EXPERIMENTAL RESEARCHES OF SAFETY OF ARMOURED PERSONNEL CARRIER CREW DURING COLLISION WITH OBSTACLE

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Summary

The paper presents problems related to dynamic loads of armoured personnel carriers design as well as soldiers located inside them. In order to assess the exposure of soldiers while overcoming terrain and engineering obstacles experimental studies were performed covering a carrier's collision with a concrete obstacle. The scope of the tests included a collision of the armoured personnel carrier with obstacle for two speeds: 6 and 12 km/h. During crash tests, anthropomorphic measurement equipment – Hybrid III 50th Male Dummy type – was used for recording the values of loads affecting the soldiers. During crash tests, two fast video cameras were used for recording motion of the carrier and obstacle's plates. The vehicle body accelerations were recorded as well.In the paper the research conditions and used measurement equipment were described. Some results of experimental studies were presented. Typical phases of motions of dummies located in driving and landing troop compartmentwere presented. The values of the carrier's body accelerations in driving and landing troop compartment were compared,displacements of barrier's segments were described. Obtained results indicated that carrier's driver is subjected to higher loads. During crash test at low velocities, the limit values were not exceeded in any analysed case.

Keywords: passive safety, dynamic loads, crash tests, personnel carrier, HYBRID III

1. Introduction

The procedure for use the armed forces changes continuously. Besides conducting operations in classic military conflicts, the armed forces are used increasingly to carry out the preventive tasks in the framework of the multinational stabilisation and peacekeeping mission. Conditions of the mission causes that armoured personnel carrier (APC) are mainly

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used. The requirements of tactic and technical characteristics assume that this type of vehicles should ensure rapid movement of infantry along the roads as well as off-road driving and provide effective protection against bullet. Along with the change of the concept of the use of troops the constant change in armour and military equipment must be done simultaneously to meet required standards. The new type of tasks include ramming different obstacles such as fences, entry gates, light engineering obstacles (barbed or concertina wire, barricades) and also pushing other vehicles aside the road in order to return it passability. A significant slope of roads as well as reduced the effectiveness of the braking system caused by high temperature and significant growth of the vehicle weight (about 125% of vehicle operating in the country) increases braking distance. As a result, there are also cases of collision one vehicle to another in a column. During the preliminary analysis [1,3], it was found that the serious limitation of the possibilities of ramming is not the structure of the vehicle, but the risk of crew injury, due to the high level of dynamic forces acting during the crash. Unlike cars, in which a crumple zone absorbs a large part of the impact energy, in the military vehicles which design is based on a rigid frame or integral body, there is no technical solutions to mitigate the effects of a crash. The fact should be taken into account that into a typical APC besides the driver and vehicle commander, additionally approximately eight troops are located. Due to the need of quickly exit the carrier through the rear doors, soldiers' seats are placed along the walls of the vehicle perpendicular to the direction of motion. Moreover, the only element of safety are lap seatbelts, which in frontal-impact situation are not able to protect the passengers effectively.

The basic purpose of this paper was to define a level of dynamic loads affecting an armoured personnel carrier and its crew during a frontal collision with a concrete obstacle at low impact velocities.

2. Research object and methodology

Due to a lack of access to Rosomak armoured personnel carrier, which could be destroyed during the crash tests, a four-axis SKOT personnel carrier, command centre version, out of service, was used for the tests. The tests were carried out within the area of the Military Institute for Armoured and Automotive Technology in Sulejówek, using their vehicles and test dummies.

Fig. 1. APC SKOT and concrete obstacle before test

Fig. 1 presents a view of a concrete obstacle and a personnel carrier prepared for a crash test. The obstacle consisted of twelve elements: seven plates and five concrete blocks. The face of the barrier measured 1.5 x3m. Total mass of the obstacle was 19 780 kg, whereas mass of the vehicle prepared for attempts was 12 200 kg.

During crash tests, anthropomorphic measurement equipment – Hybrid III 50th Male Dummy [5] type – was used for recording the values of loads affecting the soldiers. 50-centile male test dummy Hybrid III is the most common dummy used in the automotive industry. It is used to evaluate the safety and structure. It allows for acquisition of physical values truly reflecting a possible influence on a human body. That kind of equipment is basically designed for frontal car crash tests. A dummy located in the driver compartment was placed on a standard seat of the SKOT vehicle, without a headrest, and fastened with four-point seat belts. A dummy located in the landing troop was placed on a seat making standard equipment for aAPCRosomak and it was fastened with a lap belt. (fig. 2).

