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Pedestrian CAE Models & Codes

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Pedestrian CAE model		Pedestrian Sizes	Level of Biofidelity	References	Notes
Honda Human FE model (Adult) Version 13th June 2011	Geometric reconstruction derived from CT/MRI scans (bones, ligaments) - pelvis and lower limb Articulated rigid body for upper body (lumbar and above) - neck and lumbar divided into 7 and 5 segments	Baseline model represent anthropometry close to 50th percentile male; baseline model can be scaled to any sizes of adult population	whole body kinematics (head, T1, T8, pelvis) during an impact against a small sedan and a large SUV at 40 km/h	Small sedan: Kerrigan, J. R., Murphy, D. B., Drinkwater, D. C., Kam, C. Y., Bose, D., Crandall, J. R. : Kinematic Corridors for PMHS Tested in Full-Scale Pedestrian Impact Tests, 19thESV, Paper number 05-0394 (2005) Large SUV: Kerrigan, J. R., Kam, C. Y., Drinkwater, D. C., Murphy, D. B., Bose, D., Ivarsson, J., Crandall, J. R. : Kinematic Comparison of the POLAR-II and PMHS in Pedestrian Impact Tests with a Sport-Utility Vehicle, IRCOBI Conference (2005)	Source of human response data
				Kikuchi, Y., Takahashi, Y., Mori, F. : Full-Scale Validation of a Human FE Model for the Pelvis and Lower Limb of a Pedestrian, SAE World Congress, Paper Number 2008-01-1243 (2008)	Source of validation results
			Dynamic lateral compression of pelvis (Force-deflection at acetabulum and ilium in both acetabulum and iliac loadings)	Salzar, R. S., Genovese, D., Bass, C. R., Bolton, J. R., Guillemot, H., Damon, A. M., Crandall, J. R. : Load Path Distribution within the Pelvic Structure under Lateral Loading, International Crashworthiness Conference (2008)	Source of human response data
				Takahashi, Y., Suzuki, S., Ikeda, M., Gunji, Y. : Investigation on Pedestrian Pelvis Loading Mechanisms Using Finite Element Simulations, IRCOBI Conference (2010) (To be published)	Source of validation results
			Dynamic 3-point bending of lower limb long bones in lateral-medial direction at mid-shaft, distal third and proximal third	Kerrigan J. R., Bhalla K. S., Madeley N. J., Funk J. R., Bose D., Crandall J. R. : Experiments for Establishing Pedestrian-Impact Lower Limb Injury Criteria, SAE Paper #2003-01-0895 (2003)	Source of human response data
				Takahashi, Y., Kikuchi, Y., Mori, F., Konosu, A. : Advanced FE Lower Limb Model for Pedestrians, 18th ESV, Paper number 218 (2003)	Source of validation results

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			Dynamic 3-point bending of thigh and leg (with flesh on) in lateral-medial direction at mid-shaft, proximal third (leg only) and distal third	Ivarsson, J., Lessley, D., Kerrigan, J., Bhalla, K., Bose, D., Crandall, J., Kent, R. : Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities, IRCOBI Conference (2004)	Source of human response data
				Kikuchi, Y., Takahashi, Y., Mori, F. : Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb, SAE World Congress, Paper number 2006-01-0683 (2006)	Source of validation results
			Dynamic knee ligament distraction to failure at different loading rates for MCL, LCL, ACL (anterior and posterior parts individually) and PCL (anterior and posterior parts individually)	Bose D., Sanghavi P., Kerrigan J. R., Madeley N. J., Bhalla K. S., Crandall J. R. : Material Characterization of Ligaments using Non-Contact Strain Measurement and Digitization, International Workshop on Human Subjects for Biomechanical Research, (2002)	Source of human response data
				Takahashi, Y., Kikuchi, Y., Mori, F., Konosu, A. : Advanced FE Lower Limb Model for Pedestrians, 18th ESV, Paper number 218 (2003)	Source of validation results
				Van Dommelen, J. A. W., Ivarsson, B. J., Jolandan, M. M., Millington, S.A., Raut, M., Kerrigan, J.R., Crandall, J.R., Diduch, D.R. : Characterization of the Rate-Dependent Mechanical Properties and Failure of Human Knee Ligament, SAE Paper number 2005-01-0293 (2005)	Source of human response data
				Kikuchi, Y., Takahashi, Y., Mori, F. : Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb, SAE World Congress, Paper number 2006-01-0683 (2006)	Source of validation results
			Dynamic 4-point bending of knee joint in valgus bending	Ivarsson, J., Lessley, D., Kerrigan, J., Bhalla, K., Bose, D., Crandall, J., Kent, R. : Dynamic Response Corridors and Injury Thresholds of the Pedestrian Lower Extremities, IRCOBI Conference (2004)	Source of human response data

