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Effects of Deceleration on Secondary Collisions between Adult Occupants and Vehicle in Frontal Crash Accidents

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ABSTRACT

The paper seeks to highlight and analyze the relationship between the occupants' displacements of chest and pelvis and the deceleration of vehicle in frontal crash accidents. A testing scheme including 5 groups of dynamic tests was devised and conducted. Totally, 5 kinds of acceleration pulses were employed to simulate the real crash. The experimental finding indicates that the integral values and shapes of vehicle's deceleration pulses can influence the occupants' chest and pelvis displacements to some extent; thus, having effects on the risks of secondary collisions between occupants and the vehicle. How the deceleration pulses of vehicle influence the secondary collision is also clarified in the paper by a comprehensive comparison of testing results between different groups. Further research can be carried out on optimization of deceleration pulses of vehicle in the frontal collisions and on how to reduce the risks of secondary collisions based on the findings.

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1. INTRODUCTION

Deaths and injuries from road traffic crashes continue to be major global public health problems and gradually draw more attention. In some countries, reduction in fatalities from road traffic crashes has been treated as one of public policy objectives. Many researches have been conducted and many measures have been taken to tackle the problems [1-3]. As a kind of protection device widely used in the field of passive safety of vehicles, seat belts are of great importance in securing safety and saving lives in frontal crash accidents by restraining the occupants and preventing secondary collisions between drivers or passengers and the vehicle [4]. Without the use of seat belts, frontal crash accidents could actually cause severe injuries and fatalities that should have been preventable or reduced to some extent if occupant restraint systems such as seat belts are employed and function normally [5]. Thoracic injury, lumbar spinal injury, pelvic injury, abdominal injury and many other kinds of injuries are common in crash accidents, and to a great extent may occur in the secondary collisions without the proper restriction upon the adult occupants' chest and/or pelvic displacements [6, 7]. Displacements beyond limits have become an obvious phenomenon related with the secondary collision directly. Generally speaking, the fewer traffic-related injuries and deaths of occupants are reported in crashes in places with the higher usage rate of seat belts [8]. Therefore, it is necessary to improve seat belt usage rate and public awareness [9, 10]. In addition, measures could be taken to find the factors that affect the usage rate and to curb the misuse and neglect of seat belts crucial for occupants [11].

In many cases, occupants still suffer from injuries or fatalities even if they wear seat belts, for various factors including deceleration of the vehicle which influences occupant restraint systems' safety performance in frontal crash accidents that usually bring about abrupt deceleration [12, 13]. Especially in extreme cases, chances of restraint systems' failure increase and the occupants are exposed to the danger of secondary collisions. Therefore, it deserves deep research on the failure mechanism of seat belts under

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specific testing conditions and how to avoid the risk of secondary collisions. To ascertain the effect of vehicle deceleration on the secondary collision between occupants and the vehicle is the essential prerequisite of further research, and also the emphasis of current research.

Compulsory seat belt legislation and corresponding technical standards play an important role in improving seat belt usage rate and promoting safety and standardization of products [14-16]. UN Regulation No. 16 being the uniform provisions concerning the approval of seat belts, specifies the requirements and test methods required for assessment of the safety performance. According to the test methods, dynamic tests can be conducted to obtain the information about the manikin's kinematic characteristics, thus simulating the real crash accidents. The process of real crash reconstruction involves choosing the proper equipment such as trolley and dummy, finishing the specified test procedure, collecting the essential information and analyzing the data obtained, and aims to provide test results as accurately as possible. Even though UN Regulation No. 16 provides a good reference for the current research, the test methods specified by the regulation are executed under the condition that the curve of trolley's acceleration or deceleration is within the zone defined by the low and high corridors. Meanwhile, in order to ensure the objectivity, accuracy and generality, a set of deceleration or acceleration curves should be taken into consideration, and could include but not be limited to the curve specified by the regulation, in view of various factors [17].

Until now there are fewer researches on the effect of vehicle deceleration on injury potentials of adult occupants caused by secondary collisions comparatively. Due to the rapid development of computation and inspection technologies, numerical simulations and experimental research have been conducted to optimize the restraint system, to evaluate the ability of seat belts to protect occupants, and even to investigate injury mechanisms in the crash, etc. [18-20]. As a complement to experimental study, numerical simulation can be used to predict the trends, and yet it needs to be validated by experimental methods [21, 22]. Besides, the accuracy is limited to the algorithm [23]. The research exclusively employs the experimental methods with the aim of getting the more exact results.

