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A Review Article: Proposed Experimental Model for Rollover Testing

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ABSTRACT:
Automotive companies are devoting a large amount of time and resources in the development of extremely safe vehicles. Roll over crash is one of the serious accidents among the vehicles, responsible for various lives.
Different standards for roll over testing procedure under CMVSS and FMVSS are presented in this paper. This paper provides standard and alternative test methods that have been used to provide data for rollover protection system of vehicles. Roll over testing method using FEA system is also discussed. The impact points are marked on the vehicle roof and testing is done. The roll rate vs. time and acceleration vs. time curves are obtained using differential transducers.

1. INTRODUCTION

The main goal of an automotive company is to provide a vehicle which is suitable in safety and comfort for driver over the life of a vehicle. So, these companies always focus on designing automobiles which are suitable in every condition of weight, cost, and fuel efficiency and designed the vehicle as outlined by government rules and regulations of safety. To achieve certain tests are performed on the vehicles to improve safety features by the engineers. [11] Vehicle rollover tests are performed on test specimen in the laboratory to know the safety offered by a vehicle to the driver and passengers. This event includes full vehicle simulation test to determine the safety of a driver in the vehicle. The following diagram shows the distribution various crashes in day to day life.

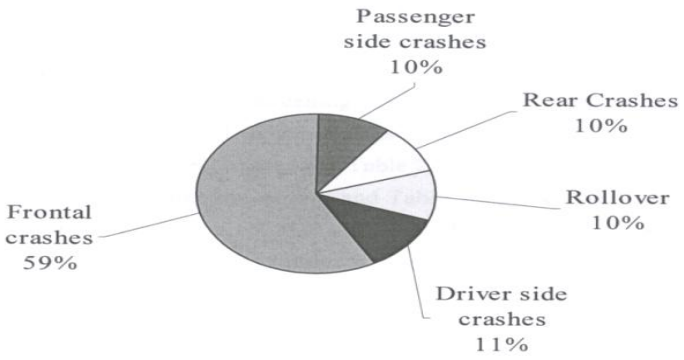

Fig. 1. Distribution of various crashes [10]

So, we can say that automobile rollover is very multifaceted phenomena. Earlier, rollover accidents accounted for only two percent of all vehicular accidents but now a days it becomes a most serious problem for all types of vehicles like light trucks, vans and sport utility vehicles (SUVs). So, several studies were conducted in the past decades to thoroughly understand the mechanism of rollover.

2. LITERATURE REVIEW

The vehicle is tested for the safety of the driver by considering various rules and regulations of the various governments like Canadian Motor Vehicle Safety Standards and Federal Motor Vehicle Safety Standards. These tests are made to test the safety of the passenger by the vehicle considering the various standards like CMVSS 208 or FMVSS 208 (occupant restraint system in frontal impact) [1,4], FMVSS 216 (roof intrusion protection) [2,5] and FMVSS 220 (rollover protection) [3,6] developed by National Highway Traffic and Safety Administration of United States. Main purpose of these standards is to protect the passengers of the vehicle during rollover accidents by making standard test procedures to test the vehicle by considering the above said the standard for the safety of the drive and the vehicle itself. The number of injuries and deaths caused by this rollover should be reduced to some extent if we are able to know the variable factors which are responsible for these rollover accidents.

These standards provide necessary details or information required for the testing of the vehicle, for the protection of the passengers in the vehicle and also to reduce these rollover injuries. The above described standards enable automotive companies to develop an automobile which provides greater safety to the occupants and higher performance of the vehicle.

