate representation on the vehicle during roll over the position of the centre of gravity was defined as the position of the vehicle itself raised for the centre of gravity of the compartment together with the mass of the crew and baggage.

- all the compartment elements are modeled as shell triangular and quadratic elements with three integration points. The number of elements of the passenger compartment is 120814 and the element size is 15mm. All of the parts are connected using spot weld elements. The material properties are some of the examined parameters. The numerical simulation runs for 18 hours on a stand-alone 8 core 2.5GHz CPU with 16 GB of RAM.

- element mass was used on all of the compartment nodes. Element mass is a virtual mass that is added on the elements without changing the parts inertial properties. In this case it was used to achieve the weight of the passengers together with the baggage in the virtual simulation of the rollover test, Figure 5.

- contact surface to surface was defined between the square block representing the snow groomer and the tilting platform. One of the problems that were faced during the modeling was contact between two rigid bodies. In our case that was the rigid block and platform. This was overcome by first defining surfaces that will be in contact and then the contact type that prevents penetration between master nodes and slave elements.

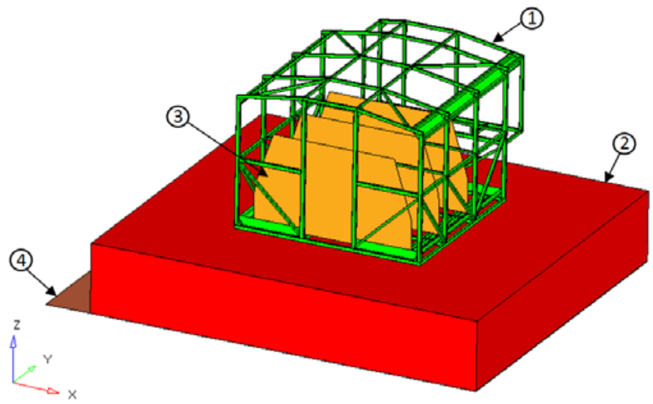

Fig. 4 *Virtual model components 1) passenger compartment 2) snow groomer vehicle 3)passenger surviving area 4) tilting platform*

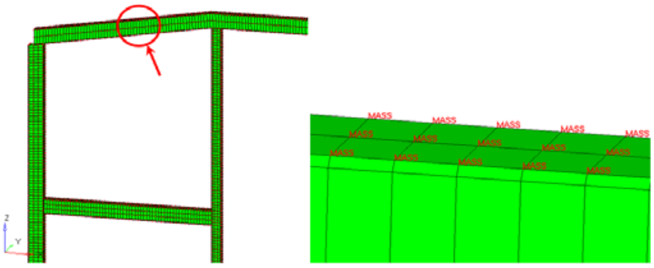

Fig. 5 *FEM element mass distribution*

4. Performing virtual testing

The virtual testing procedure according to the ECE R66 with a tilting platform was conducted on a passenger compartment together with the snow groomer. The compartment itself should be strong enough to restrain the inertial mass of the rigid block during rollover. The starting angle of rotation 75° is used as a point before which no change in the conditions occurs. The rollover happens after the rotation angle of 75°. The results are compared with the prescribed values in the standard. Or the minimum surviving area for group of passengers in the compartment are boundary limits from the sidewalls, top and bottom [1]. In the following are given some of the parameters of the virtual simulation:

- the snow groomer mass or the shell block in the model weights 7.3t. This is the vehicle mass given in the technical sheets.

- the passenger compartment, structure only without passengers, weights 517kg.

- for 12 passenger, each with average weight of 68kg plus 3kg of baggage gives 71kg. The total weight of 12 passengers together with baggage is 812kg.

- the rotation angular velocity is 0.1 radians/sec and that is equal to 5.7 degrees/sec.

- the passenger compartment or its frame is made out of square and rectangular steel tubes with thickness of 3mm. Each of them is made either S235JR or S355J2 according to the European designation system (EN10027) [3]. The minimum yield strength or the yielding point for the first steel is Reh=235 MPa and Reh=355 MPa for the second.