Actually, it is of benefit to ascertain the effect for improving the passive safety related with seat belts further. On the one hand, the vehicle deceleration influences the safety performance and poses risks for occupants when seat belts work normally [24]. Most of the time, seat belts can effectively restrain the adult occupants and protect them from the potential secondary collisions. But it doesn't mean that such restraint systems as seat belts can provide comprehensive protection absolutely, instead it is still of great use in figuring out how to give full play to seat belts' functions. All possible aspects should be taken into consideration in the process, and the effect of vehicle deceleration undoubtedly belongs to the most obvious ones. On the other hand, the vehicle deceleration may be fatal under extreme conditions [25]. Once damages caused by the abrupt deceleration to seat belts make it unable for seat belts to function, or the failure of seat belts restraining occupants' displacements to a safety range occurs, secondary collisions become inevitable and subsequently result in injuries, and even fatalities [26]. Although all kinds of occupant restraint systems including seat belts reduce the risks of collisions between occupants and the vehicle, possibilities of secondary collisions still exist, for the fundamental reason is that the vehicle deceleration makes occupants subject to inertial forces that are closely related with thorax and pelvis displacements. There is a causal link between vehicle deceleration and secondary collisions to some extent. Values of displacements exceeding norms permitted constitutes part and parcel of secondary collisions, and therefore this research focuses on studying and exploring the relationship between vehicle deceleration and displacements of the chest and pelvis.

2. METHODOLOGY

2.1 Dynamic test preparation In frontal crash accidents, the vehicle undergoes rapid or violent deceleration and in the process, the deceleration could be deemed as a function of time within stopping distance. Deceleration versus time profile could be obtained by an accelerometer mounted on the trolley that is employed to simulate real crashes and reproduce the required pulses. Trolleys can be classified into 2 kinds, one being the deceleration type, and the other being the acceleration type. The latter is convenient to use and has excellent properties of repeatability and reproducibility, with a lack of efficiency being the main disadvantage of the former. Therefore, acceleration trolley was chosen as the key equipment to conduct the research and acceleration pulses of the trolley were collected accordingly. Meanwhile, UTAC R16 dummy conforms to the technical regulations such as UN Regulation No. 16, and is suitable to measure the thorax and pelvis displacements. Cable extension position sensor shown in Figure 1 has the advantage of accuracy and reliability, and outweighs other devices used to measure displacements in dynamic tests. Two cable extension position sensors being the better means to measure the parameters required than high speed camera which induces deviations because of camera angles, could be adopted as the measurement devices for collecting the data of displacements, as displayed in Figure 2.

Deceleration pulses that occur in real crashes could be easily reproduced and simulated by acceleration trolley, and reconstructing the frontal crash is mainly based on the reproduction of the pulses. Only under the conditions that pulses of acceleration are nearly identical to the ones in real crashes, specified by certain regulations or defined regularly can test results be comparable and analyzed. Hence, a testing scheme incorporating a set of dynamic tests using different acceleration pulses was devised in order to ensure objectivity and universality. The testing scheme contains 20 tests involving 5 different kinds of pulses, as is shown in Table 1, and tests generating pulses of the same kind are listed into the same group.

In order to reduce the interference of installation mode, 20 3-point seat belt samples of the same kind were used in the tests, and the coordinate values of anchorages were identical to each other. The recommendations about anchorages by UN Regulation No. 16 were given priority to, and the seat belts were all installed according to the requirements so as to ensure the consistency of test conditions.

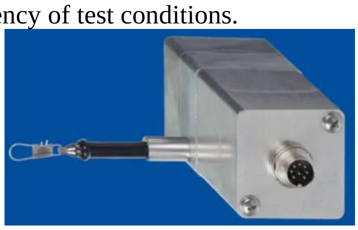

Figure 1. Cable extension position sensor

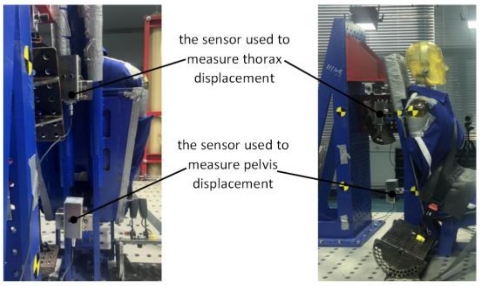

Figure 2. Two sensors installed respectively to measure thorax and pelvis displacements