2.1 Rollover:

Rollover is a variety of vehicle accident which occurs when a vehicle takes a turn at extremely high speeds or takes very sharp turn which is responsible for a vehicle to roll over its side or roof. More than 90% of vehicle rollovers occur around the longitudinal vehicle axis. The NASS-CDS database characterizes rollover into following types:

1. Trip-over - When the lateral motion of the vehicle is unexpectedly slowed or stopped it results in rollover of a vehicle. The opposing forces are produced a number of factors like a curb or pavement which responsible for the vehicle wheels digging into.
2. Fall-over – When the vehicle is travelling downward with the slope on the road surface which sometimes results in the outboard movement of a vehicle wheels due to the Centre of gravity. The main difference in this and turn-over is a negative slope.
3. Flip-over - When a vehicle is rotating around its longitudinal axis by a slope such as a turned down guardrail. Then it is possible that vehicle may be in between the yaw when it comes in contact with a slope.
4. Turn-over – A very sharp turn or vehicle rotation results in the centrifugal forces but these are opposed by normal surface friction which is common for all vehicles' having higher CG. The surface includes pavement surface, gravel, grass and dirt there is no grooving or mark at the point of impact. So, if rotation or surface friction causes a trip, the rollover is classified as a turn-over. [13]
5. End-over-end – In this, a vehicle rolls about its tangential axis as shown in following fig.
6. Climb-over - When vehicle climbs up and over a guardrail or barrier, which is high enough to lift the vehicle wholly off the ground. The vehicle must roll on the opposite side from which it approached the guardrail or barrier.[13]
7. Bounce-over - When a vehicle jump back from a flat object and turnover as a consequence. The rollover must occur in proximity to the object from which it is deflected.
8. Collision with another Vehicle - When a vehicle strikes with another vehicle on the road sometimes it causes the rollover. This type of must be the immediate result of an impact between the vehicles. [13]

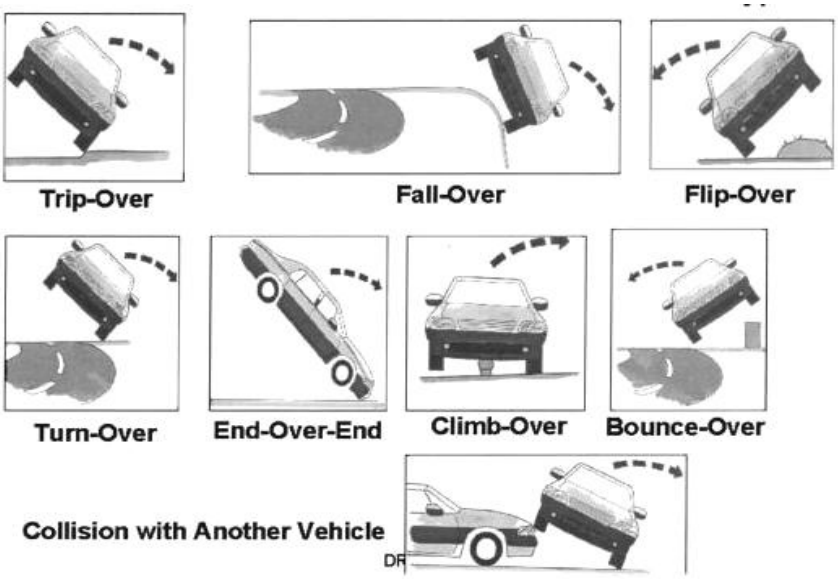

Fig. 2. NASS classification of rollover types [14]

Using NASS-CDS definitions, it was found that trip-over had the highest percentage for passenger cars (57%) and for light truck vehicles (52%) which occurred after contacting the ground, followed by a fall over. Other rollovers are equally dangerous but their occurrence is extremely rare. After extensive research it was found that it mainly depends upon the static stability factor (SSF) which is given by:

S= T/2H

Where,

S – Static stability factor

T- Vehicle track width

H- Vehicle center of gravity. [7]

It includes drifting off the edge of a road, directional stability on slippery roads, collision avoidance, tire de-tread, and tripping or furrowing in soil. The NASS database characterizes rollover into eight types: Trip, fall, flip, turn, climb, bounce over, vehicle collision and end-over-end pitch. [7] In order to have a better understanding of roll over phenomena number of laboratory tests was performed on the vehicles depending upon the various factors which are responsible for these types of accidents. The following are the some tests which are performed on the vehicle:

