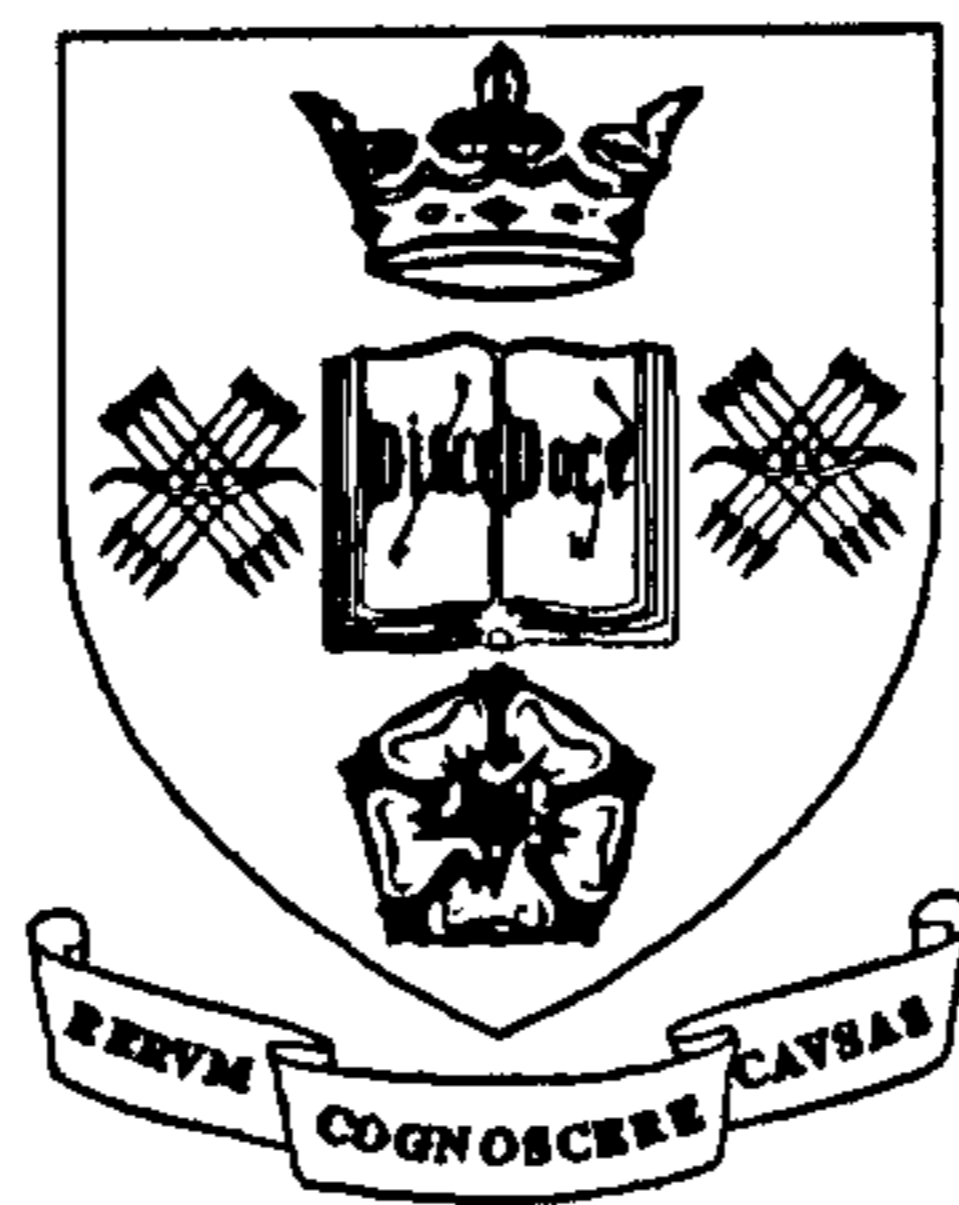


**SOME ASPECTS OF THE
CRASHWORTHINESS OF RAIL
VEHICLES : VOLUME II**

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A thesis submitted for the degree of
Doctor of Philosophy at the University of Sheffield



Department of Mechanical and Process Engineering

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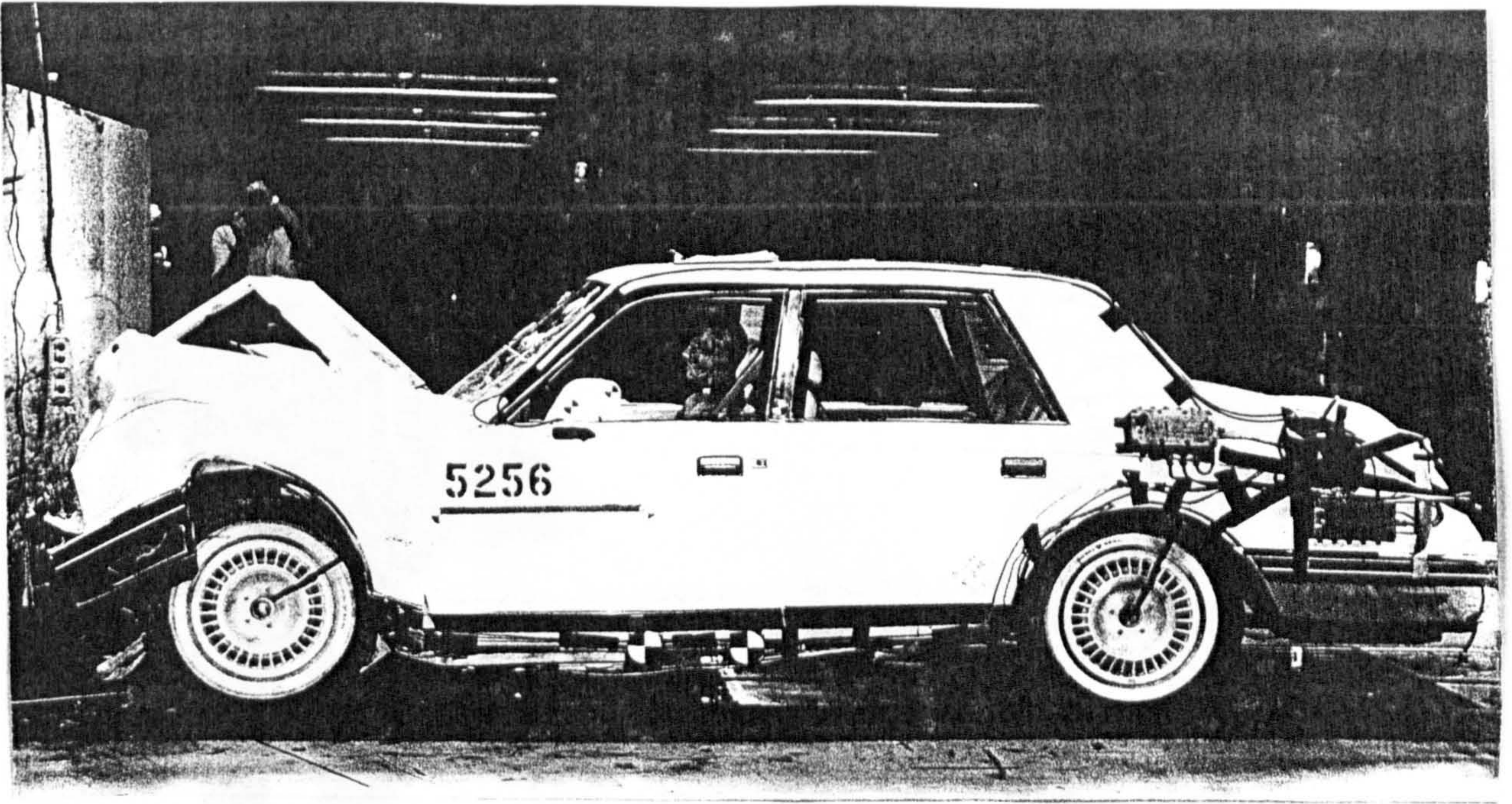


Figure 1.1 : A crush zone situated well away from the passenger compartment provides the necessary survival space for the passengers [3].



Figure 1.2 : The Volvo dummy family [7].

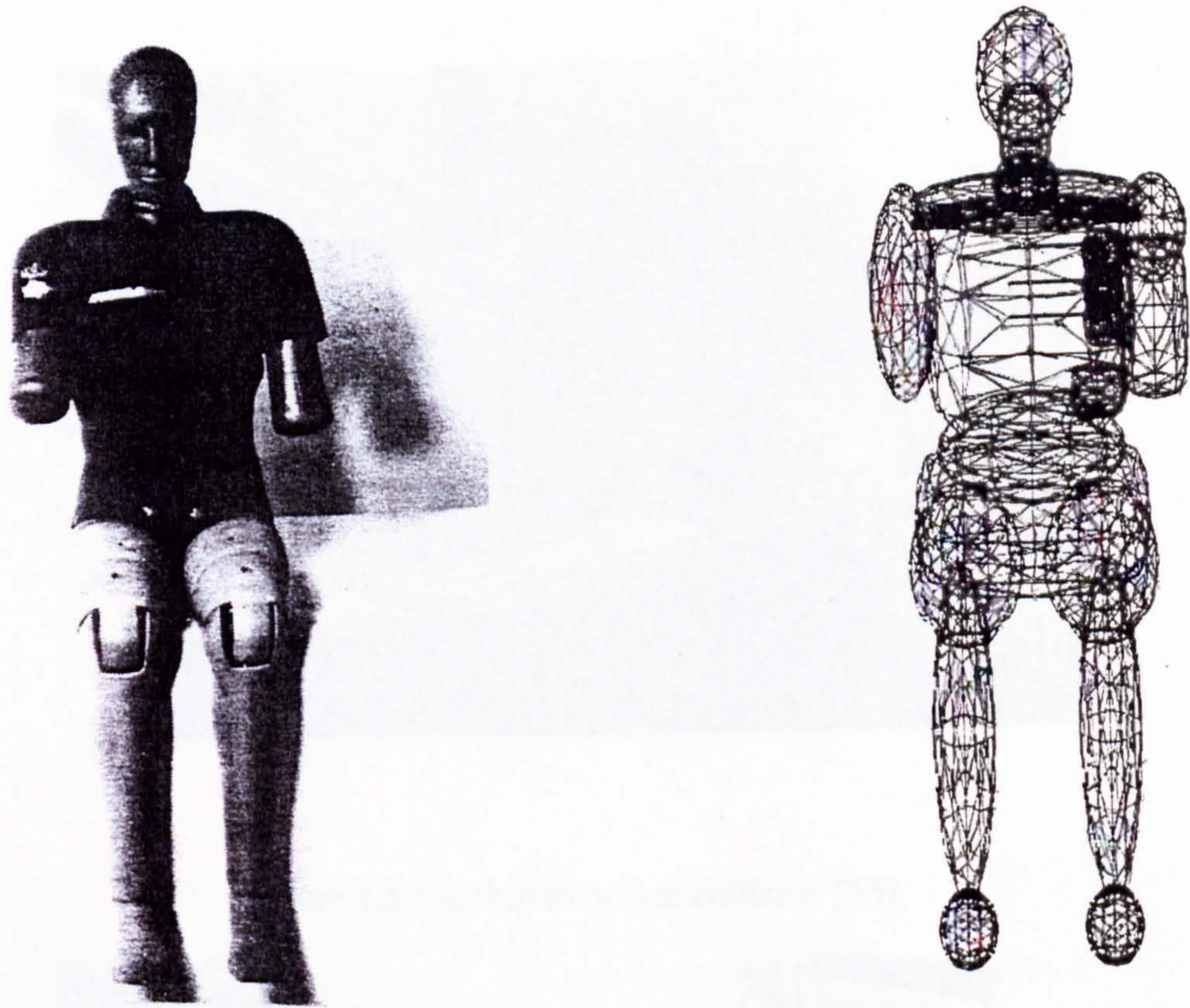


Figure 1.3 : EUROSID --- Actual dummy and its F.E. model [6].

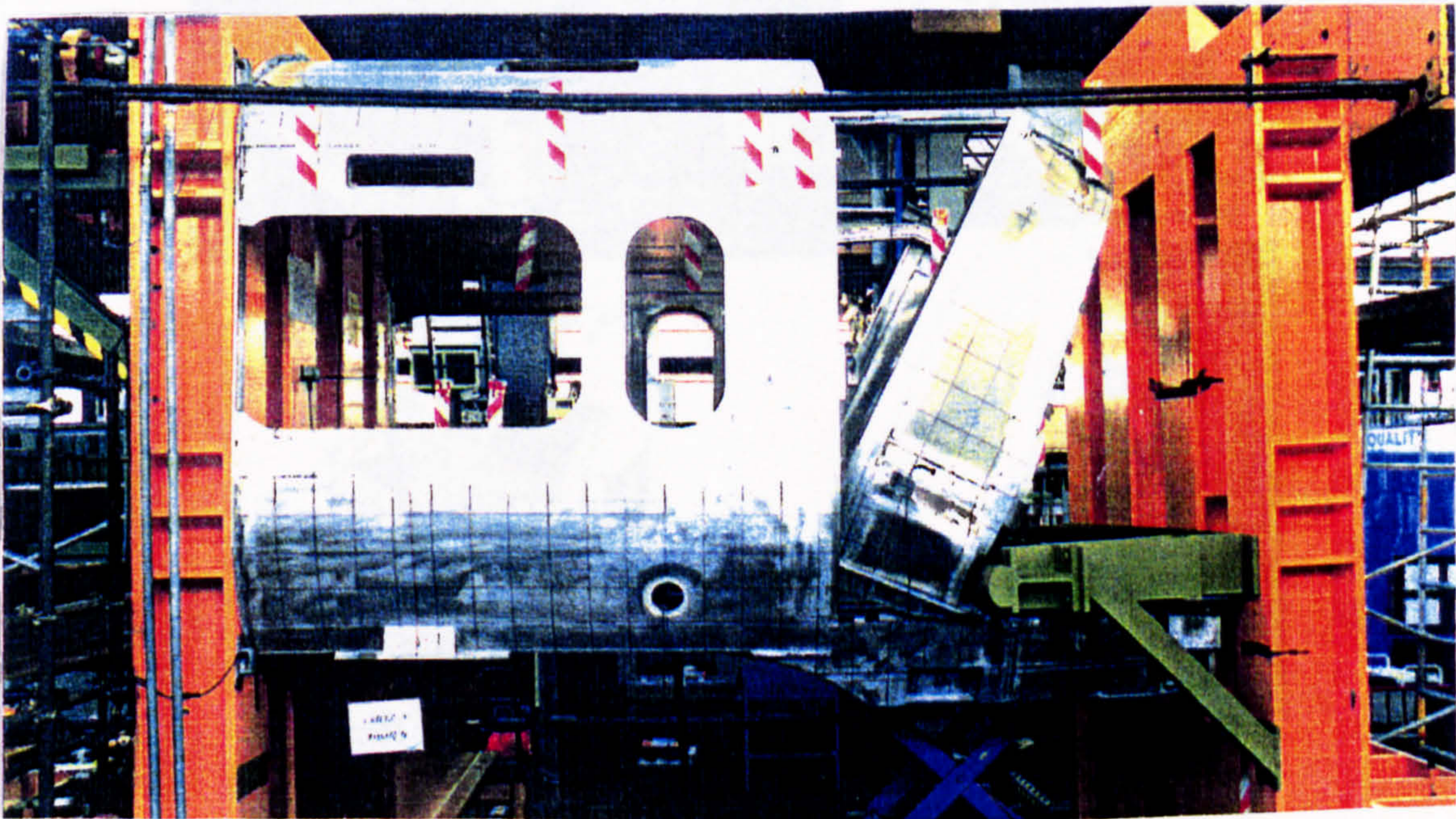


Figure 1.4 : BR static crush test on vehicle end structure [9].

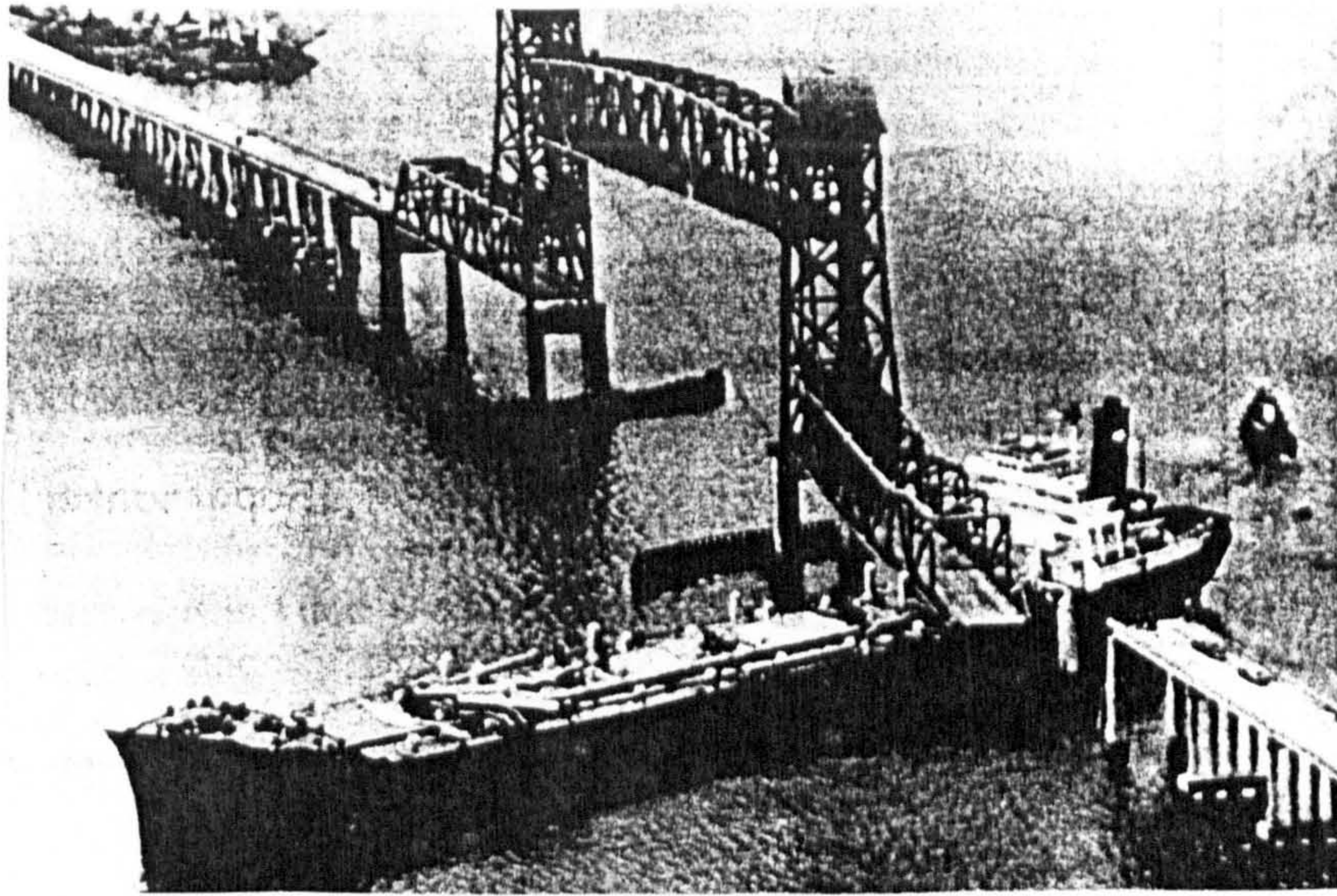


Figure 1.5 : A ship to bridge collision [15].

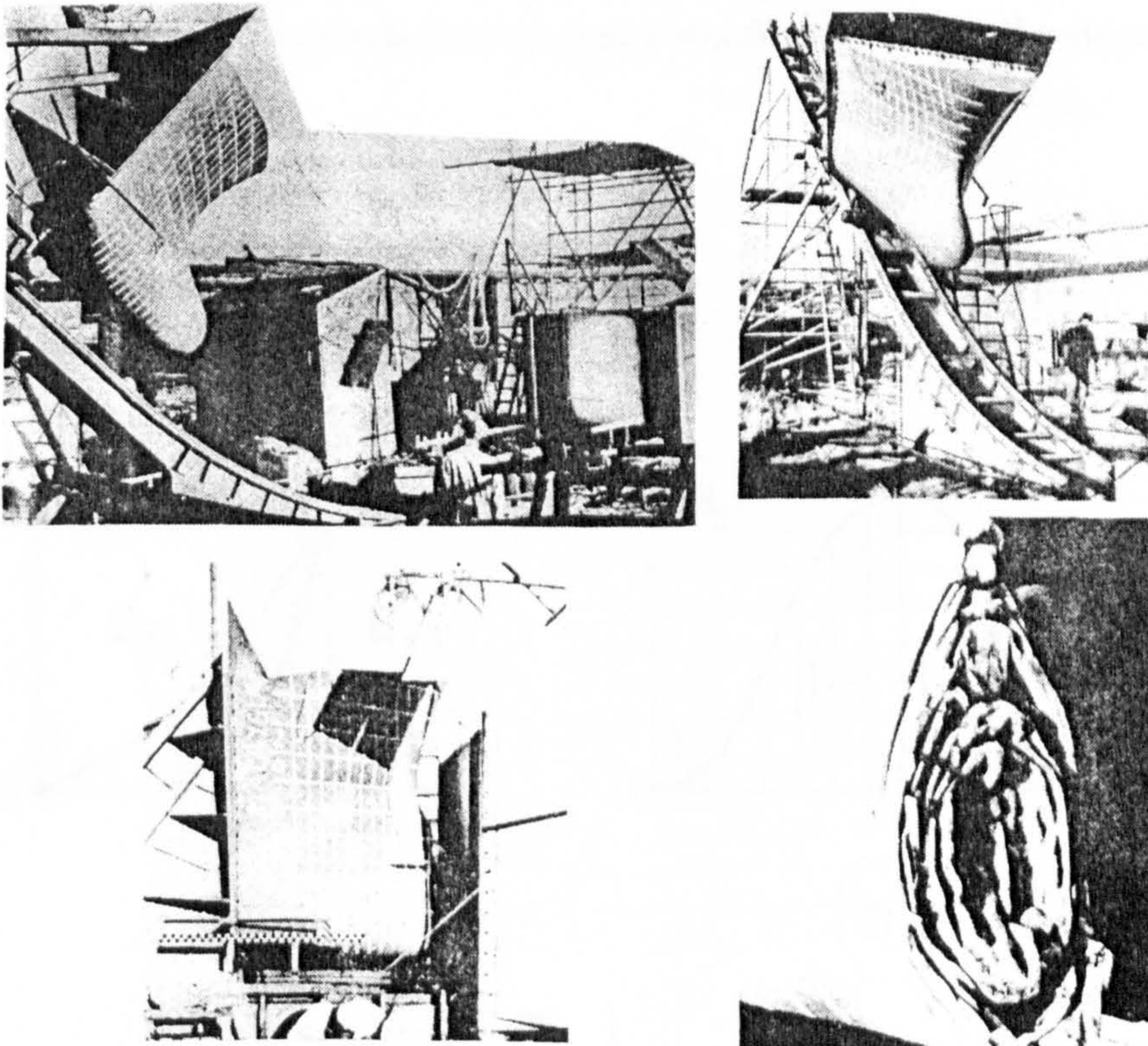


Figure 1.6 : The impact test on a ship's bow [15].

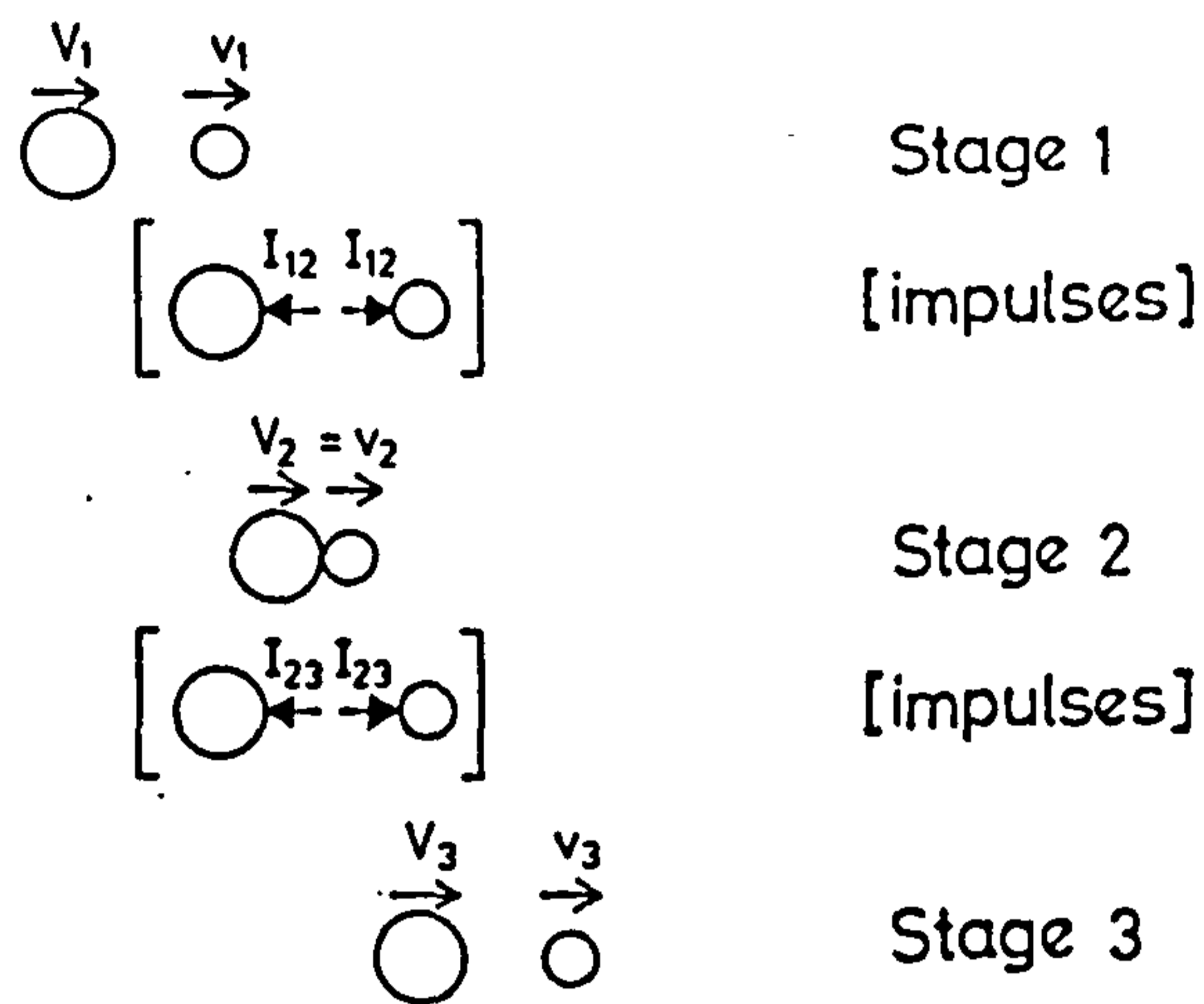


Figure 2.1 : Stage 1 is prior to impact. Stage 2 is the instant at which the centroids of M and m have exactly equal velocities. Stage 3 represents their separation. The intermediate diagrams show the impulses I which act between the stages [9].

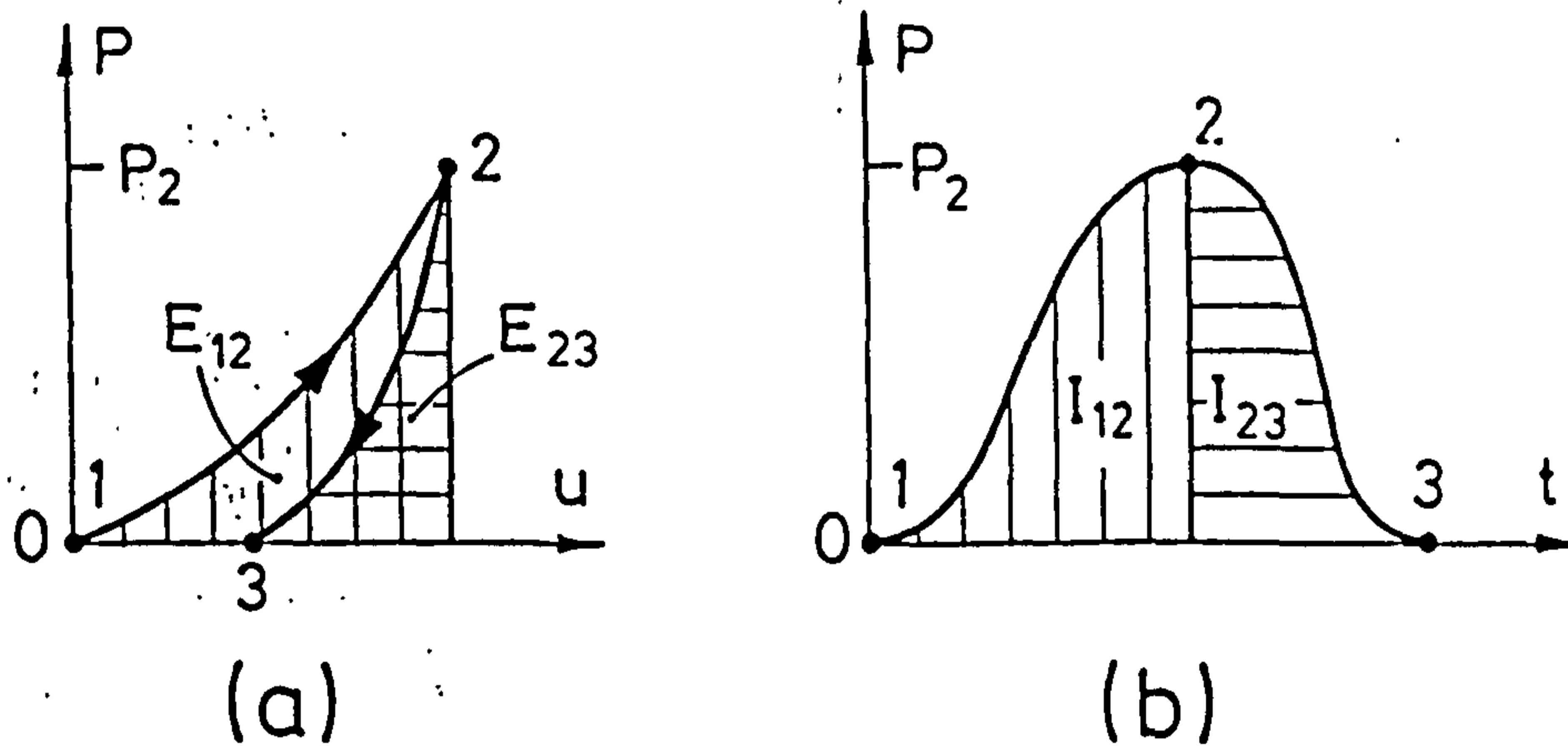


Figure 2.2 : (a) Load-deflection curves of typical loading and unloading path for the contact region. (b) Force-time plot corresponding to (a). After [9].

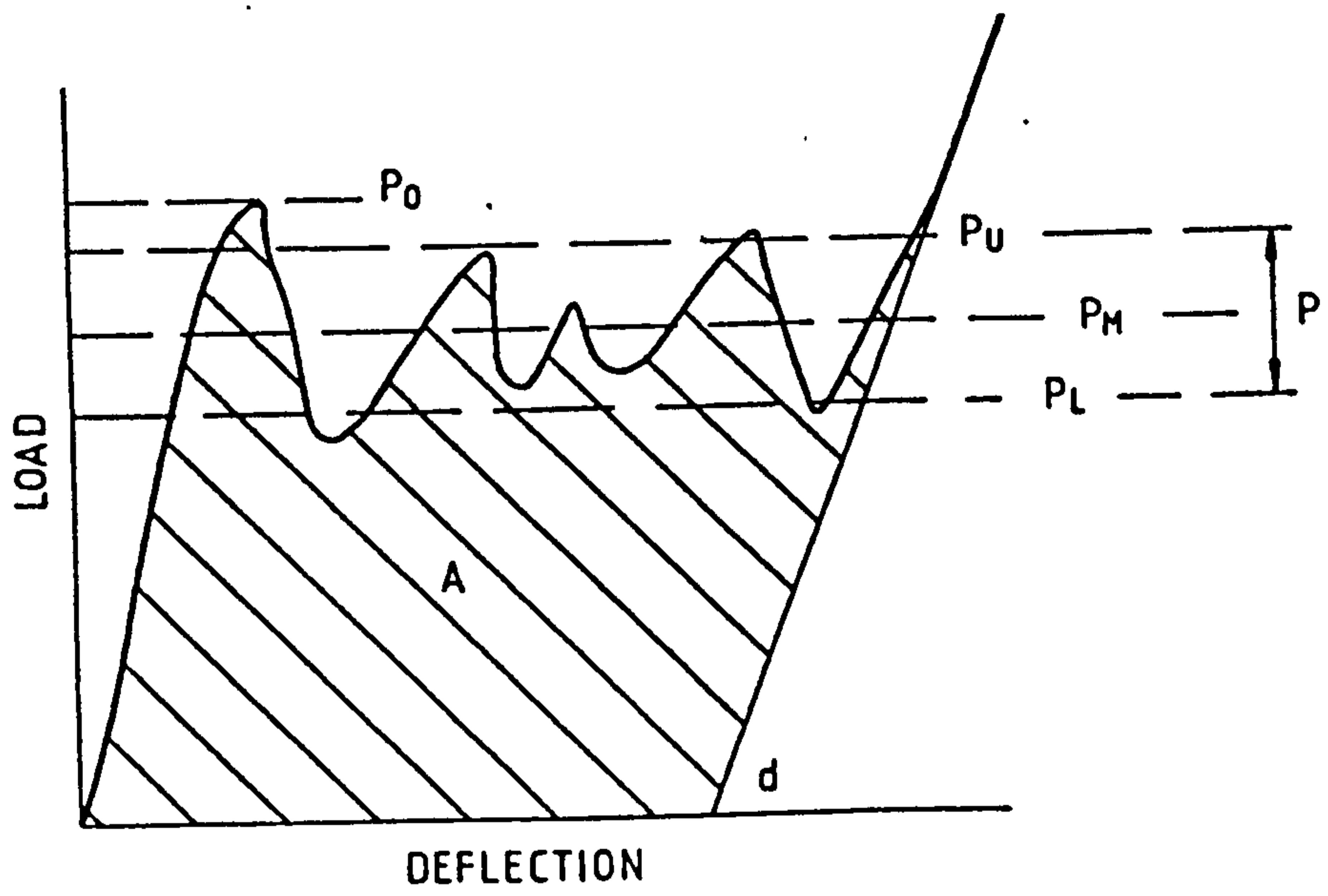


Figure 2.3 : Measures of energy absorption efficiency [10].

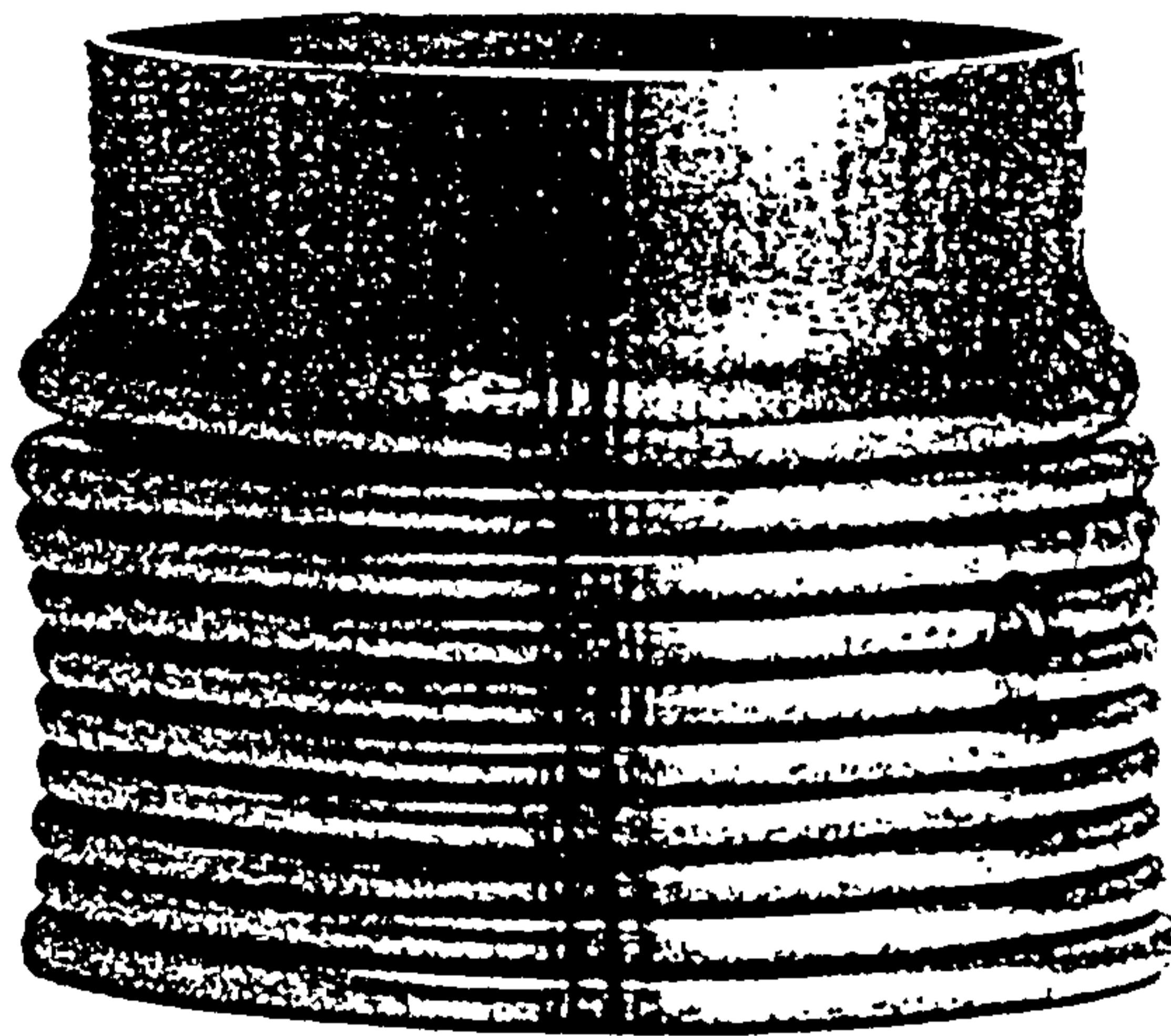


Figure 2.4 : Axisymmetric buckling mode for tubes [16].

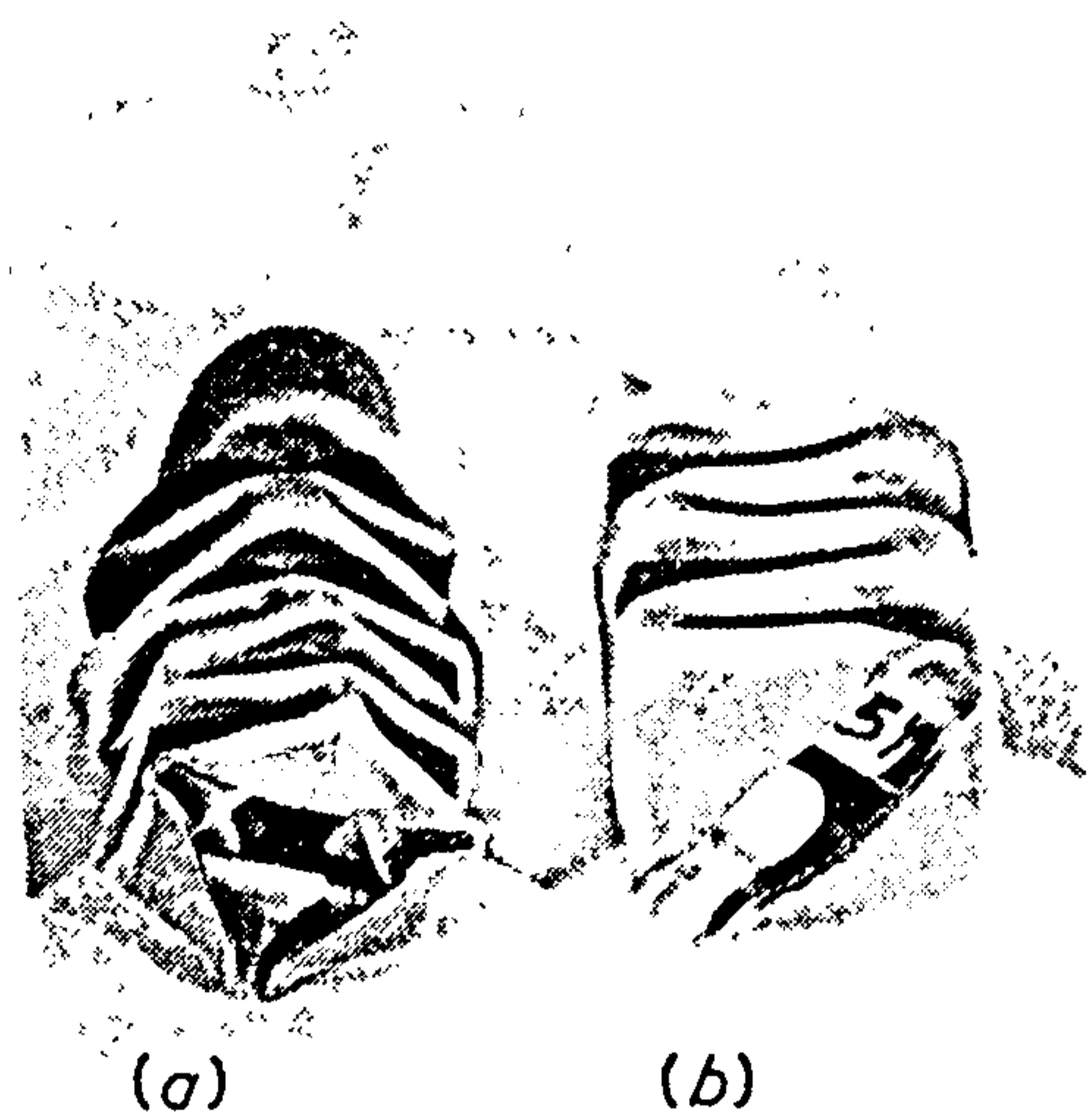


Figure 2.5 : Diamond-lobe buckling mode. Here specimen (a) has a 3 diamond-lobe collapse mode and (b) has a 2 diamond-lobe collapse mode [28].

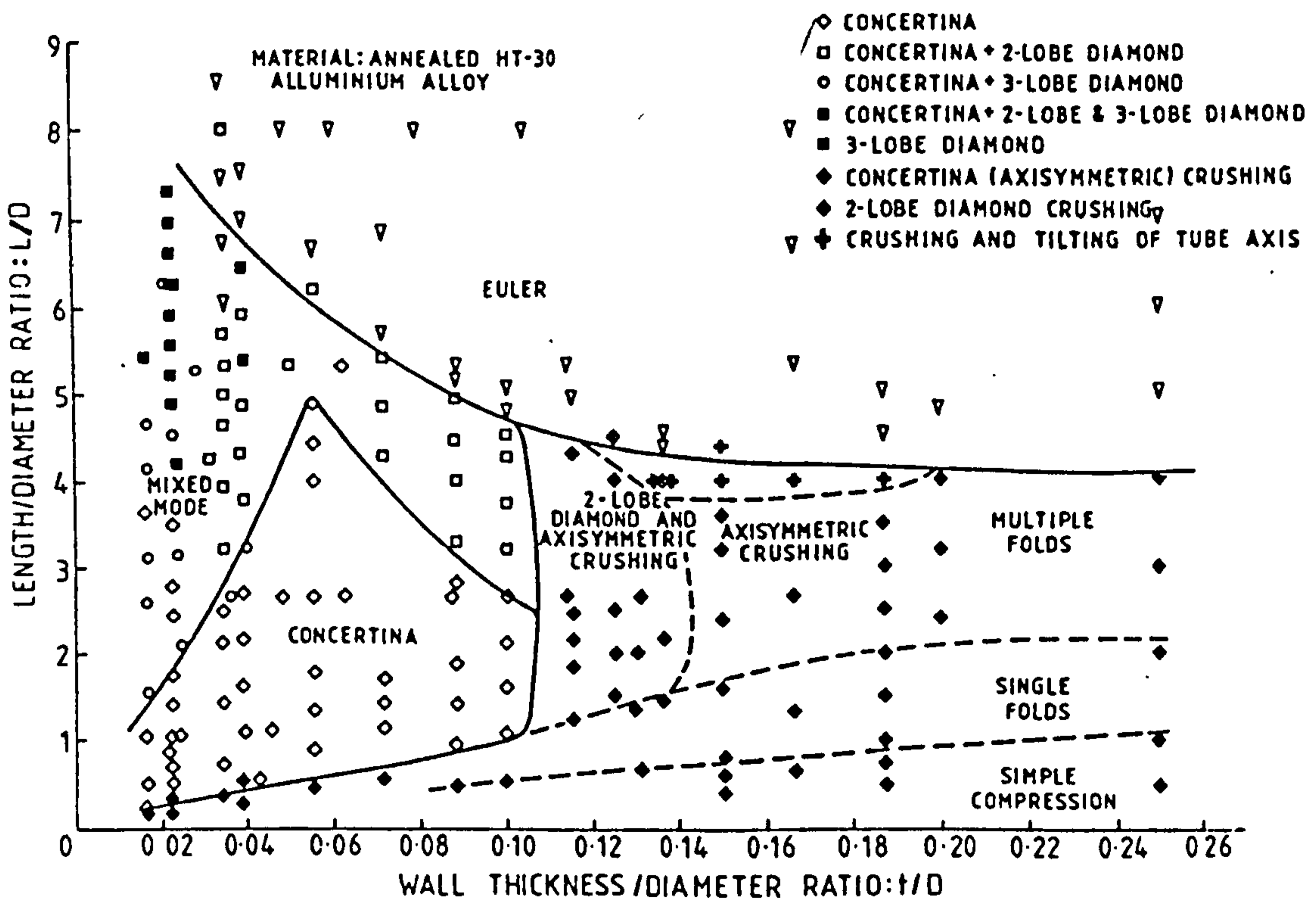


Figure 2.6 : Collapse-mode classification chart for aluminium alloy tubes [20].

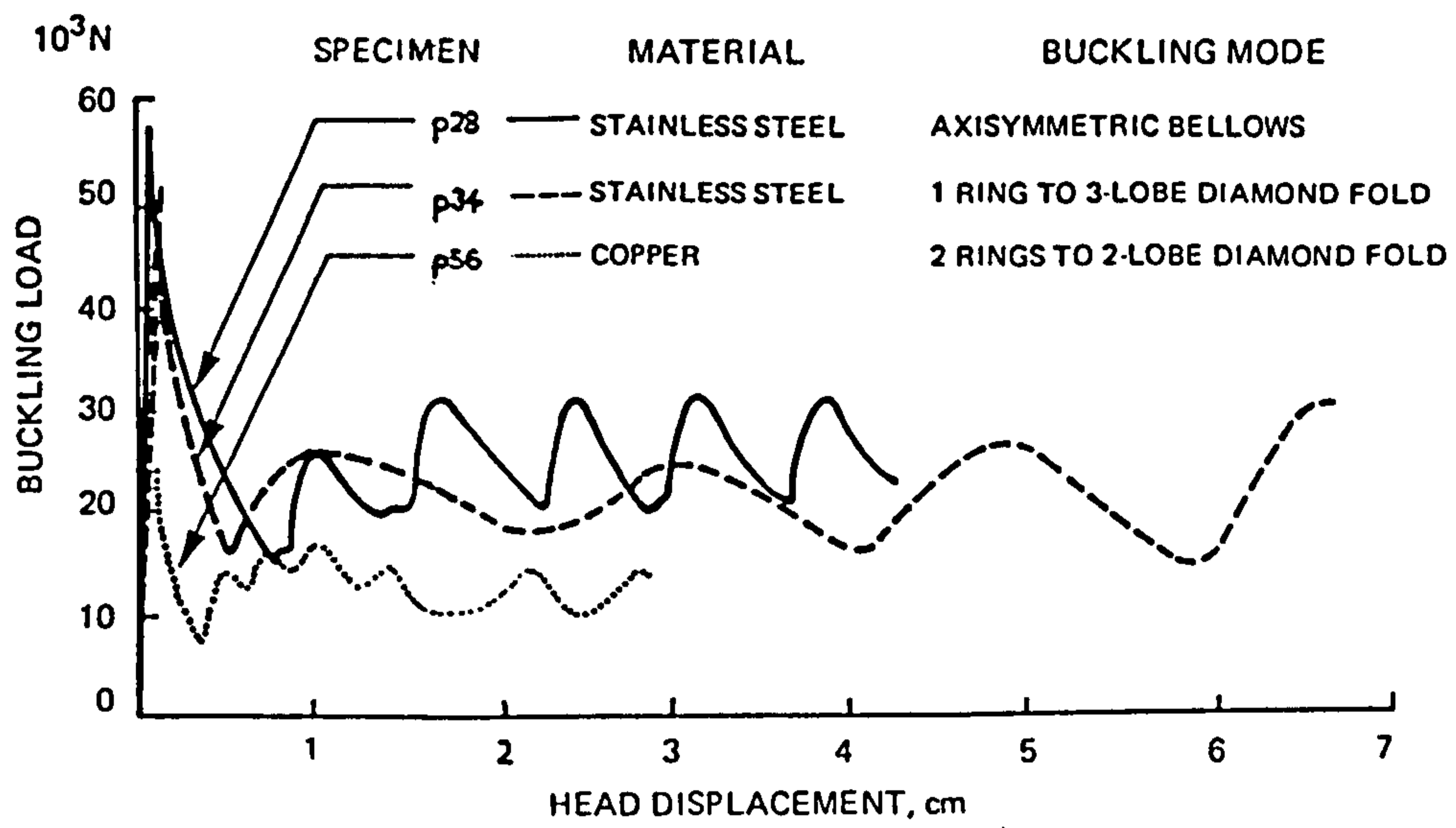


Figure 2.7 : Load-deflection characteristics of axially compressed tubes from reference [19].

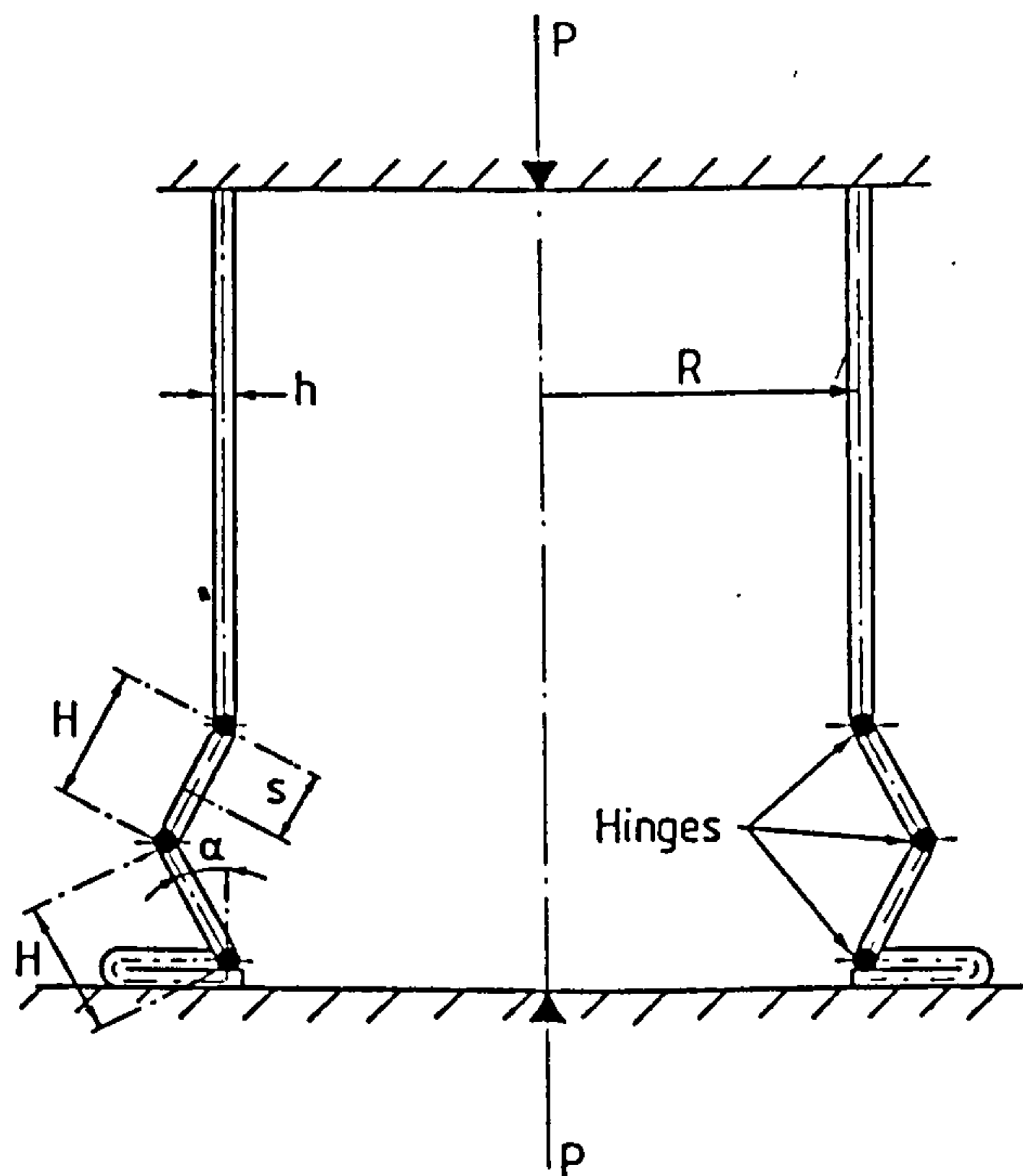


Figure 2.8 : Alexander's idealized axisymmetric collapse mode for cylindrical tubes [24].

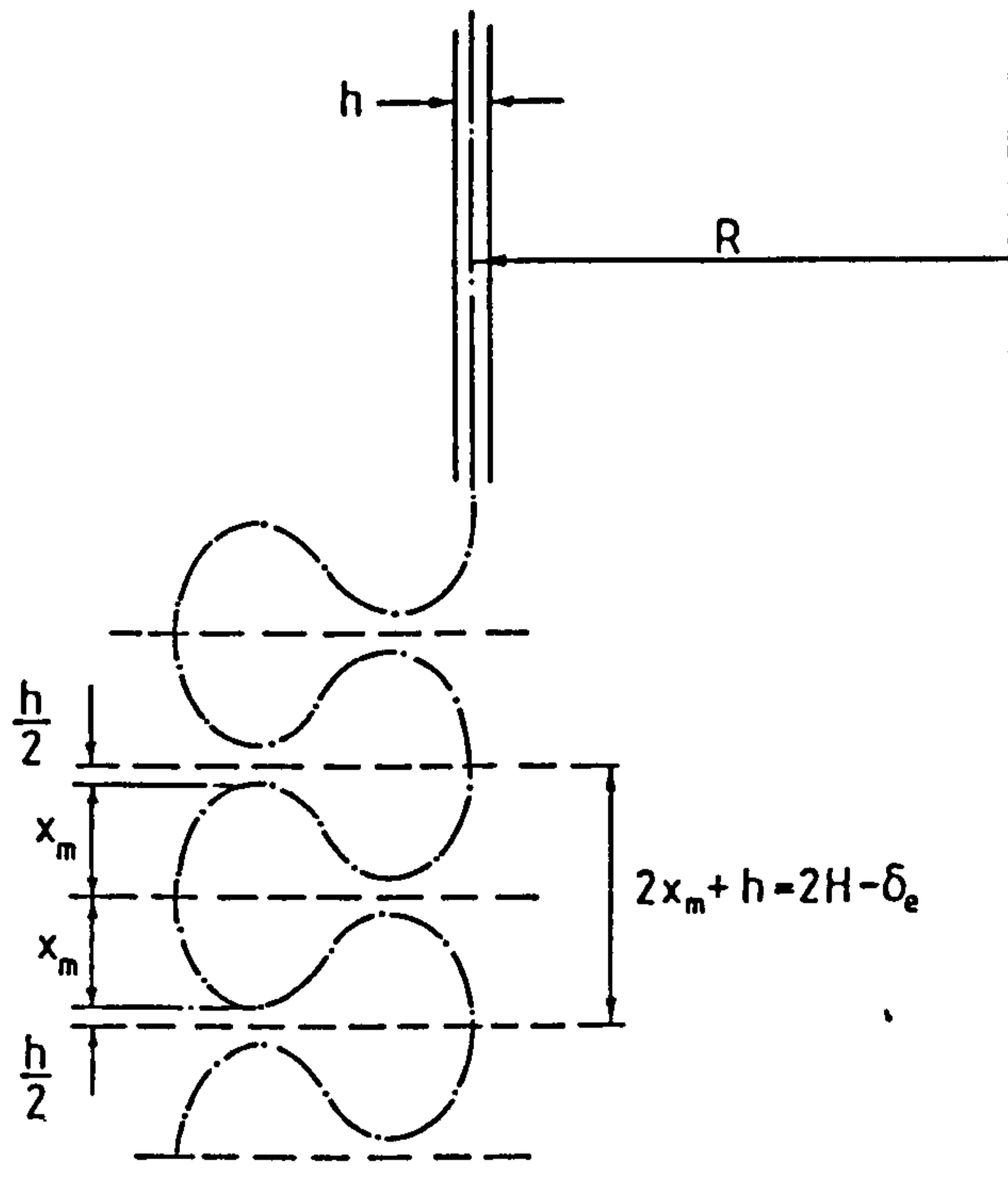


Figure 2.9 : The improved axisymmetric collapse mode. Axial deflection is now governed by an effective crushing stroke [25].

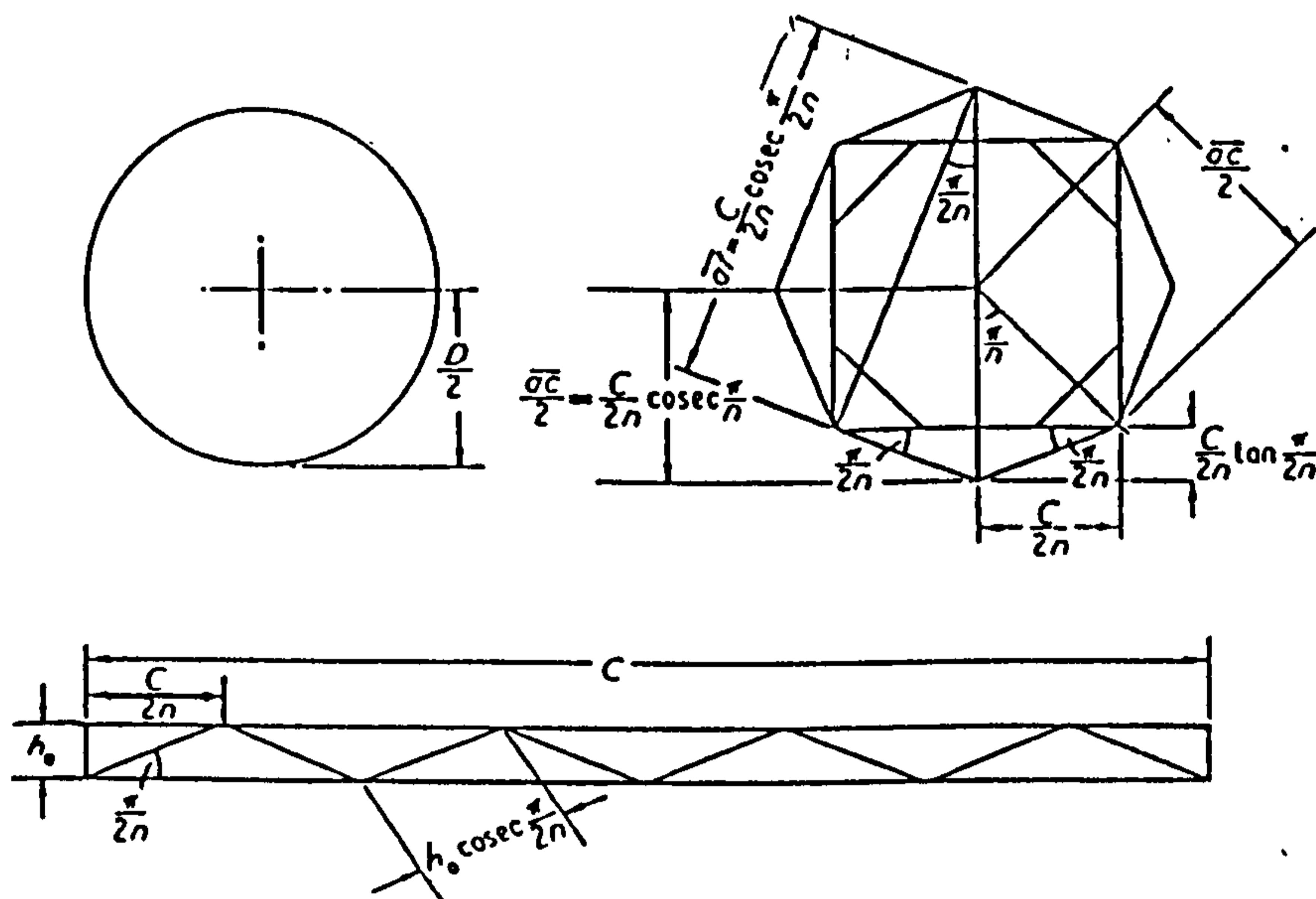


Figure 2.10 : The geometric relationships for diamond collapse modes of PVC tubes as described in [27].

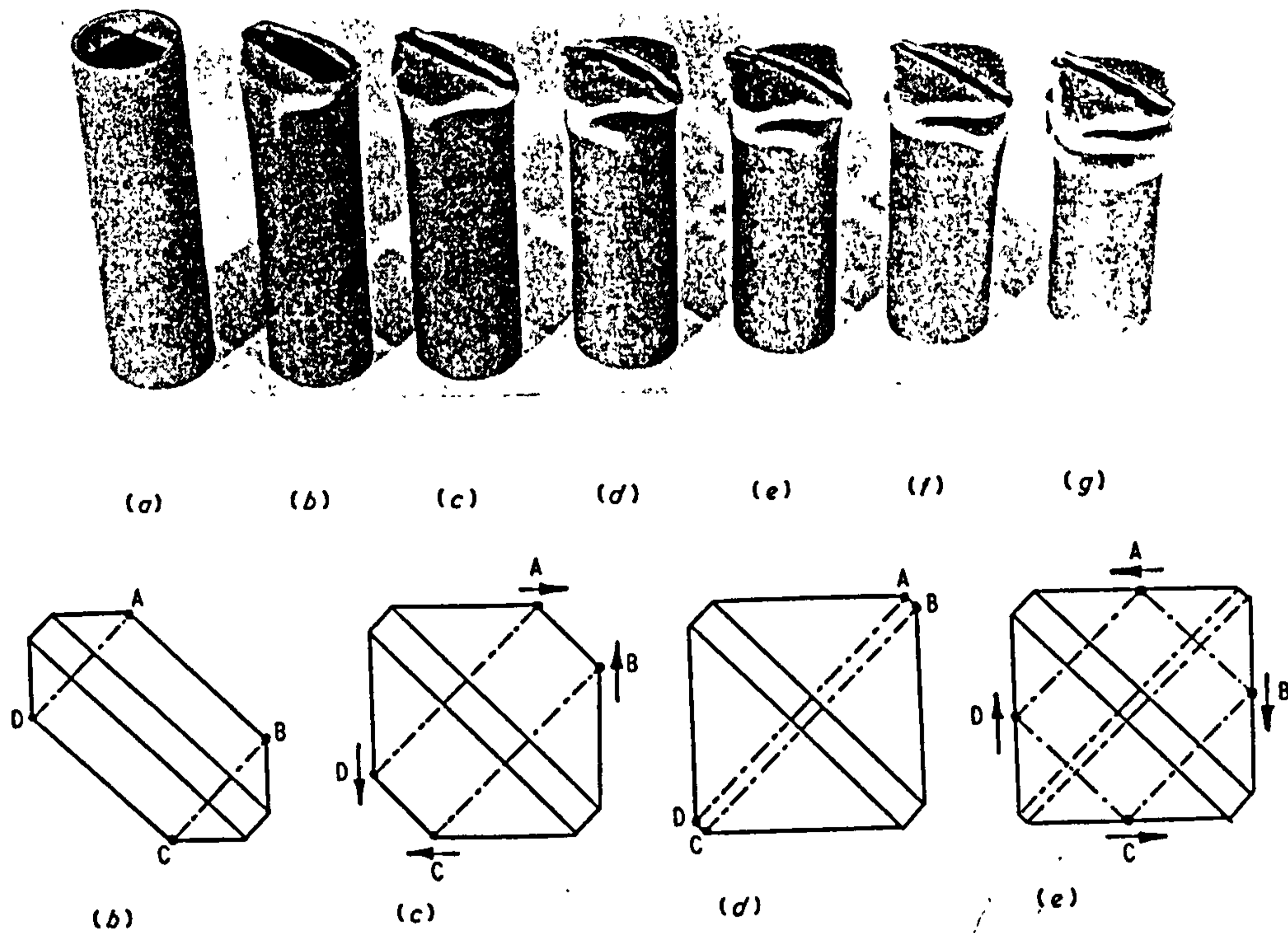


Figure 2.11 : The travelling-hinge mechanism for tubes collapsing in the diamond-lobe mode. [28].

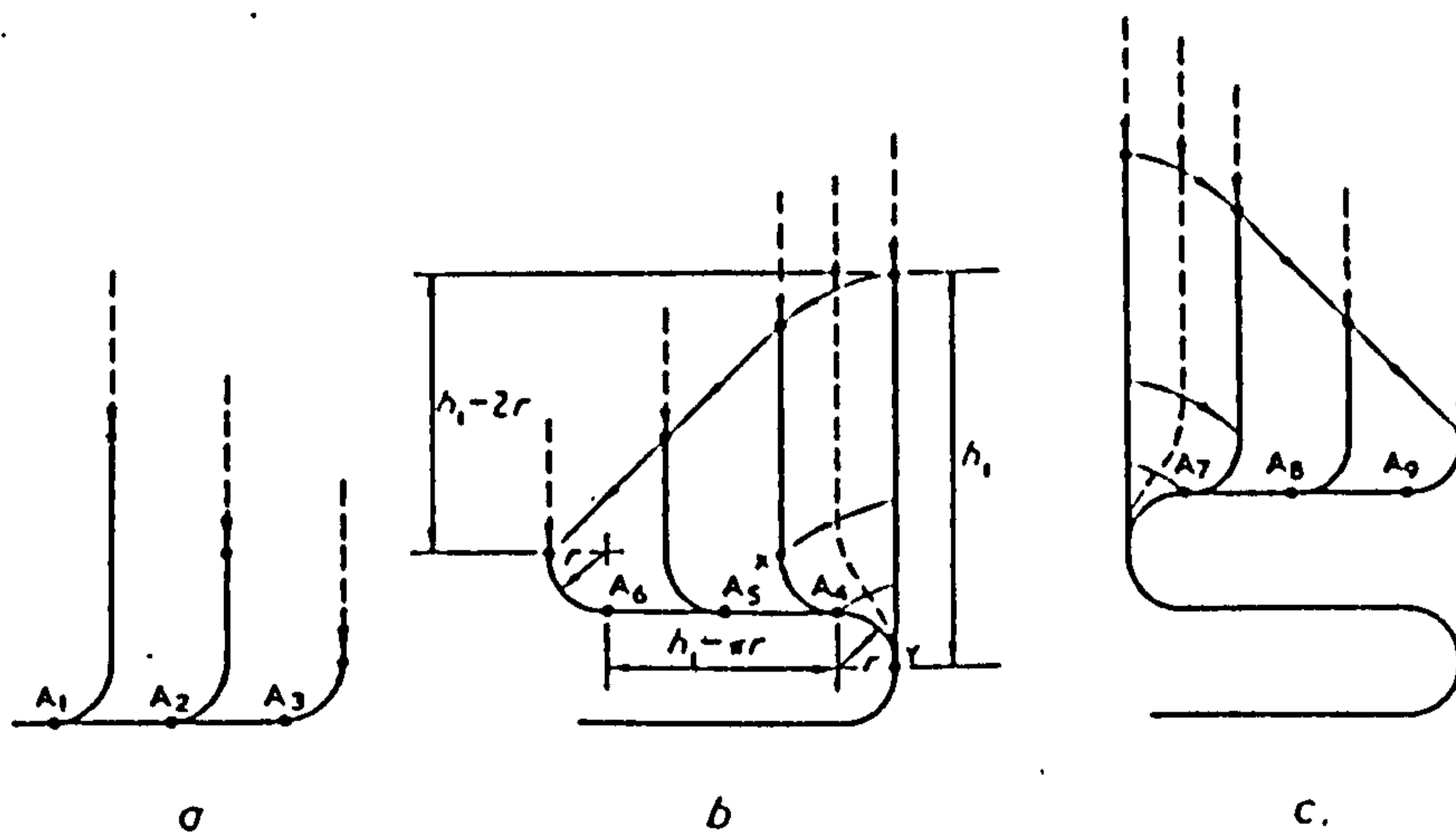


Figure 2.12 : Formation of horizontal hinges in Johnson *et. al.* theory. The radius ' r ' is obtained by minimum energy principle [27].

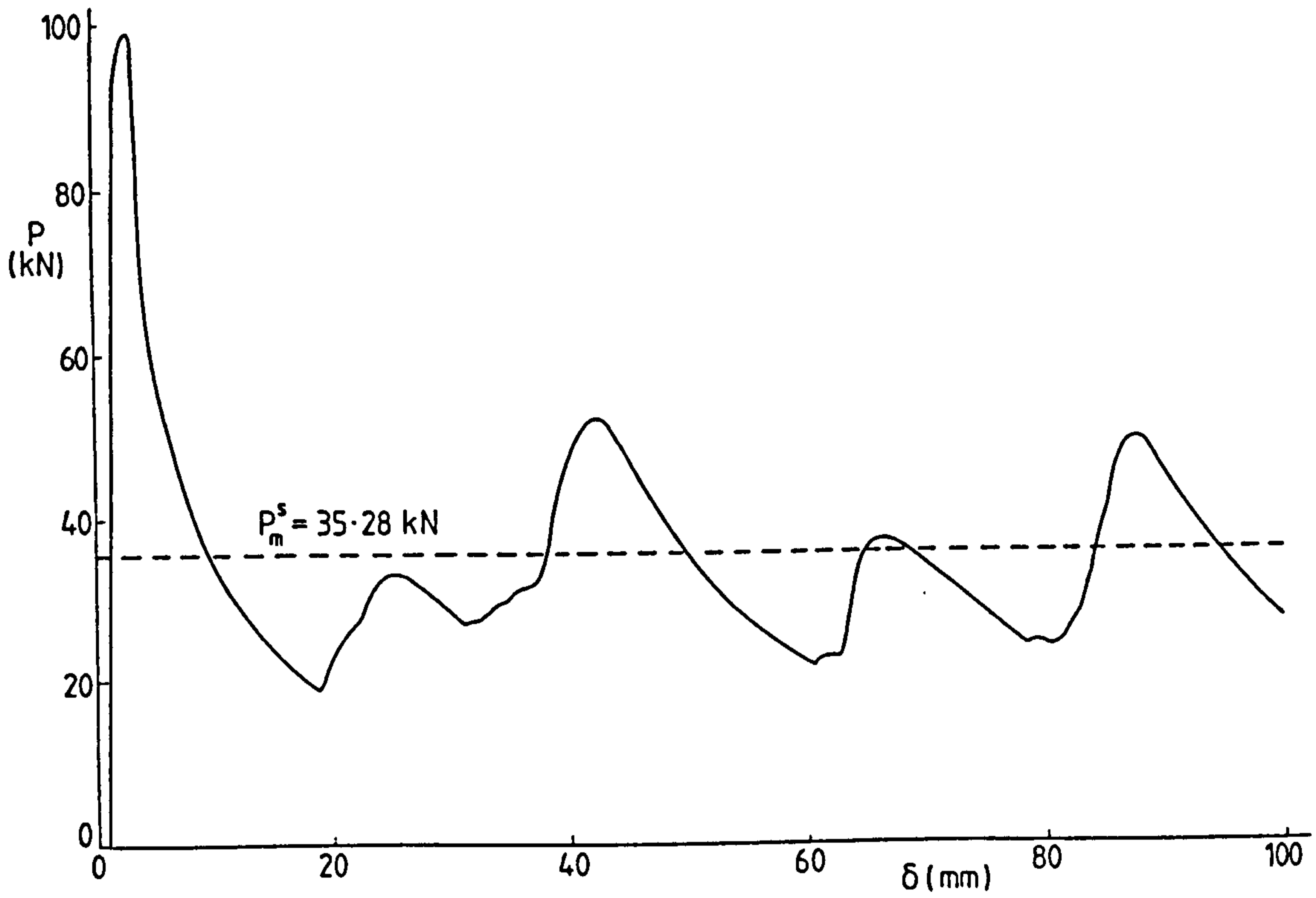


Figure 2.13 : Static axial crushing load versus axial displacement for a square tube of side 49.3mm, wall thickness 1.63mm and tube height 244.1mm [32].

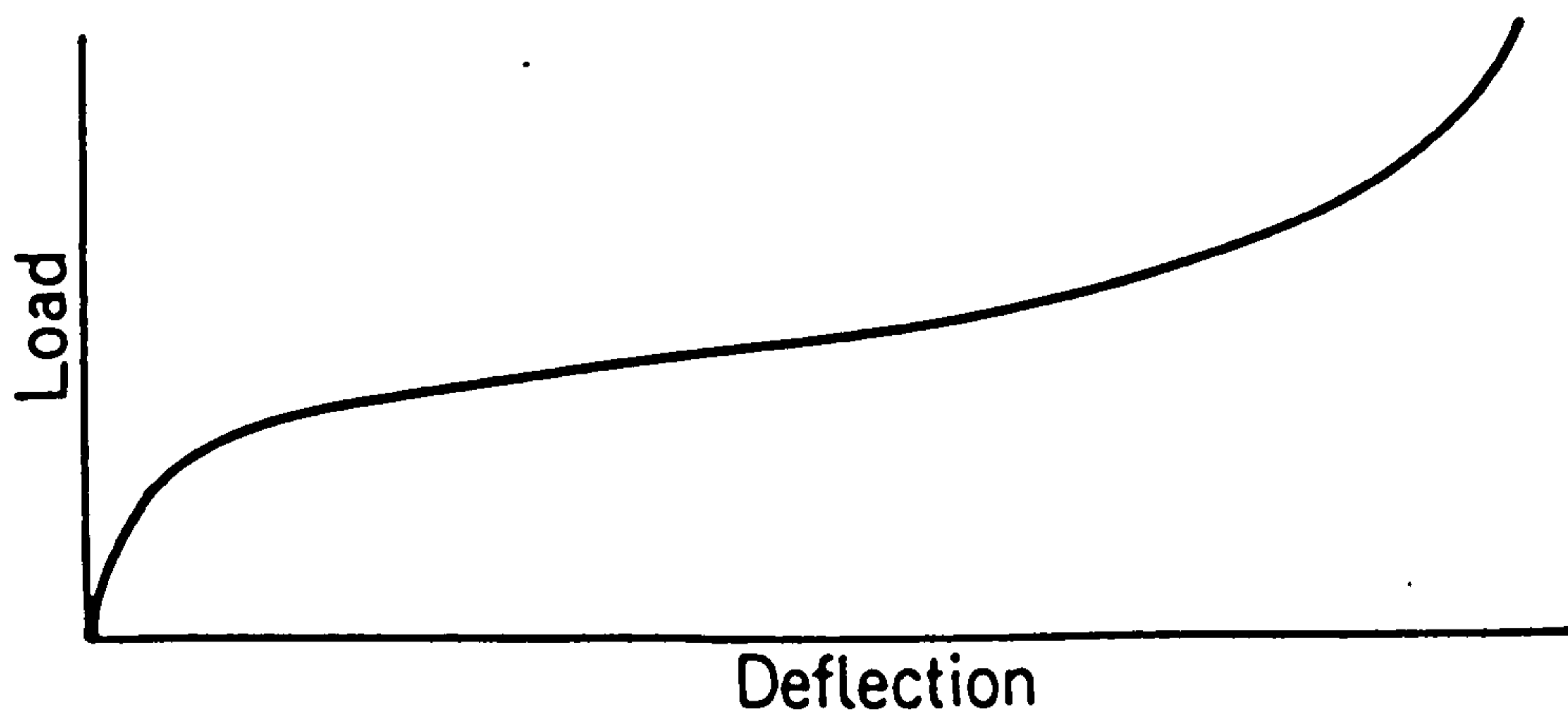


Figure 2.14 : Load-deflection characteristics for a single tube crushed transversely [5].

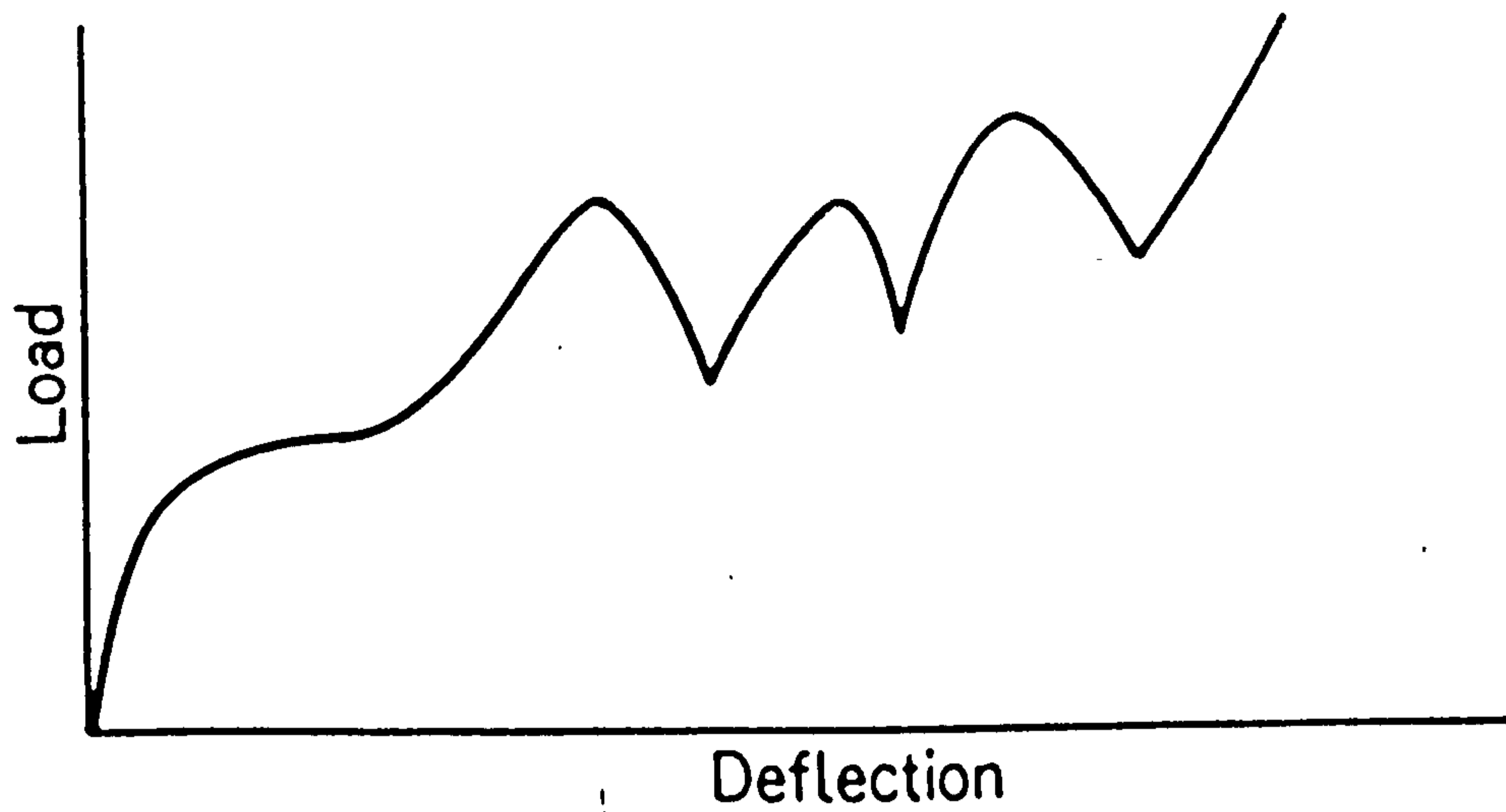


Figure 2.15 : Load-deflection characteristics for three layers of crossed tubes crushed transversely [5].

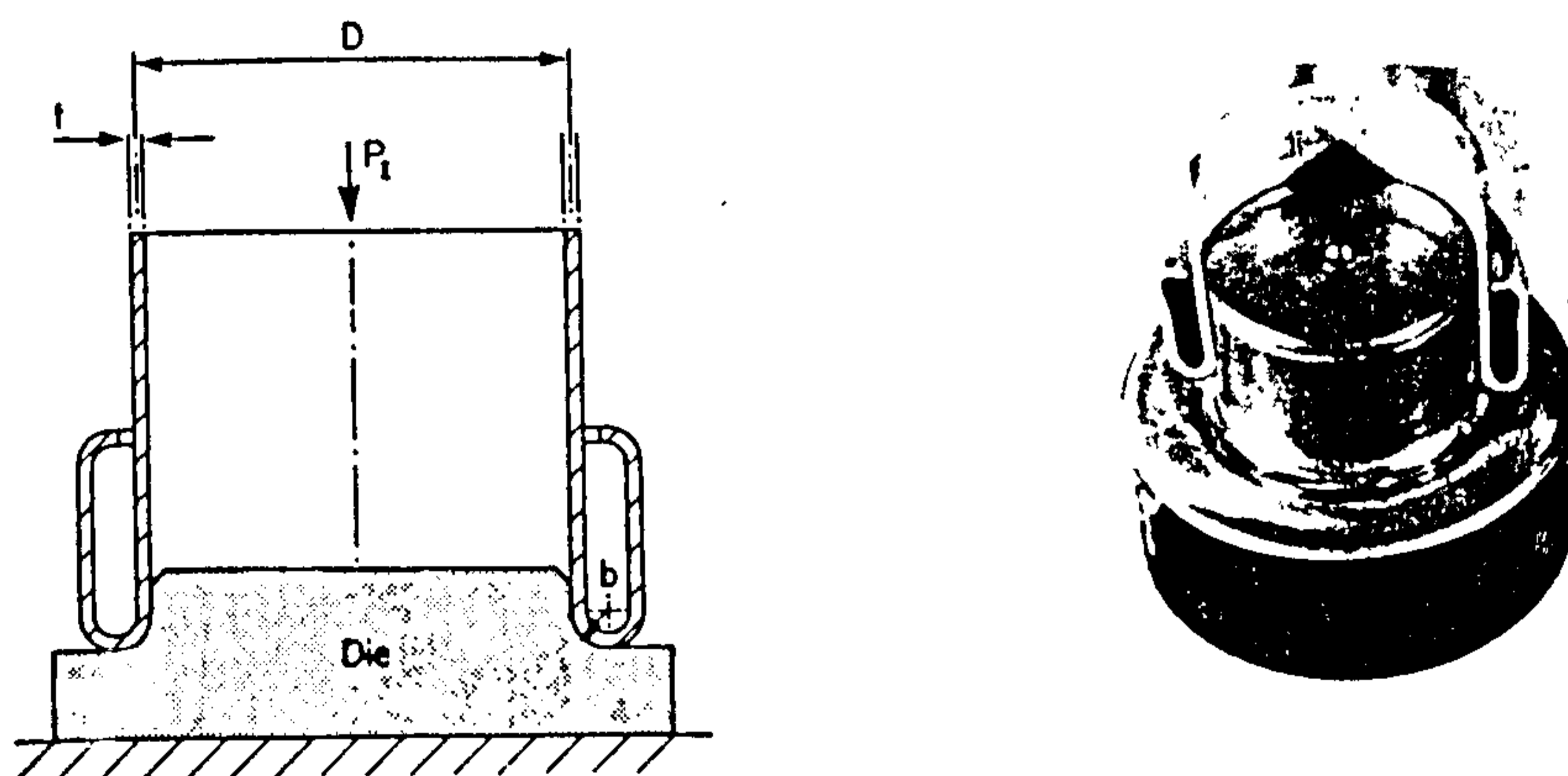


Figure 2.16 : An externally inverted tube [5].

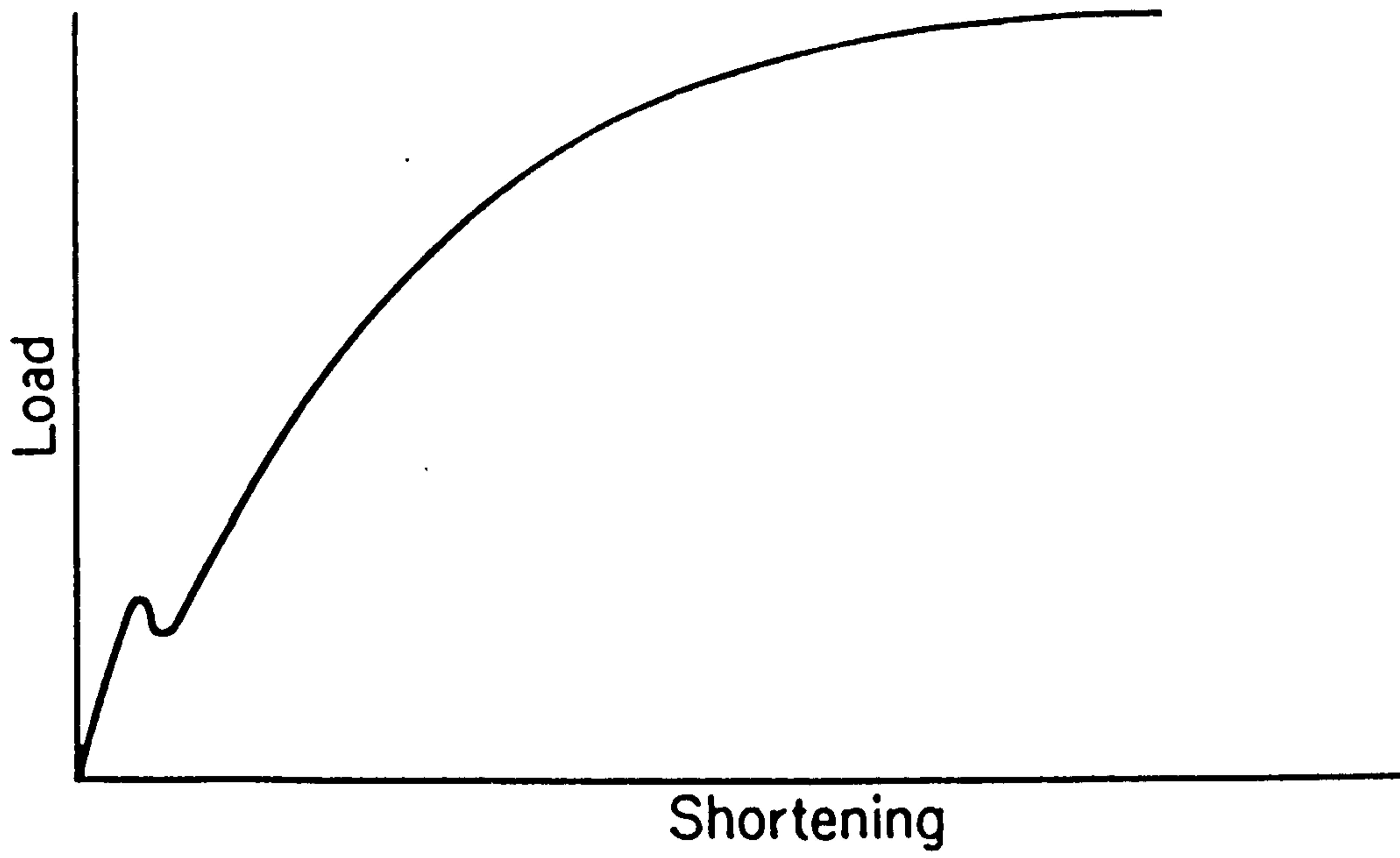


Figure 2.17 : Typical load-deflection characteristics for a tube inverted externally [5].

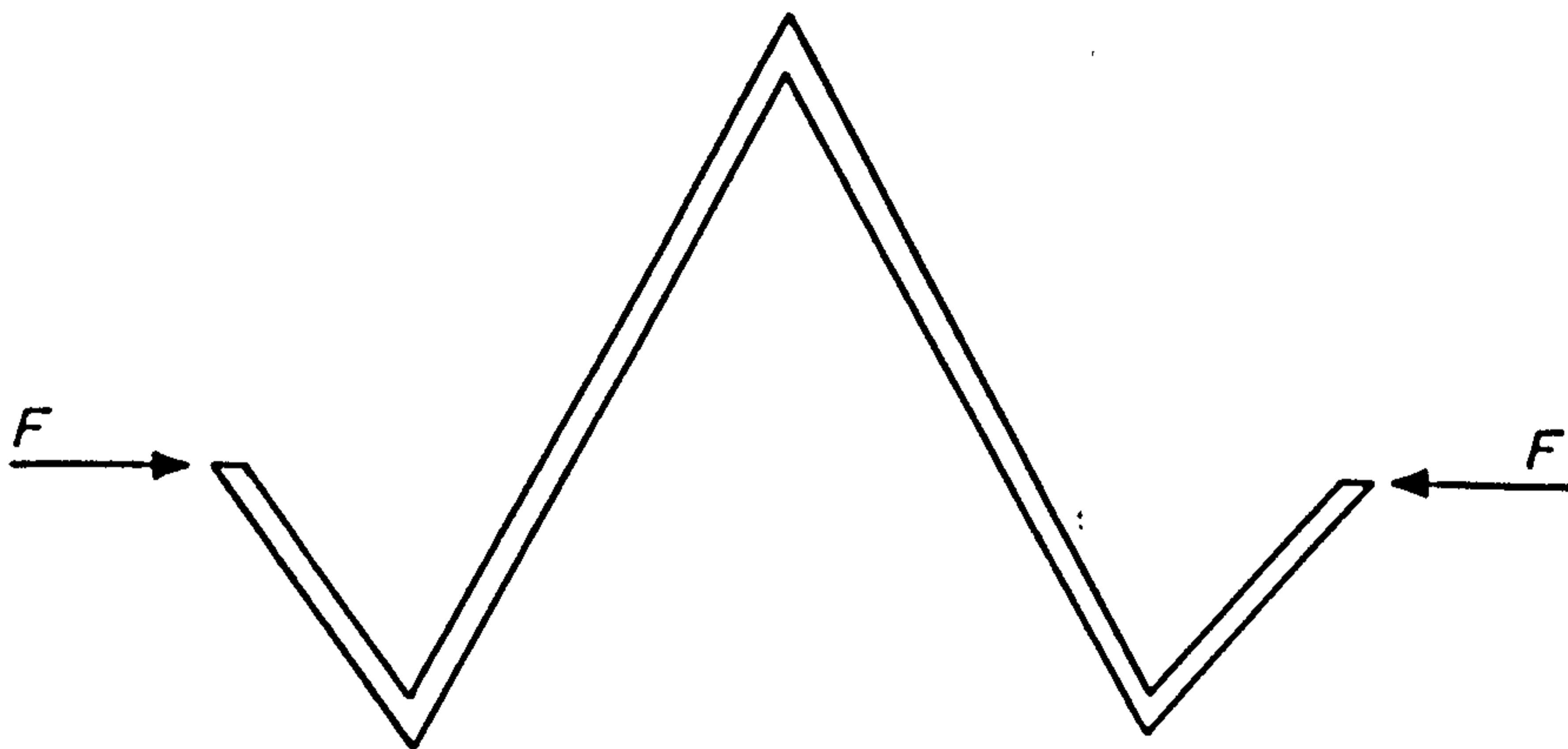


Figure 2.18 : A 'W' frame changing compression into bending [5].

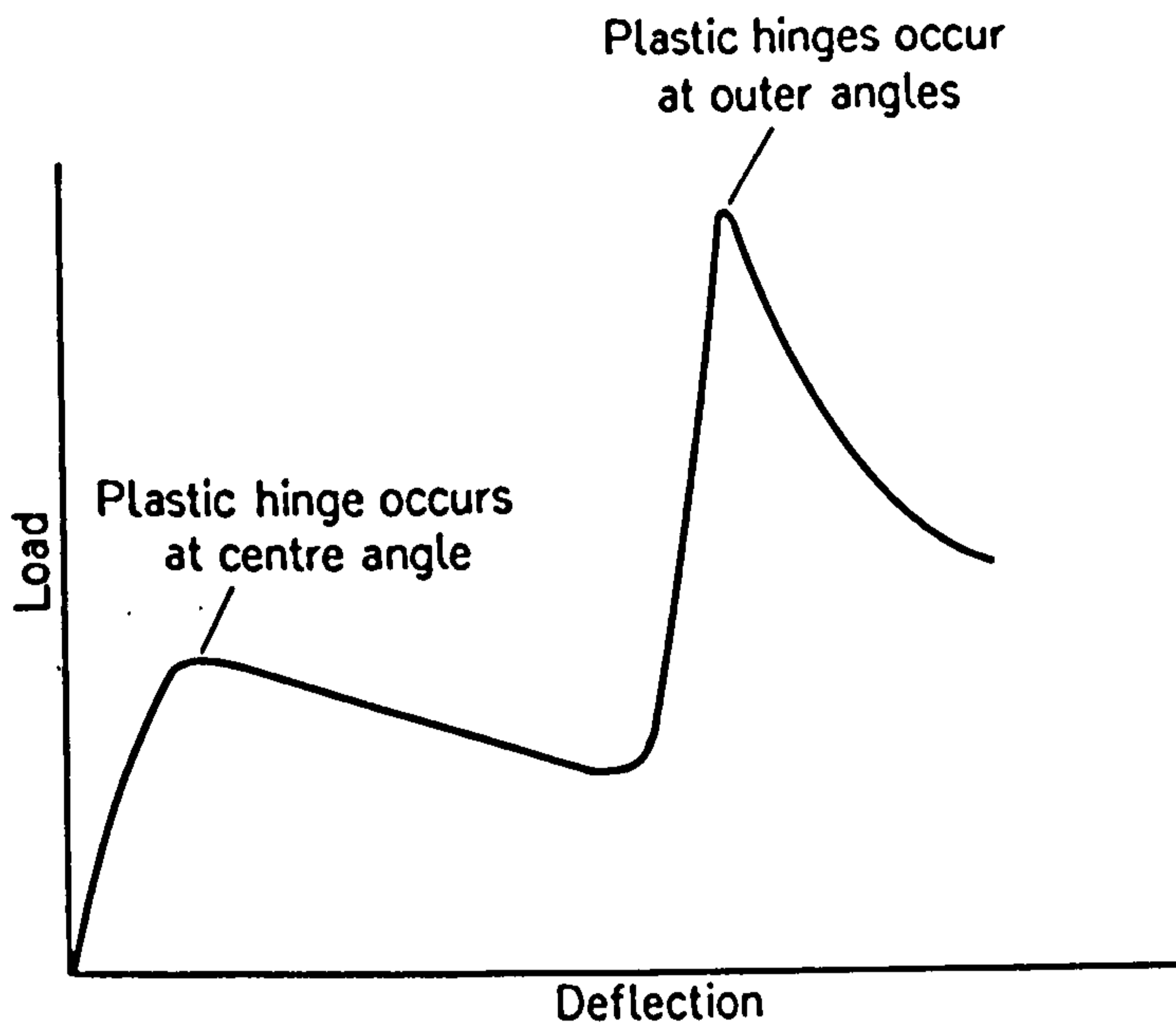


Figure 2.19 : Typical load-deflection characteristics for a 'W' frame [5].