2.2 Test procedure The R16 fixture was employed to install seat belts and restrain UTAC R16 dummy to the seat. Before each test and in the process of installation, the retractor had been so installed that the retractor was able to operate correctly and stow the strap efficiently. A board 25 mm thick was placed between the back of the dummy and the seat back. The belt was firmly adjusted to the dummy. The board was then removed so that the entire length of its back was in contact with the seat back. A check was made to ensure that the mode of engagement of the two parts of the buckle would entail no risk of reducing the reliability of locking. The final state of the dummy restrained by a 3-point seat belt just before a dynamic test starts is illustrated in Figure 3. The mode was repeated in every installation process to ensure the same initial state before the acceleration trolley was propelled each time.

Besides, the accelerometer was mounted directly at the bottom of the trolley. As the device to monitor the acceleration of trolley, it collected the essential data and then the acceleration pulses were obtained in the tests. Cable extension position sensors were mounted behind the dummy and their heights were equal to those of the dummy's thorax and pelvis measuring positions respectively. Similarly the displacement pulses of dummy were captured and served as the information input for analysis of the risks of secondary collisions. The acceleration trolley was propelled to the acceleration strictly according to the target curves set previously.

Figure 3. R16 dummy restrained by a 3-point seat belt on the trolley of acceleration type

2.3 Safety assessment Only when the thorax and pelvis displacements of R16 dummy are controlled to a certain range, the possibilities of secondary collisions can be reduced. As specified in most regulations including UN Regulation No. 16, in the case of 3-point seat belts, the forward displacement shall be between 80 and 200 mm at pelvic level and between 100 and 300 mm at chest level. The evaluation criteria being oriented to injury prevention, are based upon comprehensive consideration of factors such as the inner space of a vehicle, injury mechanism of occupants, and emergency locking properties of seat belt assembly, etc. So values of displacements exceeding the limits could be perceived as non-conformance with regulations concerned, and then risks of collisions are generated.

Furthermore, safety assessment is made under certain conditions that test results are compared and analyzed within groups of tests generating the acceleration pulses that have certain relations with each other. On account of regularity of the test scheme especially in the physical specifications of acceleration pulses, the trends of displacements could be displayed by comparing the values acquired by sensors and pulses acquired by the accelerometer.

3. RESULT AND DISCUSSION

After all the dynamic tests, acceleration pulses of the trolley and dummy's displacements of chest and pelvis were collected, classified, and analyzed. As displayed in Figure 4, the first 3 groups of tests were carried out at 3 different settings of amplitudes of acceleration pulses, while the shapes of pulses showed no obvious differences except for the amplitudes, i.e., the lasting time and the trend of each pulse were almost identical to others, but the integral values of the pulses varied to some extent when different acceleration curves were adopted in tests. The integral value of acceleration pulse for the continuous time is equal to the velocity of the trolley, and the velocity has a positive effect on the trolley's kinetic energy, while the deceleration pulse which is related with many factors such as the vehicle structure, the weight, and collision angle etc., in real crashes, determines how the energy can be absorbed. A total amount of 12 pulses of 3 different kinds were generated in groups I, II and III of tests, as is illustrated in Figure 4. Among the 3 kinds of pulses, one kind is in compliance with requirements about the acceleration curve specified in UN Regulation No. 16, as Figure 5 shows. Figure 6 displays the differences of velocities of trolley. The differences between the 3 kinds of acceleration pulses mainly lie in the amplitudes that are related with the magnitude of kinetic energy under the condition that the lasting time or pulse width of deceleration in each test undergoes few changes. It can be seen from the test results that the condition has been satisfied. Therefore, further inferences can be made based on comparison between the displacement pulses of chest and pelvis, in view of the energy transfer from the trolley to the dummy. As is shown in Figures 7 and 8, the displacement pulses show obvious regularity accompanying the changes of acceleration.

