

ROADSIDE BARRIER AND PASSIVE SAFETY OF MOTORCYCLISTS ALONG EXCLUSIVE MOTORCYCLE LANES

A.B. IBITOYE^{1*}, R.S. RADIN¹, A.M.S. HAMOUDA²

¹Road Safety Research Centre
Faculty of Engineering, University Putra Malaysia, 43400 UPM, Serdang, Selangor,
MALAYSIA.

²Mechanical and Industrial Systems Engineering, Faculty of Engineering, Qatar University,
Doha, QATAR

*Corresponding Author: biliyamin@yahoo.com

Abstract

The tremendous increase in number of motorcycles and fatalities in some ASEAN countries is becoming a main concern for the safety of motorcyclists along exclusive motorcycle lanes. The existing w-beam guardrail system along exclusive motorcycle lanes was originally designed to reduce severity of a crash when cars and trucks involve in run-off road accident – but not specifically to protect motorcyclists during such accident. However, the consequences of this guardrail design on the passive safety of motorcyclist have been given little consideration. Thus, Probability of the motorcyclists getting injured on collision with guardrail is higher compared to other motor vehicle's driver. In order to investigate the passive safety of motorcyclists while in collision with this guardrail, this study carried out computer simulation of typical crash scenario and conducted a physical crash test to validate the simulation model. The study examines the crash mechanism as related to injury severity when motorcyclist interacts with W-beam guardrail. A three-dimensional computer simulation of a scaled Hybrid III 50th percentile Male dummy mounted on a motorcycle and colliding with W-beam guardrail was carried out. Multi-body model of motorcycle and finite element model of guardrail were developed with commercially available software called MADYMO. The simulation model is validated with a simple crash test conducted with same initial impact configuration. The subsequent simulations were set up for impacting the existing w-beam guardrail with 110 kg motorcycle using eighteen impact conditions that consist of impact angles 15°, 30° and 45°, impact speeds of 32, 48 and 60km/h as well as post spacing of 2m and 4m. The predicted rider's injury risk criteria were used to assess safety of guardrail response to motorcyclists. The obtained results confirmed that the existing w-beam guardrail is not safe to motorcyclist, especially for the head injury at impact speed 48km/h and impact angle of 45 degree.

Keywords: Passive safety, Guardrail, Simulation, Crash test, Injury.

Nomenclatures

\underline{A}_i	Direction cosine matrix for the orientation of the body i
\underline{A}_j	Direction cosine matrix for the orientation of the body j
\underline{a}	Nodal acceleration vector
\underline{C}_{ij}	Time-dependent direction cosine matrix for the orientation of the joint coordinate system on body i relative to the body local coordinate system
\underline{C}_{ji}	Time-dependent direction cosine matrix for the orientation of the joint coordinate system on body j relative to the body local coordinate system
c_{ij}, c_{ji}	Position vectors of the origins of the joint coordinate system on body i and j respectively
c	Dilatational wave speed
\underline{D}_{ij}	Direction cosine matrix for the orientation of the joint coordinate system on body i relative to the joint coordinate system on body j
d_{ij}	vector from the origin of the joint coordinate system on body i to the joint coordinate system on body j
E	Young's modulus
I	Moment of Inertia of complete motorcycle
I'	Moment of Inertia of each body constituting motorcycle
L	Characteristic length of the element
m	Mass of motorcycle
n	Degree of freedom
r	Radius of the disk
r_i	Position vector of the origin of local coordinate system on body i
r_j	Position vector of the origin of local coordinate system on body j
Δt	Time step
t	Current time
\underline{u}	Nodal displacement vector
\underline{v}	Nodal velocity vector
x	Semi-axis of body along x-axis
y	Semi-axis of body in y direction
z	Semi-axis of body in z-direction
x'	Transferred distance along x-direction from centre axis of body
y'	Transferred distance along y-direction from centre axis of body
z'	Transferred distance along z-direction from centre axis of body
<i>Greek Symbols</i>	
ρ	Density of Materials

1. Introduction

In Malaysia, like most Asian countries, motorcycle usage is predominant on highways and W-beam guardrail system is widely seen on these roads as roadside safety barrier. On average, motorcycle accounts for 49% of registered vehicles in Malaysia [1]. About 68% of all road accident injuries involved motorcyclists with overall relative risks of about 20 times higher than that of passenger cars [2]. As the total number of registered motorcycle continues to increase, motorcycle crashes also increases resulting in severe injuries to motorcyclists. Some of these crashes involve interaction with roadside barrier, which at times result in death of motorcyclists. Studies have identified interaction of motorcycle with w-beam guardrail as unsafe to motorcyclists. However, w-beam guardrail system was originally designed to protect occupants of cars and trucks – but not specifically to protect impacting motorcyclists.

Globally, frequency of motorcycle crashes with guardrail has been reported to cause severe injuries to motorcyclists due to inadequate safety measures. In California, Ouellet [3] reported that out of 900 motorcycle accidents, collision with barrier accounted for 63 somatic region injuries and 37 head-neck region injuries, totalling 98 injuries overall. Similarly in Los Angeles, it was found that bodily impacts with W-beam crash barrier resulted in AIS3+ injuries that occurred in 66% of head impacts with barrier [3]. In West Germany, 66% of motorcyclists suffer very severe trauma after impacting with guardrails [4]. A real world data regarding motorcyclist impacts with crash barriers in Germany put severity of injuries as three deaths out of 50 motorcyclists impacting crash barrier, 31 seriously injured and less than one third escaped with minor injuries [5].

FEMA [6] reports a study conducted in France between 1993 and 1995 on motorcycle accident with guardrail accounting for 8% of all motorcycle fatalities and 13% of fatalities on rural roads. In a similar study in France, Quincey [7] compares motorcycle-barrier crashes with other types of motorcycle crashes and found that motorcyclists are over 5 times more likely to be killed or seriously injured in impacts with crash barrier than in other types of crashes. In Denmark, as reported in FEMA [6], 10% of motorcyclists that run-off the road hit a crash barrier and 20% of these died because of the crash barrier while 60% of them were seriously injured.