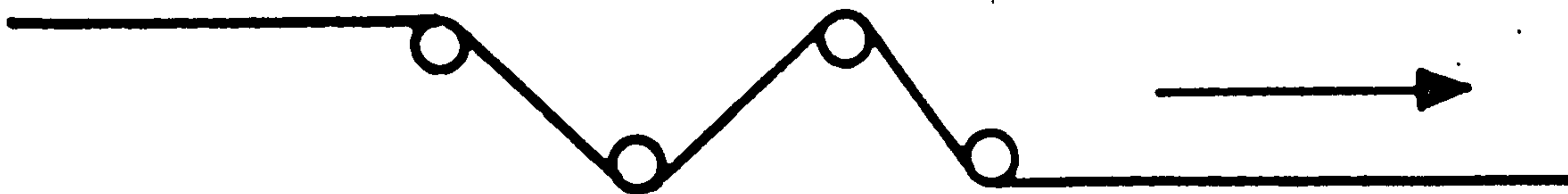


Figure 2.20 : Pulling a wire plastically through four fixed rollers [5].

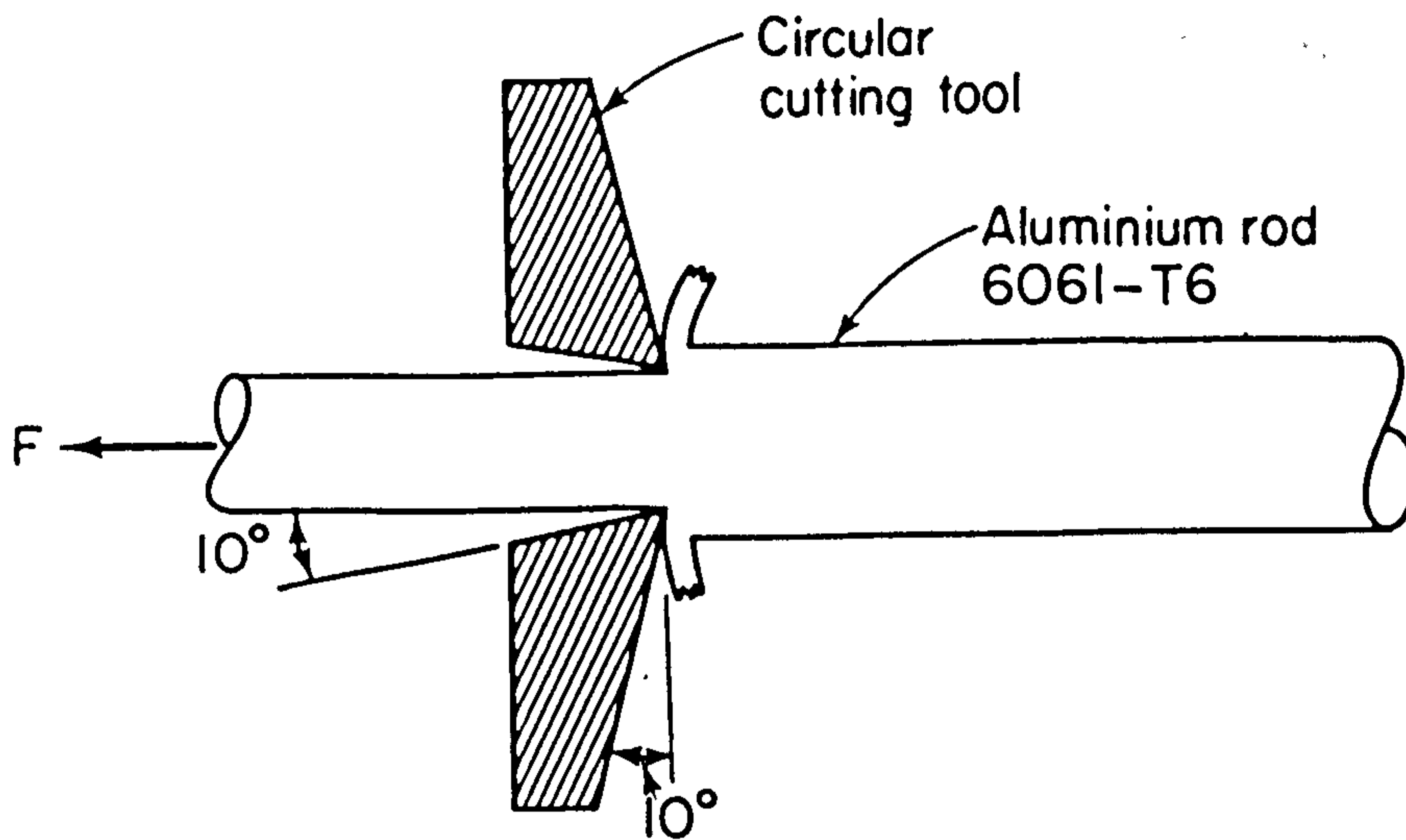


Figure 2.21 : Schematic diagram of a metal skinning device [2].

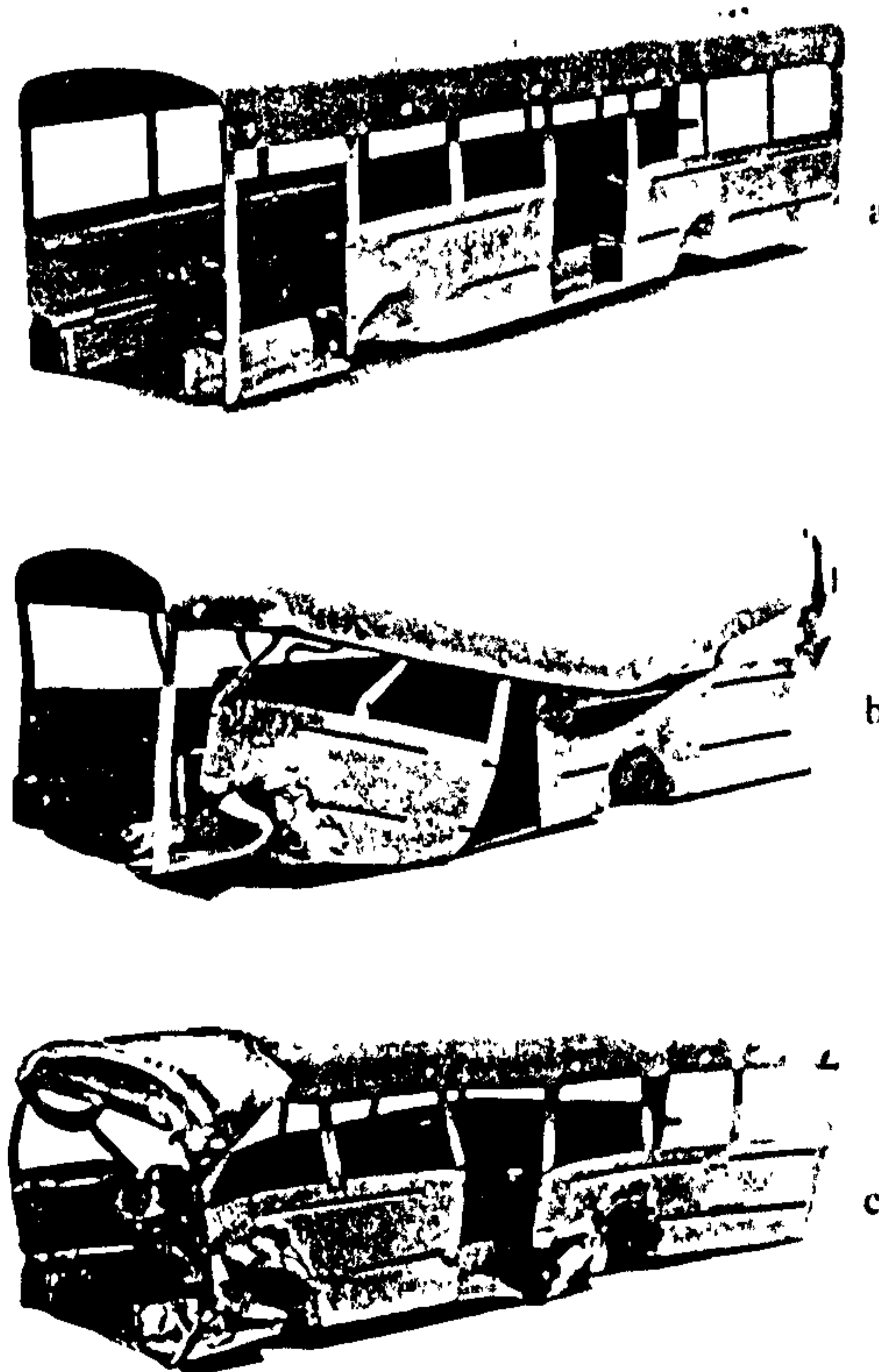


Figure 2.22 : Motor coach models. (a) was the original model, (b) was crushed quasi-statically and (c) was impacted dynamically. [30].

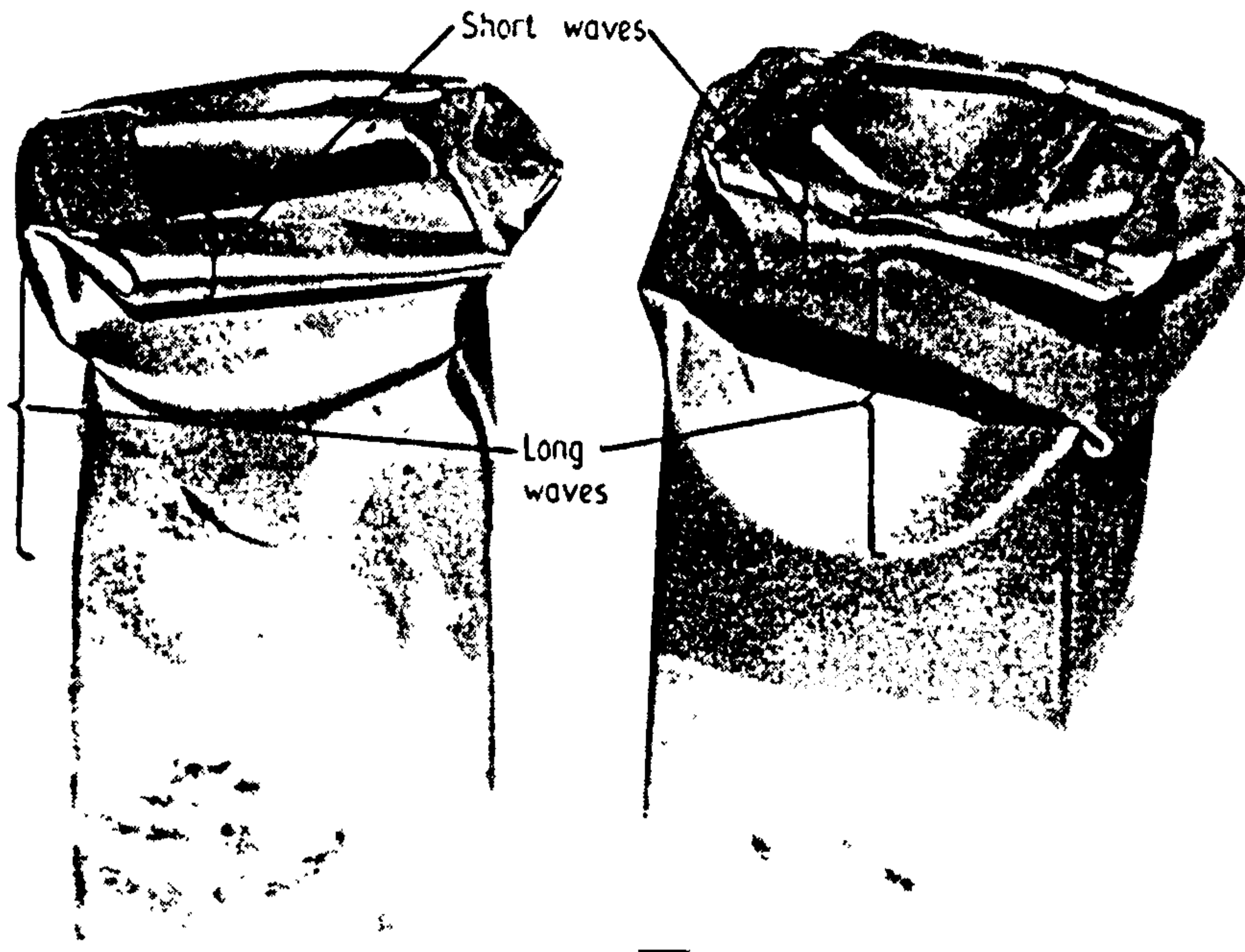


Figure 2.23 : The square tube on the left suffered dynamic crushing, and the one on the right was crushed quasi-statically [41].

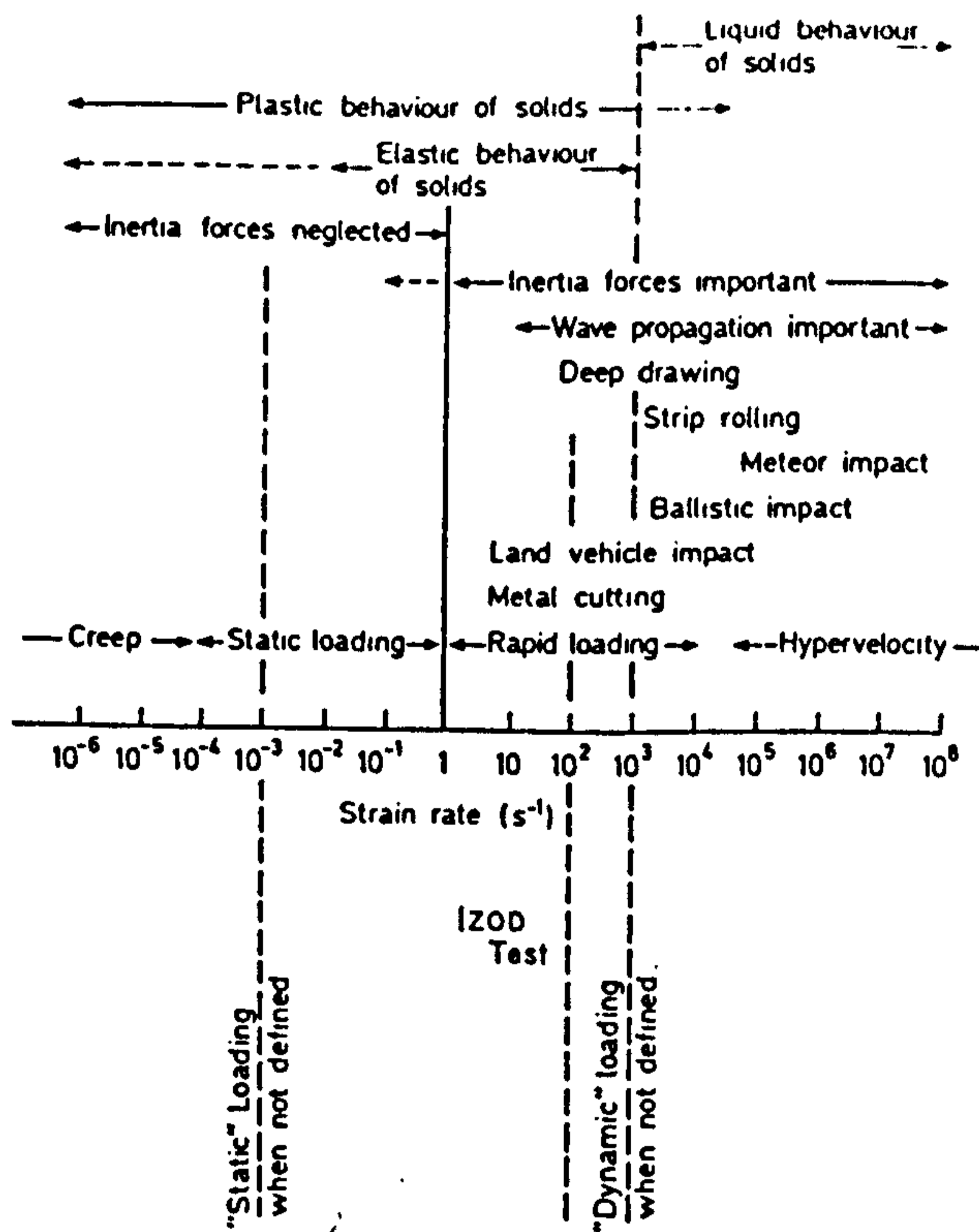


Figure 2.24 : Range of strain rates that are of practical interest [5].

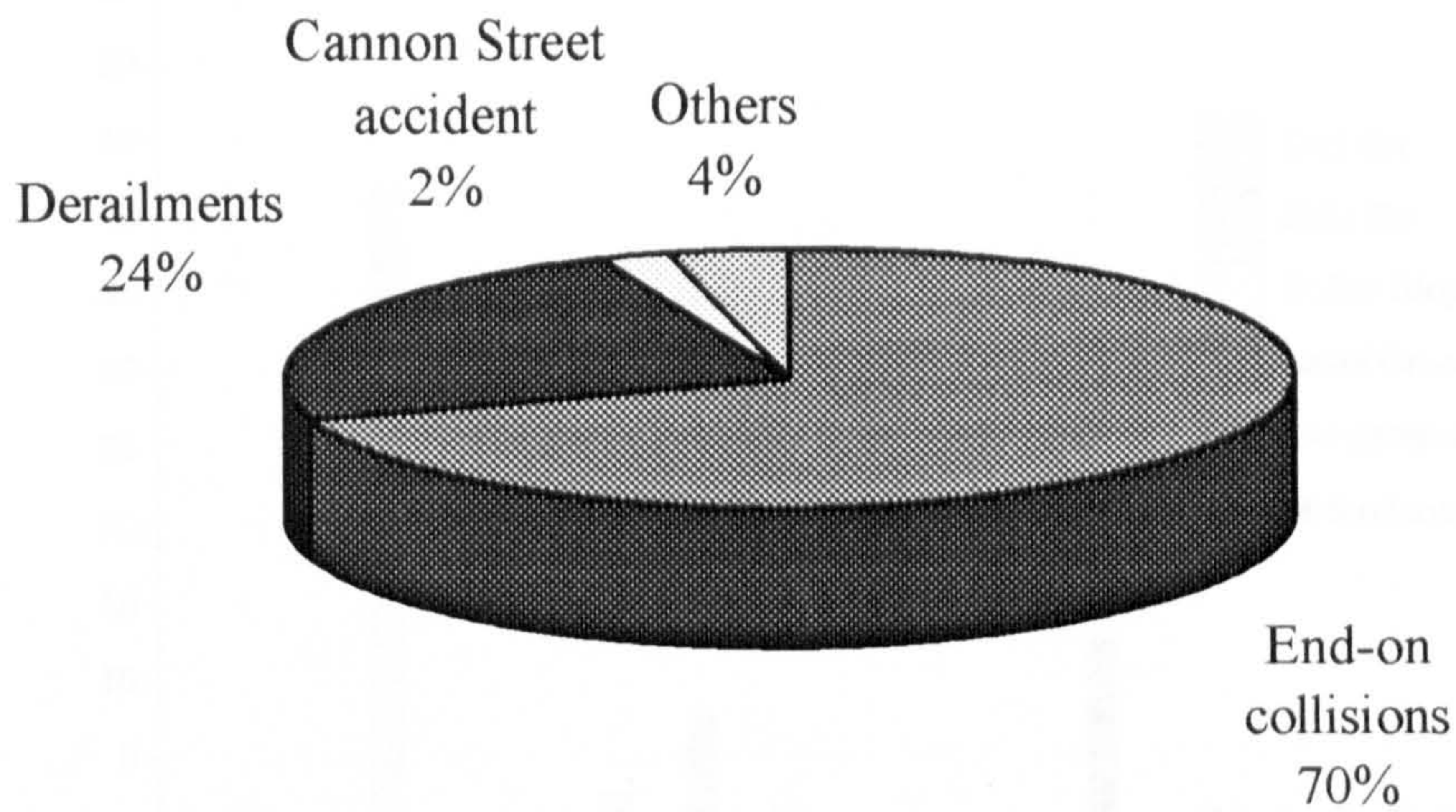


Figure 2.25a : The distribution of past BR accident fatalities according to the type of collisions [47].

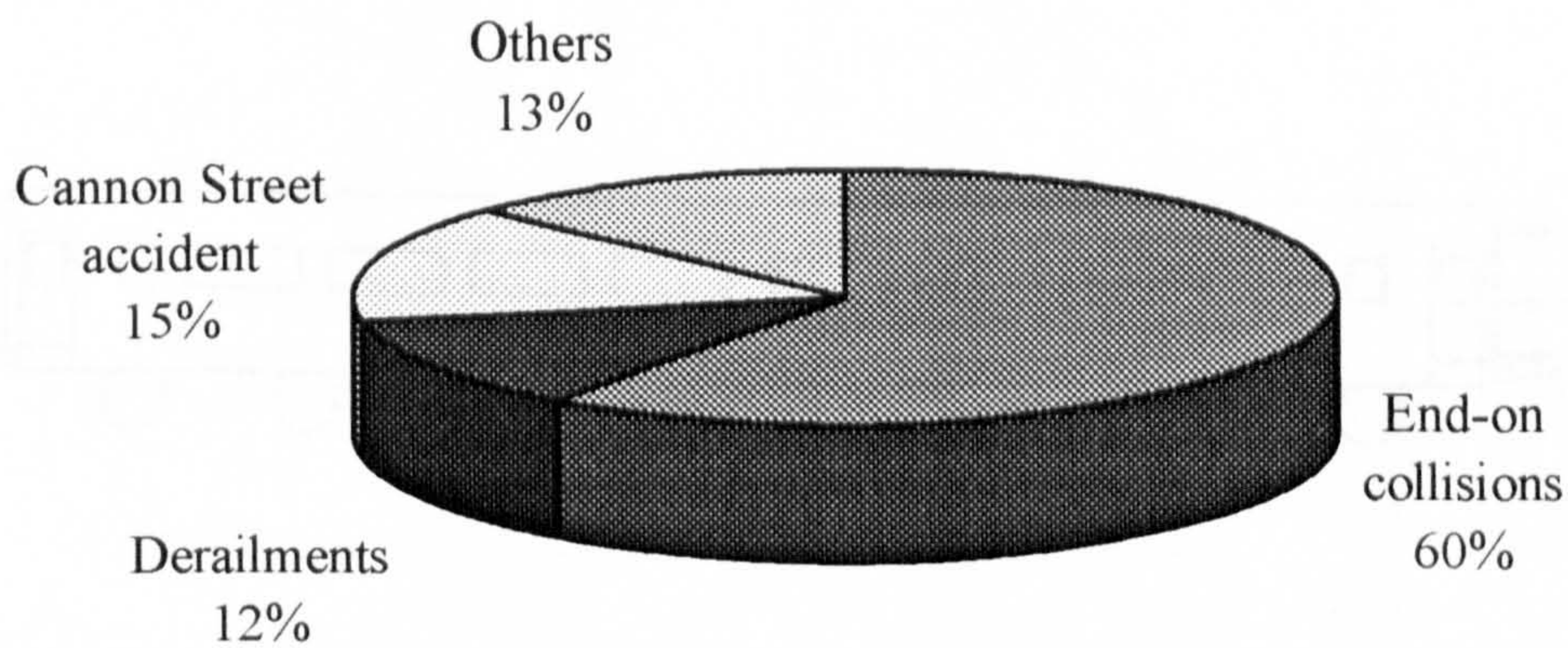


Figure 2.25b : The distribution of past BR accident serious injuries according to the type of collisions [47].

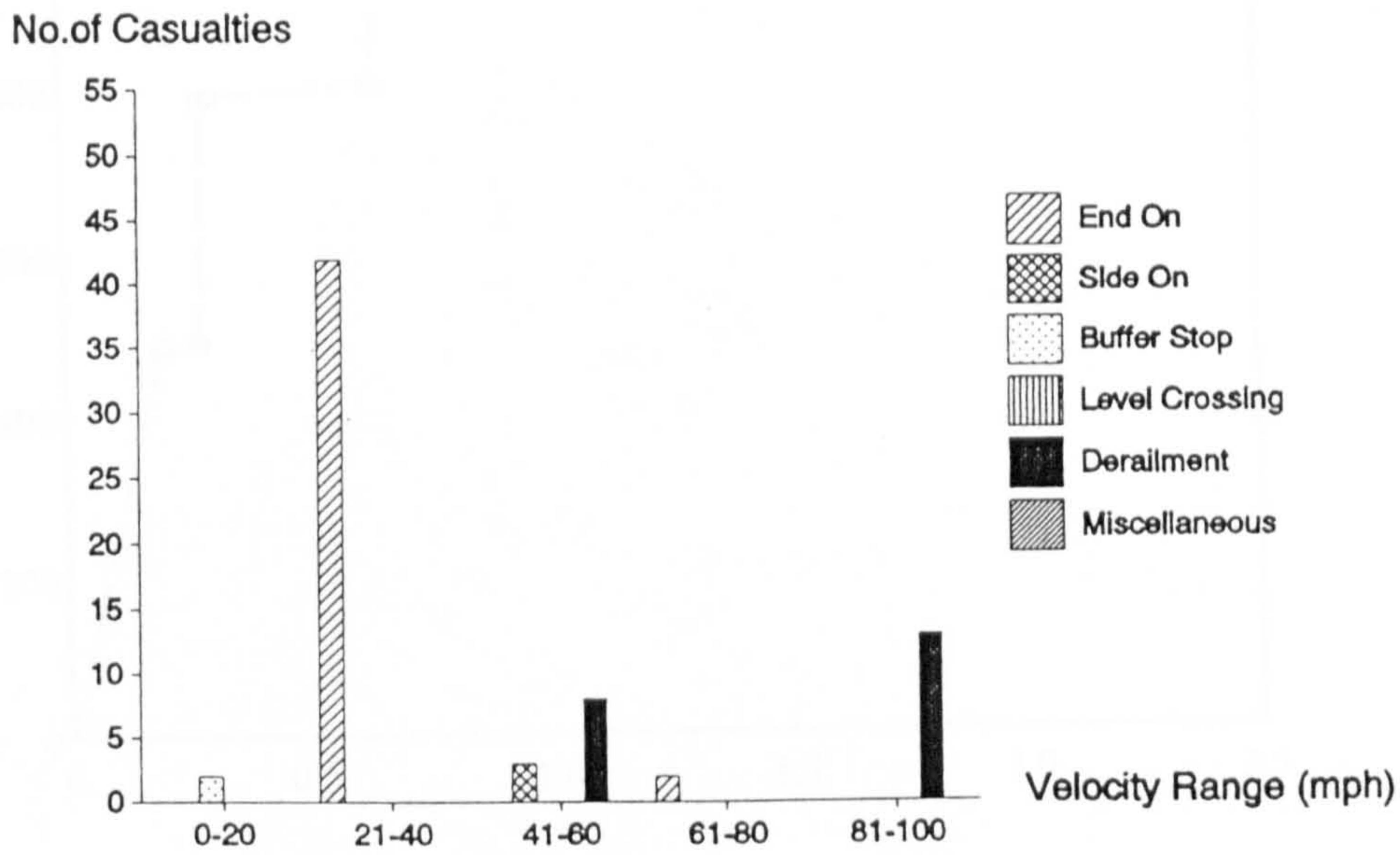


Figure 2.26 : Distribution of passenger fatalities according to velocity and accident type. This chart suggests that derailment is a high speed phenomena [47].

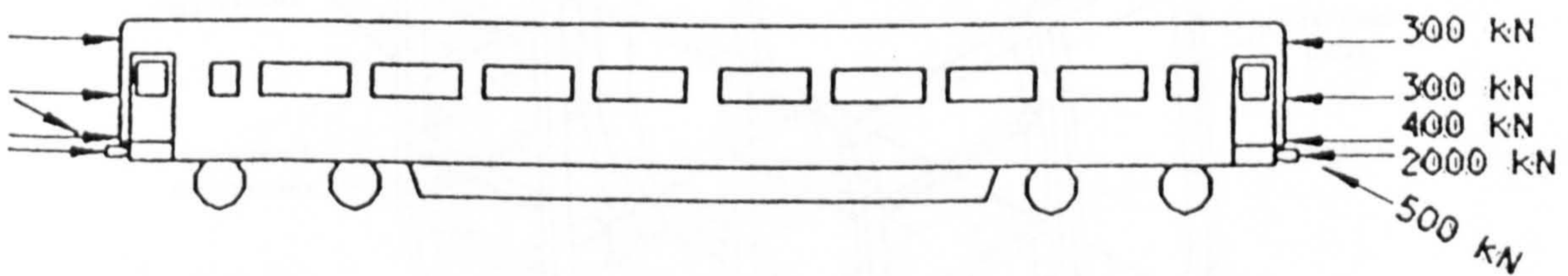


Figure 2.27 : UIC longitudinal loading specification [48].

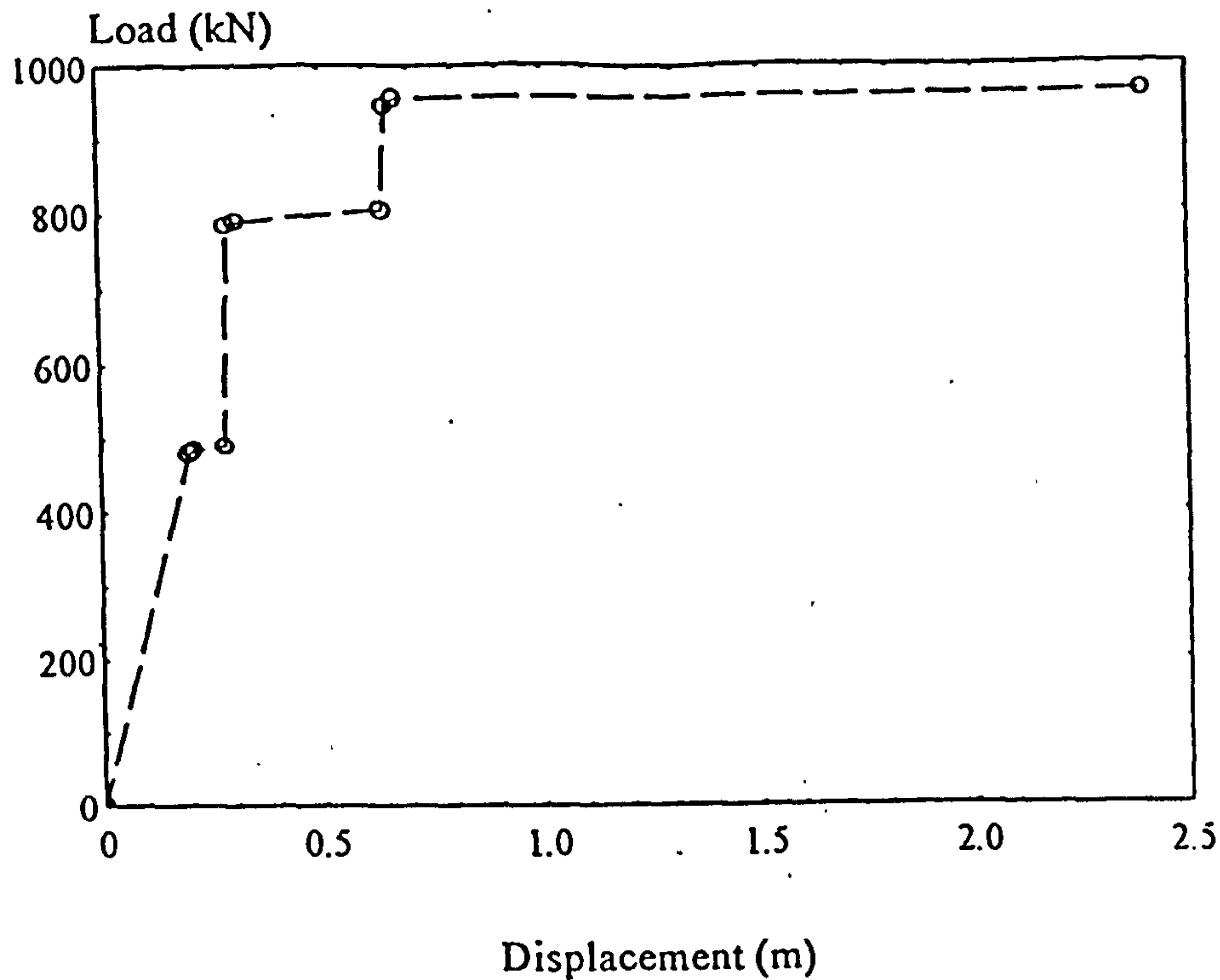


Figure 2.28a : The load-deflection characteristics of the crashworthy coach end-structure as mentioned in reference [50].

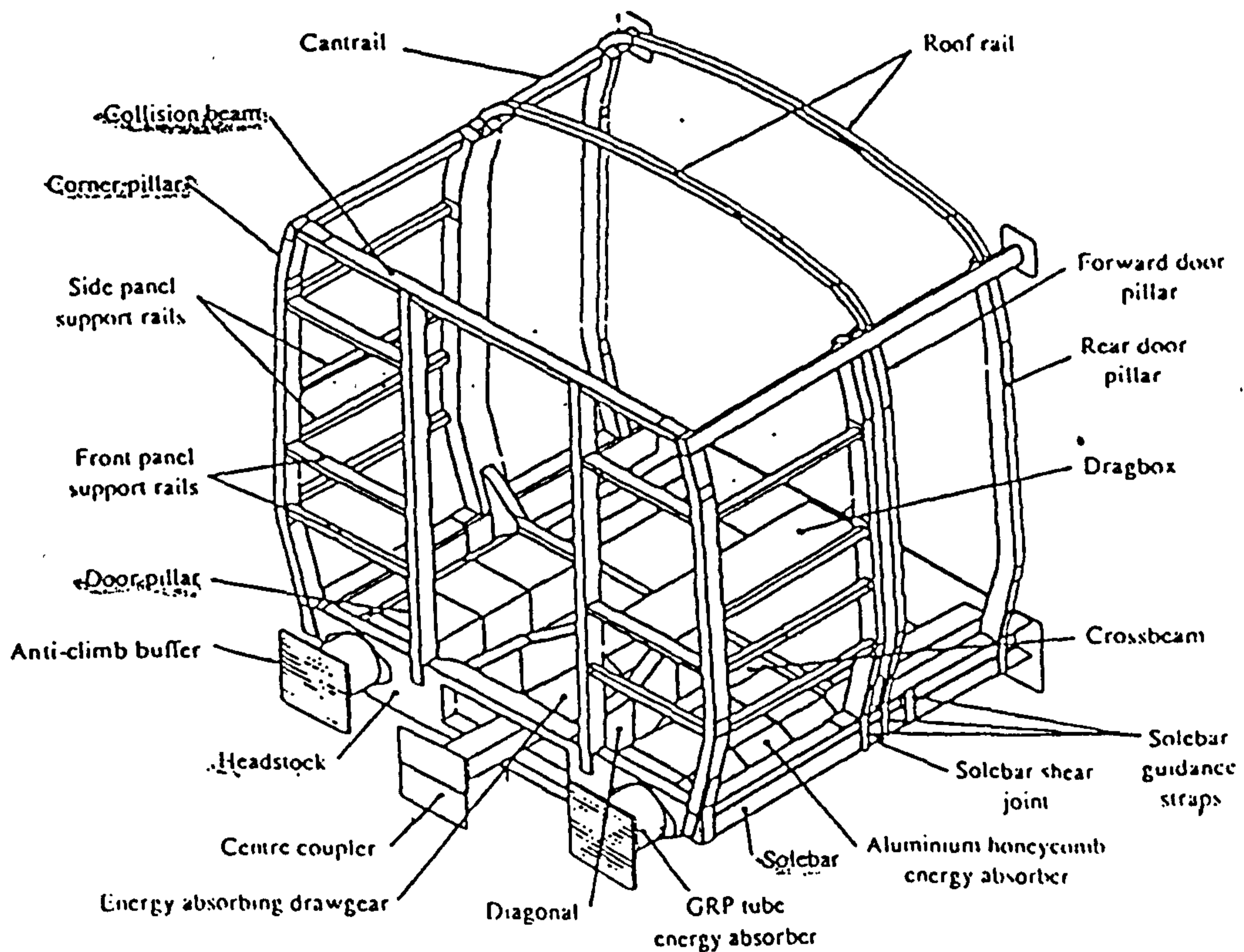


Figure 2.28b : The prototype of the crashworthy coach end-structure as mentioned in reference [50].

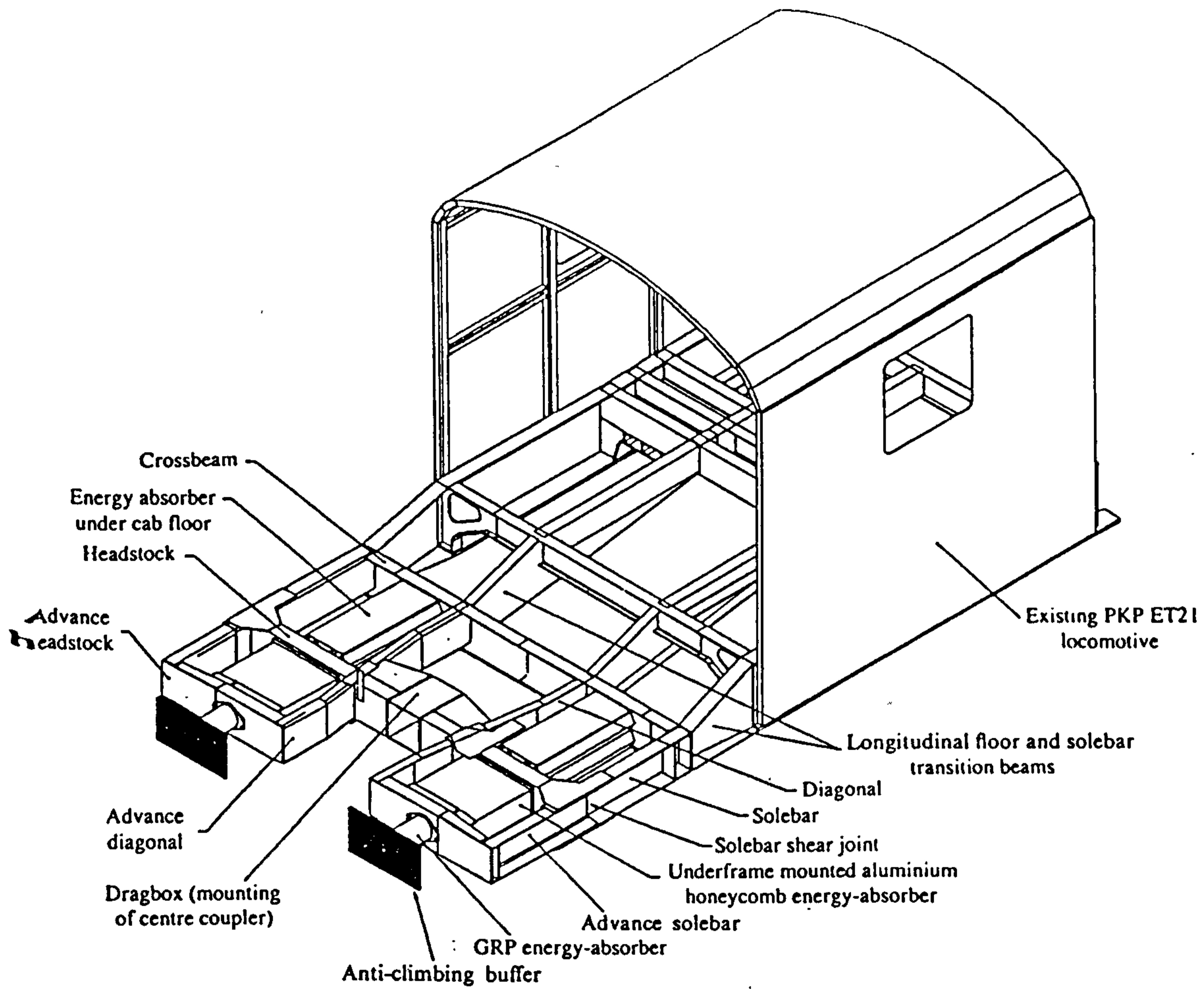


Figure 2.29a : The prototype of the crashworthy coach end-structure used in ORE collision test [50].

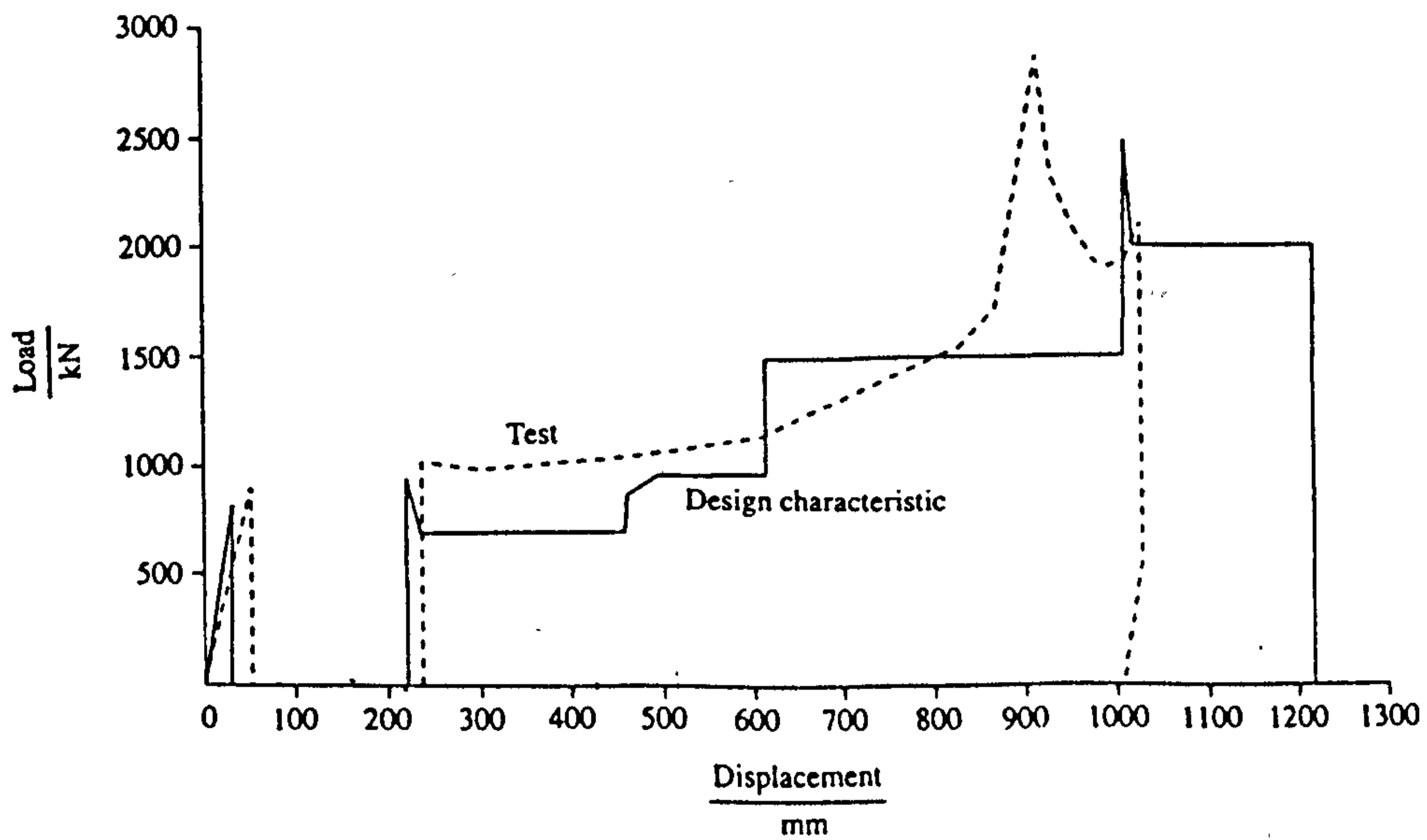


Figure 2.29b : The corresponding load-deflection characteristics of the crashworthy coach end-structure used in ORE collision test [50].

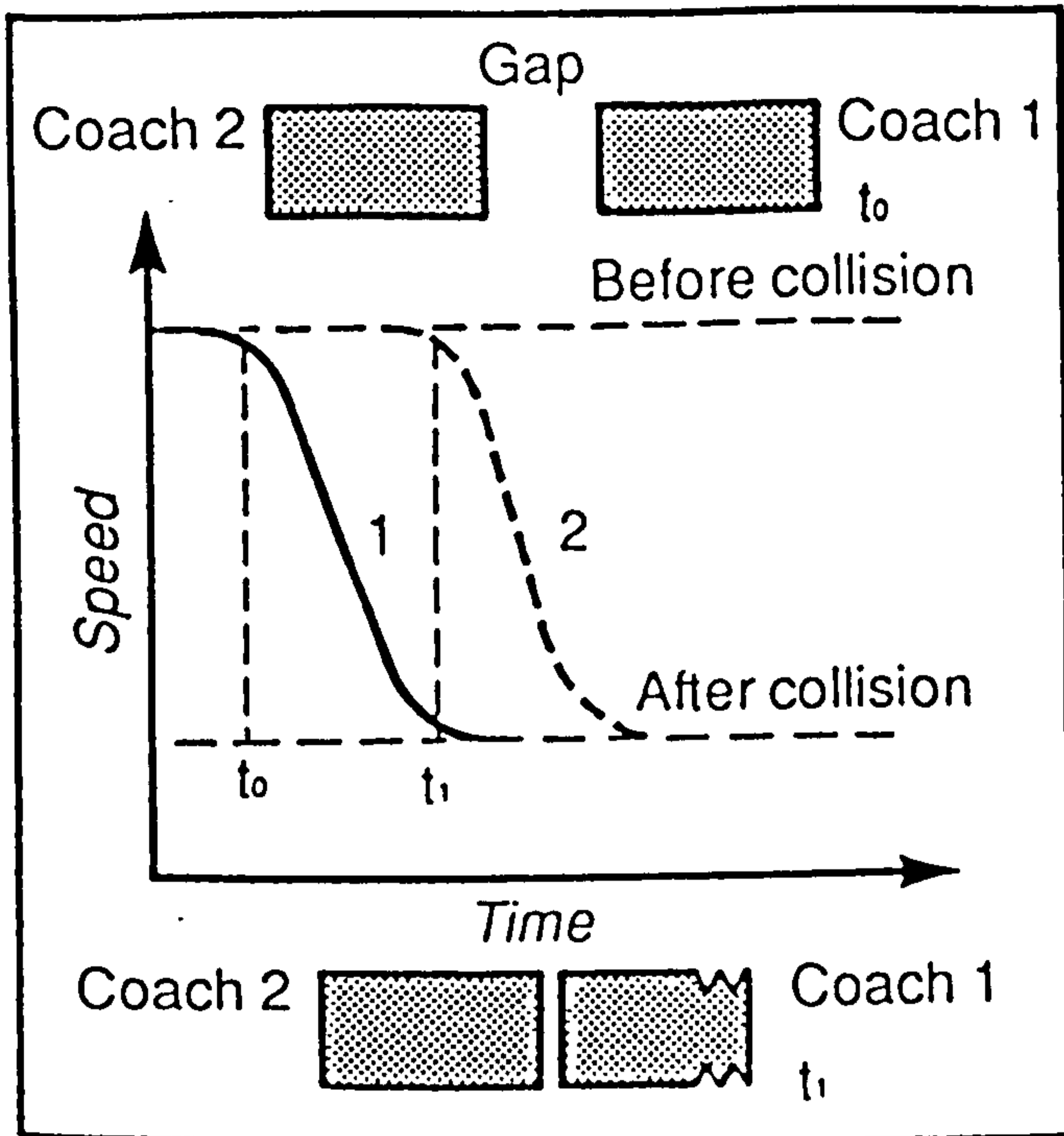


Figure 2.30 : Velocity-time graph showing the concept of energy absorption through sequential collisions along the train [52].

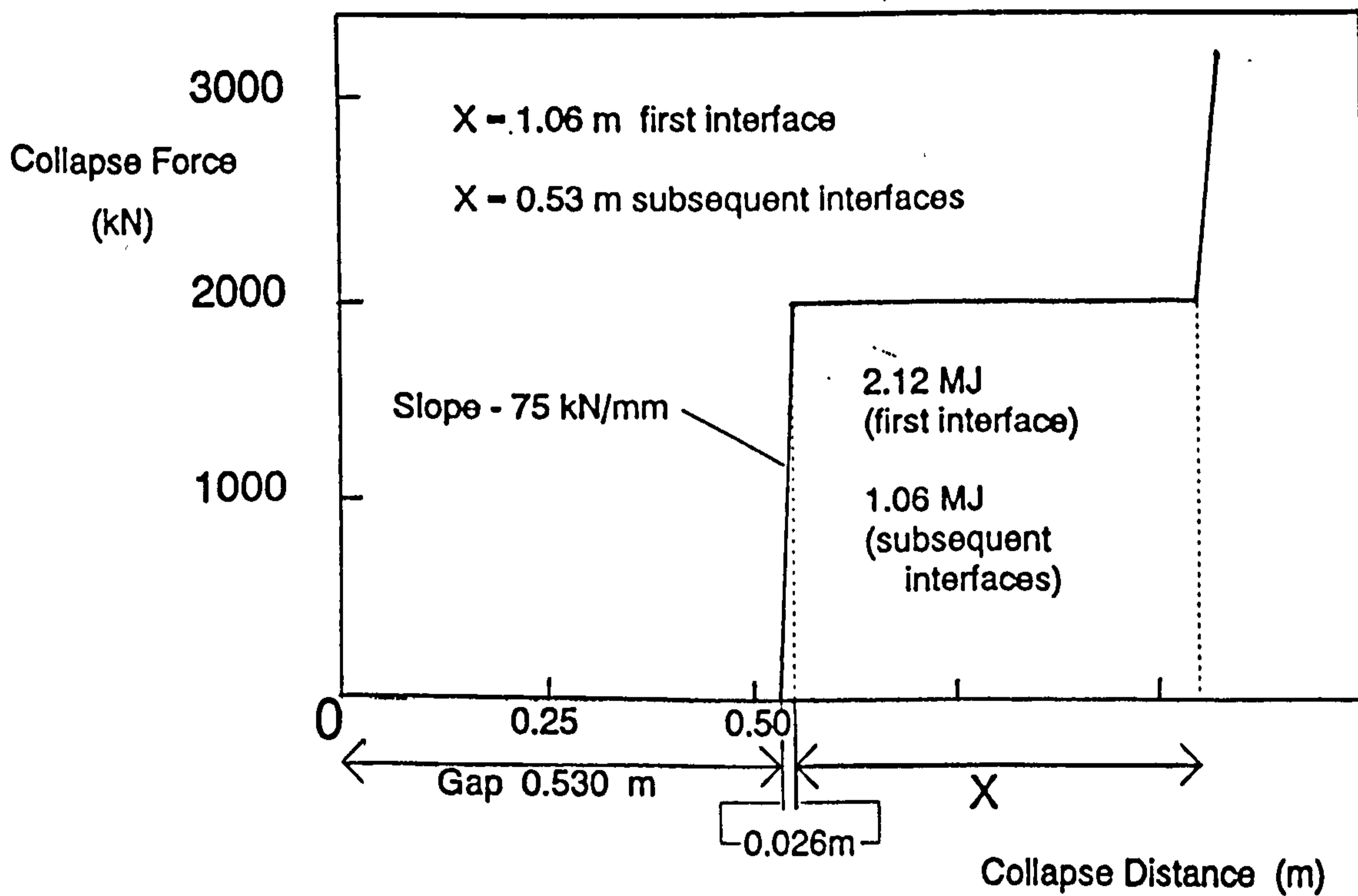


Figure 2.31 : Assumed load-deflection interface characteristic for idealized collisions used in Reference [58].

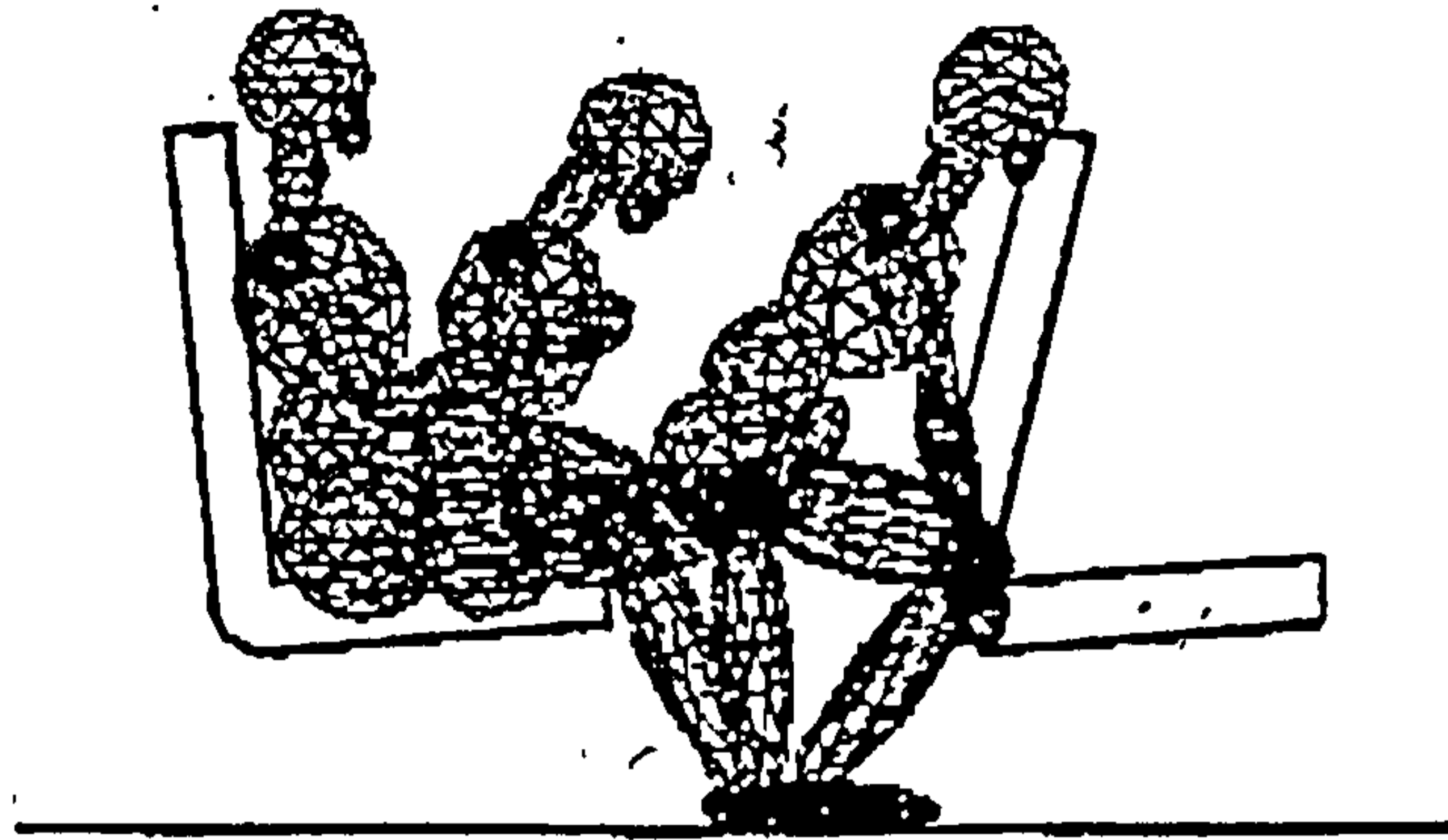


Figure 2.32 : Unrestrained occupant experiencing a secondary collision [60].

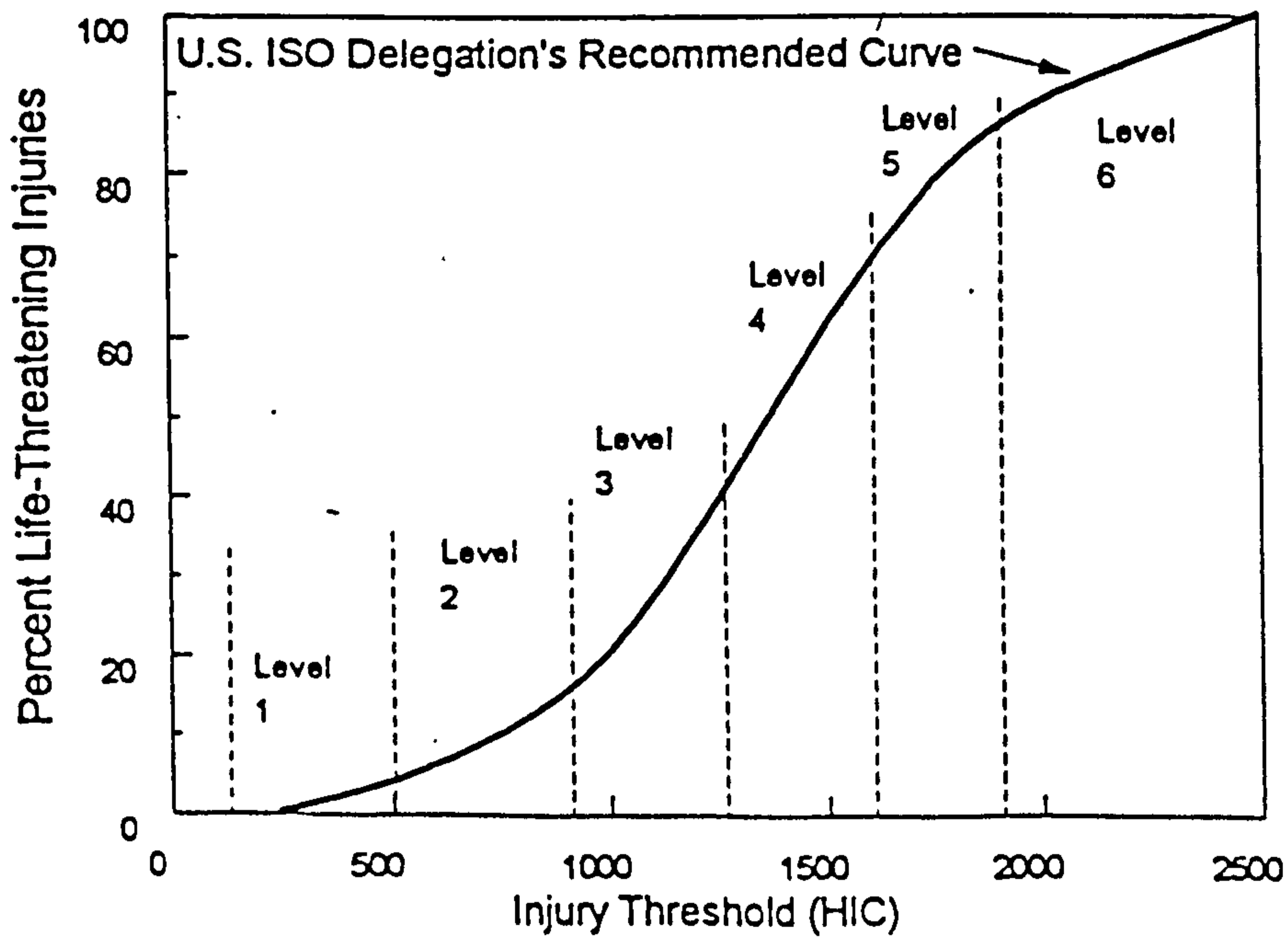


Figure 2.33 : Probability of fatalities as a function of *HIC* [60].

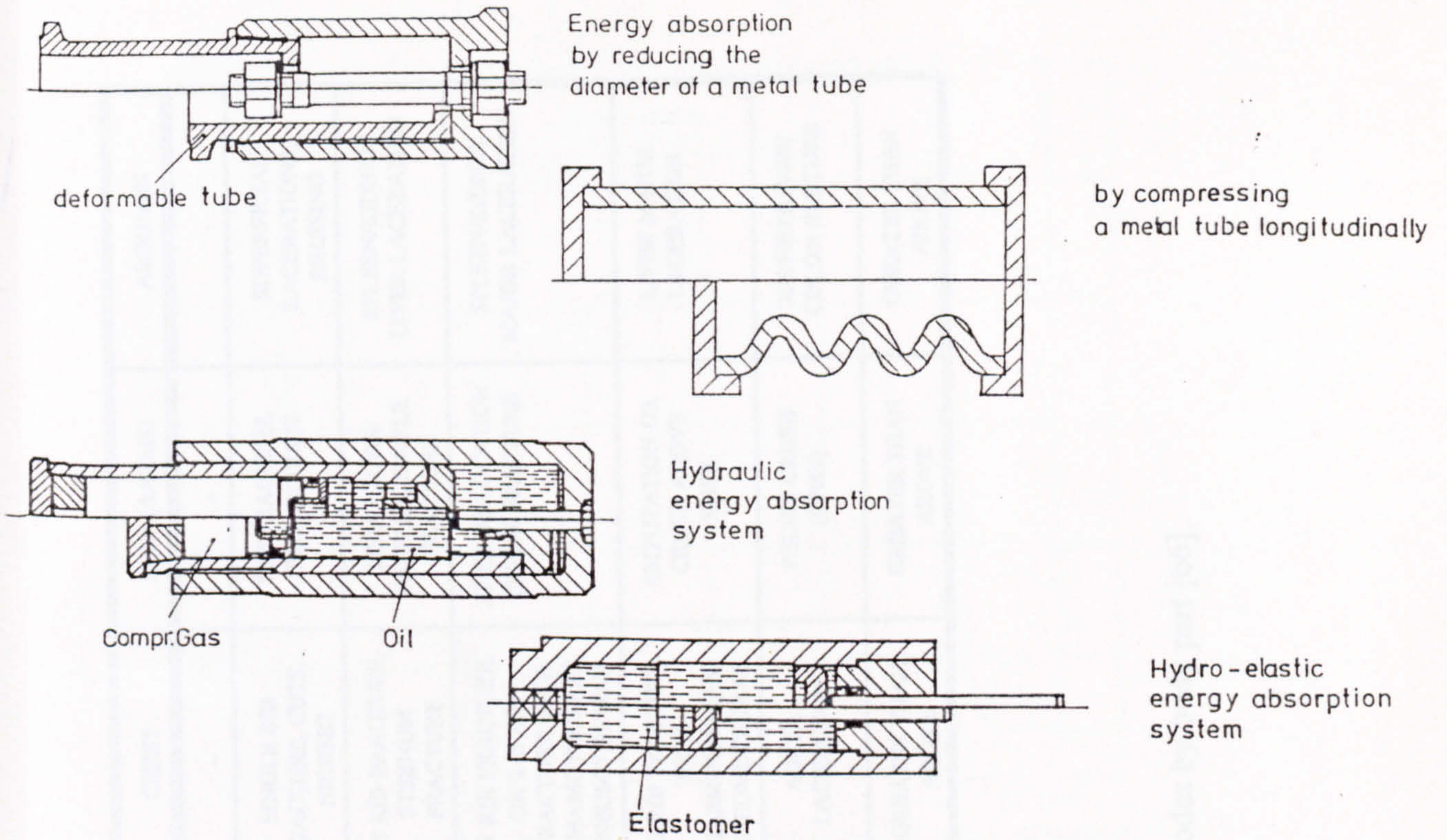


Figure 2.34 : Various type of energy absorbing couplers [61].



Figure 2.35 : A rake of coaches fitted with crashworthy end-structures in pre-test condition [49].

AIS SCORE	GENERAL DESCRIPTION	HEAD	NECK/SPINE	CHEST	LEGS (& ARMS)	ABDOMEN
0	NO INJURY	-	-	-	-	-
1	MINOR INJURY	HEADACHE, CUTS, BRUISES, BROKEN TEETH/NOSE	ACUTE STRAIN, CUTS, BRUISES	SINGLE RIB FRACTURE, CUTS, BRUISES	TOE FRACTURE, CUTS, BRUISES	SUPERFICIAL LACERATIONS, BRUISING
2	MODERATE INJURY	UNCONSCIOUS LESS THAN 1 HOUR, LINEAR FRACTURE	MINOR FRACTURE, NO CORD INVOLVEMENT	2-3 RIB FRACTURE, STERNUM FRACTURE	TIBIA/PELVIS/PATELLA, SIMPLE FRACTURE	SPLEEN/KIDNEY/LIVER LACERATION
3	SERIOUS INJURY	UNCONSCIOUS 1-6 HOURS, DEPRESSED FRACTURE	RUPTURED DISC, NERVE ROOT DAMAGE	>3 RIB FRACTURE OR 2-3 RIB FRACTURE WITH HAEMOTHORAX/PNEUMOTHORAX	KNEE DISLOCATION FEMUR FRACTURE	SPLEEN/KIDNEY MAJOR LACERATION
4	SEVERE INJURY, WITH SIGNIFICANT THREAT TO LIFE	UNCONSCIOUS 6-24 HOURS, OPEN FRACTURE	INCOMPLETE CORD SYNDROME	>3 RIB FRACTURE WITH HAEMOTHORAX/PNEUMOTHORAX	AMPUTATION OR CRUSH ABOVE KNEE	LIVER MAJOR LACERATION
5	CRITICAL INJURY, WITH MAJOR THREAT TO LIFE	UNCONSCIOUS >24 HOURS, LARGE HEMATOMA	QUADRIPLEGIA	AORTA LACERATION	PELVIS CRUSH (OPEN)	KIDNEY/LIVER/ COLON RUPTURE
6	MAXIMUM, CURRENTLY UNTREATABLE	GREATER THAN ABOVE	GREATER THAN ABOVE	GREATER THAN ABOVE	GREATER THAN ABOVE	GREATER THAN ABOVE

Figure 2.36 : Description and examples of AIS codes by body part [66].

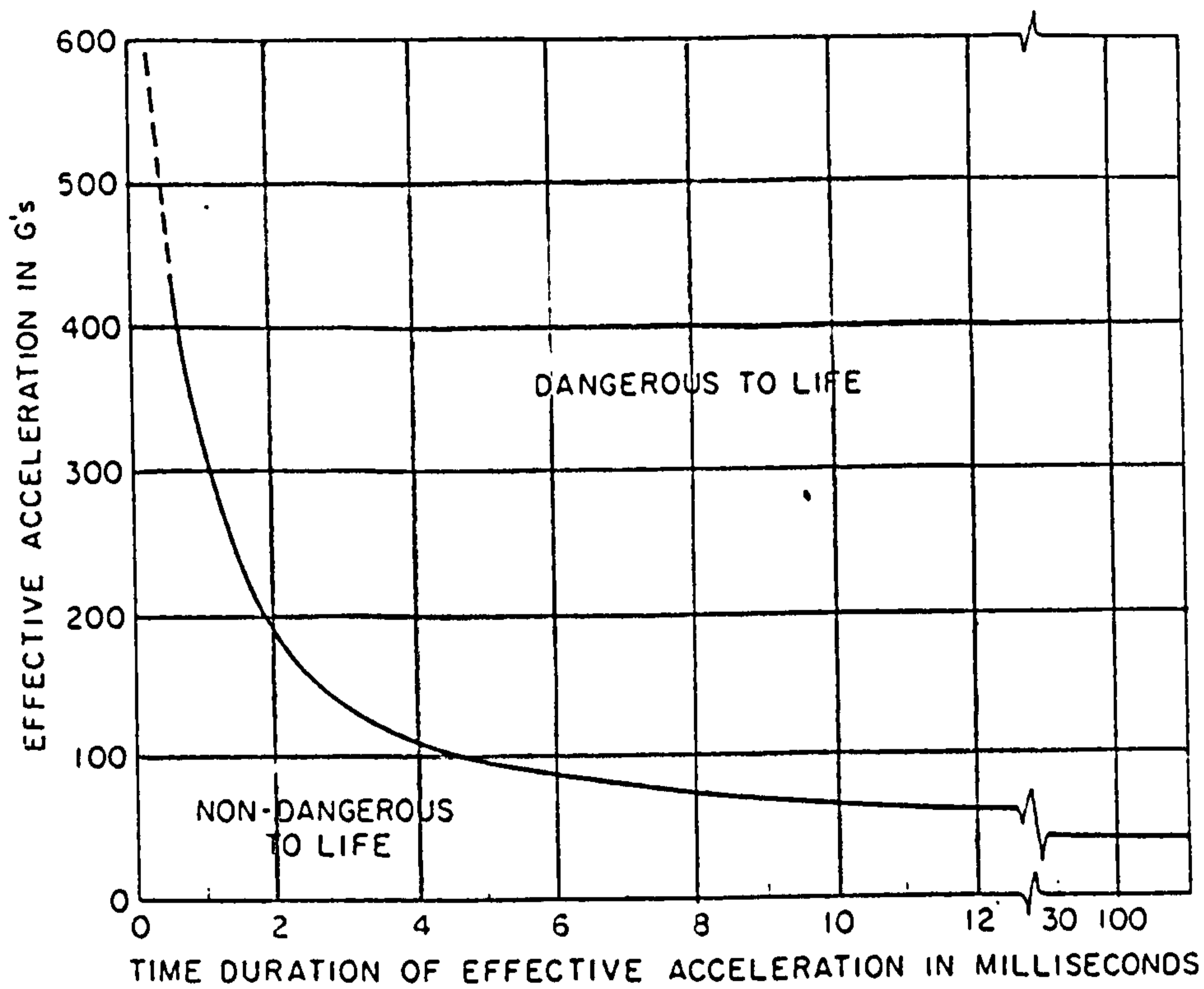


Figure 2.37 : Impact tolerance for human brain in forehead impacts against plane, unyielding surfaces [68].

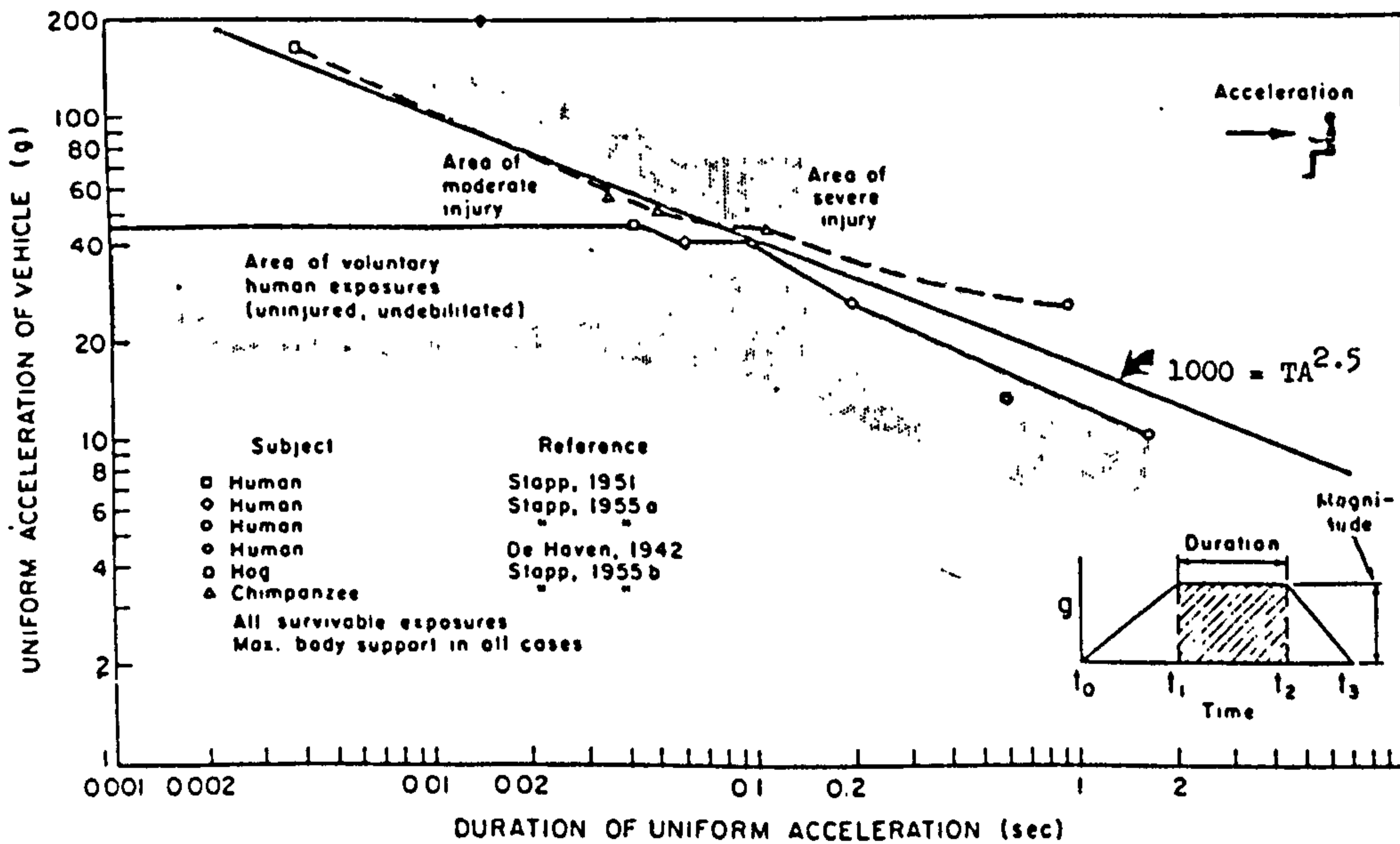


Figure 2.38 : Frontal deceleration versus duration threshold from experimental data. [68].

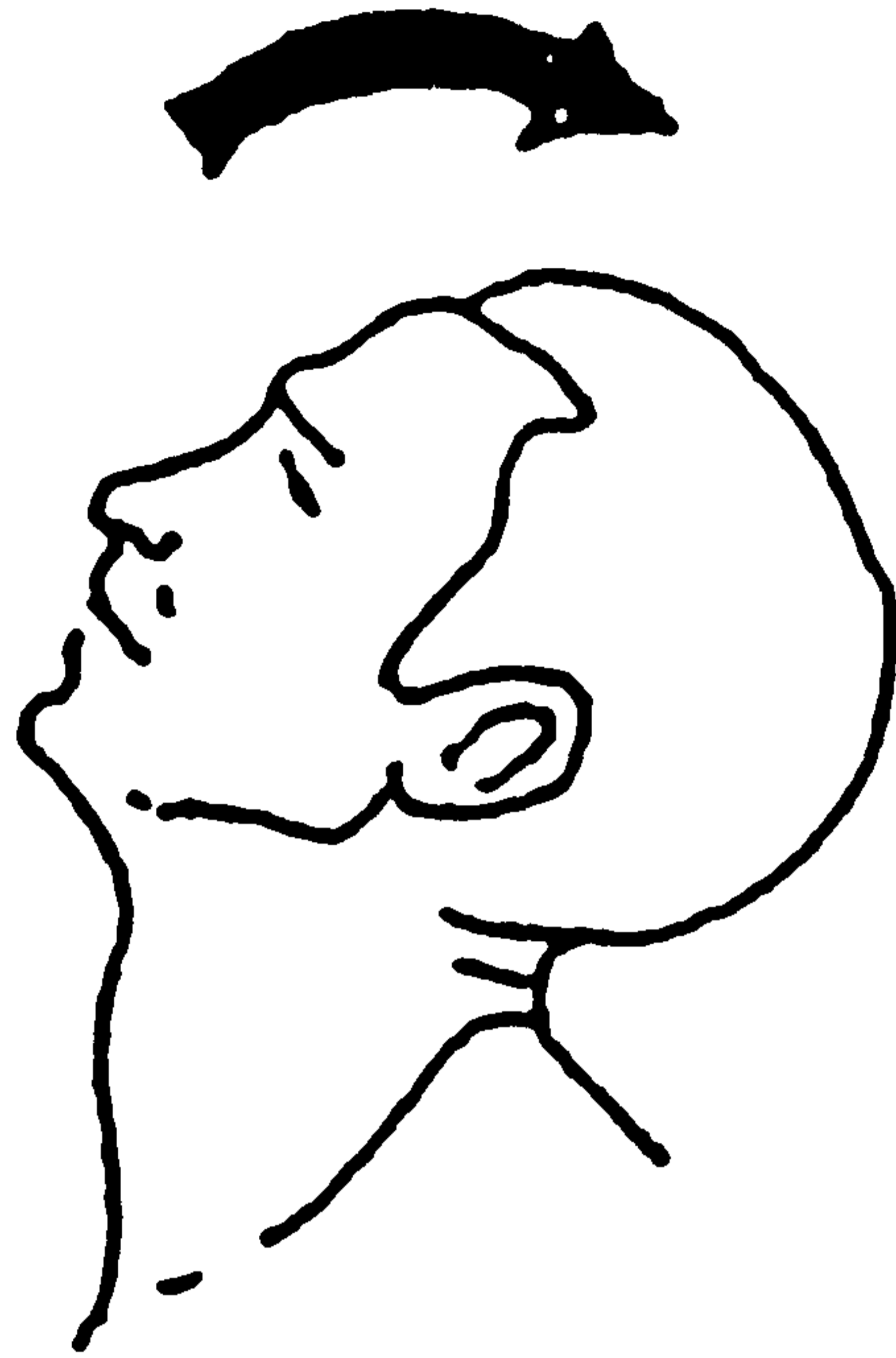
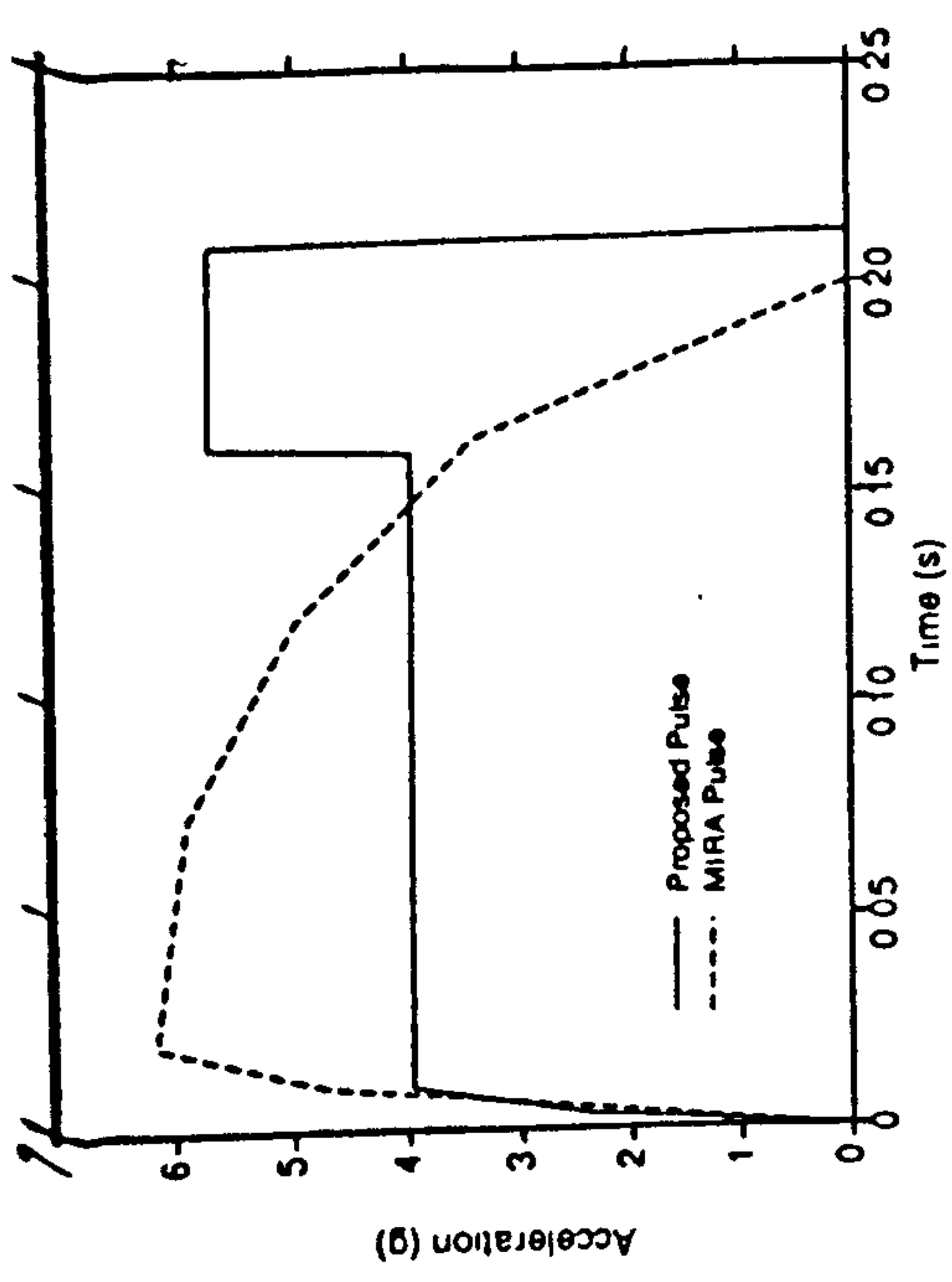
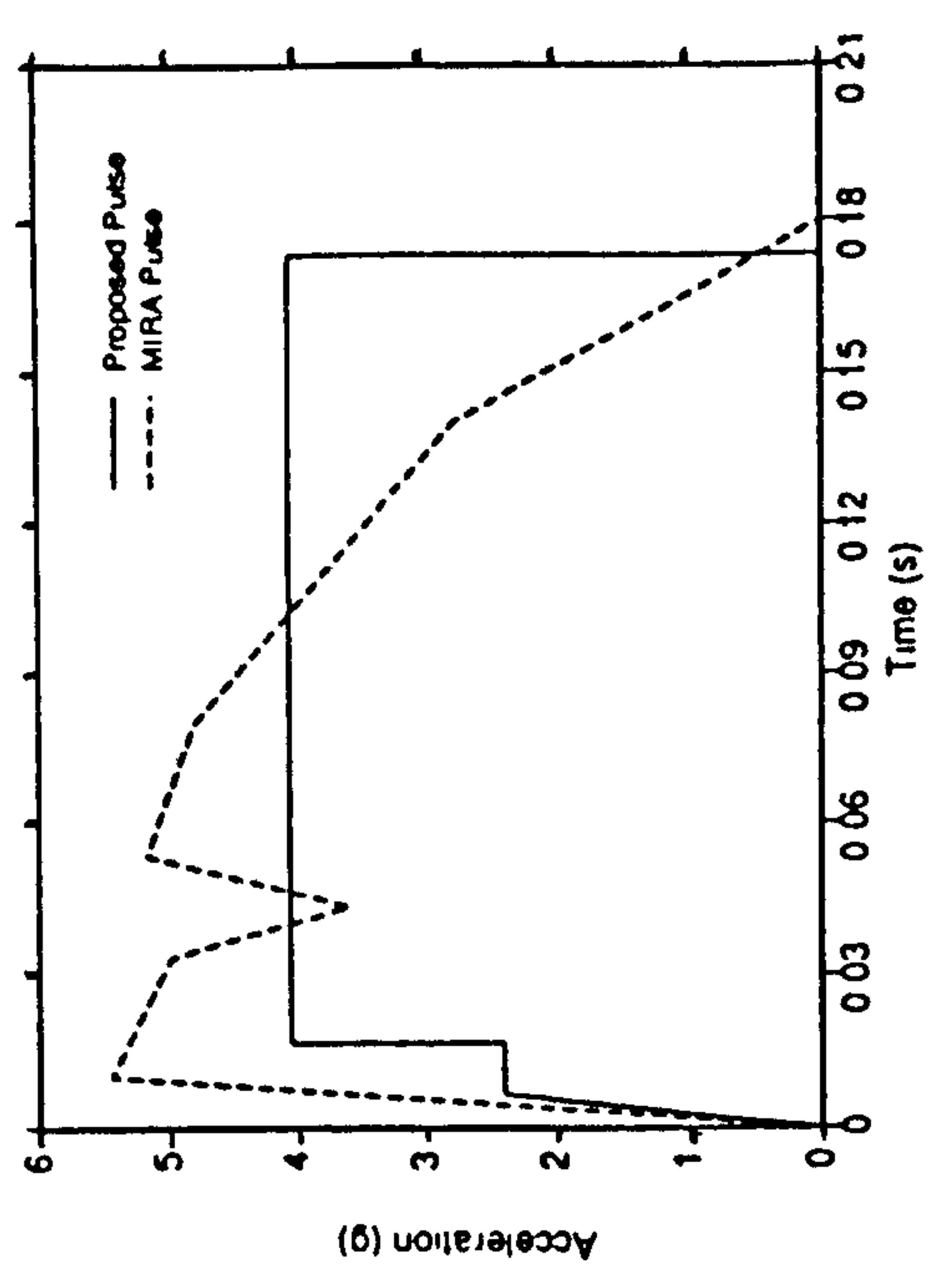


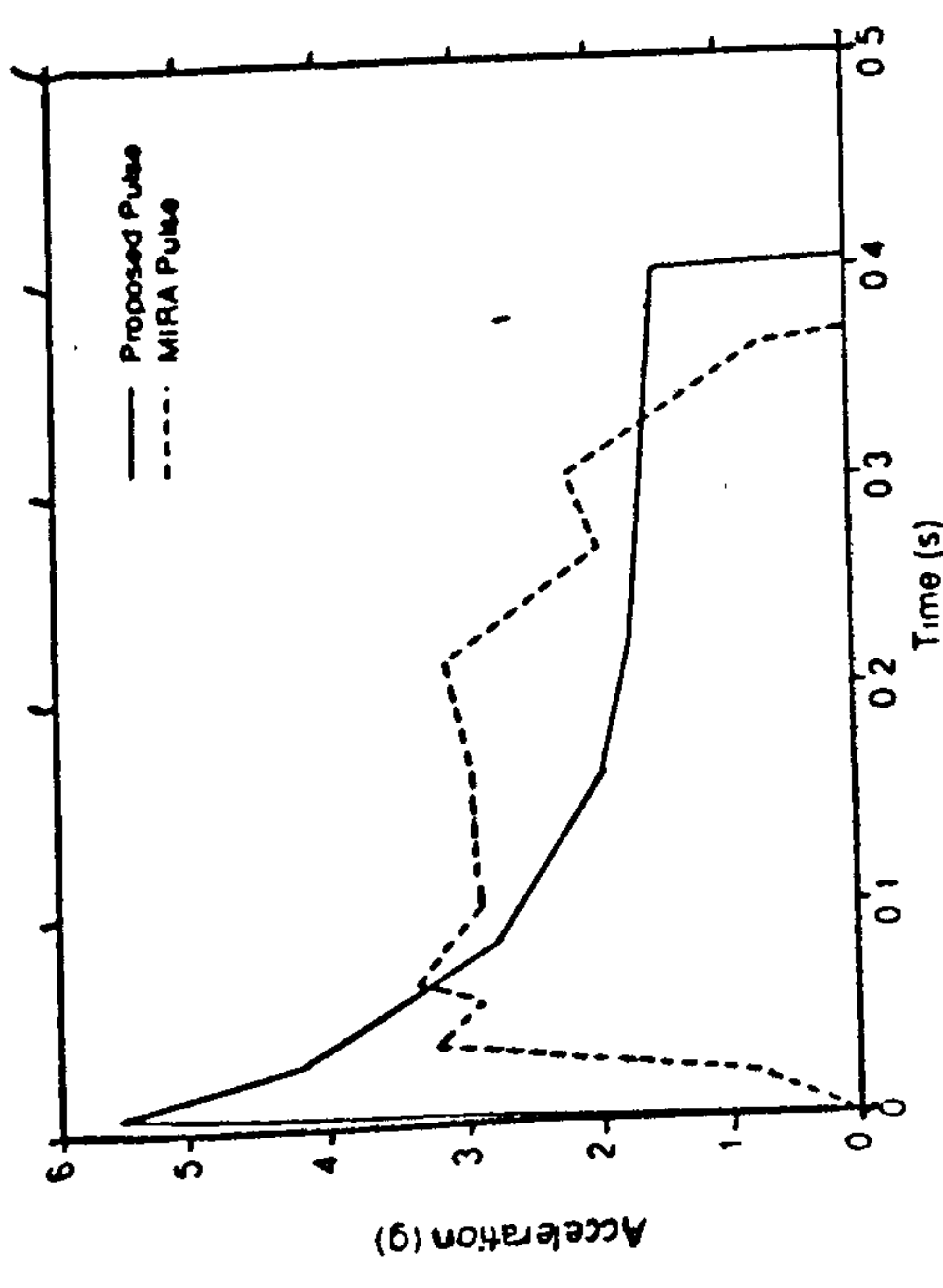
Figure 2.39 : The extension bending mechanism, commonly caused by a low level seat back to a backward facing occupant [65].



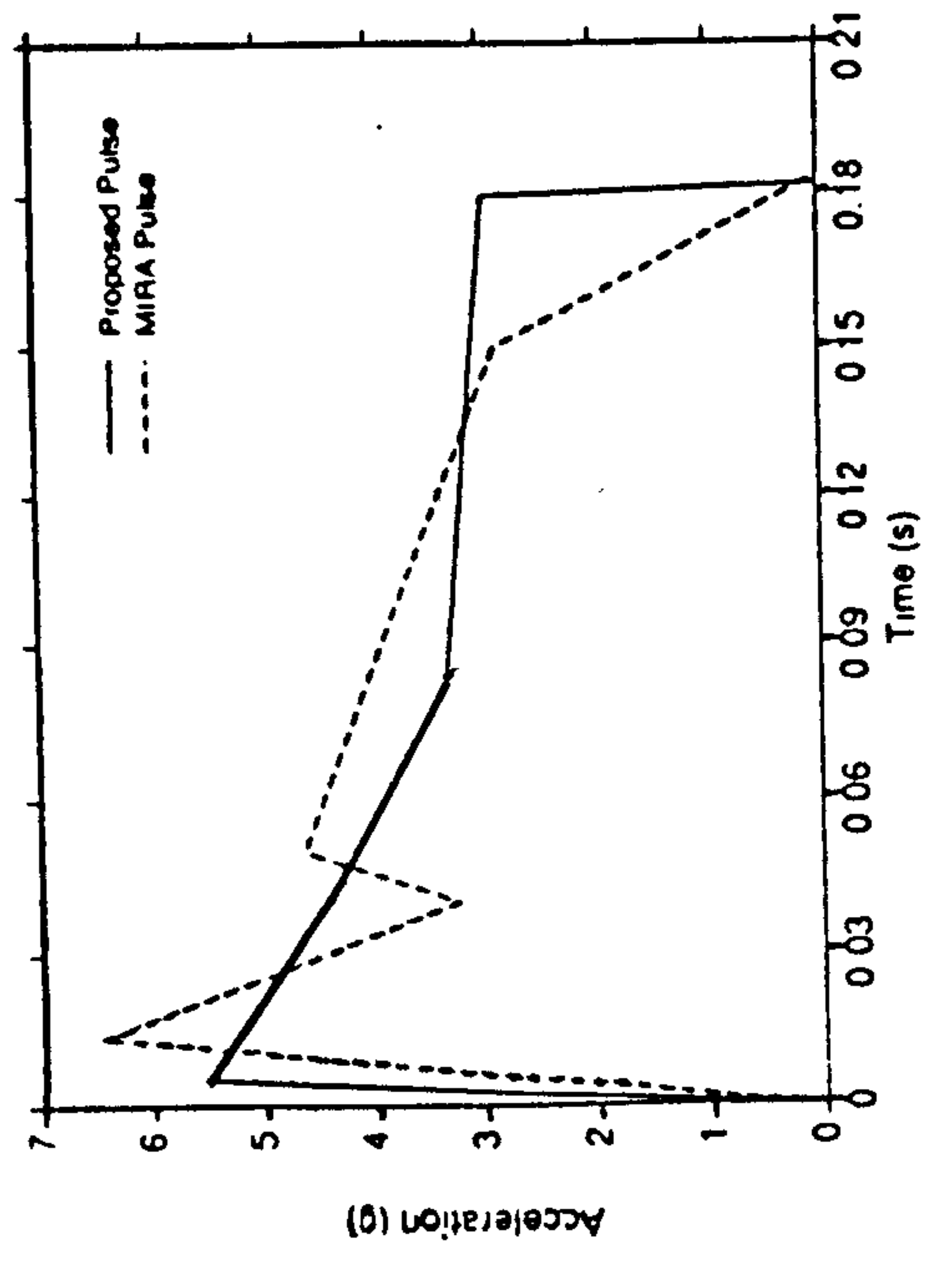
C3 PULSE



C7 PULSE



C2 PULSE



C6 PULSE

Figure 2.40 : Proposed crash pulses and pulses used in MIRA sled tests [71].

