INTRODUCTION

The article concerns organization, logistics and preparation of large projects such as a project of crash tests on railway vehicles. Large objects, railways, high-speed, cost, uncertainty and exposure to judgments of media etc. make appear various difficulties. A characteristic feature is also a large number of participants and their diversity because a project consortium consists of institutions, universities and companies that even during the period of activity of this body often change its names and business configurations. This obviously is a necessity, but it also extends the time of the consultation and the findings concerning specific assumptions, data, and expected results. Therefore, the project plans should include not only the overall schedules, but should also include links between individual events, since they can decide about the success of the whole or part of the project.

Due to the statistical analysis of collision accidents, e.g. [1], [2], the most dangerous in the effects of accidents involving rail vehicles are those in which there is a frontal collision (figure 1), and those which are accompanied by the derailment of the vehicles.

The passenger vehicles are now designed in such a way as to meet the requirements intended to protect vehicle occupants against the effects of the disasters. These requirements are defined briefly as ‘passive safety’. The requirements do not cover all possible accident scenarios but provide a level of crashworthiness that will reduce the consequences of an accident, when active safety measures have been inadequate. The requirement is to provide a level of protection by addressing the most common types of collision that cause injuries and fatalities.

Principles of the passive safety can be fulfilled based on a theoretical solutions (e.g. FEM simulation), but the best results provide the crash tests. The crash test is a very good tool for the verification of the proposed design solution. Validation of the vehicles designed as complying with the rules of the passive safety is complicated and expensive, therefore it is so important to collect the experiences gained during each of this type of experiments.

Railway Institute in Warsaw (IK) is one of the few such research centres in Europe, which owns an experimental track, [3]. It is placed in Żmigród near Wrocław, Poland. In addition to the routine testing of rail vehicles, such as brake testing or different types of operational tests conducted so far, the series of advanced experiments like the crash tests were realized, too. It should be mentioned, for example:

• crash tests for ORE B165 Committee in 1990,
• crash tests for project SAFETRAIN in 2000, [1],
• crash tests for project SAFETRAM in November 2003, Passive Safety of Tramways for Europe(Competitive and Sustainable Growth Programme, 5FP EC, 2001-2004), [2], figure 1ab.

Due to these projects a high level of experience in preparing and carrying out the crash tests on a scale of 1:1 has been achieved. Next, a number of high-energy crash tests for other cabs of railway vehicles were carried out. The exemplary configurations of the crash tests were illustrated in figure 2abcde. The IK has done: the crash test on a prototype of a locomotive cab of TRAXX Bombardier Transportation, figure 2c, the crash test on a prototype of an end cab of high speed train designed by KRRI (Korean Rail Research Institute, [4]), figure 2d, a cab of EMU V250 train designed by Ansaldo Breda (Italy), figure 2e, a test on a cab of EMU ED74 of PESA as well as more other. Special tests on
samples used as components absorbing energy were also carried out. The front end impact between two identical locomotives with one cab (illustrated in figure 1f) was not realized but analysed theoretically by the author.

For example, below is characterized the SAFETRAM research project. The consortium consisted of 7 countries, such as France, Germany, Italy, Poland, Portugal, Switzerland and the United Kingdom: 5 leading European manufacturers of rail vehicles, 4 tram and railway operators, 2 research institutes and 2 universities. Two types of tramways: “city” (municipal) - plying within a town and "peri-urban" (agglomeration) - used for carrying passengers from suburban areas to the city center and being used on the conventional railroad tracks were the objects of researches in the project. Some zones of supporting structures of the vehicles as designed to crumple have been defined in order to protect spaces occupied by passengers or by the motorman. In the cabs, removable energy-absorbing devices were used as the most important components, which were tested by the crash experiments.

1. CONFIGURATIONS OF CRASH TESTS

Research projects concerning resistance of vehicles to the effects of accidents (crashworthiness) most start from statistical surveys for the determination of typical accident scenarios involving the rail vehicles. This is one of the most important stages of such projects. The object of such studies is the incidence of various collision scenarios for the type of the vehicles. The statistical analysis is done for the selection of cases of collisions of rail vehicles according to the criterion of occurrence, or according to the criterion of released energy. Such selection is necessary to minimize the number of the cases.

According to the norm [5] crashworthiness design categories of the railway vehicles are as follow:

- C-I - vehicles designed to operate on TEN2 routes, international, national and regional networks, which have level crossings (e.g. locomotives, coaches and fixed train units)
- C-II - urban vehicles designed to operate only on a dedicated railway infrastructure, with no interface with road traffic (e.g. metro)
- C-III - light rail vehicles designed to operate on urban and/or regional networks, in track sharing operation, and interfacing with road traffic (e.g. peri-urban trams)
- C-IV - light rail vehicles designed to operate on dedicated urban networks interfacing with road traffic (e.g. city tramway vehicles).