In recognition of the severity of motorcycle crashes involving w-beam guardrail system, this paper used computer simulation to investigate the passive safety of motorcyclists during such impact. Crash scenario of motorcyclist remaining on an upright motorcycle and having direct collision with guardrail was assumed. However, simulation of this type has been reported as a worthwhile research that will benefit directly the rider involving in these crash events [8]. The paper then developed simulation model, validate the model and simulate subsequent simulation models with eighteen impact conditions as described in the following sections.

2. Simulation Model

Motorcycle crash is a multifarious event involving the interaction of rider, guardrail and the motorcycle itself. In this study, modelling and simulation of motorcycle crash was carried out using MADYMO software. MADYMO software was used because it

combines in one simulation program the capability offered by the multi-body and finite element techniques. The eighteen impact conditions considered in this simulation were based on the outcome of literature review on the previous crash simulations and the reported real life accidents. For instance, EEVC [9] reported that majority of motorcycle collisions take place at speeds between 30 and 60 km/hr. The impact angles of 15, 30 and 45 degree considered was based on the suggestion in literature, especially in Gibson [10]. The post spacing of 2m and 4m used are in accordance to the existing standard for installing w-beam guardrail. The impact point was taken as the mid span of the rail for maximum deflection and in regard to the conducted crash test for validation purpose.

Simulation process involved modelling of four systems including road as inertia reference space as well as crash interaction of these systems. The other three systems are the motorcycle, dummy and guardrail models, which are also described in the following sections.

2.1 Reference space

A plane surface road was used as the reference space on which the coordinates of other three systems were connected. The coordinate of the road surface was defined with three points. The first two points represent the vertices on one edge of the rectangle and the third point is on the opposite edge of rectangle. MADYMO program calculates the remaining vertices on the opposite edge to complete the rectangular shape. The origin and orientation of this reference space was selected with the positive Z-axis vertically upward, positive X-axis chosen along the direction of travel and the positive Y-axis is then chosen to the right. The motion of all other systems was defined relative to this coordinate system.

2.2 Motorcycle model

A KRISS SG motorcycle type of size 110cc produced by Modenas Malaysia Bhd was chosen as a design motorcycle because it is most commonly used motorcycle in Malaysia. This motorcycle was modelled as a multi-body system with four rigid bodies interconnected by kinematics joints. In multi-body dynamic methods, body fixed coordinate frames are generally adopted to position each one of the system components and to allow for the specification of the kinematics constraints that represent the restrictions on the relative motion between the bodies [11].

For modelling the motorcycle, the body local coordinate system was chosen based on the assumption that motorcycle bodies move symmetrically about the longitudinal axis. This implies that the centre axis of each body is parallel to the centreline of the road, which is the reference space for the system. The motorcycle was then modelled to move with a steady speed on a straight line prior to impact. Data corresponding to each specific body was then defined with respect to this body local coordinate system. As the study is primarily concerned with predicting motorcyclists' injuries due to impacts rather than motorcycle crashworthiness, the assumption is valid as asymmetrical movement of motorcycle may result in its instability during

impact with guardrail at a predefined impact point. Therefore, this system of bodies was then defined by the bodies, surface, kinematics joints and initial conditions as described in the following subsections.

2.2.1 Bodies

Each of the four motorcycle bodies were defined by the mass, inertia matrix and the location of the centre of gravity. The geometry and mass of the real motorcycle (Fig. 1) were measured in the laboratory and the values obtained were compared to the manufacturer's specifications. The wet weight of motorcycle (110 kg) was considered in this study and this includes an increase of 14kg added to the specified dry in order to compensate for the topped up fuel and other fluids as exists in real life situation.

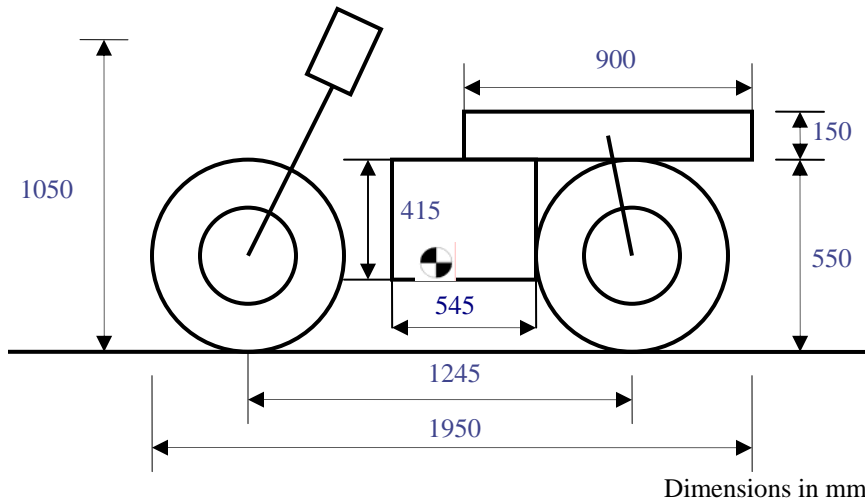


Fig.1. Schematic Drawing of Motorcycle Model.

The inertia matrix and location of the centre of gravity were defined in accordance to MADYMO Reference Manual [12]. The inertia matrix of each rigid body of motorcycle was determined using the conventional equations for regular shaped bodies as contain in Ferdinand and Johnston [13].