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				Kikuchi, Y., Takahashi, Y., Mori, F. : Development of a Finite Element Model for a Pedestrian Pelvis and Lower Limb, SAE World Congress, Paper number 2006-01-0683 (2006)	Source of validation results
			General	Takahashi, Y., Kikuchi, Y., Konosu, A., Ishikawa, H., *Development and validation of the finite element model for the human lower limb of pedestrians*, Stapp Car Crash journal, Vol. 44, 2000-101-SC22 (2000)	
Honda Human FE model (Child) Version 1st April 2009	Geometric reconstruction derived from MRI scans from a 6YO child (whole-body external shape, lower limb bones and ligaments) FE model for thigh and leg; Articulated Rigid Body model for pelvis and above representing freedom of motion of spine Represent child-specific anatomical structures such as cartilaginous layers at ends of long bones	Represent 6YO child anthropometry	Dynamic 3-point bending of child femur and child tibia in lateral-medial direction	Ouyang, J. et al.: *Biomechanical Character of Extremity Long Bones in Children and its significance*, Chinese Journal of Clinical Anatomy, Vol.21, No.6, p620-p623 (2003), (in Chinese)	Source of human response data
				Ito, O., Okamoto, M., Takahashi, Y., Mori, F. : *Validation of an FE Lower Limb Model for a Child Pedestrian by Means of Accident Reconstruction*, SAE paper number 2008-01-1240 (2008)	Source of validation results
			Leg fracture prediction validated against CIREN in-depth accident data by means of accident reconstruction	Ito, O., Okamoto, M., Takahashi, Y., Mori, F. : *Validation of an FE Lower Limb Model for a Child Pedestrian by Means of Accident Reconstruction*, SAE paper number 2008-01-1240 (2008)	Source of validation results

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THUMS Version 1.0, 3.0, 4.0, Daimler THUMS-D based on v3.0		AM50, AF05, 6YO, AM95	injury parameters are accurately predicted	T. Yasuki and Y. Yamamae, Validation of Kinematics and Lower Extremity Injuries Estimated by Total Human Model for Safety in SUV to Pedestrian Impact Test, Journal of Biomechanical Science and Engineering Vol. 5 (2010) , No. 4 Special Issue on Biomechanics in Cardiovascular Systems T. Maeno et al., Development of a Finite Element Model of the Total Human Model for Safety (THUMS) and Application to Car-Pedestrian Collisions, ESV 2001 Watanabe, R., Miyazaki, H., Kitagawa, Y., Yasuki, T., : Research of Collision Speed Dependency of Pedestrian Head and Chest Injuries Using Human FE Model (THUMS Version 4), 22nd ESV, Paper number 11-0043 (2011)	Commercially available (AM50) Toyota in-house models (AF05, 6YO, AM95)
JLR Human FE model Version 8.1, 9.0		child, 5th 50th 95th	See references	HOWARD, M., THOMAS, A., KOCH, D. W., WATSON, J. & HARDY, R. (2000) Validation and Application of a Finite Element Pedestrian Humanoid Model for Use in Pedestrian Accident Simulations. IRCOBI. Montpellier, France, IRCOBI. Developments in the simulation of real world car to pedestrian accidents using a pedestrian humanoid finite element modelR Hardy, J Watson, M Howard - International Journal of Crashworthiness, 2000. HOWARD, M. S. (2002) Pedestrian Accident Simulation and Protection. Technology Evaluation. School of Engineering. Cranfield University.	JLR in-house model