1. ADAC Corkscrew Test
2. Ditch Test (Fall Over)
3. Bounce over Test
4. Gravel Induced Trip over Test
5. High Friction Trip over Test
6. Pitch-Over Test
7. Soil Trip over Test
8. High and Low Speed Curb Trip Tests
9. Dolly Test (SAE J2114). [12]

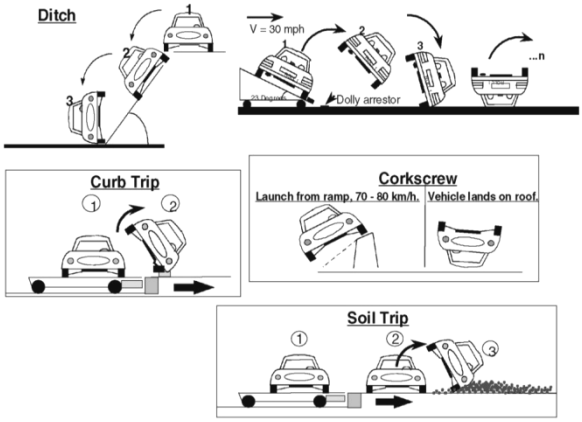

Fig. 3. Representation of various laboratory tests performed on the vehicles [14]

However these tests are still under deep research. But out of these, Dolly rollover or FMVSS 208 dolly is the main test which is performed on vehicles under the rules and regulations of federal motor vehicle safety standard to understand the effects of rollover on the passenger or the driver of the vehicle.

2.2 Standard rollover testing procedure (SAEJ 2114)

There are no rules and regulations which simulate the actual vehicle/occupant kinematics in a rollover. At present in the US, FMVSS 208 dolly test was often used to evaluate vehicle and occupant kinematics in a rollover environment. The main purpose of this was to examine the various injuries caused by factors like roof strength, belted and unbelted occupants response during a rollover. No special improvements were made to the vehicle.

In this dolly rollover test, a vehicle should be placed on the fixture which is also knows as dolly with the vehicle's center of gravity centered between the tires of the fixture. The vehicle is inclined at 23-degree angle and accelerated at 30 mph with Hybrid III dummy (to account a driver in the vehicle) must be placed at driver seat and does not have a tendency to eject during the roll and doors should be closed. [8] When the dolly (fixture) and vehicles are running at constant speed then decelerate the dolly which instantaneously results in the rolling of the vehicle.

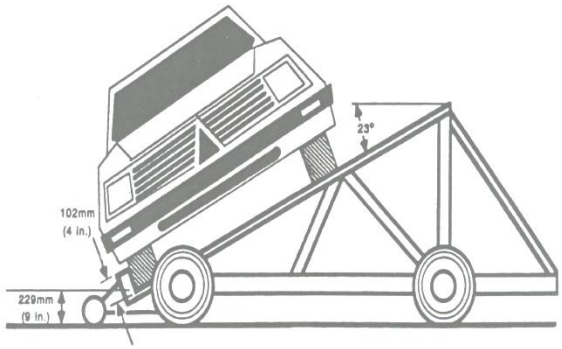

Fig.4. Dolly rollover test set-up [8]

This type of rolling is initiated by tripping which actually consists of two types: curb strike and soil furrow type vehicle rollover. The surface on which the vehicle is rolling should be of uniform concrete of a skid number of 75 when tested according to ASTM E 274-90 at 64.4 km/h (40 mph) and for 48 km/h (30mph) a surface which allows unobstructed rolling which is necessary for most passenger cars. [8] The rolling vehicle

in the 208 dolly test rolls for 2 to 5 times during the test to achieve the desired results. Different trips are achieved by changing the conditions like

1. A curb trip is achieved by accelerating a vehicle to a prearranged velocity and tripping it with an obstacle.
2. A soil is also achieved in the same but instead of hitting a curb it is released to loose soil or gravel. [8]

Due to a short period of rolling of 4 to 6s, high speed movie or video cameras at different locations inside and outside vehicle are fitted to record this test data. The test specimen (vehicle) is instrumented with crash worthy instrumentation and data acquisition system was used to collect the acceleration time histories for each roll over tests. These data collection consists of following necessary components to record the various movements of the vehicle.