The collision scenarios recommended by the norm [5] for C-I (locomotives, coaches and fixed train end) are (figure 1):

- scenario 1 - a front end impact between two identical train units
- scenario 2 - a front end impact with a different type of railway vehicle (e.g. freight wagon)
- scenario 3 - train unit front end impact with a large road vehicle on a level crossing
- scenario 4 - train unit impact into low obstacle (e.g. car on a level crossing, animal, rubbish).

Having pre-selected of the most common cases of the accidents one can establish a single or more representative. Then, these scenarios are the basis for designing of an appropriate test configuration, such as in figure 2. The test configurations depend on type of the object and must take into account the hardware capabilities of the research center, including: the experimental track, special test vehicles, set of measuring apparatus as well as a staff experienced in design and research. Very important are also costs of the project necessary to ensure the fulfillment of selected test parameters, because the test object usually becomes completely destroyed and there is no possibility to repeat the experiment.

Following scenarios of the tests have been chosen for the above mentioned SAFETRAM project:

1. The collision between the two identical city trams, in which the role of the sample object is played by a prototype of the cab of the city tram attached to the specially designed test wagon. The sample cab has been made of aluminium. The test vehicle invades a rigid wall mounted on another test vehicle with the speed of 14 km/h. A significant part of the kinetic energy has been taken over due to the system of absorbers fitted to the front of the cab. This test has become the standard

\[2\] Trans European Network
scenario 1 (similar to the scenario 1 shown in figure 1, but for the category C-IV) recommended by the later developed standard [5].

2. The collision between the peri-urban tram and the UIC freight wagon. The role of the sample object is played by a steel prototype of the cab of the peri-urban tram mounted on another specially designed test wagon. The test vehicle invades at the buffers of the freight wagon with the speed of 25 km/h. As a result of the collision the absorption capacity of the wagon bumpers has been firstly exhausted. Next, the cab has got permanent deformations in places, which have been previously identified as a result of a computer simulation. As in former case, a significant part of the kinetic energy ought to be taken over due to the system of absorbers fitted to the front of the cab. This test has become the standard scenario 2 (similar to the scenario 2 shown in figure 1, but for the category C-III) recommended by the norm [5].

![Scenario 1. Collision between two identical high speed train-sets](image1)

![Scenario 2. High-speed train-set against a four-axle 80 t freight wagon](image2)

![Scenario 3. Collision at a level crossing with a lorry represented by a rigid mass presenting a vertical surface for impact](image3)

Fig. 1. Three main scenarios of collisions on example of C-I vehicle

There are following steps of the experiment:

1. coupling the impacted vehicle with a shunting locomotive and departure at an appropriate distance
2. acceleration of the impacting vehicle to release velocity \( v_r \), slightly greater than the velocity \( v \)
3. disconnection of the impacting vehicle when exceeding a predetermined point at the testing track – i.e. so called release point
4. in case when the speed of the impacting vehicle is different than the previously determined velocity \( v_r \) or for other reasons, it can be assessed that the impact velocity \( v \) will not be reached on, then the vehicle is remotely braked
5. raid the impacting vehicle at the obstacle (impacted vehicle)
6. proper collision phase, during which indications of strain gauges, measured velocity and acceleration as well as filming with use of high speed analog or digital cameras, are done
7. braking both vehicles but first of all braking the impacting vehicle in order to avoid further uncontrolled deformation.

Despite the use of appropriate equipment in the form of speed measuring instruments and other devices, phase 2 and 3 requires previous training of the operator team. Mostly, they are based on determining the speed \( v_r \) and also the release point. Additionally, a kind of mini-tests with the low-speed collisions are to be carried out in order to verify the quality of the measuring equipment and the cameras.
Fig. 2. Examples of crash test configurations for cabs: CT, PT, TRAXX (Bombardier), KRRI (South Corea), EMU V250 (Ansaldo Breda) and locomotive 6Dg (NEWAG) using test wagons TWA, TWB, TWC and TWD; 1 – test sample (cab), 2 – force gauge, 3 – rigid wall of impacting vehicle, 4 – impacted vehicle; \( v \) – impact velocity, \( m_o \) – mass of impacted vehicle, \( m_r \) – mass of impacting vehicle, \( E \) – predicted total absorbed energy.

2. LOGISTIC PLAN OF THE UNDERTAKING

Approach to planning the crash test project is shown on an example of SAFETRAM Work Package 7 (WP7, [2]). General timetable of the undertaking was worked out by the consortium but a flowchart showing preparation and realisation tasks of the crash tests in Żmigród (near Wrocław, Poland) - presented in figure 3 - was done by the author. The author prepared it after consultations and with collaboration of Division of Rail Vehicles and Rolling Stock Laboratory of the IK.

