# Development of a Finite Element Model of a Motorcycle

N. Schulz, C. Silvestri Dobrovolny and S. Hurlebaus

*Texas A&M Transportation Institute*

## Abstract

*Over the past years, extensive research efforts have been made to improve roadside safety hardware to reduce injury to occupants of four wheel vehicles and heavy trucks. In comparison, limited research has been conducted to address the safety of motorcycle riders when impacting roadside safety hardware. The vulnerability of motorcycle riders can lead to a high risk of injury for the rider, especially when impacting roadside barriers. In real-world motorcycle crashes there is a wide range of impacts against other vehicles and barriers. Reproducing these different motorcycle crash scenarios through physical crash testing can be considerably costly and time consuming. Computer simulations are a great tool to address the wide range of impacts in real world motorcycle crashes because they are significantly cheaper and quicker than performing full scale crash tests. Motorcycle simulation models have been developed since the 1970's and have improved in detail and complexity over the years. However, there is still a need to develop detailed motorcycle models that are geometrically accurate and can accurately predict motorcycle response behavior. The researchers have developed a Finite Element (FE) computer model of a motorcycle through reverse engineering. This model can be used to investigate impact scenarios involving motorcycles. To validate the accuracy of the model, measurements of the motorcycle computer model such as mass, geometry, etc, were compared to measurements of the physical motorcycle.*

## Background

At this time, there is no existence of an international standard procedure required to perform upright motorcycle crash testing against roadside safety devices (barriers). Worldwide, in the past decades, a few crash testing laboratories have developed their own protocols, such as L.I.E.R. in France and AENOR in Spain (LIER, 1998; AENOR, 2005; AENOR, 2008). These test procedures, however, involve impact of dummies against barriers, with the Anthropomorphic Test Device (ATD) sliding on the ground on its back. This configuration wants to represent a rider impacting a safety barrier whilst sliding on the ground, having fallen from the motorcycle. The International Organization for Standardization (ISO) developed international guidelines to cover all aspects about conducting motorcycle physical crash-testing, but this standard is referred to motorcycle impacting against a vehicle, not against a roadside barrier (ISO 13232, 2005). Moreover, since motorcycle testing is not required for federal regulation, there is not a legal requirement for crash laboratories to comply with ISO motorcycle crashing standard when developing a motorcycle crash test. The European Committee for Standardization (CEN) Technical Committee on Road Equipment (TC226) agreed on a resolution to develop a European standard for the reduction of impact severity of motorcyclist collision with safety barriers. However, even this test procedure involves impact of dummies against barriers, with the ATD sliding on the ground on its back (EN1317-8). EN1317-8 does not consider motorcycle impacts against roadside barriers while in an upright position. Moreover, it is not obligatory for any country to adopt this standard until its use is required by a national regulation.

In early motorcycle research, multi-rigid-body systems were used to model the motorcycle and rider in computer simulations. These models were advantageous due to their accuracy and quick simulation runs. However, as computational power and speeds have increased over the years, a shift has been made from multi-rigid-body modelling to finite element modelling for motorcycle computer simulations. Finite element modelling allows for increased geometrical accuracy and more accurate deformation during impact. For the purposes of this study LS-DYNA® will be used to develop the finite element model and computer simulation. LS-DYNA is a non-linear finite element analysis program and is particularly suitable for high speed impacts.

A literature review of previous computer models of motorcycles was conducted. In 2005, an extensive literature review was conducted by Rogers et al. (2005) to assess the history and current status of motorcyclist injury prediction by means of computer simulation. Many of these models were developed through multi-rigid-body (MB) methods. A few models were developed through FE methods but were very simple and contained very few motorcycle components. Since 2005 several motorcycle models have been developed through MB and FE methods. These models are summarized in Table 1 below.

**Table 1. Summary of motorcycle simulation studies conducted during or after 2005.**

| Paper Title | Authors | Year | Location | Institution | Motorcycle Model Type |
|---|---|---|---|---|---|
| A Computer Simulation For Motorcycle Rider Injury Evaluation In Collision | Namiki H, Nakamura T, Iijima S | 2005 | Japan | Honda R&D Co. | Finite element model |
| Kinematic Analysis of a Motorcycle and Rider Impact on a Concrete Barrier Under Different Impact and Road Conditions | Ramamurthy, S | 2007 | US | Witchita State University | Multi-rigid-body (6 bodies) |
| Motorcycle Safety Device Investigation A Case Study on Airbags | Chawla A, Mukherjee S | 2007 | India | Indian Institute of Technology | Finite element model |
| Simulation of Motorcycle Crashes with W-Beam Guardrail Injury Patterns and Analysis | Ibitoye A B, et al | 2009 | Malaysia/Qatar | Road Safety Research Centre/Qatar University | Multi-rigid-body (4 bodies) |
| Exploratory Study on the Suitability of an Airbag for an Indian Motorcycle Using Finite Element Computer Simulations of Rigid Wall Barrier Tests | Bhosale, P V | 2013 | India | Indian Institute of Technology | Finite element model |

To date very few models have been developed for motorcycles using FE methods. Many of these models include only main components such as the fuel tank, frame, engine and wheels.