In groups IV and V of tests, another 2 kinds of acceleration curves were used and repeated 4 times respectively and subsequently a total amount of 8 acceleration pulses were generated in dynamic tests, as is indicated in Figure 9. In order to facilitate comparison between the results, the 4 test pulses generated in line with the regulation were also displayed in Figures 9 and 10. Meanwhile, measurements of the dummy revealed different patterns of displacement pulses when tests were conducted with different setups, i.e., when different acceleration curves were selected as the objects to simulate in dynamic tests. Integral values of the 3 kinds of acceleration pulses were almost identical with each other, while the pulse widths and amplitudes were different. Although the kinetic energy of the trolley was almost the same in each test, the steep and narrow pulse had the reverse effect on the displacements of dummy with the flat and wide pulse. As displayed in Figures 11 and 12, comparison between displacements of chest and pelvis indicates that the shape of acceleration pulses can influence the possibility of secondary collision even when the velocities are the same.

The test results are summarized in Table 1. It shows that when velocity of the trolley is constant, displacement of the dummy and steepness of the pulse move in tandem, i.e., they have a positive correlation. If velocities of the trolley vary and the lasting time of acceleration pulses remains unchanged, with the shapes of pulses being similar to a great extent, the displacement of the dummy will also be influenced. Taken as 2 variables, displacement of the dummy will increase as velocity of the trolley increases, with other conditions being almost the same. Similarly, when velocity decreases, the displacement also shows the same trend.

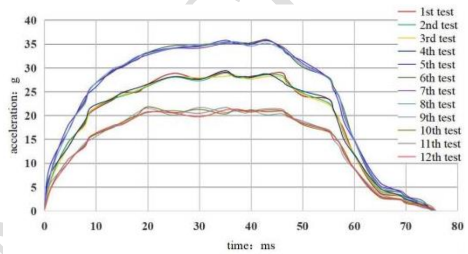

Figure 4. Comparison of acceleration pulses between groups I, II & III

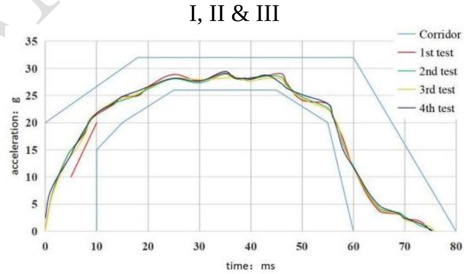

Figure 5. Acceleration pulses in the first 4 dynamic tests in accordance with UN Regulation No. 16

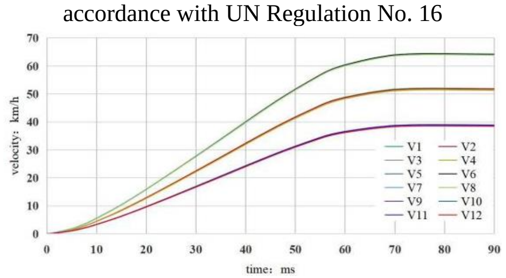

Figure 6. Comparison of velocities between groups I, II & III

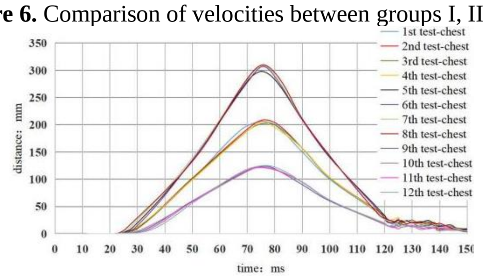

Figure 7. Comparison of distances of dummy's chest movement between groups I, II & III

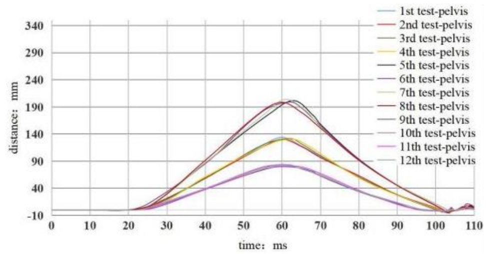

Figure 8. Comparison of distances of dummy's pelvis movement between groups I, II & III