Virtual testing procedures are known methods often used by the author as a tool for acknowledging structures behavior. One example where mathematical model was verified by laboratory experiment is the doctoral thesis realized by the author. The connection between two guardrail segments as part of the highway infrastructure was analyzed. According to the thesis methodology first one quasi-static experiment was conducted of the bolted connection between two segments and then the same experiment was mathematically modeled [4]. The experiment was used as verification mean after which model improvements were following. The same modeling techniques were used in these simulations as well.

5. Improvement of the body structure through analysis of test results

The virtual simulations were carried out as a co-simulation where HyperMesh was used for preparing the finite element models and analysis were done in the solver LsDyna. The initial and the boundary conditions or the model limitations were determined according to the standard ECE R66 [5][6].

The total mass and the centre of gravity position used in the mathematical model are identical to those of the vehicle to be approved. The friction coefficient used in the ground contact is considered so that produces conservative results. All possible physical contacts are modeled. The simulation runs from the equilibrium position till the maximum deformation. The energy and its components are calculated on every incremental time step. A lot of problems were faced defining the time step. It was computed based on the smallest element mass increased by the scale factor for resolving numerical instabilities. Non-physical mass is added to certain elements to increase stability in dynamic analysis. This can affect the outcome in a manner of inertial forces (F=m·a) and it has to be closely monitored to get good results. Numerous simulations were run and each of them with different sets of reinforcements. At first one rollover test was simulated on the preliminary passenger compartment provided as a CAD model without the trapezium inside, representing the passenger residual space. With the same impact conditions the cabin was completely wrecked by the block. Some of the modifications are shown and explained using the pictures below.

- changing the material properties of the cabin

The picture presents two identical compartments considering their construction, or no reinforcement on the compartment was made. The only difference is the material used in the FEM model. The first cabin was modeled with material structural steel S235JR as a widely used material for structure beams. The second cabin is modeled using also structural steel but with different properties S355J2. Despite the fact that the materials have different yielding point or the point where the material elastic properties end and the plasticity starts to happen. The main reason for using different type of steel is maintaining the same impact property in Joules but on different temperature ranges. The first steel has impact energy of 27 Joules but tested on room temperature (or 20°C) and the second has the same impact properties but tested on -20 degrees. This is important considering the fact that the snow groomer vehicle will be used on low environment temperatures and has to maintain impact strength on this temperature. On the left side of the picture can be seen the maximum stress in unit MPa that is reached in the most stressed elements. On the first figure the upper corner which is the initial impacting point is highly deformed and the compartment leans on the rigid trapezium simulating the surviving area. If the deformation reaches the trapezium means that it is entering inside the residual space which considering the standard is not allowed. The difference in the structure response is evident, Figure 6.

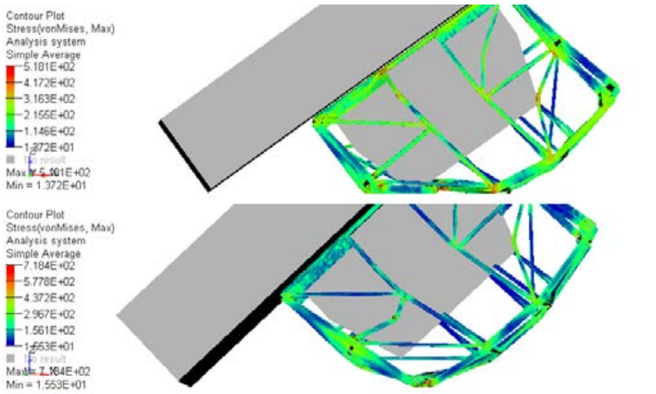

Fig. 6 Virtual simulation of a rollover test of passenger cabin made from a) steel S235JR and b) steel S355J2

Based on engineering practice and knowledge the cabin itself shouldn't be designed as stiff as possible. High inertial forces arising from the weight of the snow groomer and the sudden impact will provide enormous accelerations in the compartment. That main challenge is to construct the structure in a way to damp that huge amount of energy so that less will be transferred to the cabin.