# Modeling

As previously stated, no current standards exist for crash testing with upright motorcycles and roadside barriers. As a result, the selection of motorcycle to model was based on a critical review of previous literature review. A Kawasaki Ninja 500R was selected based on motorcycle popularity, dimensions and rider posture. It is the opinion of the researchers that this motorcycle is a popular style for younger, less experienced riders. Additionally, this motorcycle type is more likely to cause rider ejection during an impact event due to the posture of the rider and bike dimensions.

A 2005 Kawasaki Ninja 500R was used as the basis for the FE model. Using reverse engineering techniques a complete FE model of the motorcycle was developed. A complete disassembly of the motorcycle was conducted. Any non-structural parts such as wiring, gear chain, etc. were placed aside and later measured for total mass of non-structural components. For each structural part, a scan was performed to define the geometry of the part. Additionally, thickness and mass were measured for the part. Each part was also categorized into material types. The scans were each processed and used to develop geometrical surfaces and solids for the individual parts. These parts were then broken down into elements to represent the FE mesh. A flow chart was developed to illustrate the reverse engineering process (Figure 1).

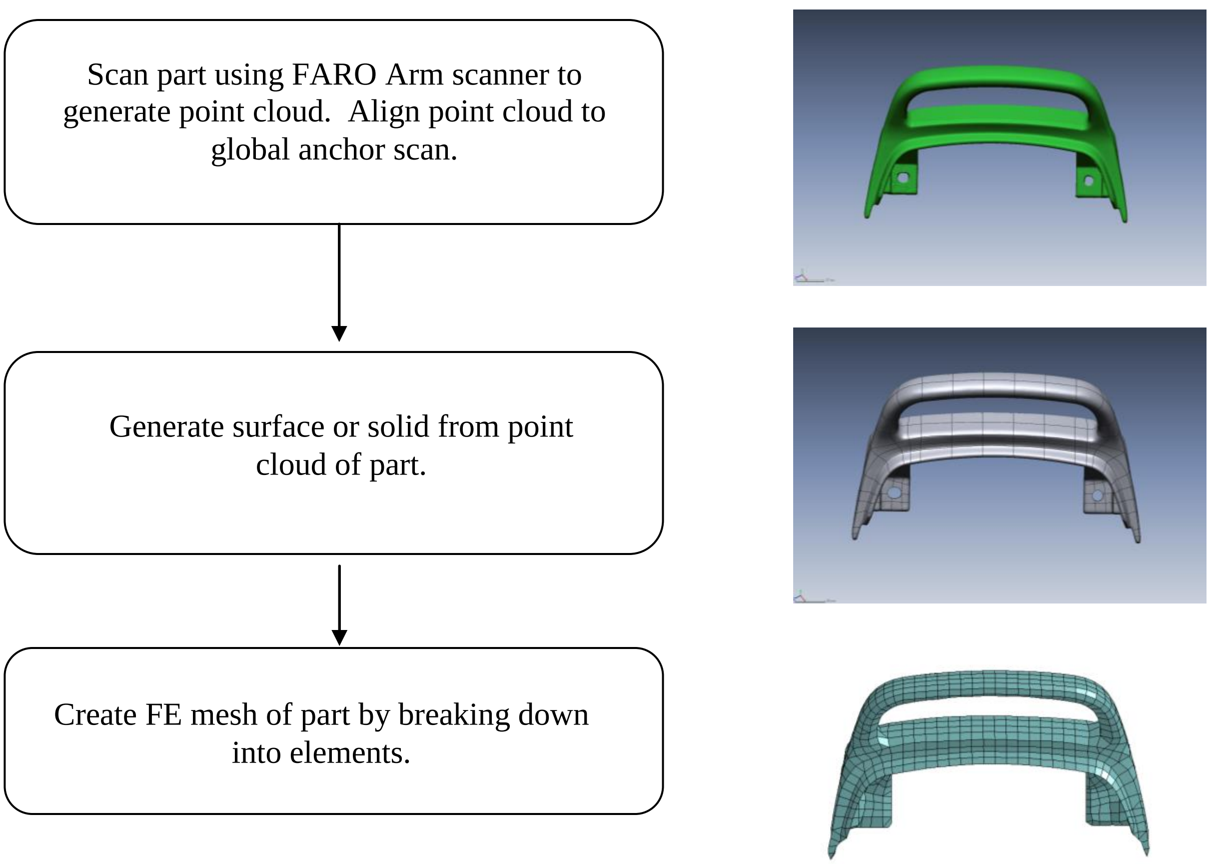