For the frame and upper front fork, equations for rectangular shape were used:

$$I_x = \frac{1}{12} m(y^2 + z^2) \quad (1)$$

$$I_y = \frac{1}{12} m(x^2 + z^2) \quad (2)$$

$$I_z = \frac{1}{12}m(z^2 + x^2) \quad (3)$$

For a cylindrical disks like front and rear wheel,

$$I_x = I_z = \frac{1}{4}mr^2 \quad (4)$$

$$I_y = \frac{1}{2}mr^2 \quad (5)$$

Using the equation of parallel axis theorem, the moment of inertia at each centre axis of each body was then transferred to the centre axis of motorcycle frame by using the following relationship

$$I_x = I'_x + m(y'^2 + z'^2) \quad (6)$$

$$I_y = I'_y + m(x'^2 + z'^2) \quad (7)$$

$$I_z = I'_z + m(x'^2 + y'^2) \quad (8)$$

Since the local coordinate system for each body was chosen at the location of its joint corresponding to the centre line of the reference space (road), the location of centre of gravity of each body was then expressed in the local coordinate system of the body as illustrated in Fig. 2. This figure shows the local coordinates of body corresponding to the joint coordinates of bodies which were used to calculate the motion of the body coordinate systems relative to the reference space coordinate system using the equation;

$$\underline{A}_j = \underline{A}_i \underline{C}_{ij} \underline{D}_{ij} \underline{C}_{ji}^T \quad (9)$$

$$r_j = r_i + c_{ij} + d_{ij} - c_{ji} \quad (10)$$

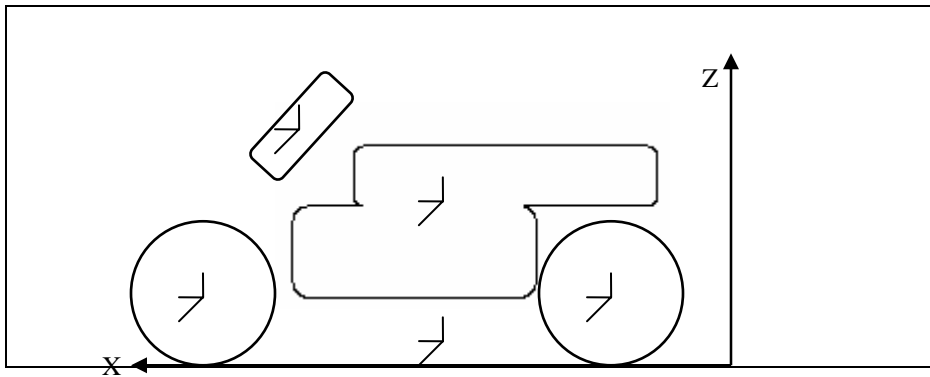


Fig.2. Illustration of Body Coordinate System.

2.2.2 Surfaces

As available within the software codes, body surfaces consisting of rectangular planes, ellipsoids and elliptical cylinders are always attached to any body of the system to represent its shape. The surface of the modelled motorcycle was then represented with ten regular shapes consisting of two ellipsoids for main frame, one ellipsoid for upper part of front fork and two ellipsoids and cylinders for the two wheels. Other ellipsoids were used to represent handle bar, foot rest and leg cover. In MADYMO, ellipsoid or hyper ellipsoid is given as:

$$\left(\frac{|x|}{x}\right)^n + \left(\frac{|y|}{y}\right)^n + \left(\frac{|z|}{z}\right)^n = 1 \quad (11)$$

For the elliptical cylinder, the equation is;

$$\left(\frac{|y|}{y}\right)^n + \left(\frac{|z|}{z}\right)^n = 1 \quad (12)$$

As the degree (n) increases, the ellipsoid will approximate a rectangular shape (hyper ellipsoid) as illustrated in Fig. 3. The figure illustrates that the direction of the semi axes can be specified by the orientation of the ellipsoid coordinate system (x_e , y_e , z_e). Thus, with origin of this coordinate system coinciding with the centre of the ellipsoid, the coordinate axes are parallel to the axes of the ellipsoid to which the body is attached. In this study, ellipsoids of the main frame were attached to the rectangular plane of the reference space (road) while the ellipsoids of front fork, the rear and front wheel were attached to the main frame. The orientation of the cylinder coordinate system for tyres was specified in accordance to the codes so that the motion of the tyre relative to the road was described with respect to the road coordinate system.

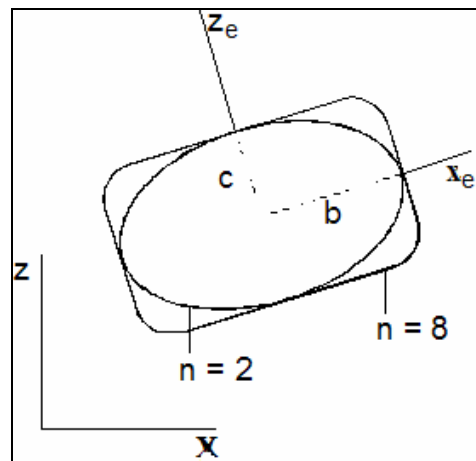


Fig.3. Illustration of Ellipsoids for Different Degree (n).

The wheel ellipsoids were defined for contact interaction with road and guardrail nodes as the only allowed surface by codes for such contact. The width of this ellipsoid had to be increased through iteration process using pre-simulation to achieve better contact interaction equivalent to real life motorcycle. This increment is necessary because the effective width of wheel ellipsoid is too small compared to its real width as the contact interaction problem was observed during simulation runs. The MF-MC Tyre model available in MADYMO codes for motorcycle tyres was used to model the wheels. This tyre model was based on the physical background of the tire, road, and the tire-to-road contact for accurate description of the steady-state behaviour of the tyre. The tyre was represented with a cylindrical disk connected to a modelled rigid body called wheel. The centre of this disk coincides with the wheel centre.