Fig. 2. A dummy located in the driver compartment (left) and in the landing troop compartment (right)

The tests were performed by accelerating the carrier by means of a truck. The carrier's driving system was disconnected for the testing time. The scope of the tests included a collision of the armoured personnel carrier with concrete obstacle for two speeds: 6 and 12 km/h. During the tests, the speed was initially defined by GPS equipment while the real speed before the crash was defined on the basis of the records made by a fast video camera each time. Three trials were carried out for each speed.

Two fast video cameras were used for recording the impact process. They were put on the left and right side of the vehicle. Additionally, in order to record displacement of the dummies located inside a vehicle, two GoPro HERO video cameras were used. One was located in a driver compartment and the other one in the landing troop compartment.

Apart from the measurement apparatus related to the Hybrid III dummies, two independent measurement tracks were installed in the carrier used for measuring the acceleration of the body during the tests. The first of them included the ACCINO system, making the integrated measurement and recording system with own supply system [4]. It was installed in the middle section of the vehicle, on the carrier's floor. Apart from the acceleration measurements in three mutually perpendicular directions, it also allowed for measuring the angle speed against the vertical axis. The second system included the ACA Digital X10D measurement computer, the DaqBook measurement card, the conditioner module and two triple-axis piezoelectric accelerometers, Brüel&Kjær 4504 type, placed on the floor in the driver compartment and on the side wall in the landing troop compartment (both in the places where the seats were mounted to the vehicle body). Measurement signal acquisition took place at frequency of 10 kHz.

3. Test results

Courses of analysed values, recorded during experimental tests, were subject to filtration and scaling. In relation to the body acceleration, a digital filter in accordance with CFC60 was used. Its cut frequency amounts to 100 Hz. Fig. 3. presents examples of longitudinal acceleration courses for two impact velocities: 5,11 and 12,96 km/h. In the case of smaller velocities during the test the hull hit obstacle's plates ones, then the carrier moved back, until it was stopped. For higher velocities of collision, concrete plates were rejected from the hull in the first stage. As a result, further carrier movement occurred and subsequent strike took place. A direct effect of it is an increase of duration of collision process and reduction of vehicle deceleration. In spite of the six-times growth of a kinetic energy (for trial 5 compared with trial 2) only a thirty percent rise of the maximal value of deceleration was recorded.

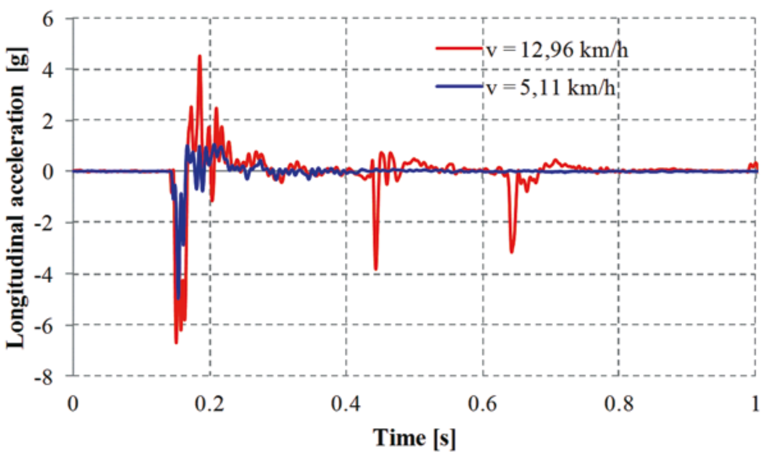

Fig. 3. Comparison of the longitudinal acceleration for the trial 2 and 5

Table 1 specifies, defined on the basis of analysis of the records from the fast video cameras, real impact speeds and recorded maximum body deceleration values in the driving and landing troop compartment for individual trials. Obtained results are illustrated on fig. 4.

Higher homogeneity of obtained results can be observed for lower impact velocities (trials 1-3), however a close relation between velocity and deceleration has not been obtained. It was mainly caused by the lack of the repetitiveness in relation to the point of the collision and the structure of the obstacle (despite it reconstruction after every attempt).At the final stage of motion the carrier did not always move perpendicularly towards the frontal surface of the barrier. In most cases, of maximum values of decelerations in the landing troop compartment were smaller than in the driving compartment.