- reinforcement using corner elements and double beams

One of the main reasons for buckling the compartment was the first contact between the upper corner of the cabin and the ground. Based on that conclusion the corners were reinforced with lager supports (as shown on Figure 7 a). Also the vertical UNP120 beams were closed having rectangular cross section. The reason is the higher bending moment of inertia of a closed area compared to the open profile of the beam. The second modification is reinforcing cabin structure by increasing the moment of inertia on the cabin roll bars. The residual space that will insure the passenger safety during vehicle rollover can be provided by constructing "cage" around that area. For that reason the beams were reinforced by second attached beam, at the begging and the end of the compartment (shown on Figure 7 b).

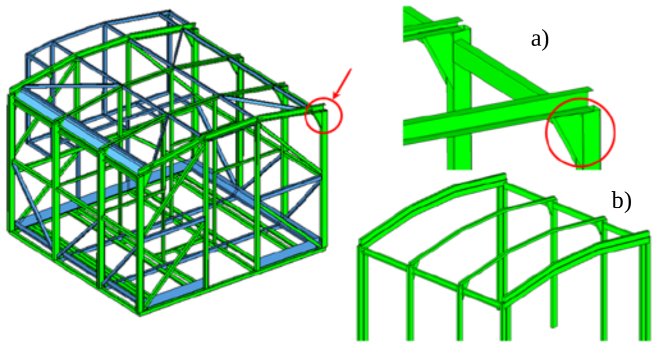

Fig. 7 Modifications in the passenger compartment using a) corner reinforcement and closed profile vertical beams b) double beams

The stress contour diagrams of the virtual simulations with the explained modifications are presented. The first situation with the corner reinforcing element dislocates the deformation but it is still reaching the passenger residual area. Compared with the stress state on the cabin made from steel S235JR can be noticed that the deformation expands in the direction of the passenger door seen as two vertical beams in the middle of the cabin front. The second modification is with double beams around the cabin. In this case the cabin remains its rectangular shape which because of the impact is just skewed, Figure 8. Still as mentioned before the impacting energy is not damped by the cabin deformation and as a result the compartment trapezium sustains on the ground.

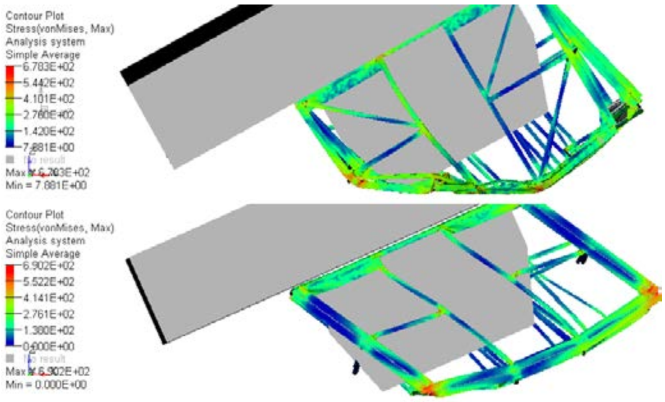

Fig. 8 *Virtual simulation of a rollover test of passenger cabin with a) corner reinforcement and closed profile vertical beams b) double beams*

- reinforcement using front and back windows frames

The most important role for keeping the passenger compartment intact in rollover test has the cabin roll bars. The front and back side of the cabin are reinforced by using other windows frames beside the existing ones. By using virtual simulations was concluded that the cabin response was much better in this case compared to the reinforcement by using just diagonal beams connecting opposite corners of the windows. Other reason not to use diagonal beams is that the window view would be as well ruined. Different offsets of the additional windows frames were tried by different simulations so that the output considering the standard will be satisfied and the maximum of the window glazing surface will be left. On the Figure 9 are shown virtual simulations with wide and narrow windows frames. Simulations were run and the satisfactory results considering the compartment strength were obtained. For strengthening not just the front and the back of the cabin other modification were done in the vehicle longitudinal direction.