2.2.3 Kinematics joints

This involved specification of two bodies to be connected by the joint, type of joint, location and orientation of the joints. The main frame was specified as the parent body and was connected to the road plane surface with a free joint to allow free movement of motorcycle in seven degree of freedom. A revolute joint connects the front fork, front wheel and rear wheel as child bodies to form a tree structure for generating the equation of motion by the codes. The rotation axis of the front fork joint is in the plane of symmetry of the motorcycle, making angle 30 degree to the vertical. The rotation axes of the wheels are perpendicular to the plane of symmetry. The spring and damper for the lower part of front fork and rear fork of motorcycle were represented with Kelvin elements as contained in MADYMO codes. This element was considered appropriate because of the parallel arrangement of the motorcycle's front fork spring and damper. The two ends of Kelvin restraints were attached to the motorcycle frame and rear wheels for rear fork restraint, and upper front fork assembly and front wheel for front fork restraint. Each of these joints has coordinate system that defines the direction of possible relative motion of the two bodies connected by a kinematics joint.

In this study, a joint coordinate system was defined parallel to the local coordinate system of the body to which it is attached. The free joint between the reference space and the frame body allows the motorcycle to translate parallel to the road. The revolute joint between the front fork and the frame has axis of the joint coordinate system parallel to the rotation axis by default. The axes of the joint coordinate systems of the front and rear wheel revolute joints are made parallel to the y-axes of the corresponding body coordinate systems so that they coincide with the wheel rotation axes.

2.2.4 Initial condition

Initially, the motorcycle was in equilibrium being upright and at vertical position such that the vertical tyre forces were in equilibrium with the weight of the motorcycle. This position was specified through pre-simulations using the reference manual of the simulation codes as guide. The defined position for the motorcycle ranges from 2.0m to 2.4 m from its local coordinate position. In compliance with MADYMO [14], a body-fixed joint coordinate system was introduced on each body to describe the relative motion of the body relative to the parent body. Initial velocity by joint degree of freedom was defined for the mainframe as the parent body in the joint direction corresponding to the travel way as required by the codes. The initial linear velocities of 8.89 m/s, 13.33m/s and 16.67m/s were specified for the joint of the main frame at various simulation runs. Body acceleration in z-direction was also defined with negative value of acceleration due to gravity (-9.81 m/s^2) from the start of simulation till end of simulation.

2.3 Crash dummy model

The dummy used in this simulation model was a non-helmeted standard 50th percentile adult male Hybrid III MADYMO dummy to represent the rider and to mimic the trajectory, acceleration and impact deformation experience by a human during crash impact. MADYMO has been shown to be a very competent tool for the prediction of human response and the calculation of occupant injury criteria [15]. MADYMO Scaler programme was used to scale down the weight of hybrid III 50th percentile dummy from 78.15kg to the same size of the crash test dummy (54.9kg) to enable accurate validation. This scaling method has been used widely in the field of crash safety. For instance, the designs of the Hybrid III 5th percentile female and 95th percentile male dummies were based on scaling and requirements for children dummy have been based on biofidelity requirement for adults.

Since there is no provision in MADYMO codes to include helmet, the use of non-helmeted dummy may represent the simulation of worst crash events a rider could experience. However, the dummy segments were oriented to replicate the posture of a real life rider. These segments include; the dummy's shoulder, Hips, Knees, and Ankles. In addition, the same initial velocities and initial position body acceleration defined for motorcycle were defined for the dummy.

2.4 Guardrail model

The existing w-beam guardrail system was composed of w-shaped, 12-gauge, galvanized steel rail attached to posts embedded into the soil at space interval of 2m and 4m. The description of this guardrail type shown in Table 1 was based on the longitudinal barrier design guidelines produced by Malaysia Ministry of Public Works (JKR). The guardrail manufacturers in Malaysia also based their production on this specification.

Table 1. Description of Existing Guardrail Model.

Standard	Parameters	Values
Beam	Overall Length	4318 mm
	Effective Length	4000 mm
	Beam Thickness	2.67 mm
	Effective Depth	312 mm
Posts and Block-outs	Post dimensions	1830 x 178 x 76 (710mm above ground)
	Block-out dimensions	360 x 178 x 76 (6mm thick)
	Post spacing	2000 mm and 4000 mm

Since the study's main aim is to assess the rider's injury risks rather than assessment of roadside barriers, MADYMO software was used only to characterize the dynamic response of guardrail structure while the stress concentration effect was ignored. Thus, the existing w-beam guardrail was modelled as a finite element system with the following steps being involved in the overall modelling of this guardrail.

1. Model discretisation
2. Mesh sensitivity
3. Material properties specification
4. Specification of nodal displacement constraint and initial condition, and
5. Specification of applied load

2.4.1 Model discretisation

In MADYMO modelling of finite element system involved definition of Cartesian coordinates for the guardrail surface. The guardrail surface was first drawn and divided into discrete variables called nodes, which were formed into elements representing the guardrail structure. Integer numbers were assigned to both nodes and elements to identify them. These assigned identification numbers have significant effect on the solution time and storage requirement by the codes. The guardrail system was modelled using four-node shell elements. Four-node shell element is two-dimensional quadrilateral elements that connects four nodes and carry in-plane loads as well as bending loads. The total number of nodes defined for both W-beam and the posts are 2720 and 480 respectively. The formulation of the shell elements was based on Lagrange mesh description available in MADYMO. The interconnection of these elements at a discrete number of nodes to describe the shape of the structure is called 'Spatial discretisation'.

The modelling also involved time discretisation which implies that the quantities describing the structural behaviour are calculated at a discrete number of points in time. The use of this direct integration method was based on the assumption that there is a variation of displacements, velocities and accelerations within each time interval. Unlike in the multi-body module where Euler method was used for time integration of

the equation of motion, finite element MADYMO uses central difference method as time integration method. This central difference method determines the support and contact forces at each time step. The relations for the central difference method with a constant time step are:

$$\underline{v}_{n+\frac{1}{2}} = \underline{v}_{n-\frac{1}{2}} + \Delta t \underline{a}_n \quad (13)$$

$$\underline{u}_{n+1} = \underline{u}_n + \Delta t \underline{v}_{n+\frac{1}{2}} \quad (14)$$

Subscripts $n - \frac{1}{2}$, n , $n + \frac{1}{2}$, and $n+1$ correspond with time points $t - \Delta t / 2$, t , $t + \Delta t / 2$, $t + \Delta t$, respectively, where t is the current time point.