1. **Accelerometers:** Three accelerometers (Model- 2262A-100) of 2 kHz anti-aliasing filter and a 10 kHz per channel acquisition data rate was used to record accelerations in the lateral and vehicle directions. Biaxial accelerations are measured with entran accelerometer (EGAX 1000). [9]

2. **Velocity transducers:** These are used to record rotational velocity of the vehicle.After recording the data it is processed and graphs are plotted for acceleration-time history for the entire duration of the test (up to 6s) to determine the kinematics of the vehicle's rollover. But the main disadvantage of this is that we cannot test the vehicle at different dynamic conditions. So, further improvement is needed for the exact evaluation of rollover effects on the passenger and the vehicle.

But later on, two new repeatable dynamic test procedures were invented known as controlled rollover Impact system (CRIS) and Jordan rollover system (JRS). In both the tests rotatingvehicle is released onto the ground to determine the effect of rollover on the passenger.

Various parameters that are controlled for the repeatability of the test are as follows:

- Roll angle (α)
- Pitch angle (β)
- Yaw angles
- Rotational velocity
- Translational velocity [10]

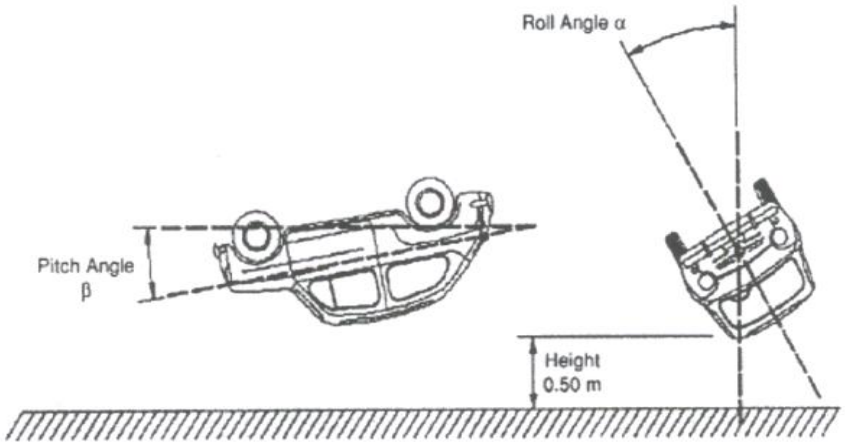

Fig. 5. Various test Parameters

In CRIS a moving semi-trailer with drop fixture which has adjustable height support pins is taken. This drop fixture is capable of rotating the vehicle about its center of gravity (CG) as it is installed with motor drive system and also it so multipurpose that it can used for testing of different vehicles with varying impact conditions.

Fig.6. Diagram showing the apparatus of CRIS [10]

Initially, it was conducted with a vehicle at zero initial pitch and yaw angles, having translating speed of 82.1 kph (51 mph) and roll rate of 149deg/sec is provided with Systron Donner solid-state inertial sensor (Model QRS12-01000-102) [9] which was mounted in the center of gravity. After considering these parameters a vehicle is dropped from a height of 5 inches so that it impacts with the ground at a 133 degree roll angle. In this, a U-shaped semi-trailer is employed for dropping the vehicle directly on to the ground at given roll rate and orientation. For the observation of this entire test a high speed cameras or video cameras are installed on the drop fixture to take close of the rollover to ground. [10] The results obtained in this testing show a remarkable difference when compared with 208 dolly rollover test. In addition, to these accelerometers, different sensors are used for measurement of roll rate.
After, evaluating the various tests this CRIS test was adopted by Society of Automobile Engineers (SAE), USA. But due to its cumbersome procedure it was so difficult to perform. So, a regulating dynamic test is still under investigation.