Tab. 1. Maximum body deceleration

Trial	Velocity [km/h]	Body deceleration [g]	
		driving compartment	landing troop compartment
1	6,05	3,704	2,692
2	5,11	4,980	3,790
3	5,94	5,946	5,363
4	12,10	5,081	4,099
5	12,96	6,700	7,055
6	10,8	2,776	3,434

Much higher dispersion in obtained results was observed for trials 4-6. Increased velocity negatively affects a possibility of directing the carrier on the obstacle. In case of attempt 4 the carrier hit the obstacle about 2/3 of its frontal plate, whereas for attempt 6 only 1/3 its frontal plate. A different motion of the barrier was noticed. Apart from its tilting, considerable rotation about a vertical axis took place as well. As a result, a stopping distance was extended and significant reduction of maximal values of decelerations was observed.

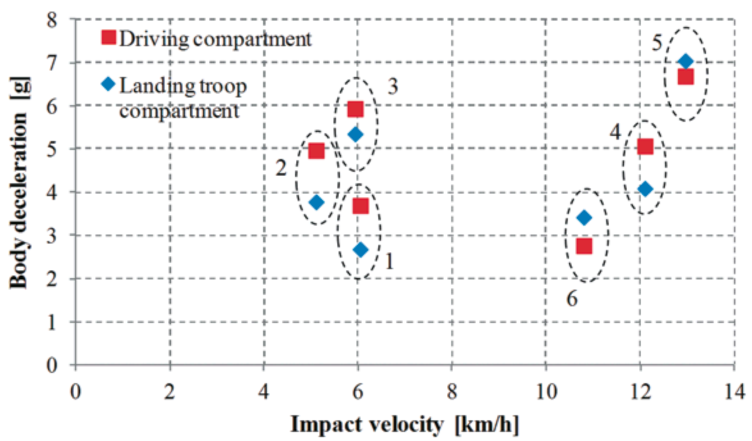

Fig. 4. The distribution of maximum body deceleration

On fig. 5. the test vehicle and a barrier were presented after collision. A lean and displacement of individual concrete blocks was different for individual attempts.

Fig. 5. The concrete obstacle after collision (v = 12,10 km/h)

For smaller impact velocities an angular displacement of concrete slabs amounted 3˚ and simultaneously its translation for about 1,5 cm occurred. Concrete blocks behind slabs were translated for about 10 cm. For comparison in attempt 5 these slabs were turned for angle 27˚ and the lower and upper blocks behind them were moved respectively for 26 cm and 53 cm. Moreover,for the attempt no. 4 and 6 first seven plates were rotated with regard to a vertical axis. For this reason, a measurement and comparison of results for individual blocks was difficult.

Fig. 6 specifies chosen phases of collision with a concrete obstacle for a trial no. 5. The impact took place at 140 ms of the measurement time (according to the courses on fig. 3 and 9). An incremental lean of concrete plates is visible on it. The carrier was stopped after about 600 ms from the moment of impact.

Fig. 7 presents three phases of motion of the dummy located in the driver's compartment. After 120 ms from the impact, the maximum bending of the dummy's neck occurs. Due to the use of a four-point seat belt, motion of the whole body is significantly limited. Only motion of the head and shoulders is visible. After 340 ms the body bends backwards which is characteristic for frontal collisions. The body is stopped on the backrest of the seat, while the head, in case of no head restrain, strongly tilts backwards.

Different behaviour can be observed for a dummy located in the landing troop compartment (fig. 8). The dummy is placed on a seat located crosswise towards direction of motion and it is protected with just a lap belt. In about 220 ms from the moment of impact the maximum dummy displacement can be observed. Due to the fact that the pelvis is held by the belt, the body and the heads bend to the right side with simultaneous bending forward and a slight turn against the vertical axis. After the impact, the dummy does not fully return to its initial position and stops after about 460 ms.