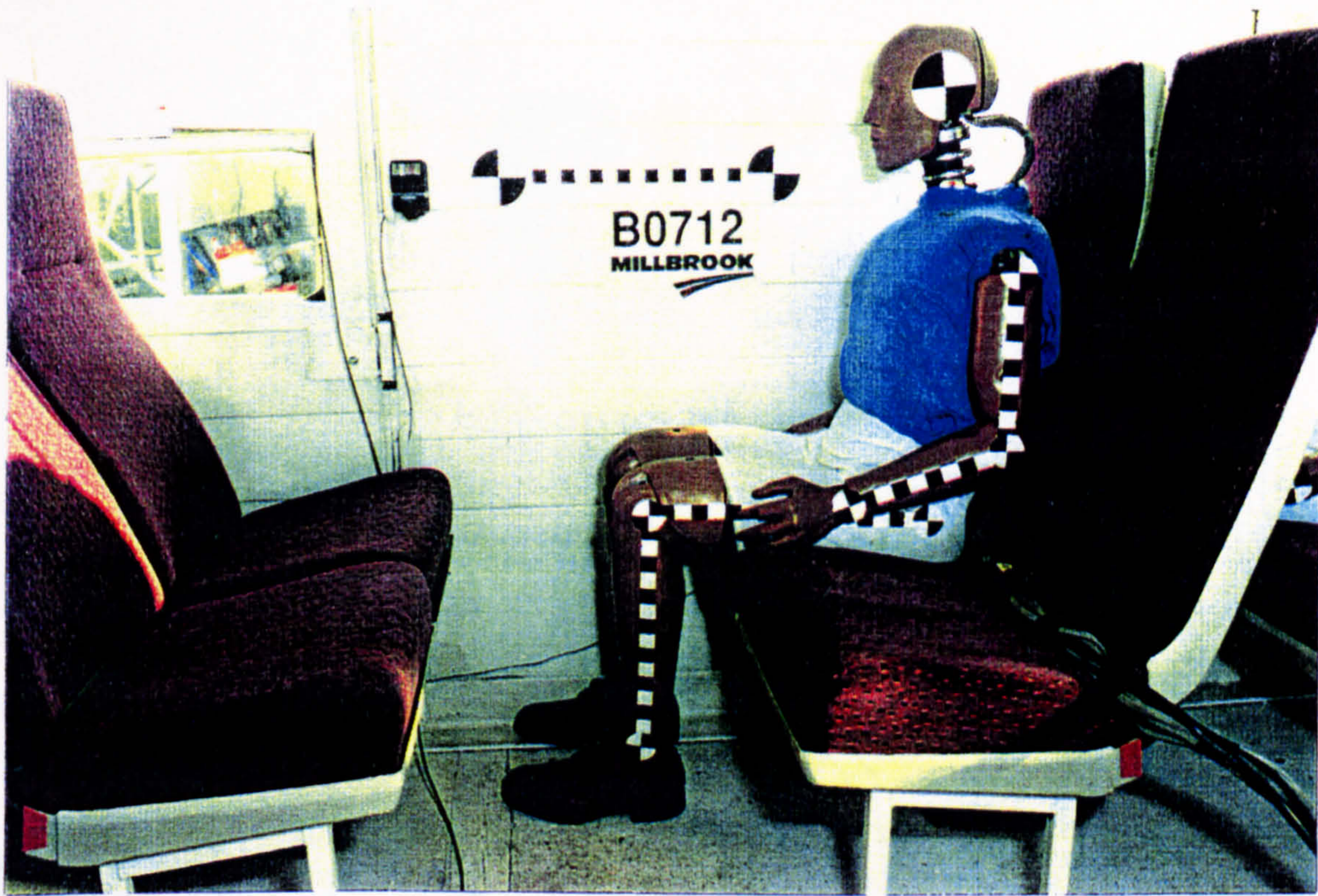


Figure 2.41a : The pre-test position of a forward facing dummy in open-bay seats [75].

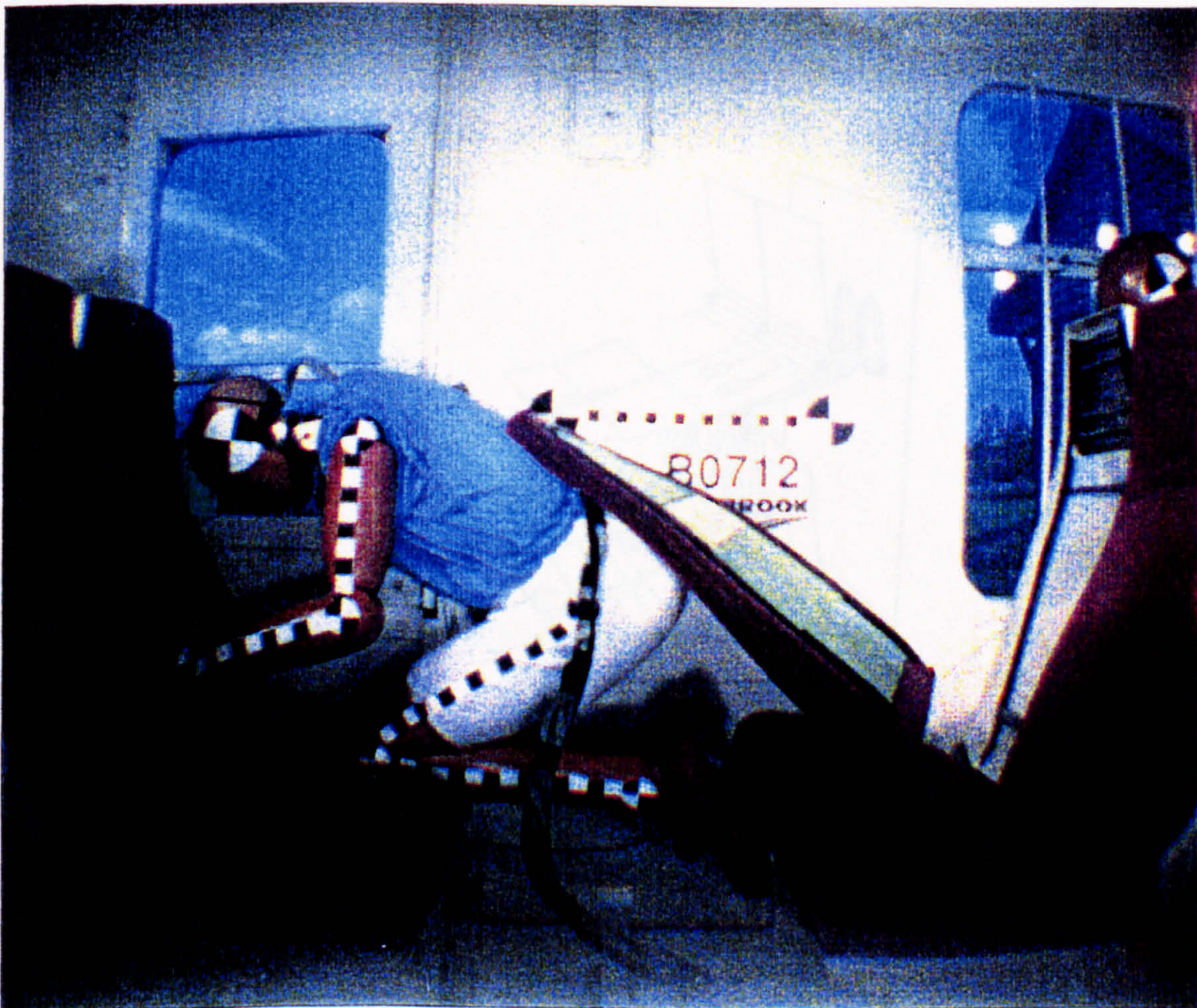
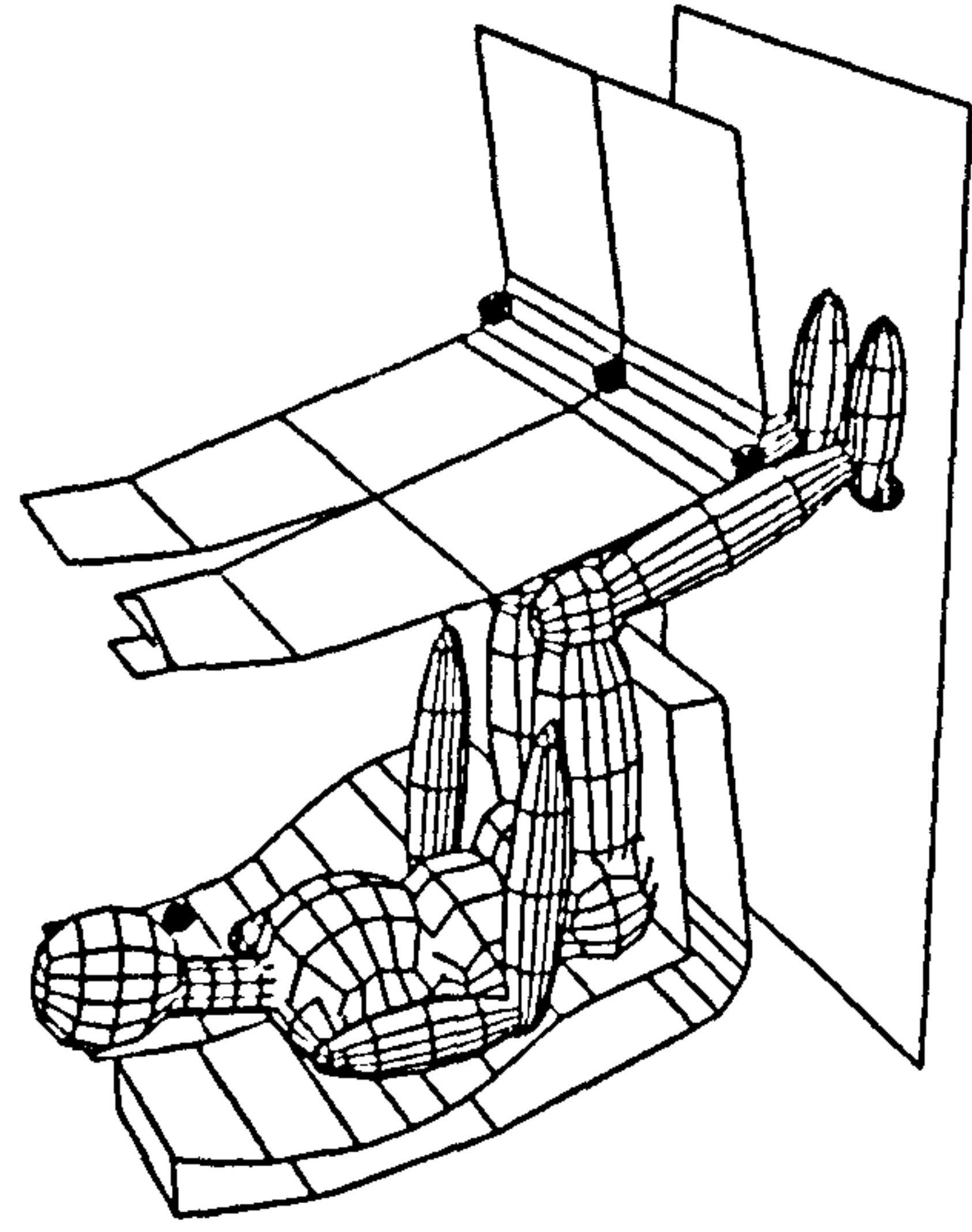
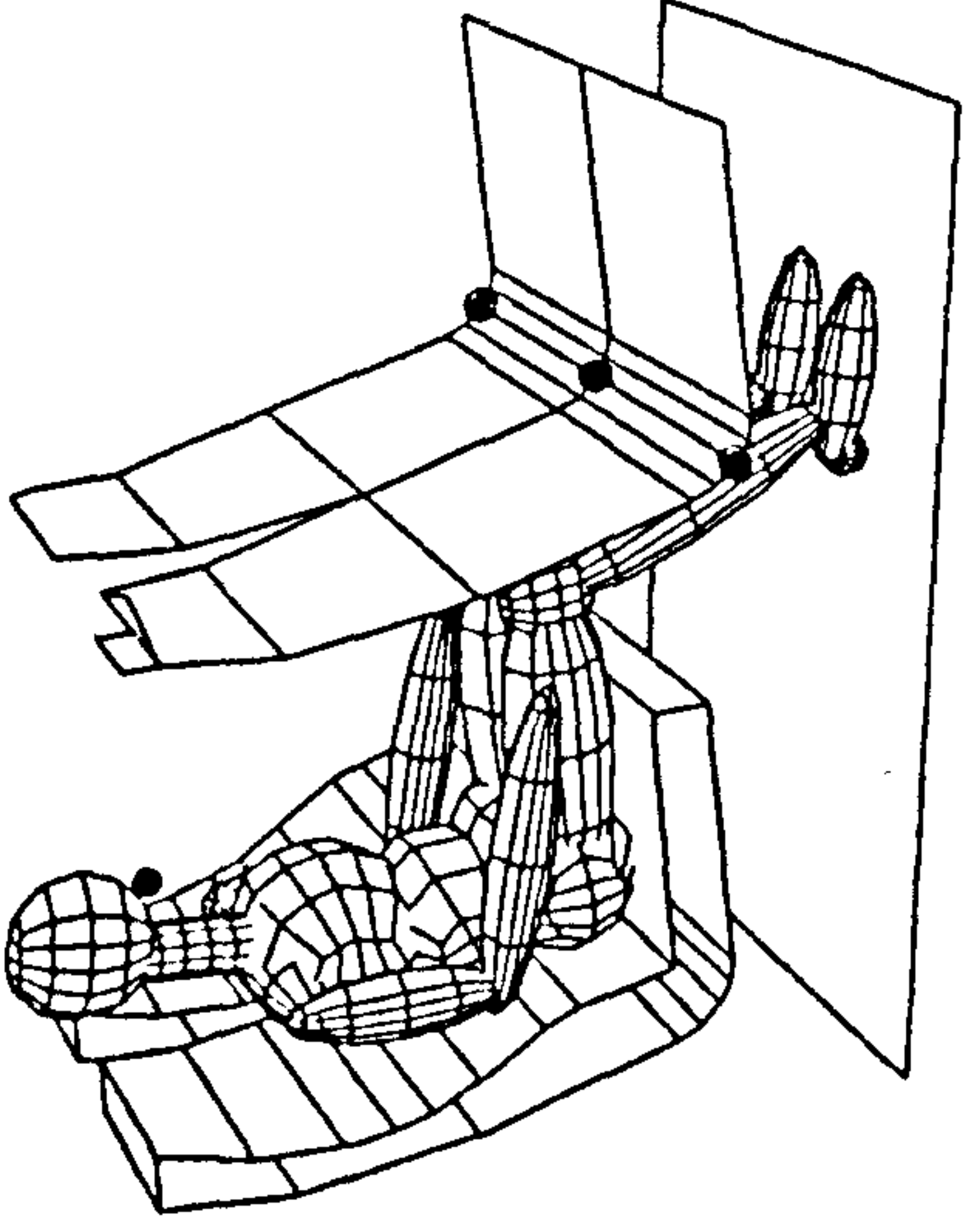


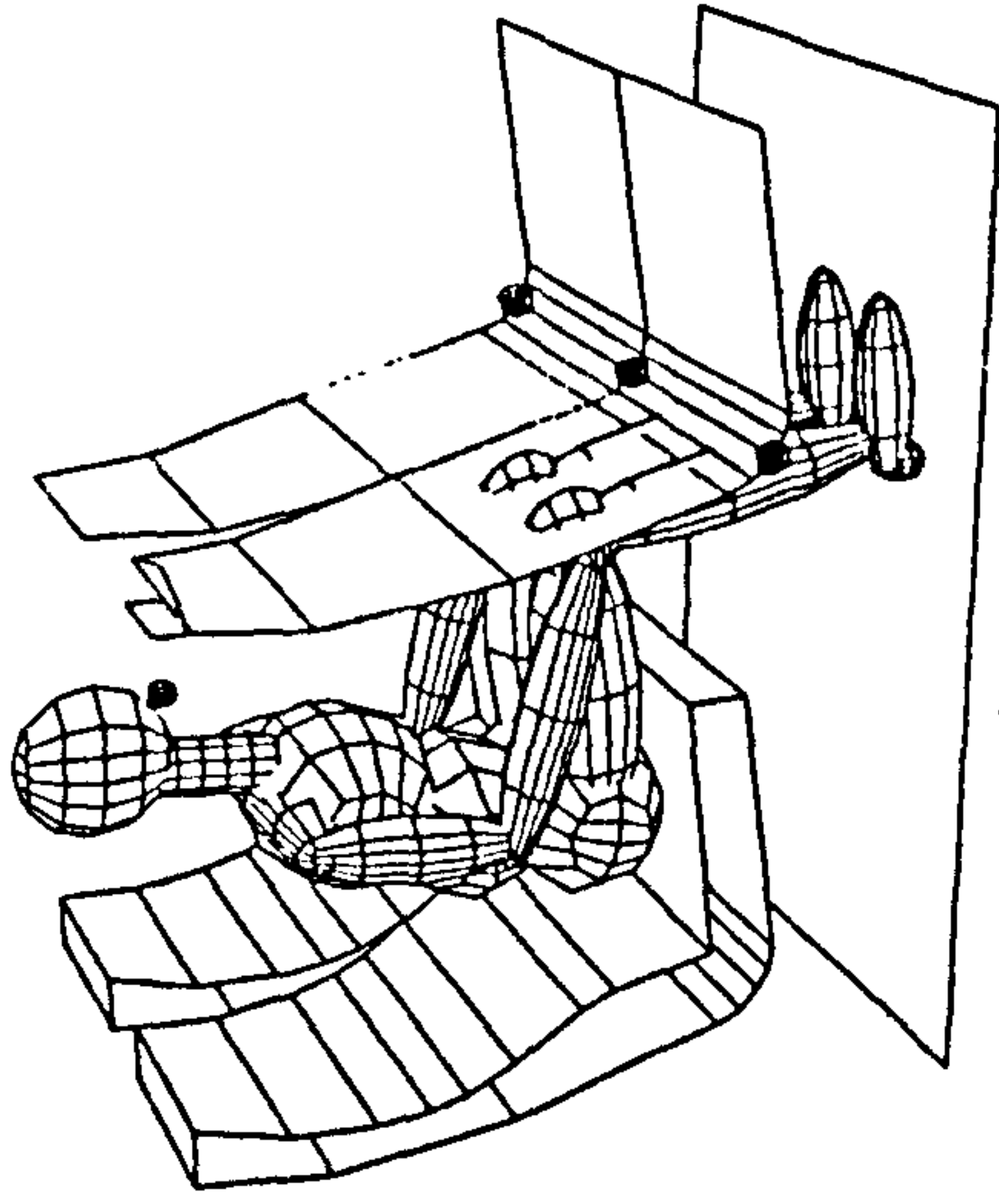
Figure 2.41b : The post-test position of the forward facing dummy in open-bay seats [75].



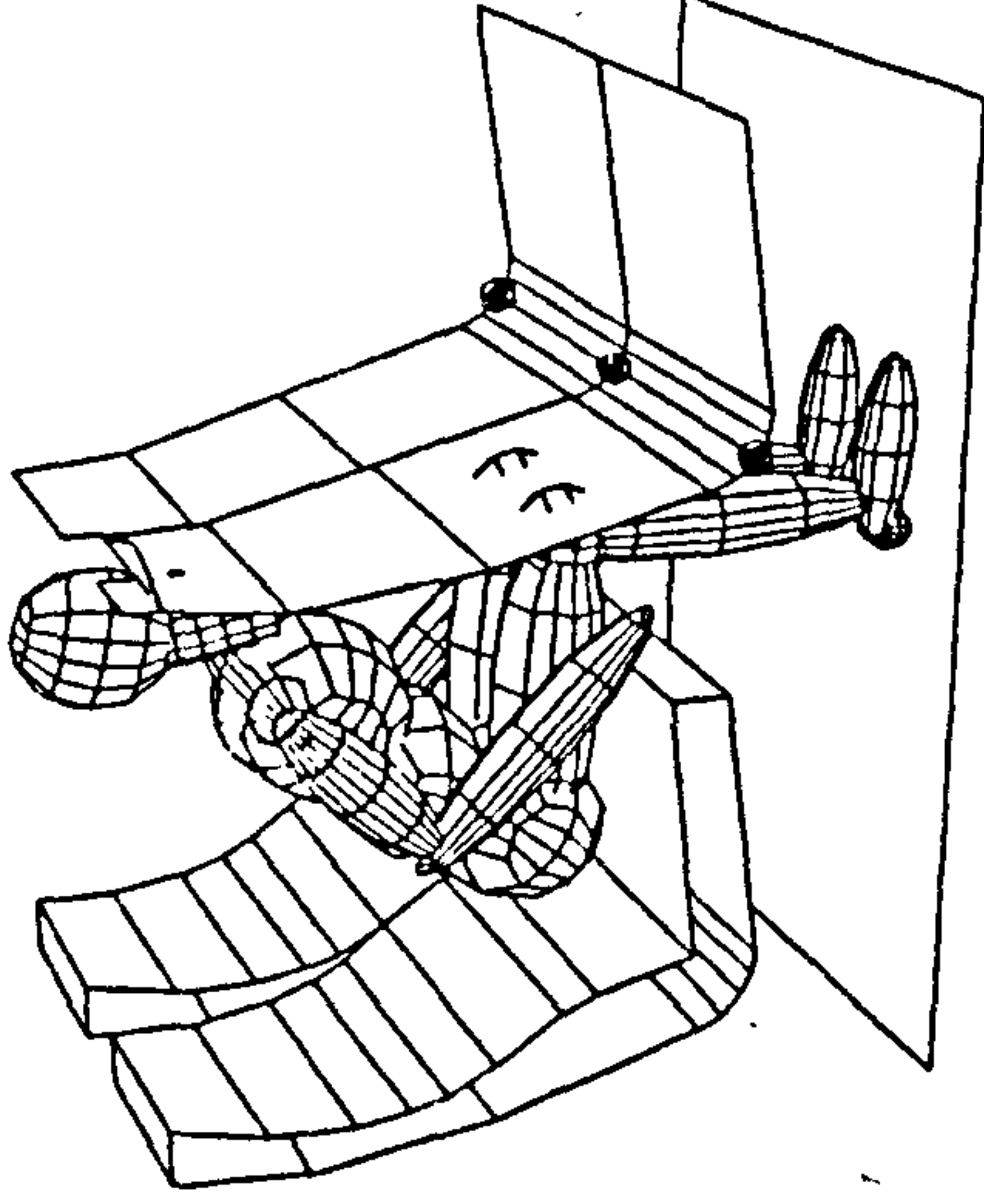
TIME=0ms



TIME=50ms



TIME=100ms



TIME=150ms

Figure 2.42 : The animation of occupant in uni-directional seats (with a grab handle) and subjected to the C3 pulse [72].

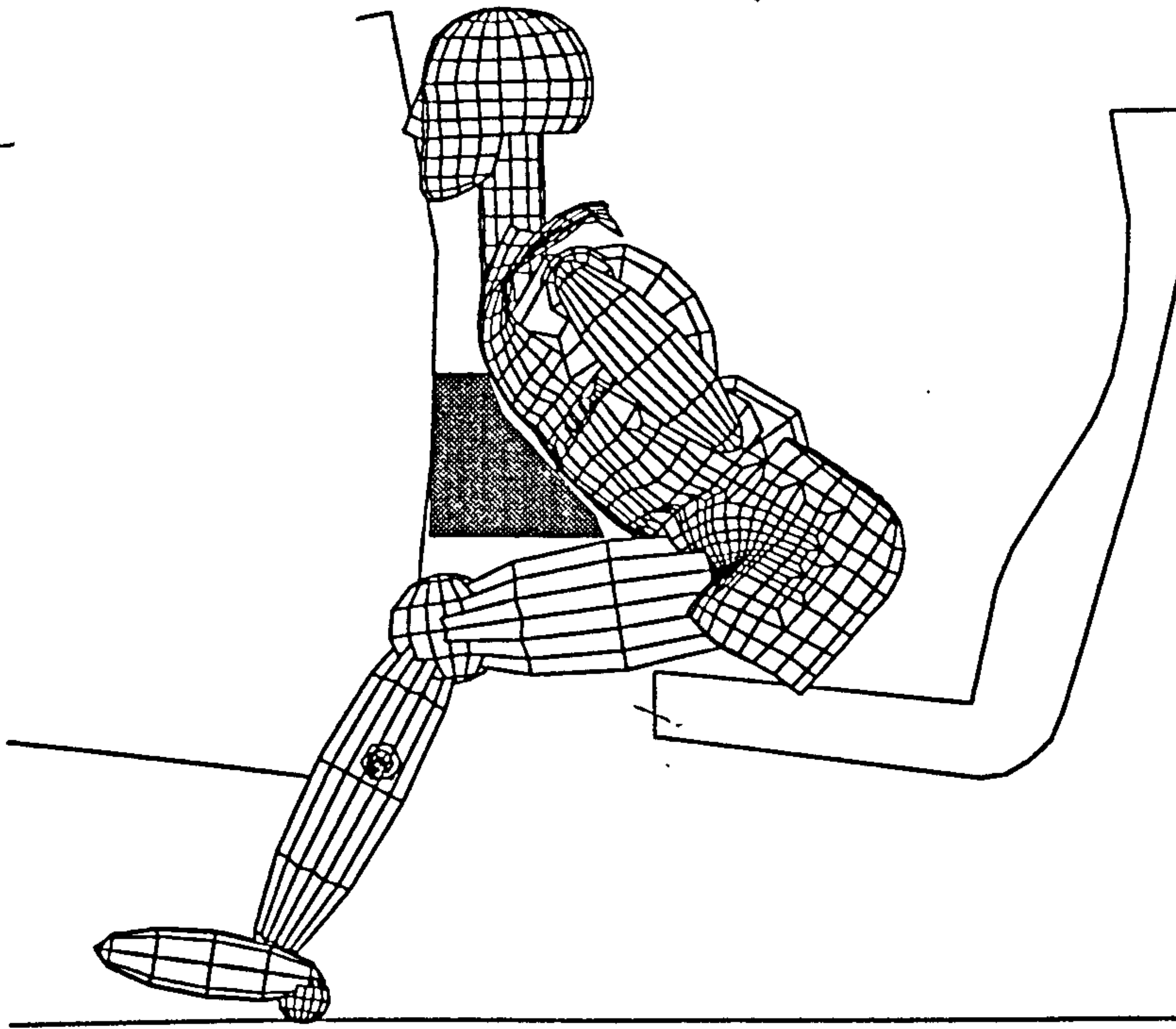


Figure 2.43 : The 'safe' space envelope for mounting a fold-down table at the rear of a unidirectional seat [73].

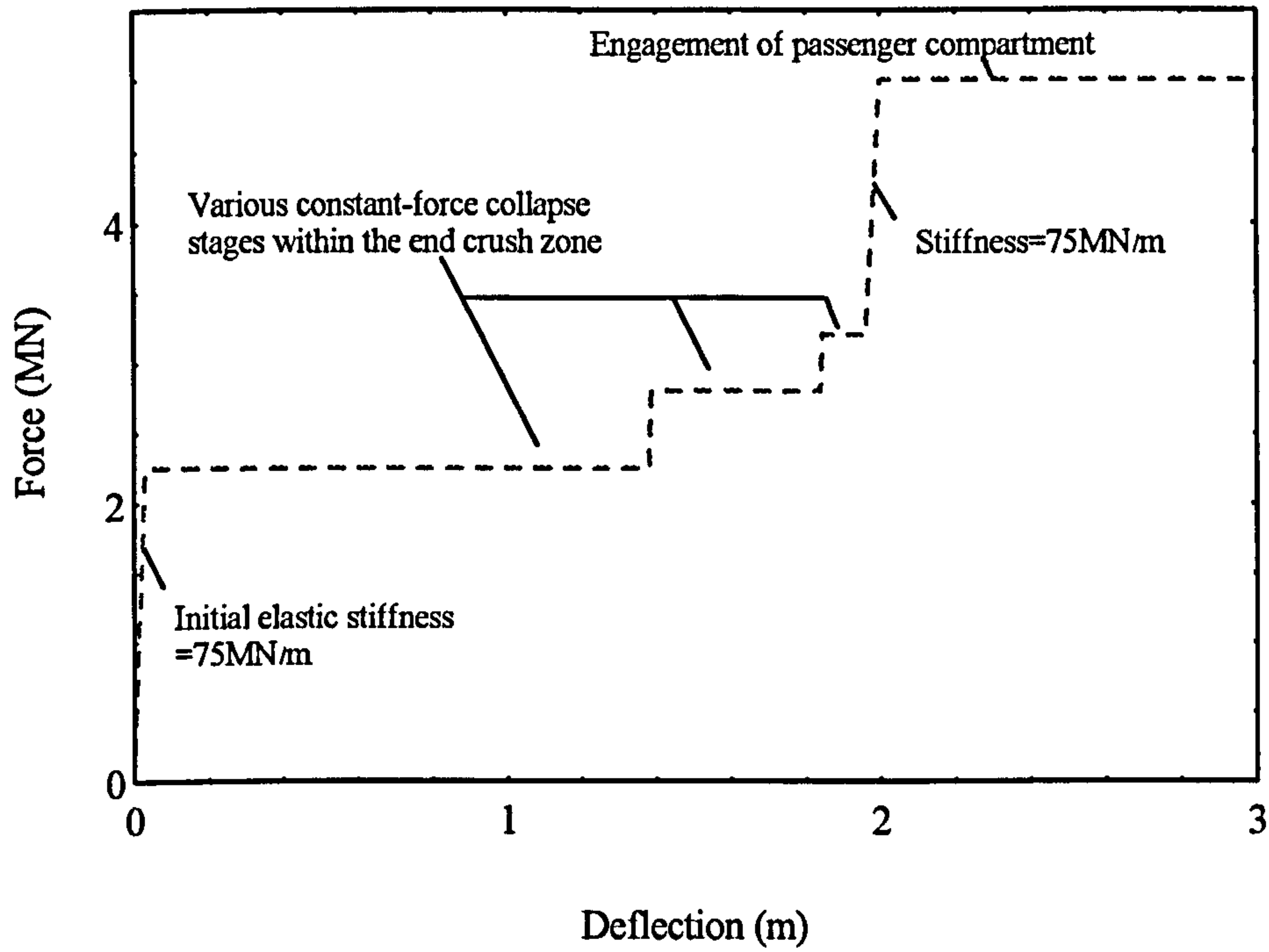


Figure 3.1 : The load-deflection characteristic of a steel crashworthy vehicle end structure designed for a 35tonne coach.

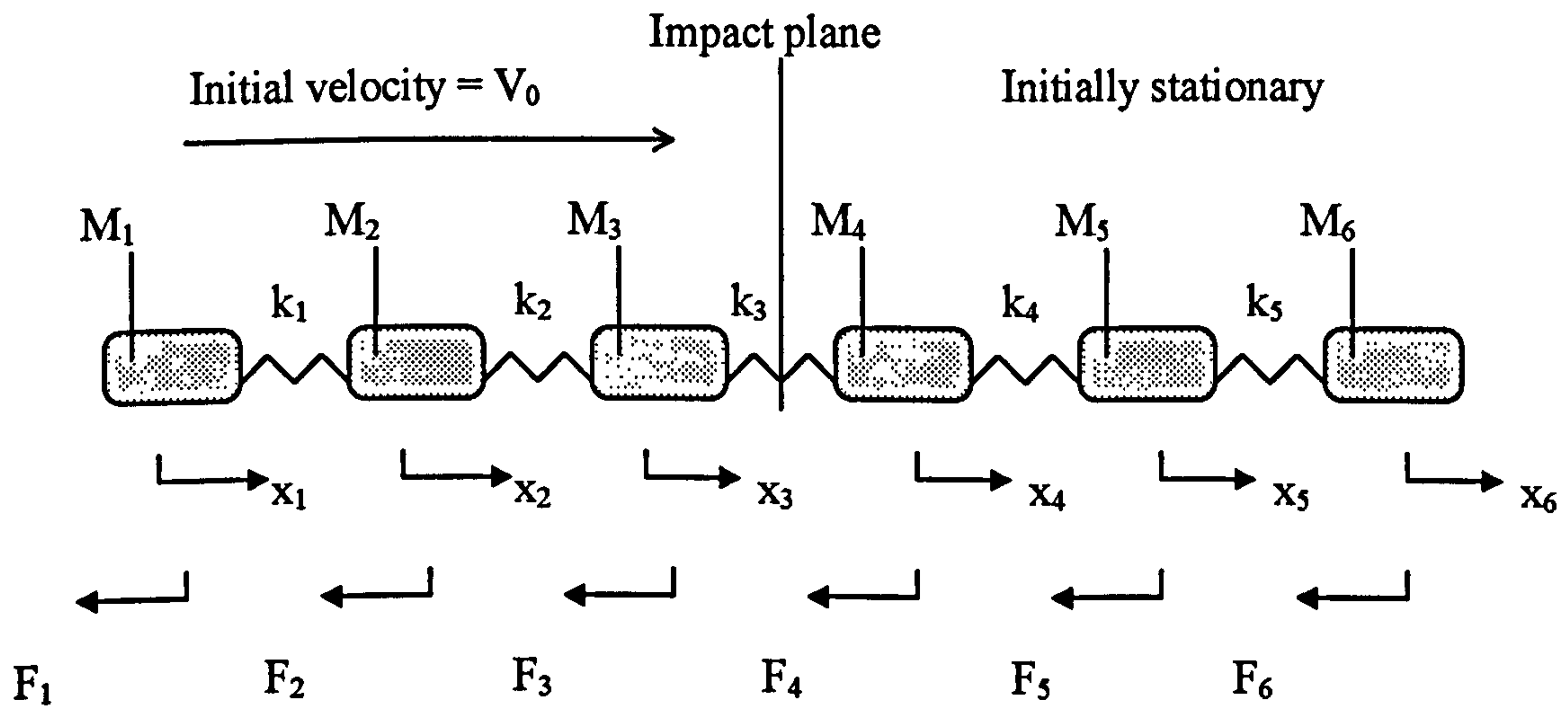


Figure 3.2 : A moving three-coach to a stationary three-coach collision model, including wheel-track friction.

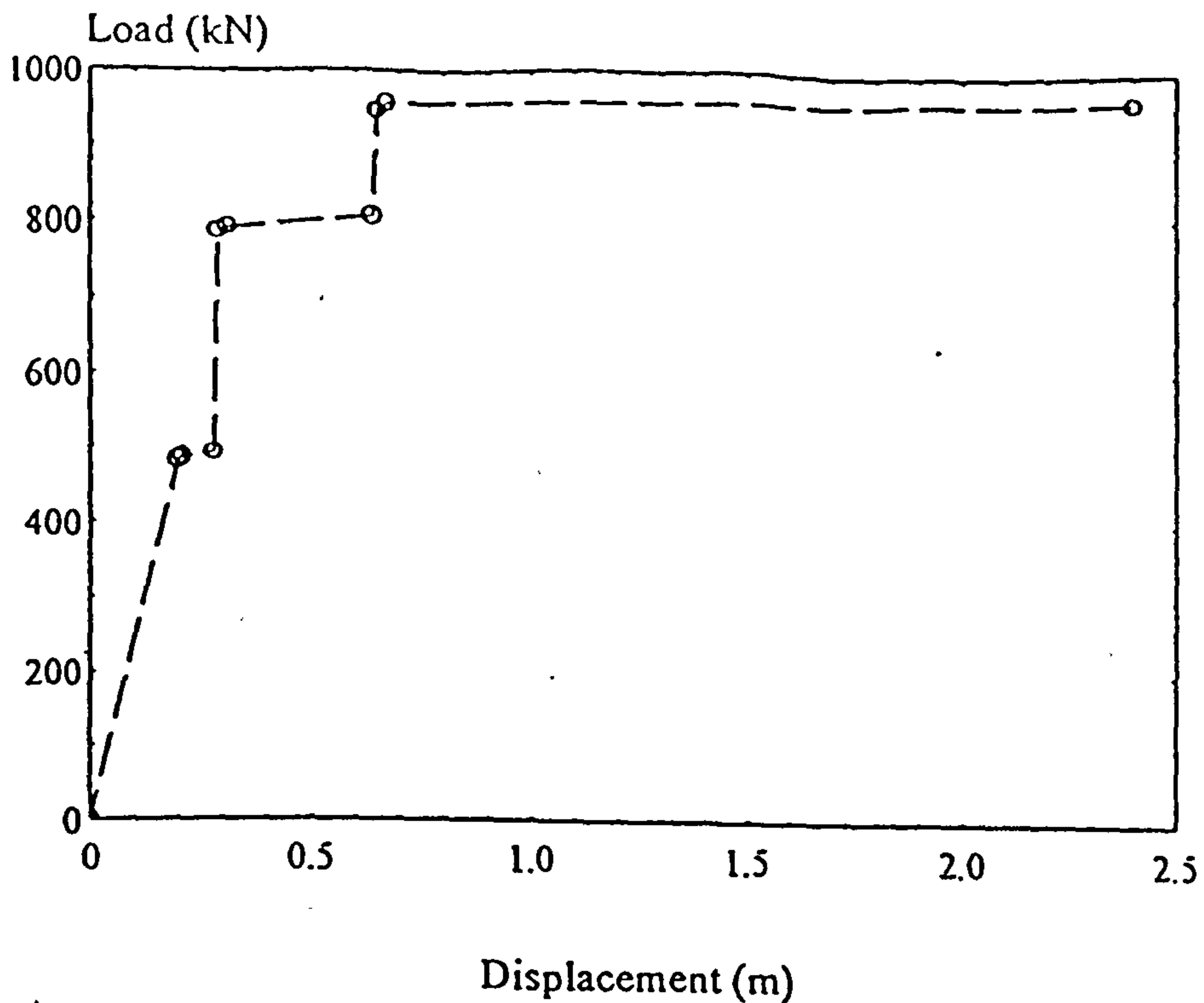


Figure 3.3a : The load-deflection characteristic of the crashworthy coach end-structure as mentioned in reference [2].

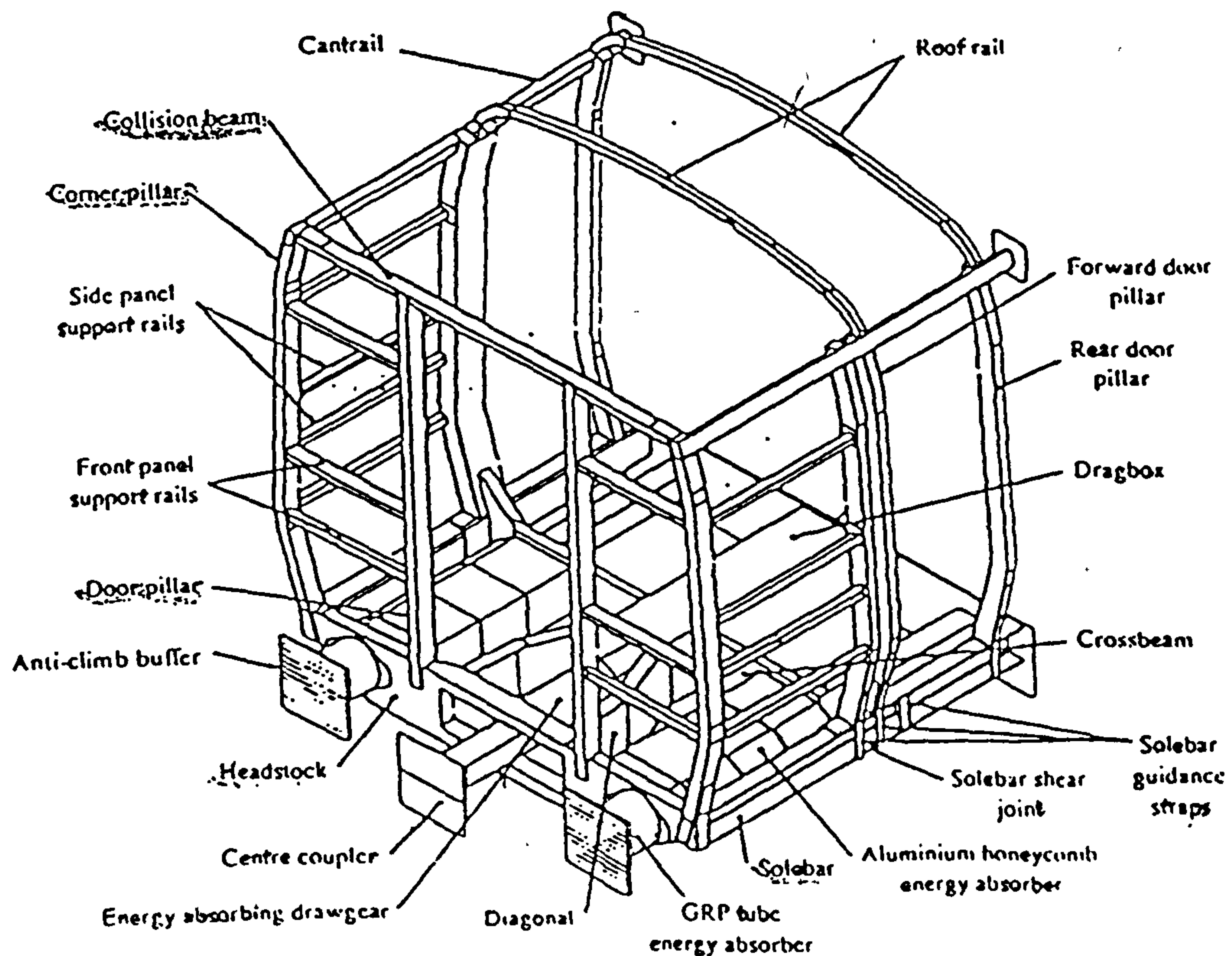


Figure 3.3b : The prototype of the crashworthy coach end-structure as mentioned in reference [2].

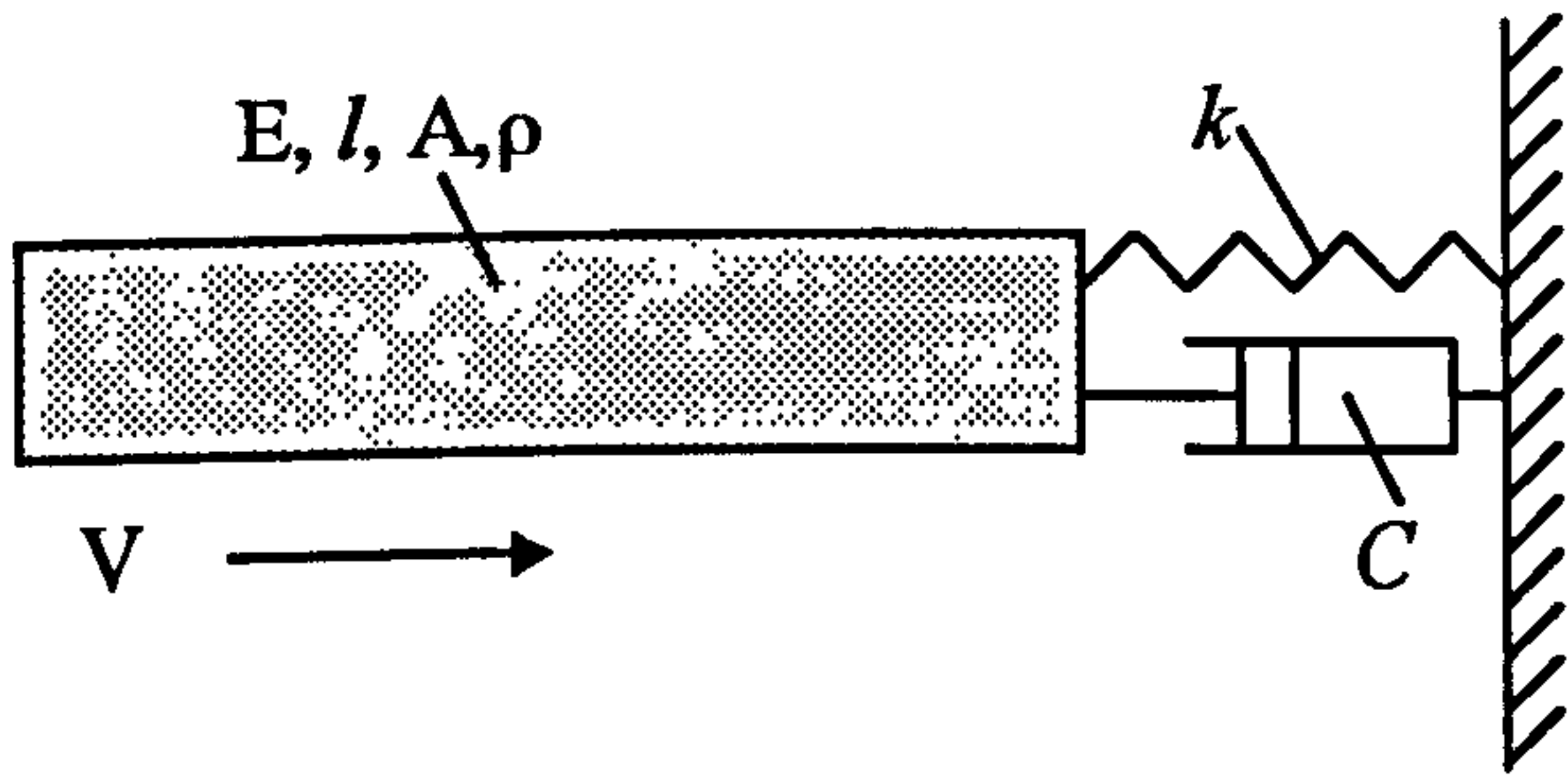


Figure 3.4a : Bar-spring model

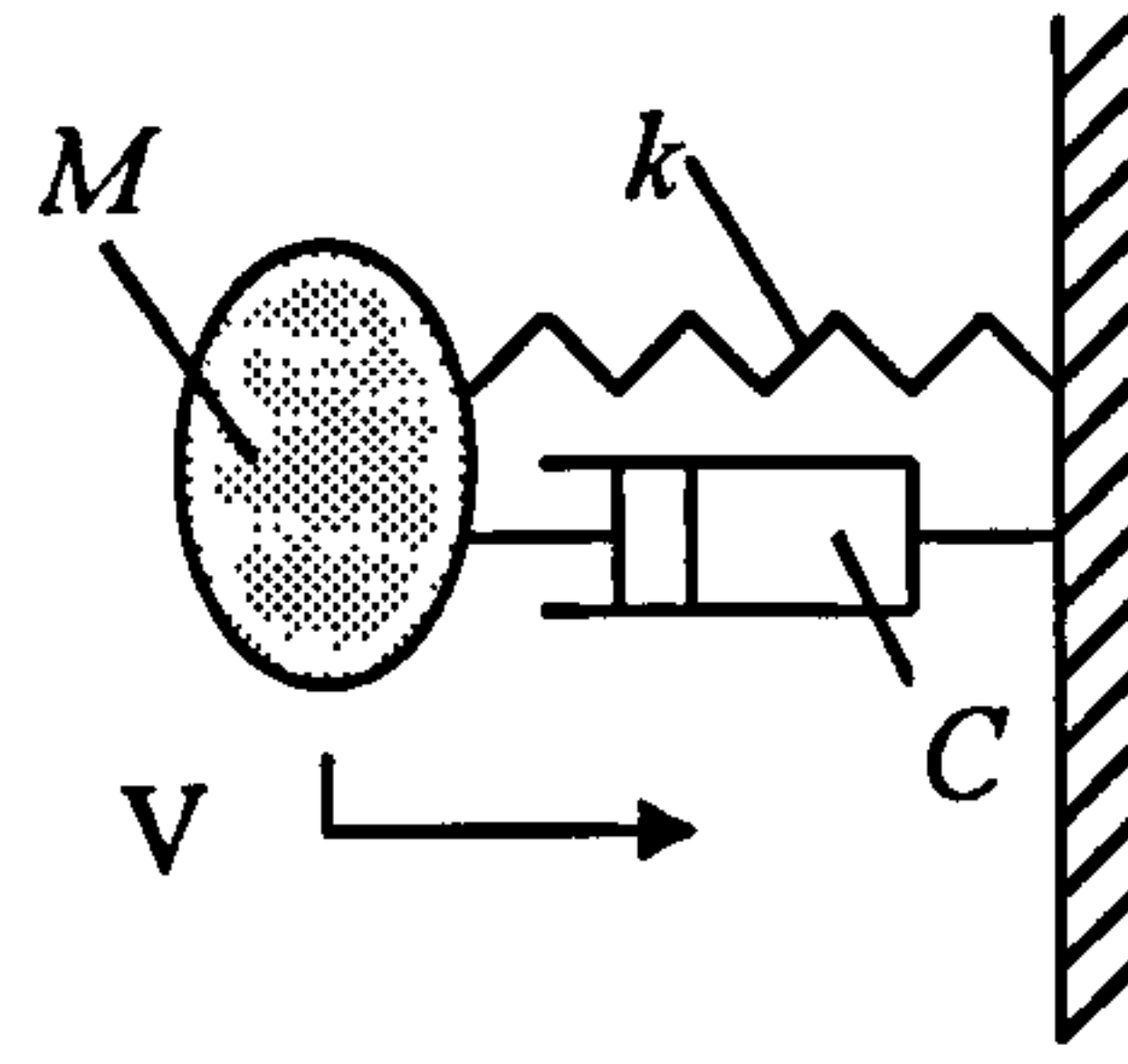


Figure 3.4b : Mass-spring model

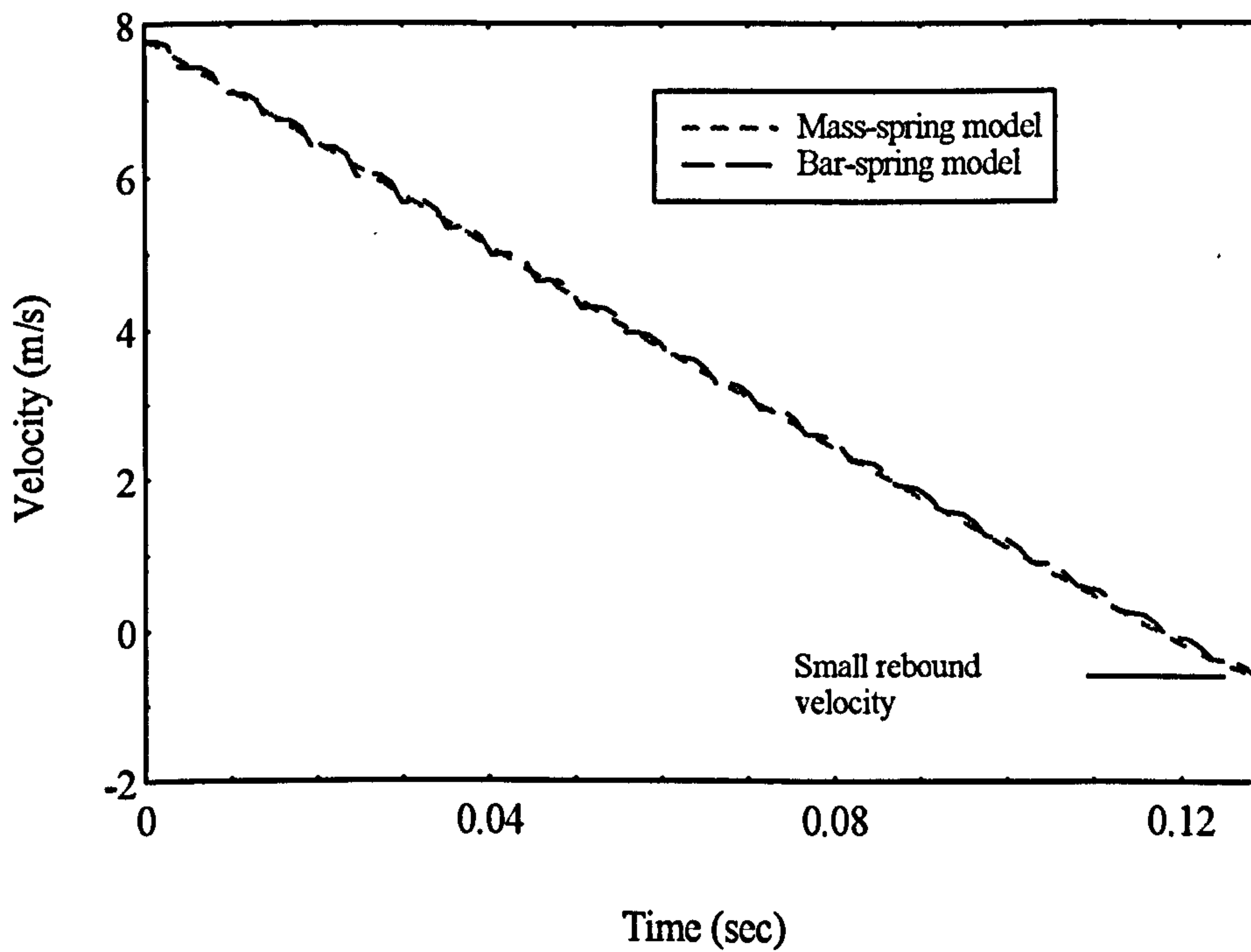


Figure 3.5 : The velocity-time history for the bar-spring & mass-spring models.

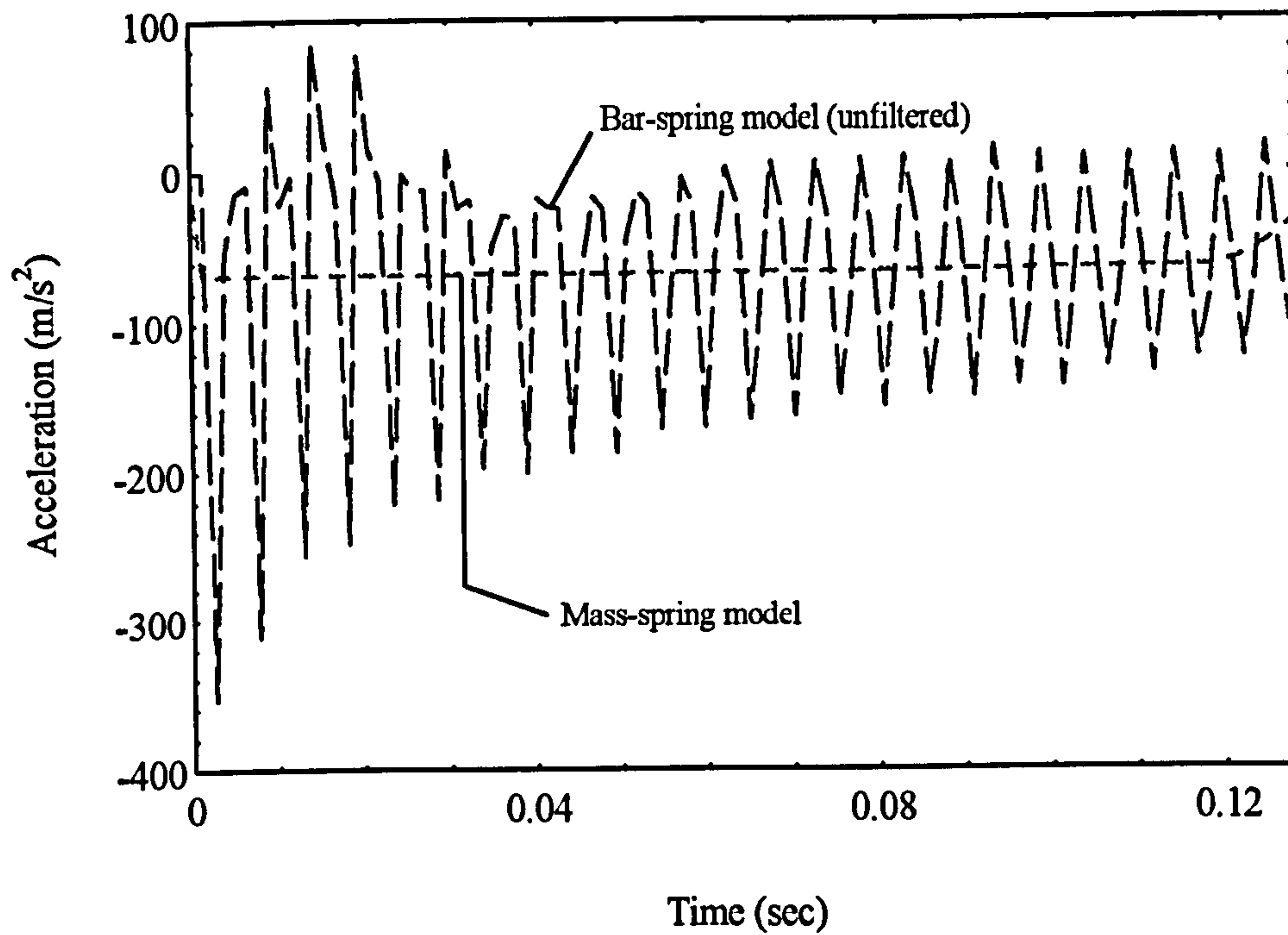


Figure 3.6a : The acceleration-time history for the bar-spring & mass-spring models.

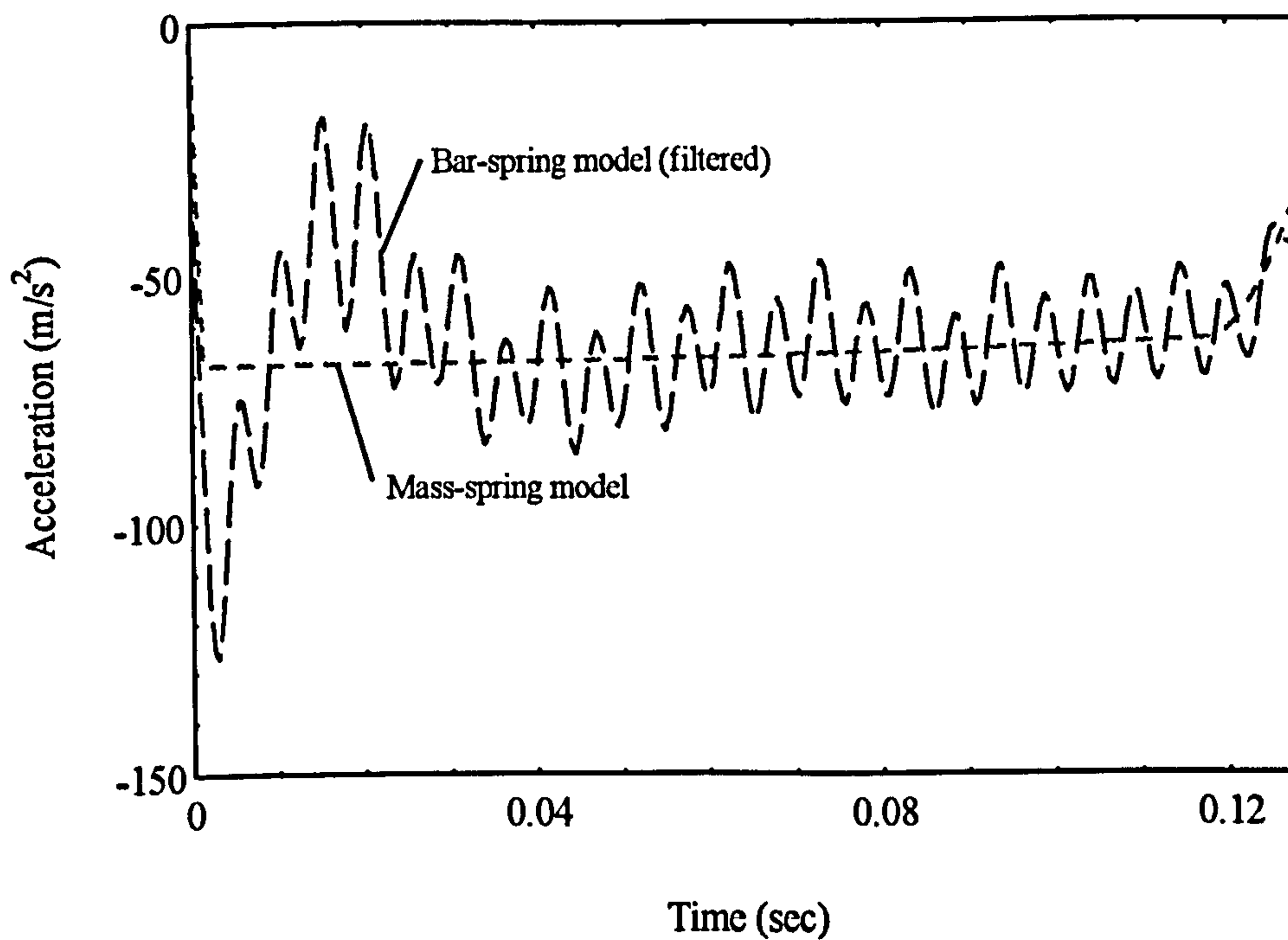


Figure 3.6b : The filtered acceleration-time history for the bar-spring & mass-spring models.

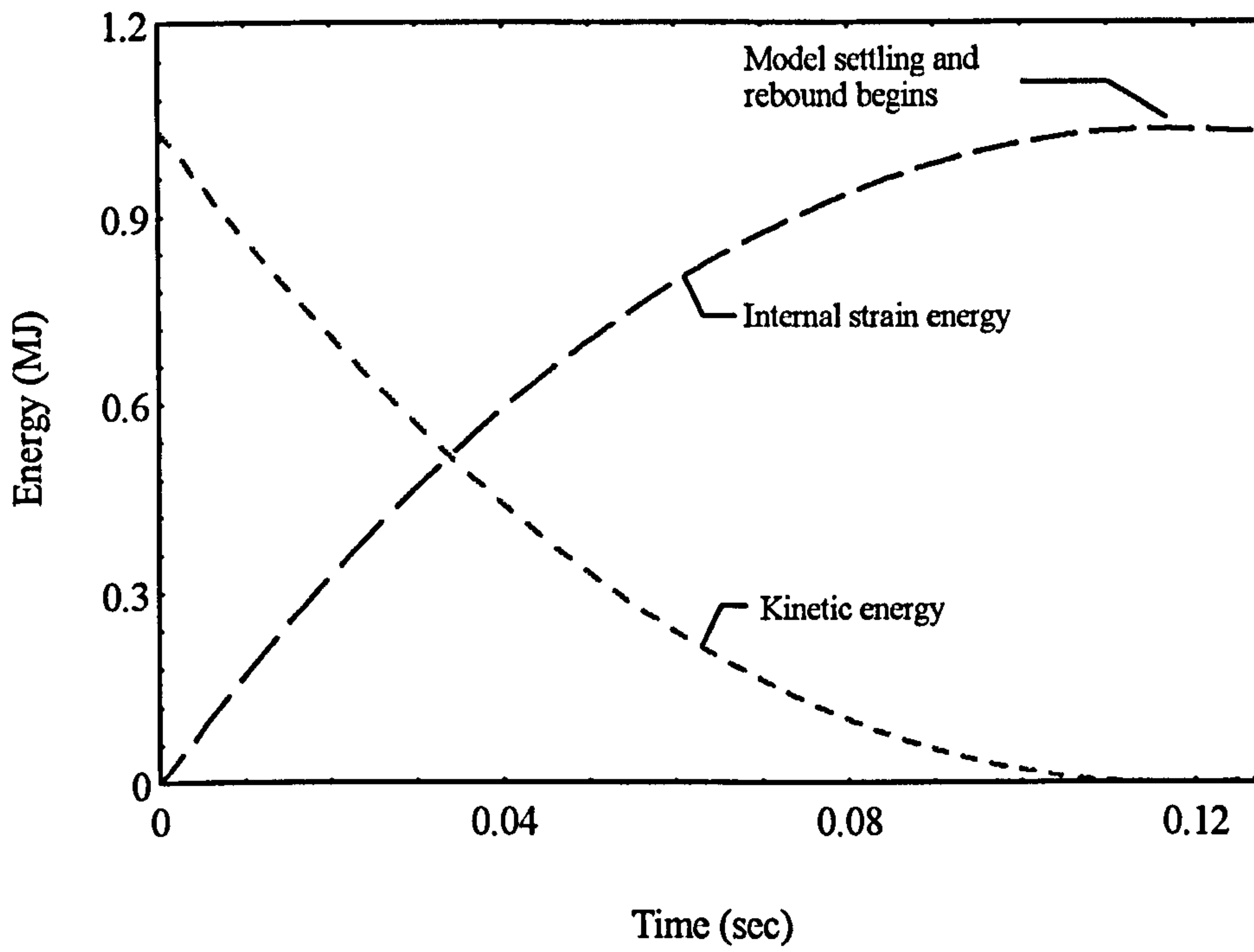


Figure 3.7 : The energy-time history for the mass-spring model.

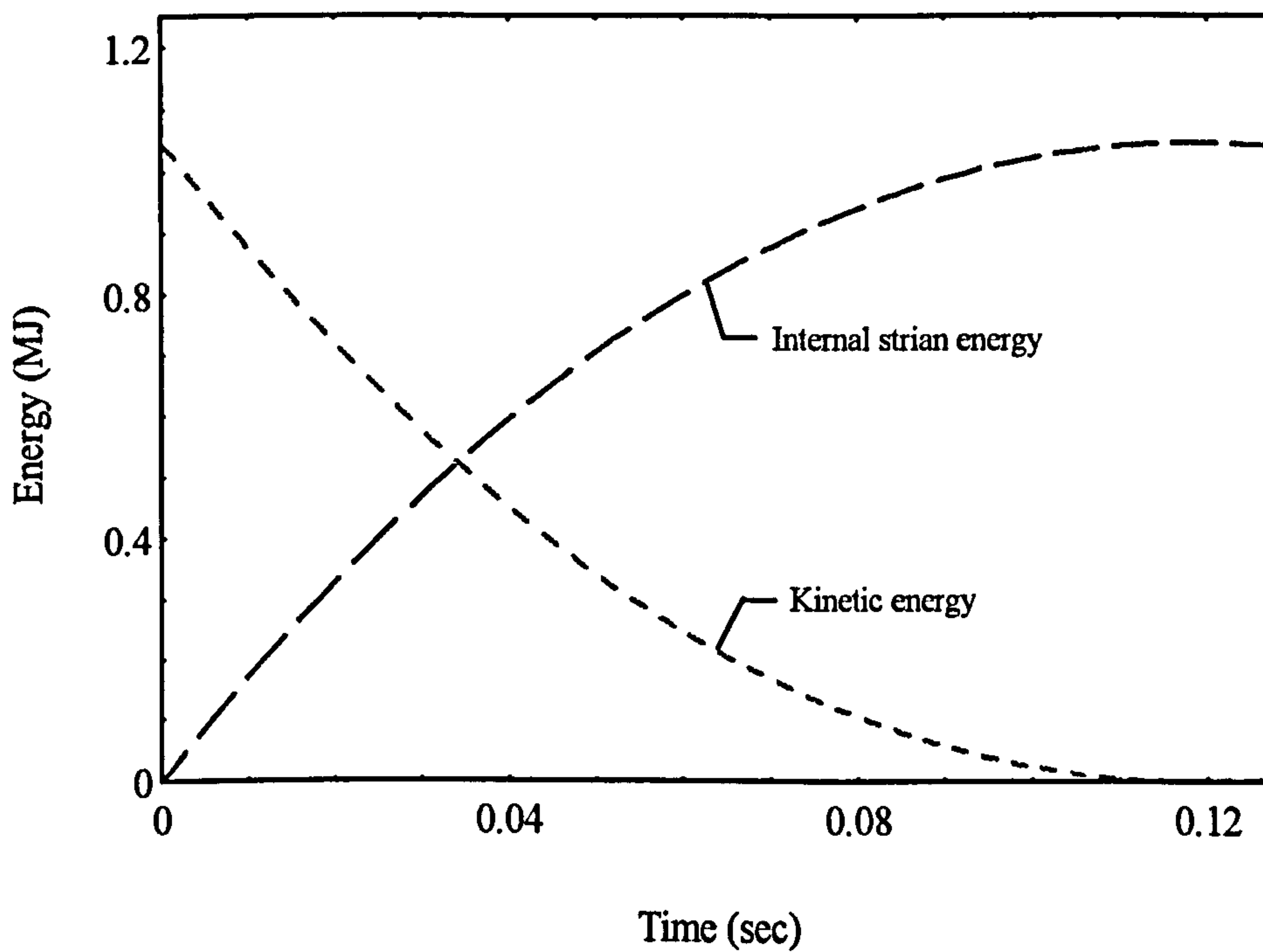


Figure 3.8 : The energy-time history for the bar-spring model.

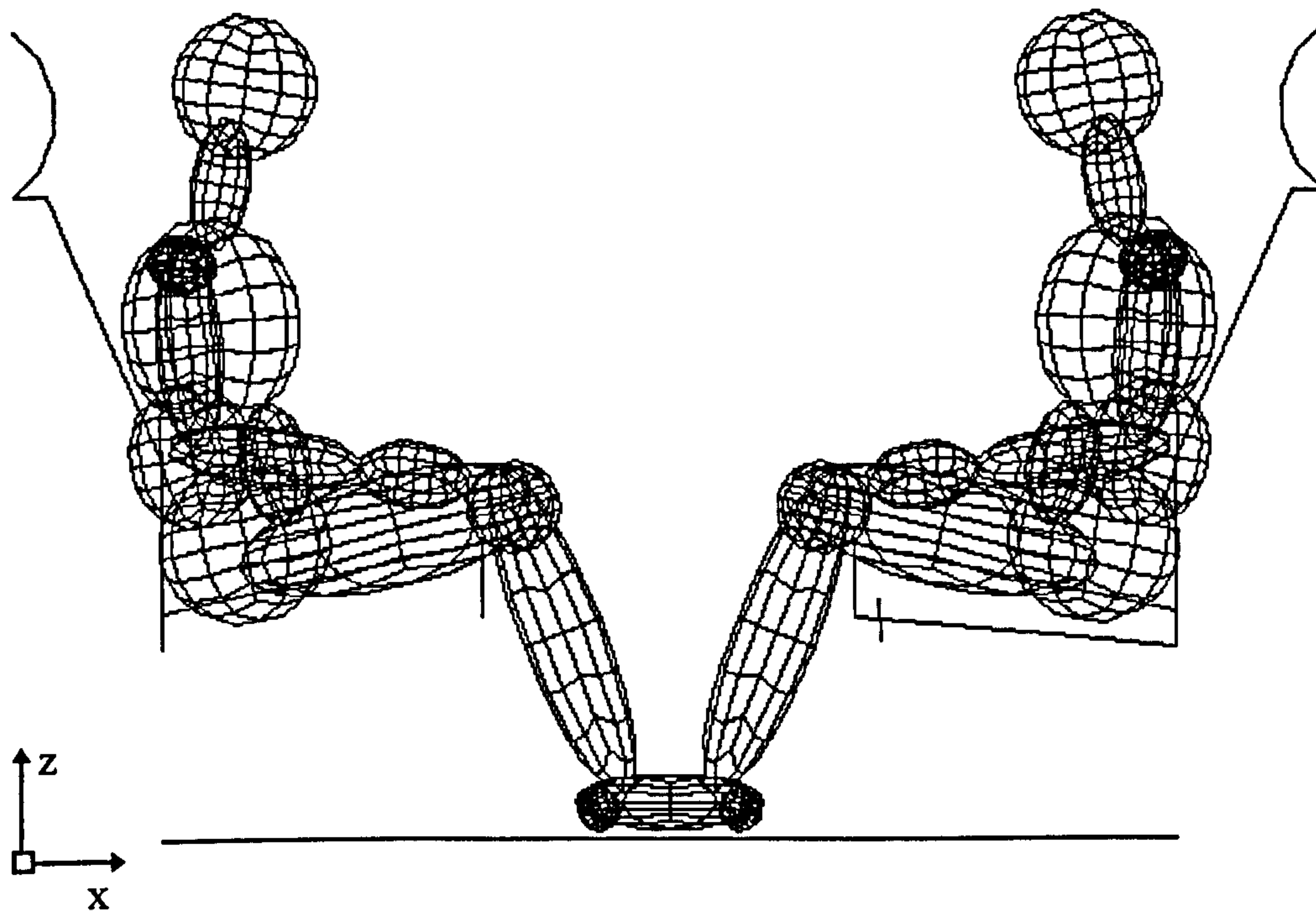
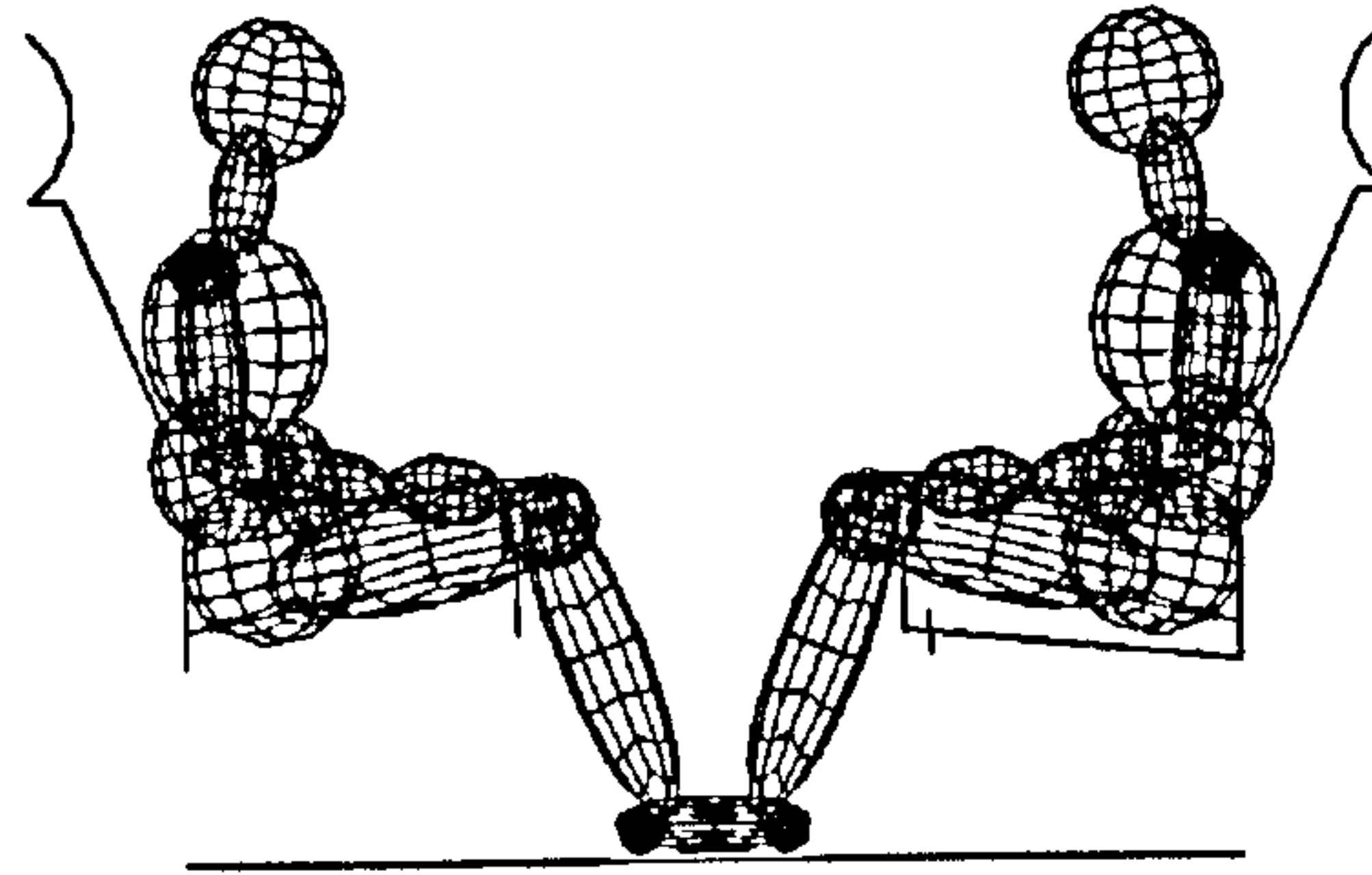
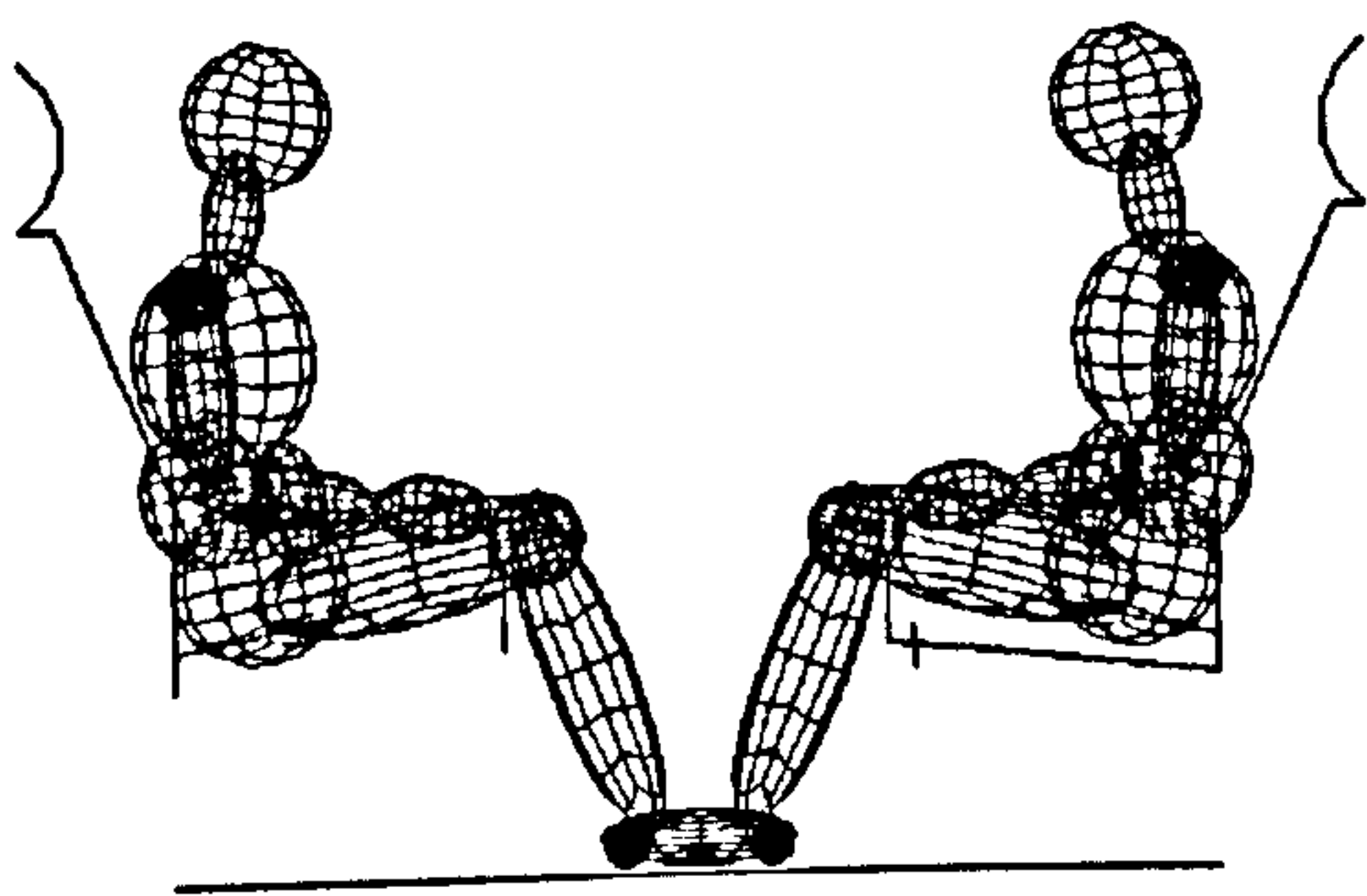


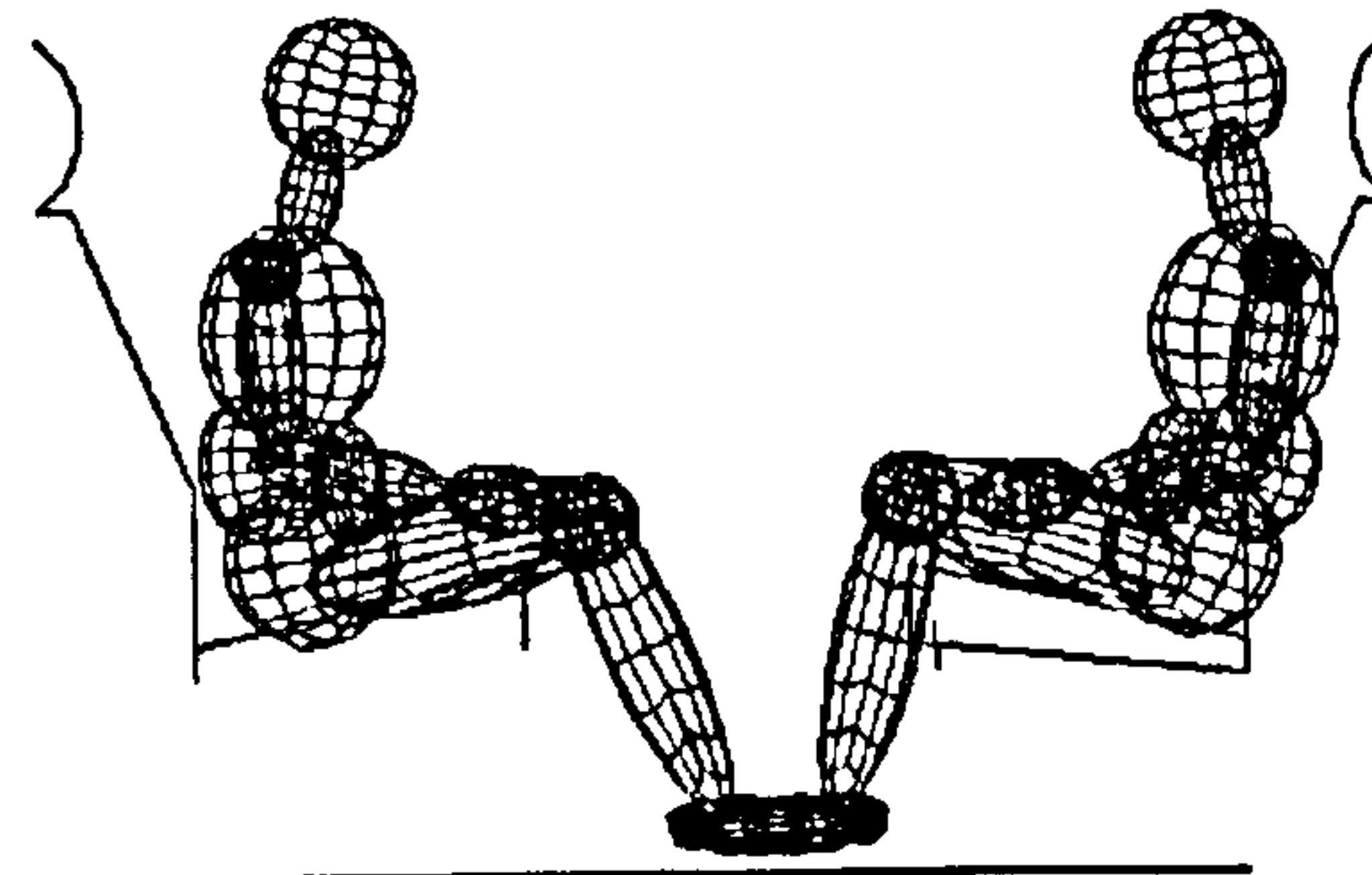
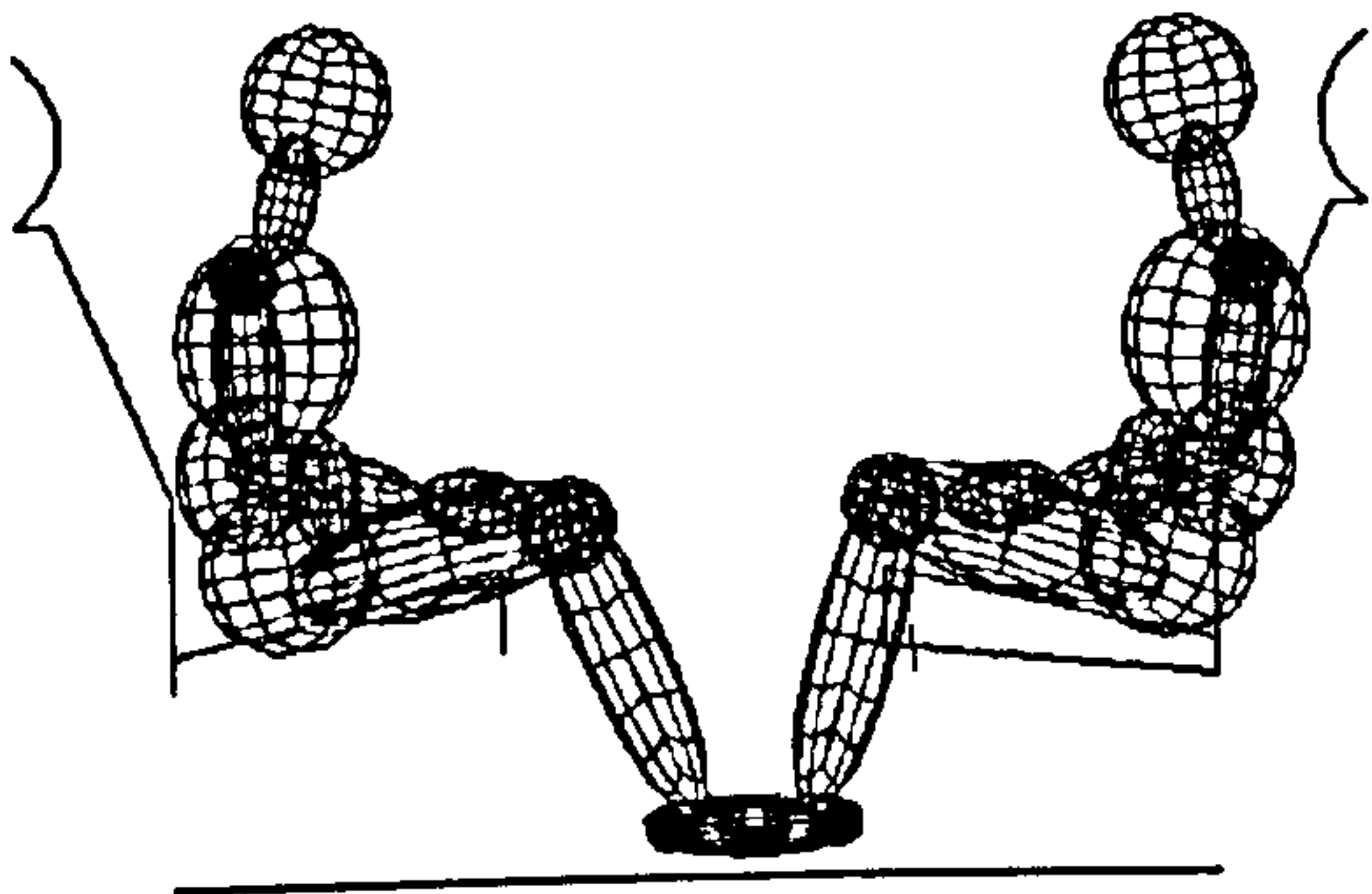
Figure 3.9a : Initial seating position of the occupants.

Bar-spring dummy model

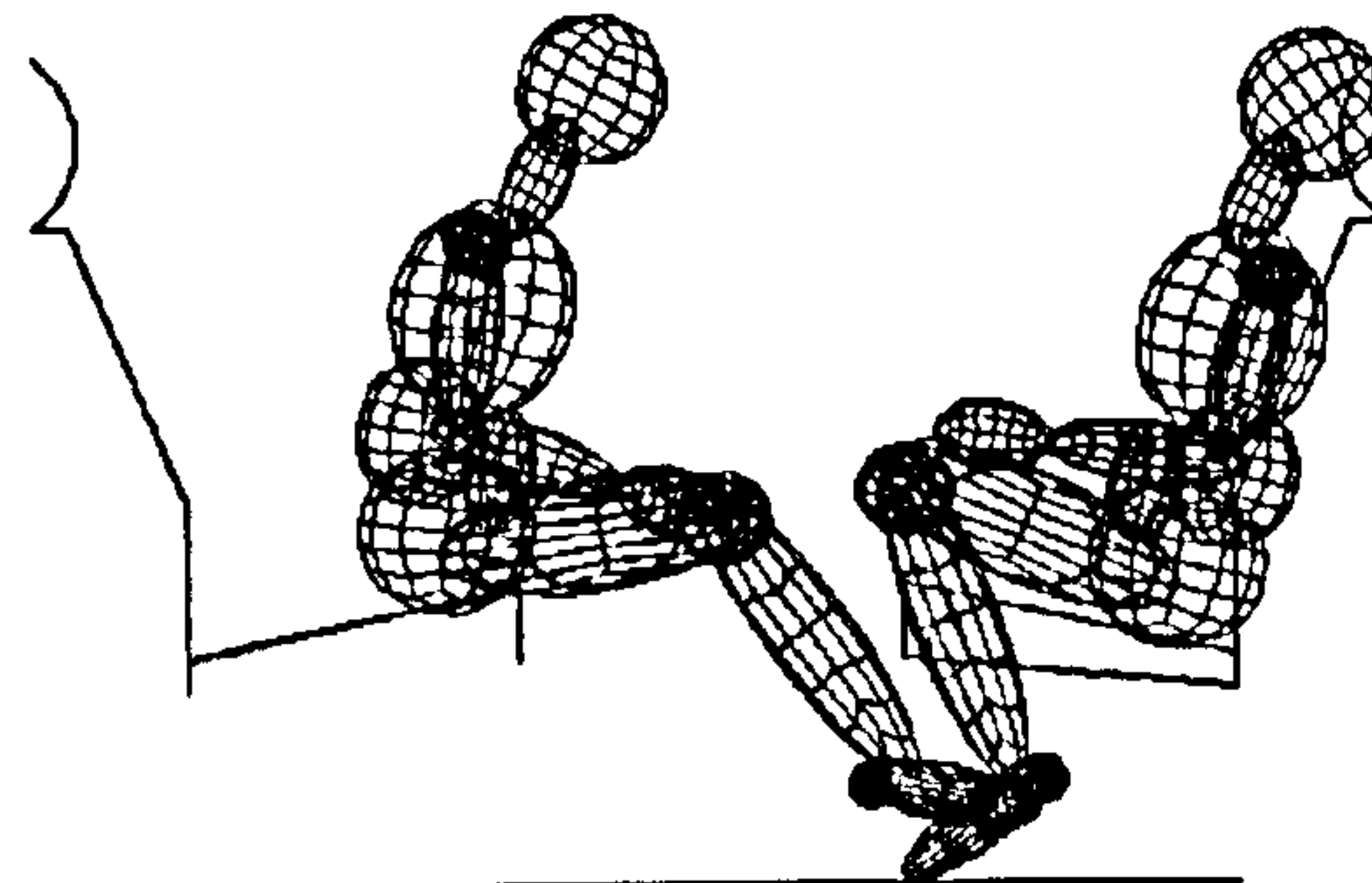
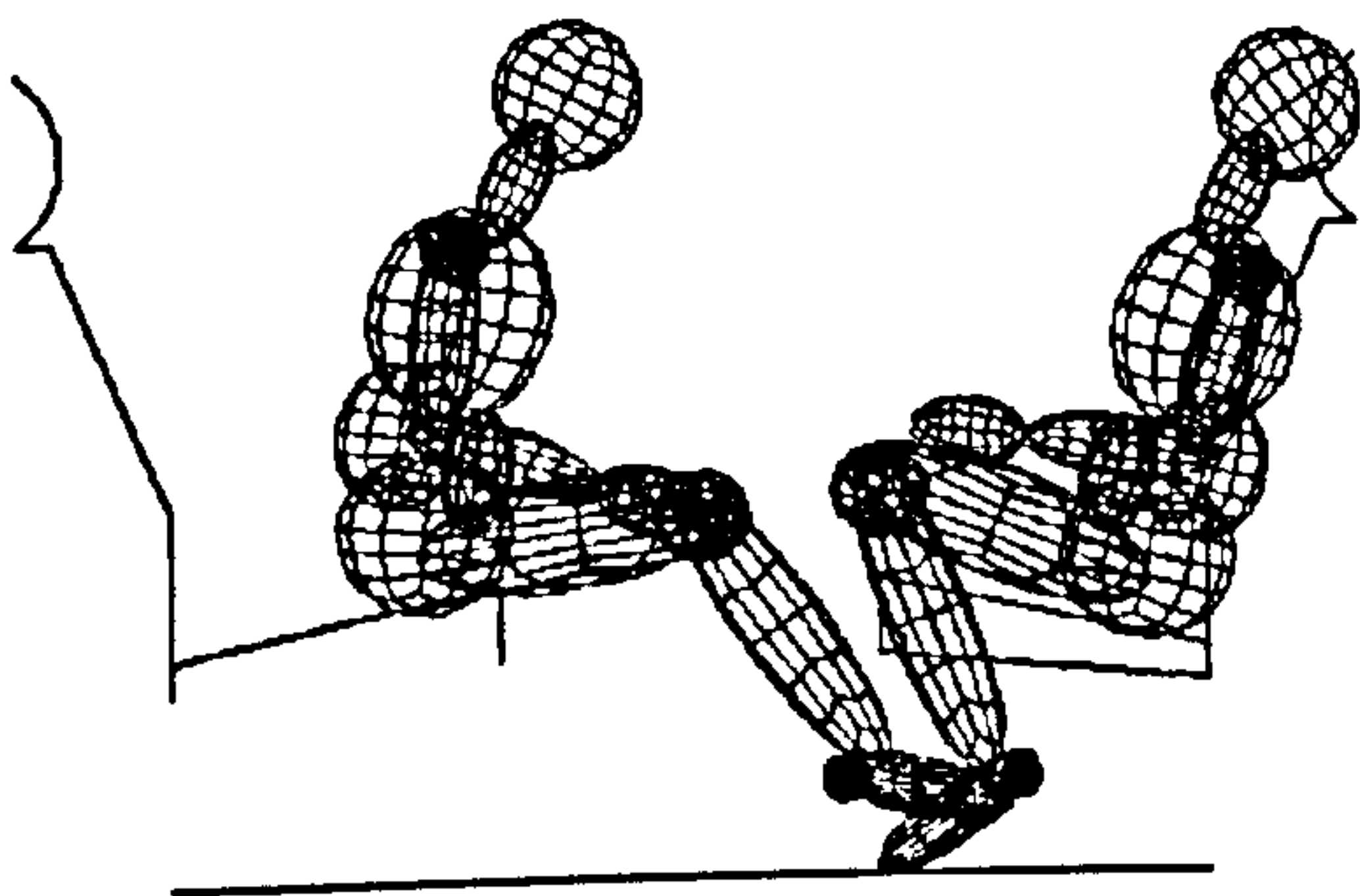
Mass-spring dummy model



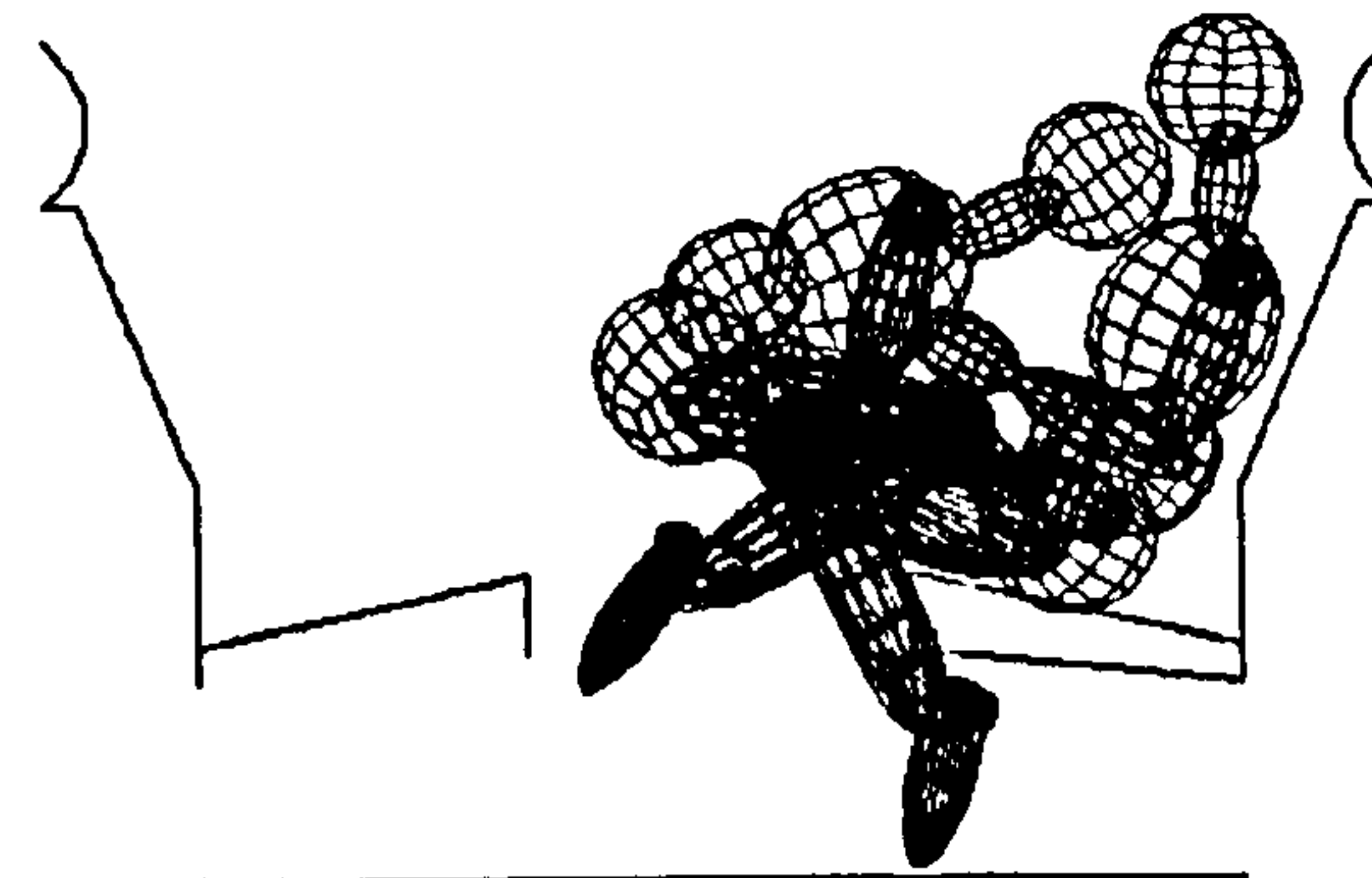
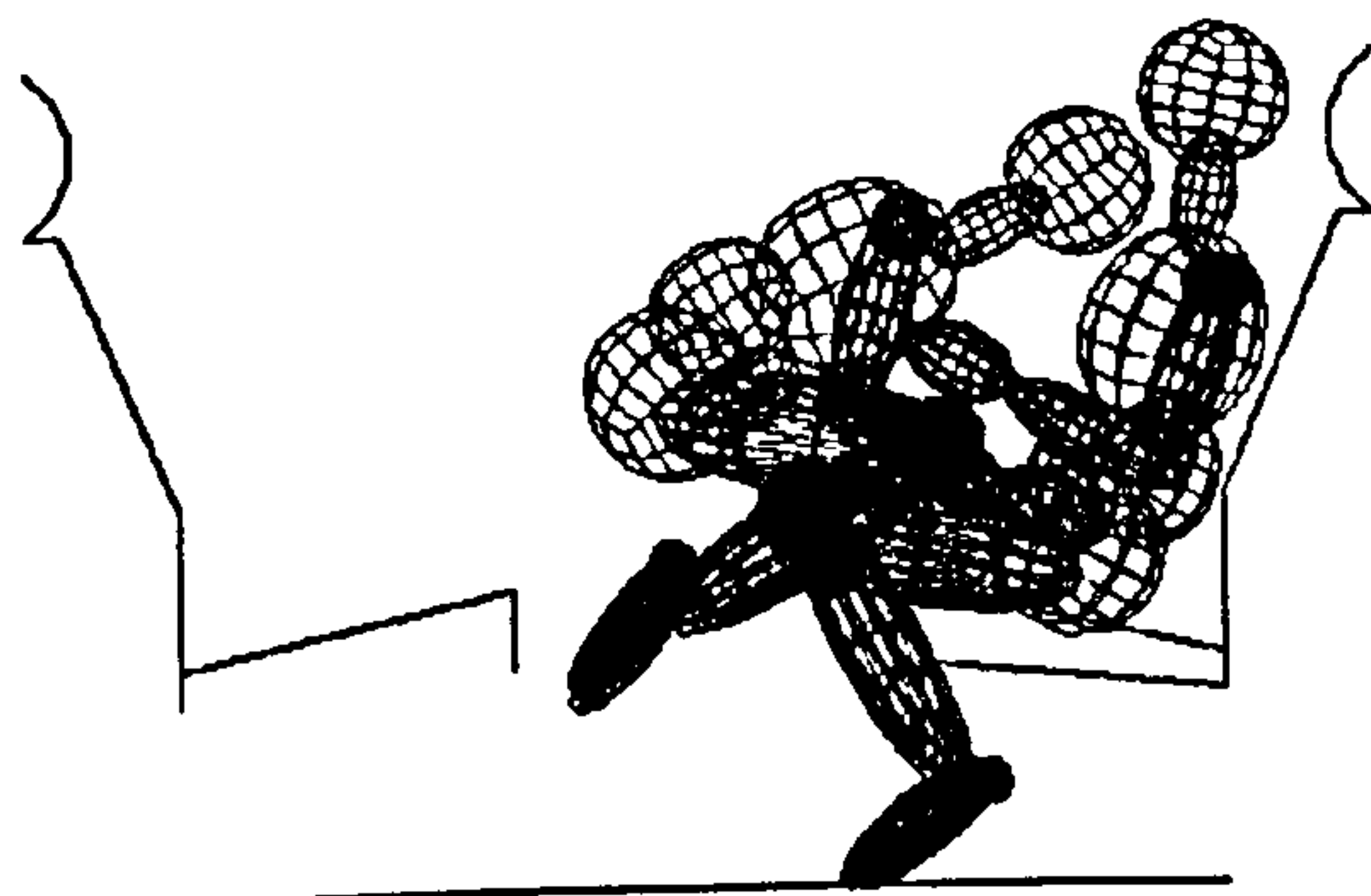
At 0msec



At 50msec



At 150msec



At 250msec

Figure 3.9b : The animation sequence for both dummy models.