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MADYMO Version 4.2,	Details see references, MADYMO Human Models Manual, Version 7.3, TNO Automotive, Delft, The Netherlands, November 2010	3yo, 6yo, 5th F, 50th M, 95th. These models result from a scalable mid-size male pedestrian model	Details see references, MADYMO Human Models Manual, Version 7.3, TNO Automotive, Delft, The Netherlands, November 2010	MADYMO Human Models Manual, Version 7.3, TNO Automotive, Delft, The Netherlands, November 2010.	Commercially available
IEE-WPI FE Model Version 1.0	Up-right pedestrian model based on WPI study with following improvements 1. introduction of upper body masses represented by rigid bodies 2. more detailed knee modelling (a. ligaments b. non-linear and strain-rate dependent material laws with appropriate failure criteria c. introduction of a simplified knee capsule 3. femur and tibia soft tissue material 4. femur meshed with shell elements	50% male available. 5% female and 6 year old child under development	Model aims at a humanlike interaction with the vehicle bumper and therefore has: - hip- / knee-joint mechanics (ligaments) - tissue / ligament / bone sub-structure - correct anthropometric proportions Rigid-body model validation according to Madymo (c.f. J.van Hoof) FE-model validation according to - J. Kajzer et al - J.R. Kerrigan et al - J.A.W. van Dommelen et al	C. Silvestri - Development and validation of a knee-thigh-hip LS-DYNA model of a 50th percentile male PhD Thesis, Worcester Polytechnic Institute, April 2008 C. Silvestri, M. H. Ray - Development of a Finite Element Model of the Knee-Thigh-Hip of a 50th Percentile Male including Ligaments and Muscles, International Journal of Crashworthiness, Vol. 14, No. 2, pp: 215-229, 2009 FE-based pedestrian modelling to simulate the collision process with a car front-end Dr. Wener Bieck (IEE S.A.) 5. pedestrian protection conference, July 2010 (by Carhs & BGS	IEE in-house model

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PAMCRASH Version 1.0		3yo, 6yo, 5th F, 50th M, 95th. These models result from a scaleable mid-size male pedestrian model	Whole body kinematics based on articulated rigid bodies with focus on humanlike whole body kinematics and head contact times based on corridors from ref. 3 + 4	1. Jason R. Kerrigan, Drew B. Murphy, D. Chris Drinkwater, Check Y. Kam, Dipan Bose, Jeff R. Crandall Kinematic Corridors for PMHS tested in full-scale Pedestrian Impact Tests University of Virginia Center for Applied Biomechanics United States 2. Jason Kerrigan, Carlos Arregui, Jeff Crandall1 Pedestrian Head Impact Dynamics: Comparison of Dummy and PMHS in small Sedan and Large SUV Impacts University of Virginia Center for Applied Biomechanics United States European Center for Injury Prevention, Universidad de Navarra Spain 3. SAE-Proposal J2782,2007, 'Performance Specifications for a 50th Percentile Male Pedestrian Research Dummy'. 4. Ishikawa H., 1993 'Computer Simulation of Impact Response of the Human Body in Car-Pedestrian Accidents'.	Available for PAMCRASH-users (development project partners from ESI).
JAMA Human FE Model Version 13th June 2011	Coupling of the upper body from THUMSTM(Ver.1.4) and the lower body from H-modelTM based Honda Human Pedestrian Model Modifications were made to improve biofidelity and computational stability.	Baseline model represent anthropometry close to 50th percentile male; baseline model can be scaled to any sizes of adult population	whole body kinematics (head, thoracic and lumbar spines, femur, tibia and foot) during an impact against four types of vehicles (minicar, sedan, SUV and minivan), only one trajectory of which is published Injuries not yet	Sugimoto, T., Yamazaki, K., First Results from the JAMA Human Body Model Project, 19th ESV Conference, Paper Number 05-0291 (2005)	Overview
				Kamiji, K., Yamazaki, K., Development of Finite Element Model of Human to Reduce Injuries in Traffic Accidents, Journal of Society of Automotive Engineers of Japan 62(5), pp. 34-39 (2008) (in Japanese)	Source of validation results