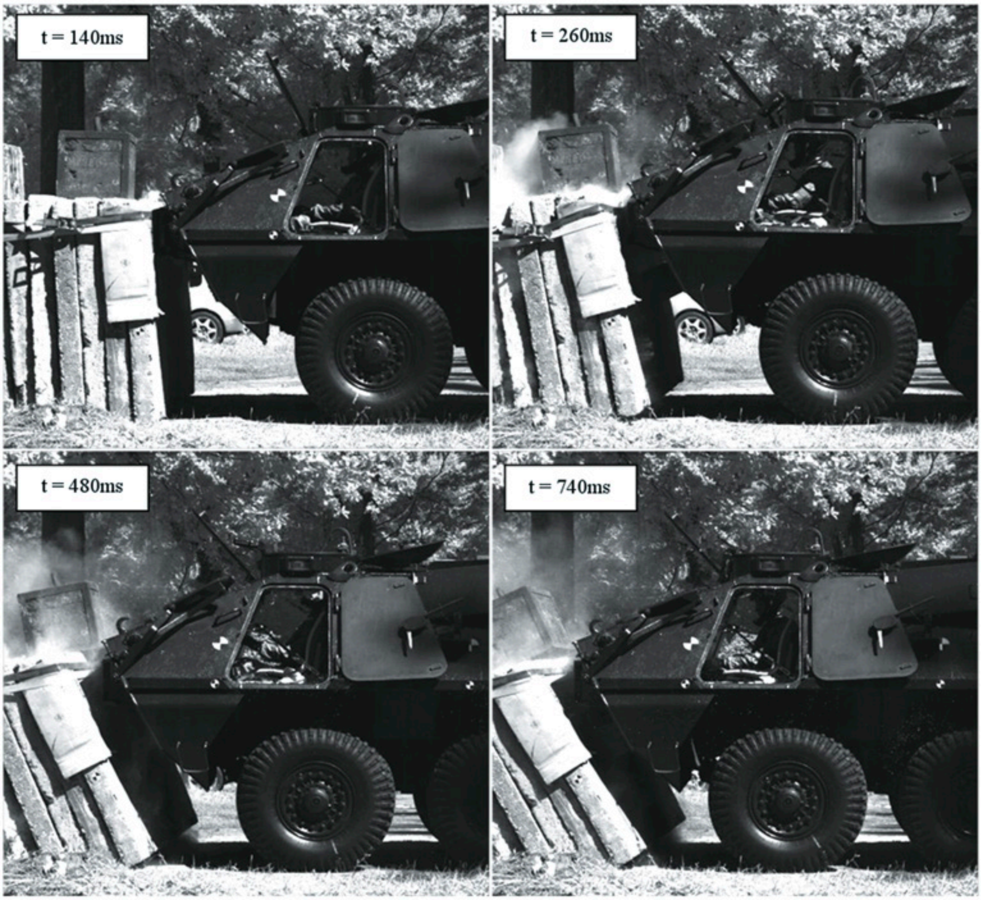

Fig. 6. Phases of APC collision with a concrete obstacle (trial no. 5)

Fig. 7. Phases of motion of the dummy located in the driver's compartment (trial no. 5)

Fig. 8. Phases of motion of the dummy located in the landing troop compartment (trial no. 5)

Fig. 9 presents an example of the course of the neck bending moment for a dummy located in the driver's compartment for a trial no. 5.

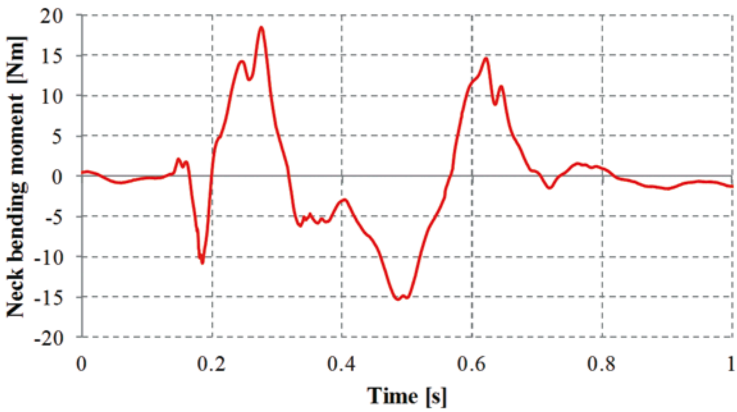

Fig. 9. The course of the neck bending moment for a dummy located in the driver's compartment (trial no. 5)

At the beginning, there is a short moment of bending the head backwards when the dummy's torso is pushed upwards. After that stage, the dummy's head is bent forwards and the maximum value of the moment is reached. It makes a basis for further evaluation. The maximum moments for individual trials are specified on fig. 10. It should be mentioned that in case of the dummy placed in the landing troop compartment, presented values refer to the moment of bending the head to the side (acting against the longitudinal axis of the dummy). The maximum values were obtained for a trials 4 and 5 and amounted to about 18 Nm. For trial no. 1 the results were not recorded properly.