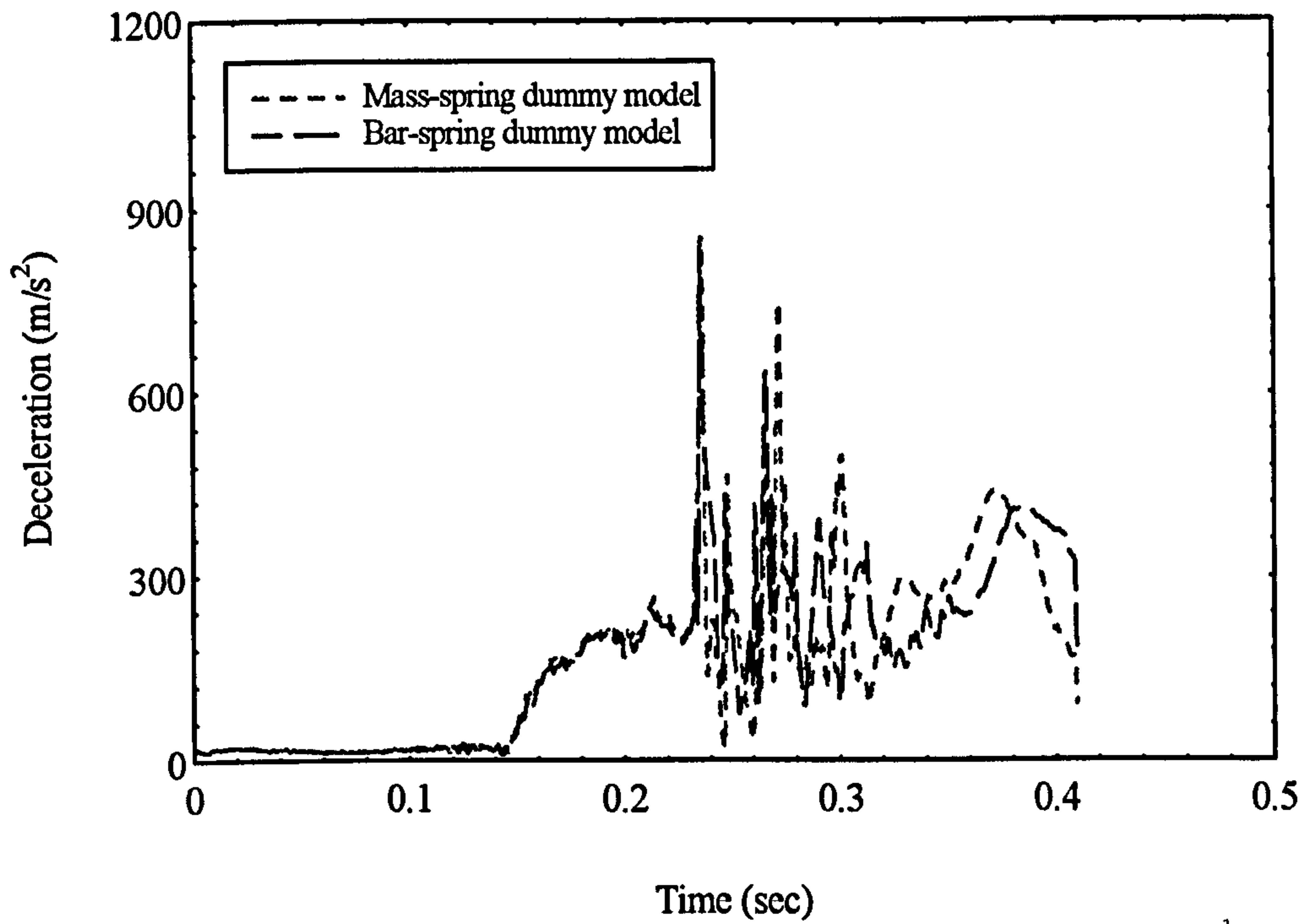


Figure 3.10 : The deceleration-time history for the striking occupants' head.

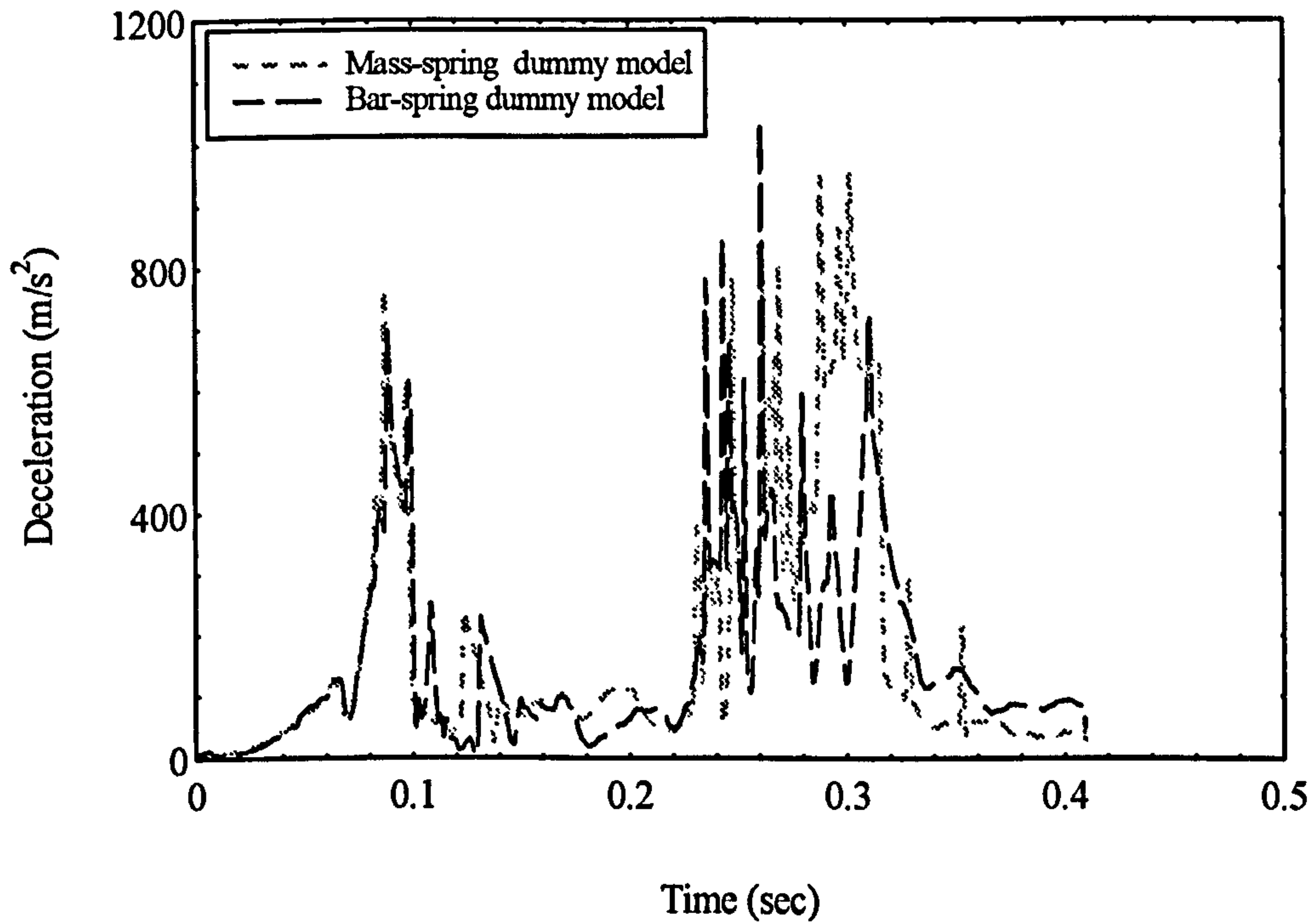


Figure 3.11 : The deceleration-time history for the struck occupants' head.

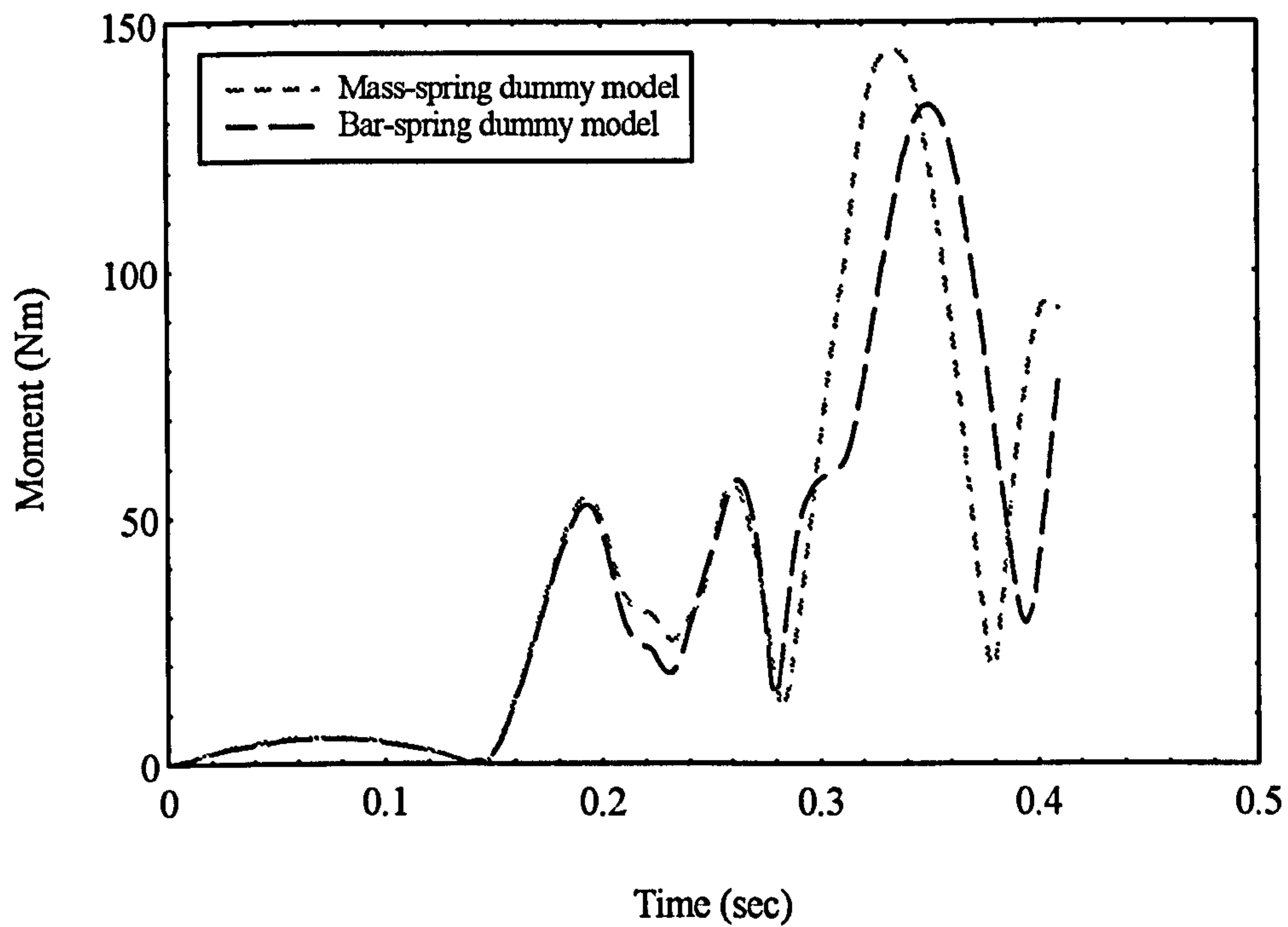


Figure 3.12 : The neck flexion bending moment-time history for the striking occupants.

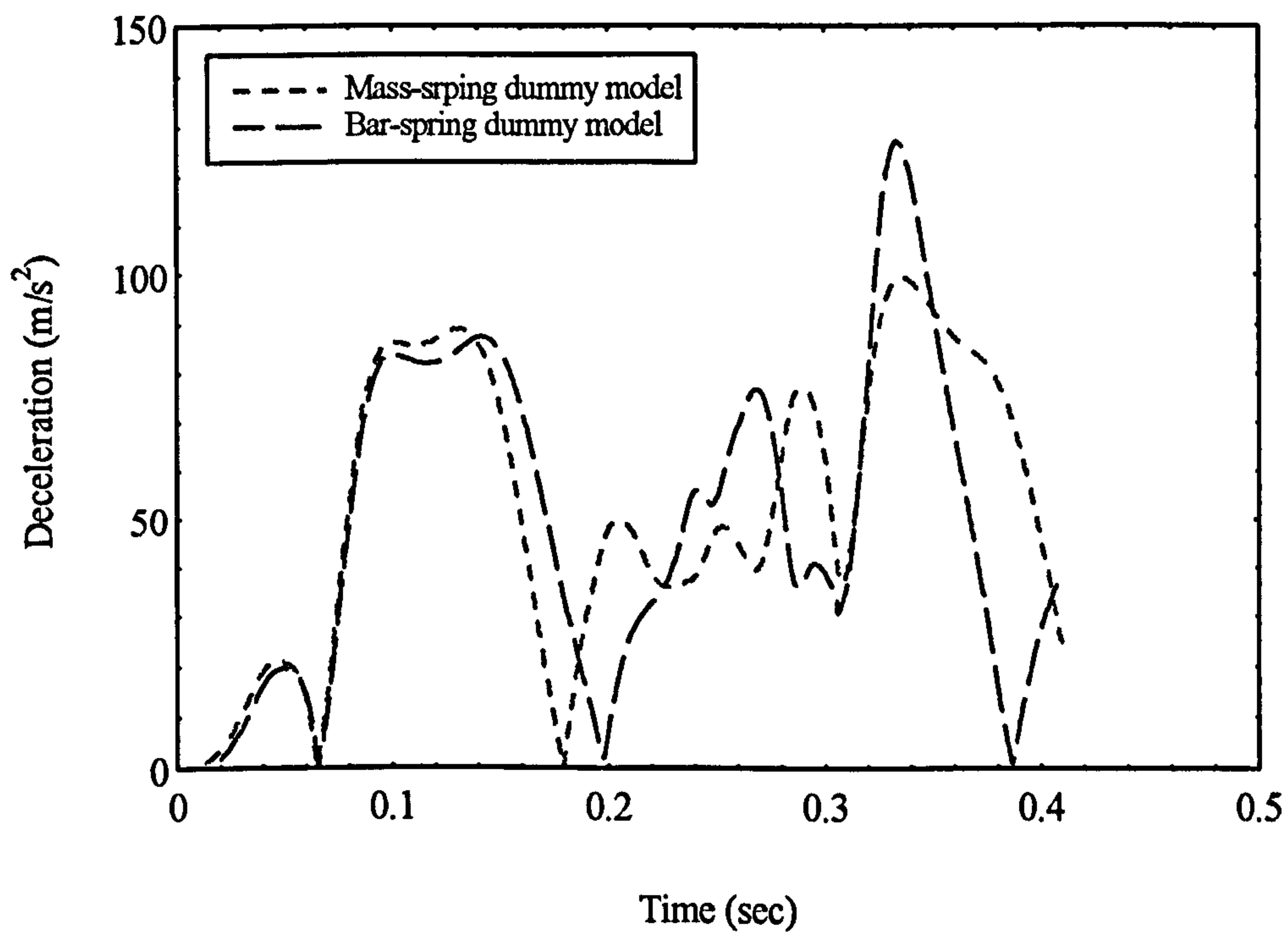


Figure 3.13 : The neck flexion bending moment-time history for the struck occupants.

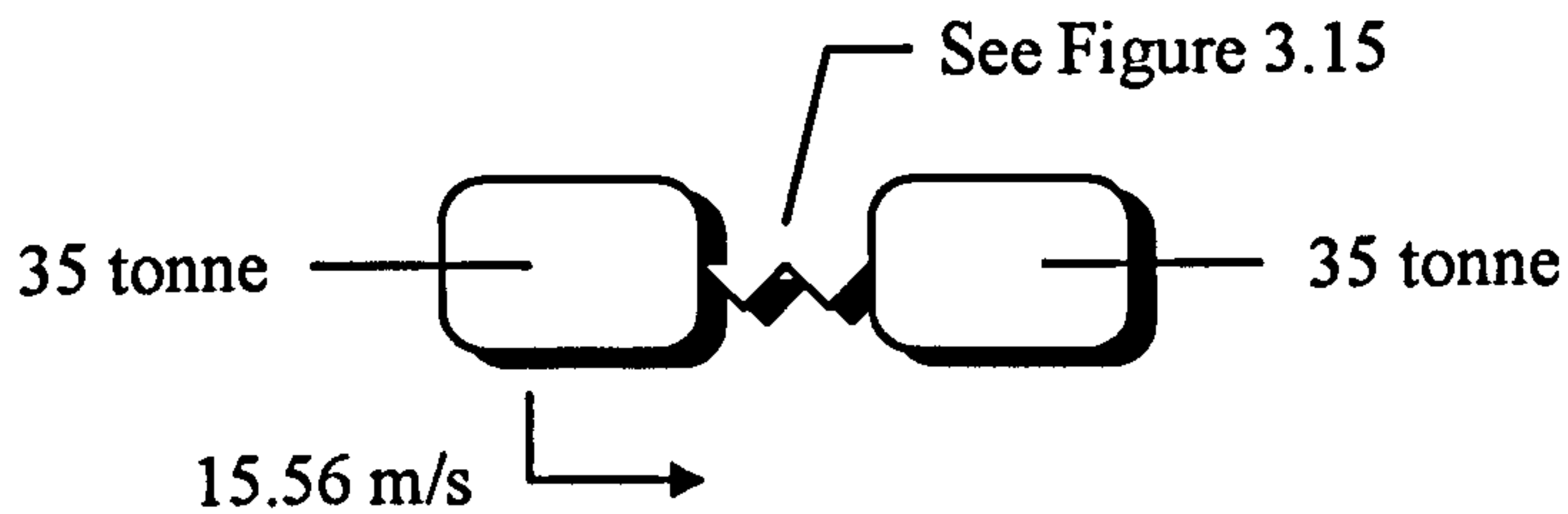


Figure 3.14 : The baseline model used for the parametric study.

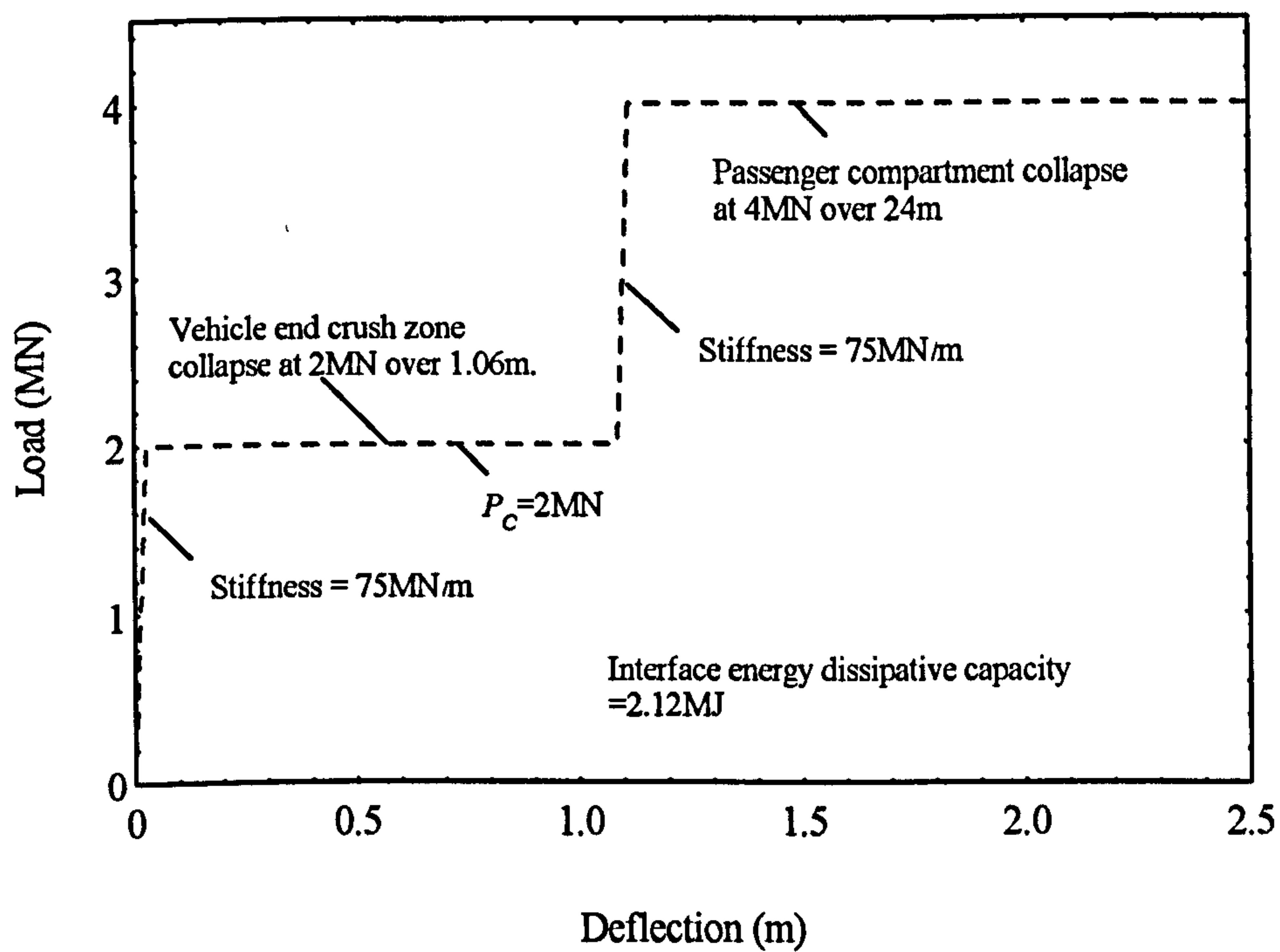


Figure 3.15 : The load-deflection characteristic for the baseline spring.

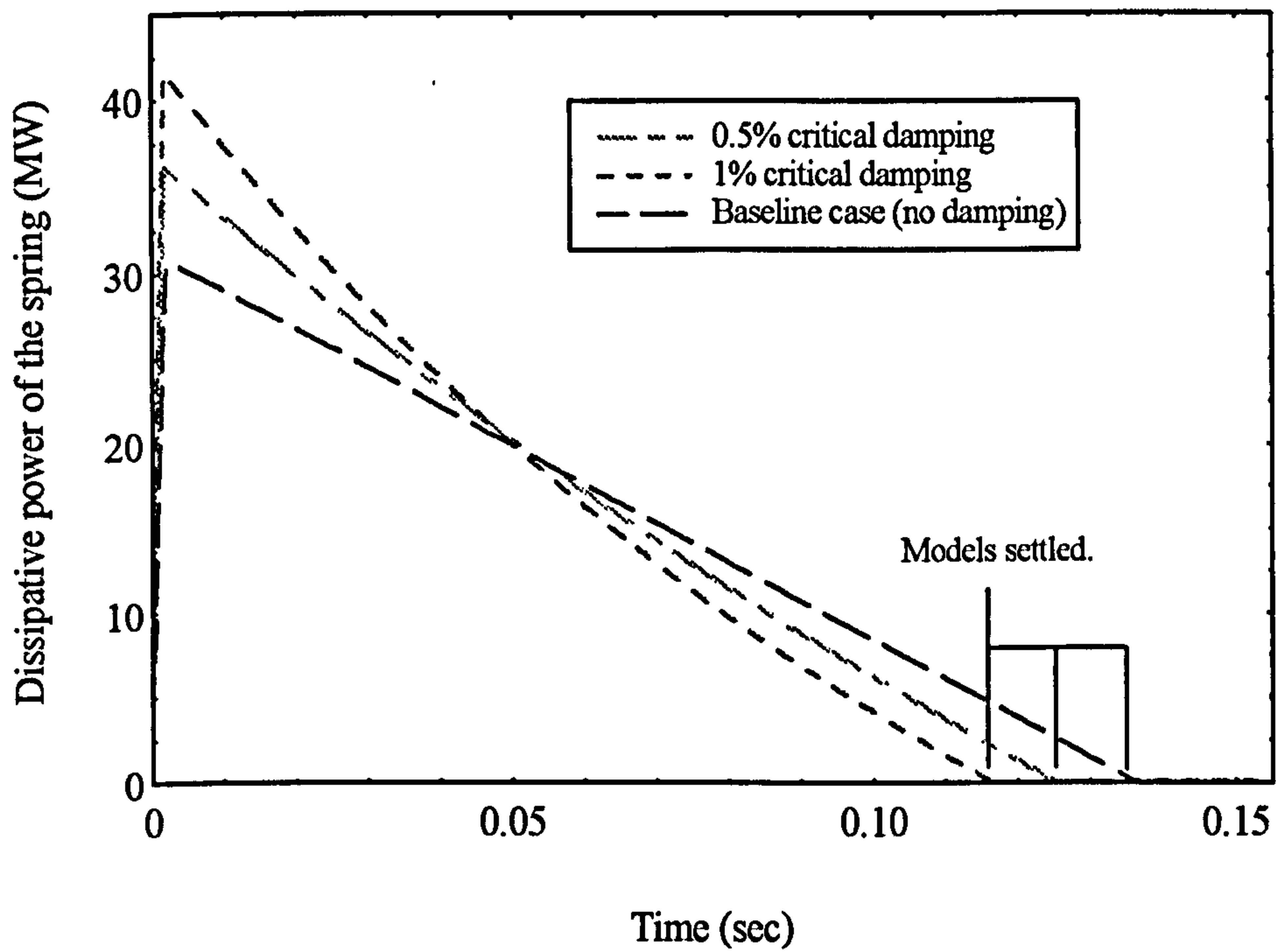


Figure 3.16 : The effects of damping on the energy dissipative power.

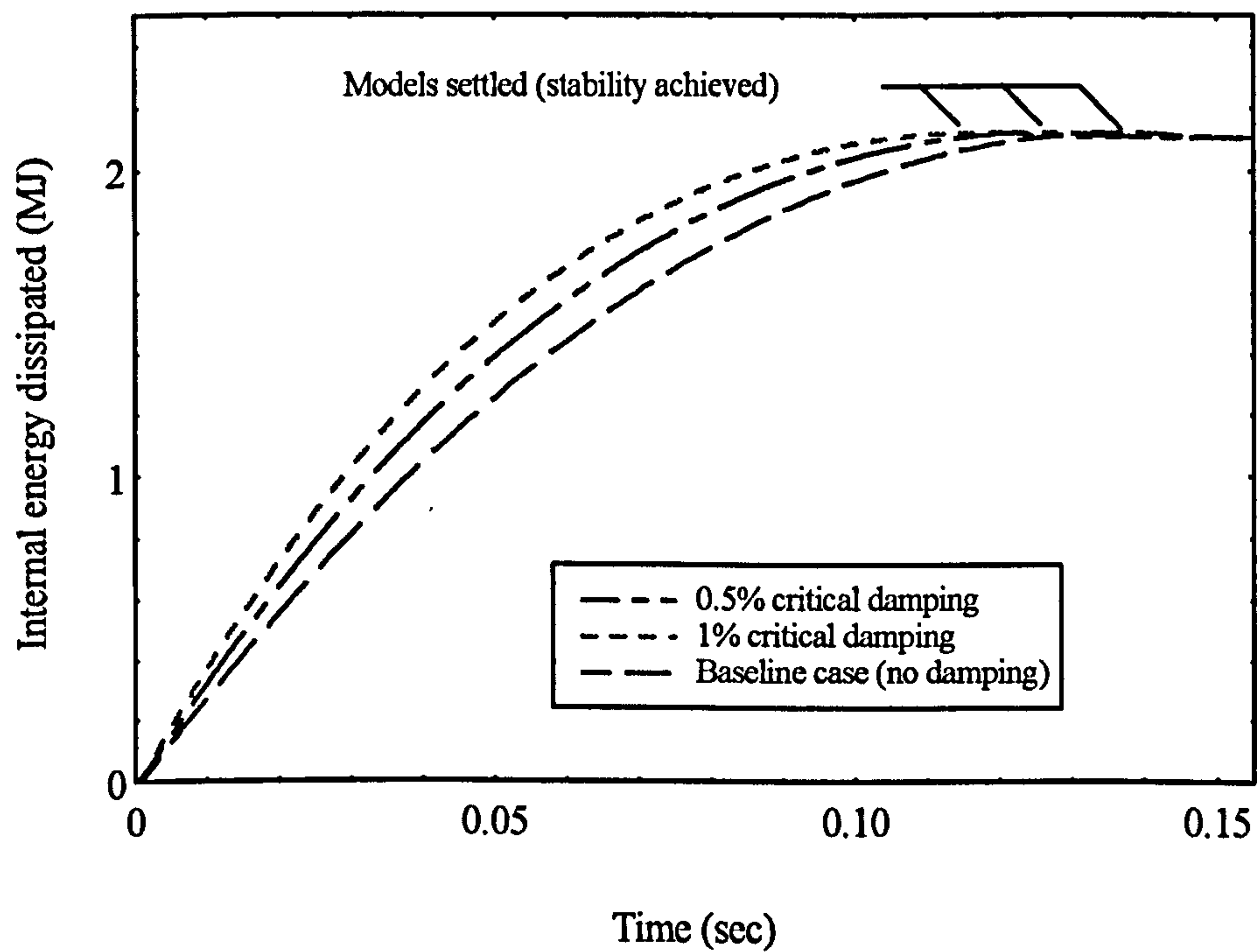


Figure 3.17 : The effects of damping on internal energy dissipation.

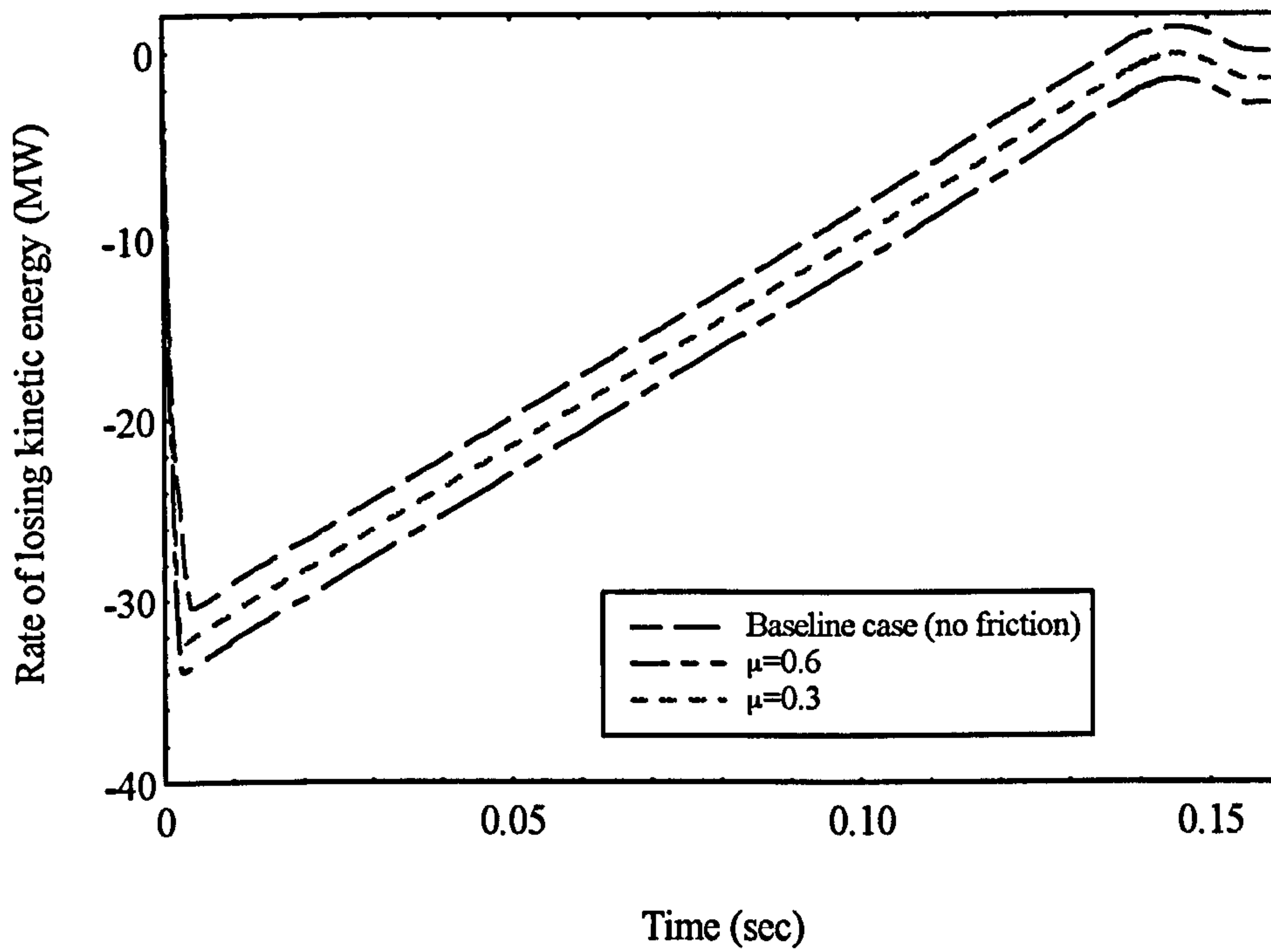


Figure 3.18 : The effects of friction on the total energy dissipative power.

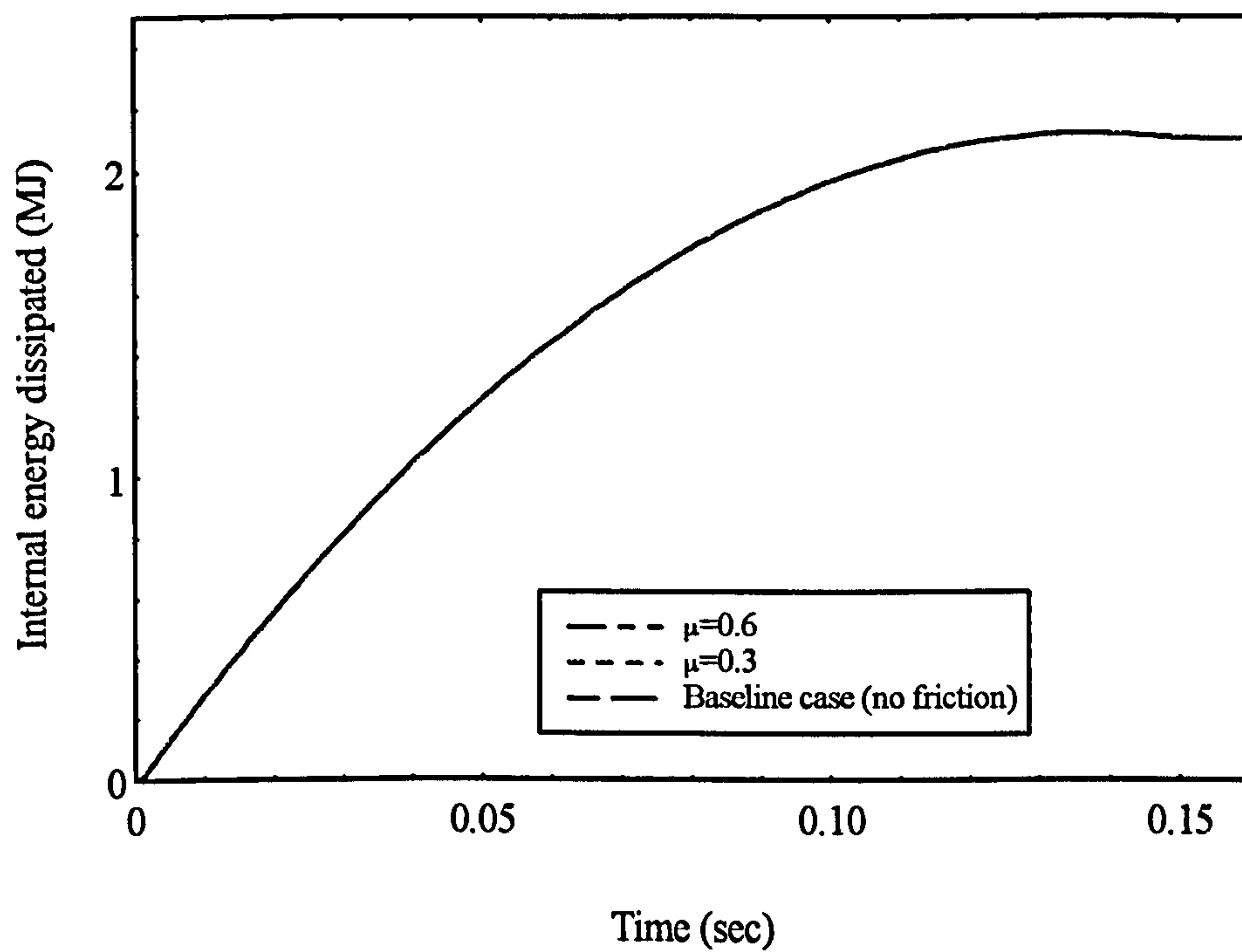


Figure 3.19 : The effects of friction on the dissipated energy.

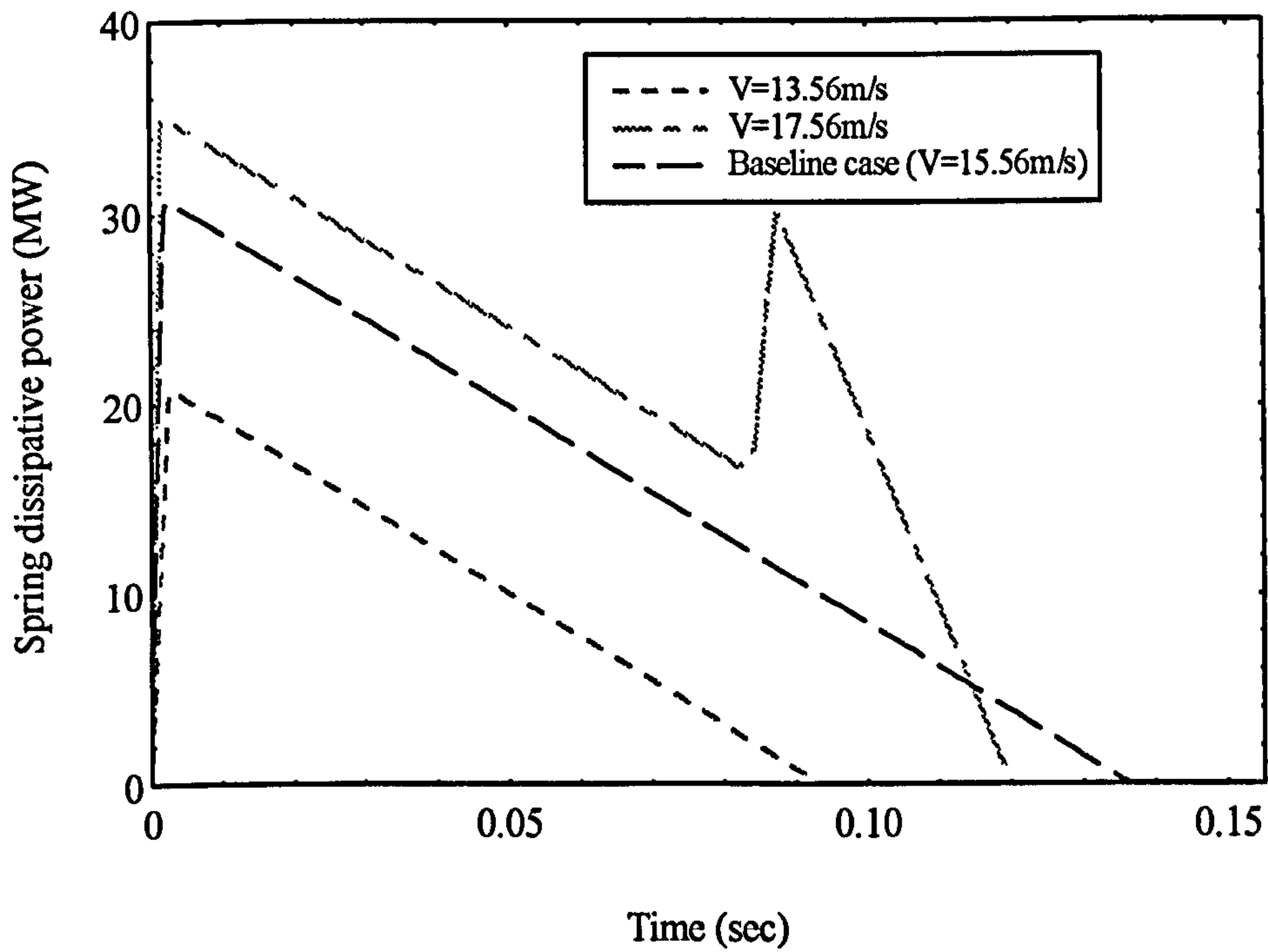


Figure 3.20 : The effects of initial velocity on the spring dissipative power.

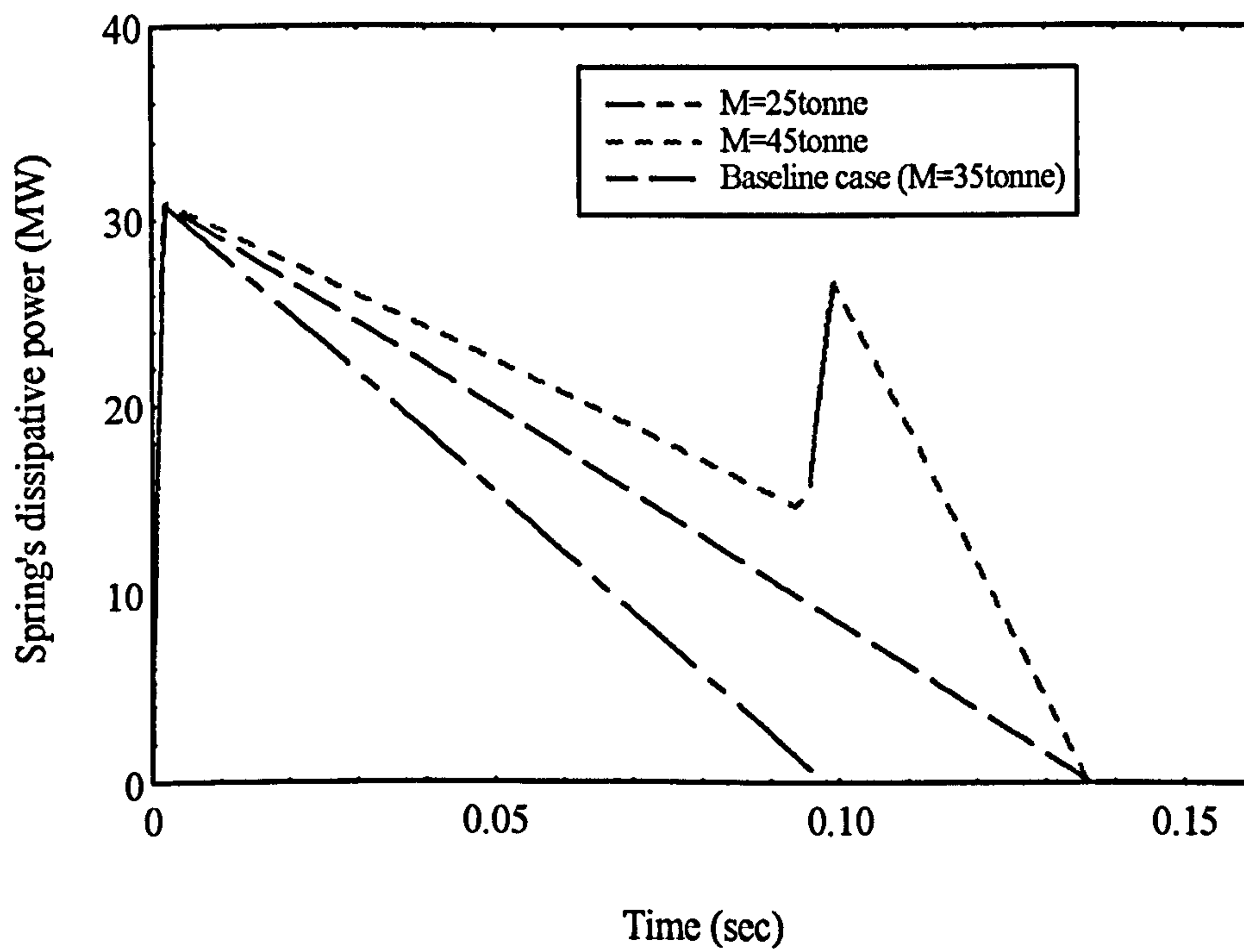


Figure 3.21 : The effects of coach mass on the spring dissipative power.

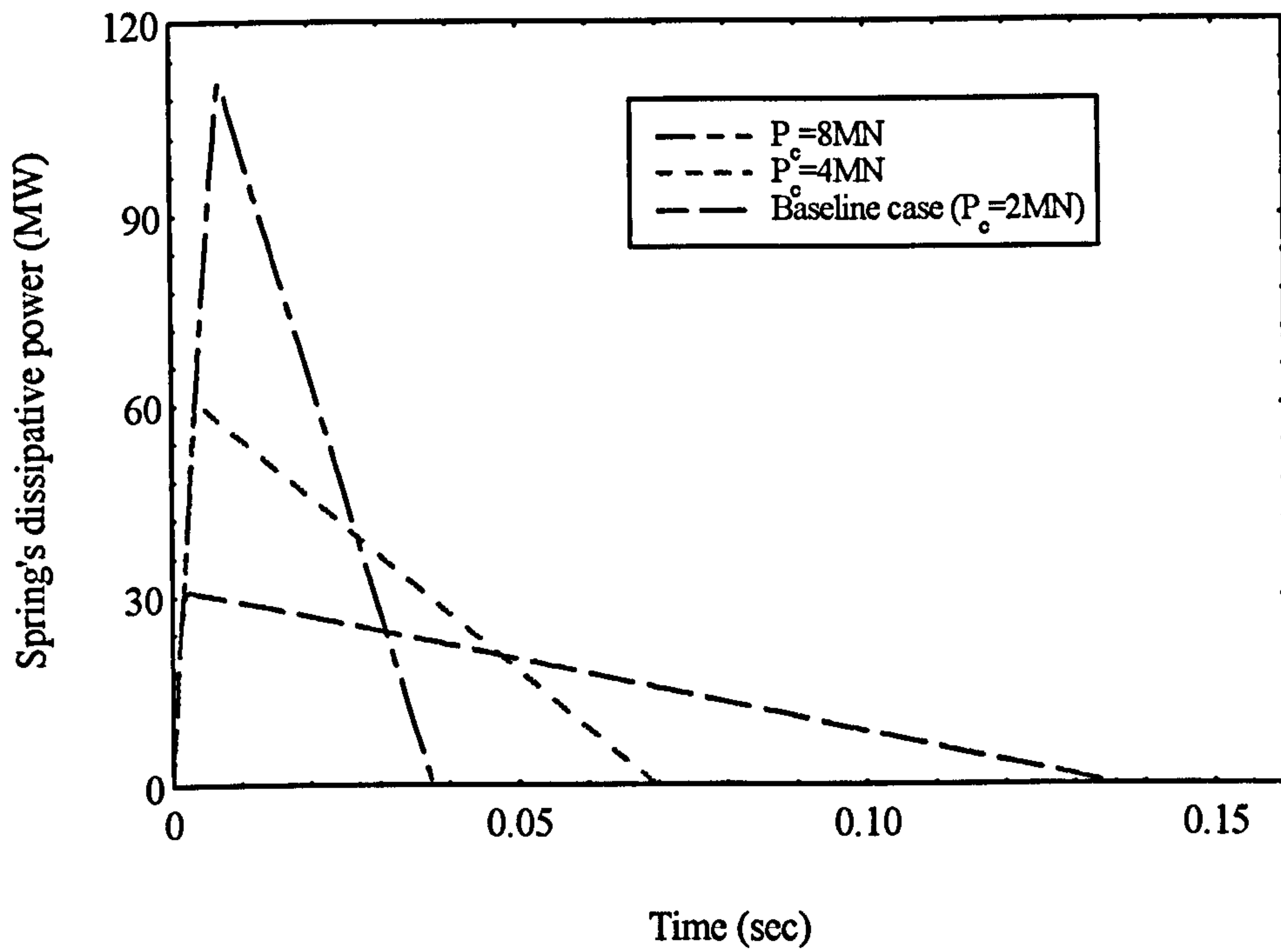


Figure 3.22 : The effects of spring collapse force on its dissipative power.

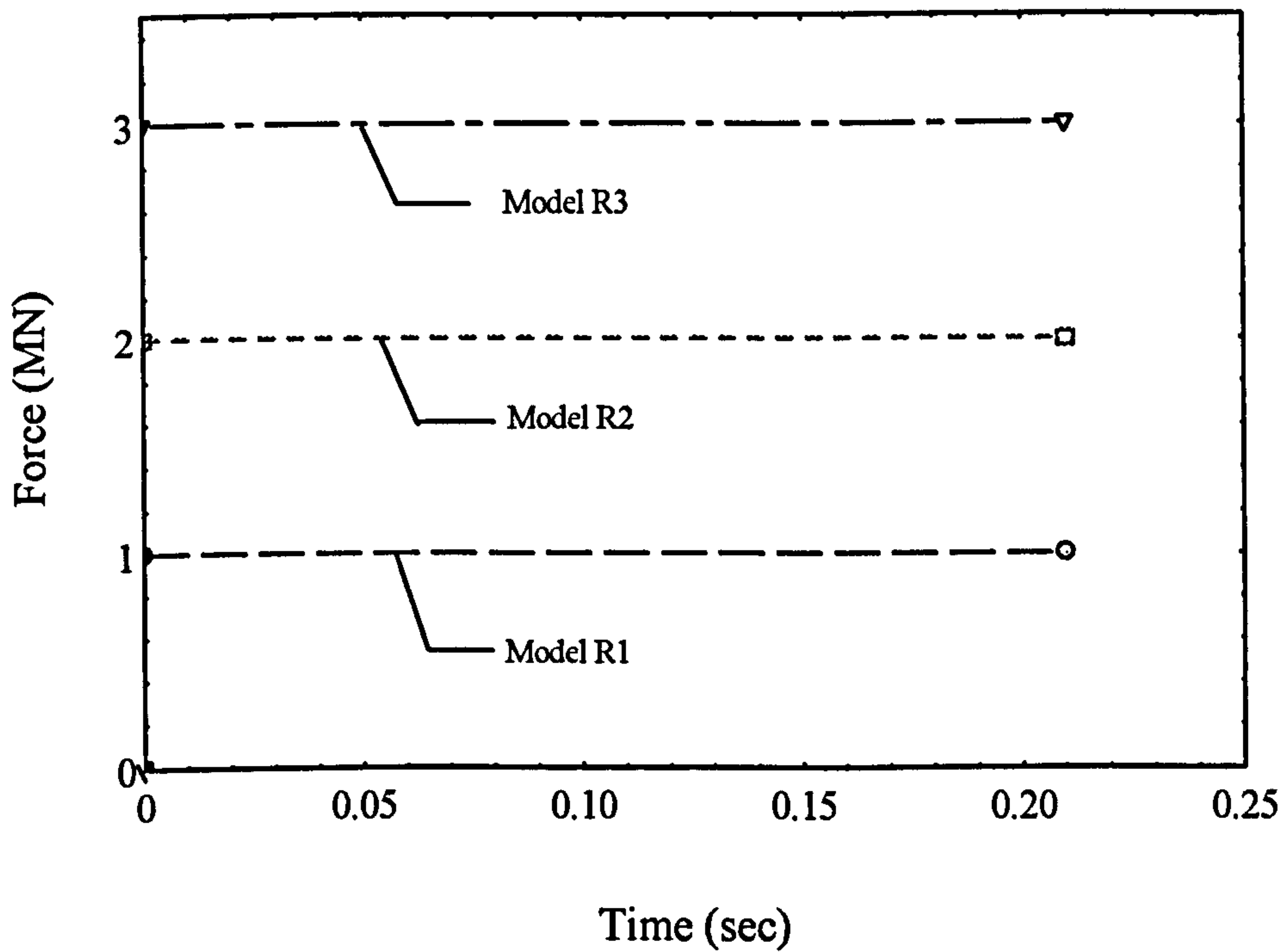


Figure 3.23 : The magnitudes of the external rectangular impulses.

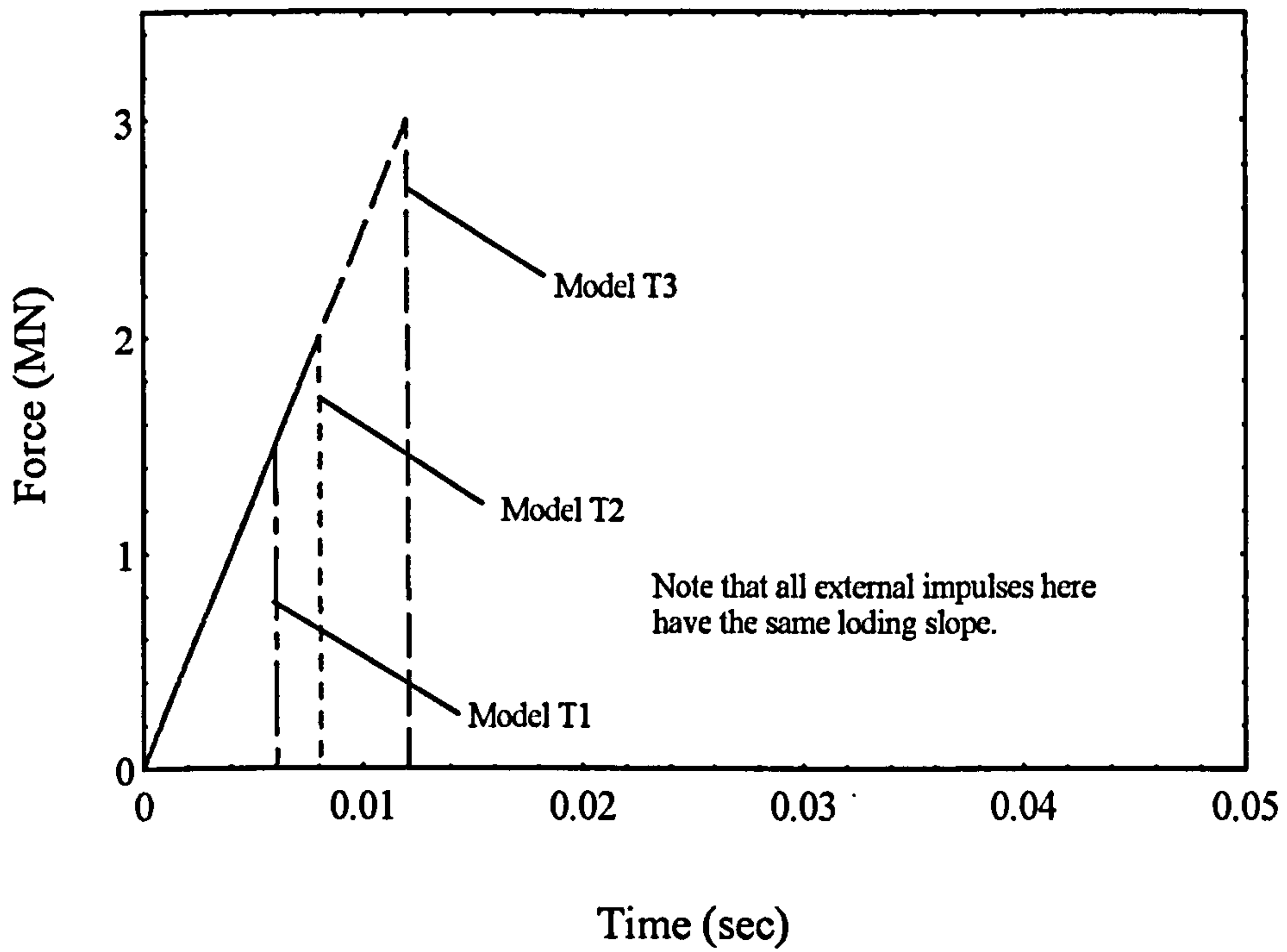


Figure 3.24 : The magnitudes of the external triangular impulses.

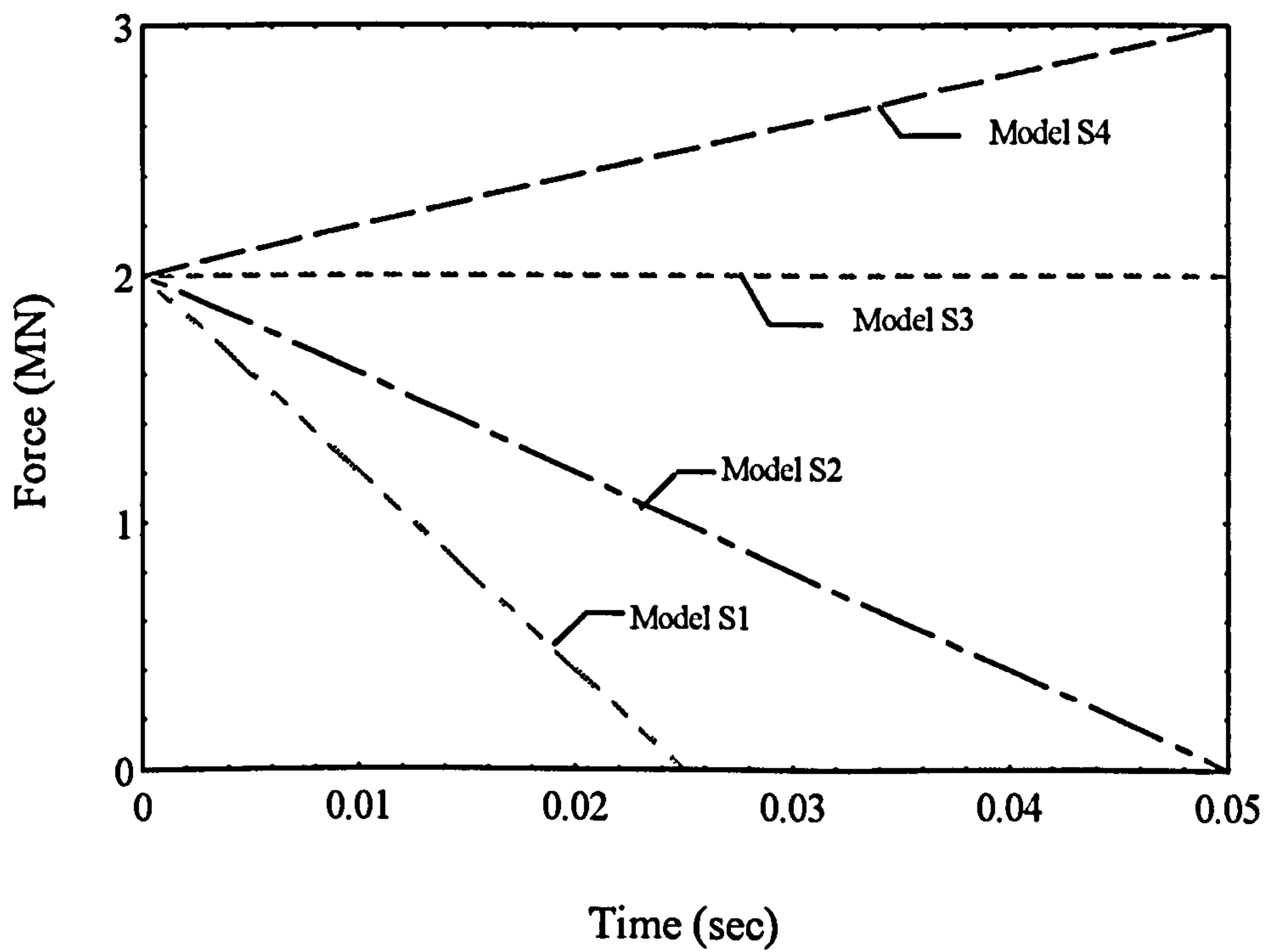


Figure 3.25 : The slopes of the external ramp impulses.

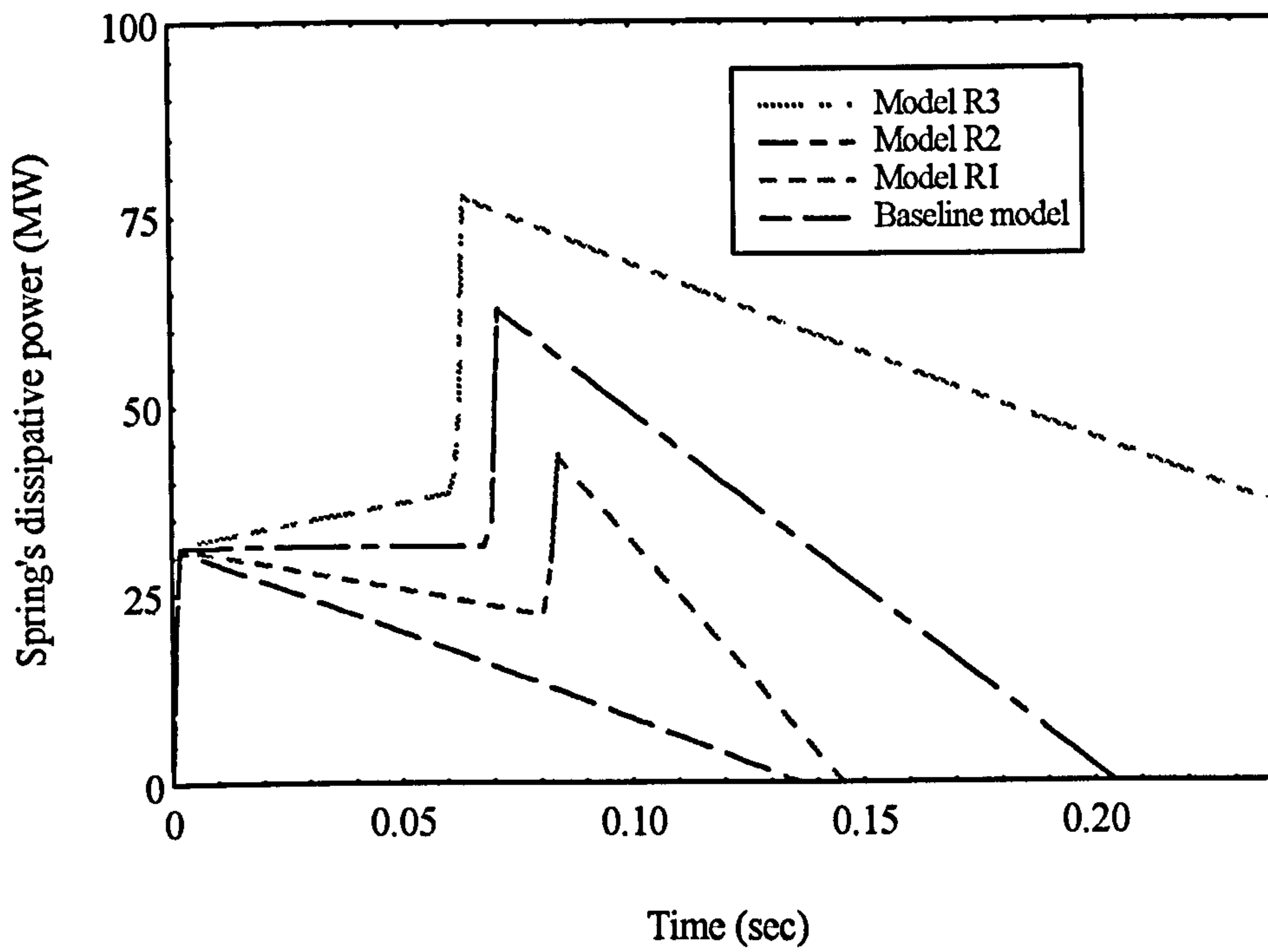


Figure 3.26 : The effects of the magnitude of external rectangular impulses.

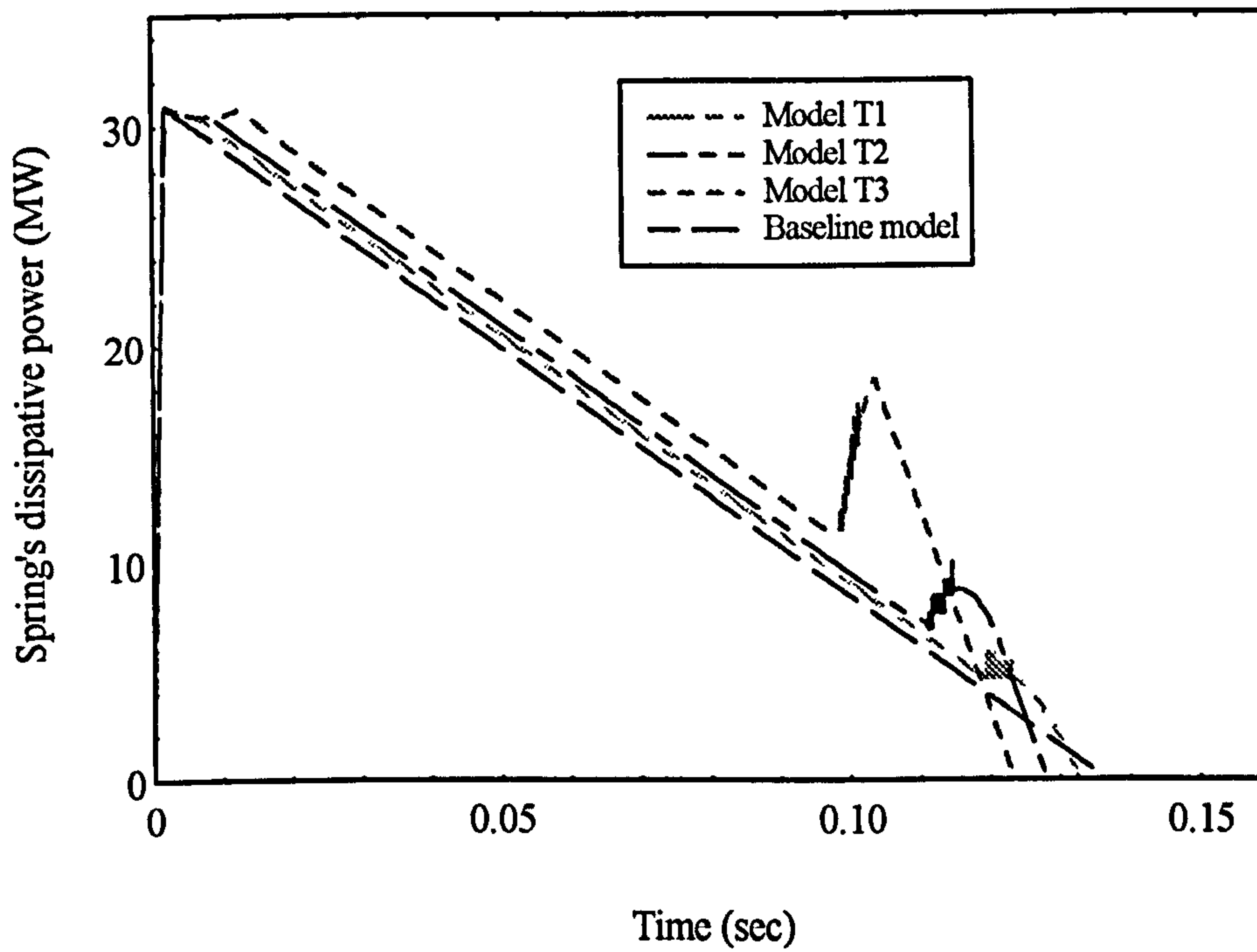


Figure 3.27 : The effects of the magnitude of external triangular impulses.

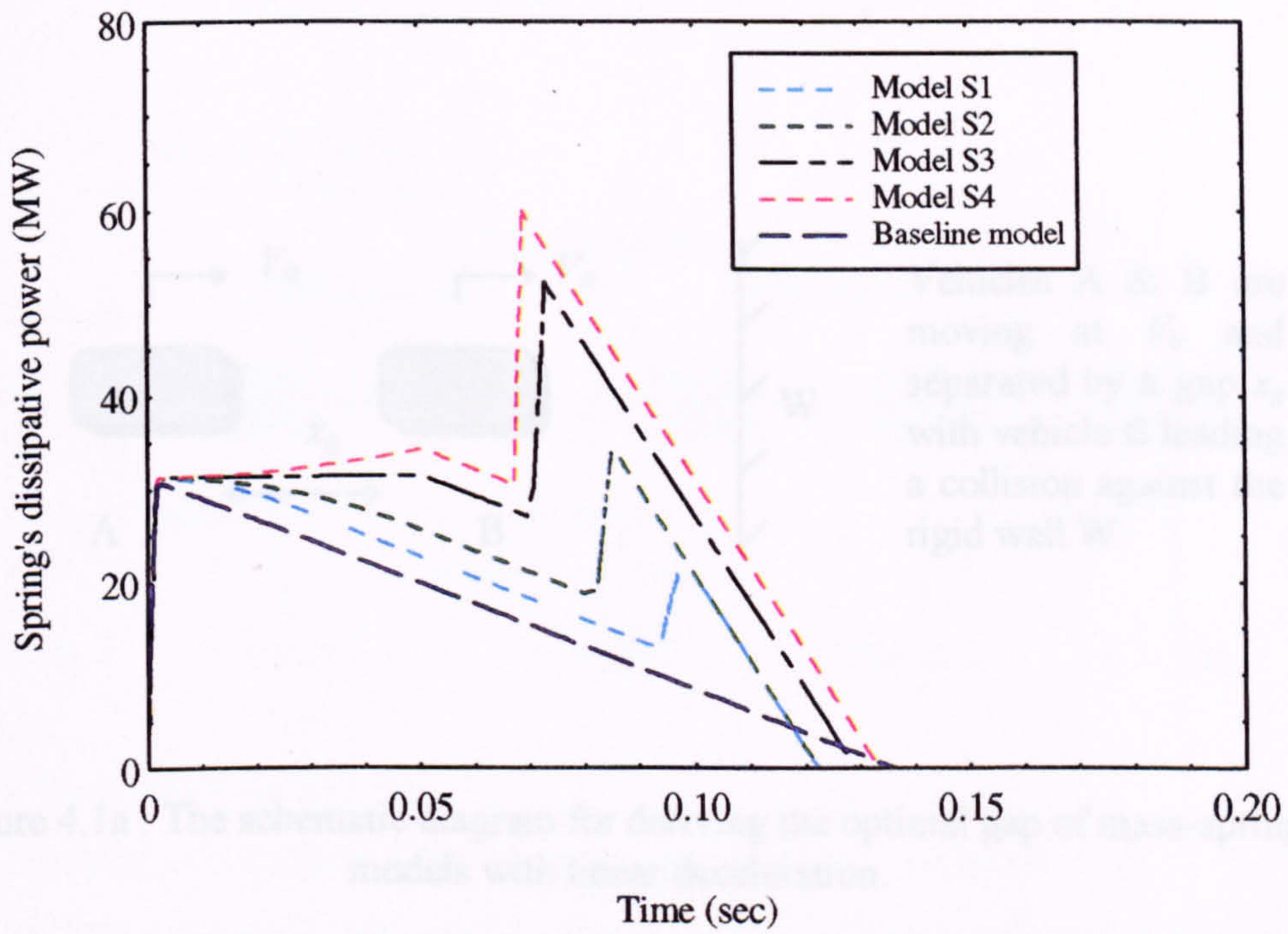


Figure 3.28 : The effects of the slope of external ramp impulses.



Figure 4.1b : The kinematics graphical interpretation of optimal gap sizes for cases with linear deceleration.

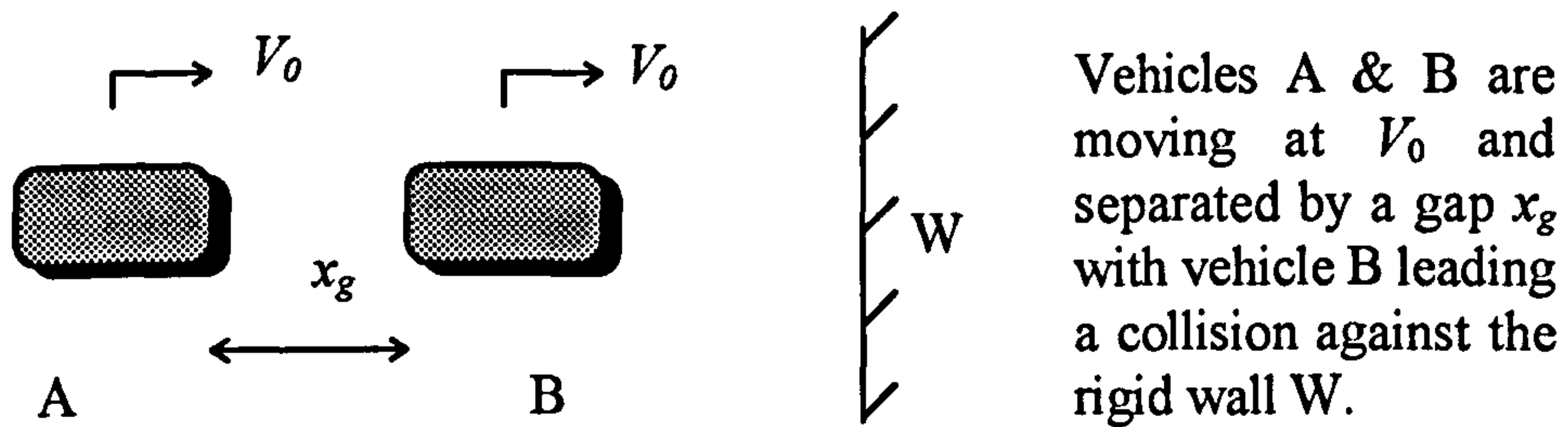


Figure 4.1a : The schematic diagram for deriving the optimal gap of mass-spring models with linear deceleration.

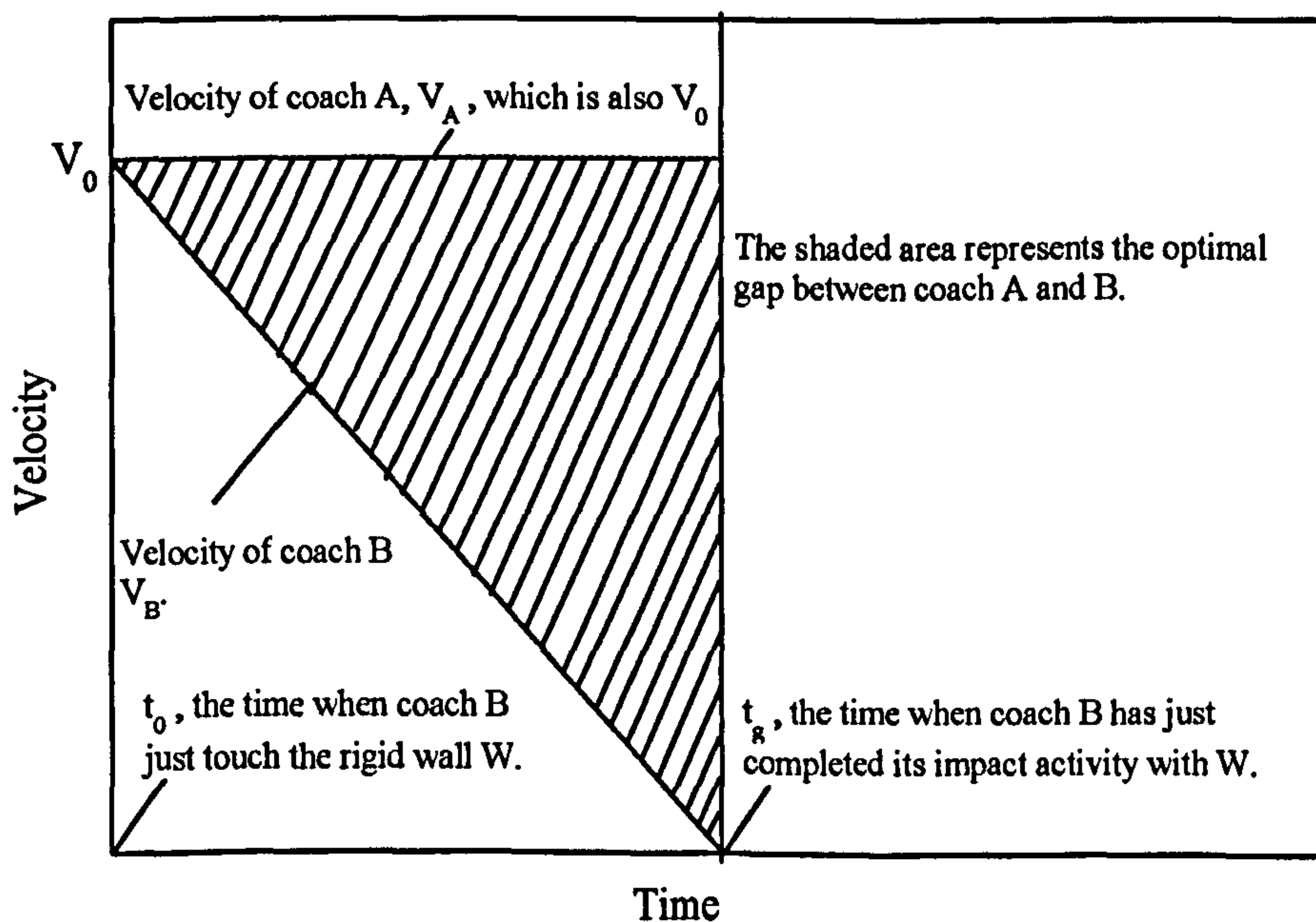
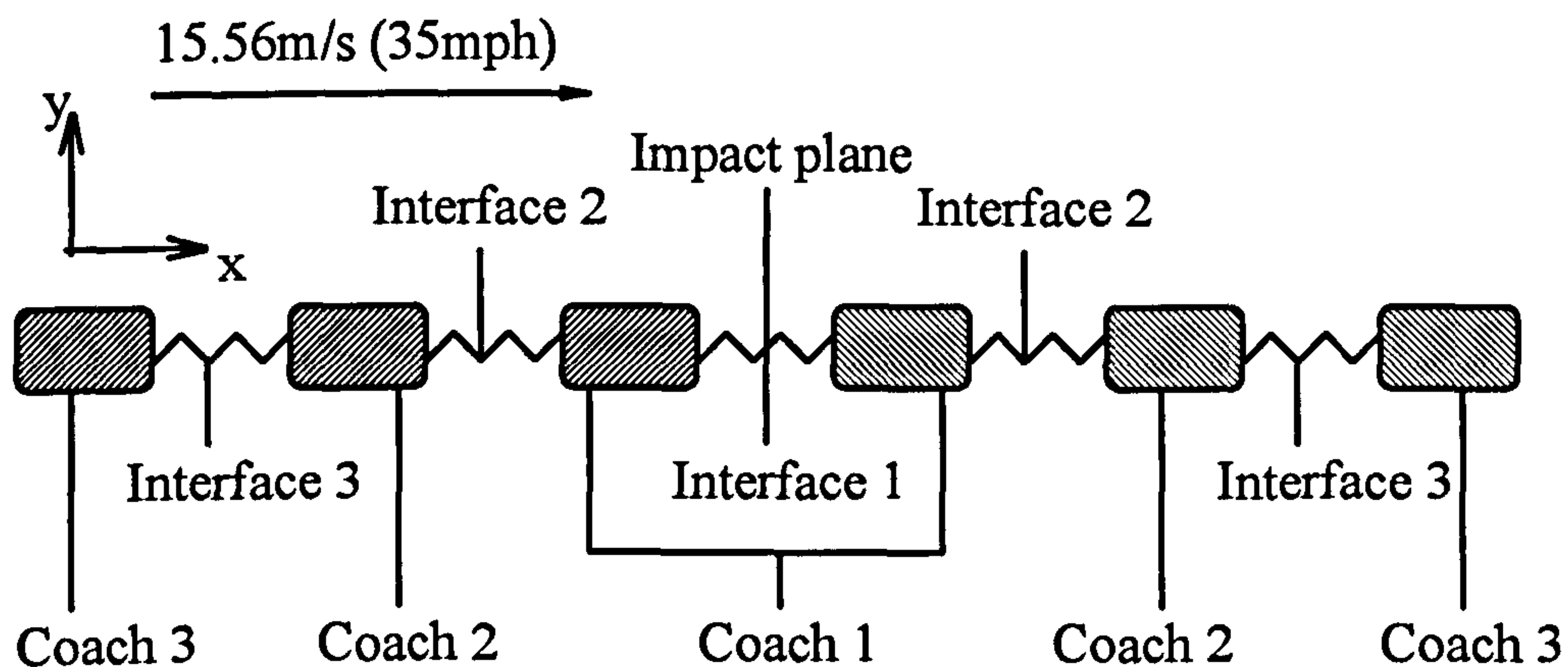


Figure 4.1b : The kinematics graphical interpretation of optimal gap sizes for cases with linear deceleration.



Note:

- (1) Each coach is 35tonne.
- (2) Spring in interface 1 has characteristics shown in figure 4.3a.
- (3) Other interfaces' springs has characteristics shown in figure 4.3b.

Figure 4.2 : The schematic description of the models used in Section 4.2.

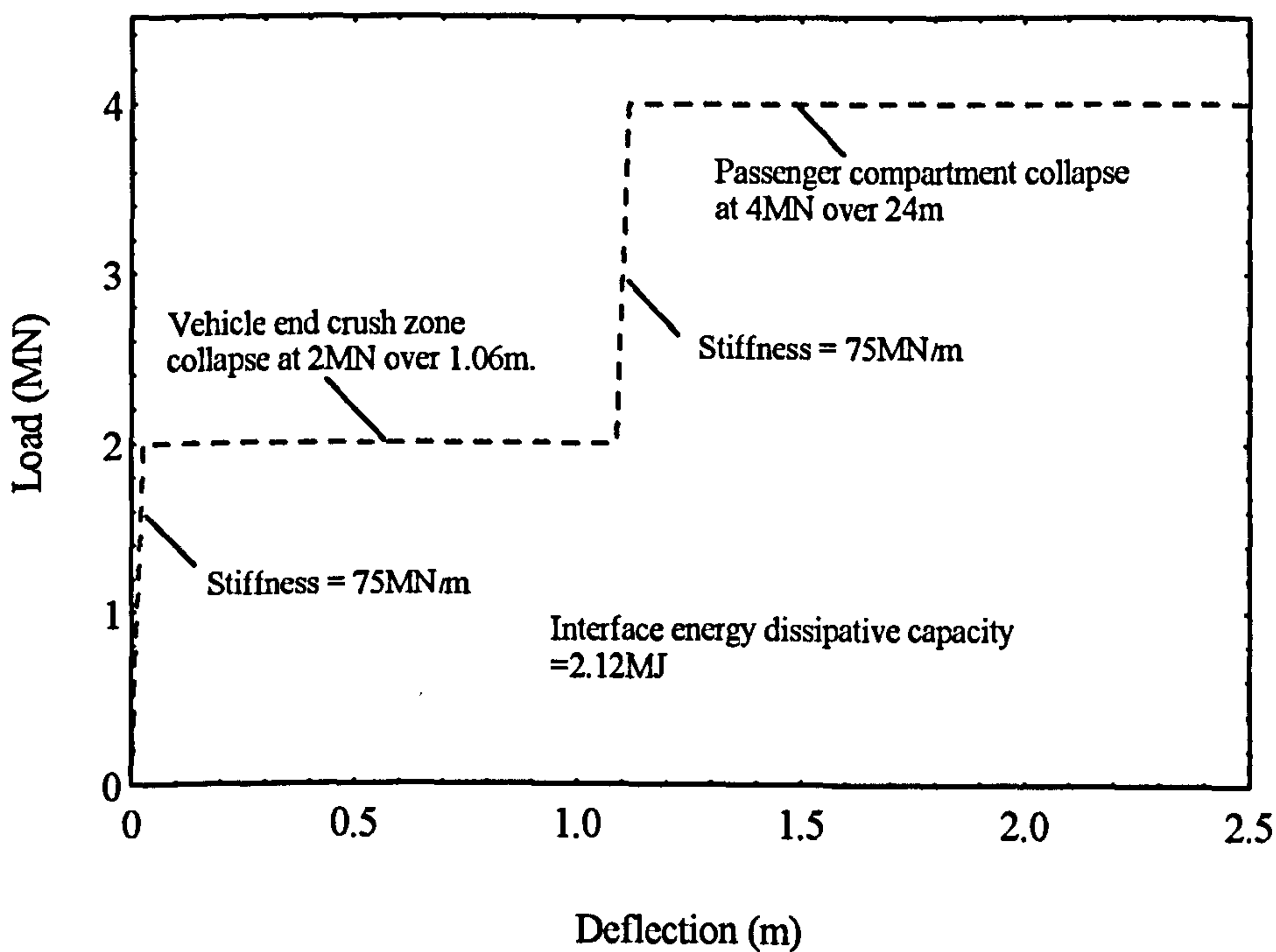


Figure 4.3a : The spring collapse characteristic of impact interface.