**Figure 1. Flow chart describing the reverse engineering process to develop FE mesh for the individual parts.**

This process described by the flow chart was similarly applied for all parts of the motorcycle. These parts were assembled to complete the FE model of the motorcycle. Figure 2 shows a comparison between the actual motorcycle and the completed FE computer model.

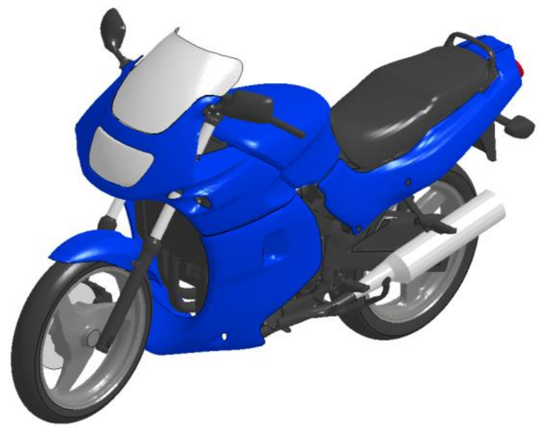


**Figure 2. Comparison of Physical and FE model of 2005 Kawasaki Ninja 500R motorcycle.**

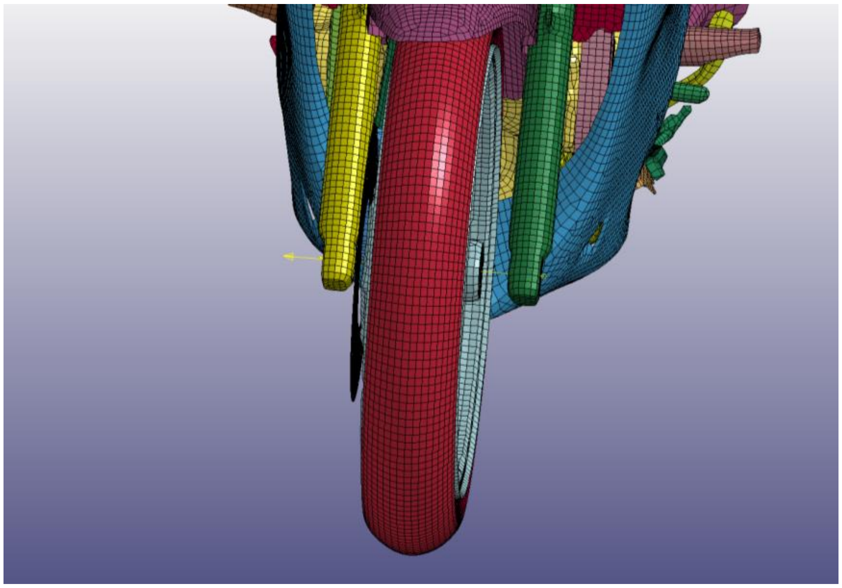
The resulting FE model consisted of 194,191 elements. Additional information about the FE model is summarized in Table 2.

**Table 2. Summary of FE motorcycle model.**

| | |
|---|---|
| Number of Parts | 102 |
| Number of Nodes | 193229 |
| Number of Elements | 194191 |
| Nodal Rigid Body Connections | 174 |
| Joint Connections | 3 |

The average element size used was 7.5 mm. Three different material types were documented for the parts of the motorcycle. This includes steel, plastic, and rubber. Material coupon testing was not conducted for the parts of the motorcycle, so available material parameters were used for the different material types.

The majority of the connections were modeled using CONSTRAINED_NODAL_RIGID_BODIES (CNRBs). However, the front and rear axles were modeled using CONSTRAINED_JOINT_REVOLUTE. Figure 3 shows the joints for the front and rear wheel.