The activities and the events to be performed are presented in form of a preliminary timetable and a flowchart. Must be noticed that the formal start of the work package is 1 July but obviously some preparatory works have to begin much earlier. Following abbreviations are used: CTe – city tram end specimen (cab), PTe – peri-urban tram end specimen (cab), TWA, TWB, TWC, TWD – test wagons, IM - inner measurements, OM - outer measurements. During the 1st test the cab CTe is coupled with the test wagon TWA and impacts a rigid wall of the test wagon TWC (CTe+TWA→TWC). During
the 2nd test the cab PTe is coupled with the test wagon WTB and hits a headstock of the test wagon TWD (PTe+TWB→TWD). Events filled in the rectangles of the flowchart □ - are the IK events and in hexagons ○ - mile stone events. Remaining ones concern other WP7 partners (DB). A time axis and predicted time points concerning the most important events were added to the flowchart.

Below, the timetable reads as follow. Formally, the WP7 part of SAFETRAM project runs from 1 July to 31 December. However, this part of the project ought to be preceded by work and time consuming activities of all members of the consortium, which would give the results for basic assumptions concerning the geometry, loadings etc.

A realistic time of duration - divided into 2 parts - and an appropriate timetable suggested by the IK is presented below. The timetable can be divided into 2 parts. The 1st part concerns the preparation of all components and to achieve all of predicted crash test events. The 2nd part concerns data processing, developing the results and the reports.

Designing the crash tests is a big and risky undertaking. Even a small mistake can lead to serious problems e.g. because the experiment may not be repeated without any additional costs. Such risk arose in the project described above because of late delivery of the tested cabs. There were also other problems with the projects as for example an effect of gravel forming the ballast, which ‘flew out’ from the wagon. Due to this effect the ballast did not take over significant part of the collision energy. This failure was corrected with use of the numerical simulation but the duration of the undertaking had to be prolonged. Another problem was with proper operation of the fast filming cameras. Some of the uncertain actions ought to be marked in the flowchart, e.g. with dashed lines as in figure 3.

3. PREPARATORY WORK BEFORE CRASH TESTS

Preparatory works concerning the crash tests for passive safety consists in following tasks: project of the entire undertaking, conferences and meetings, design of the cab structures, design and testing of selected components e.g. absorbers, numerical simulations of the crash process, project of test site, project and installation of measuring devices as well as the measurement procedures and eventually design and modifications of test vehicles.

The activities begin with a review of the basic assumptions about the main parameters of the collision, the geometry, masses and loadings of the test wagons. Before the planned date of 1 July – the test wagons A, B, C and D ought to be subjected to some modifications. These wagons were previously used for similar tests therefore should be reviewed their technical conditions and then certain elements repaired and adjusted to the needs of the planned experiment. For example, the units TWA, TWB and TWC often require to include the more strengthen end walls, whereas the TWD needs partition walls to be inserted into the loading space. Moreover, the last unit ought to have had installed the buffers of category A with round discs and with a linear characteristic (nowadays, this device is not easily available). An important and quite laborious job is a correction of a ballast of the test wagons, which ought to be completed on 15 July.

Most important for the success of the undertaking are the preparatory works and within them the modifications of the test vehicles. The impacting wagon must be prepared in such a way that the test object (sample cab) may be easily mounted on it. Usually it is the front part of the cab or of the rail vehicle of known weight. Sometimes an entire vehicle like a locomotive (figure 2f) can be the test object.

The cab may be connected with the frontal end of the test wagon with use of welding joints – but better solution is mounting it with use of coupling bushings and bolts. The bushings play the role of force gauges. In order to provide a better coincidence of a theoretical model of the cab with the behaviour of the real object, the cab should be completed by a rigid frame separated from the rigid wall of the test wagon with the force gauges, i.e. as in figure 2b. Additionally, indications of the force gauge are used to verification of the numerical simulations. The bushings as well as the bolts have to fulfill strength requirements, because they carry the weight of the cab as well as compression and shearing forces caused by the crash impacts. Moreover, the bushings of the gauges connecting the top of the cab and the wall of the test wagon are exposed to severe tensile stress that can break the bolts.
Fig. 3. Flowchart of preparation and realisation of crash tests - part 1 of 2
Fig. 3. Flowchart of preparation and realisation of crash tests - part 2 of 2
Selection according to a catalog or design of the force gauge is one of the first steps to prepare the tests. As a first approximation the estimation of the forces acting in the force gauges can be established only on the basis of the characteristic of the buffers and energy absorbers, taking into account the deformation energy accumulated by the assemblies involved in the collision, namely on the basis of the dynamic force values.