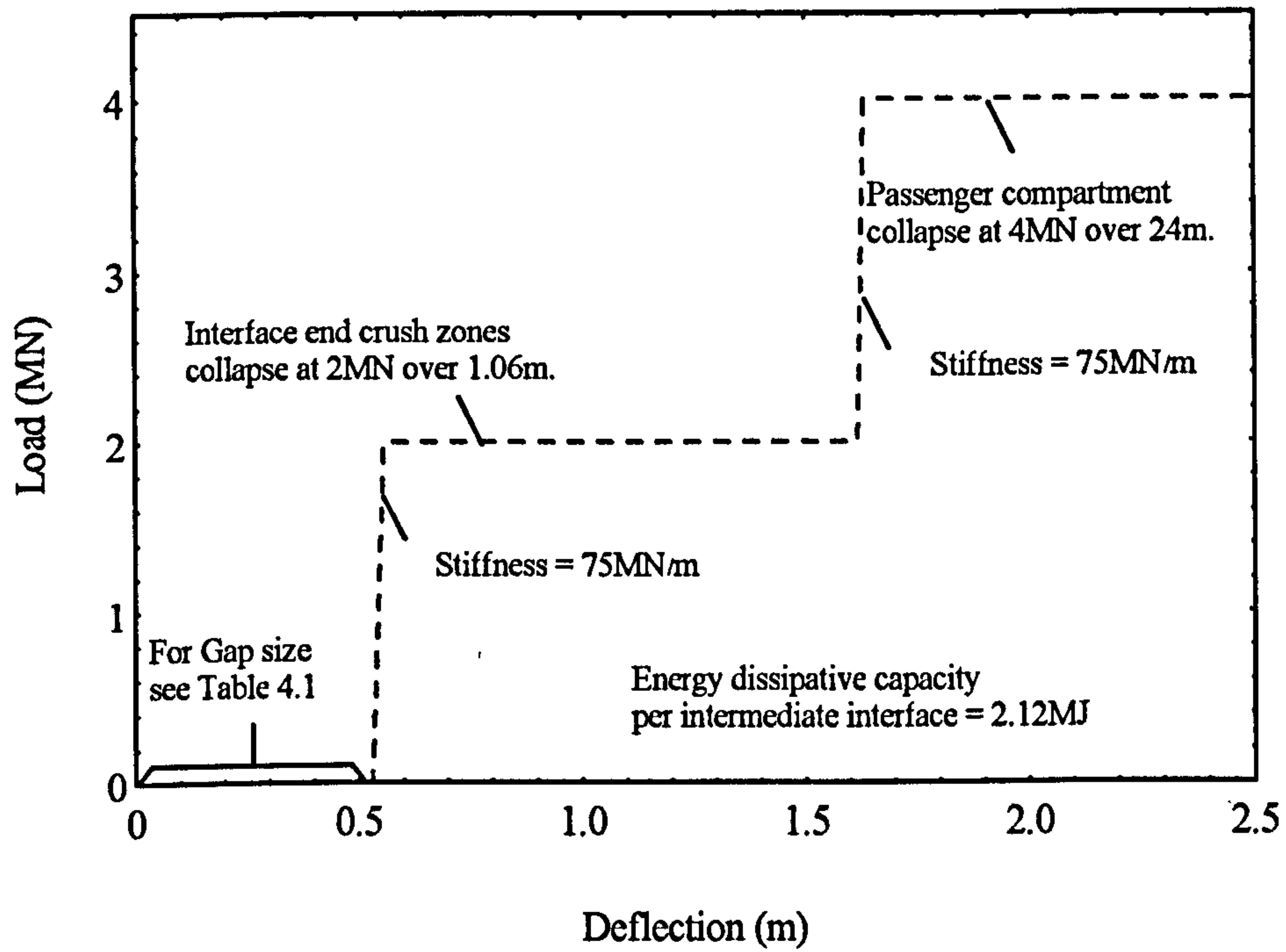


Figure 4.3b : The collapse characteristic for springs in the intermediate interfaces

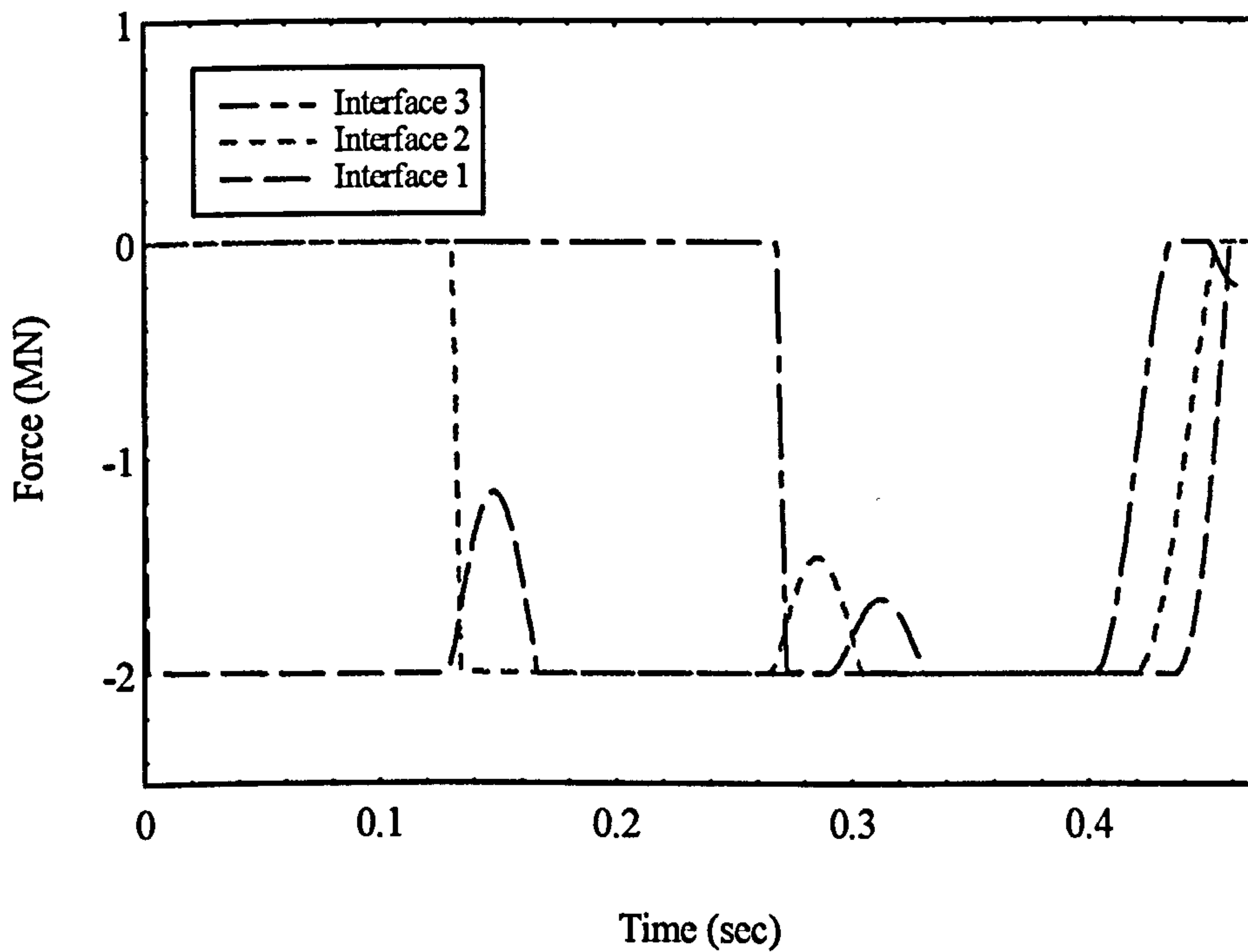


Figure 4.4a : The force-time history of various interfaces for the model Gap3.

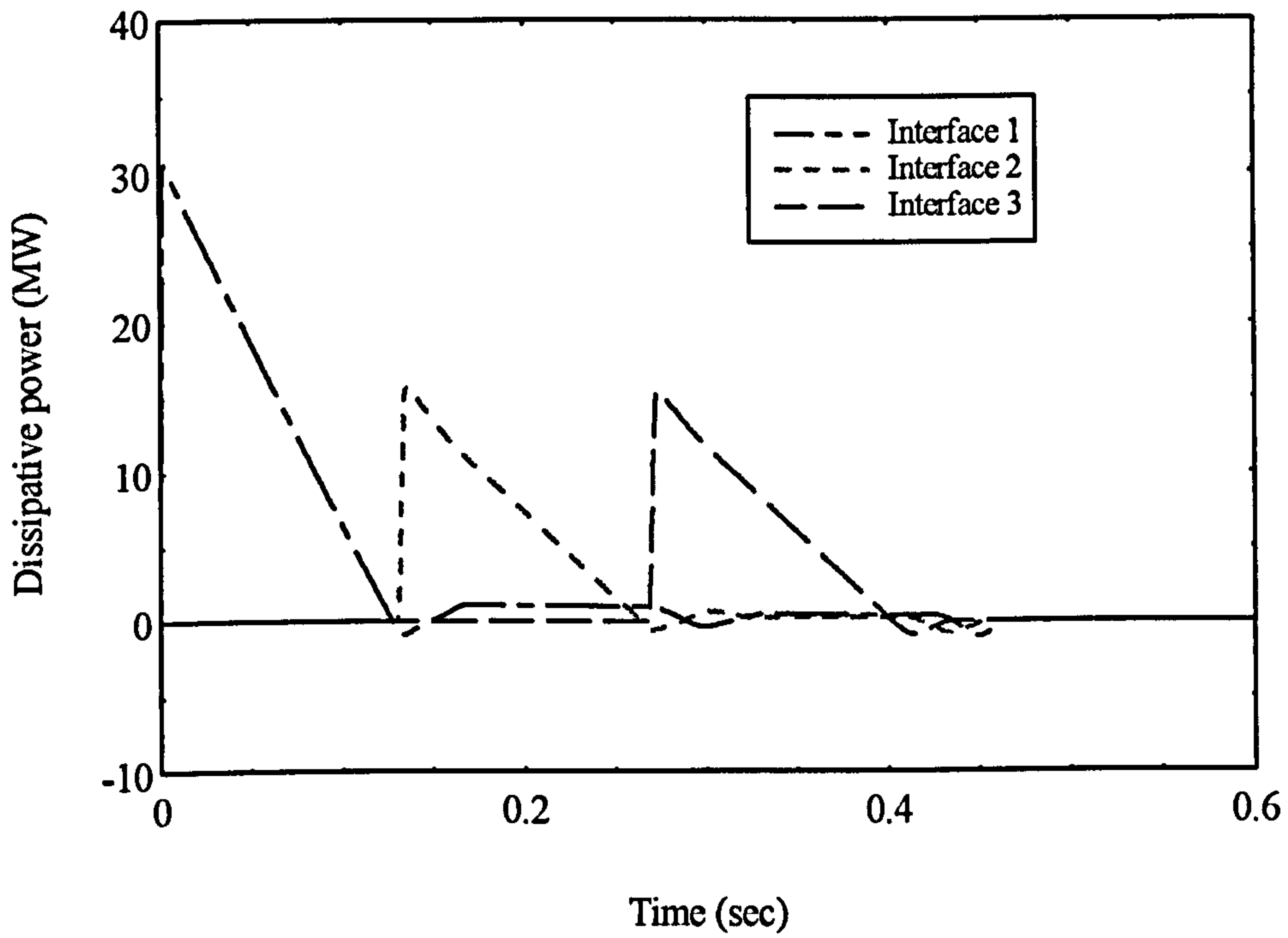


Figure 4.4b : The \dot{E} against t of various interfaces for the model Gap3.

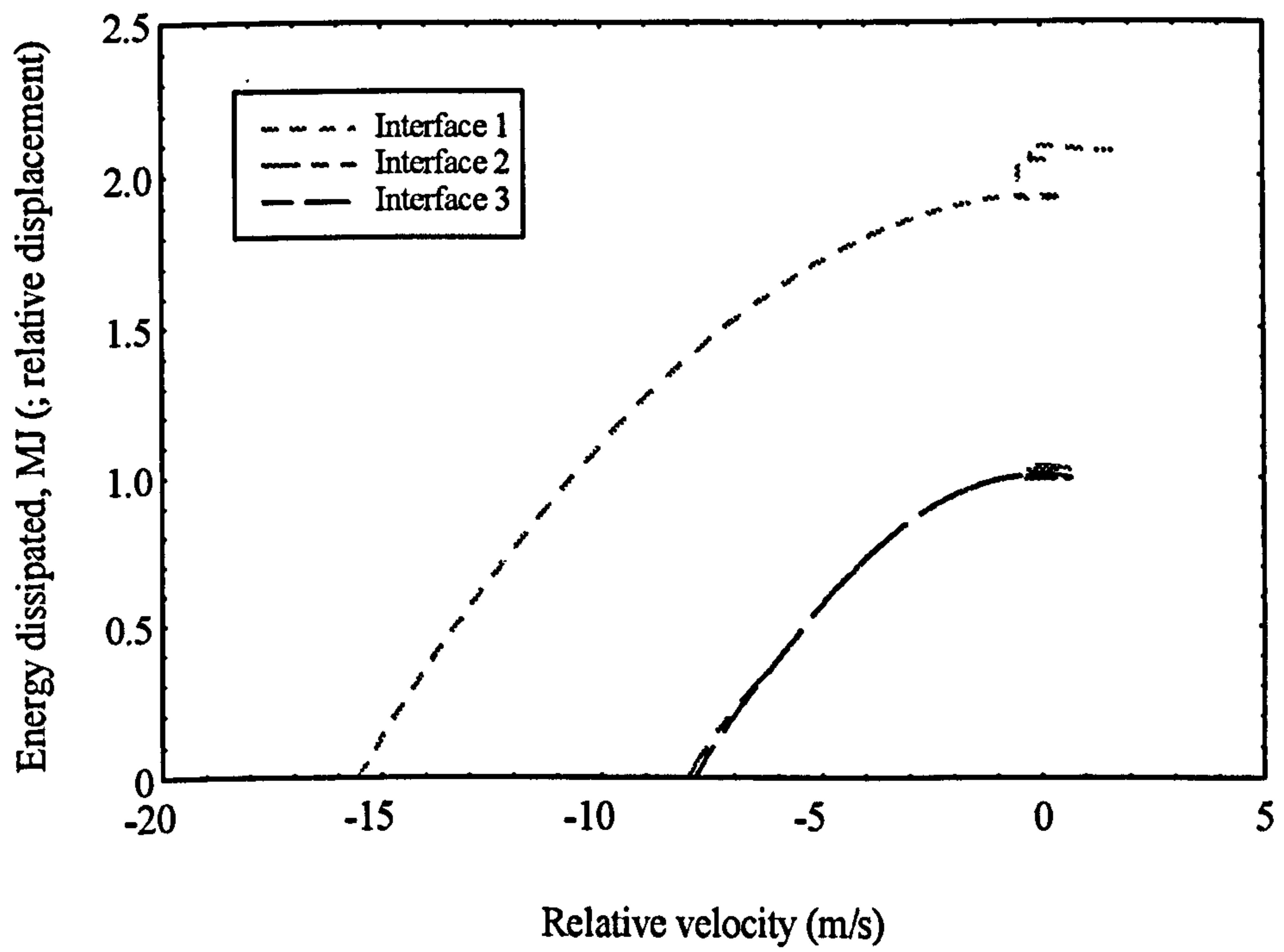


Figure 4.4c : The phase plot of various interfaces for the model Gap3.

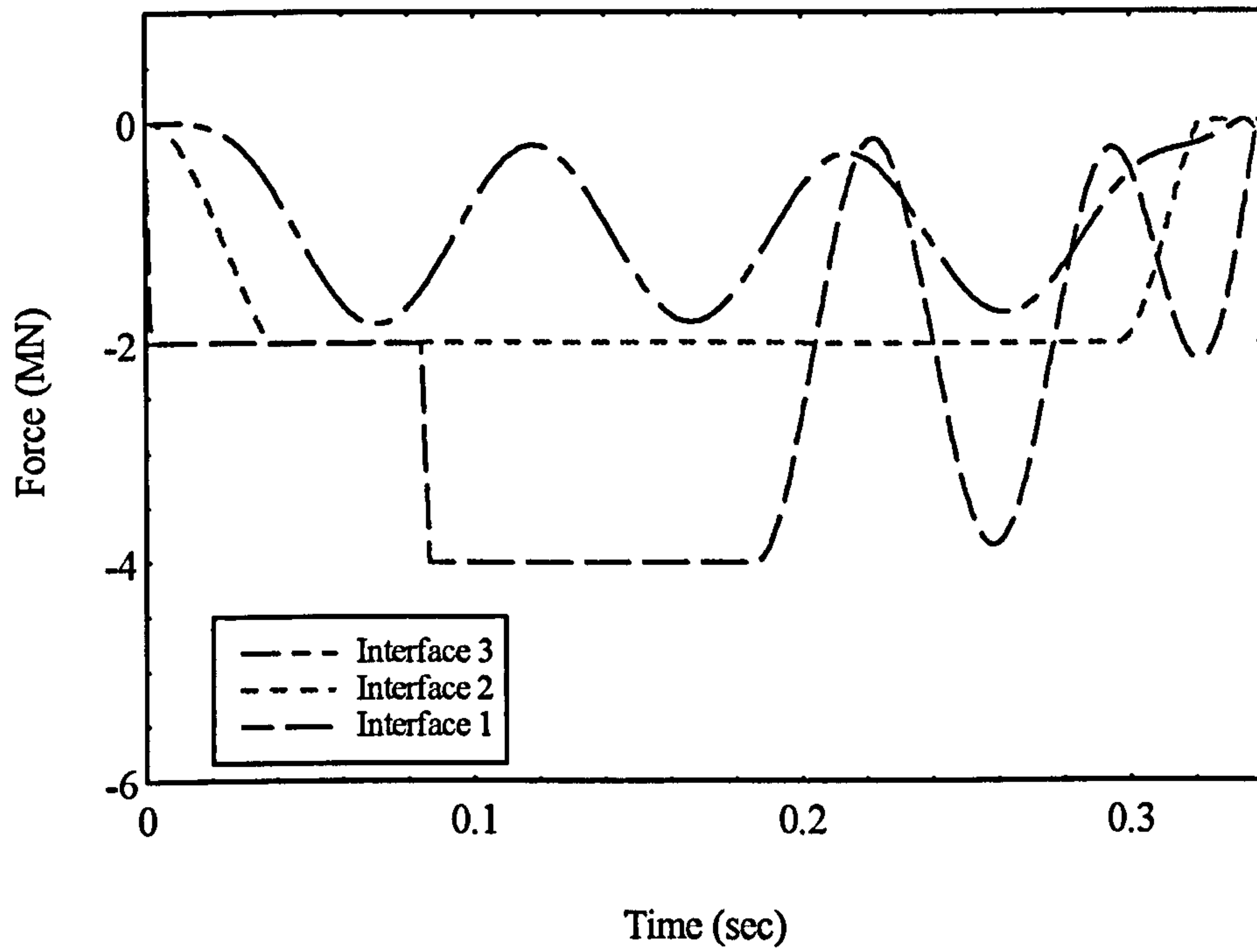


Figure 4.5a : The force-time histories of various interfaces for the model Gap1.

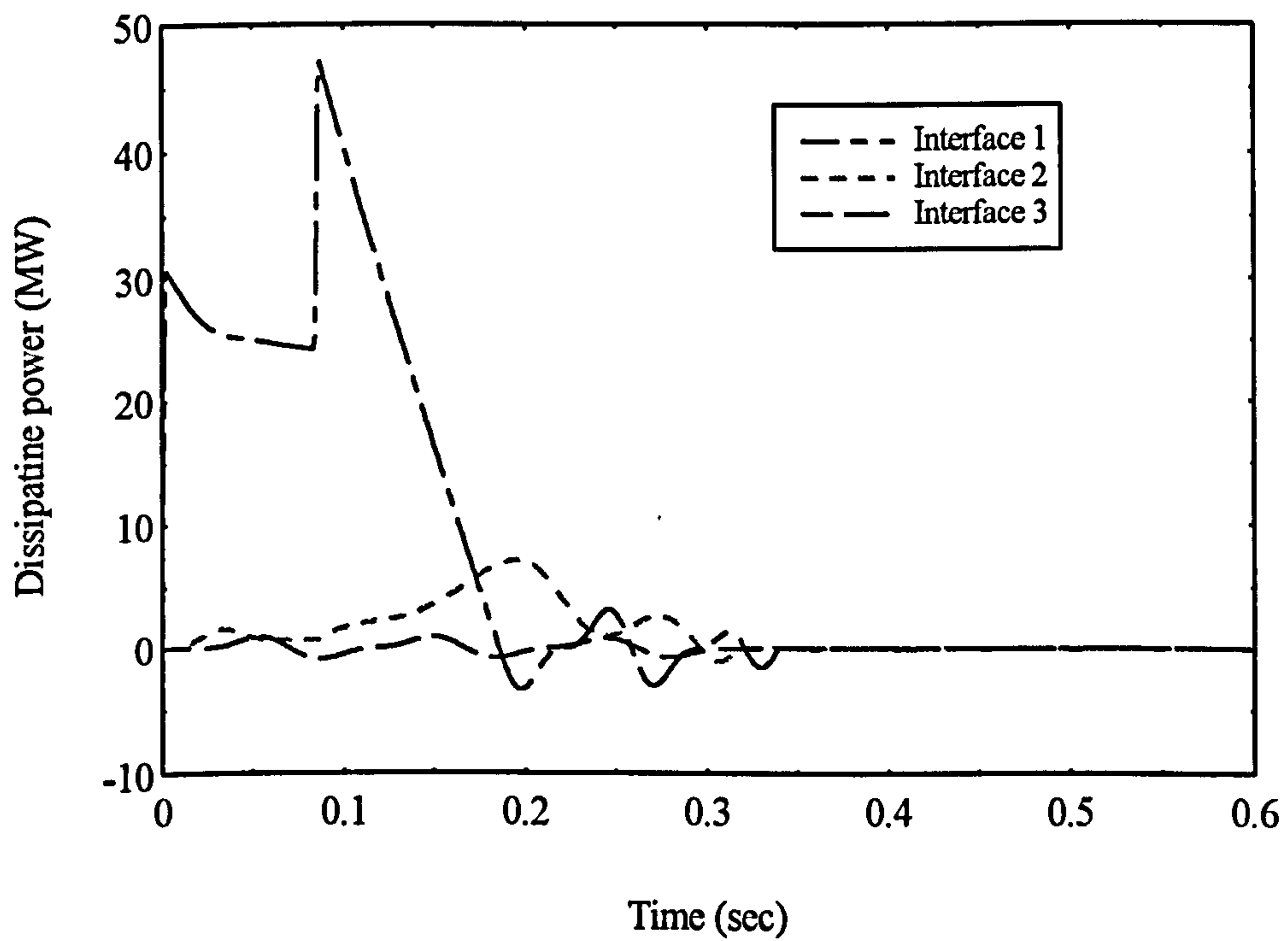


Figure 4.5b : The \dot{E} against t of various interfaces for the model Gap1.

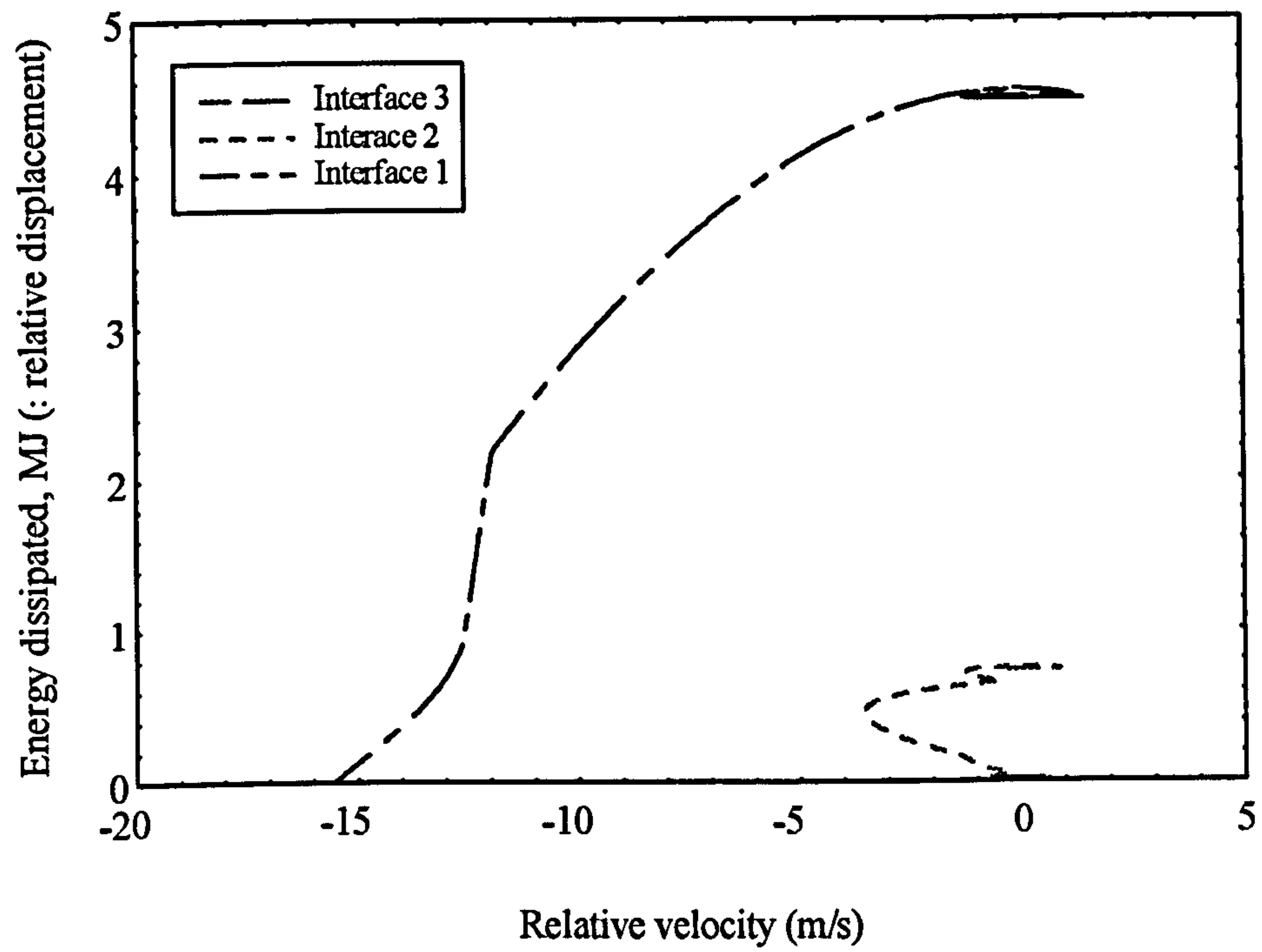


Figure 4.5c : The phase plot of various interfaces for the model Gap1.

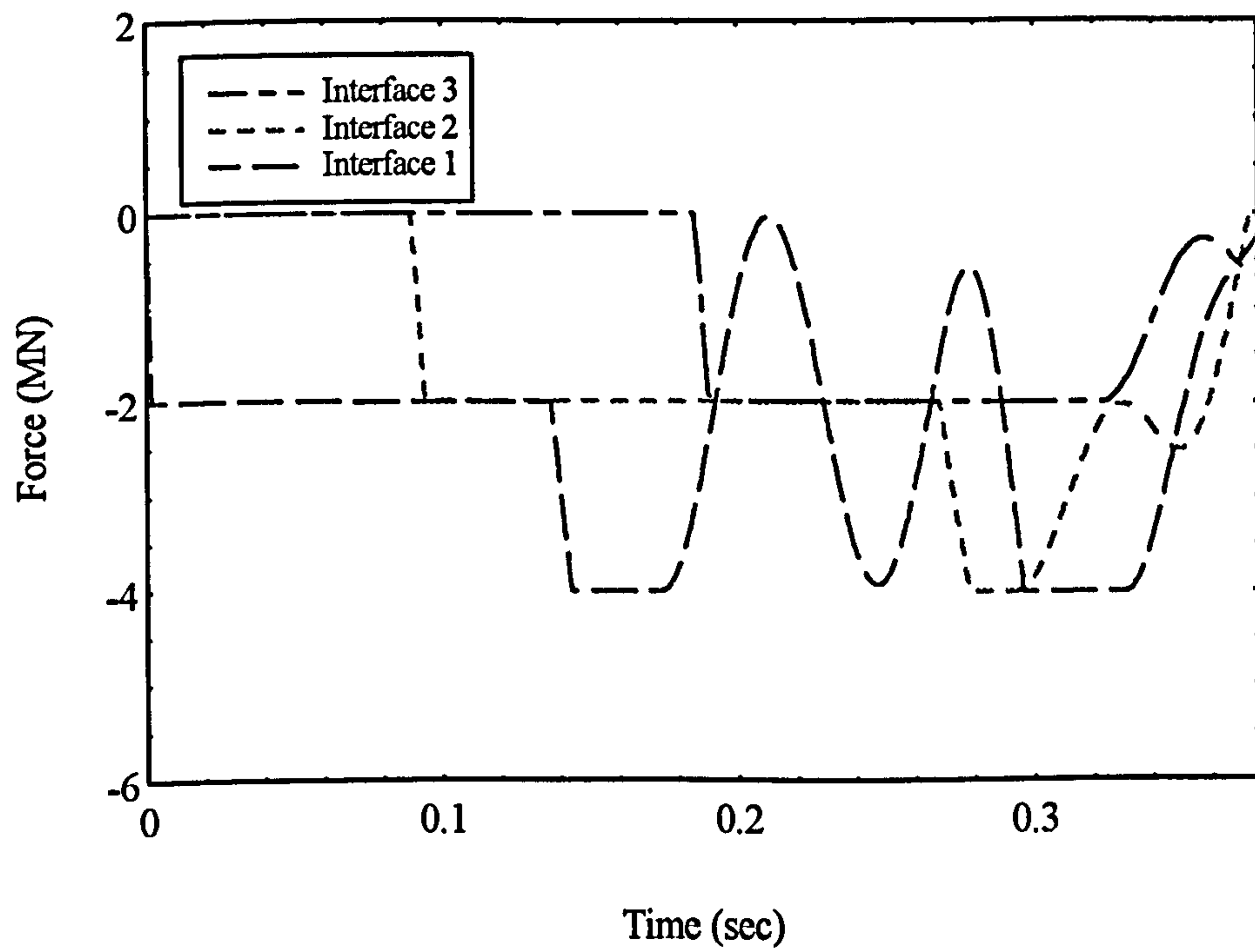


Figure 4.6a : The force-time history of various interfaces for the model Gap2.

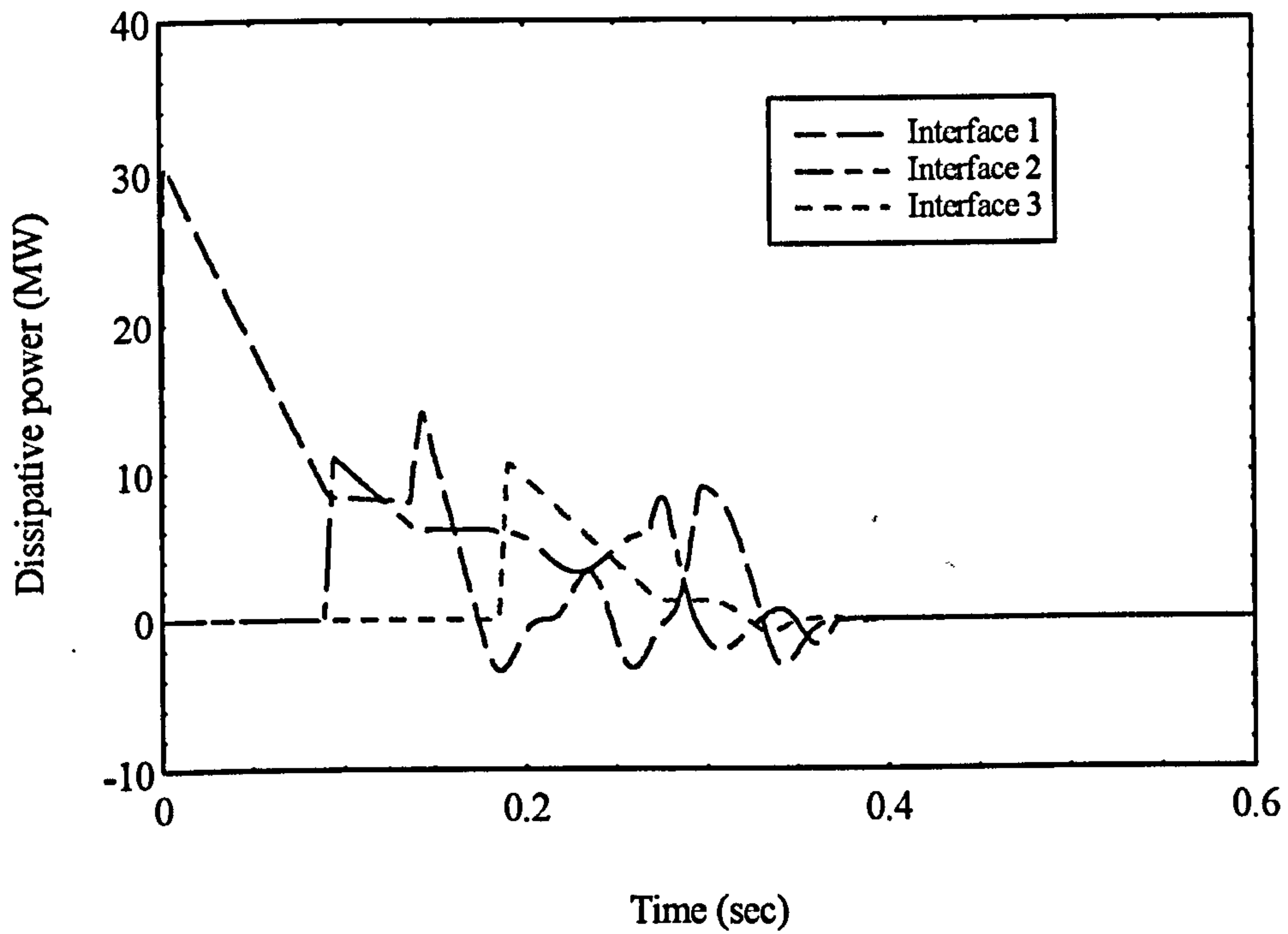


Figure 4.6b : The \dot{E} against t of various interfaces for the model Gap2.

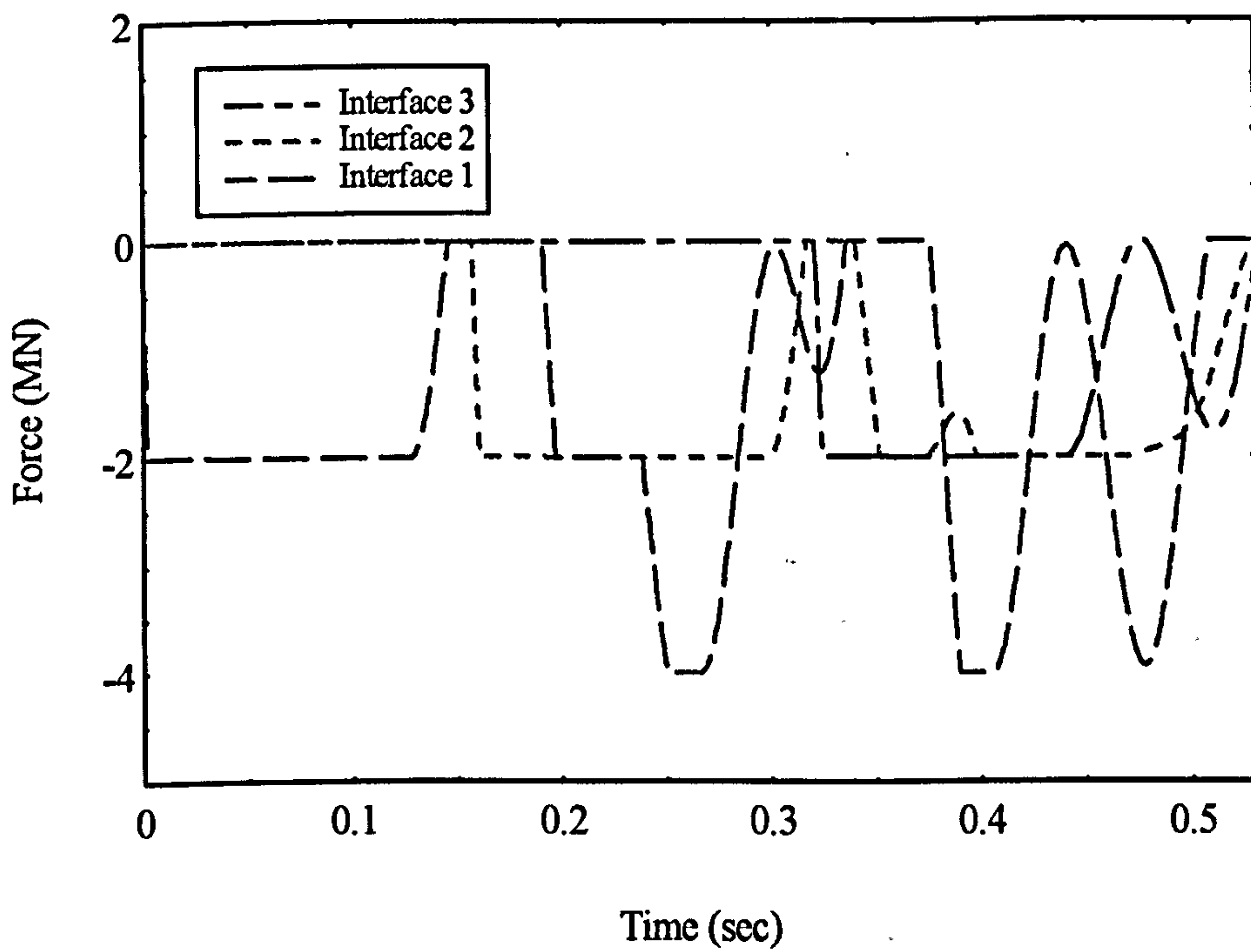


Figure 4.7a : The force-time history of various interfaces for the model Gap4.

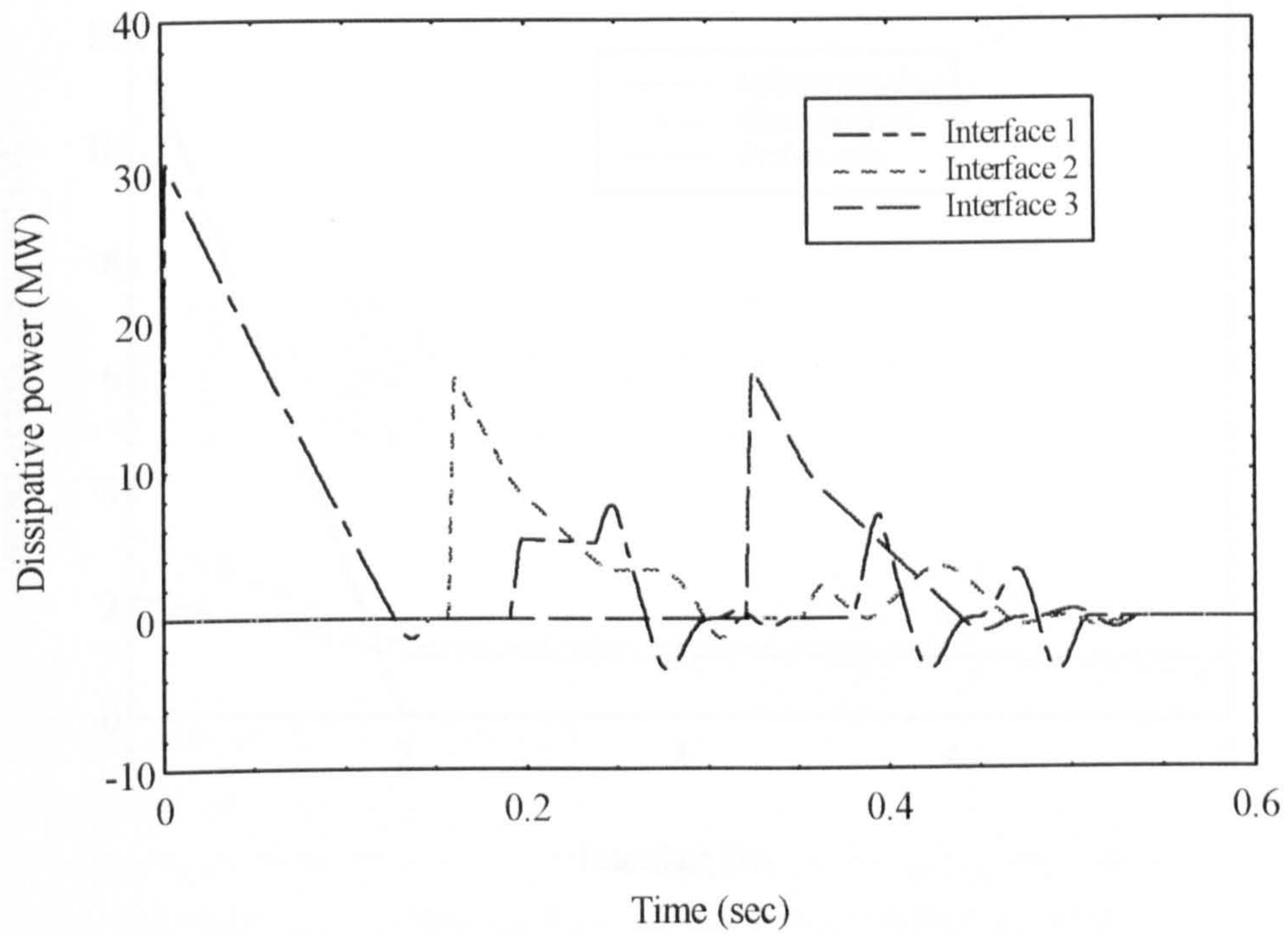


Figure 4.7b : The \dot{E} against t of various interfaces for the model Gap4.

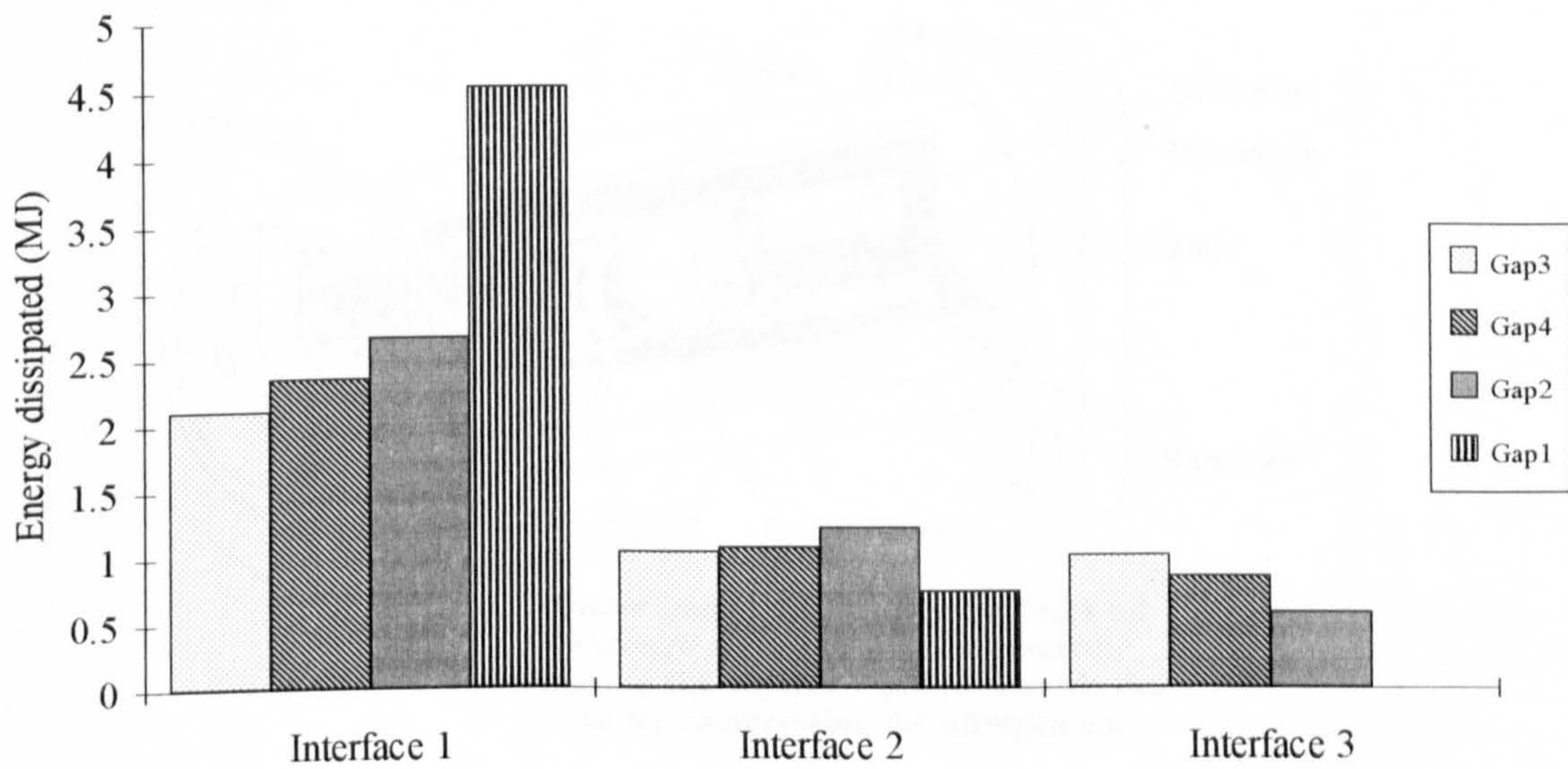


Figure 4.8 : The dissipated energy distribution among the various interfaces of the models.

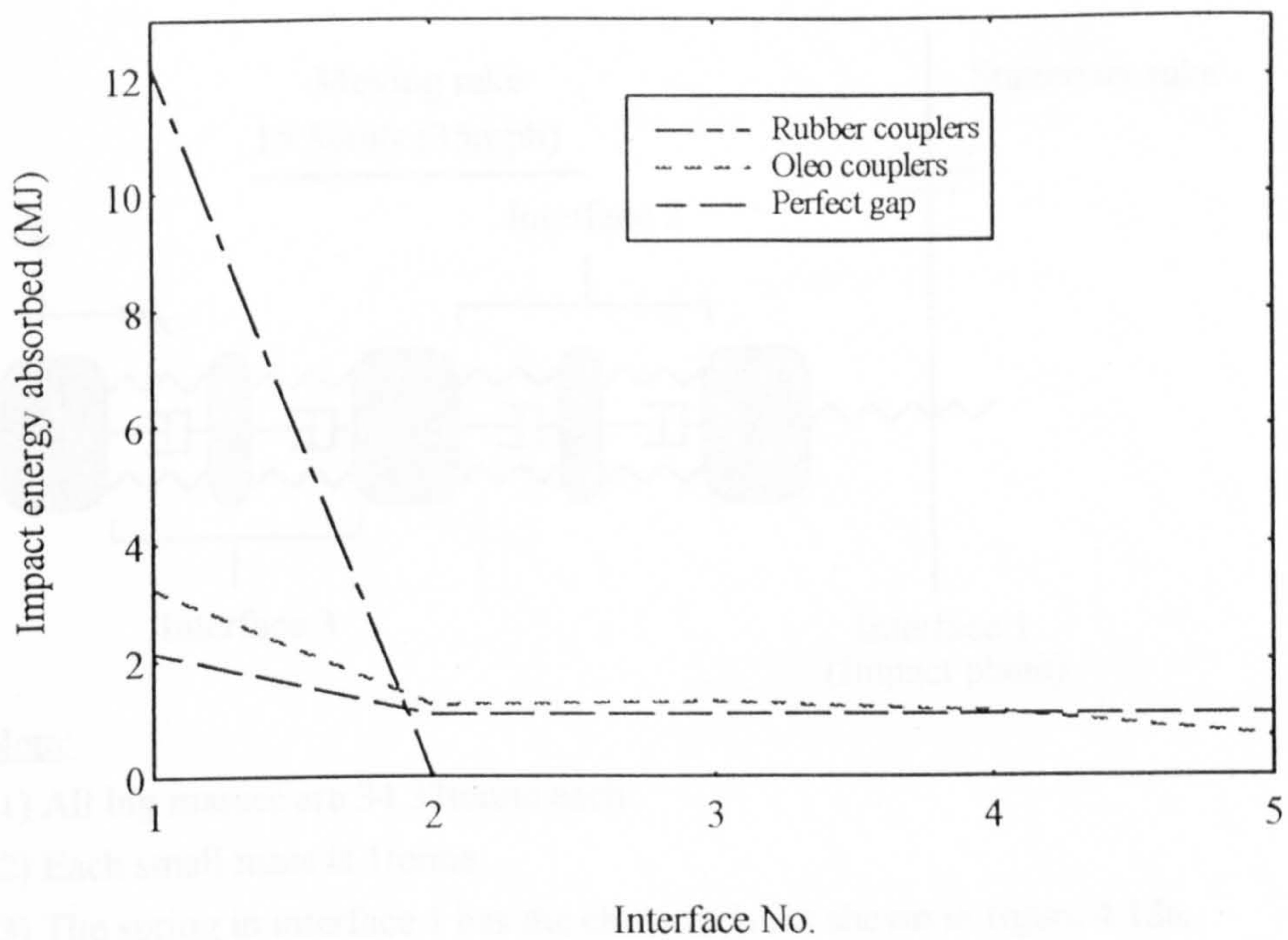


Figure 4.9 : The energy distribution comparison for various coupling arrangement [4].

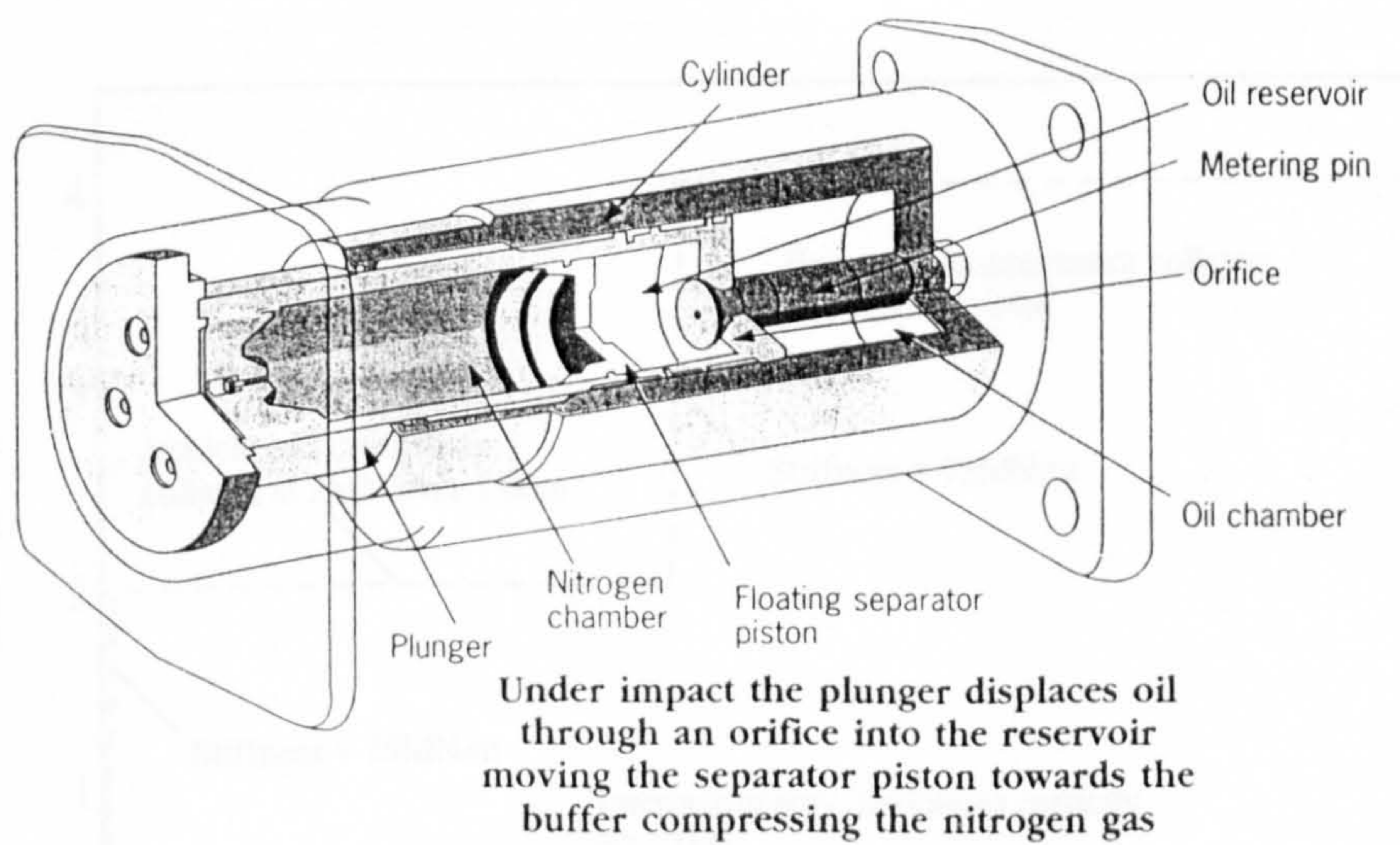
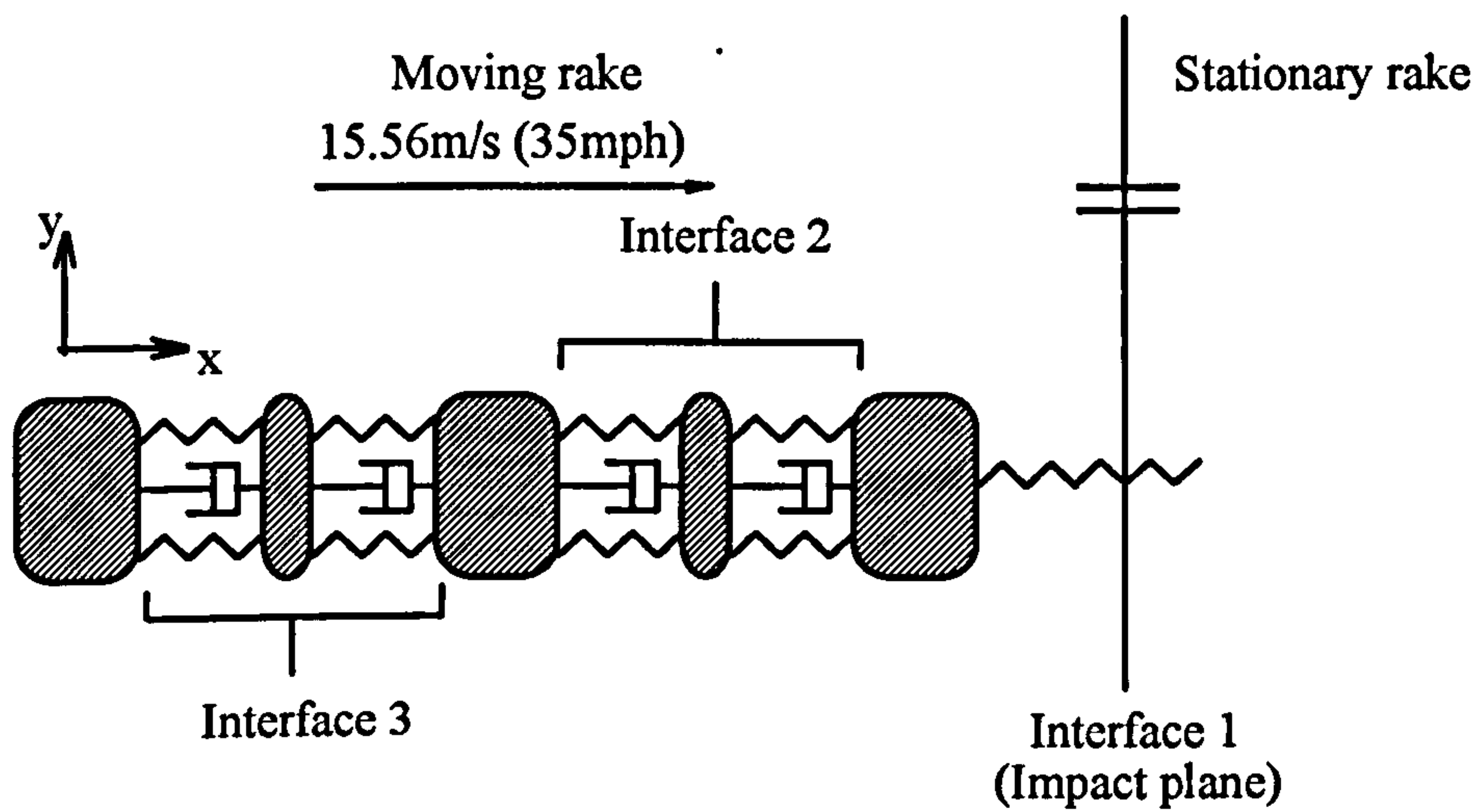


Figure 4.10 : The detail construction of an Oleo coupler.



Note:

- (1) All big masses are 34.33tonne each.
- (2) Each small mass is 1tonne.
- (3) The spring in interface 1 has the characteristics shown in figure 4.12a.
- (4) Other interfaces' top springs have the characteristics shown in figure 4.12b.
- (5) All bottom springs are representations of the hydrogen spring unit in Oleo couplers.
- (6) The central dashpot have the characteristics of Oleo hydraulic couplers.

Figure 4.11 : The non-linear mass spring model that includes Oleo hydro-pneumatic couplers.

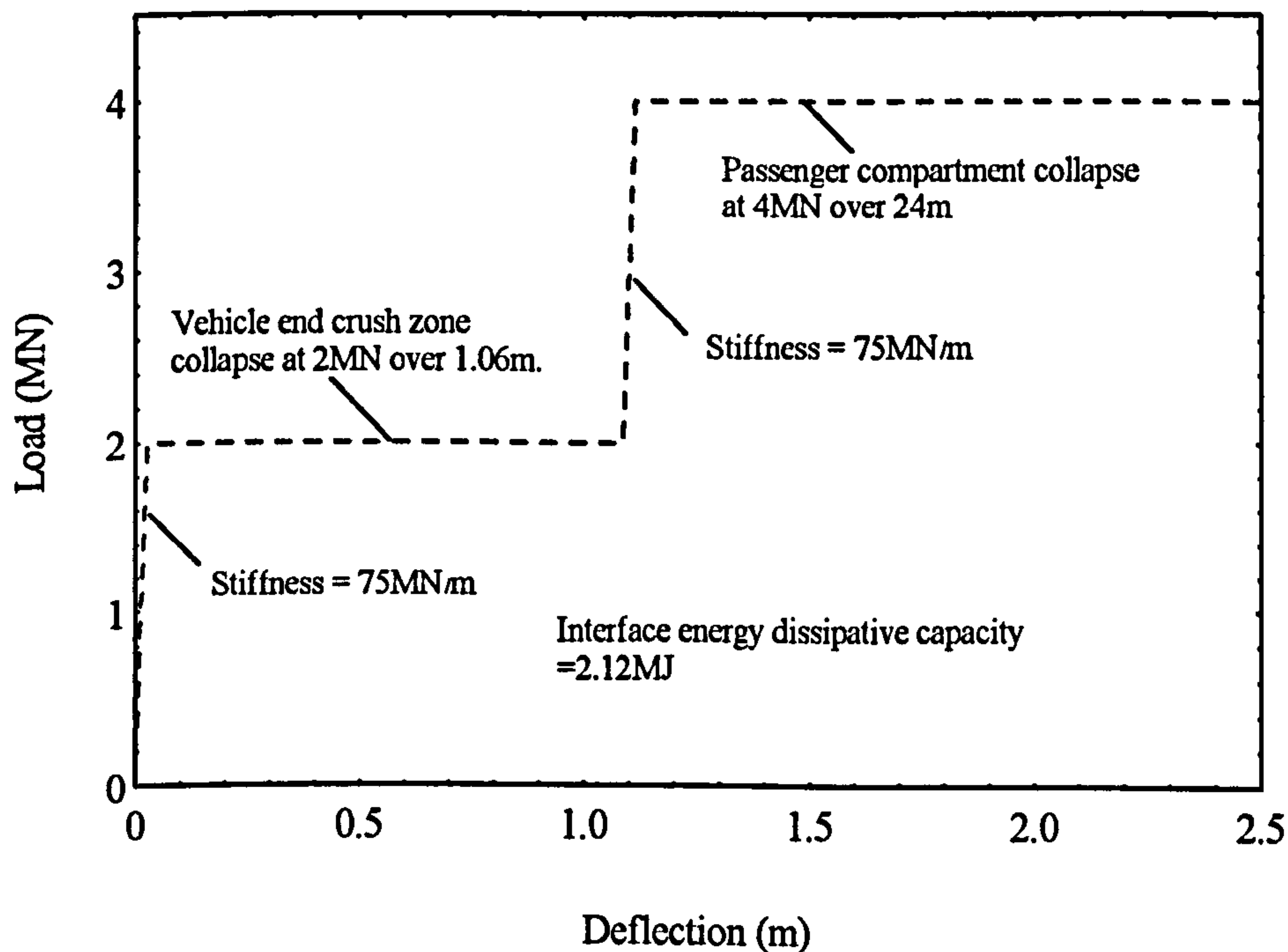


Figure 4.12a : The collapse characteristic of the impact interface spring.

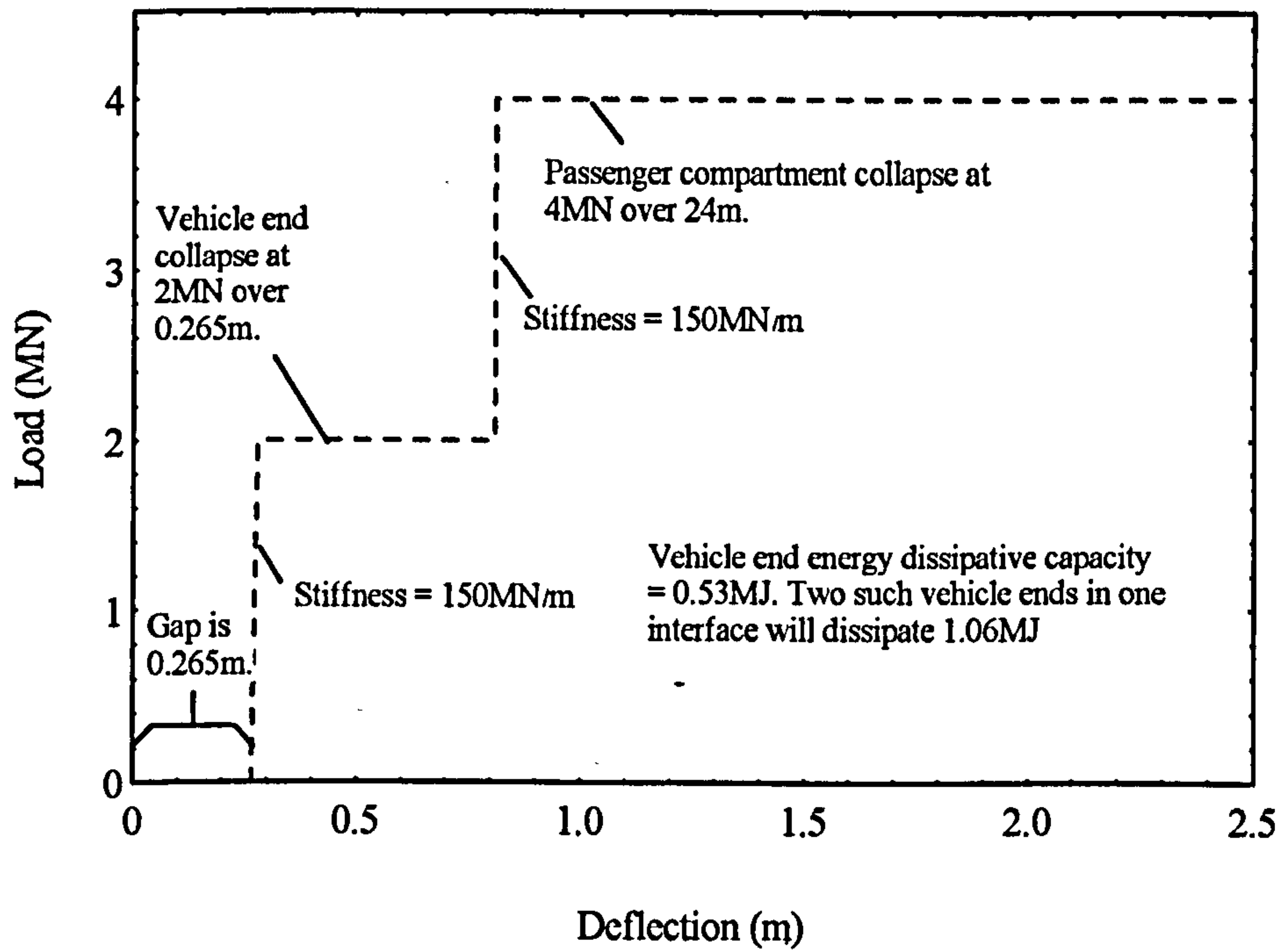


Figure 4.12b : The collapse characteristic of the intermediate springs.

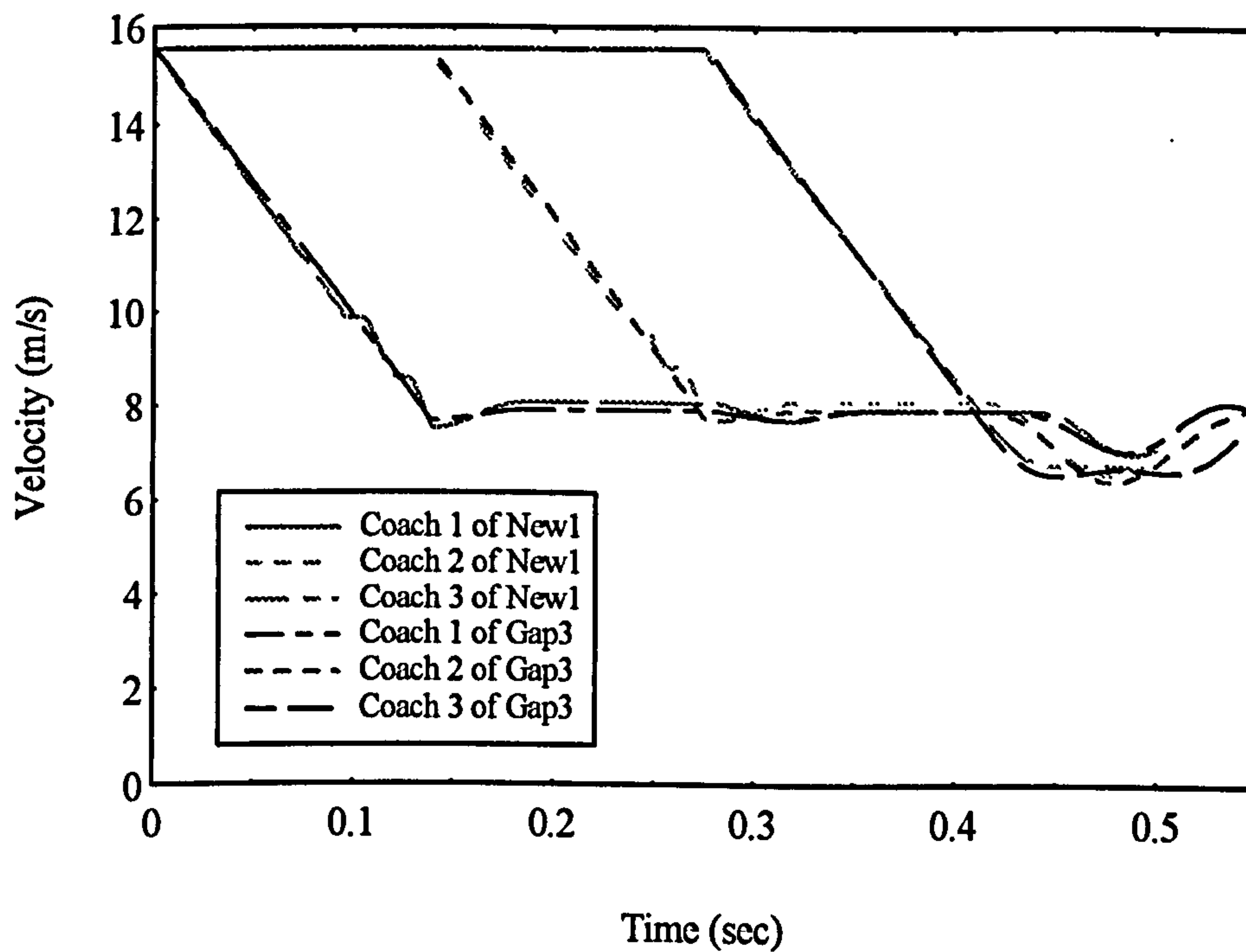


Figure 4.13 : The velocity-time history of various coaches in models New1 and Gap3.

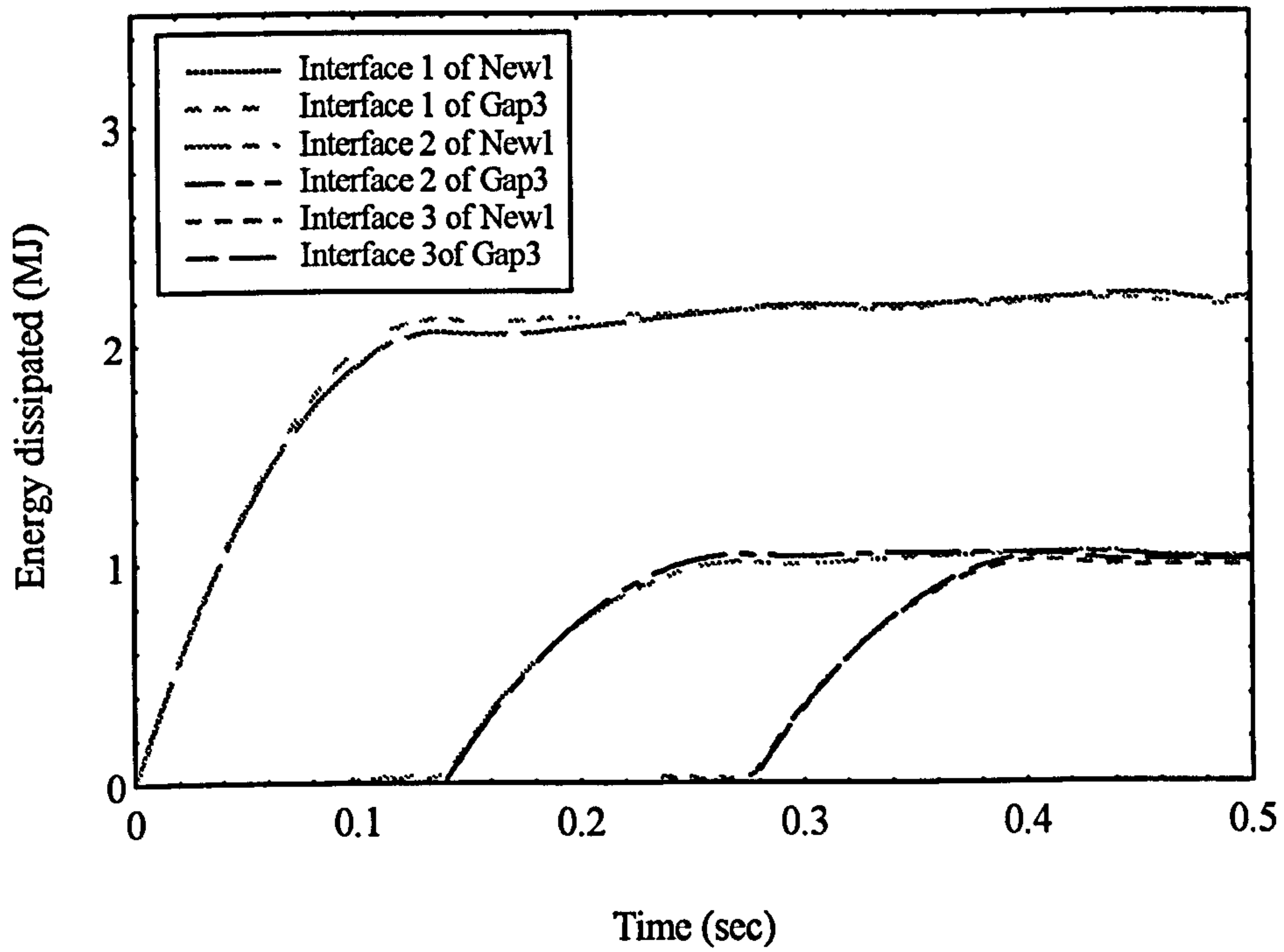


Figure 4.14 : The $E-t$ graphs of various interfaces for the models New1 and Gap3.

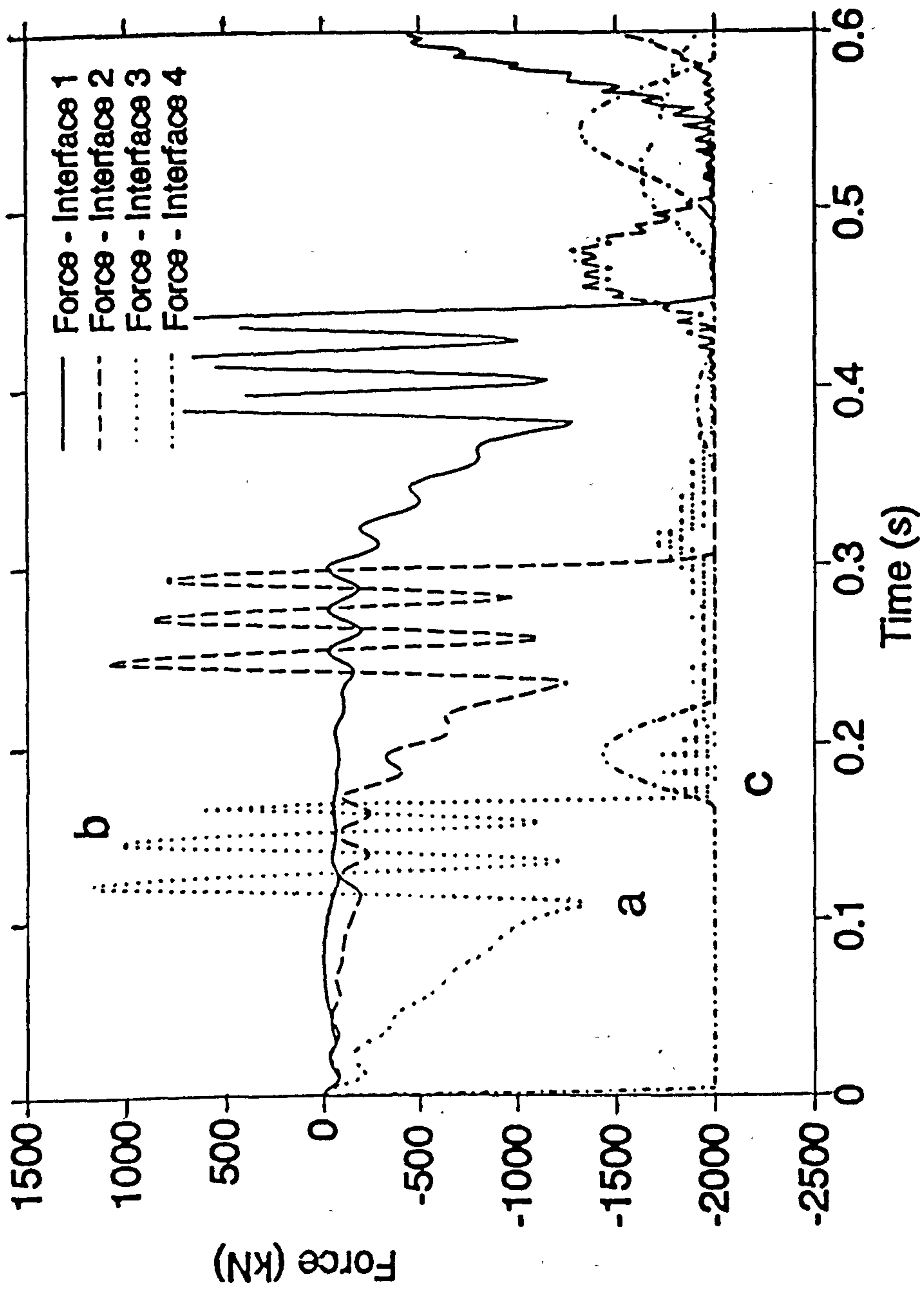


Figure 4.15 : The results produced by the BRR model which simulates a four-to-four (with Oleo couplers) collision [3].

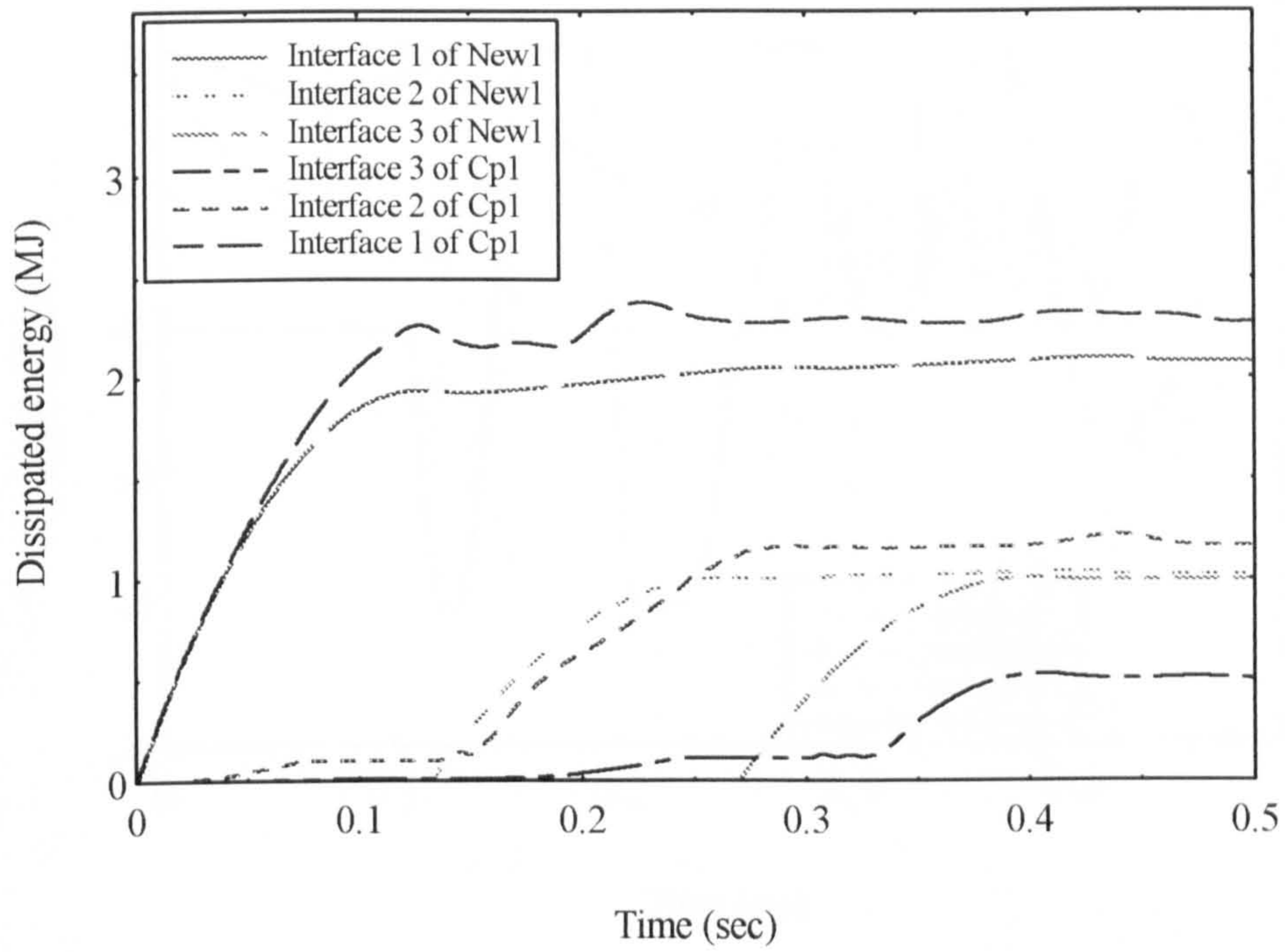


Figure 4.16 : The $E-t$ graphs for various interfaces in the models Cp1 and New1.

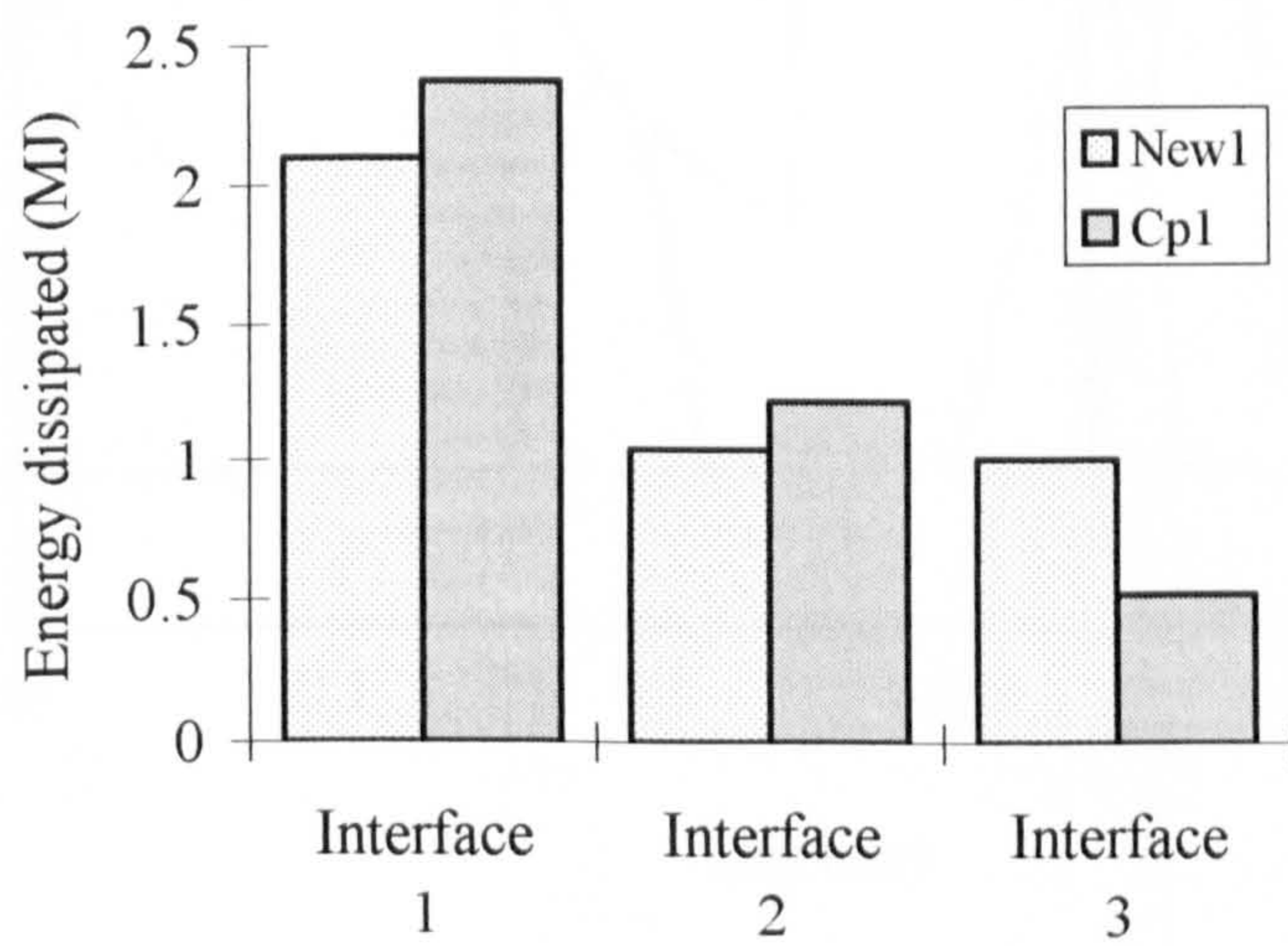


Figure 4.17 : Comparing the energy distribution between Cp1 and New1.

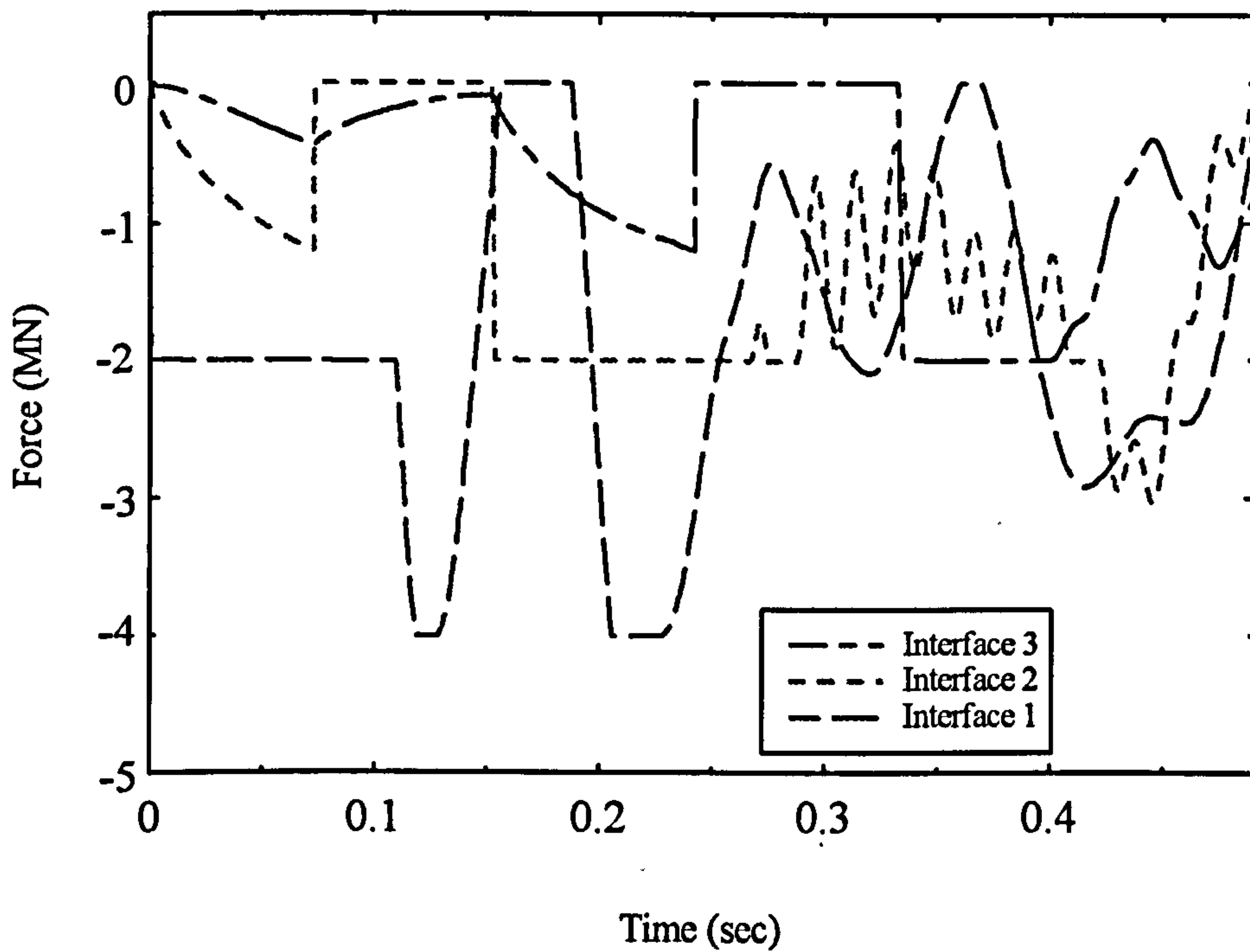


Figure 4.18 : The force-time graphs of various interfaces in the model Cp1.

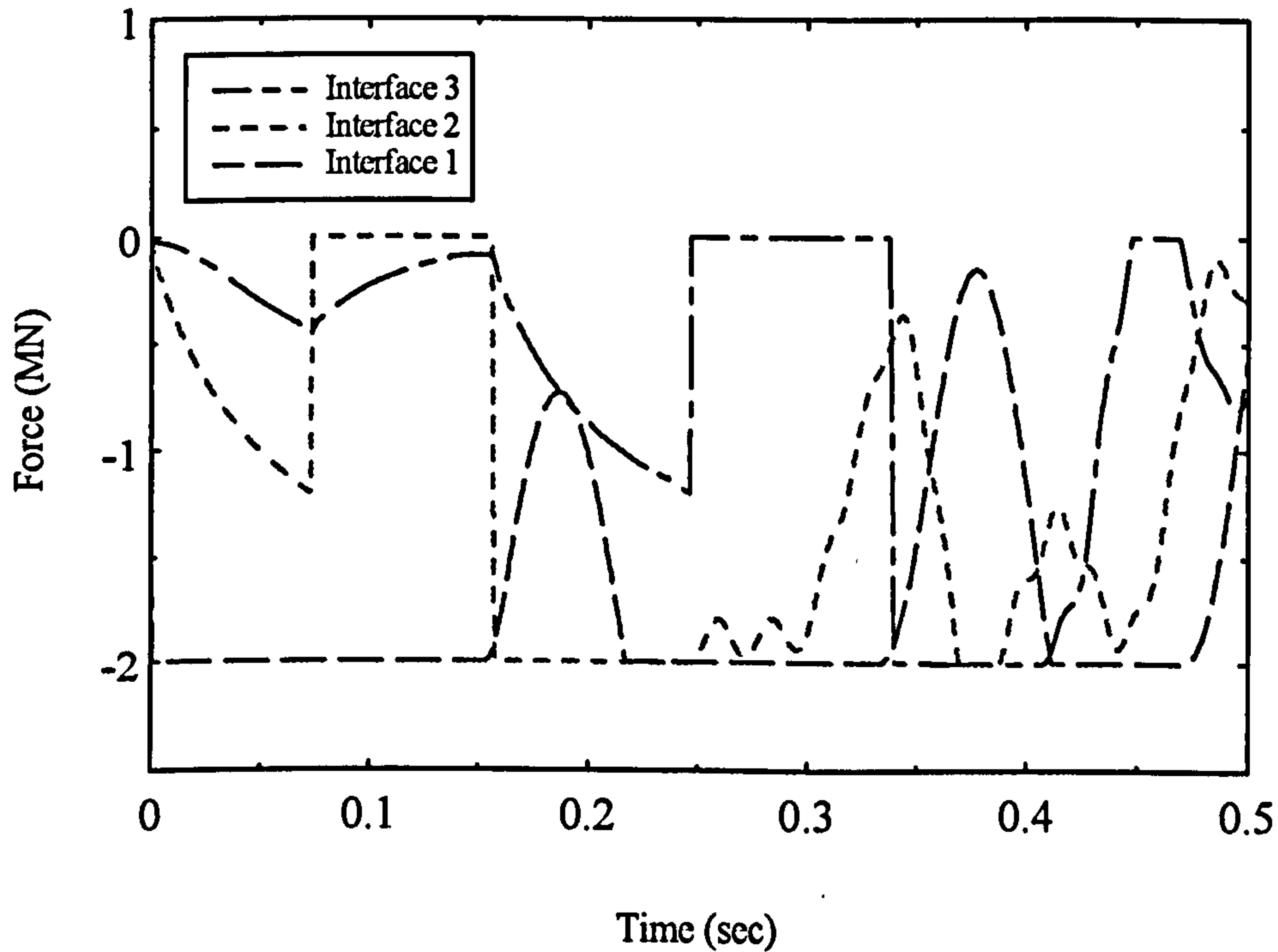


Figure 4.19 : The force-time history of various interfaces for the model Cp2.

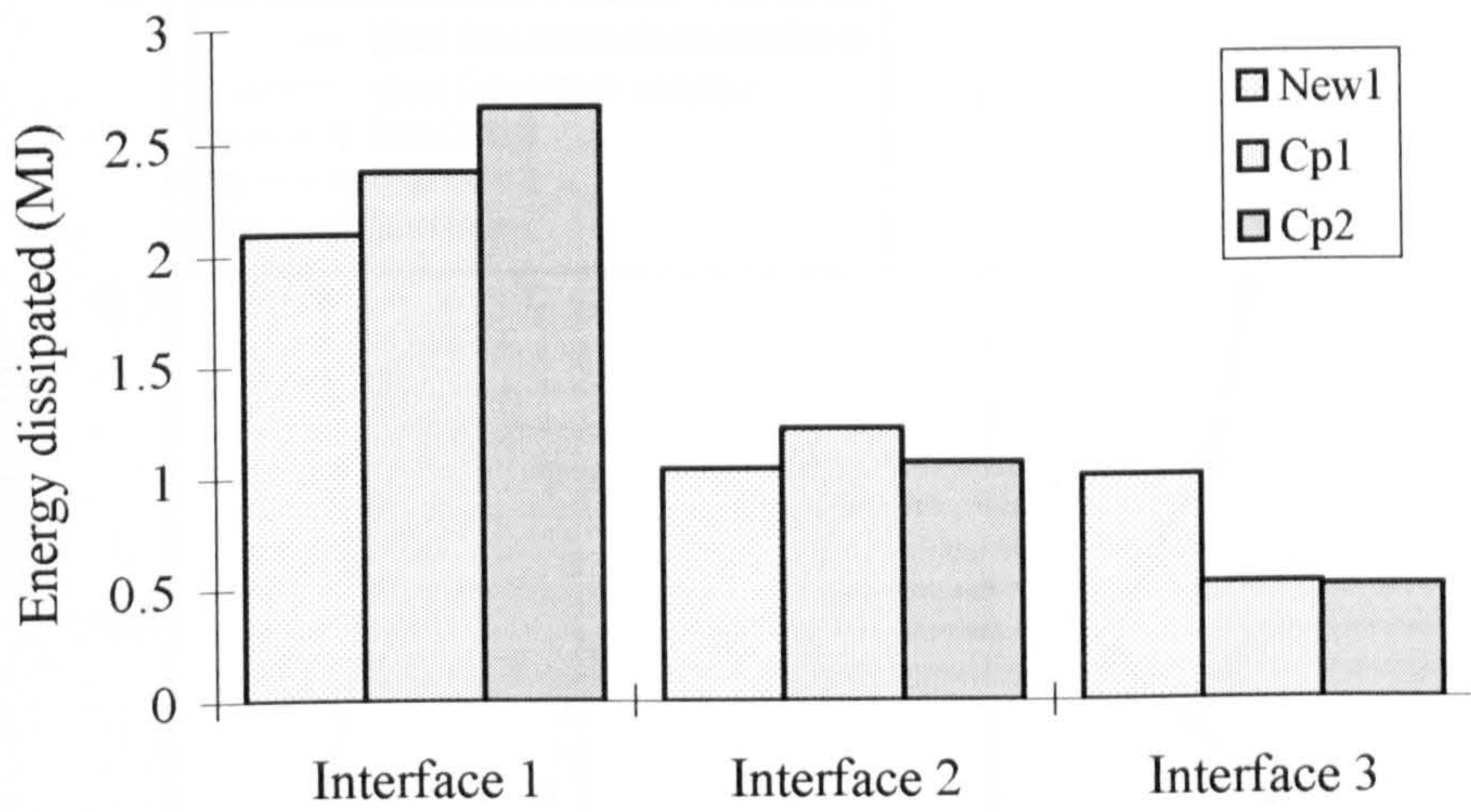


Figure 4.20 : The energy distribution patterns of the three models : New1, Cp1 & Cp2.

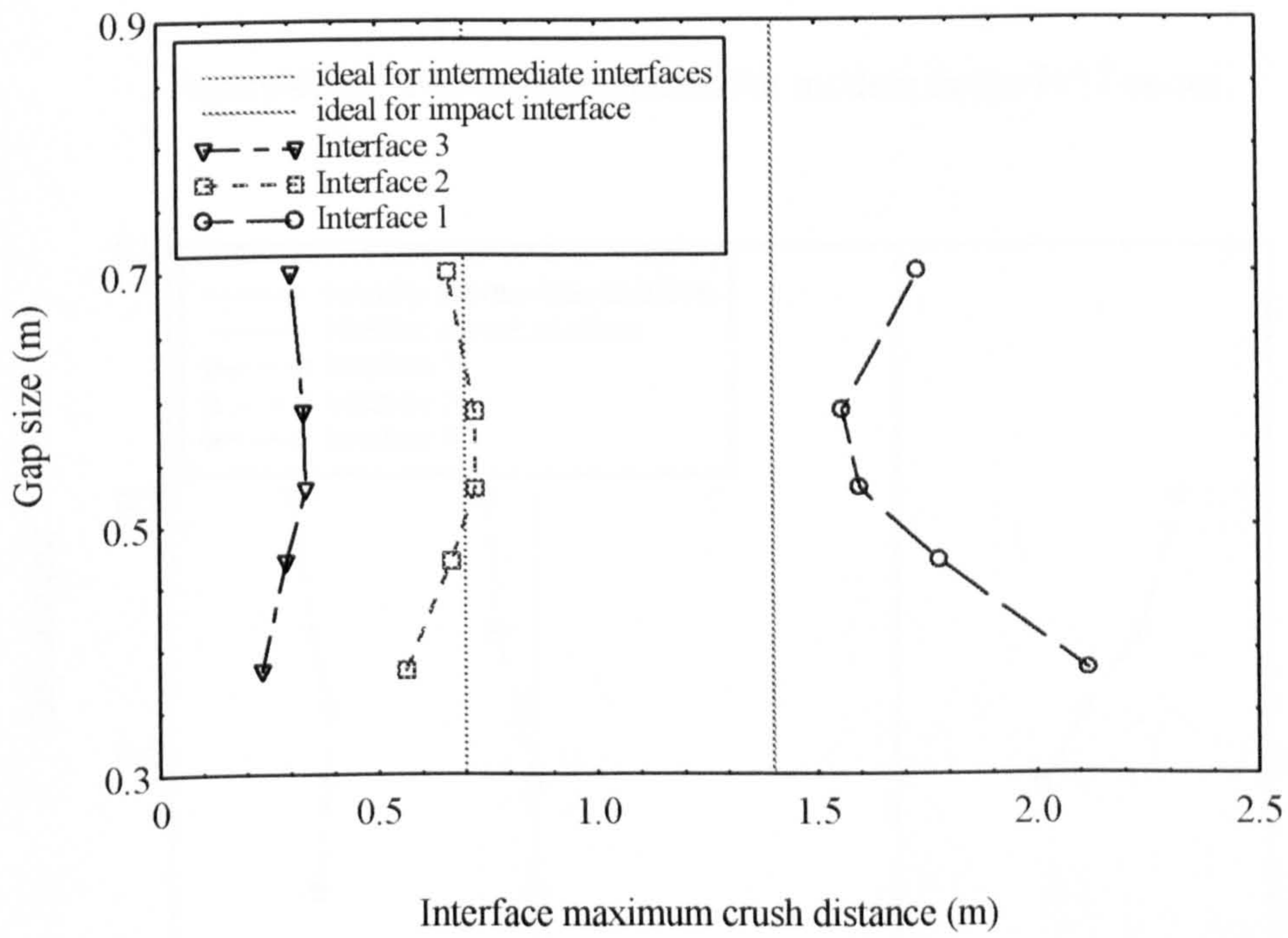


Figure 4.21 : The crush distance for models in the Iv40 series.