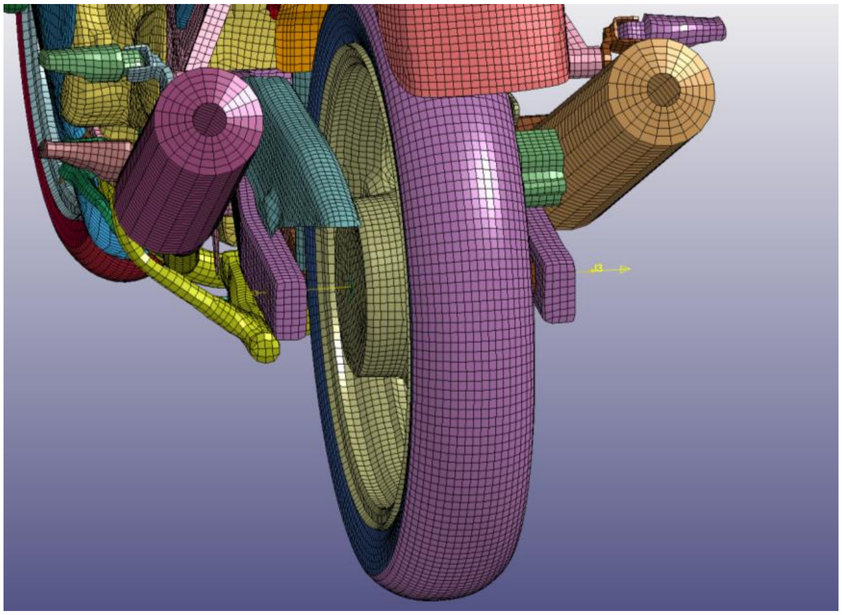


**Figure 3. Constrained Joint Revolute for front and rear wheel.**

A similar connection was modeled for the connection between the frame and upper fork holders. The front forks need to be able to rotate about the cylinder at the front of the frame. Figure 4 shows the actual rotating cylinder and the joint revolute in the FE model.

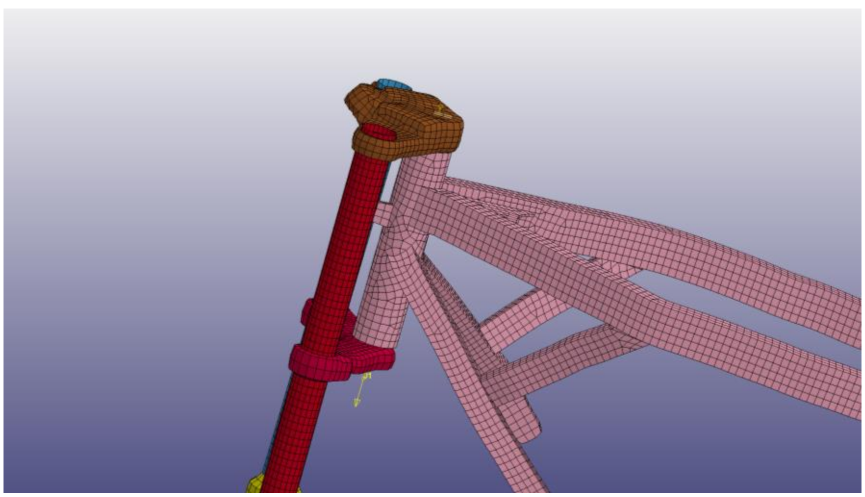


**Figure 4. Constrained Joint Revolute for frame cylinder connection.**

The FE model contains details for all structural and necessary components of the motorcycle. Figure 5 shows a side of the motorcycle. Figure 6 is a bottom view of the motorcycle. Figures 7 and 8 show perspective views of the motorcycle with and without the plastic coverings, respectively.