During the real impact - especially at the moments of activation of subsequent absorbers - there are some excess forces that must be taken into account during the selection of the force gauges. On the other hand, should be taken into account that a part of the energy is not transferred to the zone of the force measurements because the energy will be absorbed by the structural members of the cab located between the absorbers and the rigid frame.

There are some requirements which the test wagons must satisfy, [6], [7], [8]. First of all, they must have ability to easily adapt to the required weight which has been determined for the impacting and for the impacted vehicle. Seemingly an easy task, but the fact that the vehicles are used repeatedly (for economic reasons) there are practical difficulties such as determination of the mass of existing concrete ballasts, exchange of the ballast boxes, etc. The boxes must be correctly attached to the frame of the vehicle. In some test configurations, besides of concrete also bulk materials such as sand or gravel are used. Their use should, however, be preceded by the computer simulations and the experimental studies. It is observed that during the test with use of the obstacle wagon filled with bulk material a phenomenon similar to so-called 'sloshing effect' occurs. The sloshing effect takes place usually in tanks cargo traffic which reduces the amount of energy acquired by the obstacle wagon. On the impacting vehicle also a place for a box with the measuring apparatus should be found - preferably in front of the vehicle so as to minimize the wiring length.

4. NUMERICAL SIMULATIONS

After defining the parameters of the project and before the impacts, the simulation calculations have to be conducted in order to determine the dynamic forces acting on the cabs and on the test wagons. They allow to define loadings needed for calculations of strength of the force sensors and for the whole test wagons.

The test wagons TWA, TWB and TWC were built on the basis of the UIC wagons of Smms series. A rigid frame with one or two end walls, consisted of a system of “I” bars which were located aslant (see figure 2), were imposed on the Smms underframe. The test wagons almost always undergo certain modifications, because they have been chosen to participate in the crash test providing they fulfill the parameters of the research project. The most common change that has been carried out, so far – [1], [2] and [3], is reinforcement applied at the bottom of the front wall because of the low cab position and high compressive forces. Another modification is strengthening the zones of the front wall in the vicinity of the force gauges, especially at the top of the wall, where tensile loadings occur and the wall is not rigid enough.

Into some free spaces of the framework iron ballasts were inserted and were cemented with concrete. These assemblages were mapped in the FEM model, but a number of additional members, such as for example parts of braking system, and other auxiliary parts were not directly incorporated in it. However, their influence was included in the mass of the wagon, which served as inertia balancing the external forces during the impact. The FEM model also contained equivalent systems of the finite elements which were used for modelling the chests with the ballasts as well as the bogies, [8].

CONCLUSIONS

Designing the crash tests is the undertaking, in which an important role is played by organization and logistics. However, the properly prepared project leads to achieving the purpose and to minimization of its costs. On the other hand, even a small mistake can lead to a serious setback – which in this case is the experiment that could not be repeated without any additional costs. Such a risk may arise in projects similar to the described above, most often because of late delivery of the
tested cabs or other components. It should be noted that there were other problems with the projects [1] and [2] because a strange behaviour of one of the ballast was not predicted. Gravel forming the ballast did not take over quite large part of collision energy due to the sloshing effect – simply gravel spilled out itself from the wagon. Fortunately, this failure could be corrected and compensated with use of the respective simulation. Another problem is to maintain the readiness of the fast filming cameras, as well as other measuring devices.

It is worth emphasizing that the results of the project [1] and [2] were used to create the standard [5] and indirectly also the directives TSI [9]. Moreover, the knowledge gained in all of the described tests may also be useful for future testing the prototypes of the conventional vehicles as well as the high speed trains.

Abstract

In the paper, organization, logistics and preparation problems concerning large projects such as a project of crash tests on cabs of railway vehicles were described and illustrated with a flowchart. Large objects, railways, high-speed, cost, uncertainty and exposure to judgments of media etc. make that various difficulties appear. A characteristic feature is also a large number of participants (including media) and their diversity because a project consortium commonly consists of various institutions, universities and companies. Planning and preparation of the crash test is the undertaking, in which an important role plays the organization and logistics. However, the properly prepared project leads to achieving the main goals and to minimization of its cost. On the other hand, even a small mistake can lead to a serious setback – which in this case is the experiment that could not be repeated without any additional costs. The author described the examples of such projects, which gave him and teams of Railway Institute (Warsaw, Poland) a high level of experience in preparing and carrying out the crash tests on a scale of 1:1. Some exemplary configurations of the high-energy crash tests for cabs of railway vehicles which were carried out in Żmigród test site were illustrated in figures.

The results of some of the crash test projects were used to create the standard EN 15227 and indirectly also parts of some of the directives TSI. Moreover, the knowledge gained in all of the described tests may also be useful for future testing the prototypes of the conventional vehicles as well as of the high speed trains.
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