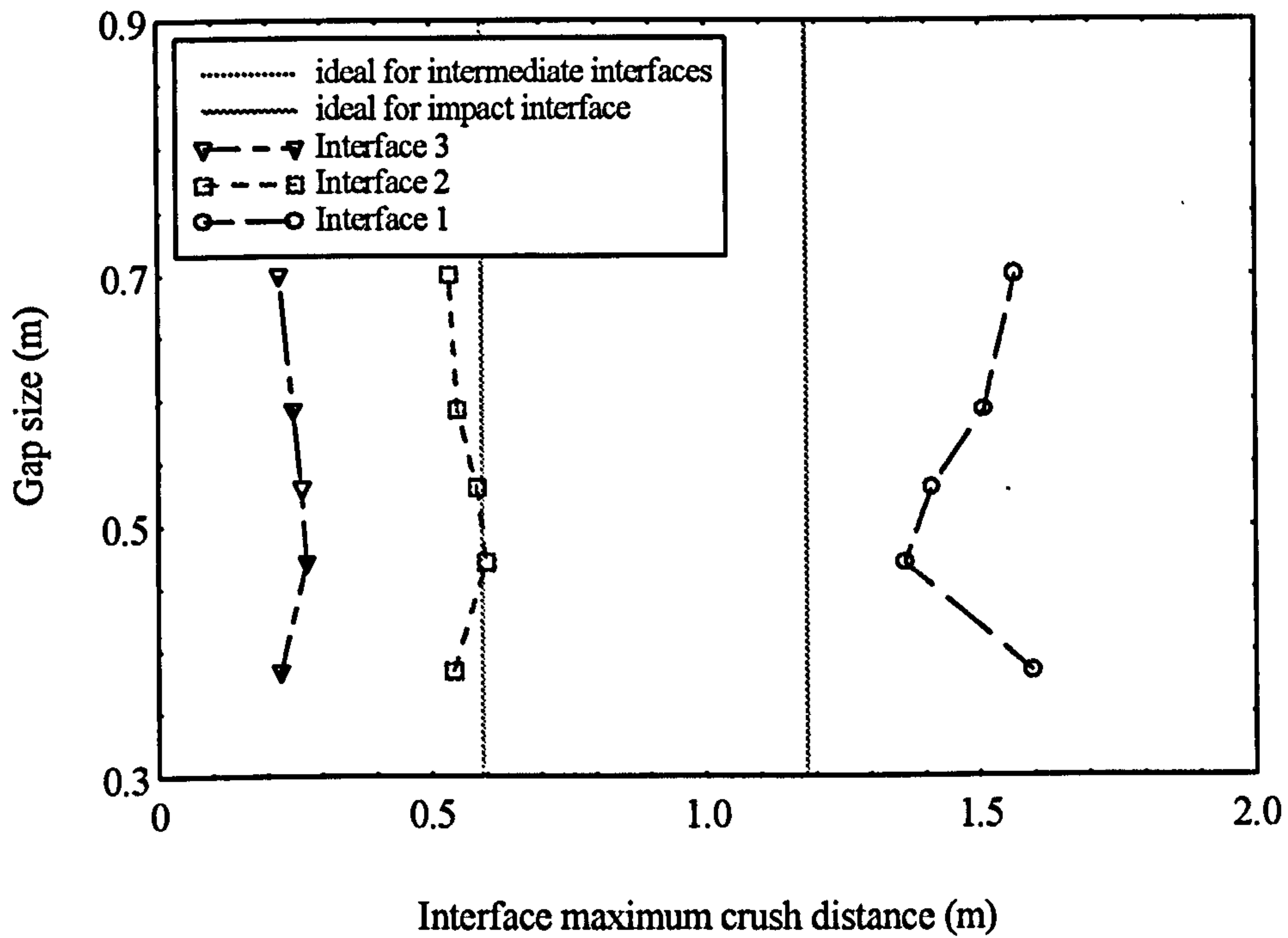


Figure 4.22 : The crush distance for models in the Iv37 series.

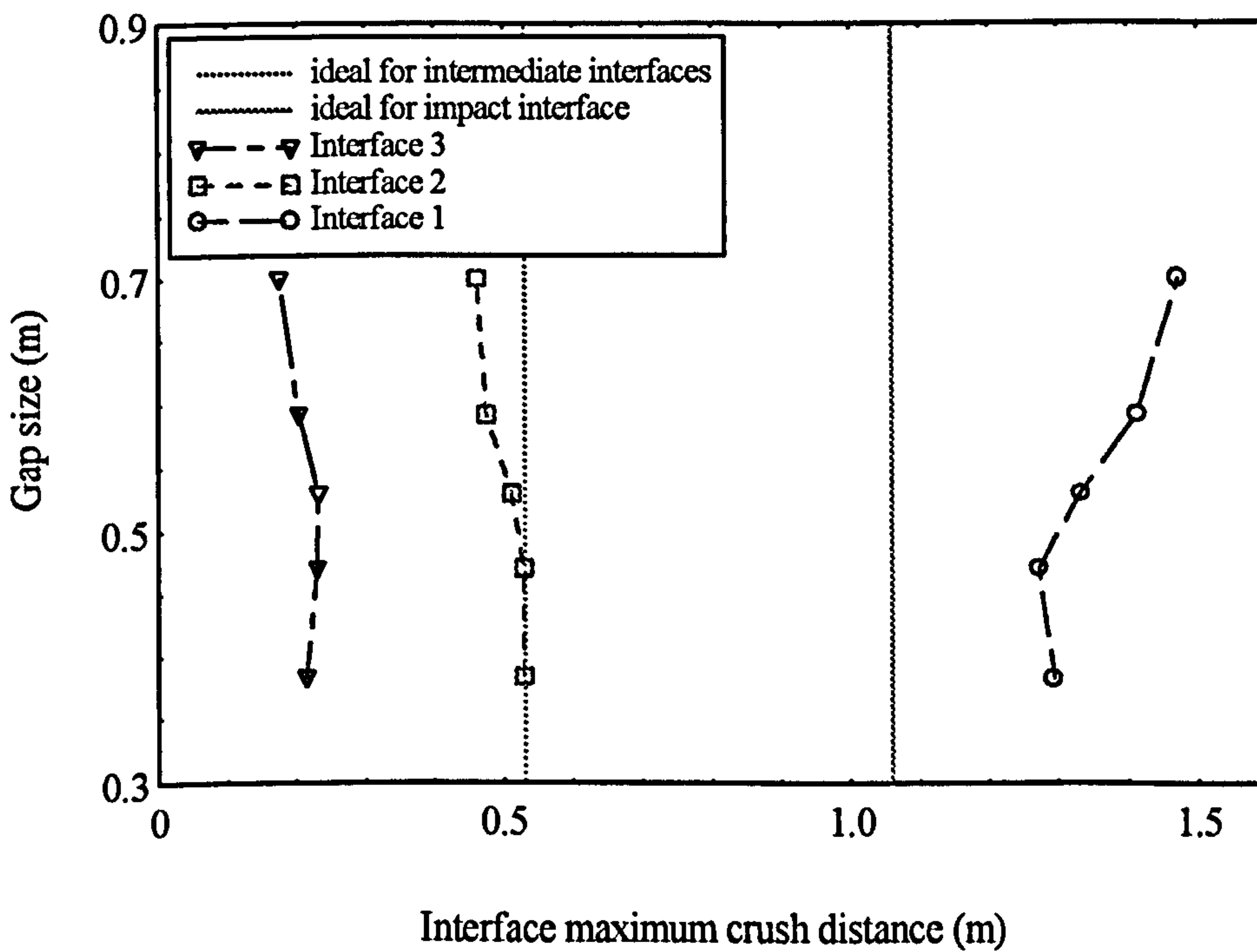


Figure 4.23 : The crush distance for models in the Iv35 series.

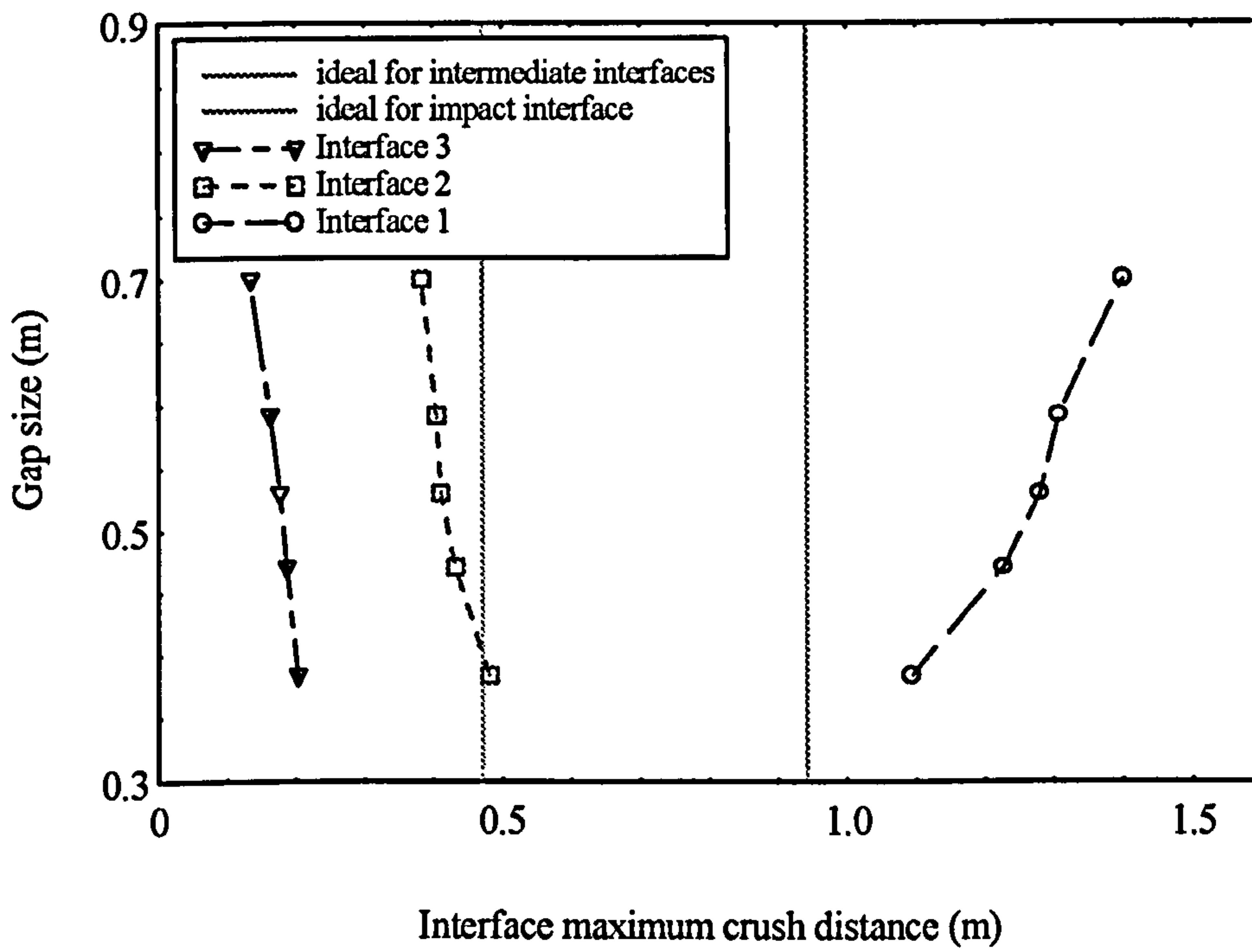


Figure 4.24 : The crush distance for models in the Iv33 series.

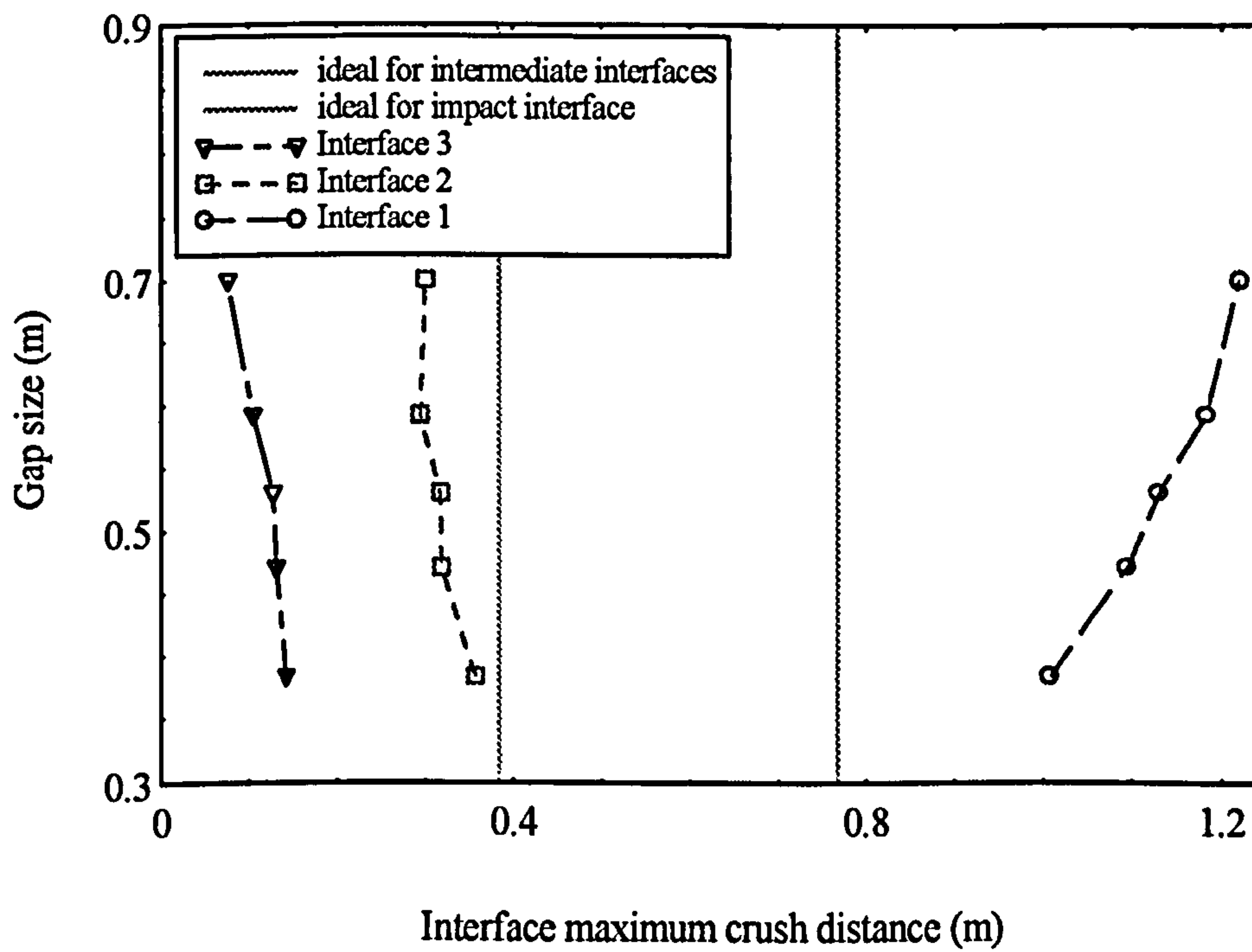


Figure 4.25 : The crush distance for models in the Iv30 series.

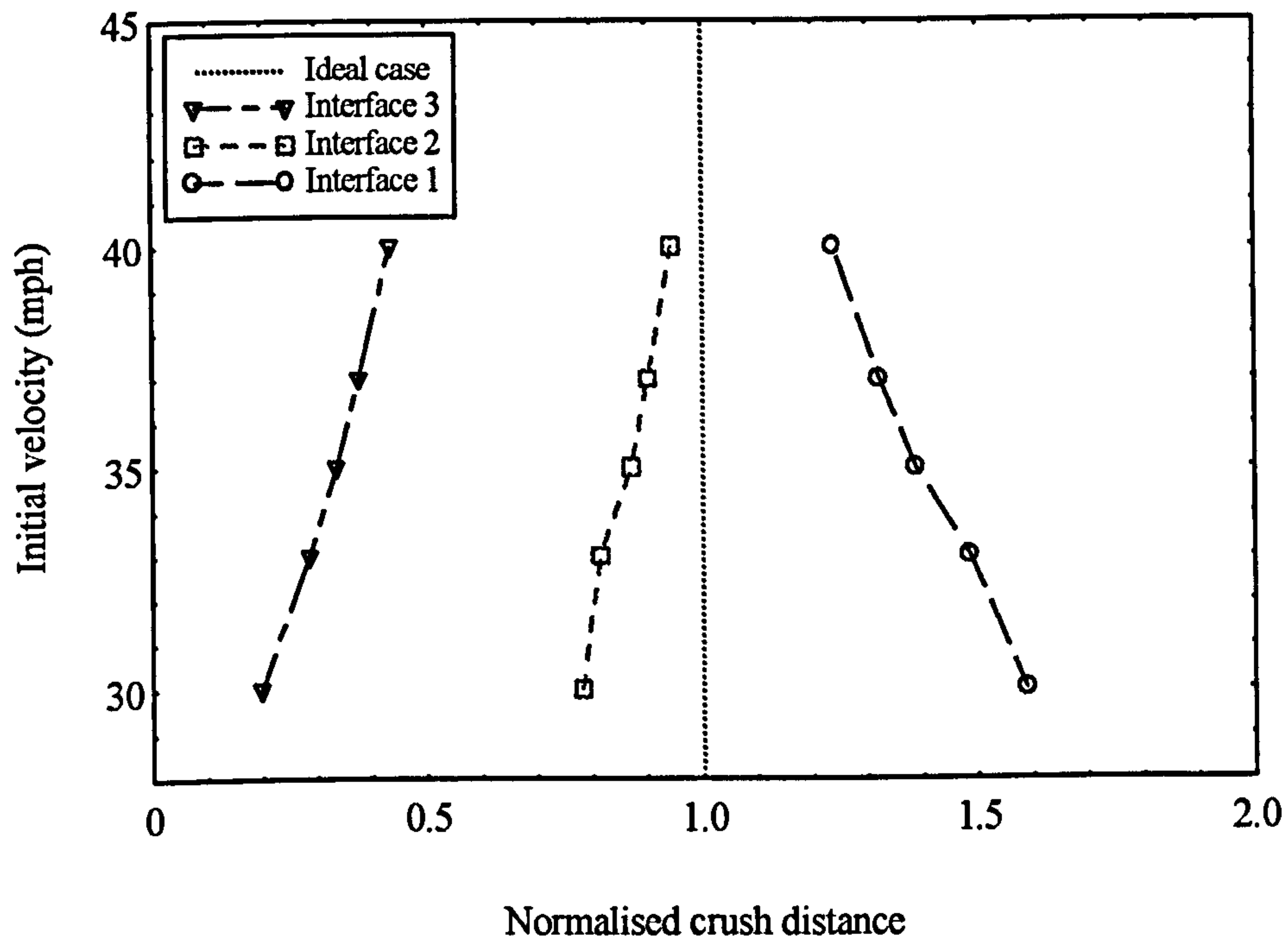


Figure 4.26 : The normalised crush distance for models in the Gp70 series.

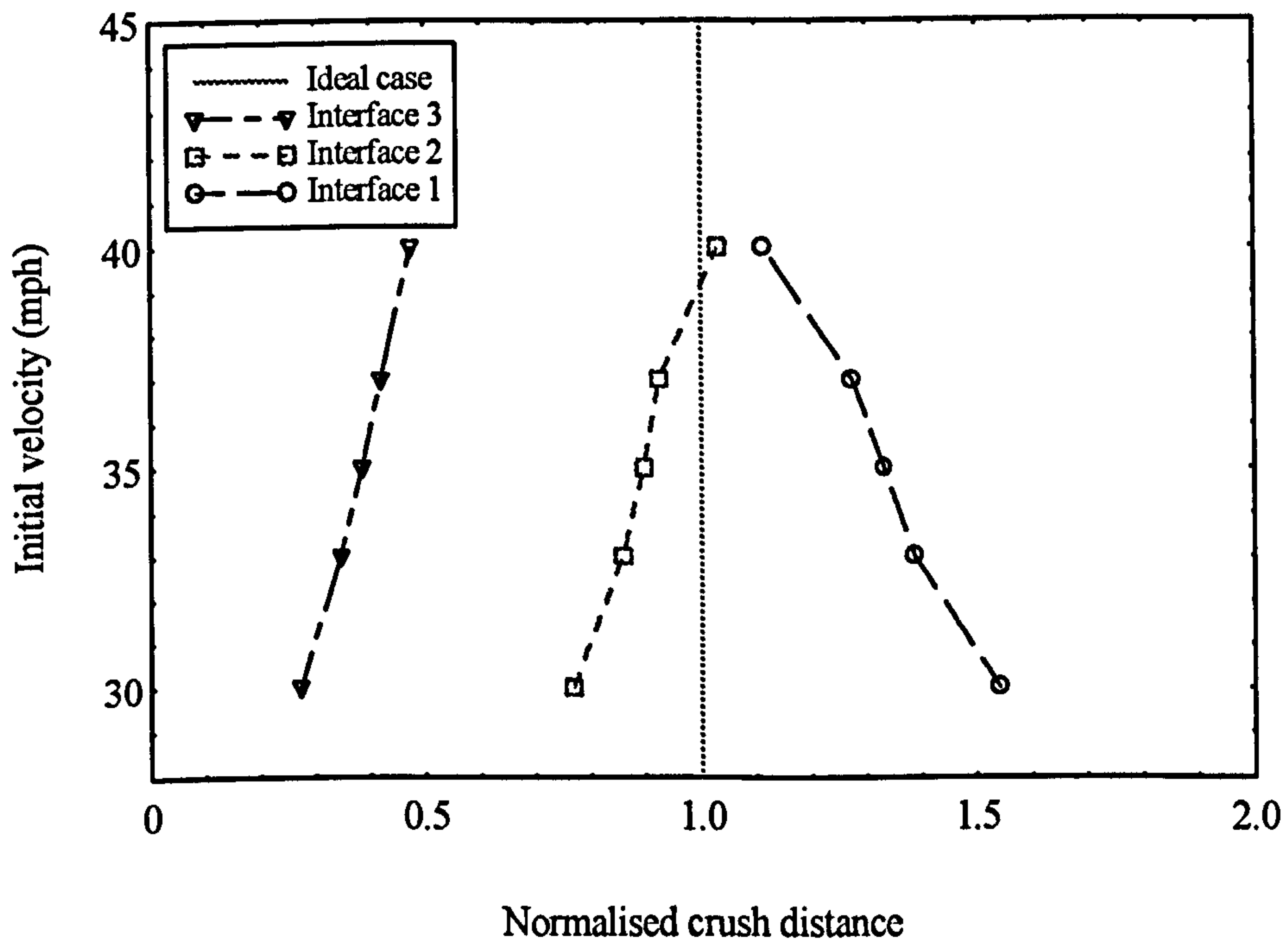


Figure 4.27 : The normalised crush distance for models in the Gp59 series.

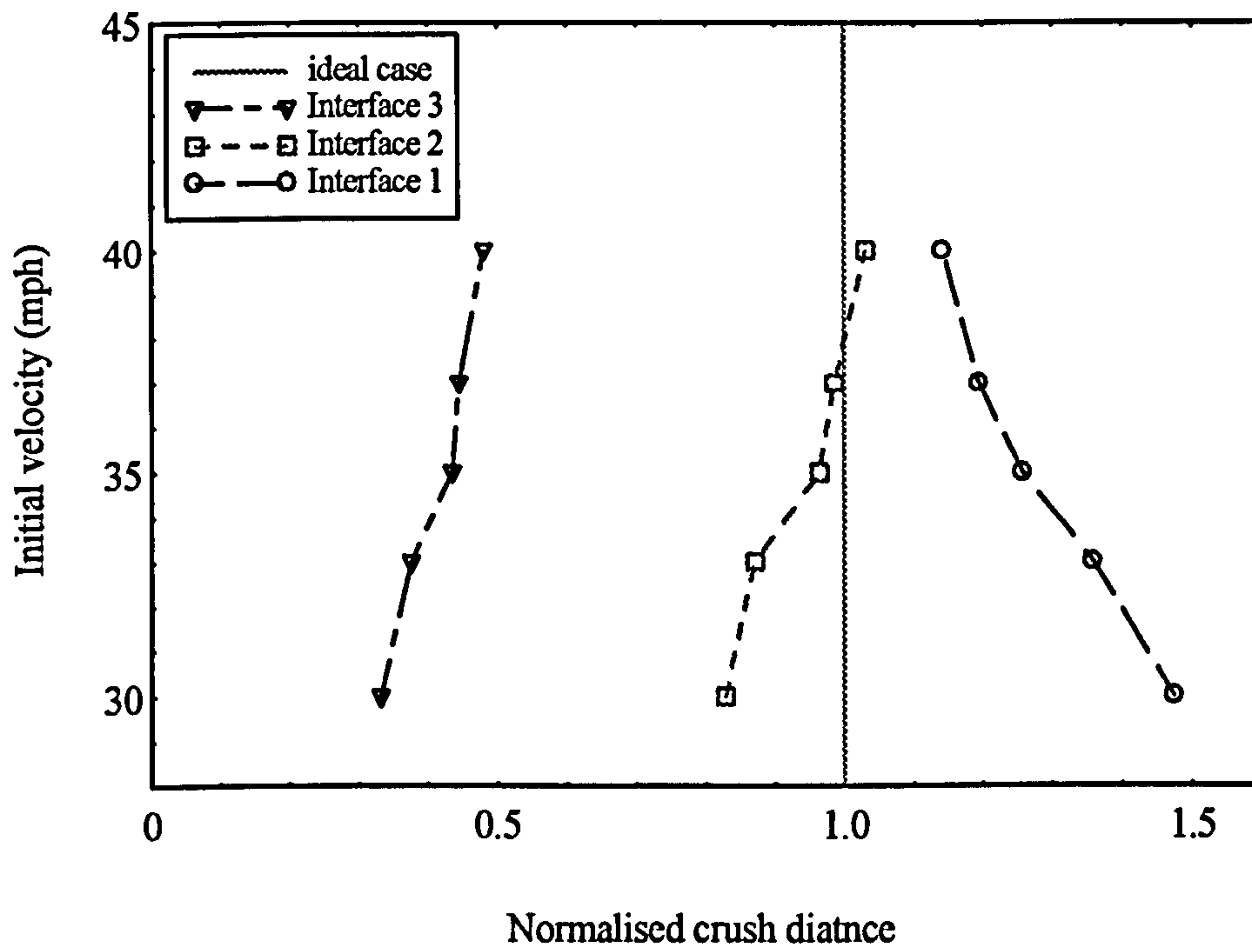


Figure 4.28 : The normalised crush distance for models in the Gp53 series.

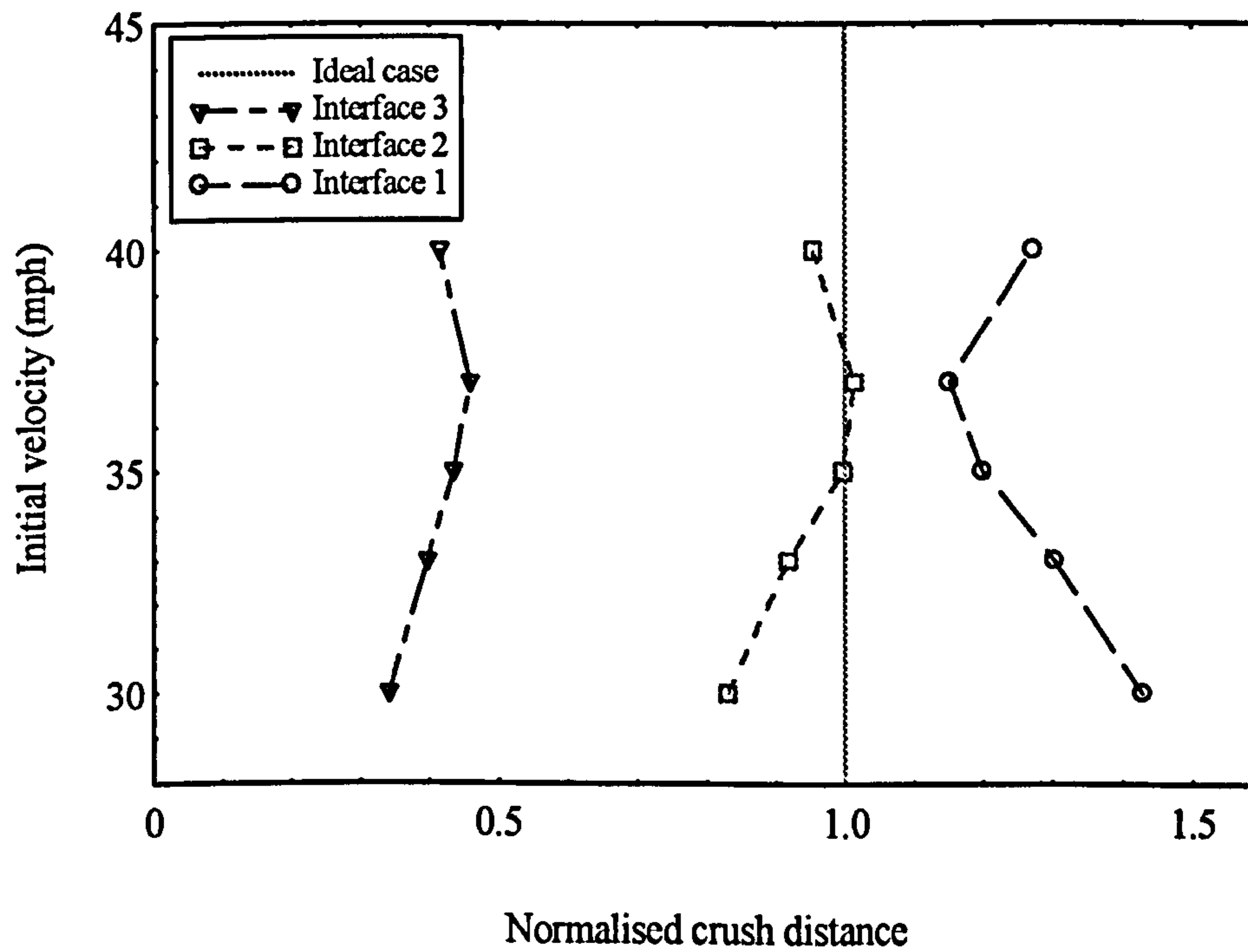


Figure 4.29 : The normalised crush distance for models in the Gp47 series.

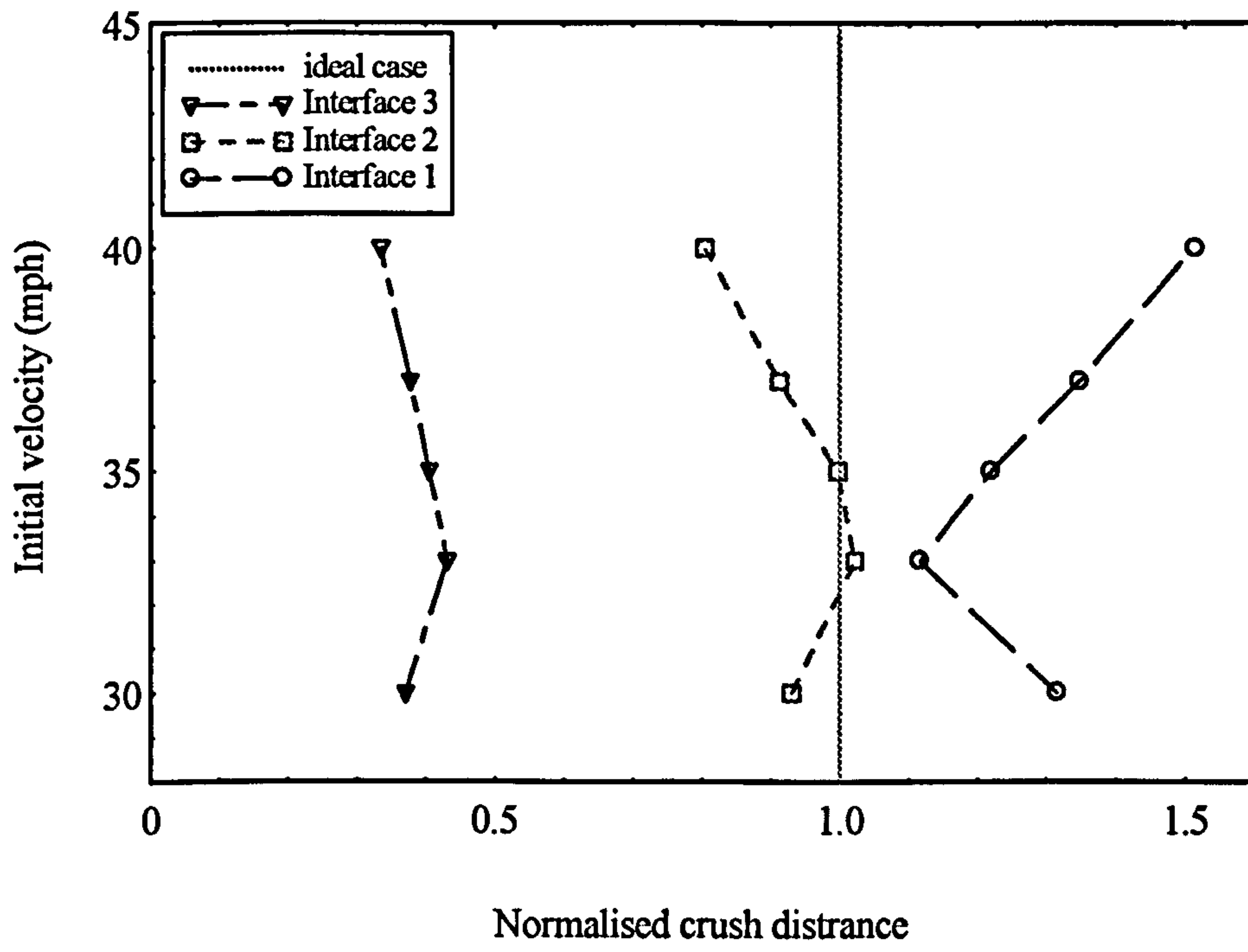


Figure 4.30 : The normalised crush distance for models in the Gp38 series.

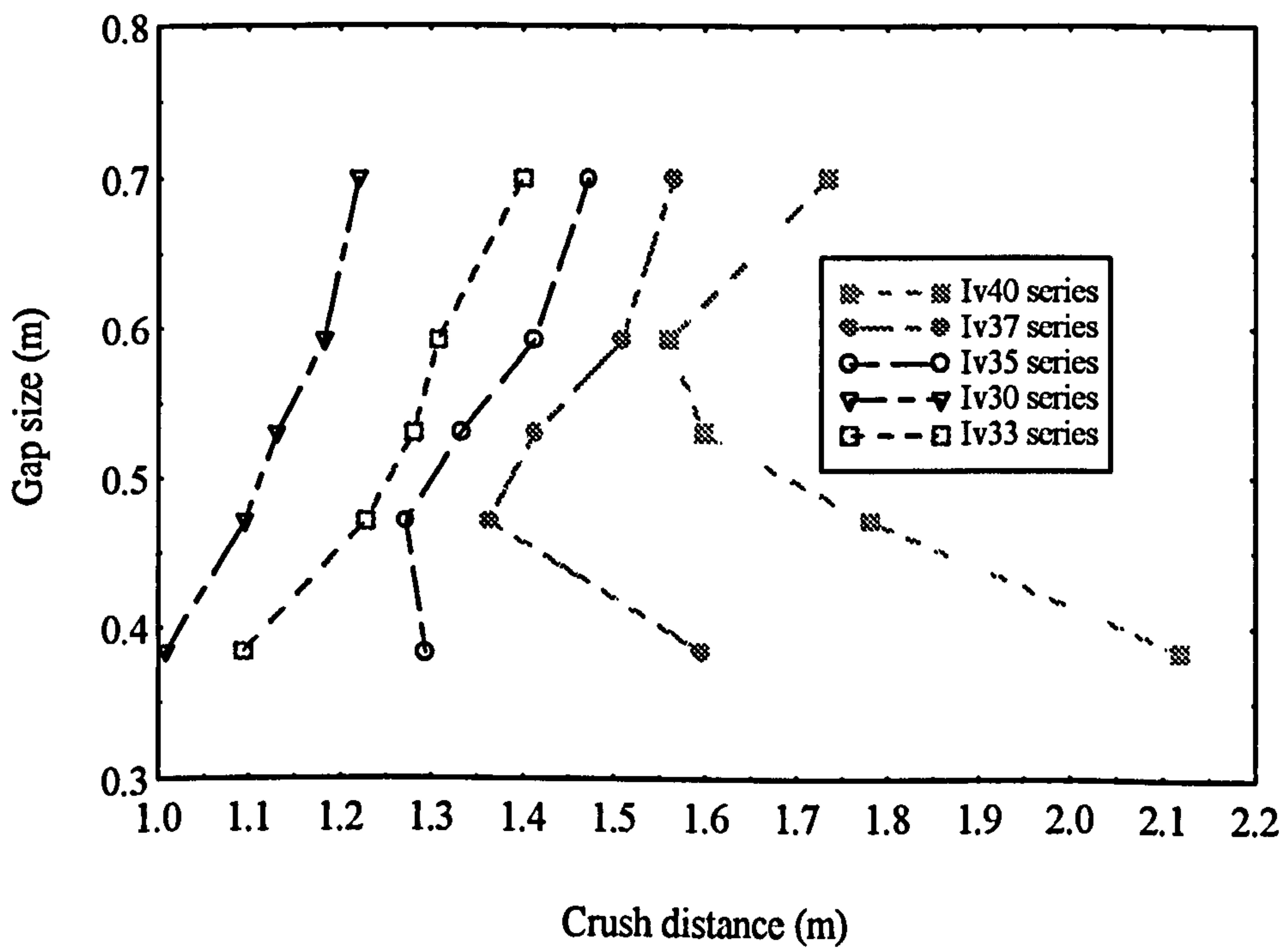


Figure 4.31 : Interface 1 crush distance for various models

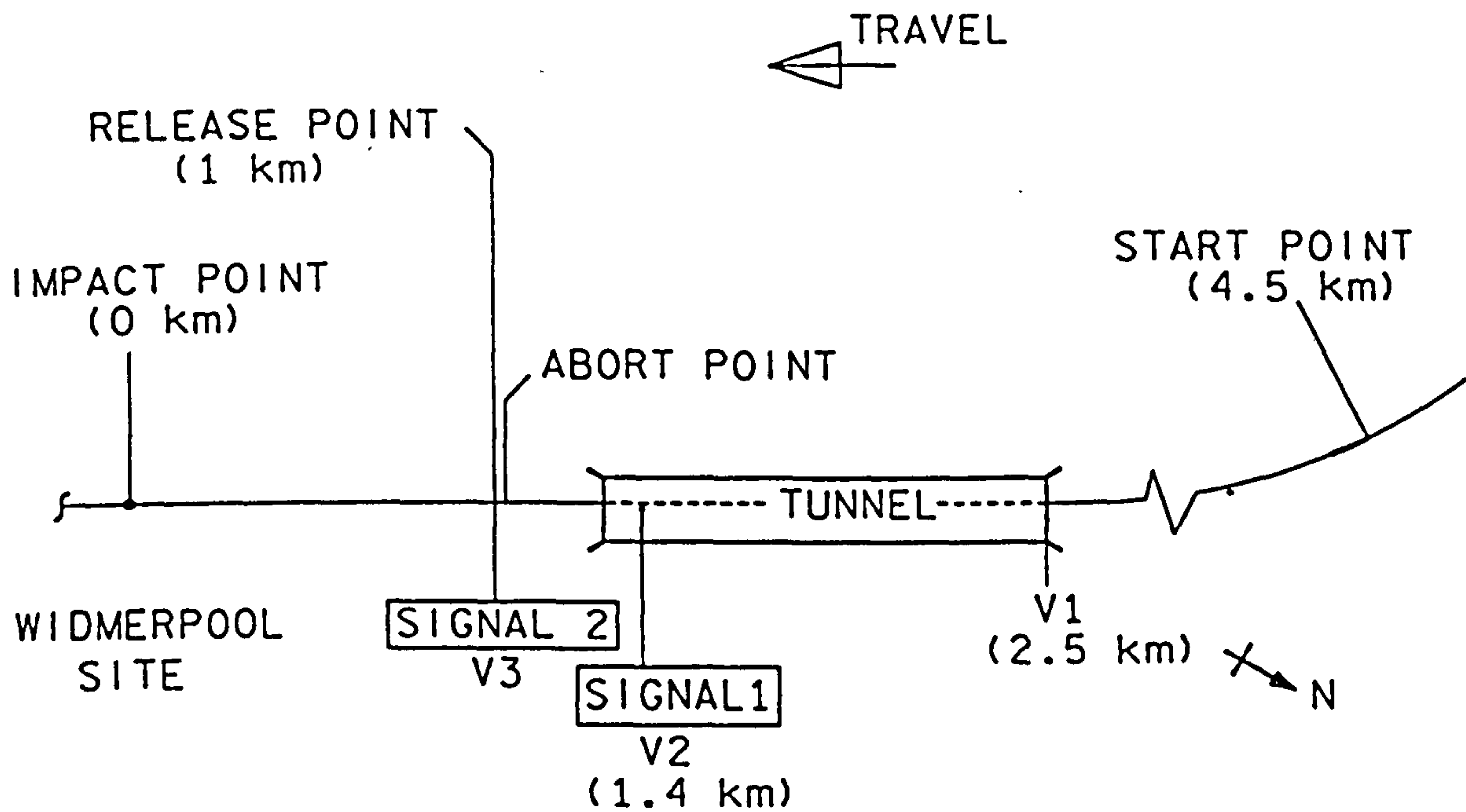


Figure 4.32 : The BR test track for the October 1994 full scale collision test. After [4]

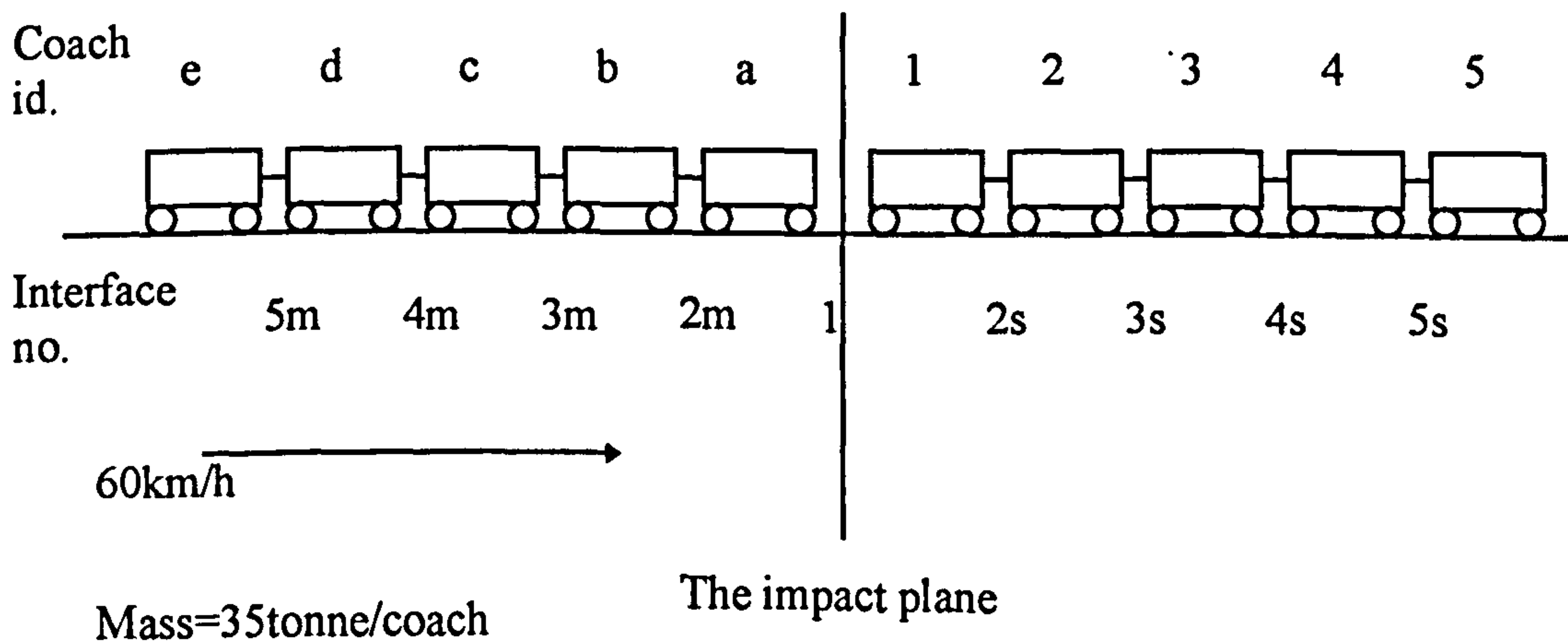


Figure 4.33 : The schematic representation of the BR October 1994 collision test.

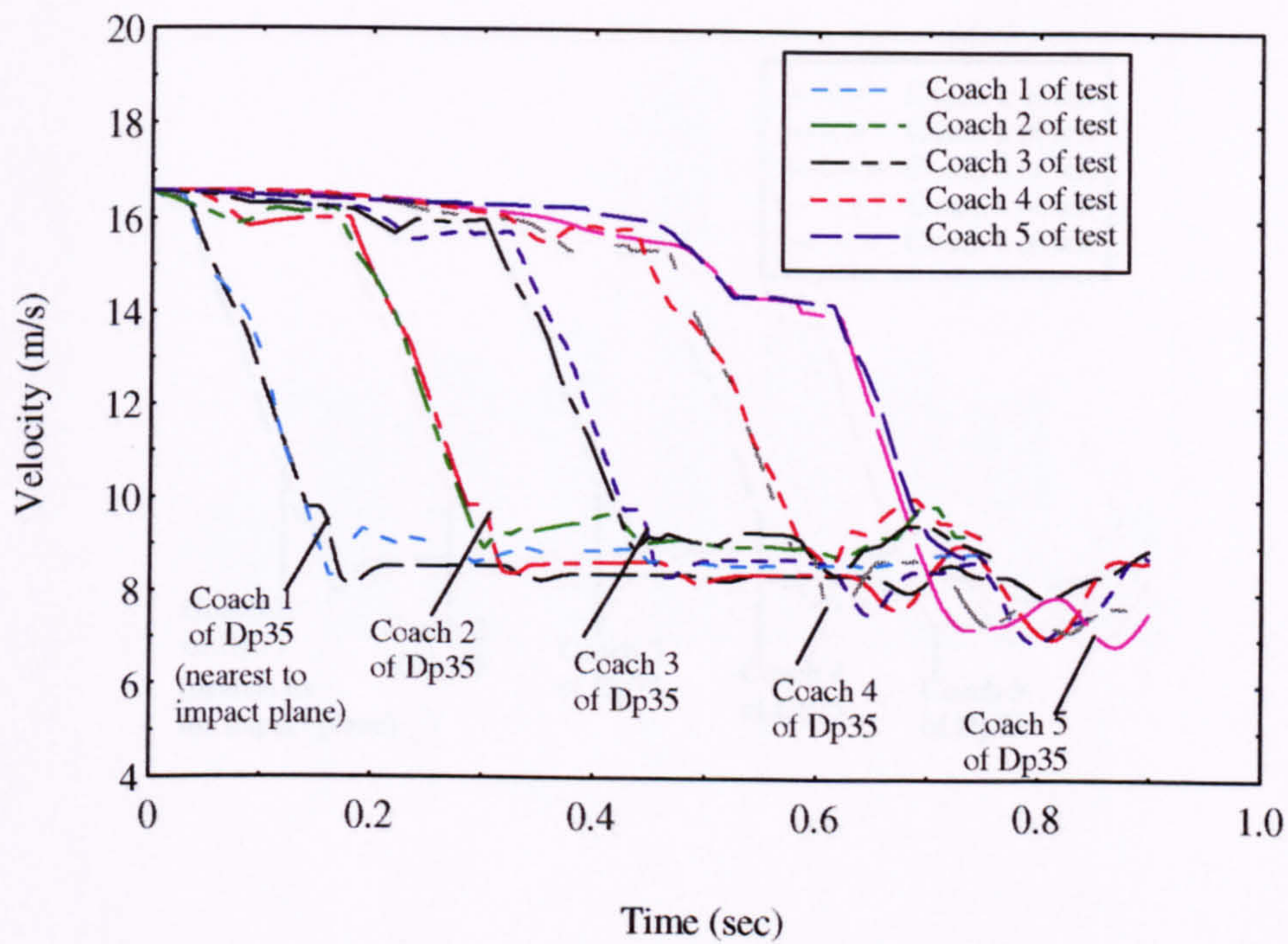


Figure 4.34 : The velocity-time history of various coaches for the test and model Dp35.

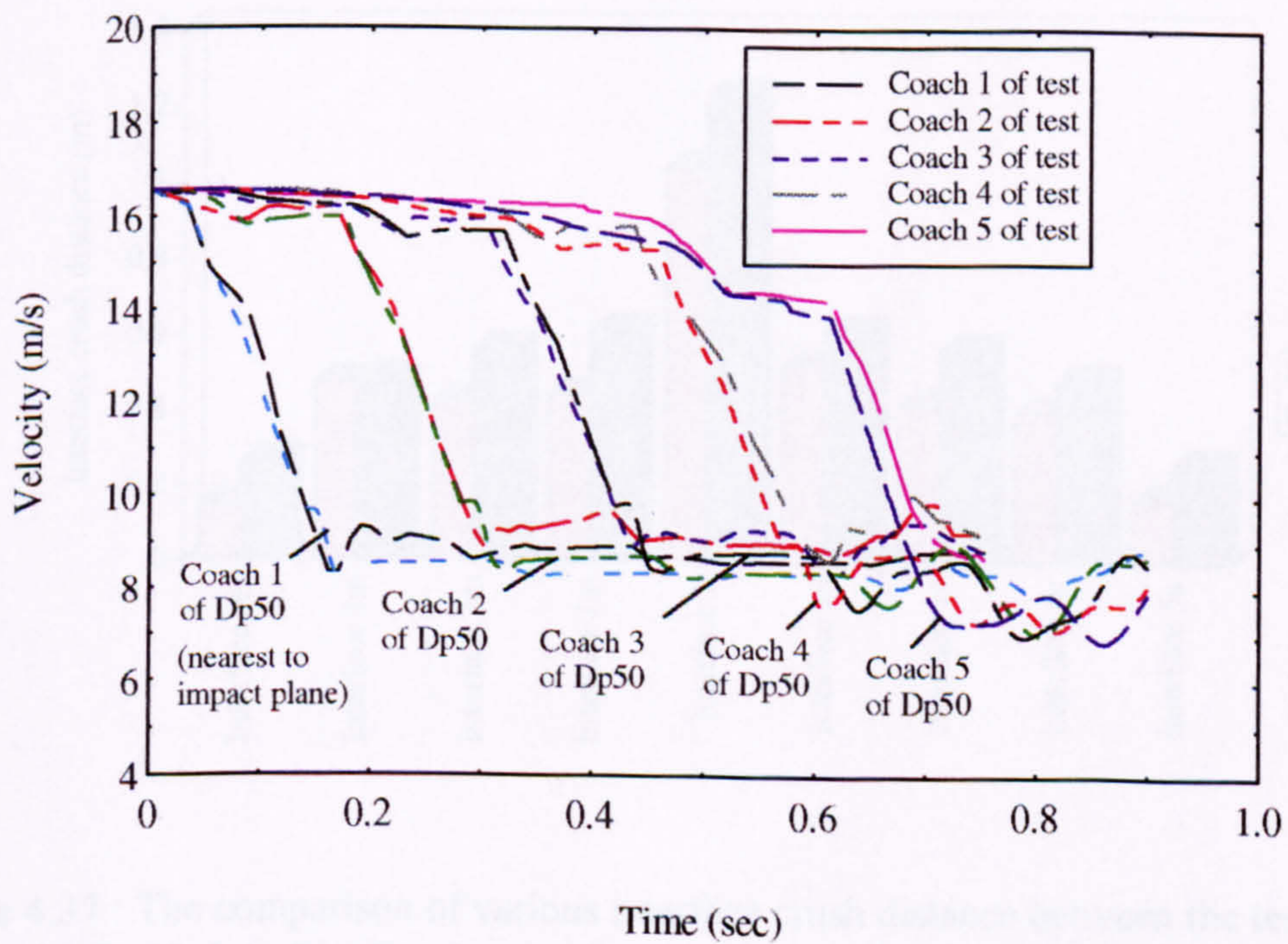


Figure 4.35 : The velocity-time history of various coaches for the test and model Dp50.

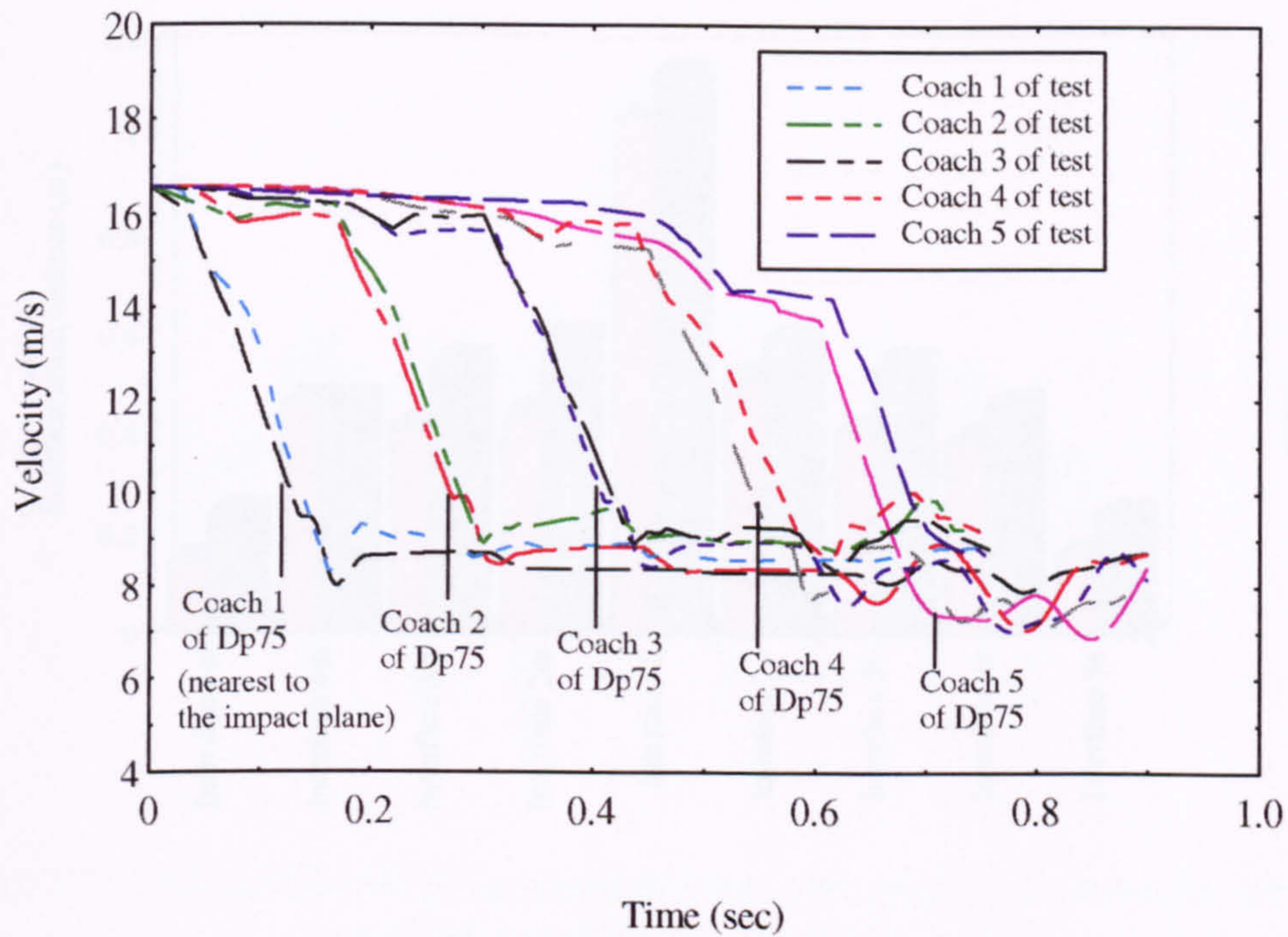


Figure 4.36 : The velocity-time history of various coaches for the test and model Dp75.

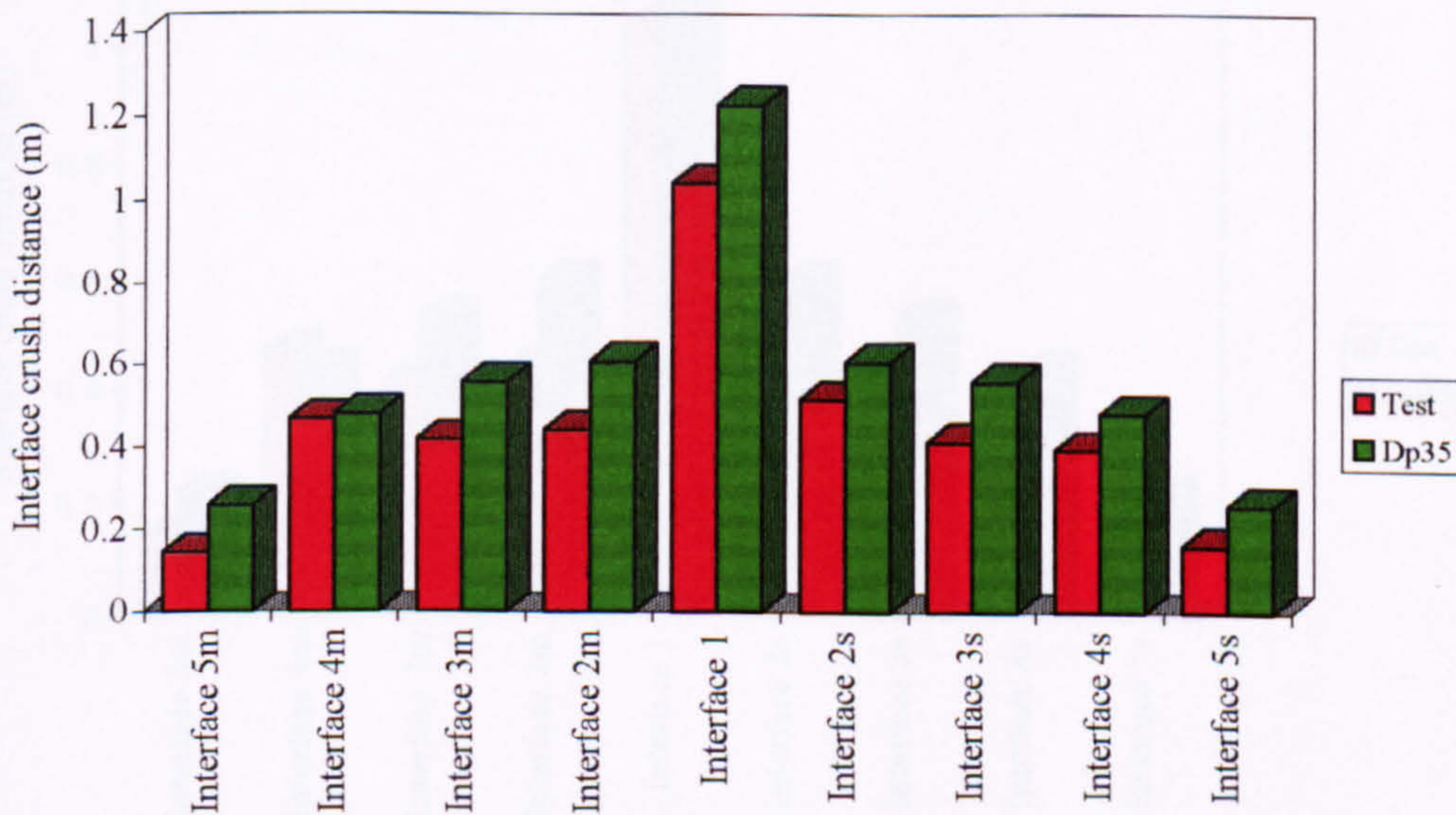


Figure 4.37 : The comparison of various interface crush distance between the test and the model Dp35. Interface 5m-2m are the intermediate interfaces of the moving rake, interface 5s-2s are in the stationary rake, interface 1 is the impact interface.

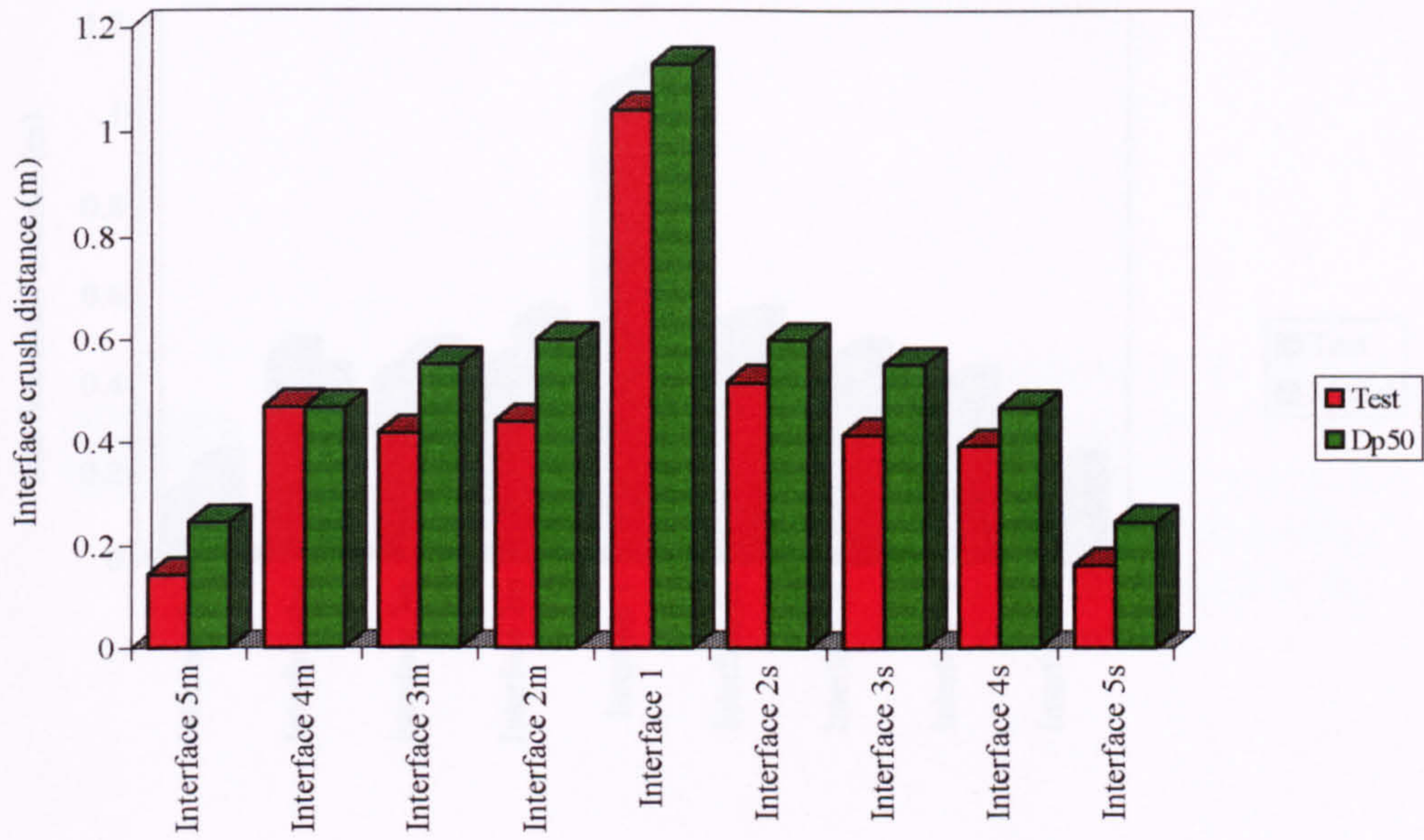


Figure 4.38 : The comparison of various interface crush distance between the test and the model Dp50.

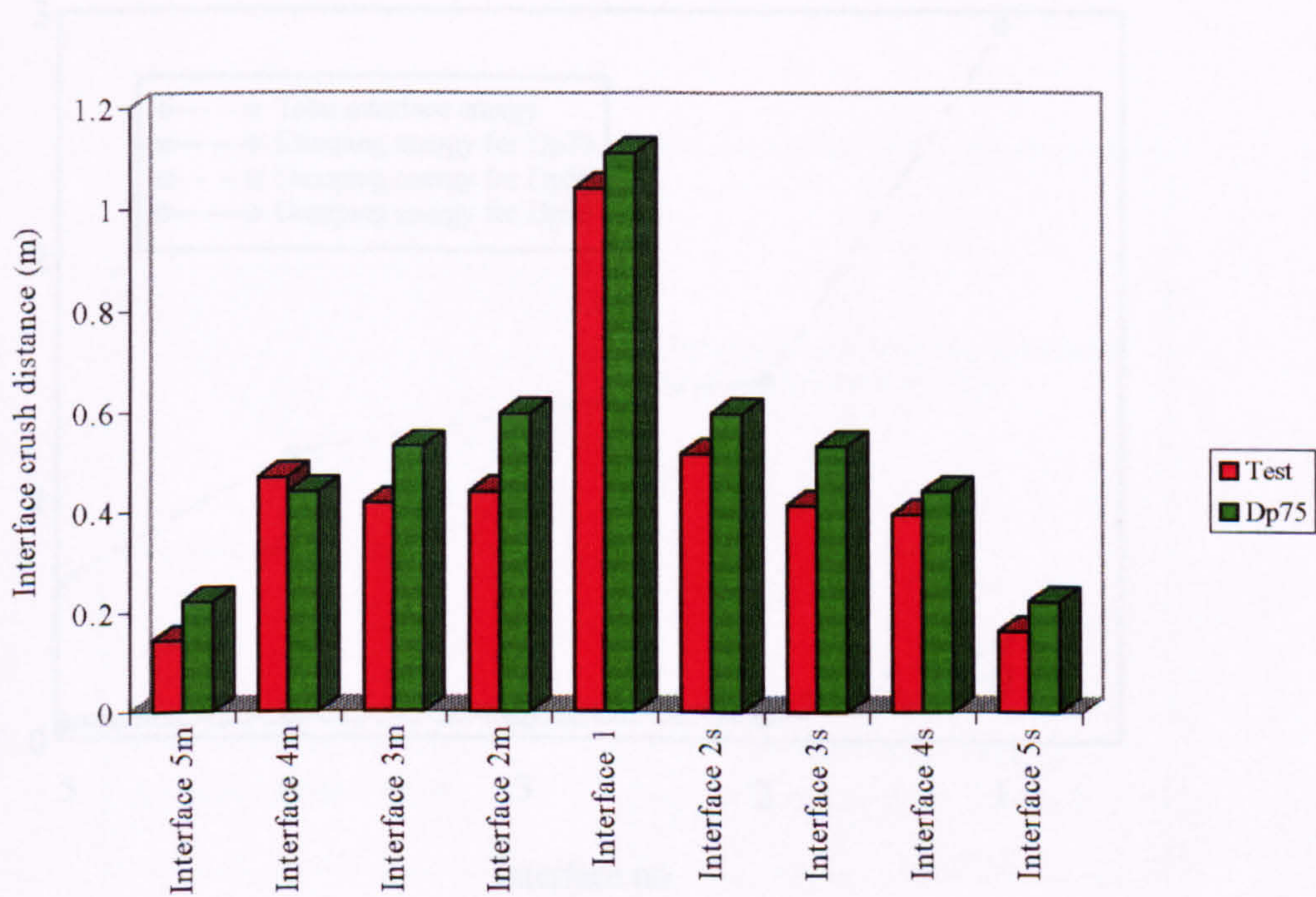


Figure 4.39 : The comparison of various interface crush distance between the test and the model Dp75.

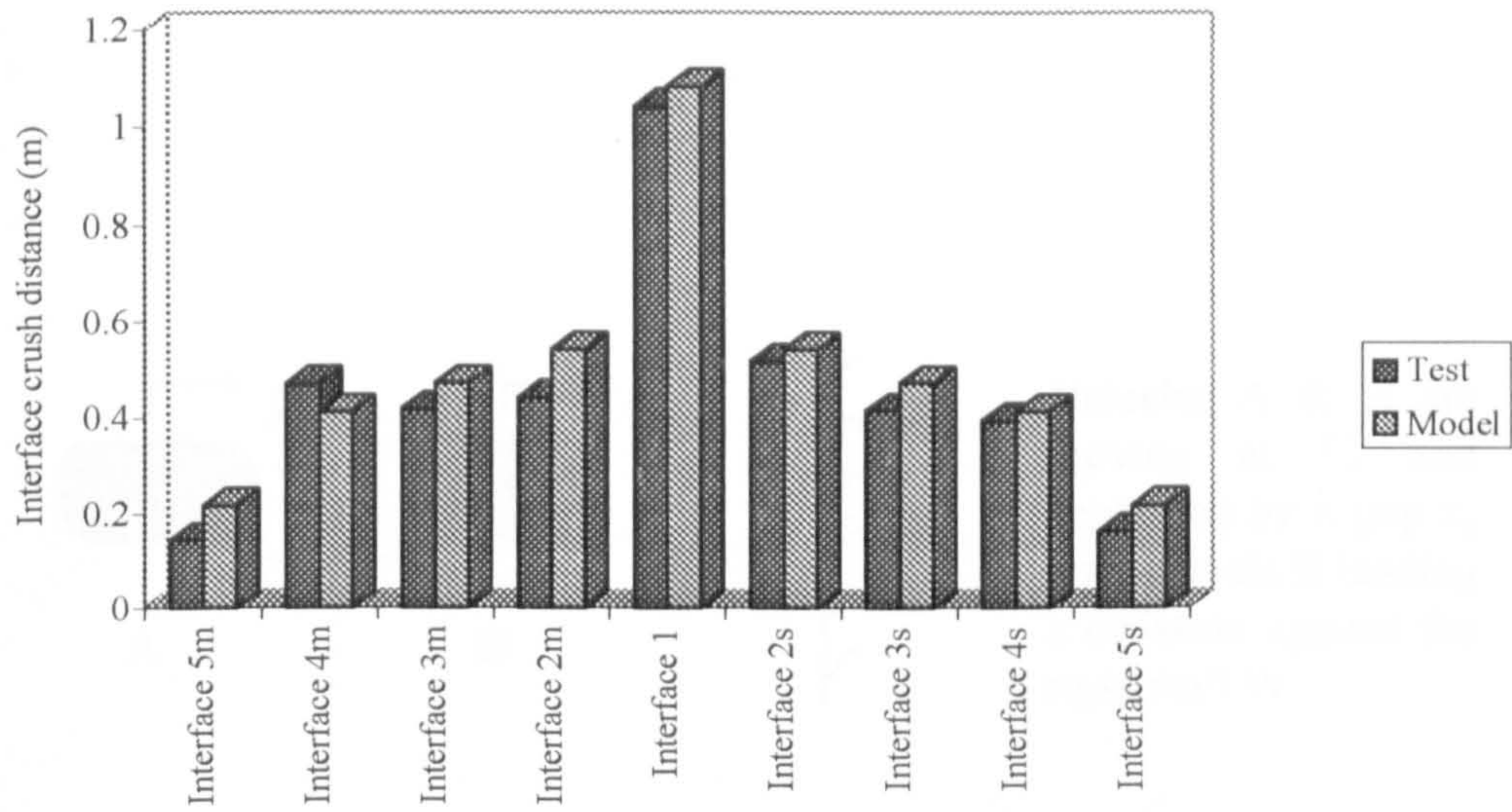


Figure 4.40 : The comparison of various interface crush distance between the test and the dynamically enhanced model.

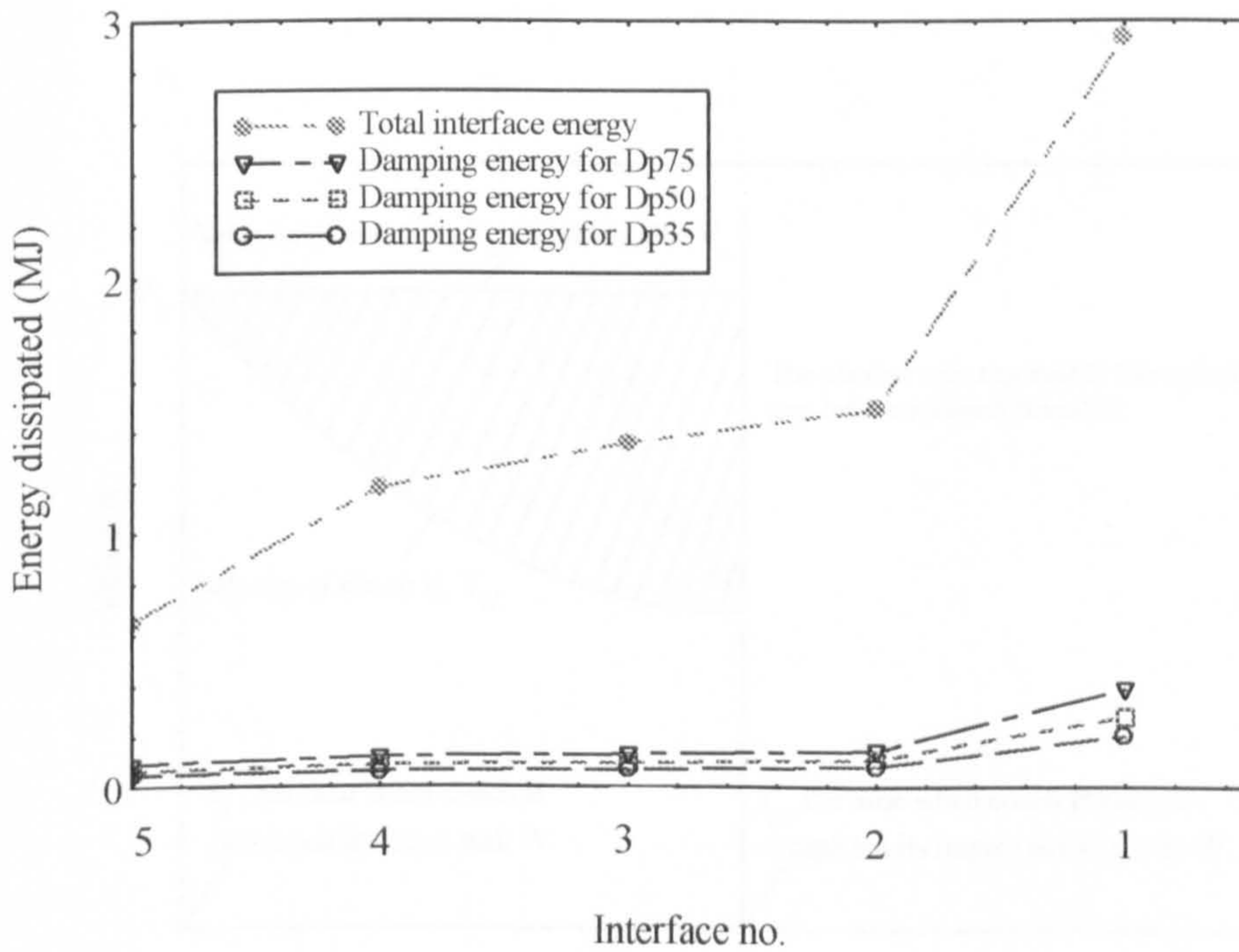
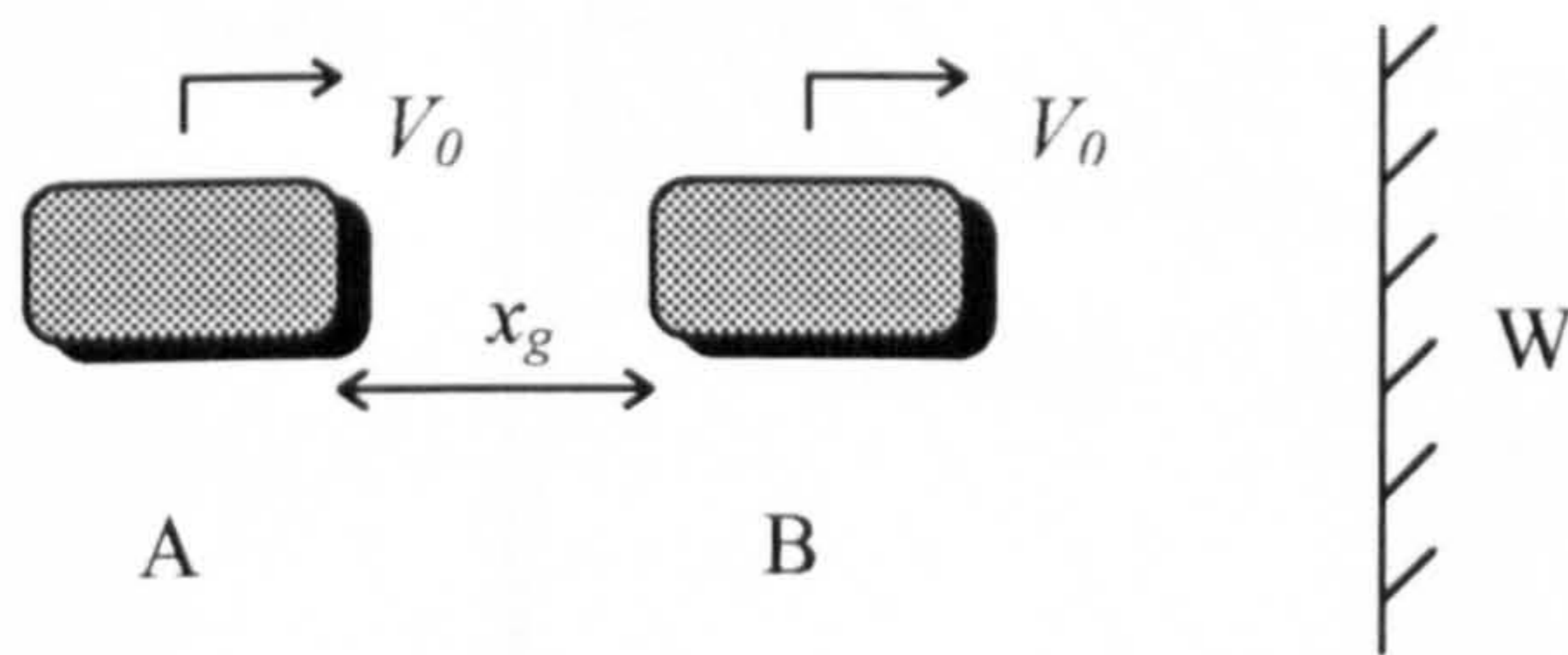


Figure 4.41 : Comparison of the damping energy with the total interface energy in various interfaces for all Dp models.



Vehicles A & B are moving at V_0 and separated by a gap x_g with vehicle B leading a collision against the rigid wall W.

Figure 5.1 : The schematic diagram for deriving the optimal gap of mass-spring models with non-linear deceleration.

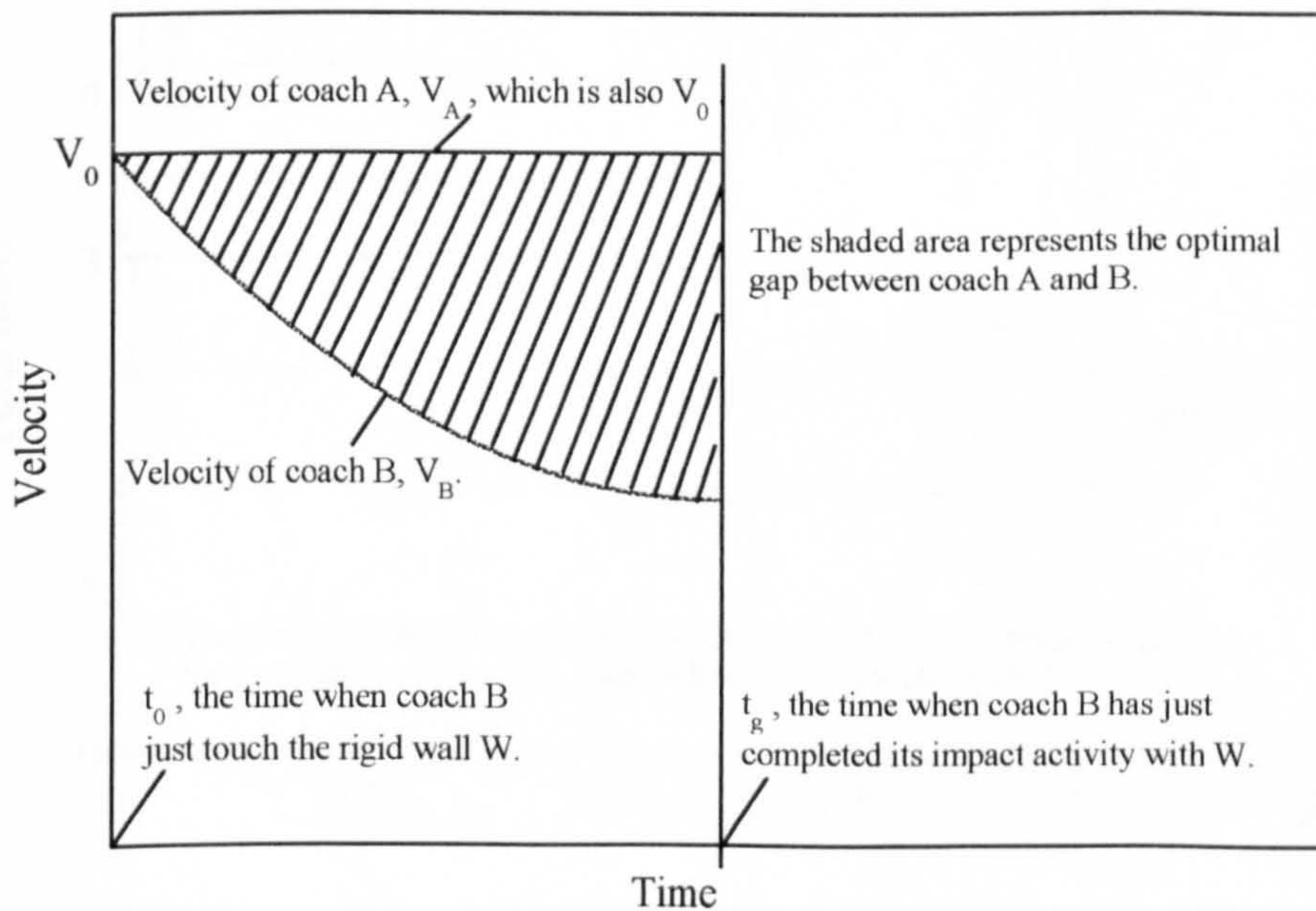


Figure 5.2 : The kinematics graphical interpretation of optimal gap sizes for non-linear deceleration cases.

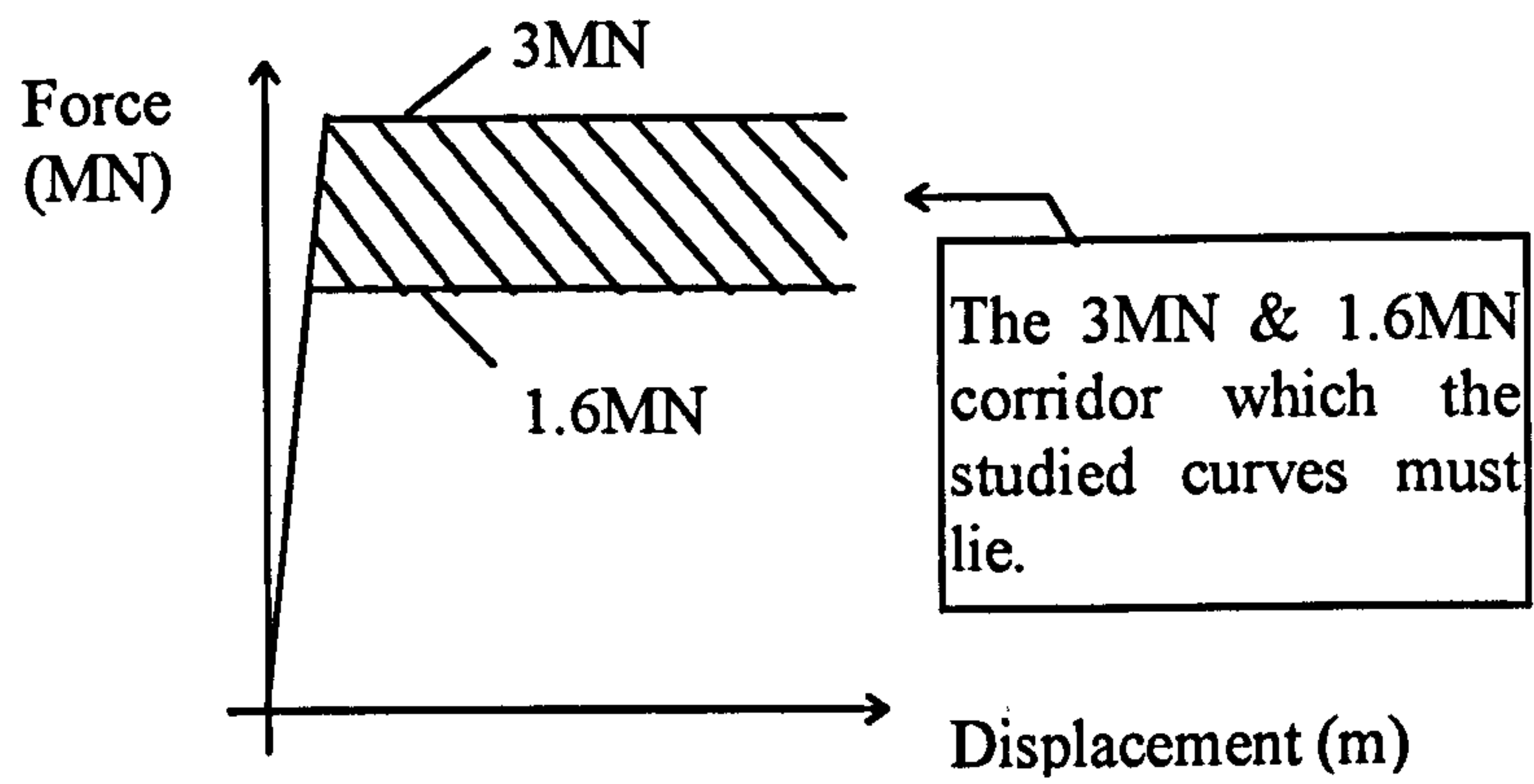


Figure 5.3 : The imposed constraints on the shapes of the spring characteristics.

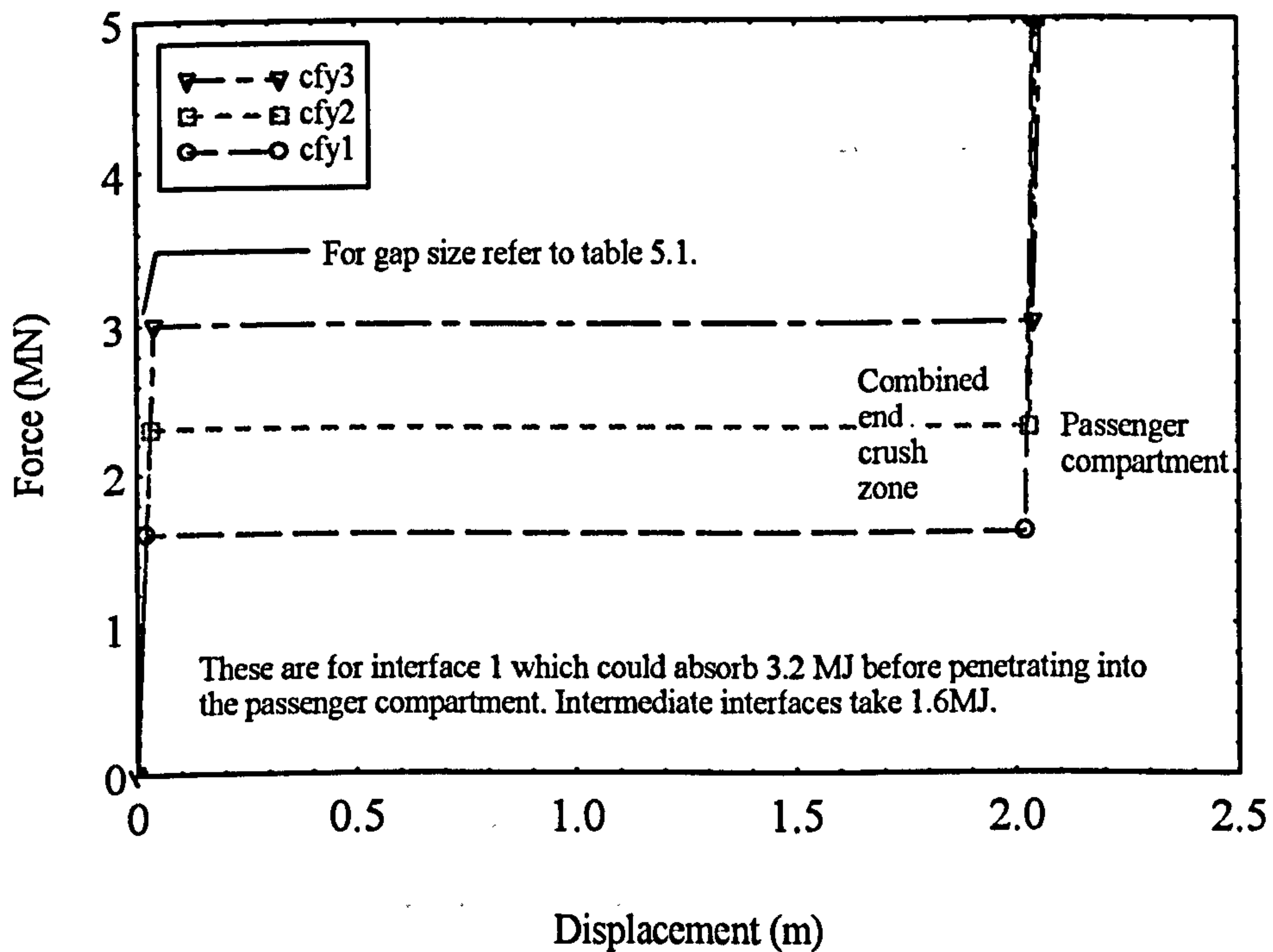


Figure 5.4 : Spring characteristic curves for constant collapse force series.

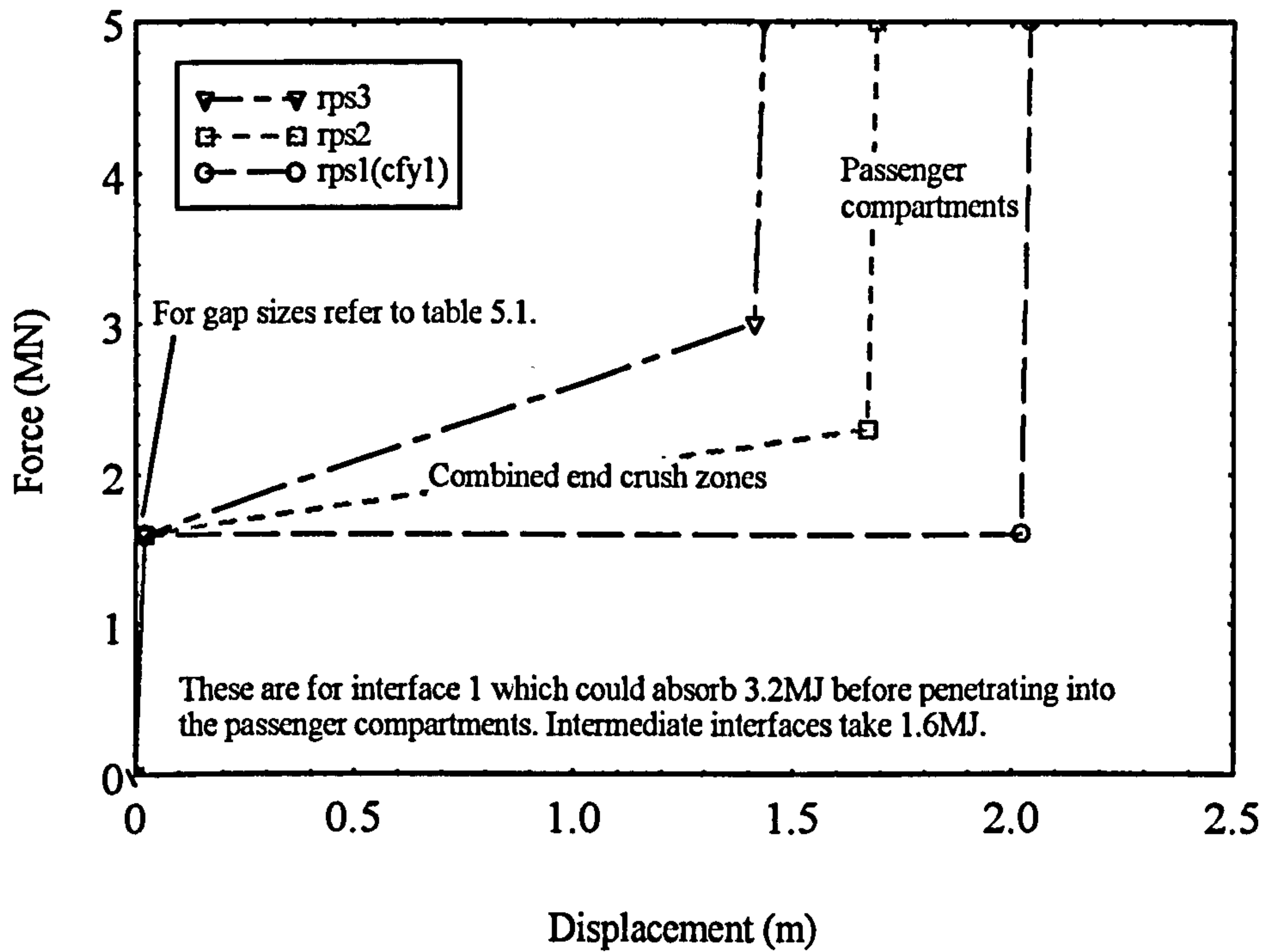


Figure 5.5 : Spring characteristic curves for ramp slope series.