The critical time step depends on the spatial discretisation of the model; the smaller the size of elements, the smaller the time step. This time step was determined based on Courant condition,

$$\Delta t \leq \frac{L}{c} \quad (15)$$

$$c = \sqrt{\frac{E}{\rho}} \quad (16)$$

This condition means that the time step must be small enough as the information does not propagate across more than one element per time step. The efficiency of the entire analysis was increased through the use of larger sub-cycling based on the determined constant time step. Thus, the minimum time step used throughout the simulation runs for finite element system was 3.333E-06s.

2.4.2 Mesh sensitivity

Formulation of mesh for elements connectivity involved definition of node numbers that are associated with that particular element. The finite element model of guardrail was ensured to satisfy model convergence based on the assumption that displacement field is continuous at all points within the model. Global model which is relatively coarse was considered adequate to characterize the dynamic response of the guardrail structure since the stress concentration effect is not the main concern of this study. The actual mesh used was based on several pre simulation and contact interaction of motorcycle wheel surface and the guardrail nodes at the mid-span of the guardrail. These preliminary investigations were carried out on several models and the acceptability of the computational results and excessive CPU's demand that had to be made was compared. Figure 4 presents an acceptable mesh density distribution of W-beam guardrail model.

In order to ensure that element shapes are maintained during simulation, the elements formation within the mesh were checked for element distortion using

'Aspect Ratio' based on the shape of the element. The aspect ratio for the model is 0.7 with the mesh density of 18 x 27. This value was checked to be constant throughout the mesh and it indicates that the mesh formation is not distorted.

Mesh instability was prevented by using hourglass control that adds artificial stiffness to the elements to suppress the zero energy modes [14]. These hourglass modes which cause mesh instability occur due to lack of enough deformation parameters in relation to the nodal degree of freedom because of reduced integration. The reduced integration makes element to be too soft so that the modes cannot be resisted by the element. This modes show up as a zero energy mode which refers to a nodal displacement vector that is not a rigid body motion but nevertheless produces zero strain energy. Therefore, there is need to stabilize the defined mesh of the model in order to achieve the required deformation of the structure.

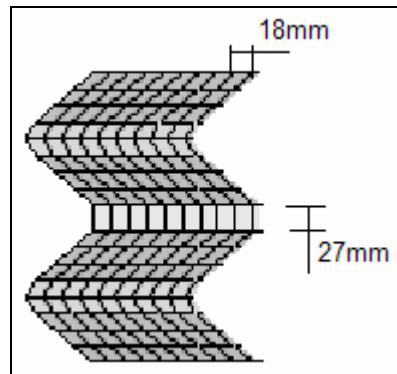


Fig. 4. Mesh Distribution of W-Beam Guardrail Model.

For the explicit calculation applicable in this study where small to moderate deformation is expected, a stiffness form of hourglass control is often preferred to prevent hourglass modes from slowly building up in the solution. The simplest formulation to control zero energy modes as applicable to the software codes used is to simply add a stiffness term to the element. Thus the meshed nodes which were uniformly spaced and linked to the material have element stiffness matrix with the integration method used for calculating the material property.

2.4.3 Guardrail material properties

The guardrail model consists of the same steel material property as for the existing w-beam guardrail. Therefore, the material properties for steel in terms of the stiffness, yield stress, density and Poisson's ratio of steel were defined for this guardrail model

as in Table 2. These material parameters were used to define elastic-plastic material model (ISOPLA) for the guardrail model.

2.4.4 Specification of nodal displacement constraint and initial condition

The nodal displacement constraints and initial condition were specified for the guardrail model. The initial conditions were defined in terms of initial position of the complete models with respect to the reference space; the road. Support nodes were defined as node displacement constraints to connect guardrail with the posts and block-outs. In MADYMO, a support node is a rigid connection between a degree of freedom of a node and the reference space or system or a body [14]. This rigid constraint was applied to prevent translation and rotation of support nodes so that the only displacement of the rail is in the direction of the applied load. Thus, the beam translates and rotates within the material property to result in dynamic deformation of the guardrail. This dynamic response of beam structure resulted in the displacement vs. time history as shown in Fig. 5. This figure illustrates how the beam structure was reduced to a single dynamic degree of freedom as it translates about the mid span and rotates about the two supports. The wavy part of the displacement vs. time history curve indicates the vibration of beam (translating in both x and -x direction) as the motorcycle body has contact with the guardrail as it slides along the beam surface.

Table 2. Guardrail Material Properties.

Parameter	W-beam
Density (kg/m ³)	7860
Elastic Modulus (GPa)	200
Yield Stress (MPa)	345
Thickness (mm)	2.67
Poison Ratio	0.28

2.5 Specification of applied load

The applied loads were specified for the model in form of contact interactions between motorcycle front wheel and guardrail nodes with impact speeds of 32, 48 and 60km/h. Kinematics contact model was used to define contact between the motorcycle front wheel surface and the nodes of guardrail. Since this contact model does not allow guardrail nodes to penetrate the front wheel surface, motorcycle wheel was placed at a least distance of 2mm to the guardrail surface. Based on surface compliance method the motorcycle being a rigid body was chosen as a master surface while guardrail which is deformable was chosen as a slave surface. The impact during the contact between the wheel surface and guardrail nodes is inelastic as their relative

velocity tends to zero. Therefore, the tangential impulse was then applied which caused sliding of the motorcycle wheel along the guardrail surface. This tangential impulse equals the product of normal impulse and friction coefficient, which was defined as input for the kinematics contact model. This friction coefficient ranges between 0.2 and 0.4 as suggested in Troutbeck [15] and confirmed through pre-simulation runs. Crash simulation model was calibrated through various pre-simulation runs in order to have accurate representative of real life crash events.