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			satisfactorily reproduced		
Nissan Human FE Model Version 3.0, 4.0 AM95 based on JAMA and GHBMC model.		6yo, 50th Male, 5th Female and 95th Male	AM50% and AC06(6-yr-old): whole body kinematics (head, thoracic and lumbar spines, femur, tibia and foot) during an impact against different types of vehicles to reproduce real world phenomena based on PCDS accident data base. AF05: Good overall kinematics, Excellent detail pelvis injury estimation. AM95%: Good (overall kinematics) Excellent (detail lower injury estimation based on real world accident data)	1. Different Factors Influencing Post-crash Pedestrian Kinematics Y. Kawabe, Murakami, C. Pal and T. Okabe, 2012 SAE International paper no. 2012-01-0271 2. Post-crash Pedestrian Head Kinematics in Real World Accidents Using 6-yr Old Child FE Model C. Pal, K. Yoshiko, O. Tomosaburo, Nissan Motor Company Ltd JSME-CMD symposium Paper no. 2402 3. Analysis of Pedestrian Kinematics and Injury Mechanism In Real World Accidents Murakami, Daisuke; *Pal, Chinmoy; Kawabe, Yoshiko; Okabe Tomosaburo Nissan Motor Company Ltd., Japan FISITA2012 paper no. F2012-F03-010 4. Human FE Model to Estimate Head Contact Time for Pedestrian Protection C. Pal, O. Tomosaburo, Nissan Motor Company Ltd. M. Muthukumar, S. Narayanan, RNTBCI Paper Number 13-0376 5. Estimation of Pelvis Injuries and Head Impact Time using Different Pedestrian Human FE Models Chinmoy Pal and Tomosaburo Okabe Nissan Kulothungan Vimalathithan, Jeyabharath	Accurate for HIT and body contact calculation requirements, as per Euro NCAP protocol. Level pelvis injuries are verified with real world accident data JAMA AM50 upper body and GHBMC AM50 lower leg models are well integrated and modified to suit Euro NCAP protocol requirements.

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				Manoharan, Muthukumar Muthanandam, and Satheesh Narayanan RNTBCI 2014-01-0522 SAE2014 6. Effect of vehicle's front end profile on pedestrian's lower extremity injury pattern in real world and verification by large male FE Human Model. Chinmoy Pal, Tomosaburo Okabe, Munenori Shinada Nissan Kulothungan Vimalathithan, Jeyabharath Manoharan, RNTBCI 2015-01-1467 SAE2015	
GM/GME Human FE Model Version 8.2.1 Version 1.0		50th Male 6yo, 5th female & 95th male.	Model aims to replace Madymo-Multi-Body -Model in case of whole body kinematics and contact times - Whole body kinematics (head, T1, pelvis, left femur and tibia) during an impact against a small sedan (1400 kg) at 40 kmph - Dynamic 3-point bending of femur in anterior-posterior direction at mid-shaft - Dynamic 3-point bending of leg (with flesh) in lateral-medial direction at mid-calf	1. Deng B et al, "Human model for real-world vehicle-pedestrian impact simulations."INFATS - Proceedings of the 5th International Forum of Automotive Traffic Safety, China : Hunan University, 2007 2. Deng B et al, "Human model for real-world vehicle pedestrian impact simulations." Paper presented at the International Symposium of Human Modeling and Simulation in Automotive Safety, Aschaffenburg, Germany, 2007 3. Unatriou C et al, “A Finite element model of the lower limb for simulating pedestrian impact”, Stapp Car Crash Journal, 49:157-181, 2005 4. Vusirikala N, “ Development of deformable pelvis model for motor vehicle crashes”, GM Internal Report, 2007 5. Vusirikala N, “ Development of whole hip capsule ligament FE model”, GM Internal Report, 2008 6. Vusirikala N, “ Estimation of pedestrian lower leg injury potential using lower extremity human body model”, GM Internal Report, 2008	

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			- 4-point bending of knee joint in valgus bending - 3-point combined loading test of knee-joint - Quasi-static 3-point bending of femur, tibia and fibula in anterior-posterior and lateral-medial directions - Quasi-static tensile test to failure and dynamic ramp-and-hold tensile test for the MCL - Dynamic lateral compression of pelvis (Force-deflection at acetabulum and ilium in both acetabulum and iliac loadings) - Pelvis – femur hip capsule ligament distraction test - Shearing and bending effects of the knee joint and low and high speed lateral loading	7. Guillemot H, et al, "Pelvic behavior in side impact collisions: Static and dynamic tests on isolated pelvic bones", SAE Paper # 98-S6-W-37, 1998 8. Stewart KJ, et al, "Spatial Distribution of Hip Capsule Structural and Material Properties", Journal of Biomechanics, Vol 35, pp. 1491-1498, 2002. 9. Kajzer J, et al, "Shearing and bending effects at the knee joint at low speed lateral loading", SAE paper No # 1999-01-0712, 1999 10. Kajzer J, et al, "Shearing and bending effects at the knee joint at high speed lateral loading", IRCOBI Conference, Germany, paper No # 1999-01-0712, 1999	