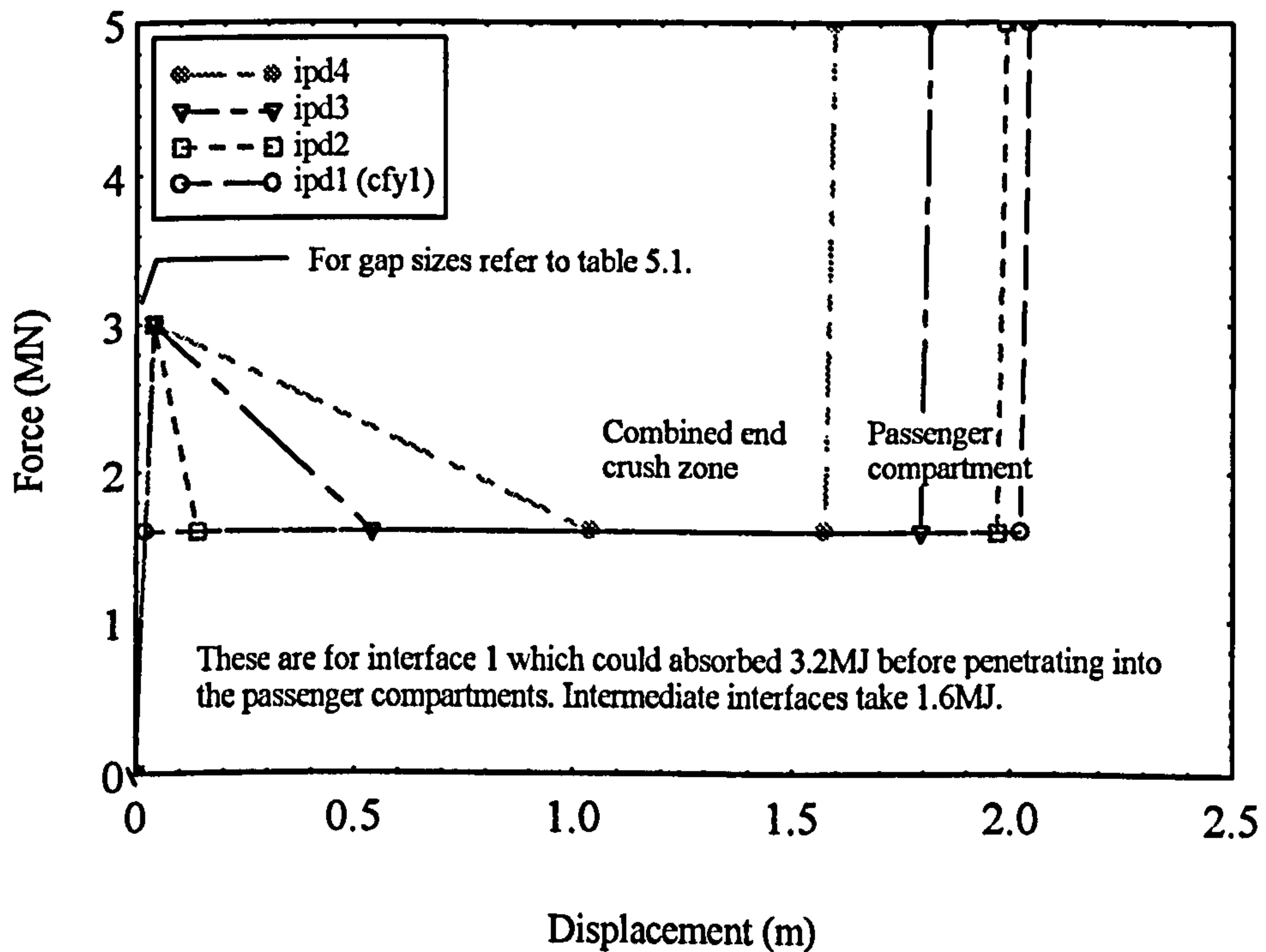


Figure 5.6 : Spring characteristic curves for softening distance series.

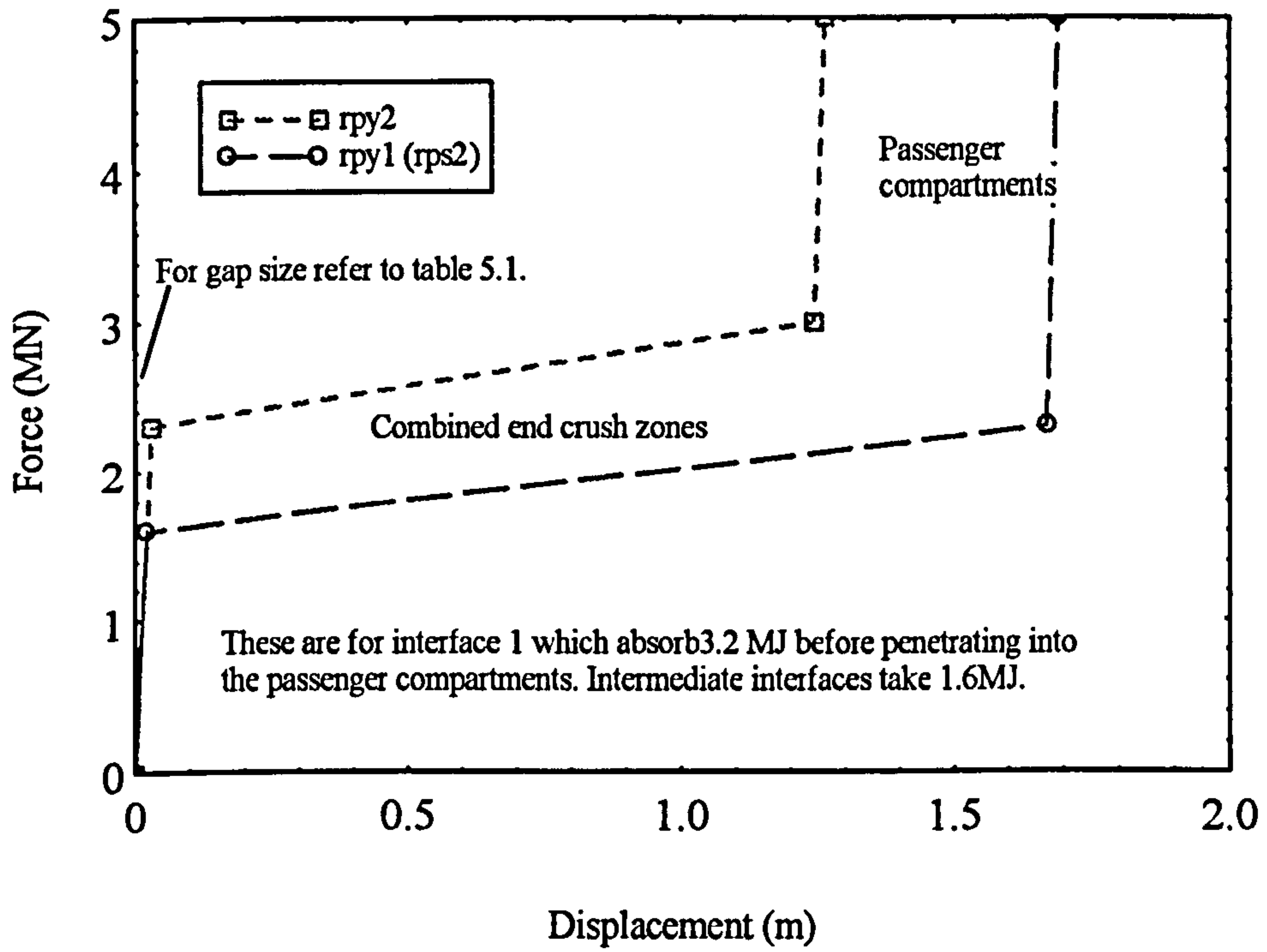


Figure 5.7 : Spring characteristic curves for ramp force series.

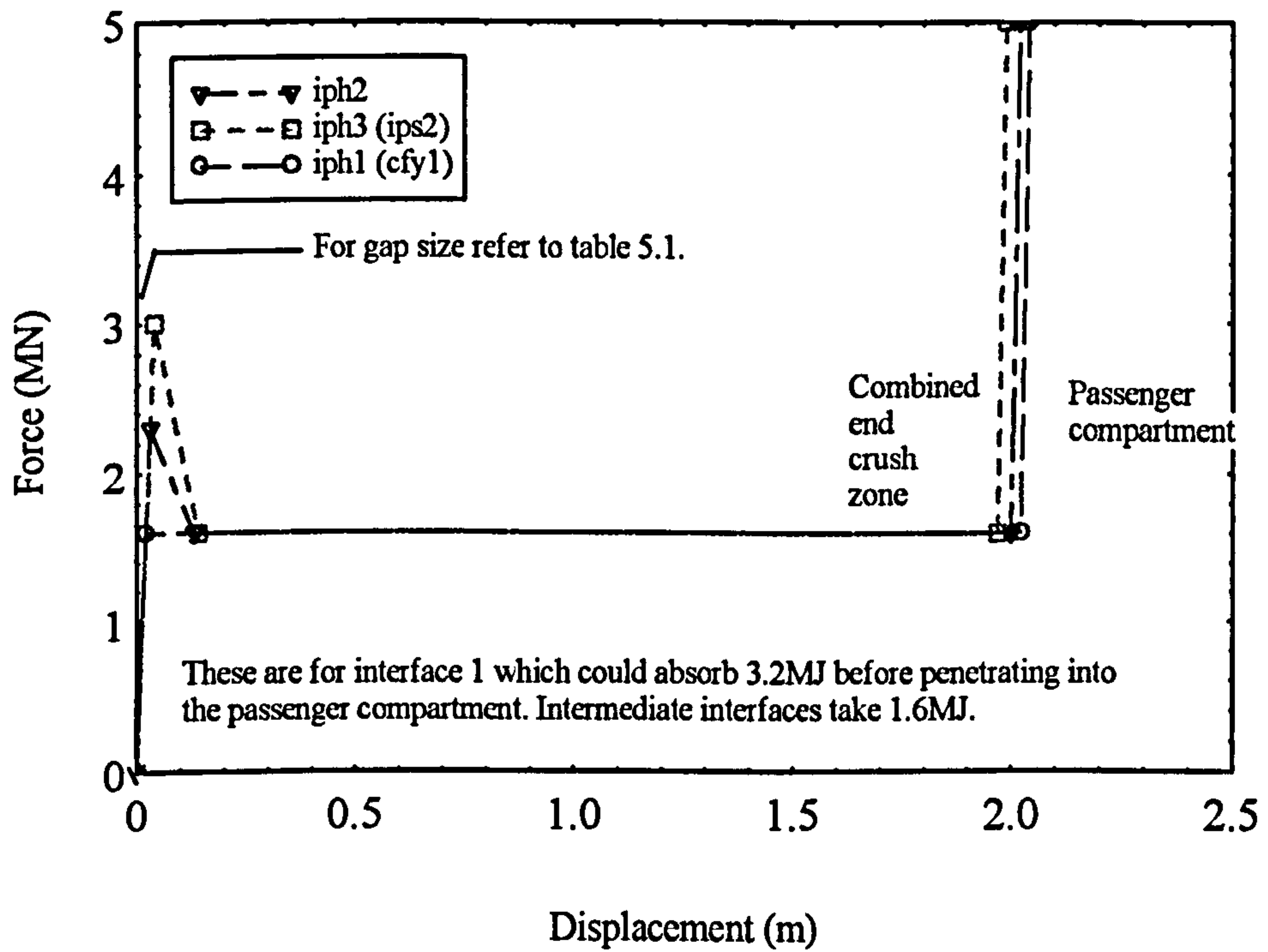


Figure 5.8 : Spring characteristic curves for initial peak force series.

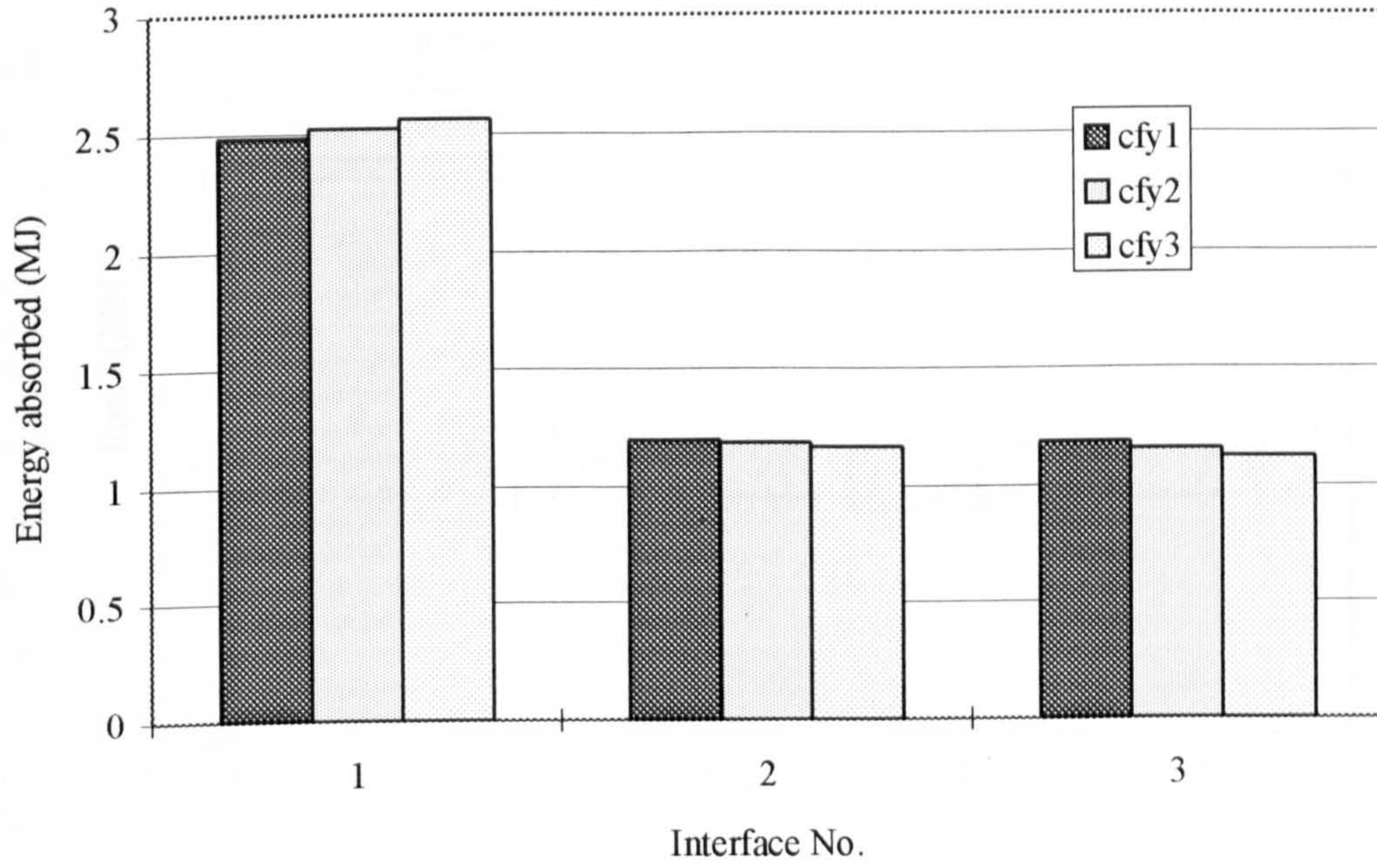


Figure 5.9 : The comparison of interface energy distribution for models in cfy series.

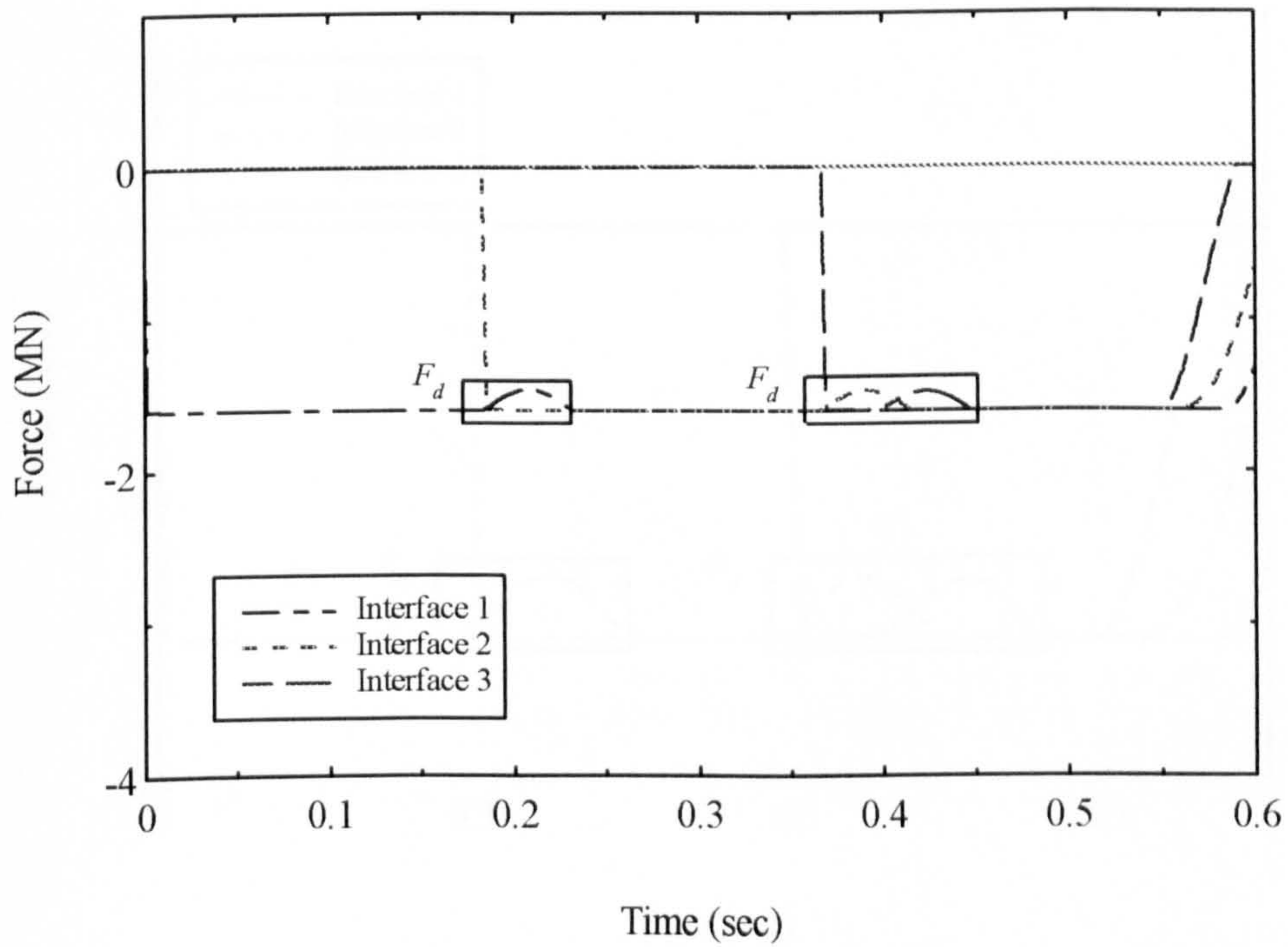


Figure 5.10a : The force-time history of various interfaces in cfy1.

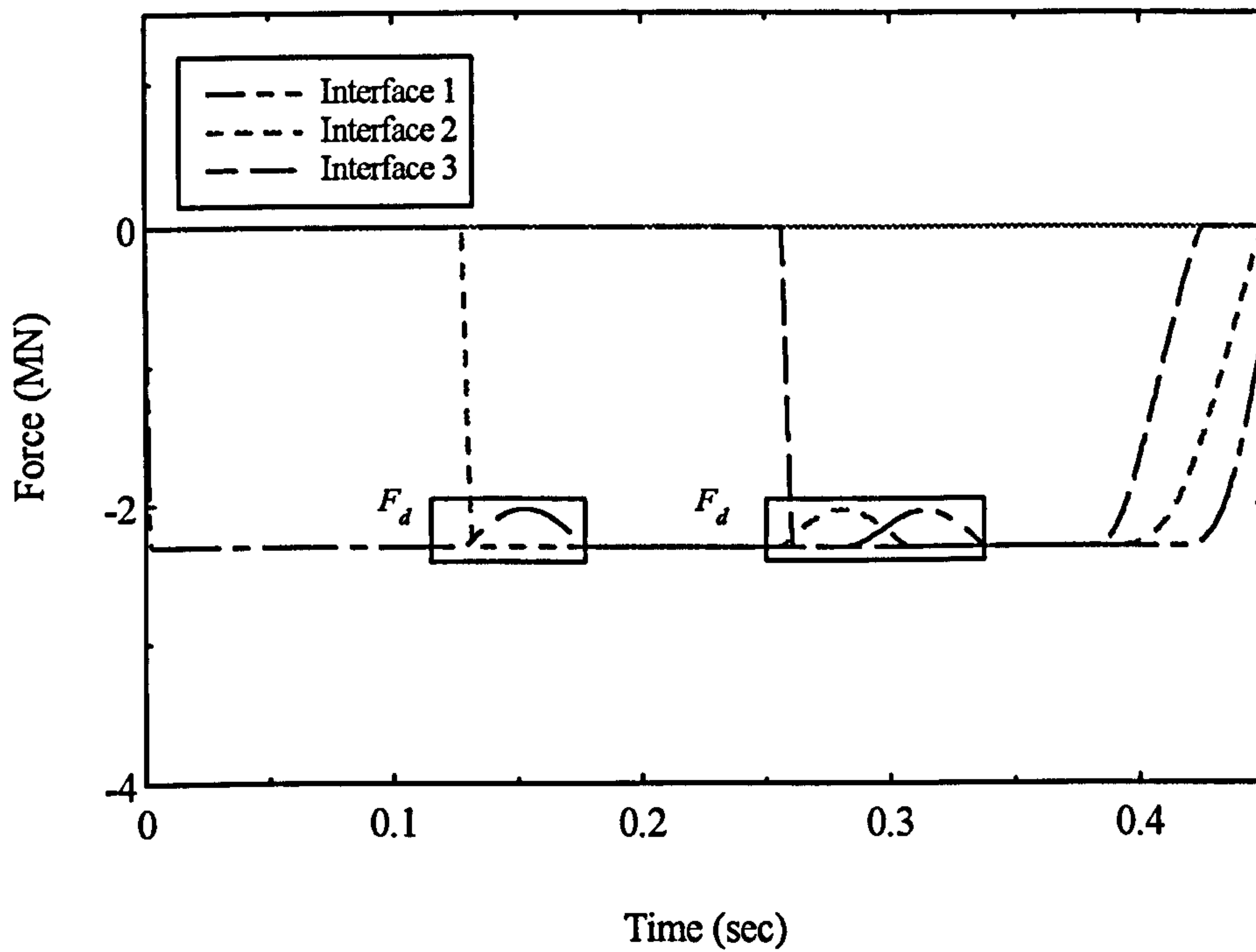


Figure 5.10b : The force-time history of various interfaces in cfy2.

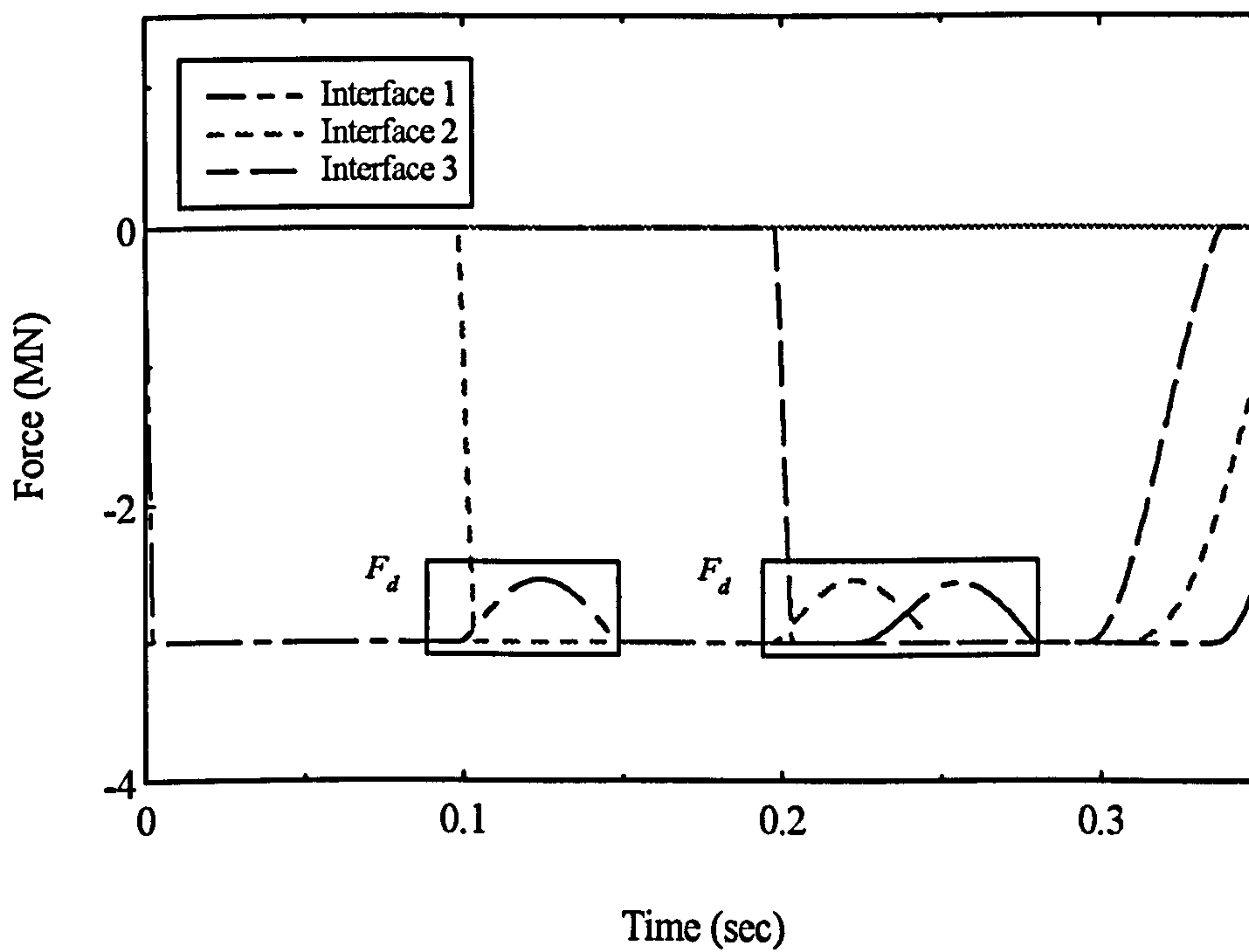


Figure 5.10c : The force-time history of various interfaces in cfy3.

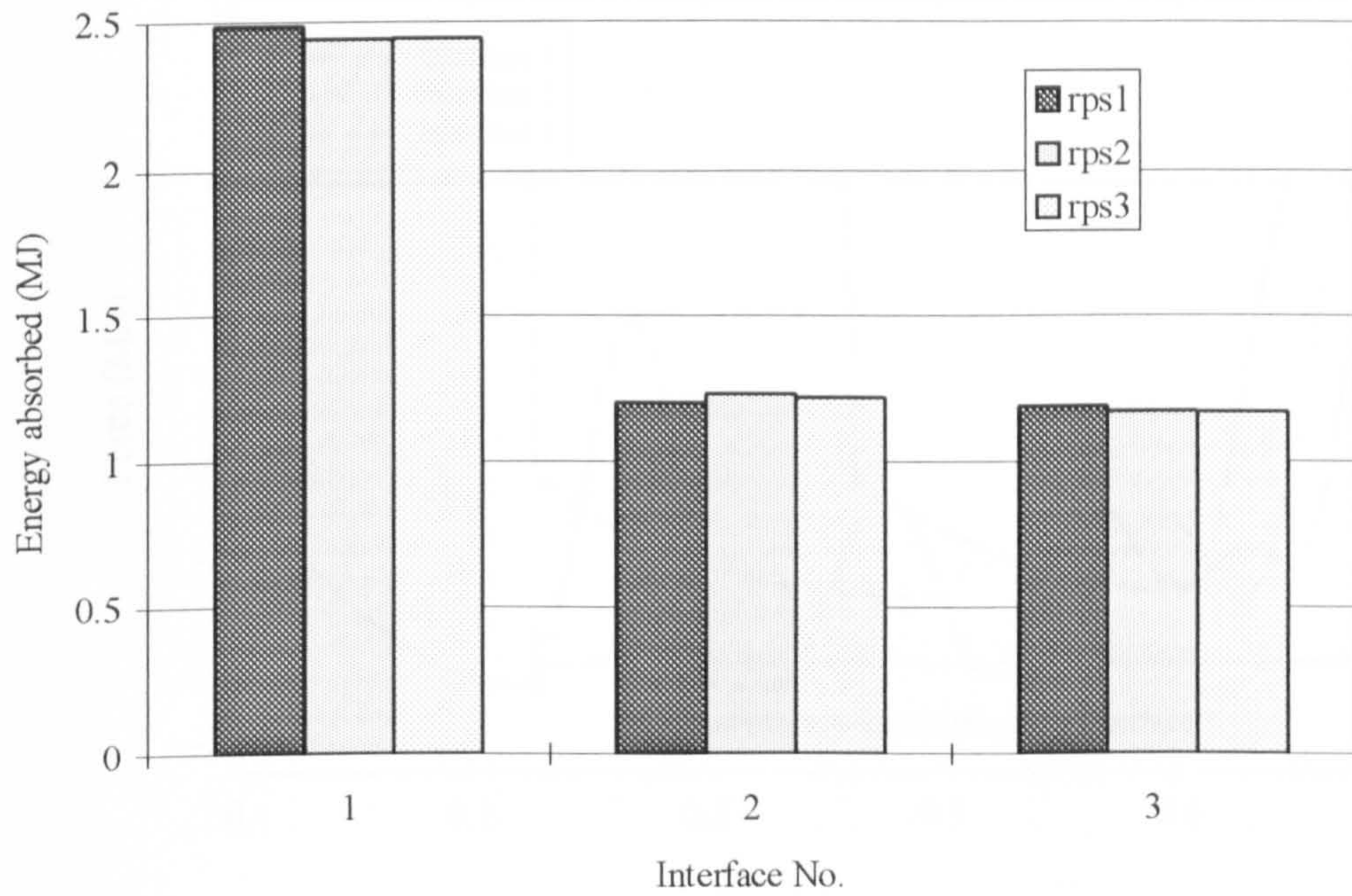


Figure 5.11 : The comparison of interface energy distribution for models in rps series.

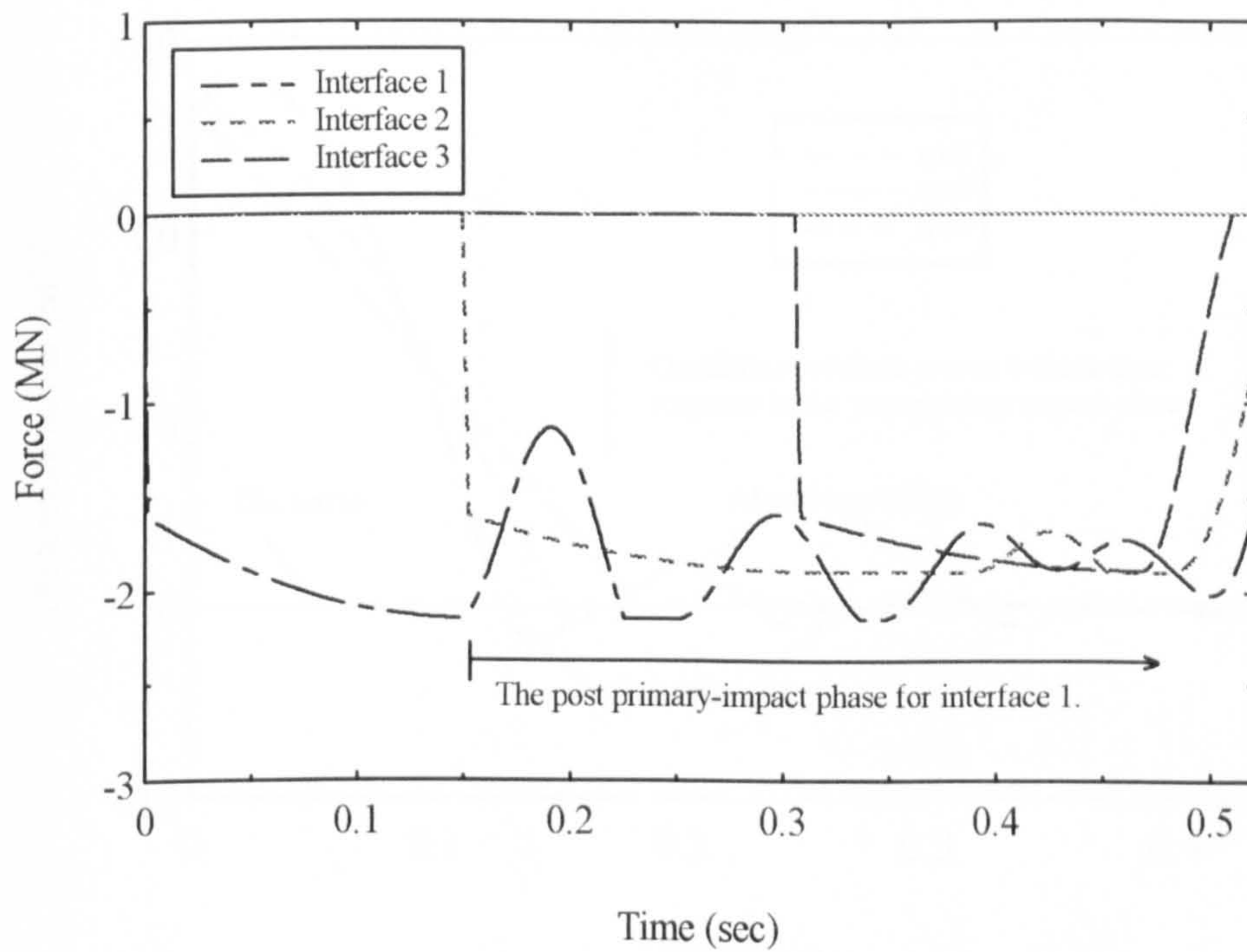


Figure 5.12a : The force-time history of various interfaces in rps2.

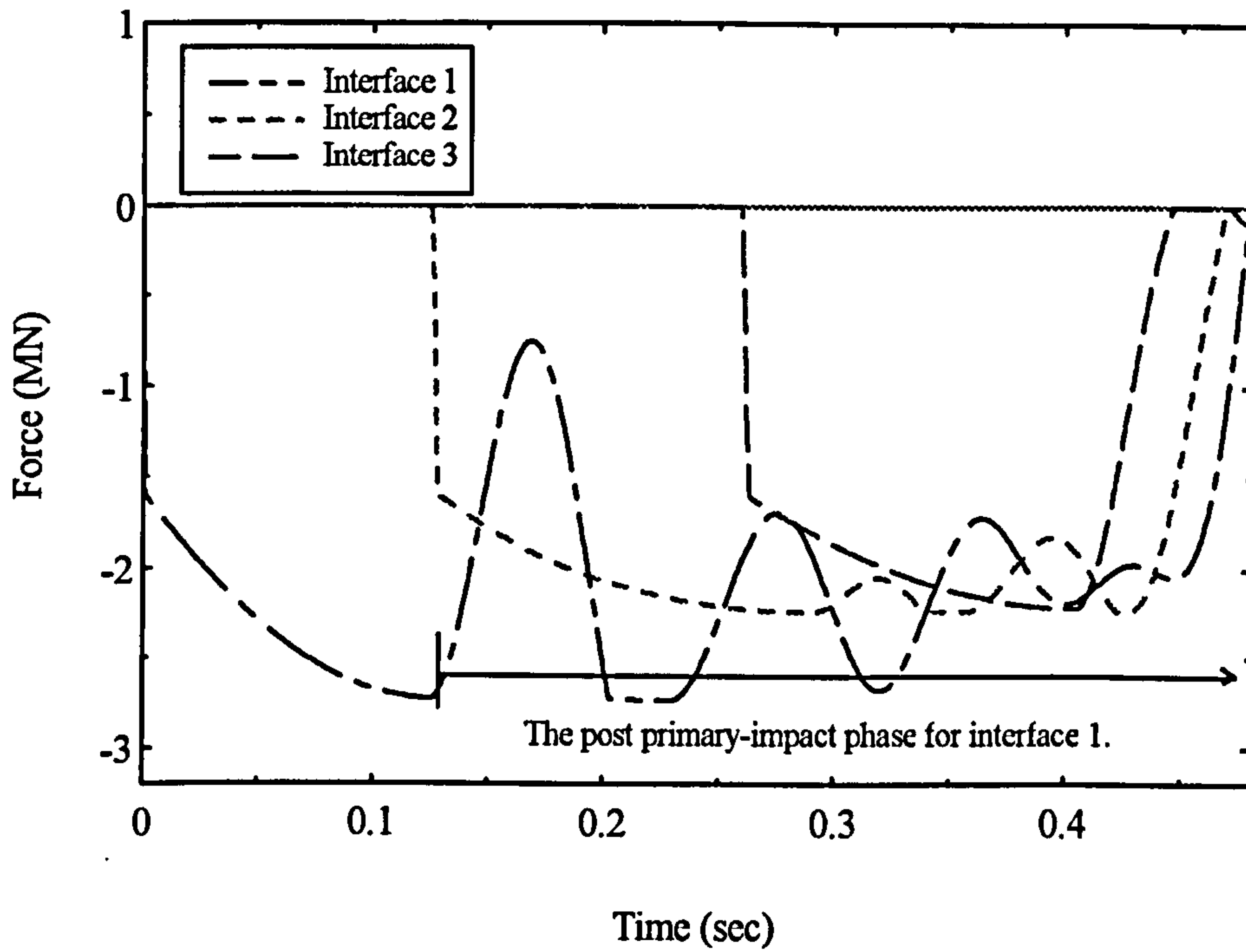


Figure 5.12b : The force-time history of various interfaces in rps3.

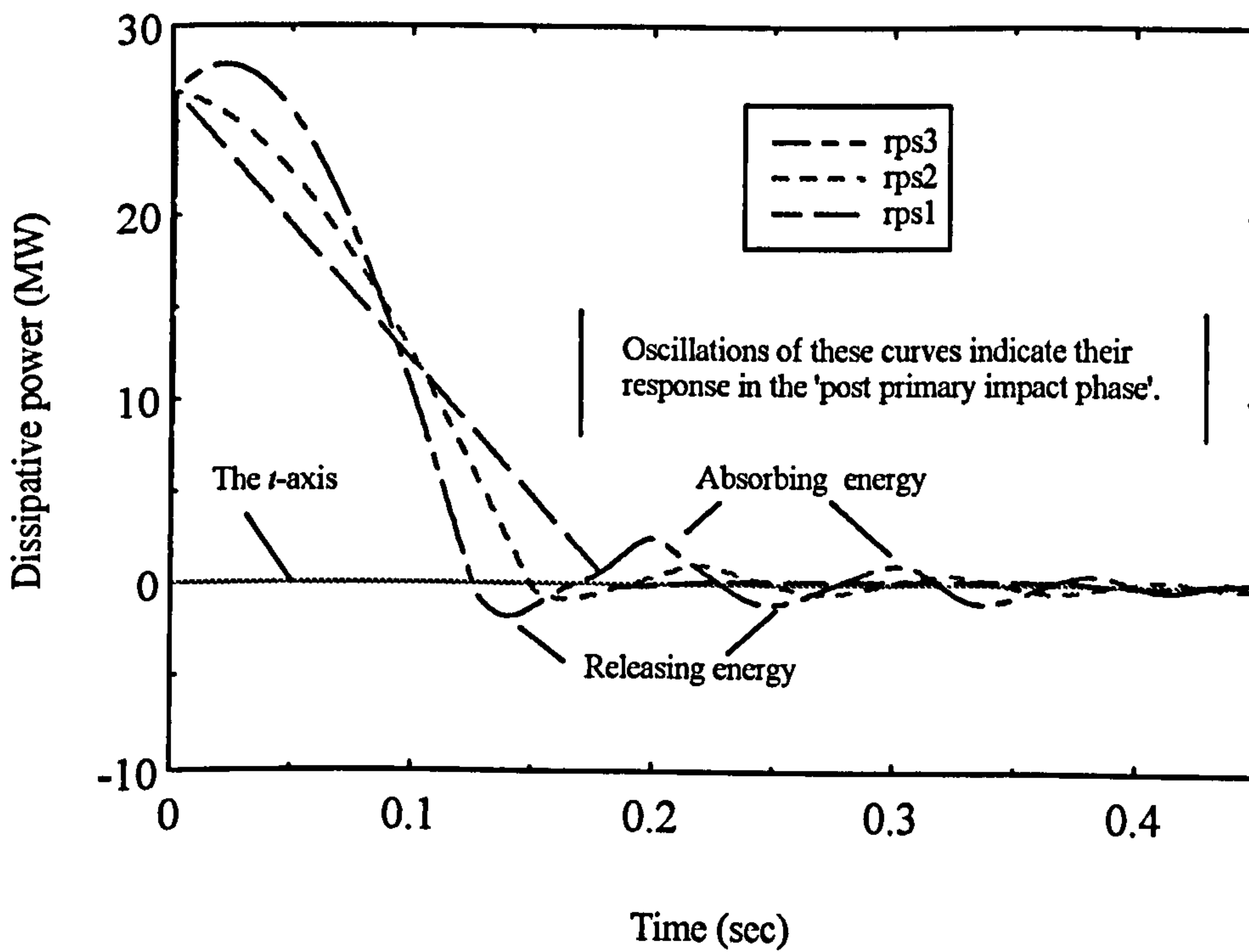


Figure 5.13 : The graph of dissipative power against time for interface 1 of models in the rps series.

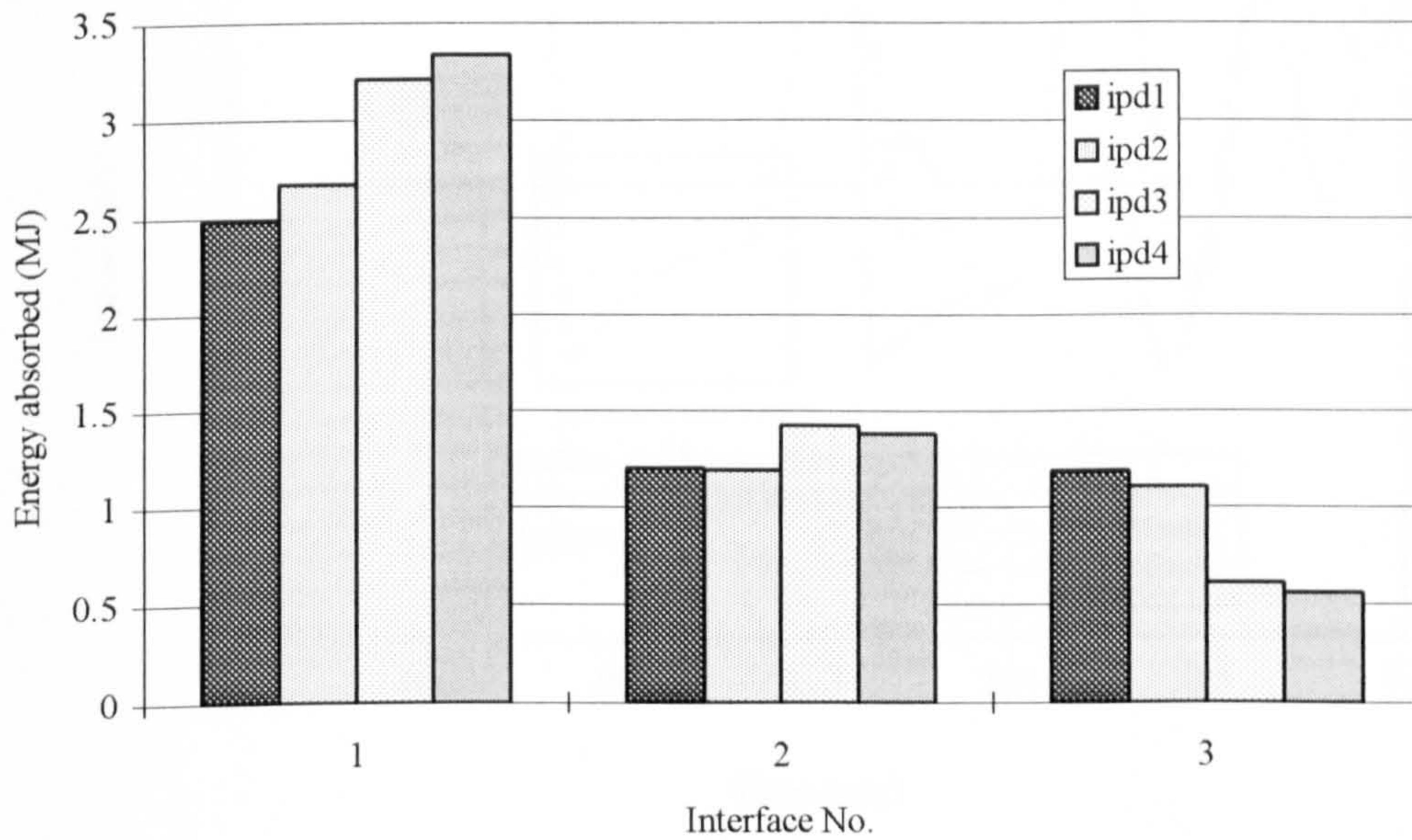


Figure 5.14 : The comparison of interface energy distribution for models in ipd series.

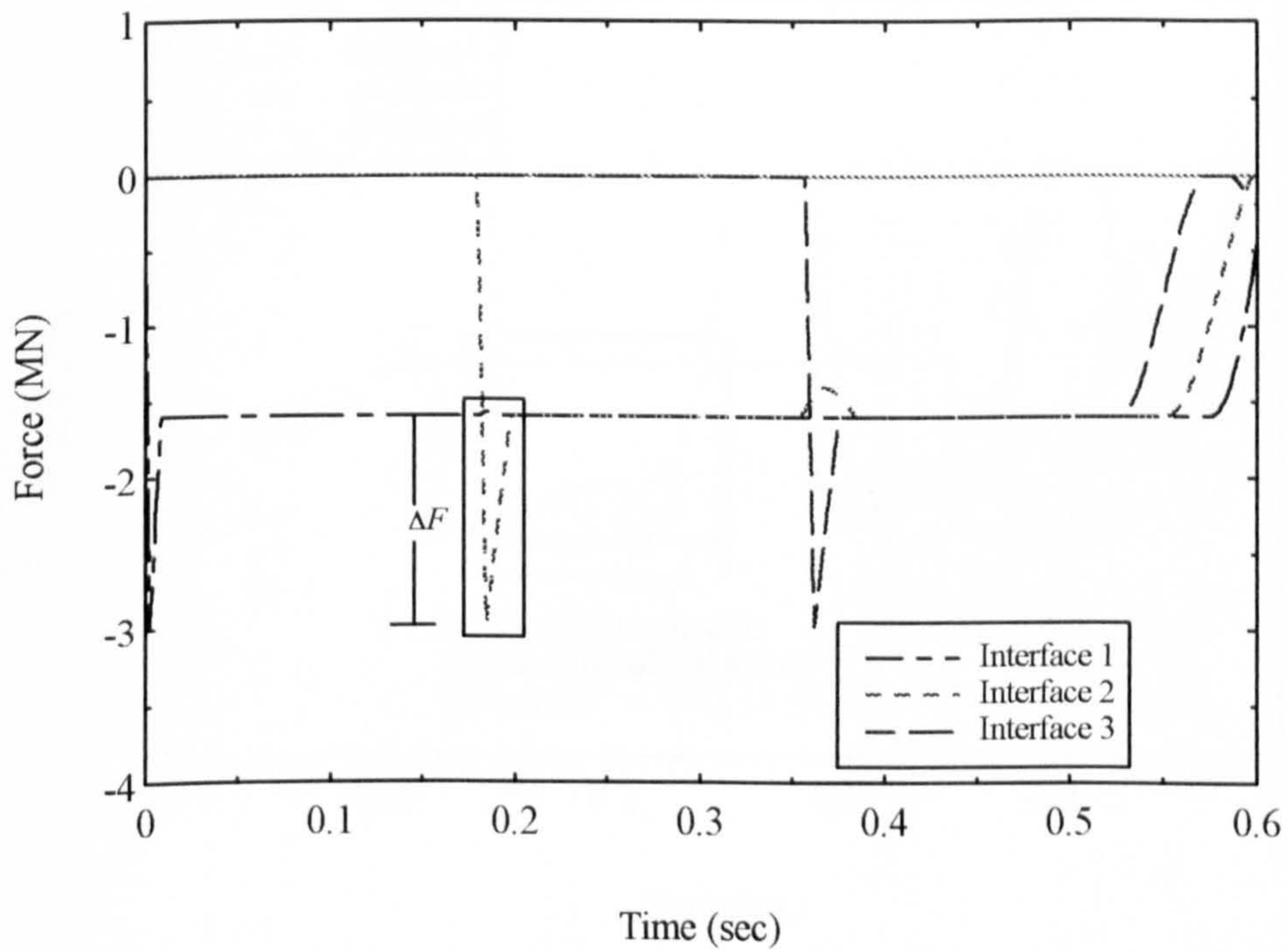


Figure 5.15a : The force-time history of various interfaces in ipd2.

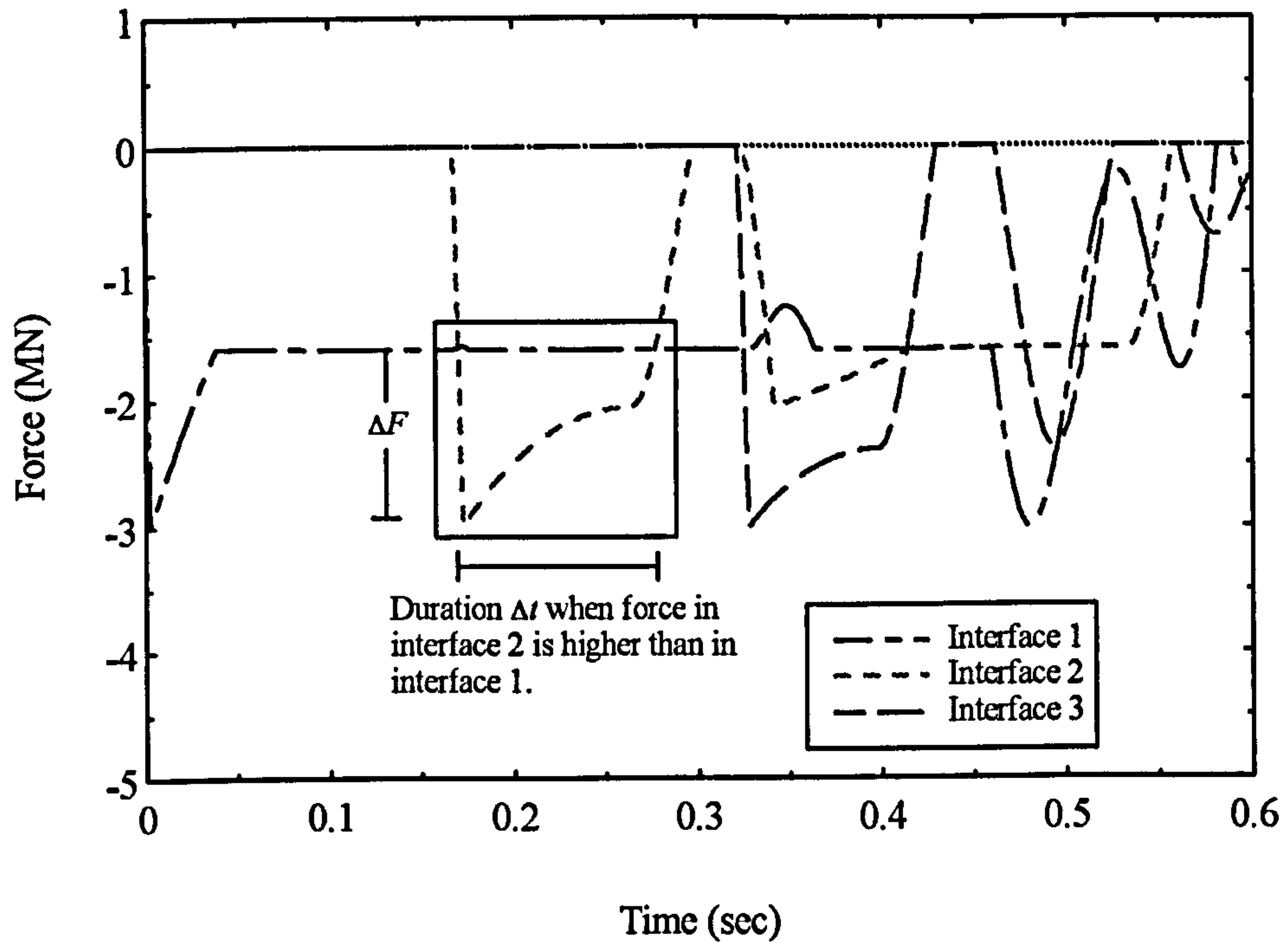


Figure 5.15b : The force-time history of various interfaces in ipd3.

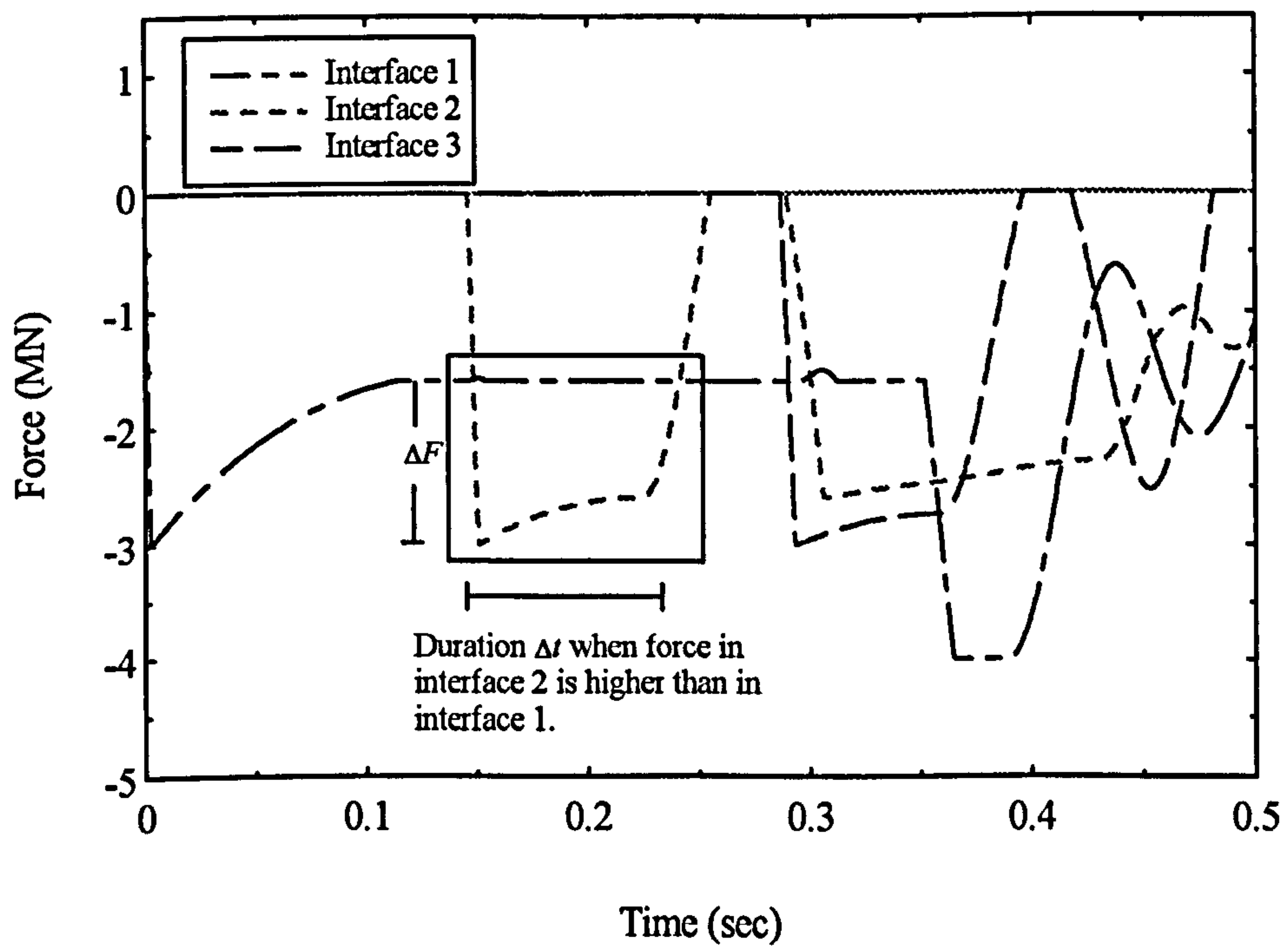


Figure 5.15c : The force-time history of various interfaces in ipd4.

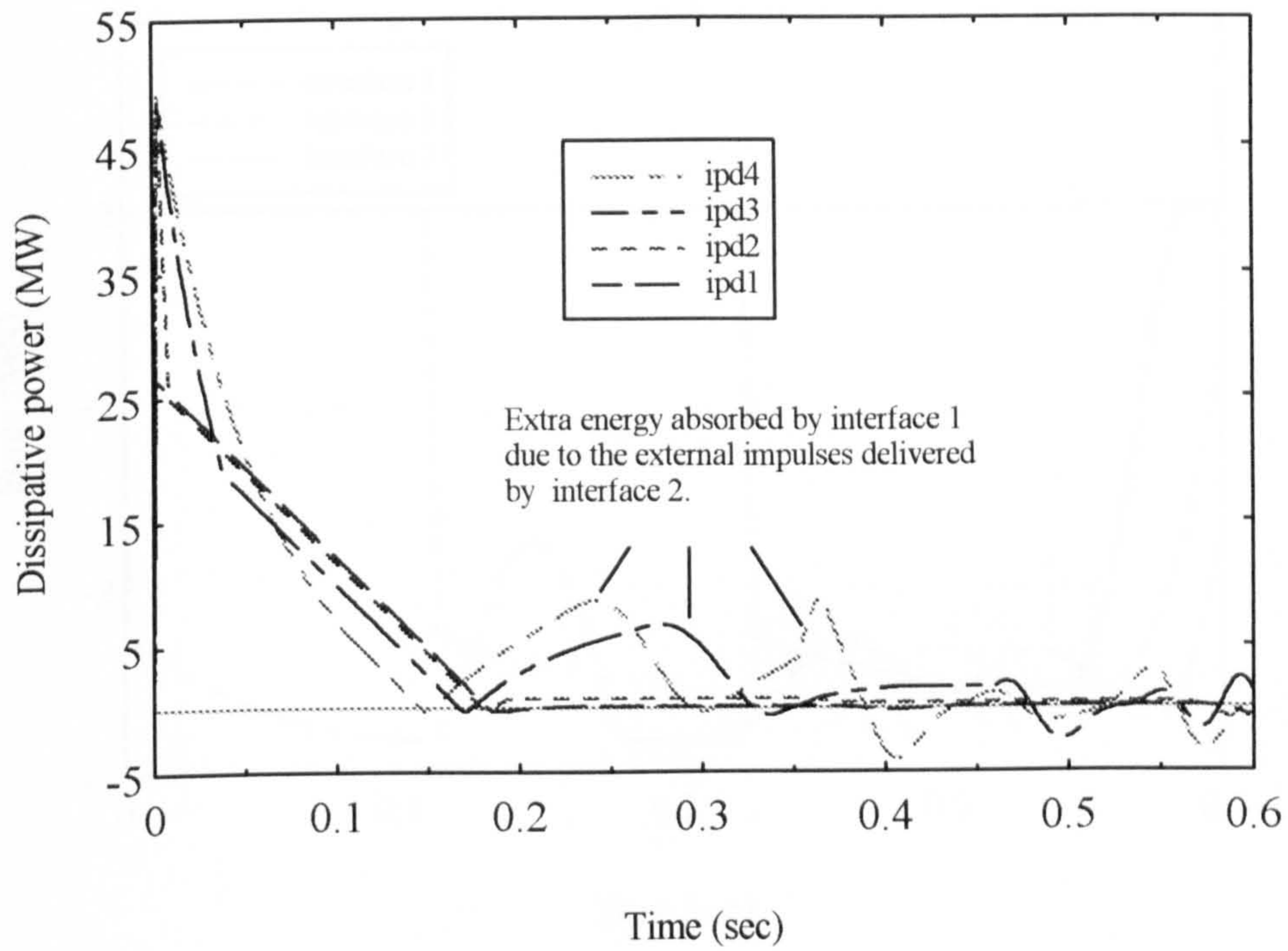


Figure 5.16 : The graph of dissipative power against time for interface 1 of models in the rps series.

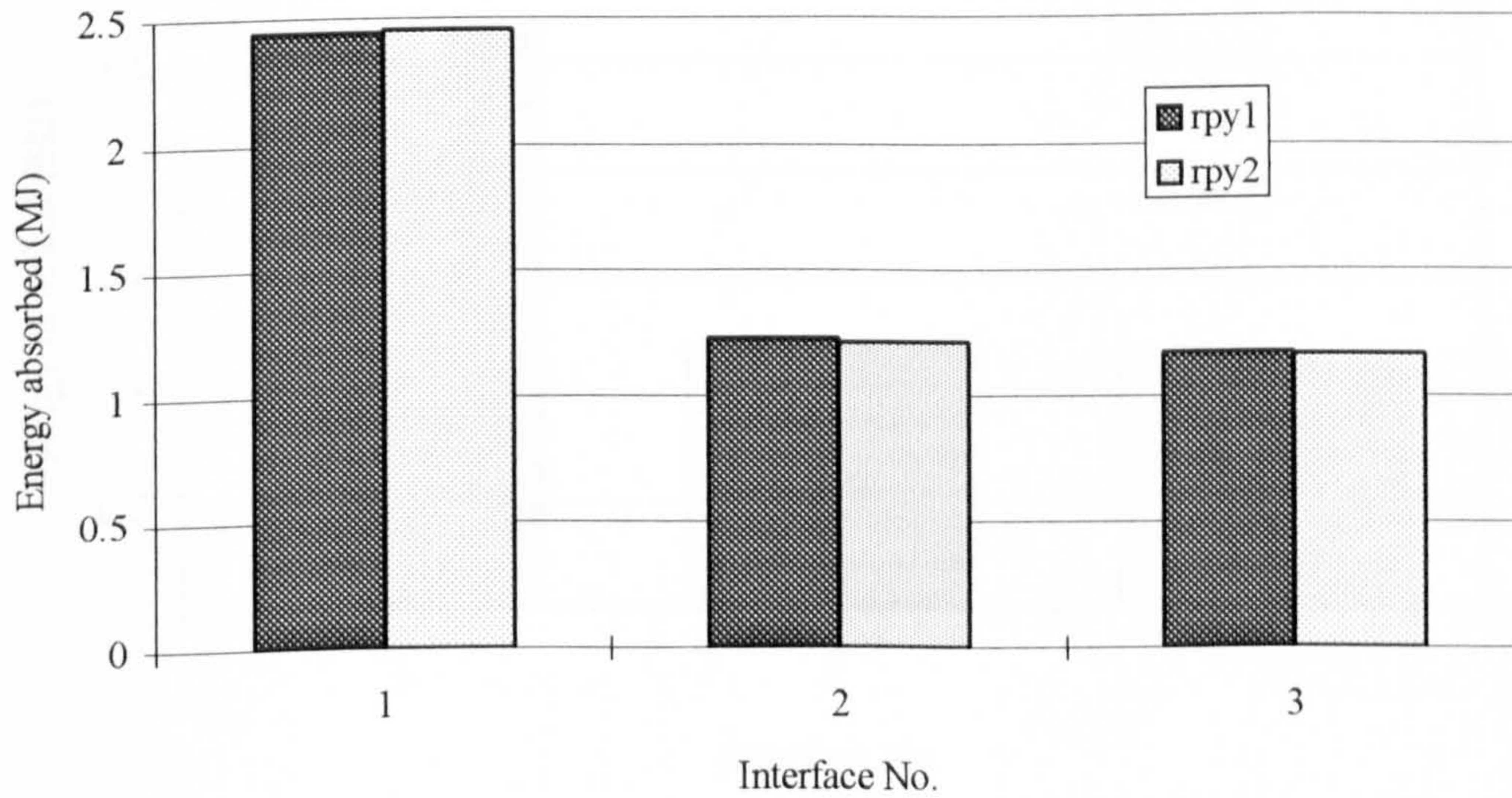


Figure 5.17 : The comparison of interface energy distribution for models in rpy series.

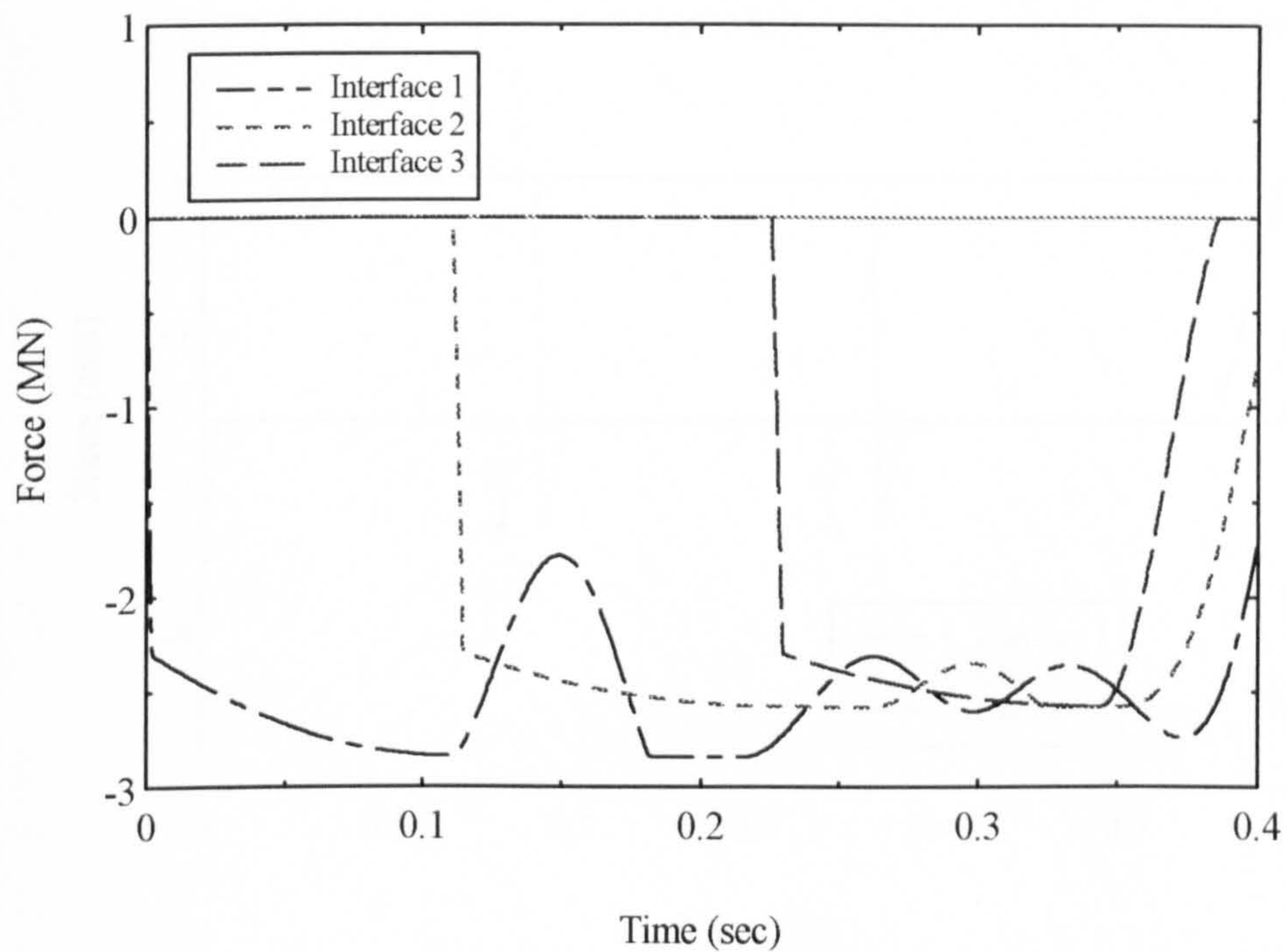


Figure 5.18 : The force-time history of various interfaces in rpy2.

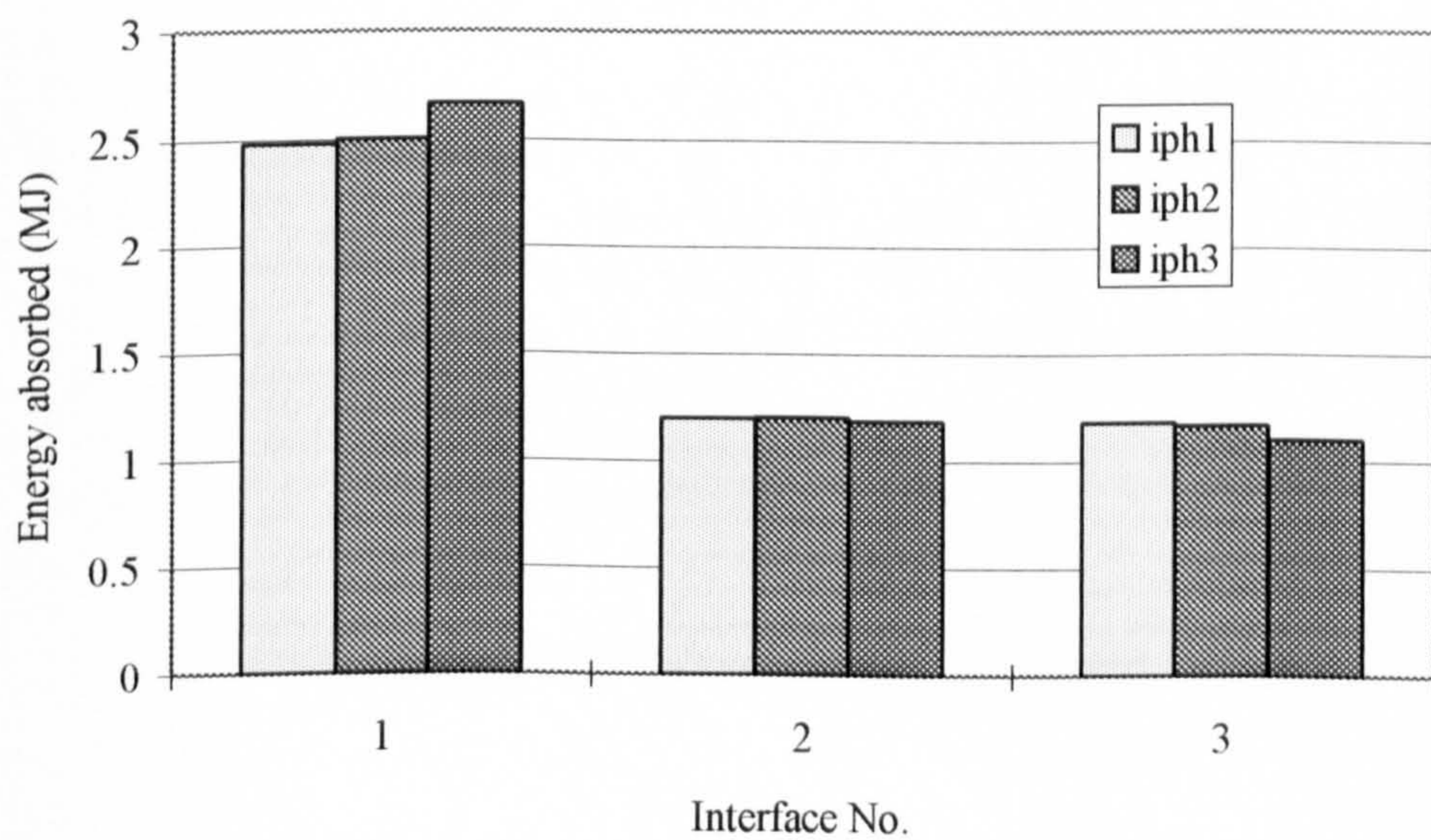


Figure 5.19 : The comparison of interface energy distribution for models in iph series.

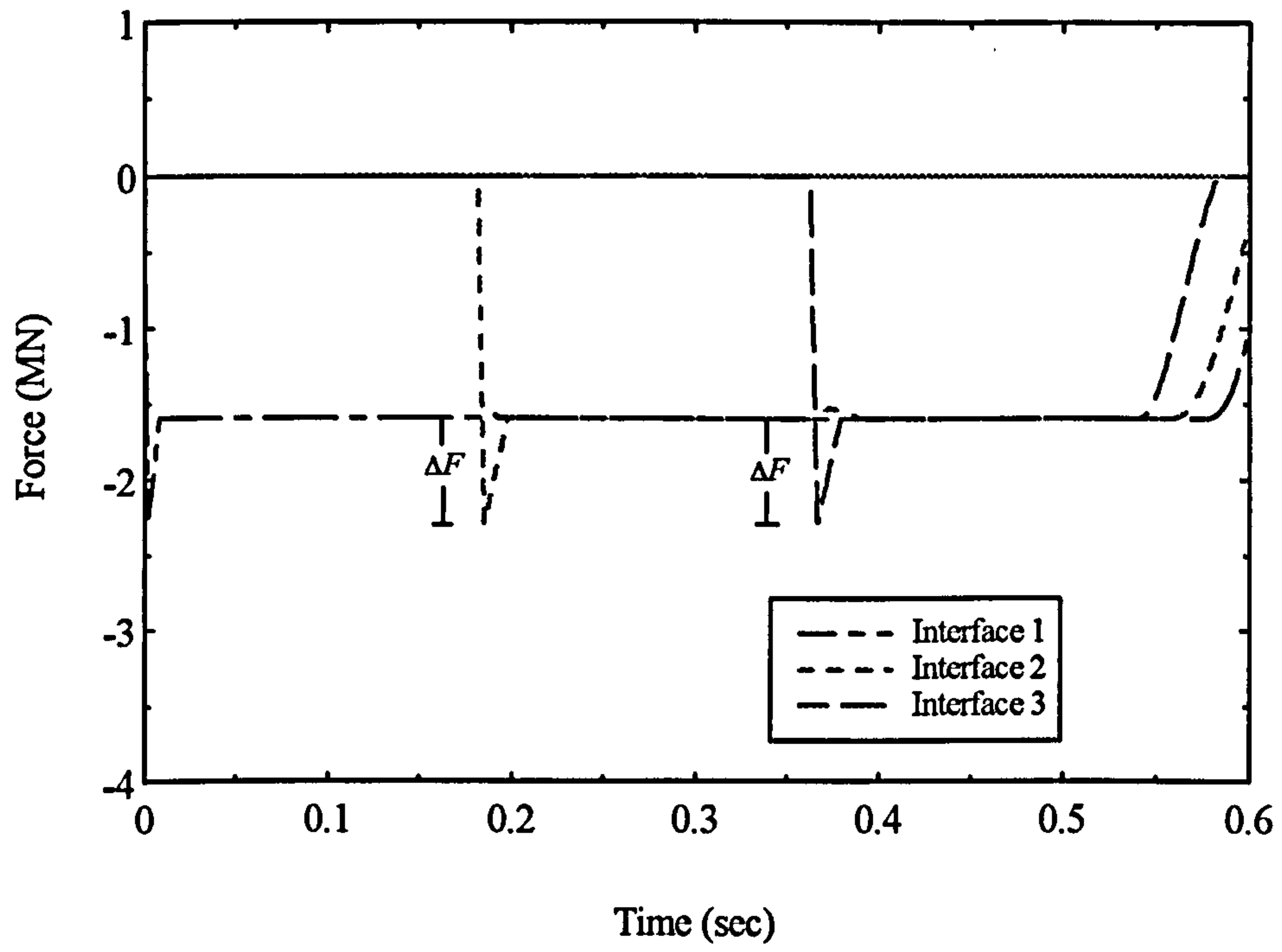
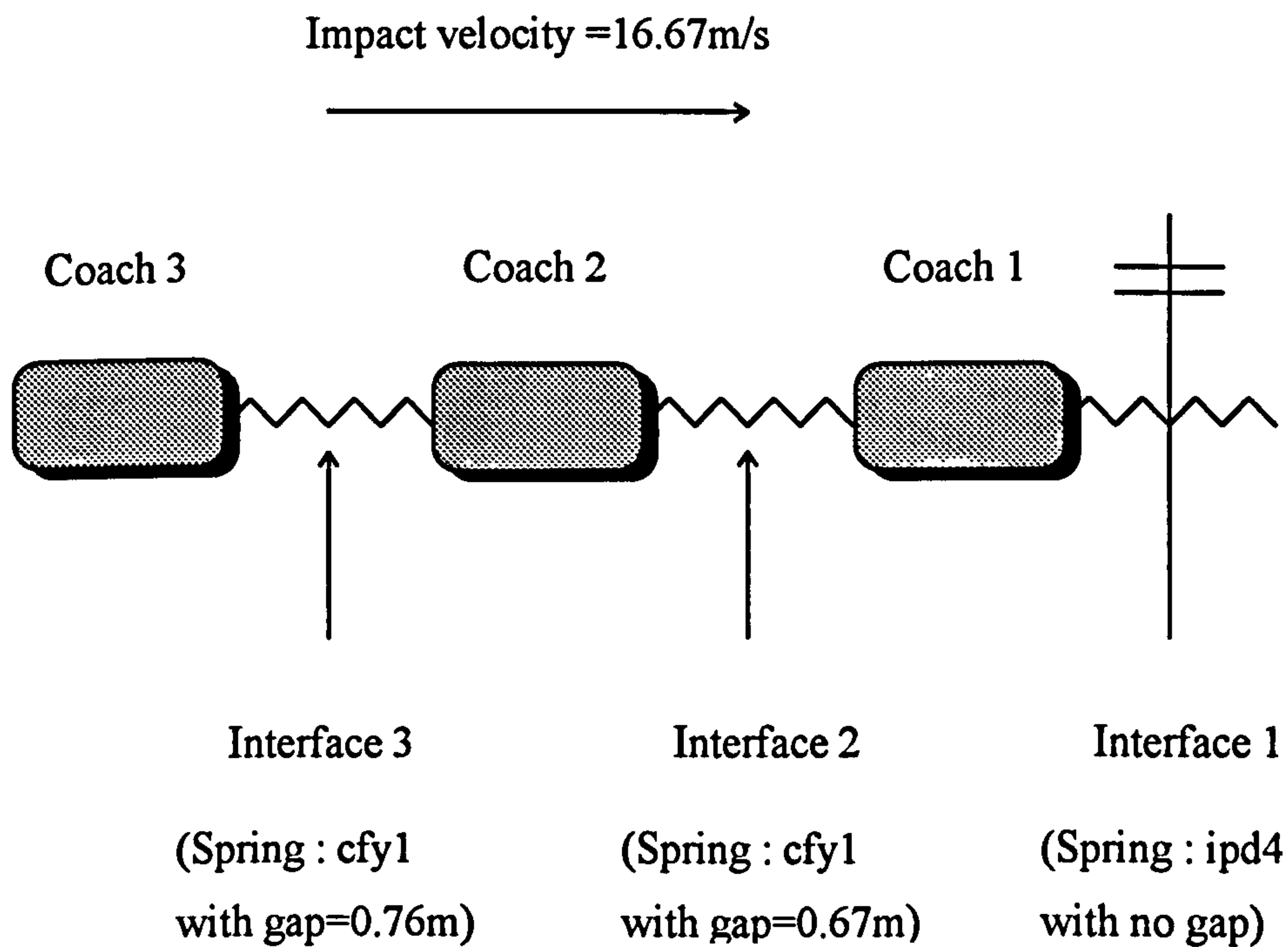


Figure 5.20 : The force-time history of various interfaces in iph3.



Note :

- The spring in interface 1 is the original spring in ipd4 with no gap since a gap in this interface serves only to delay the collision and not effect the results;
- The spring in interface 2 is taken from cfy1 and the gap is tuned for ipd4 since the leading interface in this case has a iph4 spring;
- The spring in interface 3 is also taken from cfy1 but the gap is tuned to cfy1 since the leading interface has a cfy1 spring;
- By mixing springs in the above model, no trailing interface would exert a load higher than its leading interface during an impact.

Figure 5.21 : The model of modified ipd4 and known as mod4.

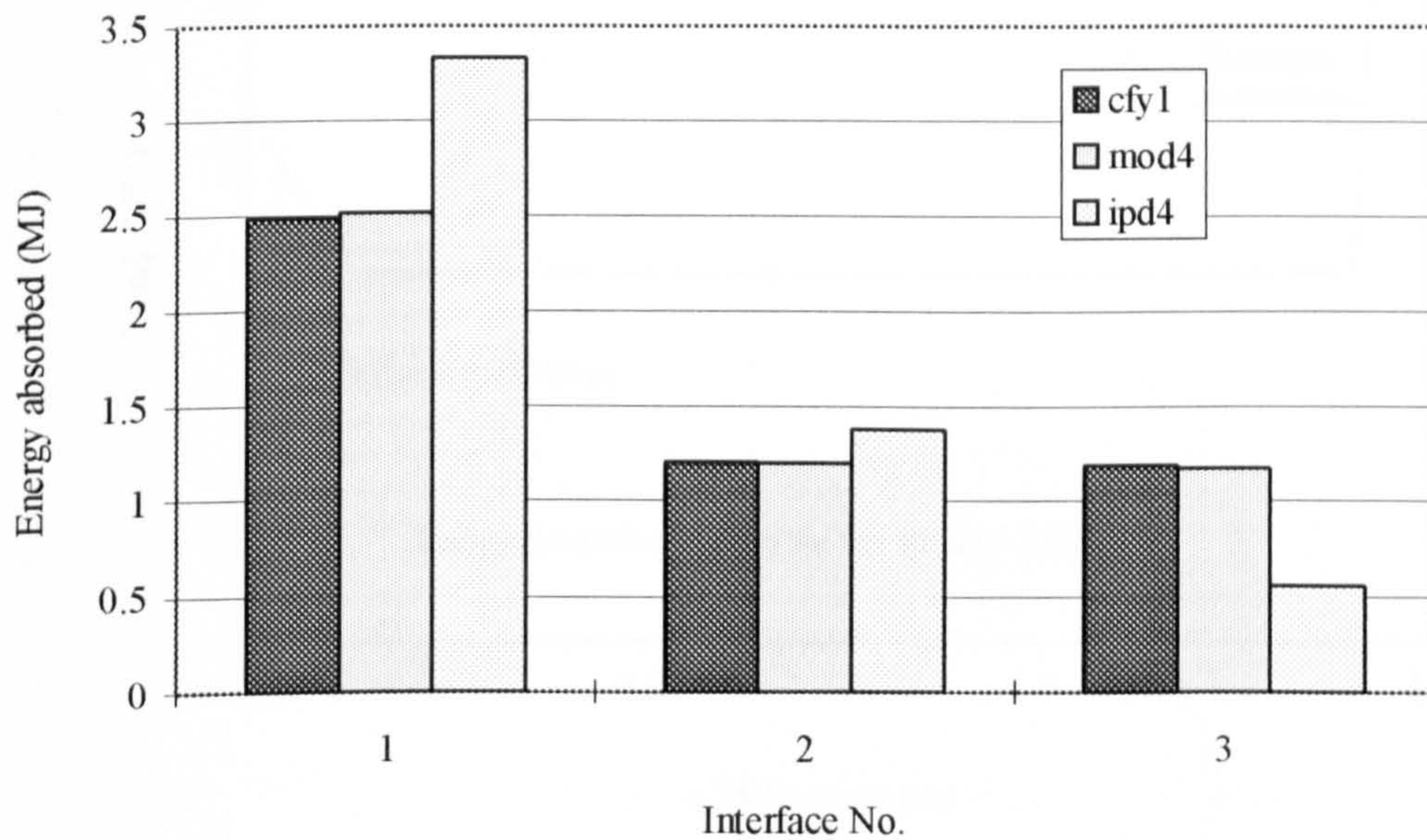


Figure 5.22 : The comparison of interface energy distribution for cfy1, mod4 and ipd4.

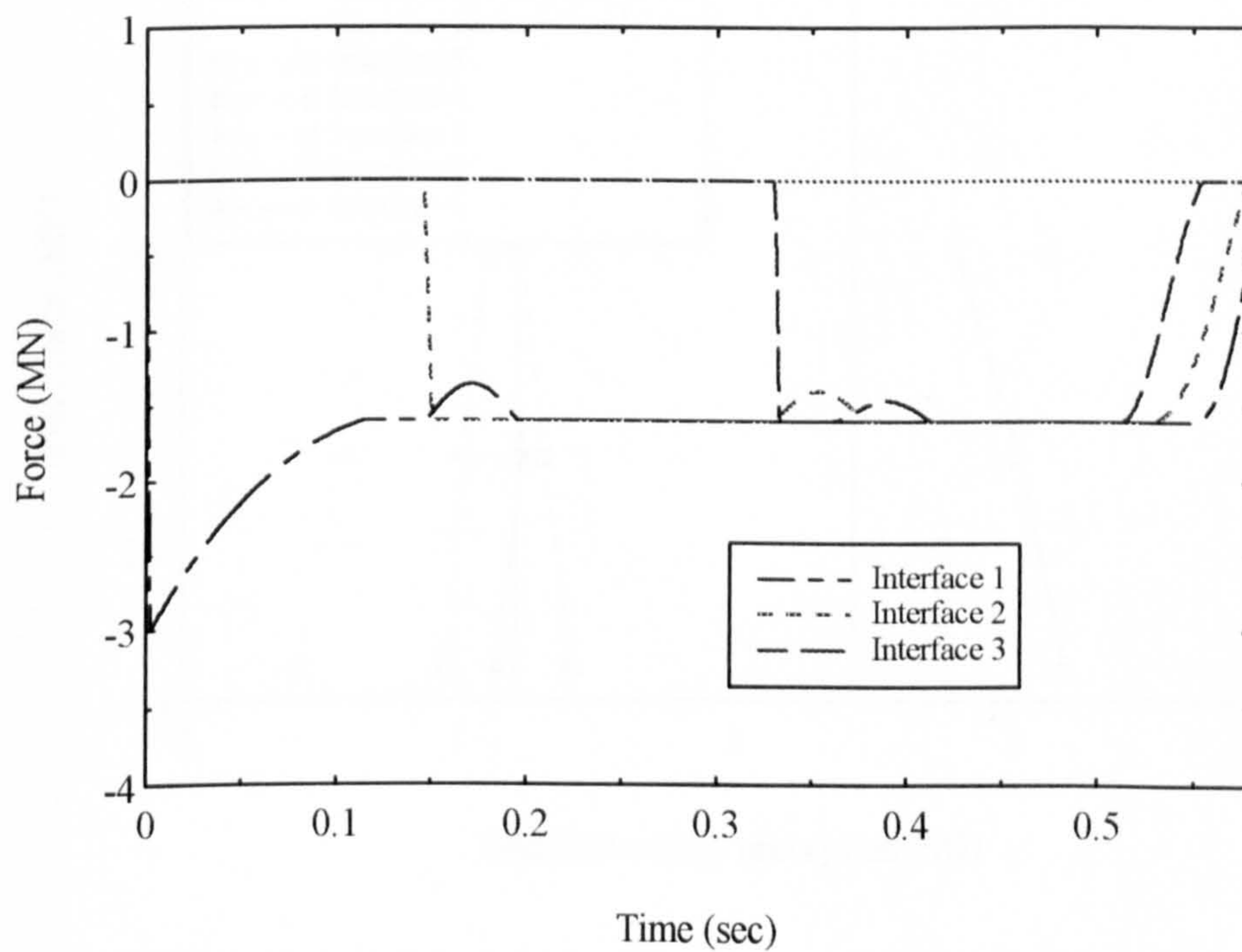


Figure 5.23 : The force-time history of various interfaces in mod4.

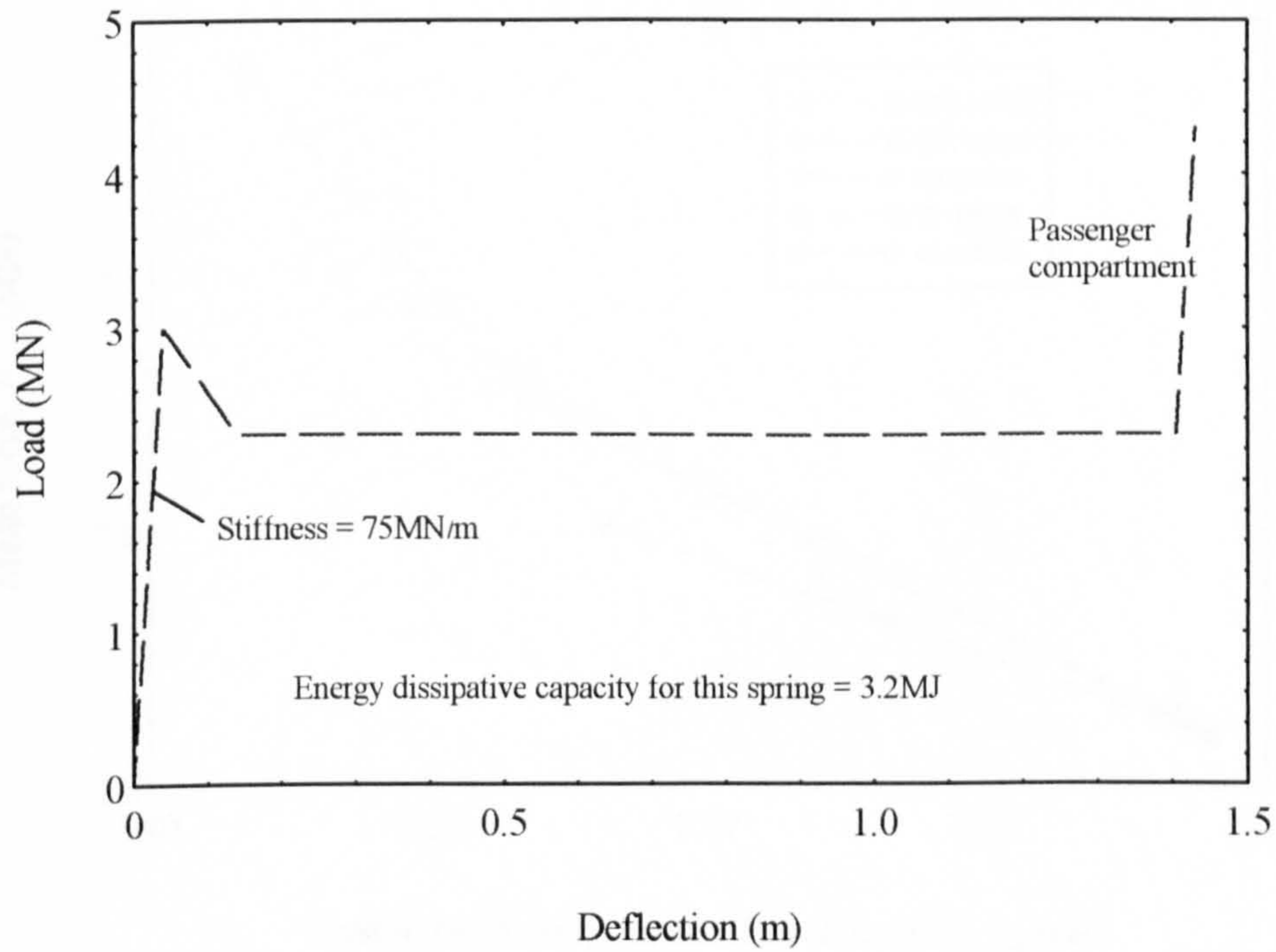


Figure 6.1 : The spring characteristics of the model ip2.33.