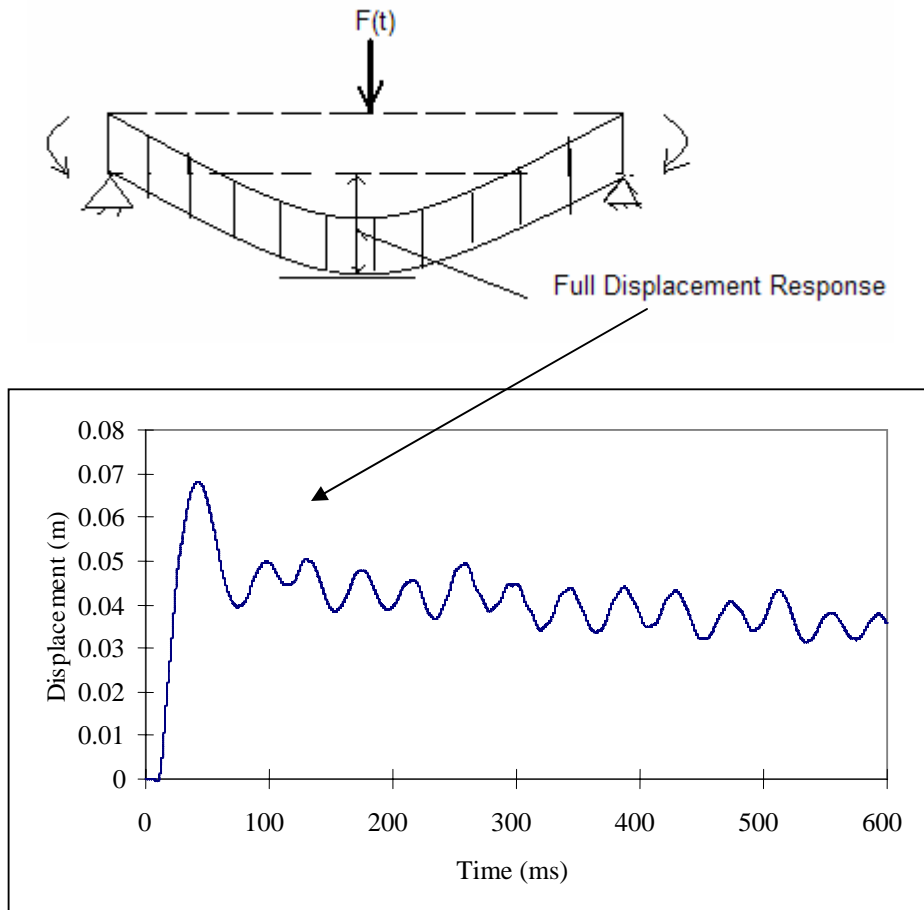


Fig.5. Guardrail Response to an Impact.

3. Validation of Simulation Model

Model validation involved comparison of crash test result with simulation output. Crash test was carried out with low cost dummy positioned on the real KRIS SG motorcycle which was guided with a designed rig to crash with w-beam guardrail. The impact speed of 32 km/h was achieved for the motorcycle and dummy collision with guardrail installed at an angle 45° to the travel way. Since the crash dummy was non-instrumented to measure dummy loads, the only available film evaluation was qualitatively compared with the predicted dummy response characteristic obtained from simulation.

The result of film evaluation obtained from crash test was converted from video file to AVS file format compatible to simulation output. Dummy trajectories from both tests were synchronised to approximately the same frame per second. Thus, the animation of the two tests was then run on the same frame size of 1011 x 673. The dummy trajectories in both tests were observed to match well except slight difference at the initial time step, which was due to small problem in the release mechanism before impact. This problem caused rotation of the dummy at $t=100\text{ms}$ which results in the stretching of the crash test dummy at $t=200\text{ms}$ up to $t=400\text{ms}$ as shown in Fig. 6.

4. Results and Discussion

In the simulation of all the eighteen impact conditions, the kinematics of rider for all impact conditions are similar during the initial stage with the dummy having leg contact with the guardrail surface and projecting with head forward. But, the dynamics of rider towards the landing depend on the impact speeds and angles. Generally, for all impact conditions, the rider fall to ground with head except at impact speed of 60km/h for impact angle 30 at 4m post spacing as well as impact angle 45 for both 2m and 4m spacing. This indicates that higher impact speed can cause high vaulting of rider and thus resulting in no head contact with the ground. Therefore, the study has been able to establish the fact that the severity of impact increases with speed as well as angle of impact and with reduced post spacing. The study also established that the likely impact speed along the exclusive motorcycle lanes in Malaysia is 48km/hr which fall within the reported mean speed 45km/h to 61km/h for low volume traffic on these roads. The obtained higher head injury value at impact angle 45 degree conforms to the requirement by ISO [16] for motorcycle impact study. However, a relationship between the head injury risks values with effect to impact angle and speed are established as presented in the Figs. 7 to 10. It can be observed from these figures that these injury patterns vary with speed and angle of impact. Highest values are obtained at impact angle 45 degree and impact speed 48 km/h while impact at 60 km/h exhibits lower values due to higher vaulting of rider that caused landing with hand or foot rather than head to ground. This effect resulted from very high decelerating rate of rider.