3. PROPOSED EXPERIMENTAL MODEL FOR ROLLOVER TESTING:
As now we are well known about the rollover and its effect on the passenger. Manufacturers spend millions on vehicle design to protect the occupants by inventing occupant defence systems to reduce the possible fatal injuries in rollover accidents. Vehicle rollover accidents are responsible for the most serious injuries to head and neck of the driver or passenger during an accident. Most of these injuries occur when a very sharp turn is taken or the vehicle skids during this turn. The driver side roof is the mostly affected portion of the vehicle, because when vehicle starts rolling vehicle roof touch the ground with some force which may destroy or crush the roof. This roof crush seriously affect the occupants head and neck which sometime may leads to the serious injury and even may lead to the death of the driver.

This rollover test is made considering various rules and regulations of CMVSS and FMVSS nos. 208, 216 and 220. This test is possible in a closed room instead of open space which were more costly and cumbersome. It is easier to perform than other rollover test like dolly rollover test or CRIS test or JRS test. The idea of this test is taken from the CRIS test and JRS test [11], as CRIS is performed in open space but it

is performed in a closed room like JRS test. The main difference between JRS test and my proposed test model is that moving flatbed surface in JRS doesn't represent the real world conditions. So, to represent real world conditions in rollover accidents, I have proposed a new experimental test model with stationary bed and translating fixture along with the rotating vehicle as shown in the following figure. The main purpose of this test is to thoroughly understand the roof-to-ground impact which may decrease the ratio of the injury to passenger or driver of the vehicle.

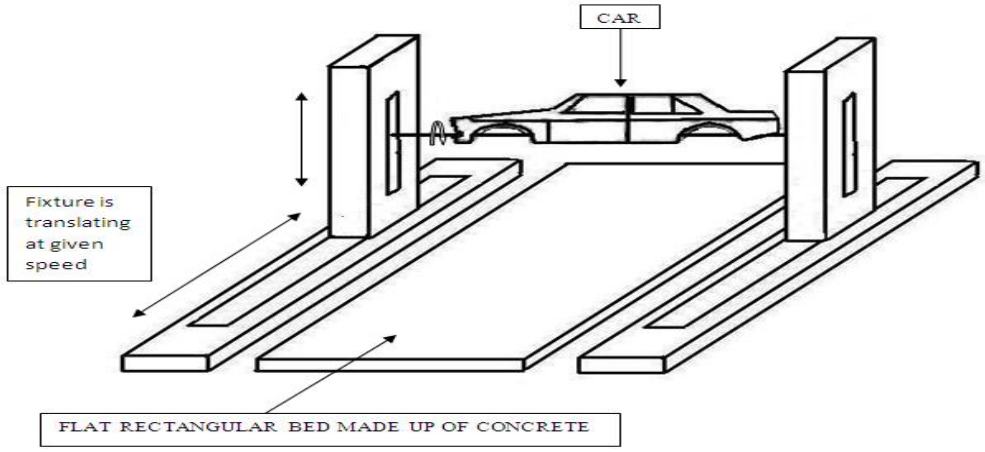

Fig.7. Experimental Set-up of rollover testing

This experimental set-up consists of following components:

1. Flat rectangular bed representing a road surface.
2. A test vehicle.
3. Fixture has a translating motion just like a vehicle.
4. Hybrid III dummy to check the impact of rollover on the driver or passenger.
5. Instrumentation data acquisition system for measurement acceleration and roll rate time histories.
6. A drive gear system mechanism is used for providing rotational and translating motion to the vehicle and fixture.