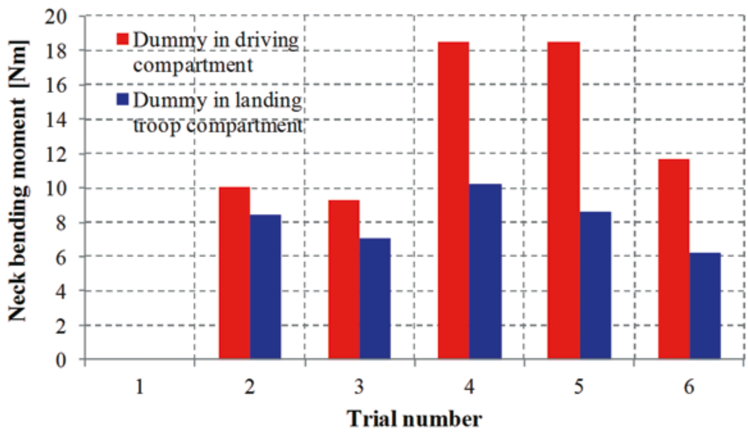

Fig. 10. The maximum values of neck bending moment

Table 2 specifies the maximum values of moments and forces in the neck and head deceleration for considered dummies as well as the limit values for frontal crash tests [2]. For the dummy located in the landing troop compartment, the value of the crosswise head deceleration was given. Due to a different dummy location against the vehicle, a direct comparison of individual measured values is not possible.

When comparing obtained results, it can be stated that the dummy located in the driver's compartment is subject to higher loads. Due to the fact that it is fastened with a four-point seat belt, its ability to move is limited and as a result it increases the loads occurring in the head and in the neck.

Tab. 2. Summary of results for test dummies

Trial	A driving compartment			A landing troop compartment		
	M_Y [Nm]	F_Z [N]	a_X [g]	M_X [Nm]	F_Z [N]	a_Y [g]
2	10.07	160.80	2.69	8.42	35.30	2.69
3	9.26	148.05	2.47	7.05	34.89	2.44
4	18.45	280.90	5.97	10.26	168.67	3.08
5	18.49	368.95	5.95	8.61	159.81	3.21
6	11.70	202.41	3.31	6.21	78.24	2.37
The limit values	57	1100	88	-----	1100	-----

M_Y–neck bending moment (head bending forward), F_Z – neck tension force,
M_Y – neck bending moment (head bending to a side), a_X –head deceleration in the longitudinal direction, a_Y – head deceleration in the lateral direction (the system associated with the dummy)

The limit values were not exceeded in any analysed case. The highest values, recorded during the tests, for the neck bending moment and the stretching force for a fourth and fifth trial are about 1/3 times lower than the limit values. Momentary head acceleration values are three times lower than the acceptable values for a 3 ms duration.

4. Summary

The results presented in this paper make a part of the experimental and simulation research carried out in order to define a level of threat for the armoured carrier crew during collision with various objects. The crash tests with a concrete obstacle were performed at lows velocities that did not result in serious vehicle damage.

On the basisof obtained results it can be concluded that the front part of the vehicle is subject to higher loads –in that part of carrier recorded value of deceleration were greater in the majority of trials. Some discrepancies were mainly due to the difficulty in maintaining a straight trajectory of the carrier. This resulted in a change of the impact angle.

Higher values of deceleration, neck forces and moments were observed for the dummy located in the driver's compartment. It mostly resulted from a different fastening method. Higher dummy displacement in the landing troop compartment reduced the values of forces and accelerations. However, it should be underlined that only a single seat was used in the tests. In the real conditions, several soldiers sit next to each other in the landing troop compartment. In such situation, there is a possibility that a soldier's head or body can hit the elements of neighbouring seat, equipment or a soldier sitting on the next seat during collision.

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References

[1] BORKOWSKI, W., HRYCIÓW, Z., *Preliminary investigation of dynamic loads of the crew of the armored personnel carrier during frontal crash,* Journal of KONES Powertrain and Transport Vol. 15, No. 4, pp. 57-62, Warsaw 2008.

[2] European New Car Assessment Programme (Euro NCAP). *Assessment protocol – adult occupant protection.* Version 5.2, June 2010.

[3] ORŁOWSKI, L., PĘDZISZ, M., RZYMKOWSKI, C., *Wyniki wstępnych badań eksperymentalnych oraz komputerowej symulacji zagrożenia osób w trakcie uderzenia w przeszkodę wojskowego samochodu terenowego,* Journal of KONES Powertrain and Transport, Vol. 14, No. 3, pp. 495-502, Warsaw 2007.

[4] PAWŁOWSKI P., CETNAROWICZ D. ACCINO. *Instrukcja użytkownika.* Wersja 3.3., Politechnika Poznańska, Katedra Sterowania i Inżynierii Systemów Pracownia Układów Elektronicznych i Przetwarzania Sygnałów, 2011.

[5] Sign Convention for Load Cells (S.A.E. J-211) 2002 Robert A. Denton Inc.