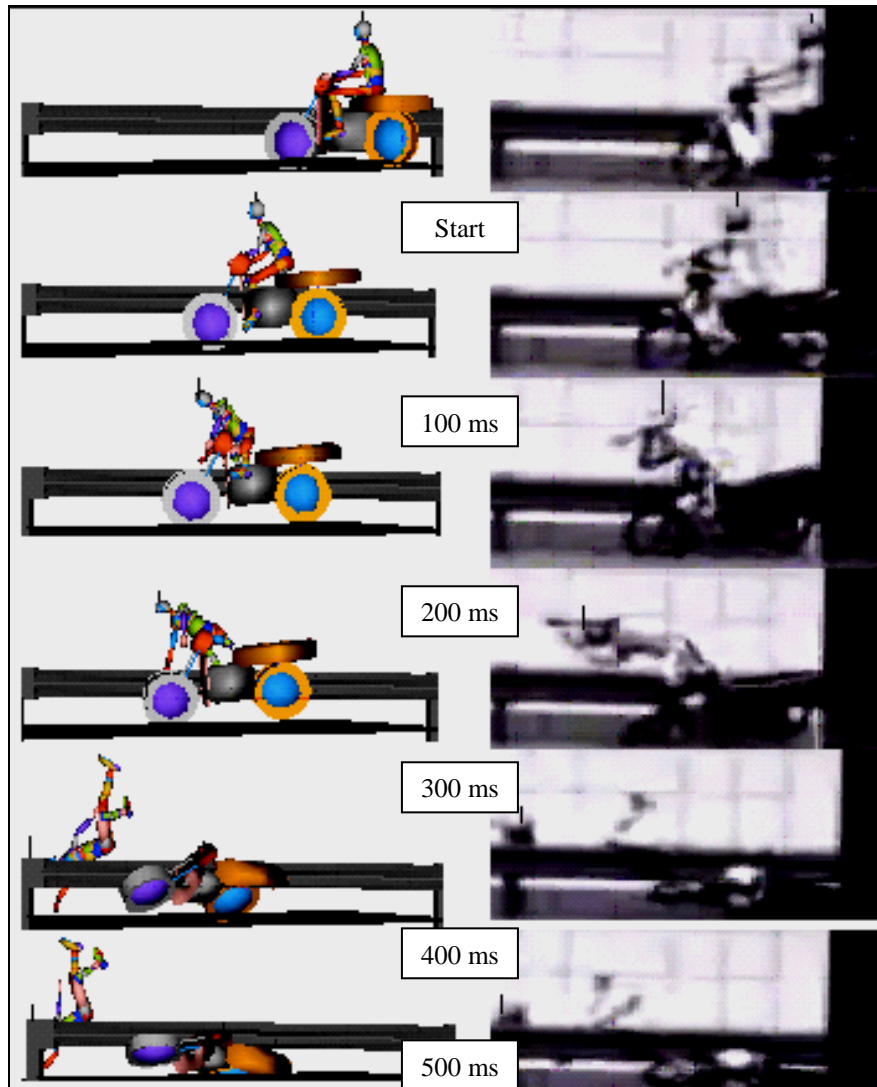


Fig.6. Comparing Kinematics of Dummy for Crash Test (Right Column) and Simulation (Left Column).

The injury criteria results obtained show that there is a relationship between specific injury criteria. As the nature of impact contributes to severity of a collision, the severity of injuries to rider colliding with rail surface and road surface was found to be severe and related to impact angle, impact speeds and post spacing. For instance, a general trend can be observed that the injury parameters for HIC and head

acceleration increases as the angle of impact of motorcycle into guardrail increases from 15° to 45°. The findings seem to be in agreement with the previous study reported in Gibson and Benetatos [10, 17] that decreasing the angle of impact with a barrier decreases the (perceived) risk of injury from impact. Injuries to head such as HIC and head acceleration were found to be higher than tolerance level for all impact condition where head impact with ground. This result implies that the rider may suffer skull fractures and brain injuries. Although, apart from injuries to head and neck, other parts of rider’s body such as legs frequently contact the guardrail surface, it is not as severe as head contact with the road surface as supported in literature [17, 18, 19].

5. Conclusions

It has been presented in this paper that a W-beam guardrail existing along exclusive motorcycle lanes is dangerous to motorcyclists as it causes the rider to slide and tumble along the top of guardrail before landing on the ground with head. This impact always results in fatalities or catastrophic injuries. The reason for these hazards has been attributed to include non consideration of motorcyclists in the design of this guardrail. This indicates that the existing guardrails along exclusive motorcycle lanes are not adequately designed to prevent run off accident involving motorcycles. Thus, future evaluation of guardrail performance needs to consider motorcycle impact for such guardrail that intends to protect motorcyclists. The high rate of fatality that may result from motorcycle crashes against guardrail along exclusive motorcycle tracks should be of great concern to road safety engineers and designers. Therefore, it is recommended for further study to consider the needs to design an alternative guardrail for exclusive motorcycle track so as to adequately protect the motorcyclists.

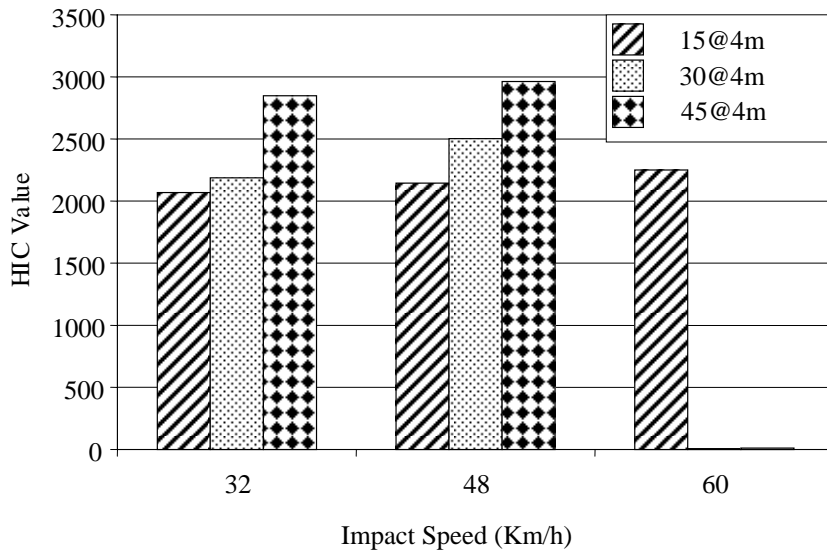


Fig.7. Comparison between HIC Values for 4m Post Spacing.