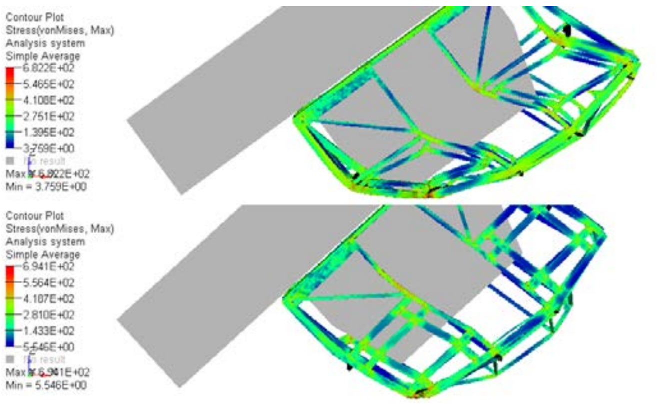

Fig. 9 *Virtual simulation of a rollover test of passenger cabin with a) wide windows frames b) narrow windows frames*

From the numerous simulations that were run below is presented the final reinforced cabin. First the stiffer compartment response during rollover was accomplished by using the material S355J2. Making the entire cabin from this material will be more expensive and more rigid solution. This as explained will lead to huge inertial force in the passenger compartment. The cabin in that case will not reside on the place of impact but because of the lack of deformation it will roll over downhill. The basic idea is to accept as mush as possible impact energy and that can only be done by structure deformation till the permitted values. The meaning of the roll bar structure was explained and achieved by larger top and vertical beams, another windows frame at the front / back side of the cabin. Also poles were positioned beside each seating place and they could be used as hand holders as well. These poles had the task of supporting the upper beams and undertaking some of the impacting energy trough the length of the passenger compartment. With red color are marked the elements made from steel S355J2, Figure 10 b.

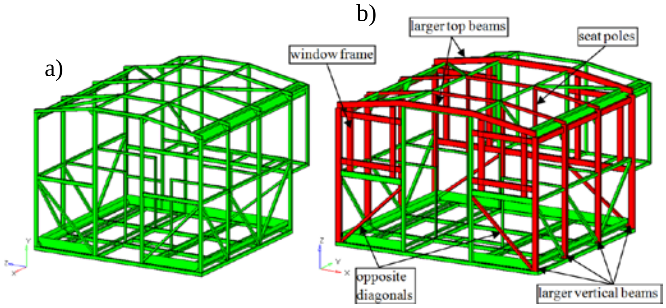

Fig. 10 *a) Preliminary passenger compartment b) Final reinforced passenger compartment*

6. Conclusions

The research effort towards analyzing snow groomer passenger structure using a computer simulations and its compliance with the regulation ECE R66 provided acceptable solution frame and large experience in the area of virtual testing as well. The developed virtual test model is capable of describing the real physical behavior of the rollover test. Proving the validity of the mathematical model and verifying the assumptions made in the model are based on the engineering practice with numerical models in similar tasks. It is expected full experimental validation process to follow that will confirm usability of the virtual testing procedure. The simulation program produces a stable solution, in which the result is independent of incremental time step. Non-physical energy components produced by the process of mathematical modeling for example the "hourglass" energy is less than the 5% of the total energy at any time. The simulation runs before the first unstable situation until maximum deformation is reached. Granting the conformity was possible only without reducing the residual space after the rollover test. This was accomplished by series of structural modifications. The basic challenge to strengthen the passenger compartment without enlarging the cabin inertial accelerations was accomplished.

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