The main advantage of using this test over other rollover tests is that stationary bed represents the road surface and moving fixture along with rotating vehicle represents real world rollover accidents conditions.

The mechanism of this system is so made that when the translating motion is provided to the fixture with the help of gear drive system, and it also causes the vehicle to rotate because it is connected to it through crank system. Gear drive system and the crank systems are is so adjusted that it controls the translating, rotational motion and the initial linear and angular impacts (Yaw, pitch angles).

Then the fixture is made to running at some speed on the rails with rotating vehicle about its central axis, and then releases the vehicle when required running fixture speed is achieved and its rotary motion makes it to roll over the rectangular bed. So that it impacts the ground at a fixed orientation. This system is repeatable as compared with others.

Various types of instruments are used for the measurement of impact conditions are as follows:

1. The loads on the roof are measured using specific load cells of desired configuration mounted between the impact bed and the fixture mounted on the rails.
2. A translating and the rotational velocities of the vehicle are directly measured with the help of transducers and accelerometers. They all capable of measuring values in the direction of impact with significant measuring speed accuracy.
3. Rotational velocity is measured with the help of optical encoder.

3.1 Testing using finite element modeling

Finite element model (FEM) method has become a popular method for calculating the response of structures and materials. FE models are created to understand the impact of rollover on the passenger and to simulate the specimens on the FE model so that if further testing under different conditions is required, it can be done by changing the conditions in the computer simulation and no physical testing will be necessary. By using finite element analysis the models of the vehicle, fixture and other necessary components and Hybrid 111 dummy model will be developed. FE modeling is done using the Hyper Mesh on the developed models tested on the sled and results will be analyzed in MADYMO.

Simulation Model of SAE J2114 using MADYMO: It consists of vehicle, test platform and ground sub-models. The vehicle model consists of a vehicle and the engine masses, where engine is connected to a vehicle with cardan joints. Hyper-ellipsoids are used to represent other parameters of the vehicle like windshield, doors, and tires. The vehicle CG and mass moments of inertia are obtained from actual vehicle test data. The vehicle is rotated at an angle of 23 degrees from the horizontal and resting on the fixture as described above. The test platform is modeled as one body system. Initially vehicle is running at 30mph along with the platform upon which the vehicle is resting, then suddenly it is stopped within a very short distance which the vehicle to roll over. Honey combs are used to stop as a mechanism. Plane-Ellipsoid is used for calculating contact forces between the tires and the platform or the fixture. [15]The following are some necessary conditions that are to be considered while generating SAE J2114 model:

1. Vehicle geometry in both exterior and interior dimensions.
2. Vehicle parameters, such as vehicle e.g. location, moments of inertia, track width, wheel base, vehicle weight.
3. Suspension system and tire parameters such as suspension linkage geometry, spring and damping characteristics, tire dimensions, moment of inertia, tire characteristics.
4. Initial conditions: vehicle test velocity, vehicle position. [15]

3.2 Observations:

Following Experimental test data will be obtained:

Table 1. Roll rate vs. Time curve

Experimental test	Impact velocity (mph)	Time (sec)	Roll rate

Table 2. Lateral Acceleration vs. Time curve

Experimental test	Impact velocity (mph)	Time (sec)	Lateral Acceleration

4. CONCLUSION

For any test to be considered having the best possible results it must undergo the conditions which it may phase in real time. This may not be possible for all times and we have to settle for an option which is closest to the real time conditions. The above test which is a modification of the earlier test helps us attain the real time conditions which have the road at a stationary state and the car is under a roll and movement states simultaneously. The earlier test where the road was rendered the movement forward and the car had the tumbling motion was close to the original state but was not the same. So the results attained hence help us have a clearer picture of the whole scenario and in turn helps us design a better role cage which would hold up in an accident in a better way.

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