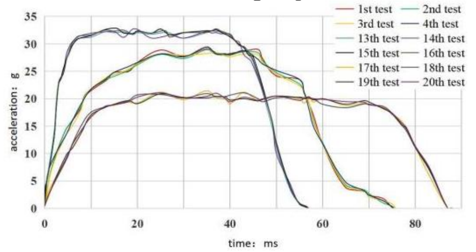

Figure 9. Comparison of acceleration pulses between groups I, IV & V

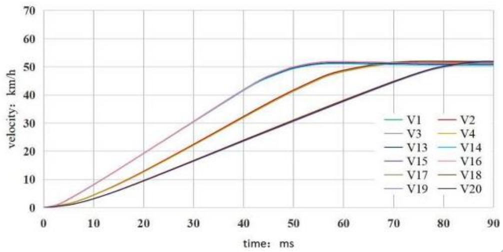

Figure 10. Comparison of velocities between groups I, IV & V

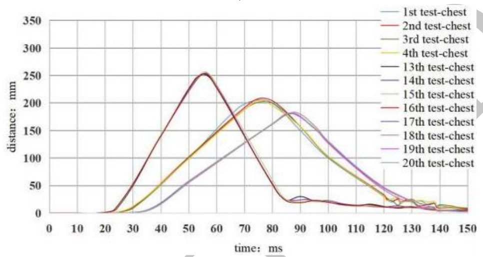

Figure 11. Comparison of distances of dummy's chest movement between groups I, IV & V

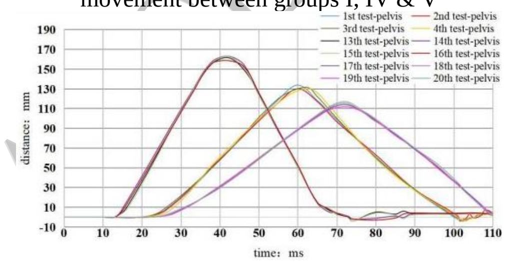

Figure 12. Comparison of distances of dummy's pelvis movement between groups I, IV & V

TABLE 1. Results of 20 dynamic tests

Group No.	Test No.	Trolley velocity (km/h)	Distance of dummy's chest movement (mm)	Distance of dummy's pelvis movement (mm)
I	1	52.1	206	134
	2	51.9	209	130
	3	51.6	202	132
	4	51.5	205	130
II	5	64.2	298	202
	6	64.4	307	199
	7	64.1	309	204
	8	64.1	310	198
III	9	38.7	124	79
	10	39.0	121	84
	11	39.0	122	82
	12	38.5	125	83
IV	13	51.4	253	162
	14	51.1	254	163
	15	51.8	257	163
	16	51.8	254	159
V	17	51.5	181	114
	18	51.9	183	115
	19	51.7	182	112
	20	52.0	183	117

4. CONCLUSION

The paper seeks to highlight and analyze the effect of deceleration on secondary collisions between adult occupants and the vehicle based on taking into consideration the relationship between the trolley's acceleration and R16 dummy's chest and pelvis displacements of movement in frontal crash accidents by means of experimental methods.

Findings of conducting the testing scheme reveal that the velocity of vehicle and the shape of vehicle deceleration pulses can both influence the displacements of occupants' chest and pelvis in a crash. Actually the velocity equals the integral value of vehicle's deceleration. In other words, deceleration of the vehicle is the main factor that has obvious effects on occupants' displacements related directly with secondary collisions. In order to avoid the risk of secondary collisions, it's necessary to reduce the vehicle velocity which may lead to different amplitudes of deceleration pulses. Meanwhile, improving the structure of vehicle and safety performance of seat belts is also of importance, for it'll optimize the deceleration pulses and bring about lower possibilities of secondary collisions.

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Persian Abstract

چکیده

این مقاله به دنبال برجسته سازی و تجزیه و تحلیل رابطه بین جابجایی سرنشینان در قفسه سینه و لگن و کاهش سرعت خودرو در تصادفات از جلو است. یک طرح آزمایشی شامل ۵ گروه آزمایش پویا طراحی و اجرا شد. در مجموع ، ۵ نوع پالس شتاب برای شبیه سازی تصادف واقعی استفاده شد. یافته های تجربی نشان می دهد که ارزش ها و شکل های یکپارچه ضربان های کاهش سرعت وسیله نقلیه می تواند تا حدی بر

جابجایی قفسه سینه و لگن سرنشینان تأثیر بگذارد. بنابراین ، بر خطرات برخورد ثانویه بین سرنشینان و وسیله نقلیه تأثیر می گذارد. چگونگی تأثیر پالس های کاهش سرعت خودرو بر برخورد ثانویه نیز در مقاله با مقایسه جامع نتایج آزمایش بین گروه های مختلف روشن شده است. تحقیقات بیشتری را می توان بر روی بهینه سازی پالس های کاهش سرعت خودرو در برخوردهای جلویی و چگونگی کاهش خطرات تصادفات ثانویه بر اساس یافته ها انجام داد.