**Figure 5. Side view of FE motorcycle model.**

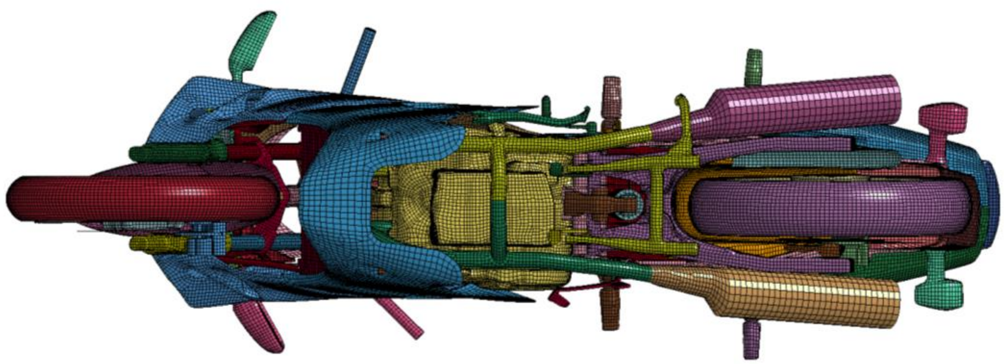


**Figure 6. Bottom view of FE motorcycle model.**

**Figure 7. Perspective view of FE motorcycle model.**

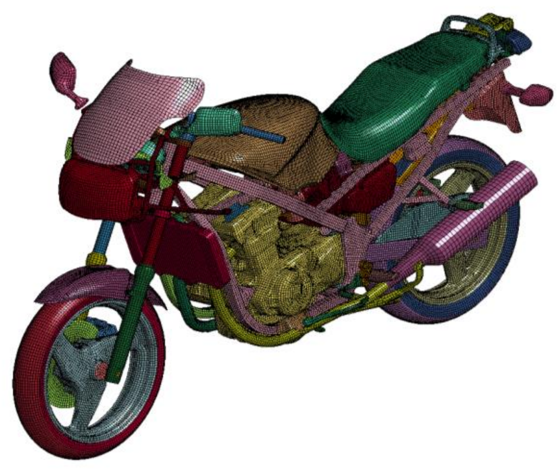


**Figure 8. Perspective view of FE motorcycle model without plastic coverings.**

## Model Calibration

The FE model was verified for accuracy by measuring mass and geometry of the physical motorcycle and comparing them to that of the FE motorcycle. The mass of the actual motorcycle was 172 kg, while the mass of the FE motorcycle was 176 kg.

Several different geometrical measurements were made for the physical motorcycle. These measurements were then compared to the measurements from the FE model as seen in Figure 9.


| | Physical Motorcycle (mm) | FE Motorcycle (mm) |
|---|---|---|
| A | 749.3 | 722.6 |
| B | 1162.1 | 1206.6 |
| C | 2019.3 | 2094.5 |
| D | 1384.3 | 1448.5 |
| E | 292.1 | 289.9 |
| F | 781.1 | 793.9 |
| G | 114.3 | 161.0 |
| H | 717.6 | 753.2 |

**Figure 9. Measurements taken for physical motorcycle compared to FE motorcycle.**

To verify adequacy of connection details, a gravity load was applied to the FE model. The resulting simulation showed adequate connections between all the motorcycle parts. Furthermore a check for completeness of elements was conducted. Efforts are currently underway to further validate the model.

## Summary and Conclusions

A finite element model of a 2005 Kawasaki Ninja 500R motorcycle was developed through reverse engineering techniques. The motorcycle model was developed to assist with future research efforts to investigate motorcycle impacts with roadside safety hardware. No standards currently exist for upright motorcycle impact with barrier. As a result the motorcycle was selected base on previous literature and engineering judgement. The entire model consisted of 194,191 elements, which represented all structural components and other necessary components.

The model was validated for geometrical and mass accuracy by comparing measurements from the actual motorcycle to the FE model. Additionally, connection adequacy and initial robustness of the model was validated through gravity simulations. Future work remains to further validate the motorcycle model for accuracy and robustness. This includes validation through component testing and physical crash testing.

## Acknowledgements

The authors would like to acknowledge Robert Wunderlich (Associate Director for CTS, TTI) and Dean Alberson (Assistant Agency Director/ Senior Research Engineer, TTI) for their support of this modeling effort.

### References

AENOR "Standard UNE 135900-1," 2005.

AENOR "Standard UNE 135900-1," 2008.

EN1317-2 "Road Restraint Systems - Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets," European Standard, European Committee for Standardization, Brussels, Belgium, 2010.

EN1317-8 "Road Restraint Systems - Part 8: Motorcycle Road Restraint Systems which Reduce the Impact Severity of Motorcyclist Collisions with Safety Barriers," European Committee for Standardization, Brussels, Belgium, 2011.

ISO 13232 "Motorcycles-Test and Analysis Procedures for Research Evaluation of Rider Crash Protection Devices Fitted to Motorcycles," ISO 13232, International Organization for Standardization, Geneva, Switzerland, 2005.

L.I.E.R. "Protocol: Motorcyclist Safety Evaluation Regarding Safety Barriers," 1998.

Rogers, N.M., J. W. Zellner, A. Chawla and T. Nakatani, "Methodologies for Motorcyclist Injury Prediction by Means of Computer Simulation," Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles (ESV), 2005.