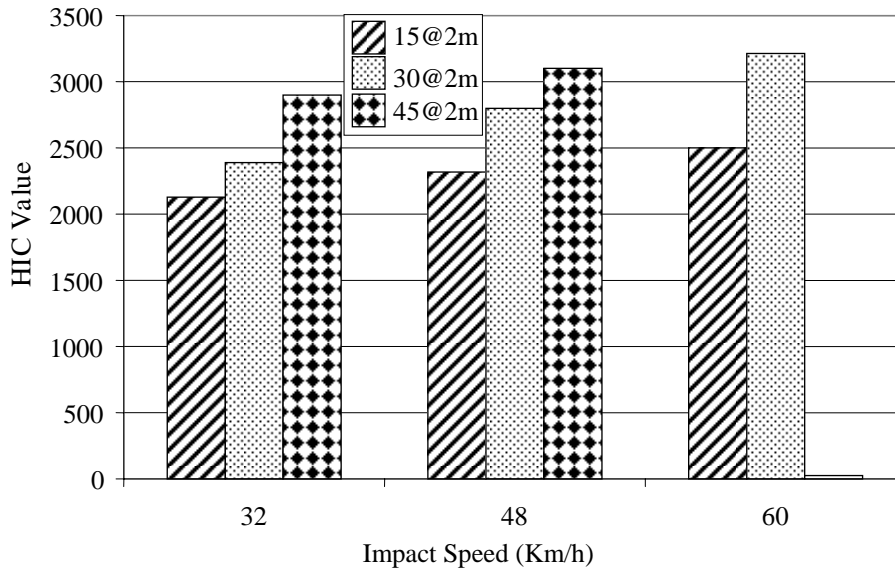


Fig.8. Comparison between HIC Values for 2m Post Spacing.

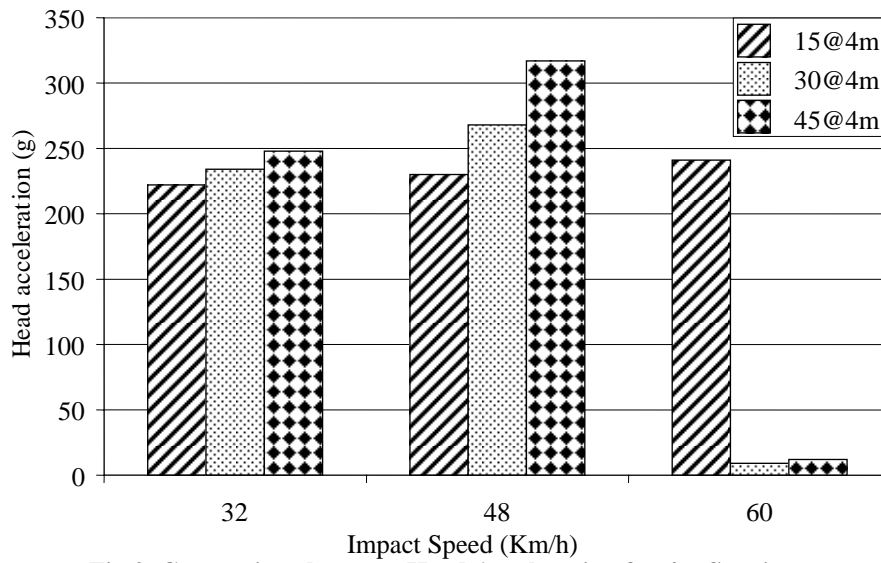


Fig.9. Comparison between Head Acceleration for 4m Spacing.

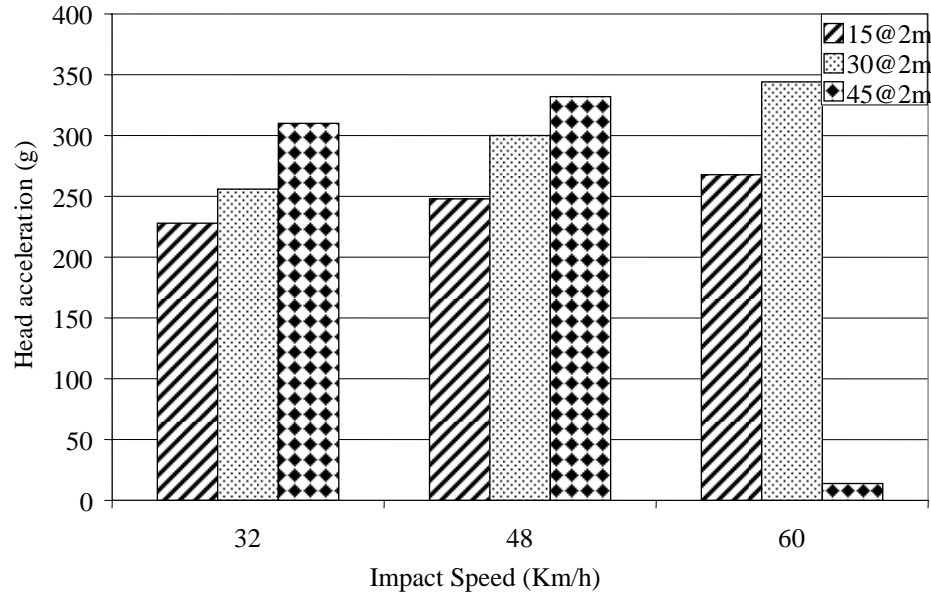


Fig.10. Comparison between Head Acceleration for 2m Spacing.

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