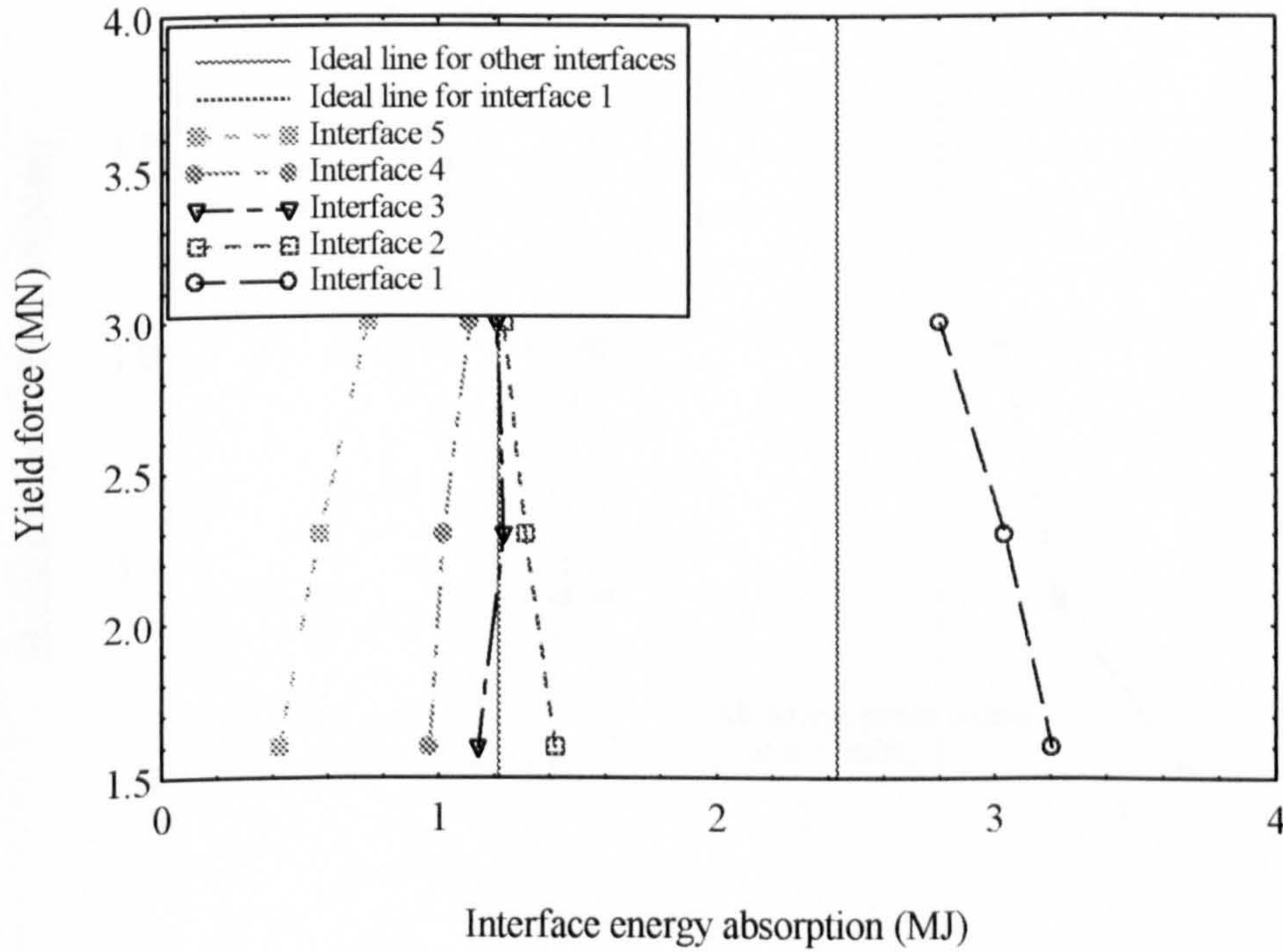


Figure 6.2 : Effect of yield force on interface energy distribution for models in the cfy series.

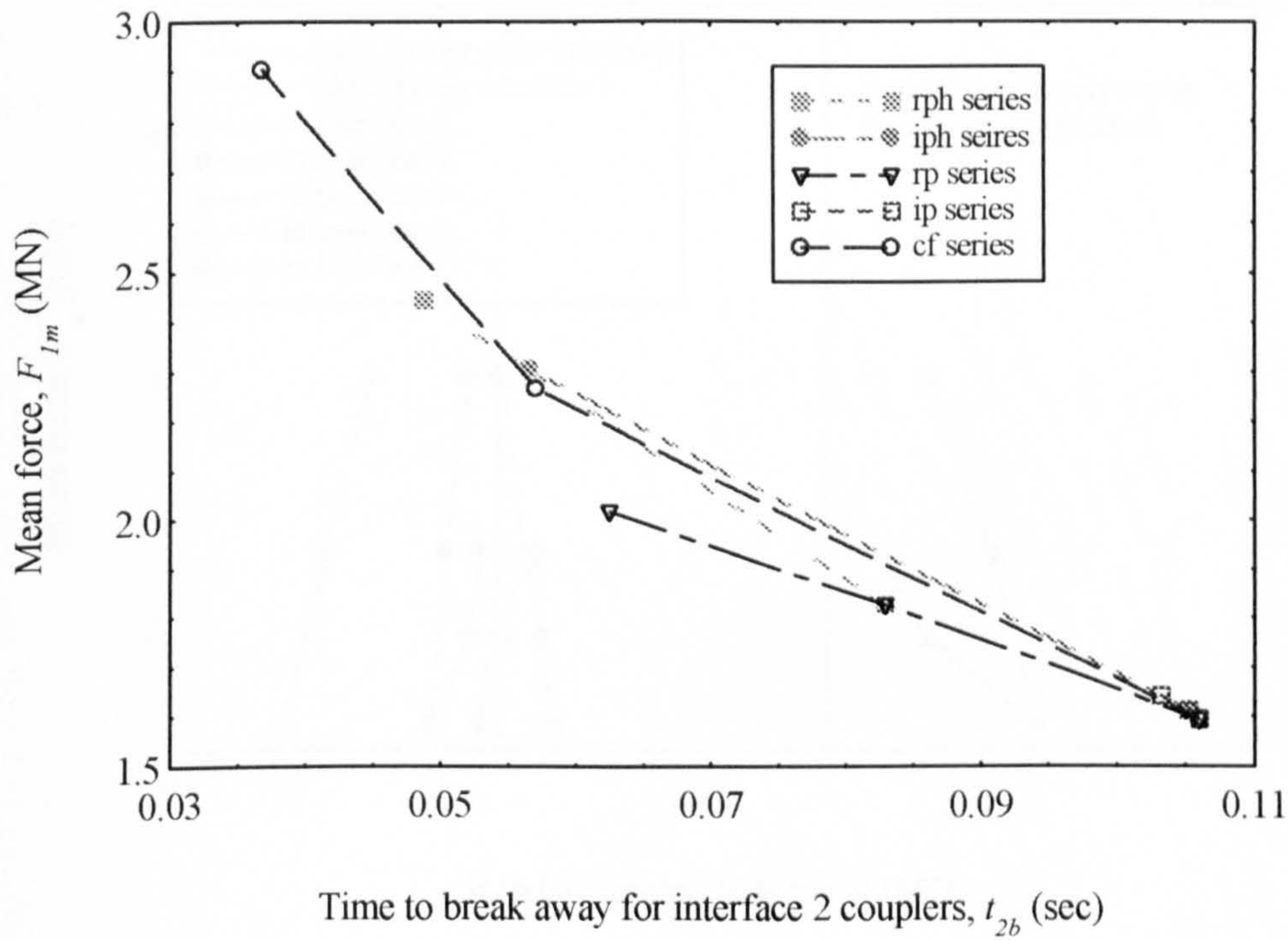


Figure 6.3 : Effects of spring average force on couplers' breakaway time.

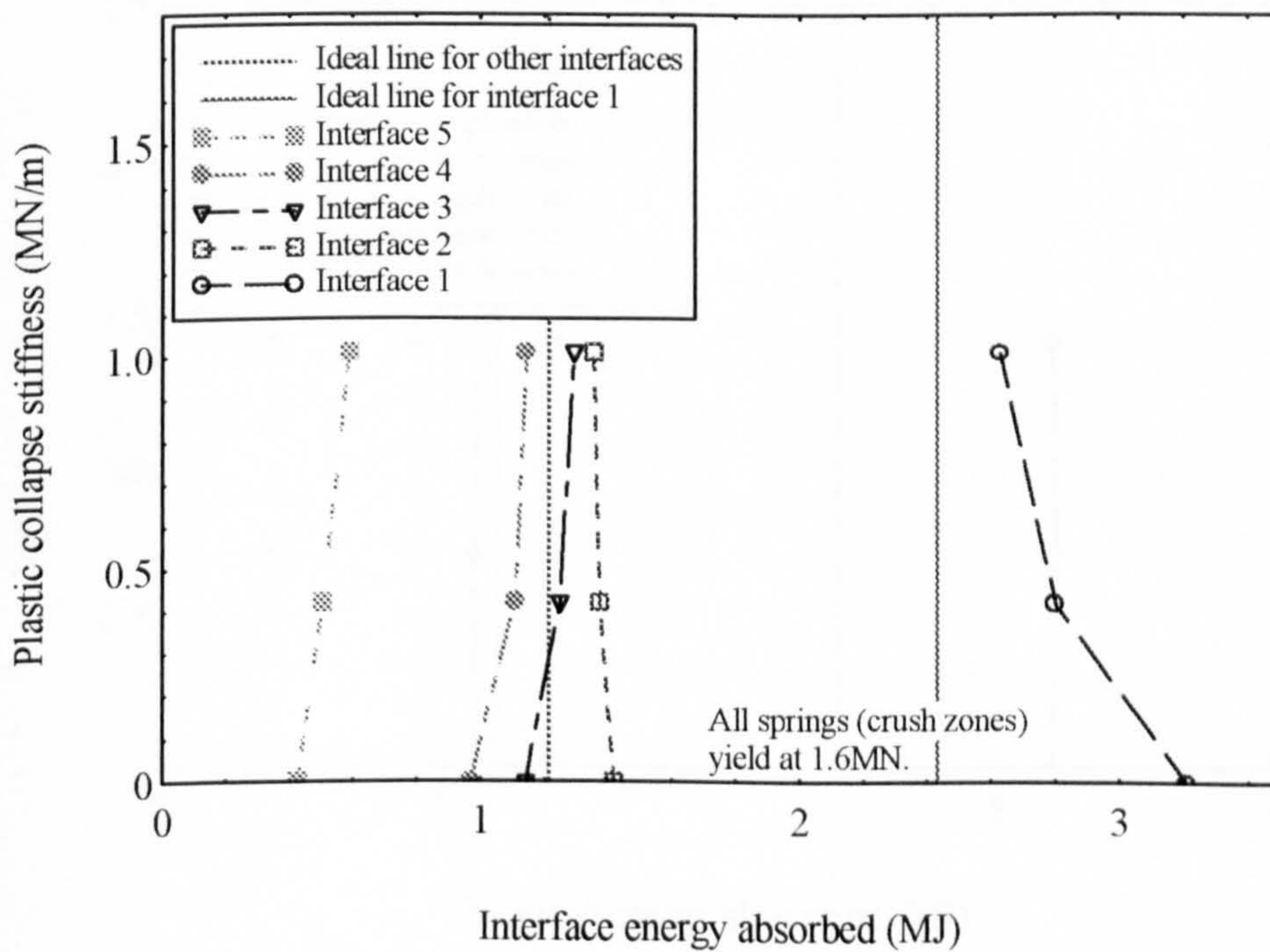


Figure 6.4 : Effects of hardening slope on interface energy distribution for models in the rps series.

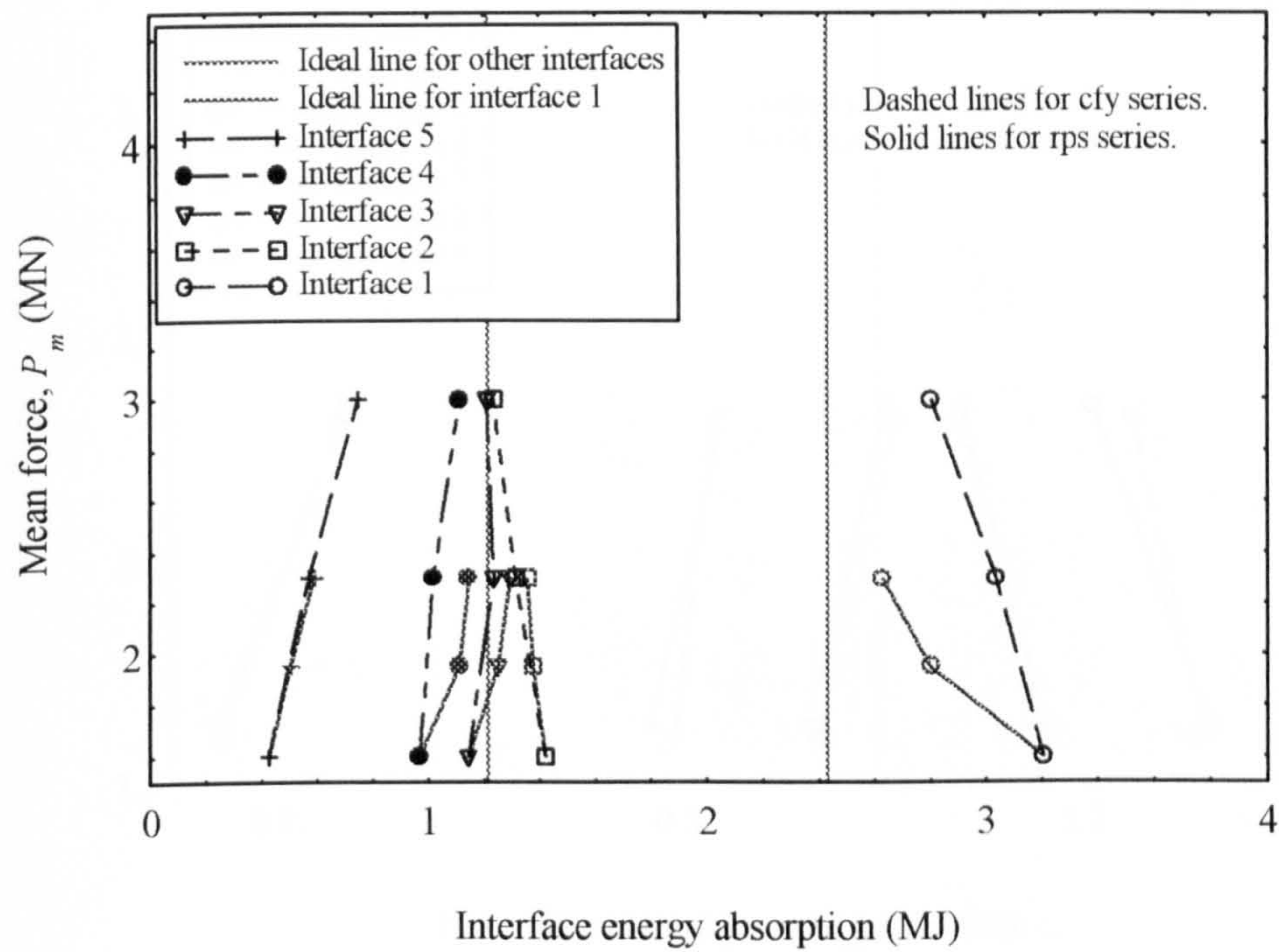


Figure 6.5 : Comparing the energy distribution for models in the cfy and rps series.

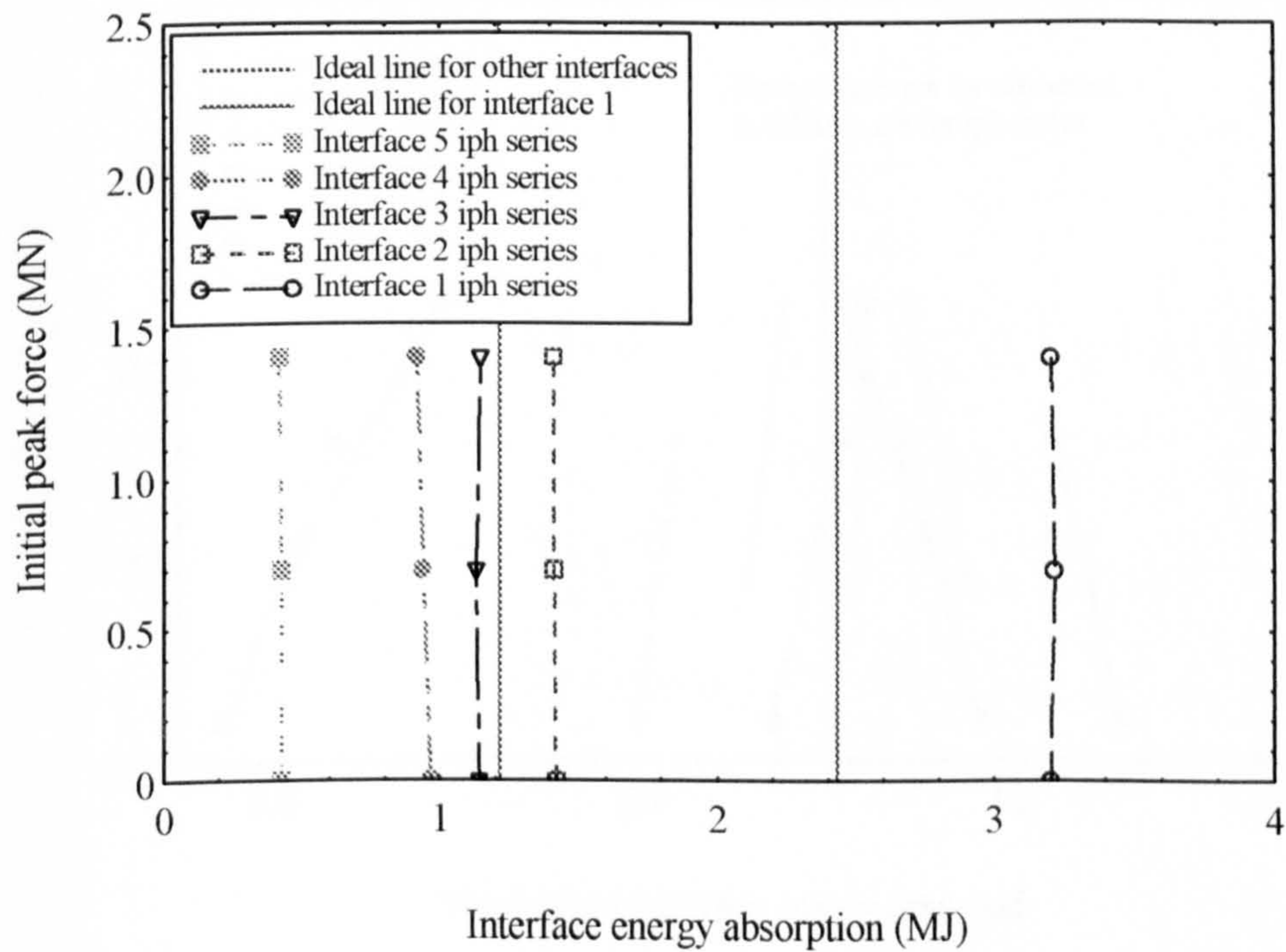


Figure 6.6 : Effects of initial peak force on interface energy distribution for models in the iph series.

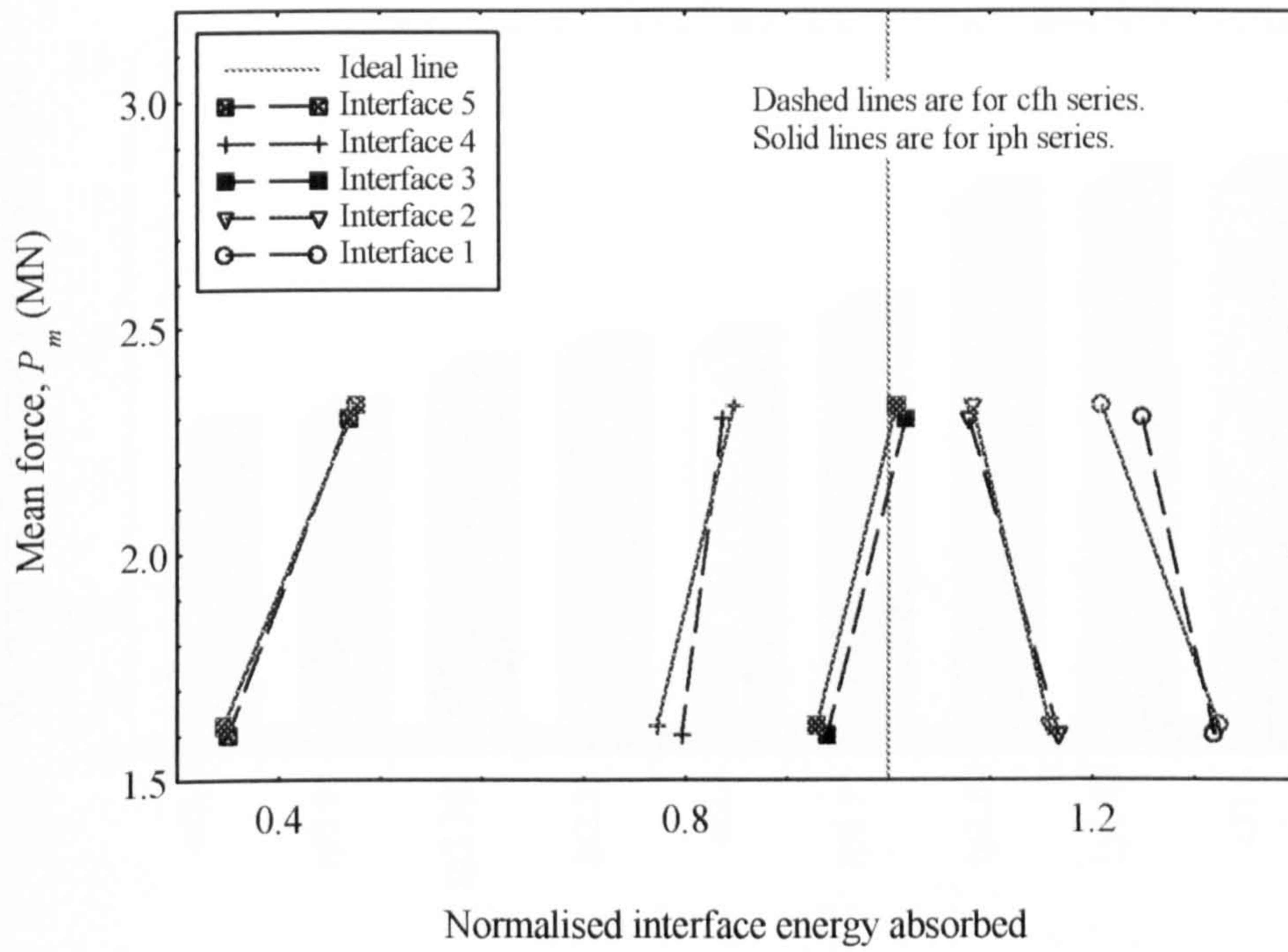


Figure 6.7 : Comparing energy distribution for models in the ipy and cfy series.

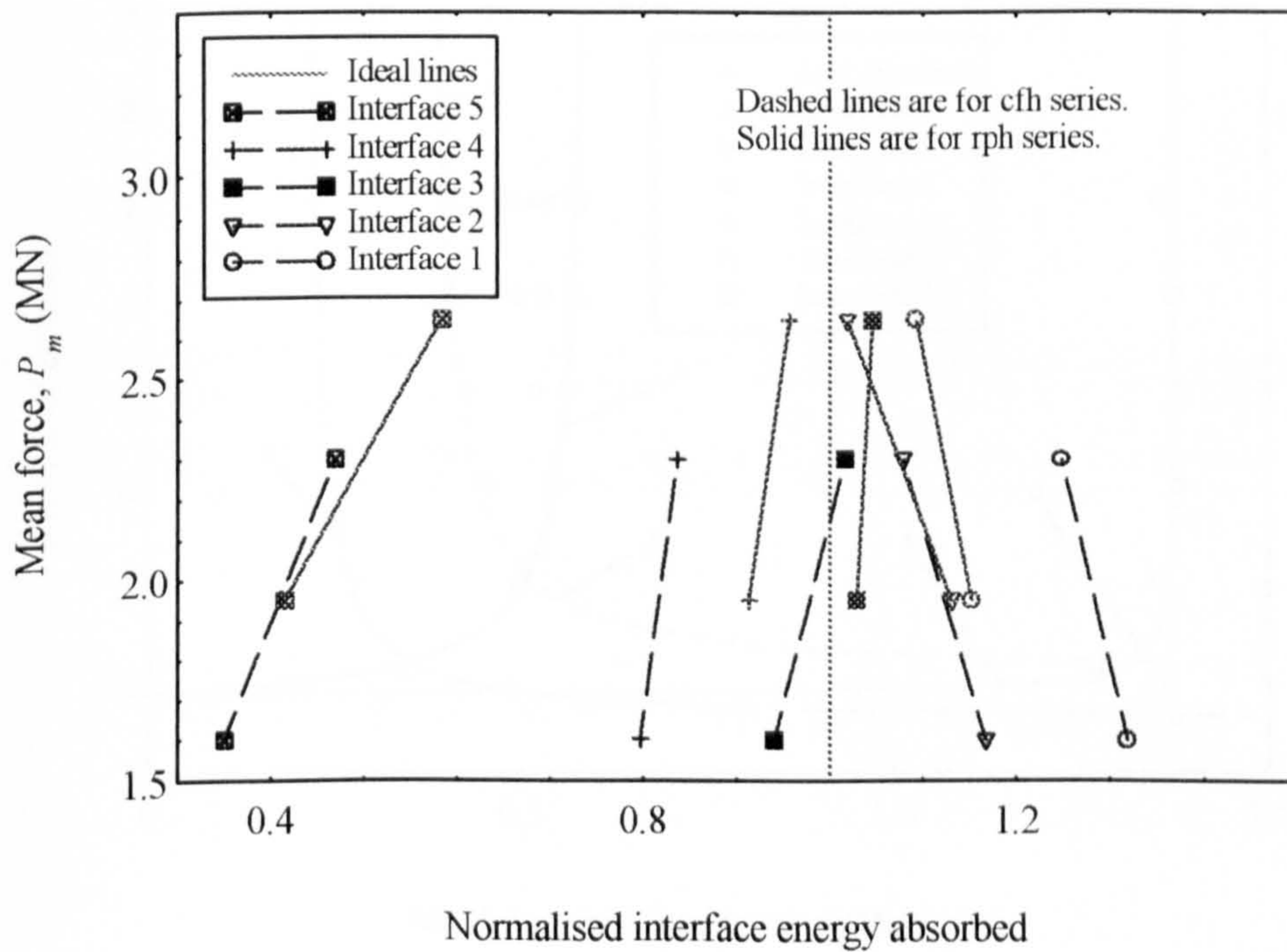


Figure 6.8 : Comparing energy distribution for models in the rpy and cfy series.

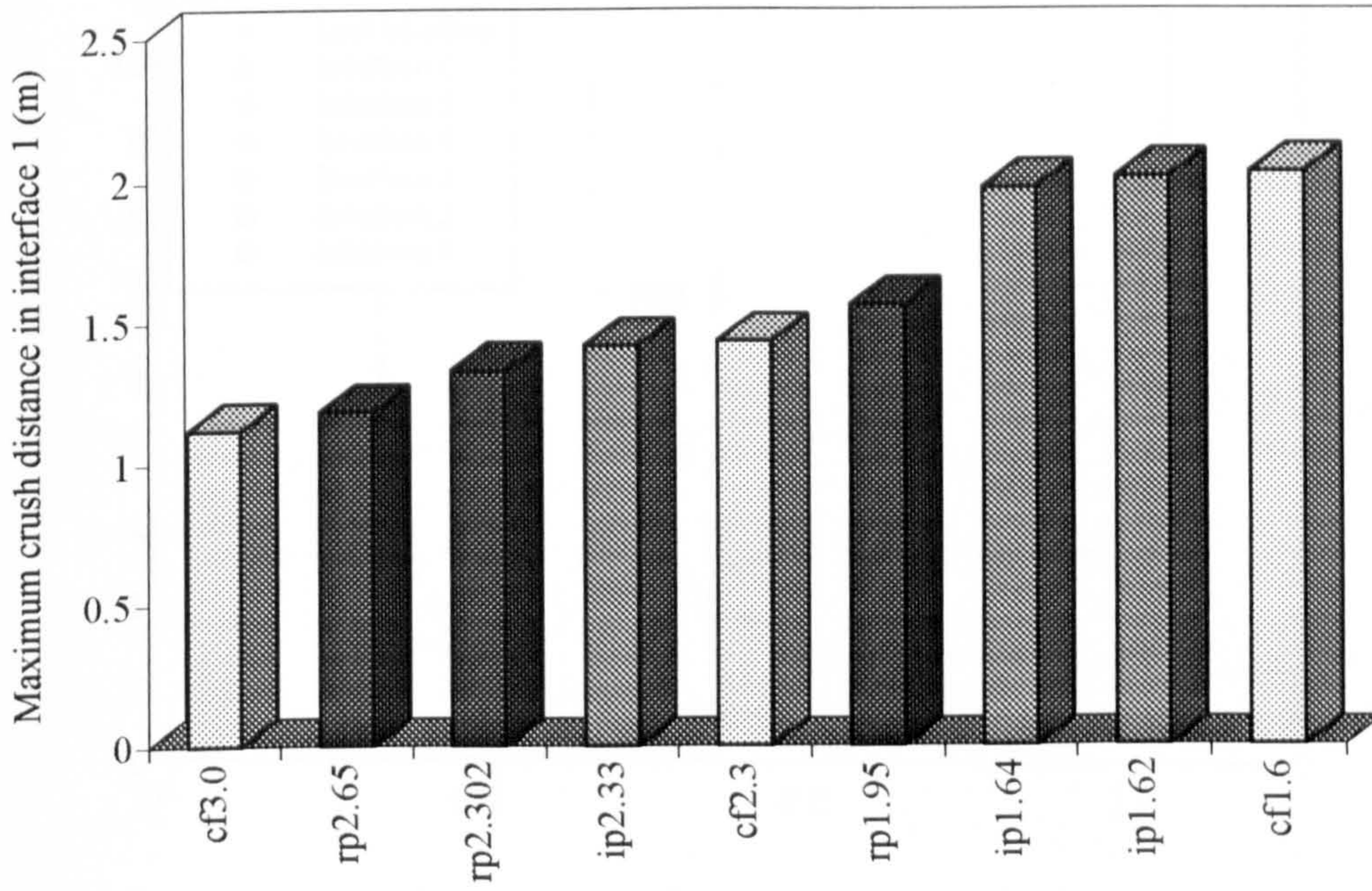


Figure 6.9 : Interface 1 crush distance for various models.

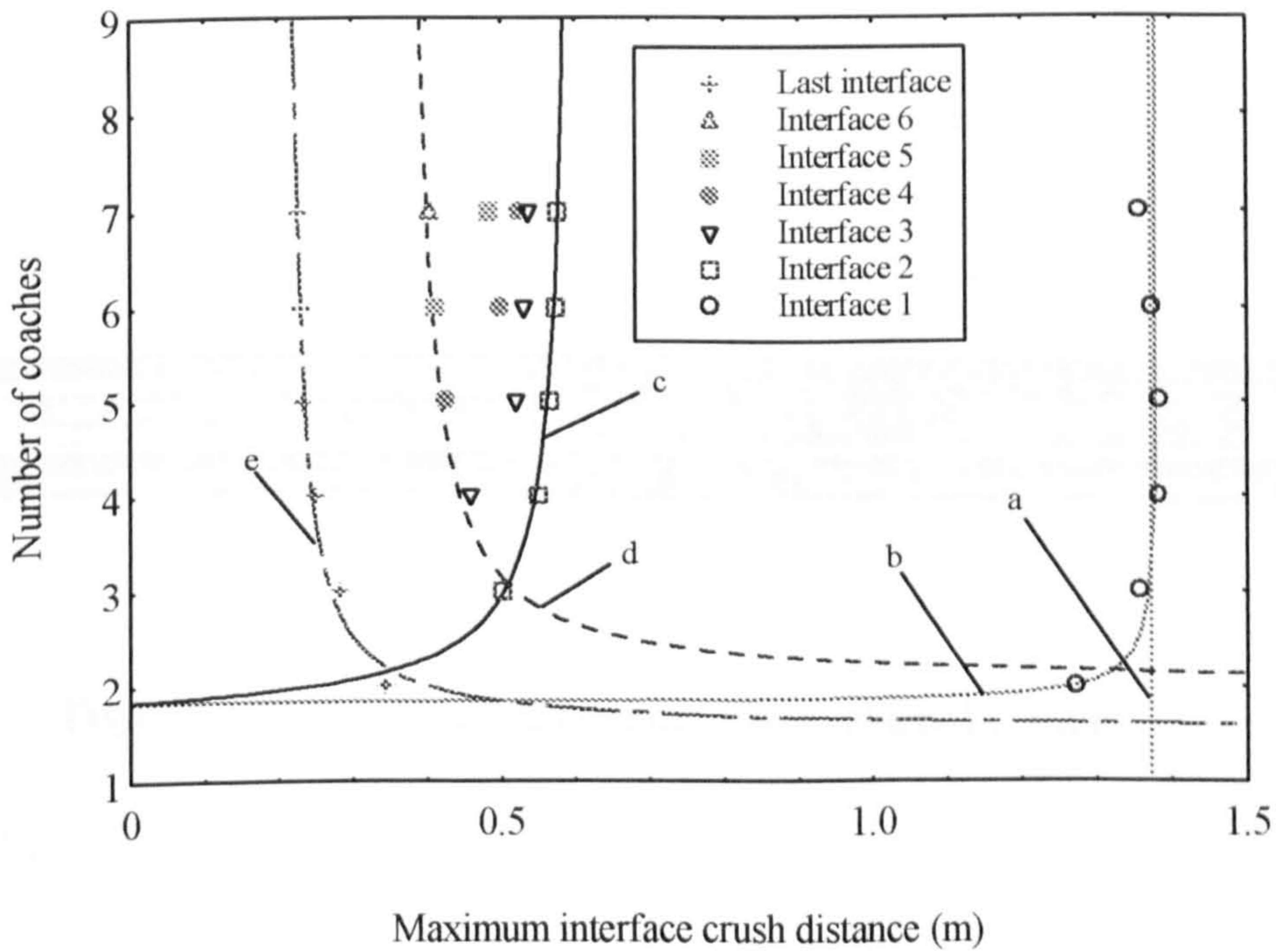


Figure 6.10 : The effects of N on interface crush distribution for models in the cfn series.

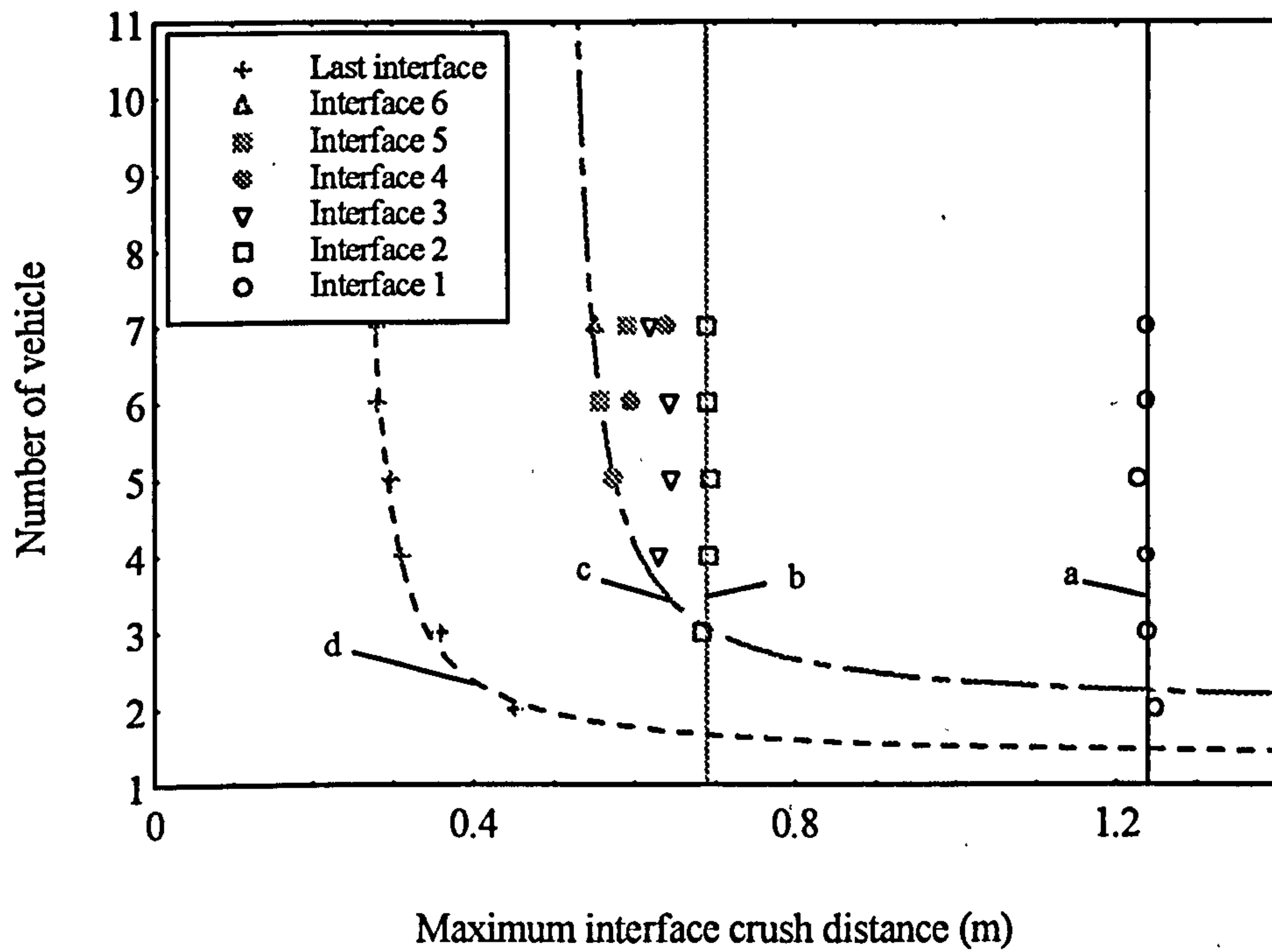


Figure 6.11 : The effects of N on interface crush distribution for models in the rpn series.

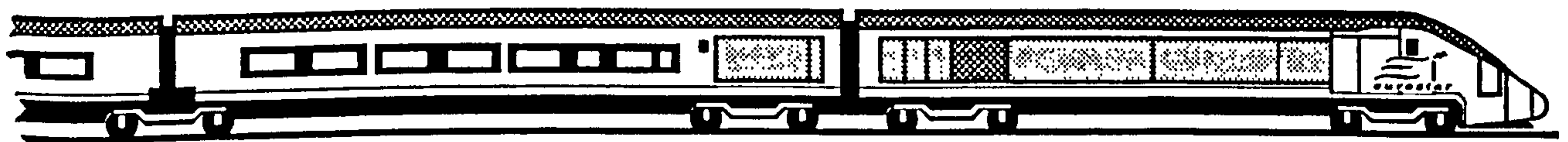


Figure 6.12 : The projected nose heading a rake of Eurostar.

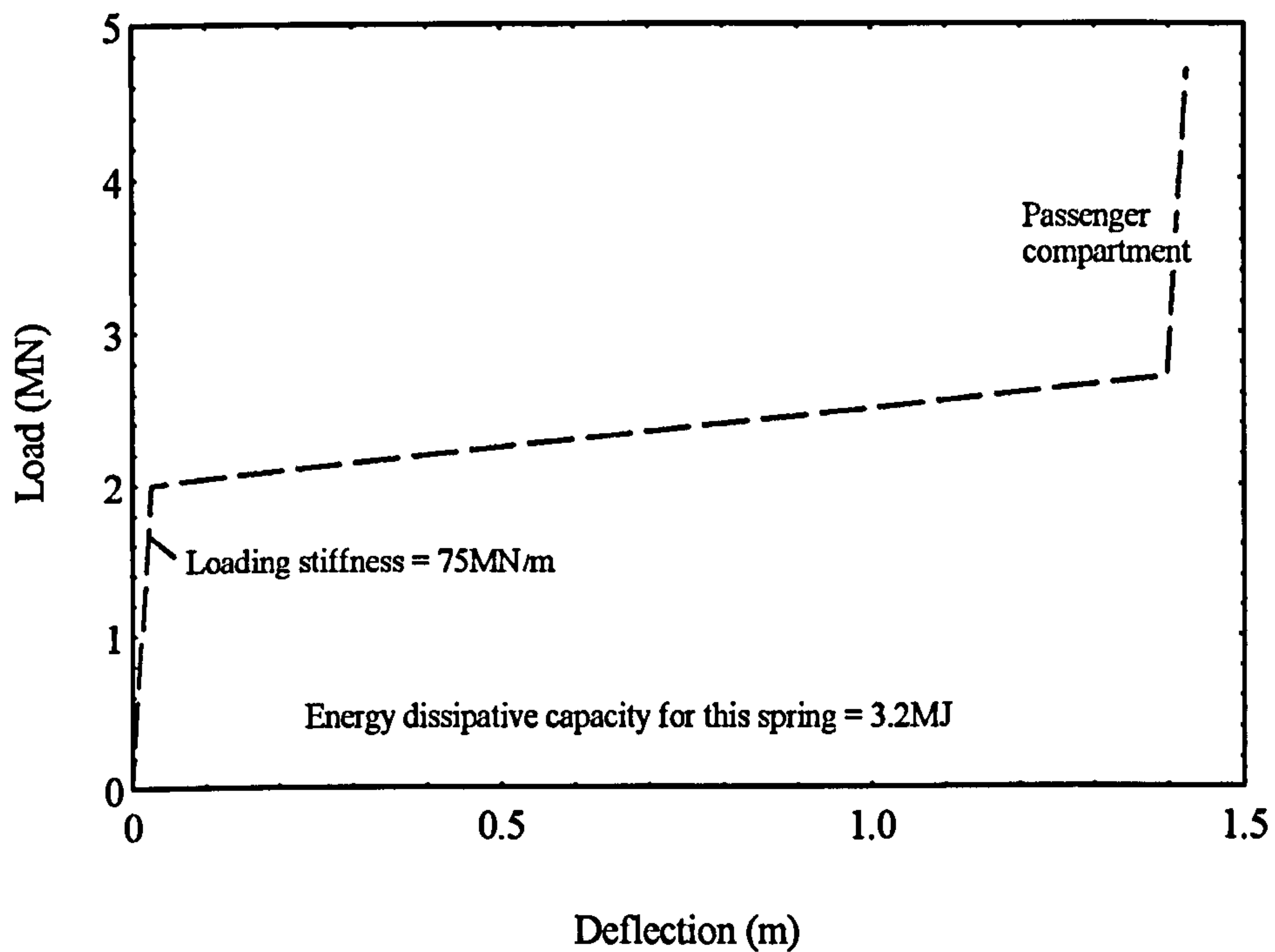


Figure 6.13 : Spring characteristics for interface 1 of mixed-springs models.

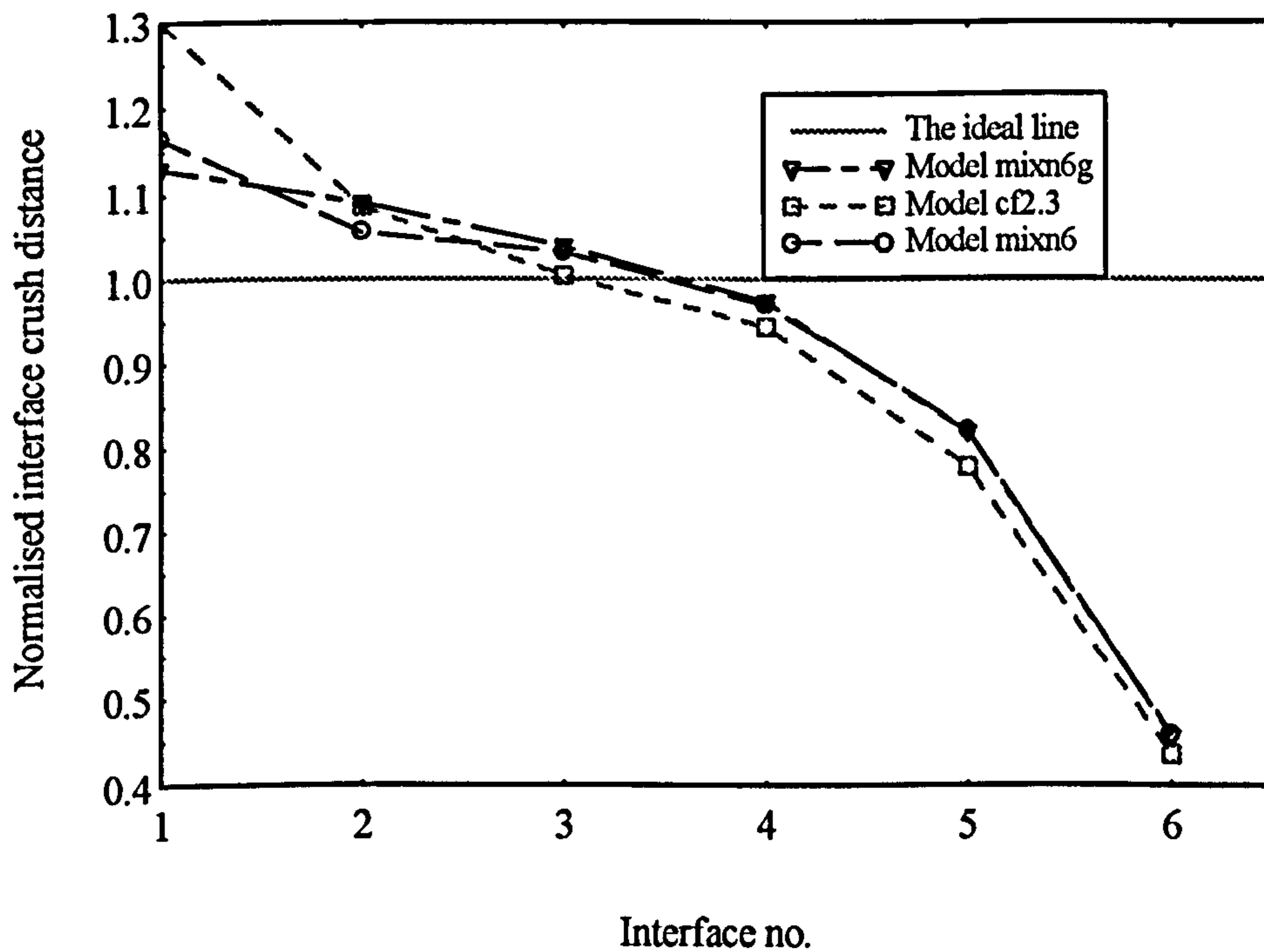


Figure 6.14 : How mixed-springs models modified the crush (energy) distribution of cfn6.

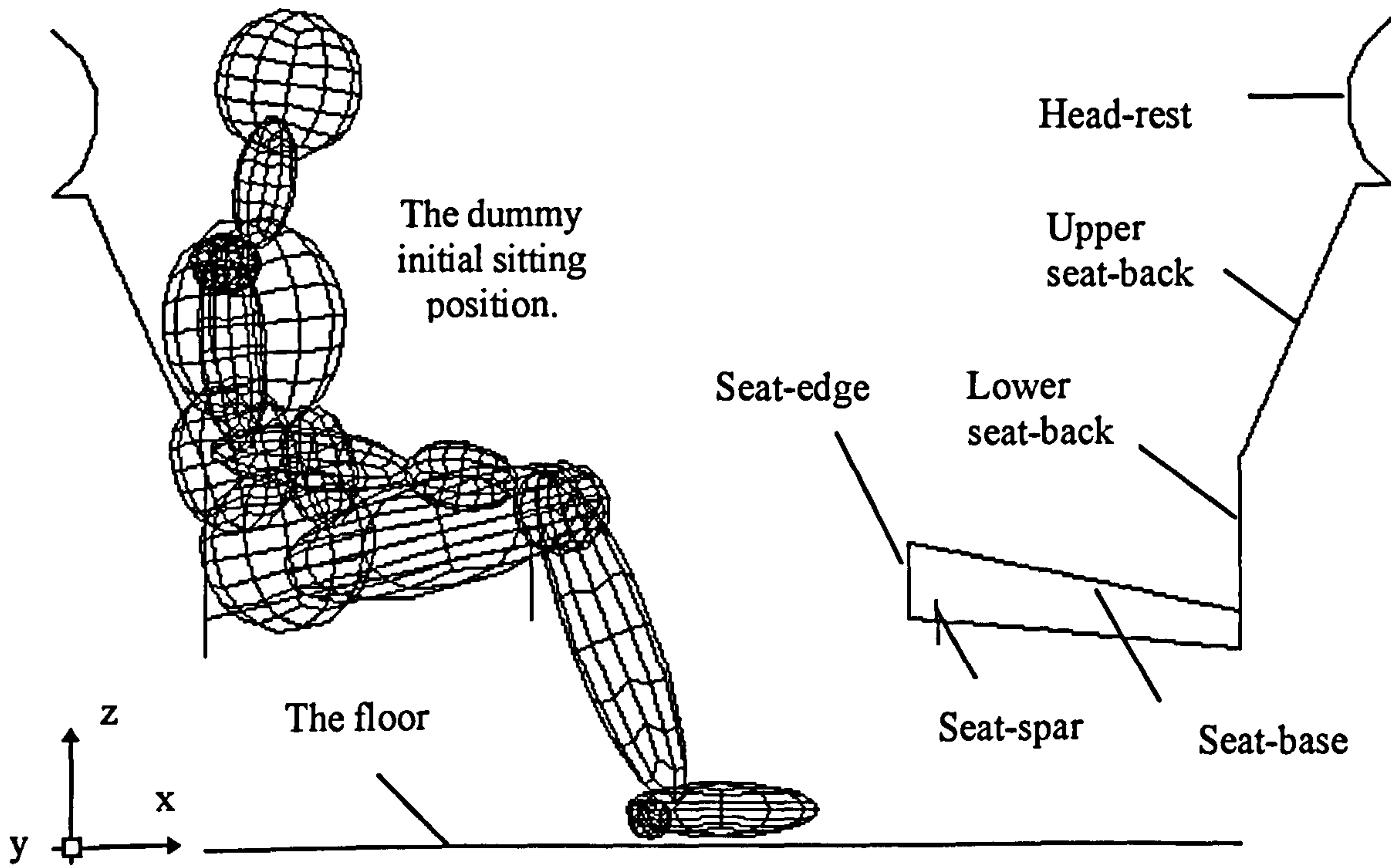


Figure 7.1 : The dummy initial sitting position.

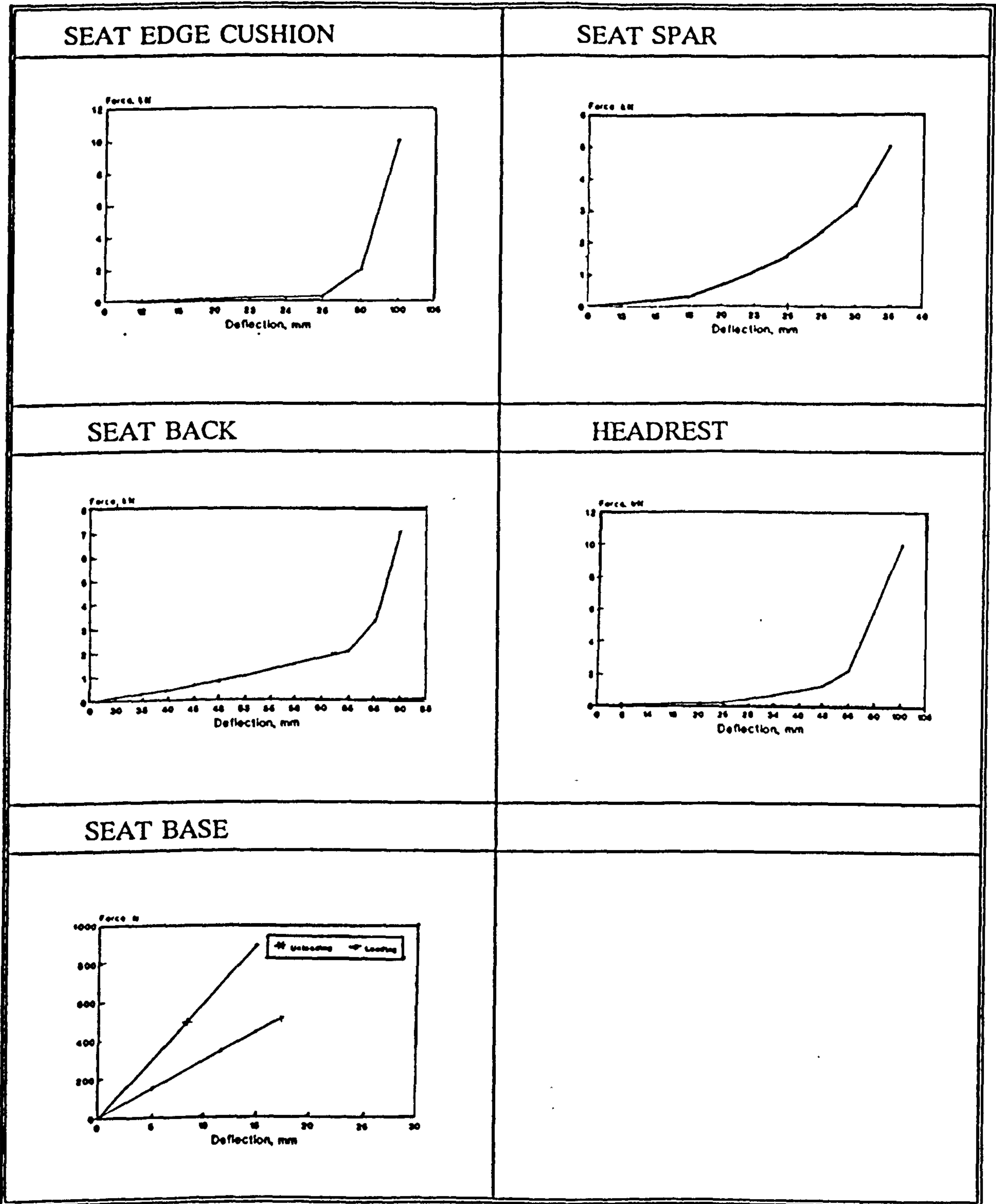


Figure 7.2 : The contact surface load curves between the dummy and various parts of the seat.

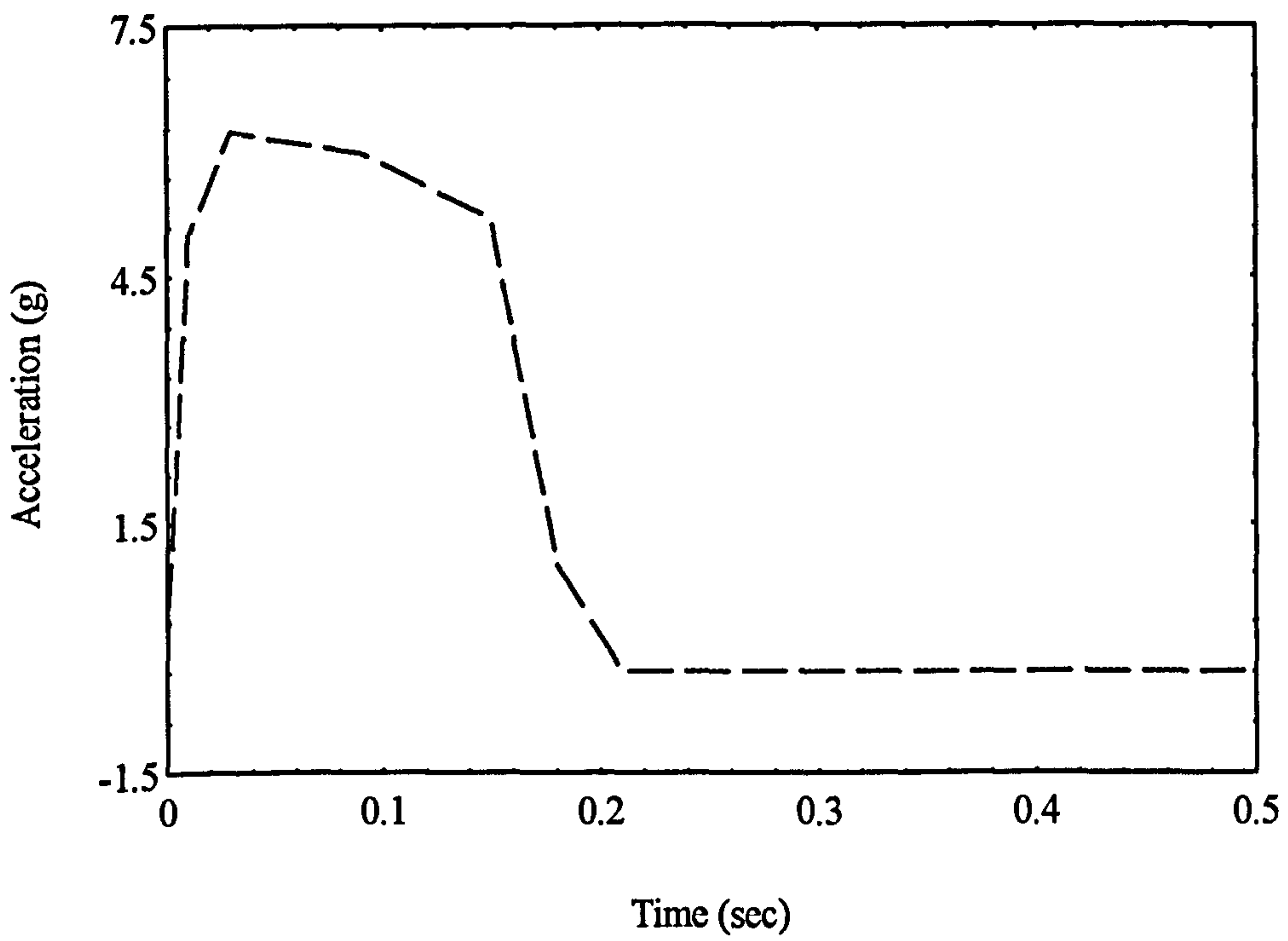


Figure 7.3 : The C3 acceleration pulse used by MIRA.

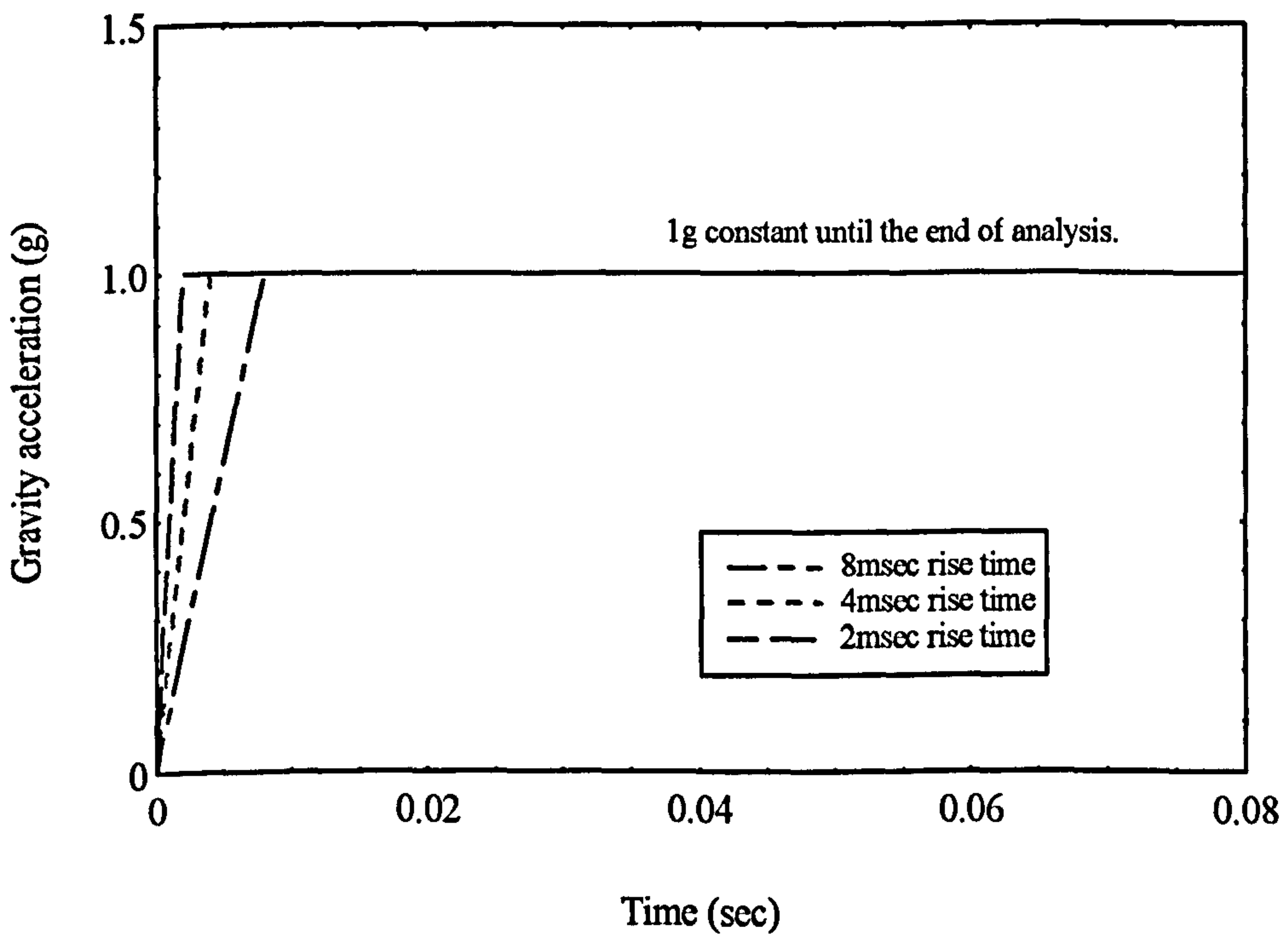


Figure 7.4 : The different rise time for gravity load curves.

PAMCRASH

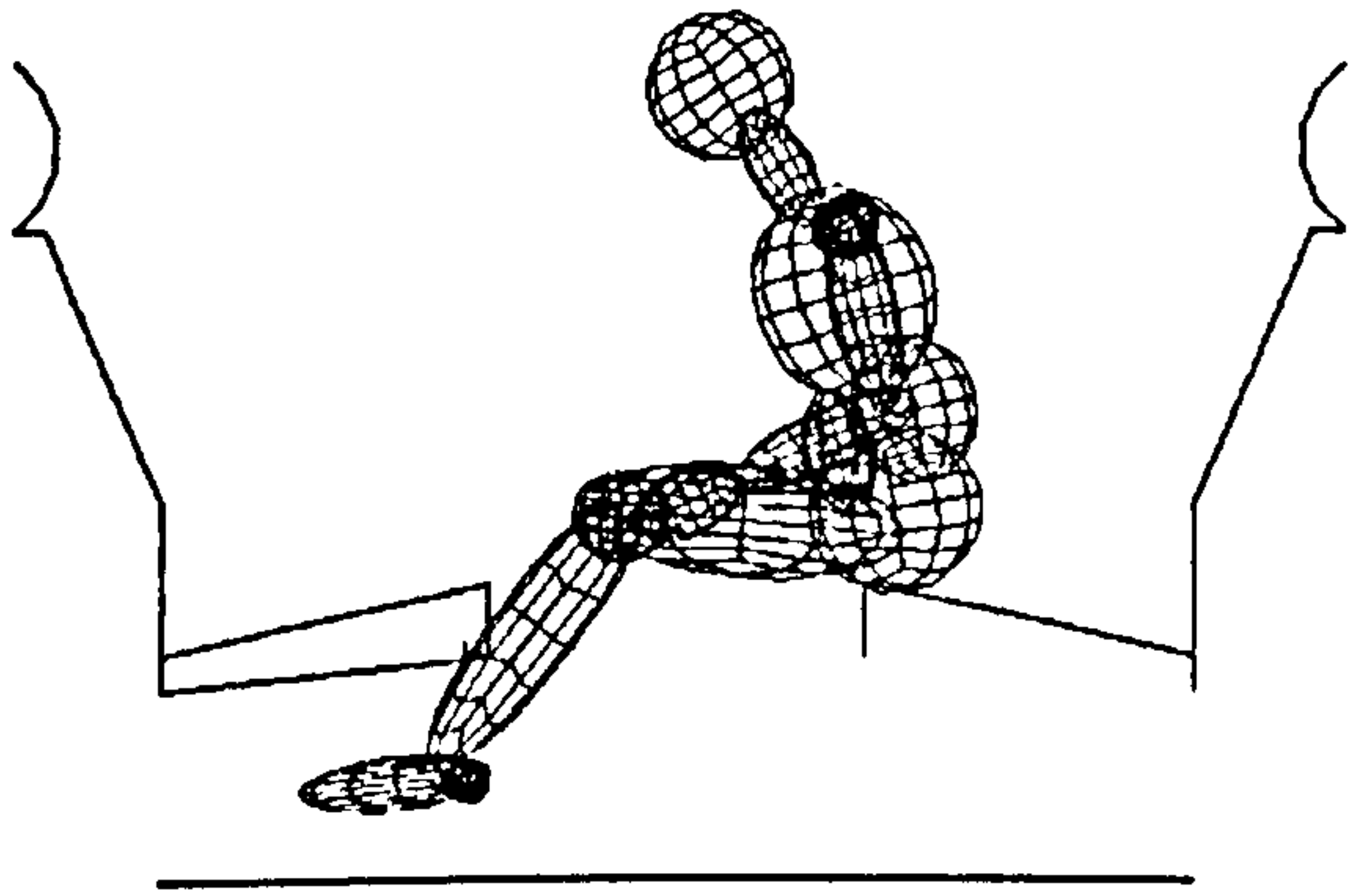


Figure 7.5a : Simulated animation at 135msec

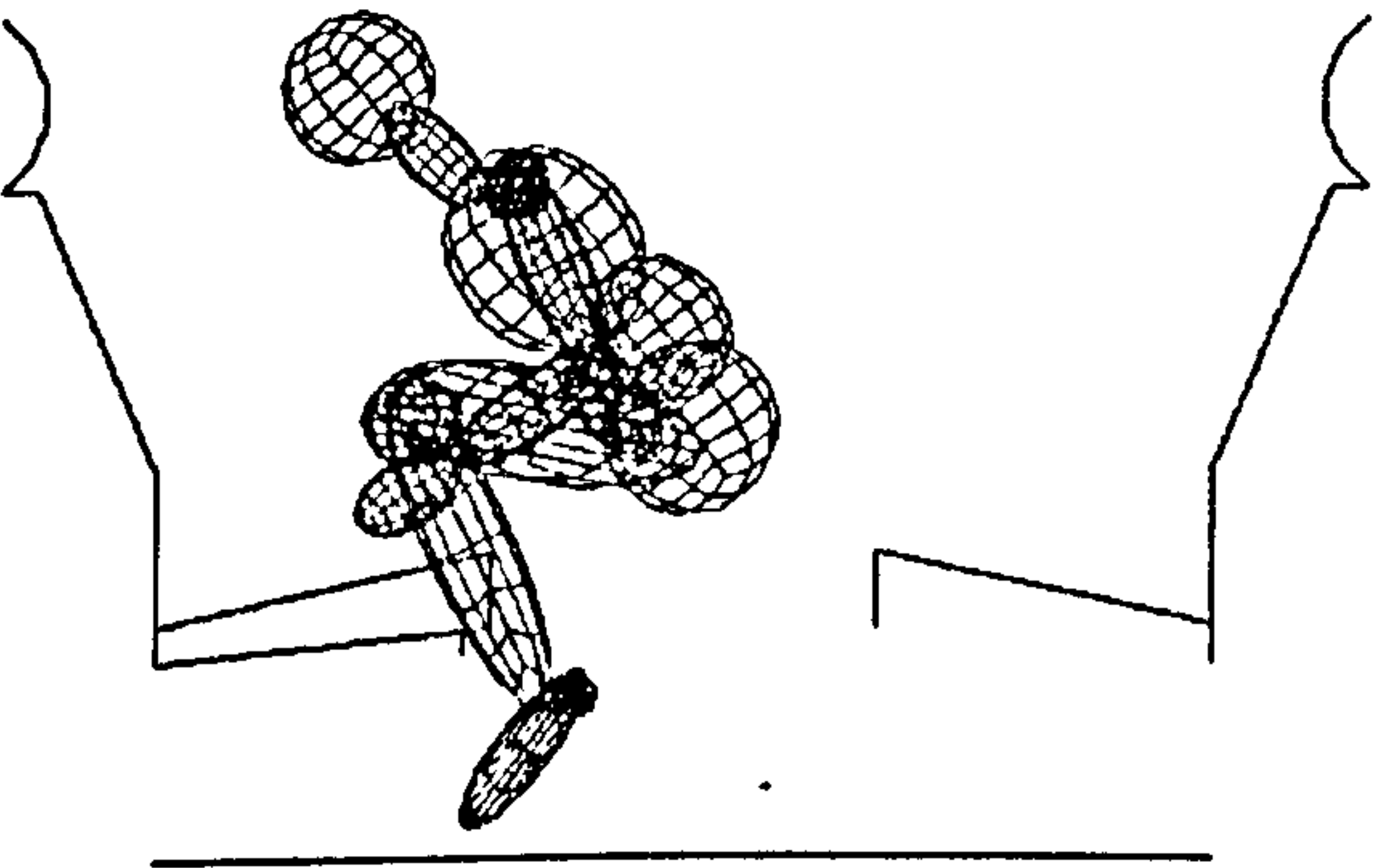


Figure 7.5b : Simulated animation at 200msec

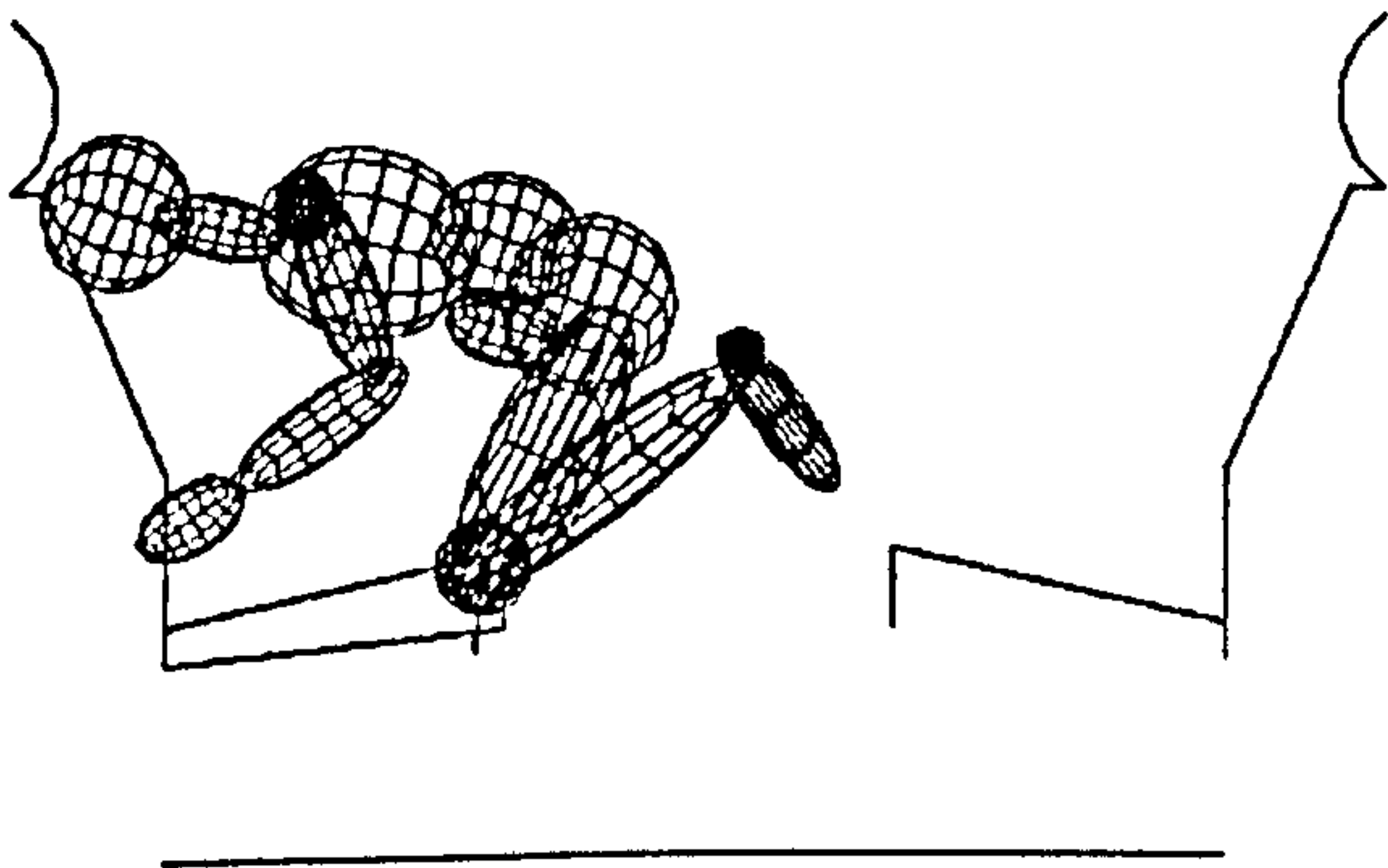


Figure 7.5c : Simulated animation at 240msec

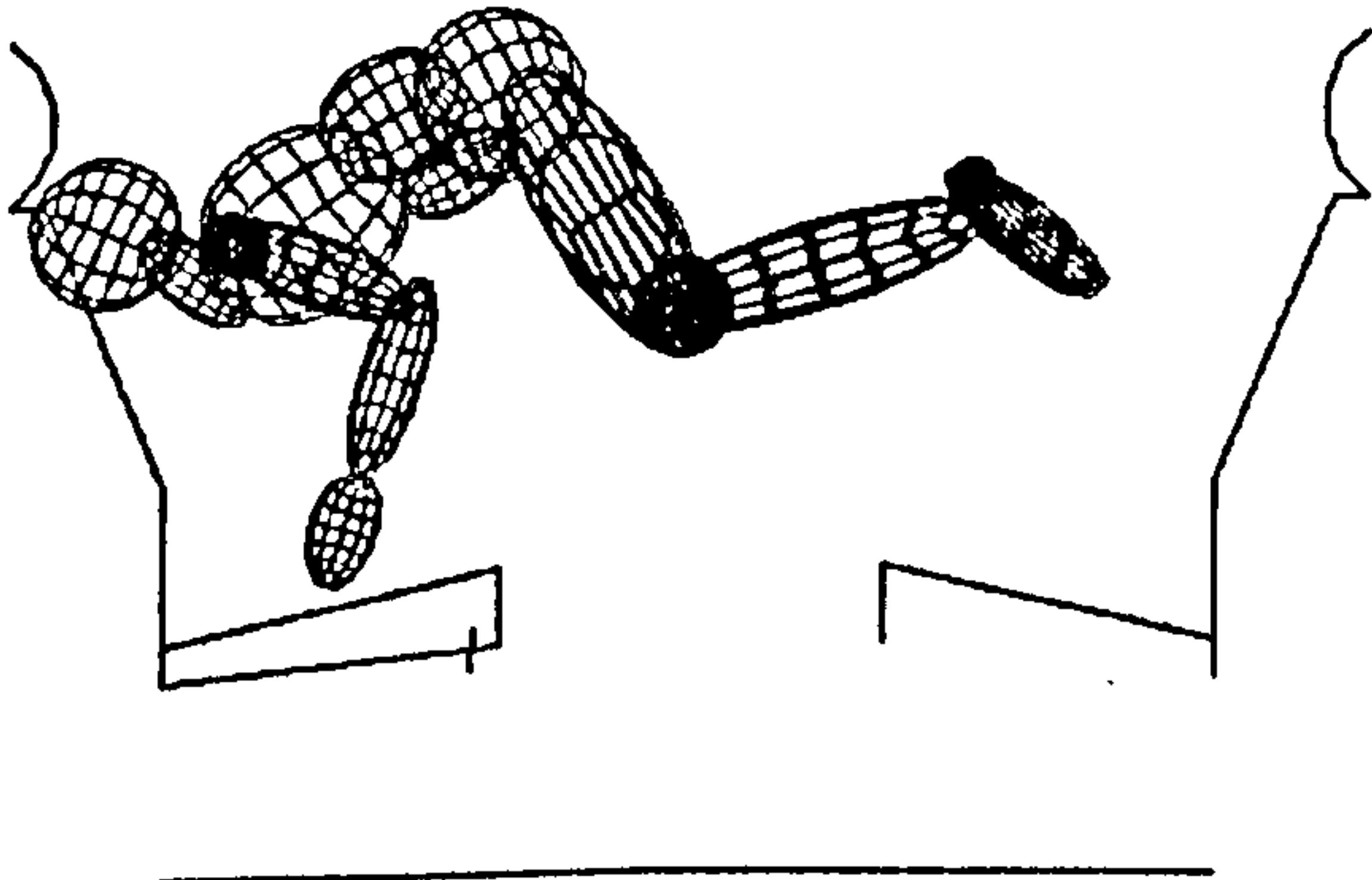
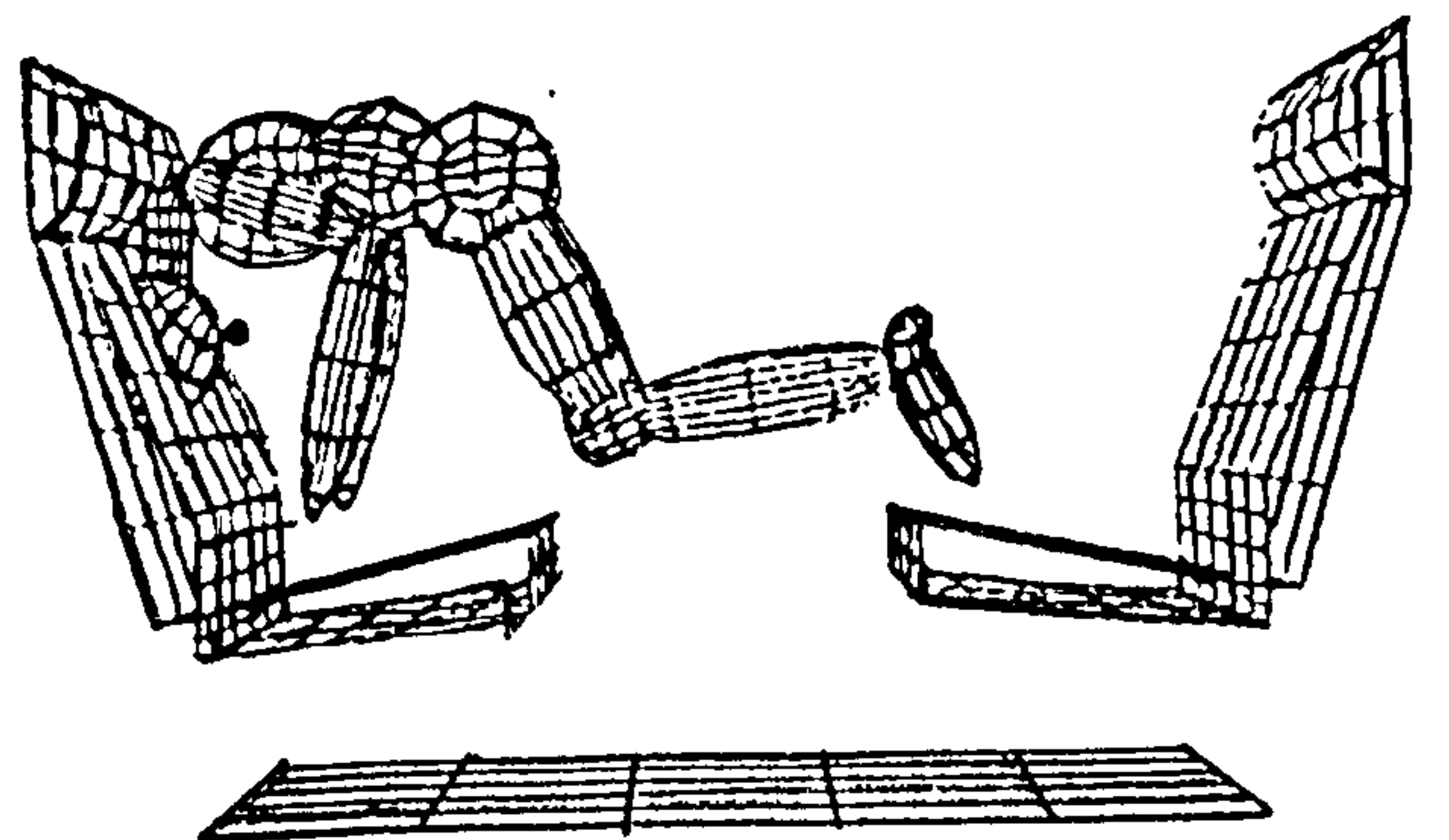
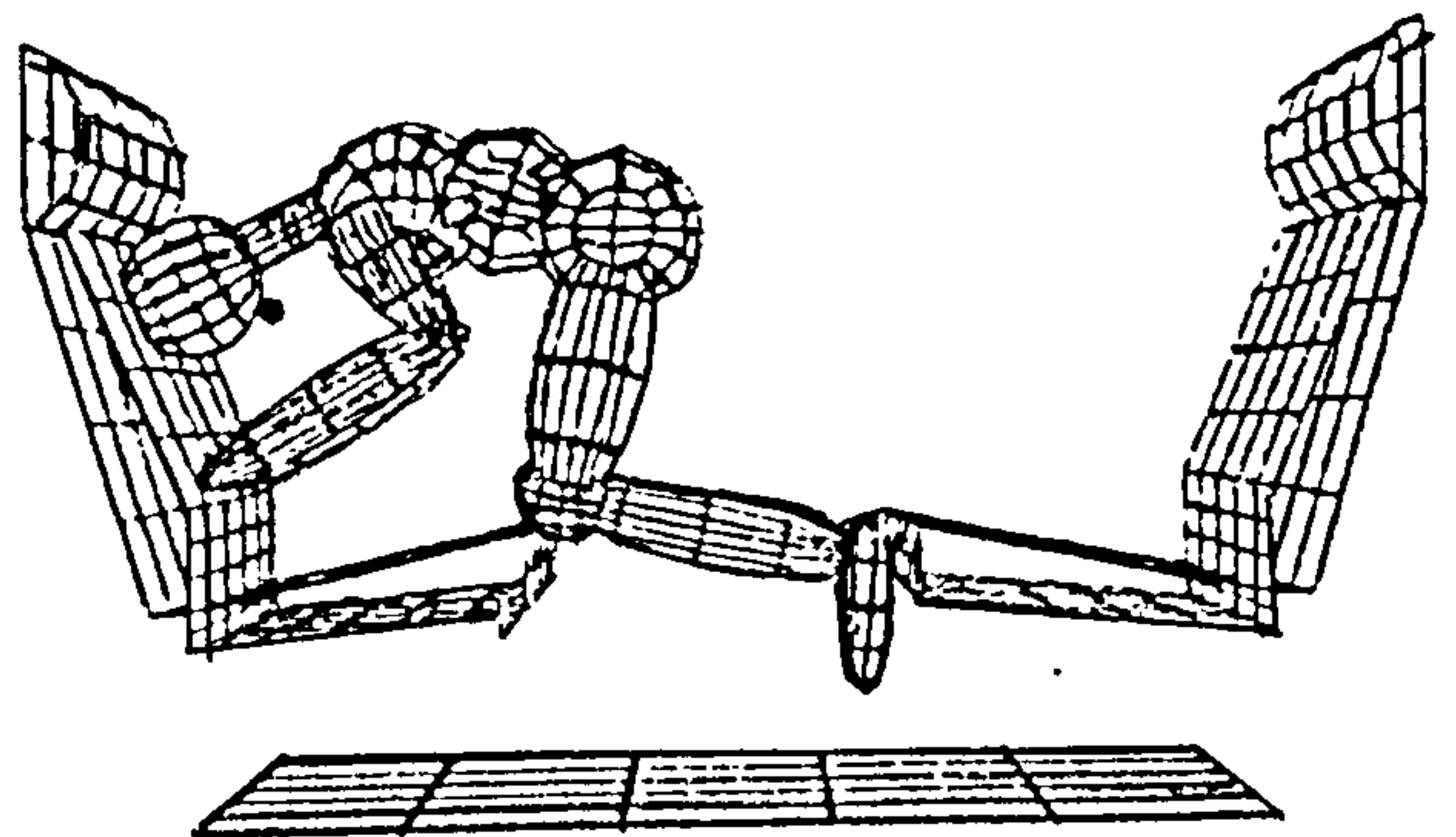
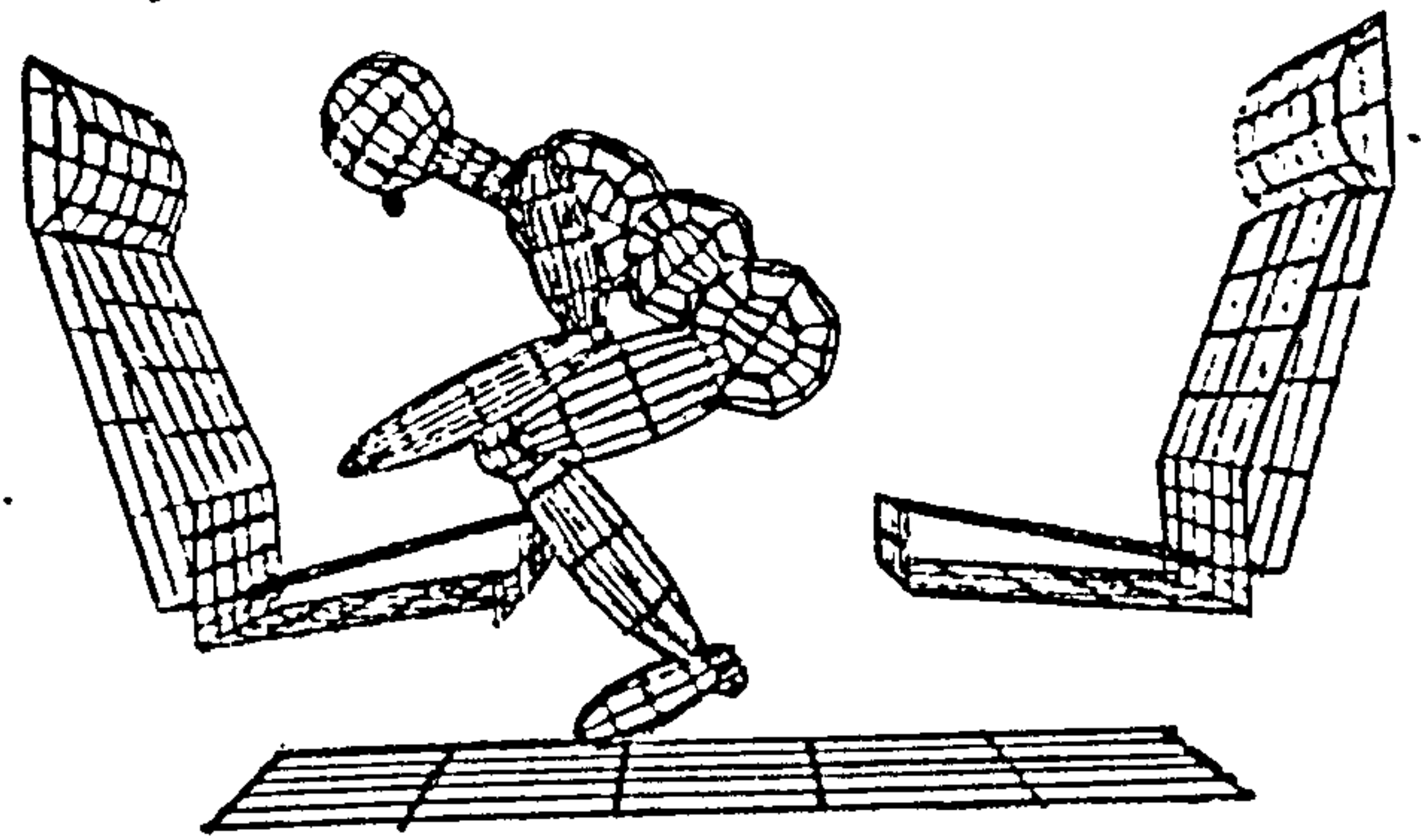
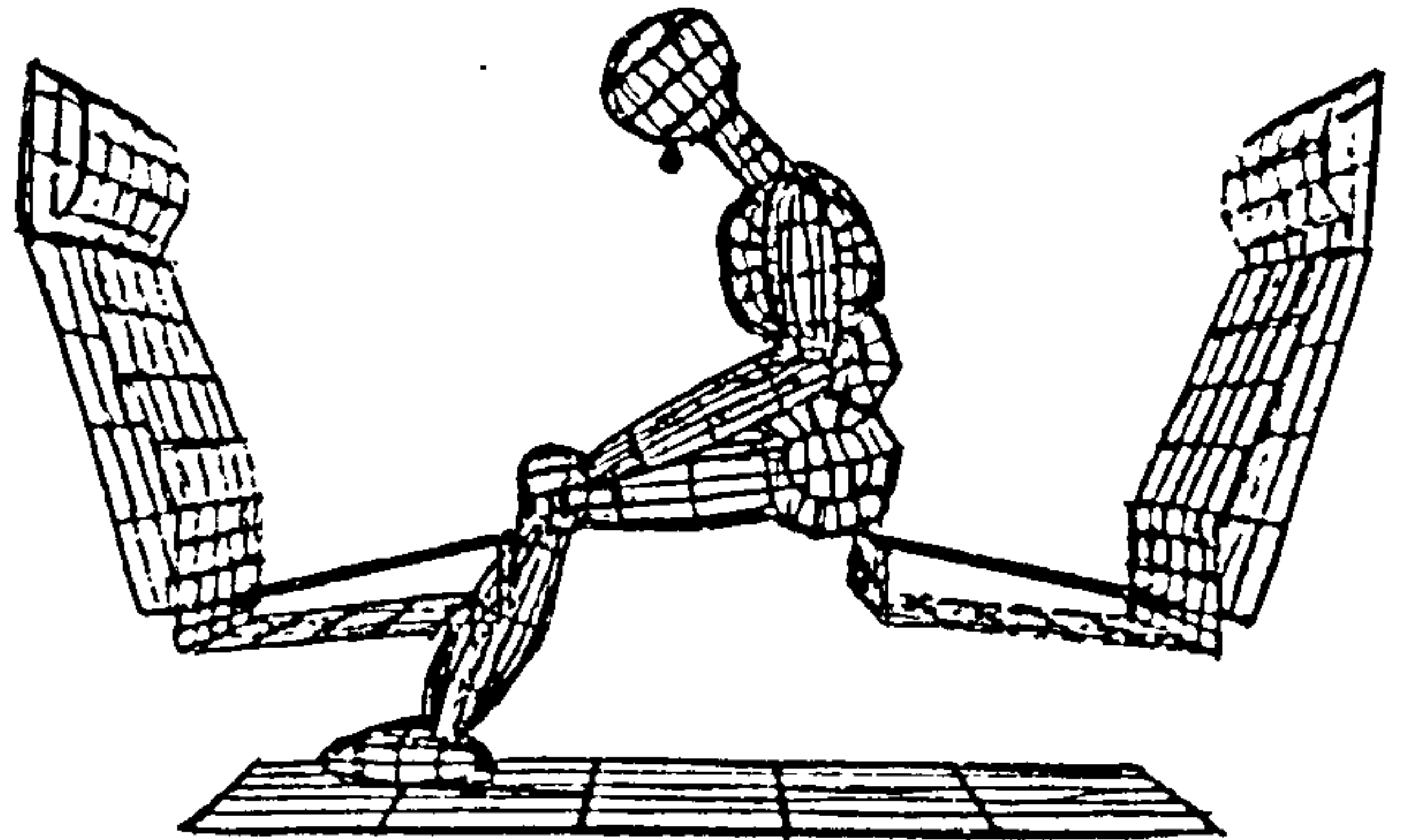


Figure 7.5d : Simulated animation at 290msec

DYNA3D



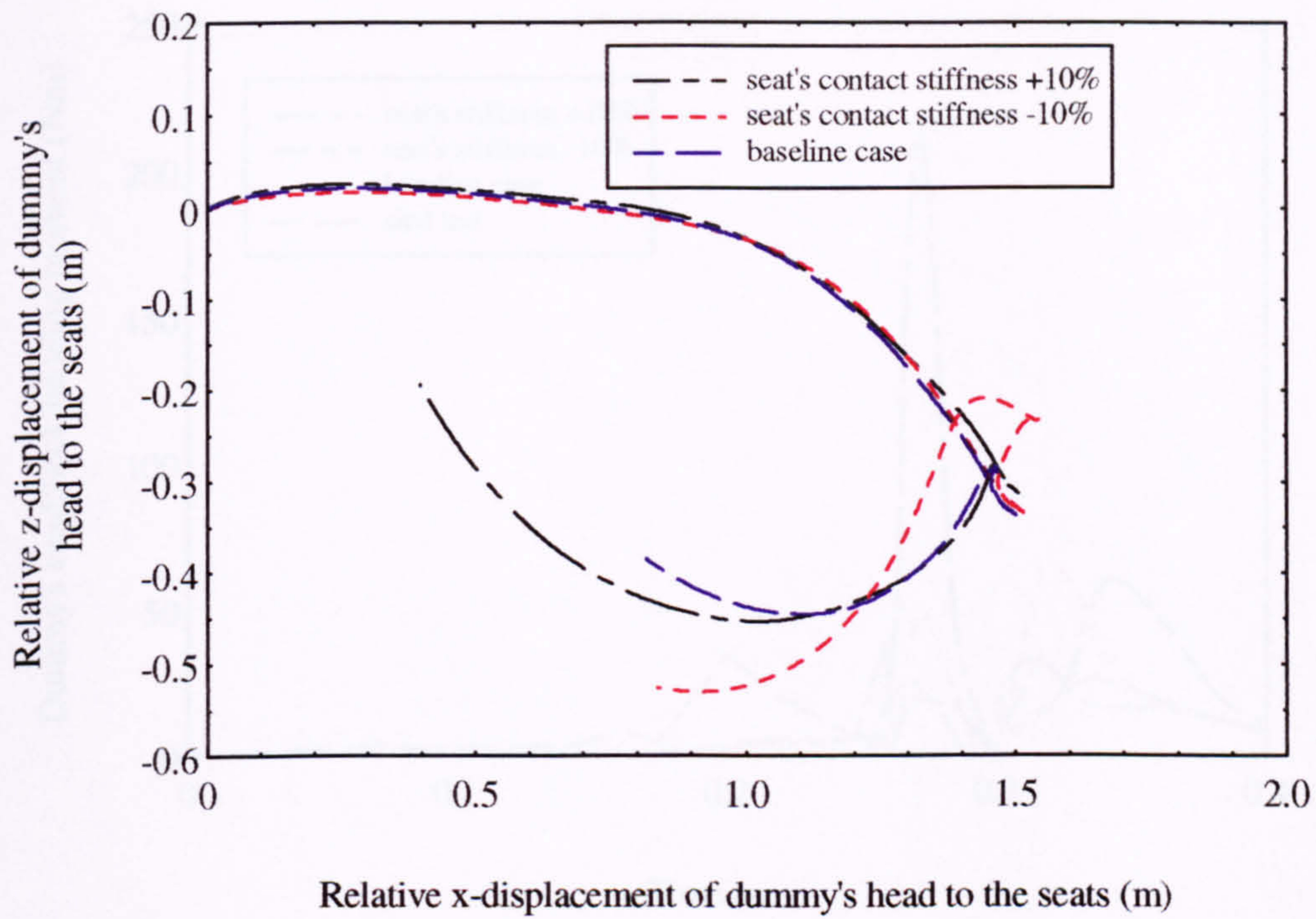


Figure 7.6 : The head's trajectories of the models studying cushion stiffness.

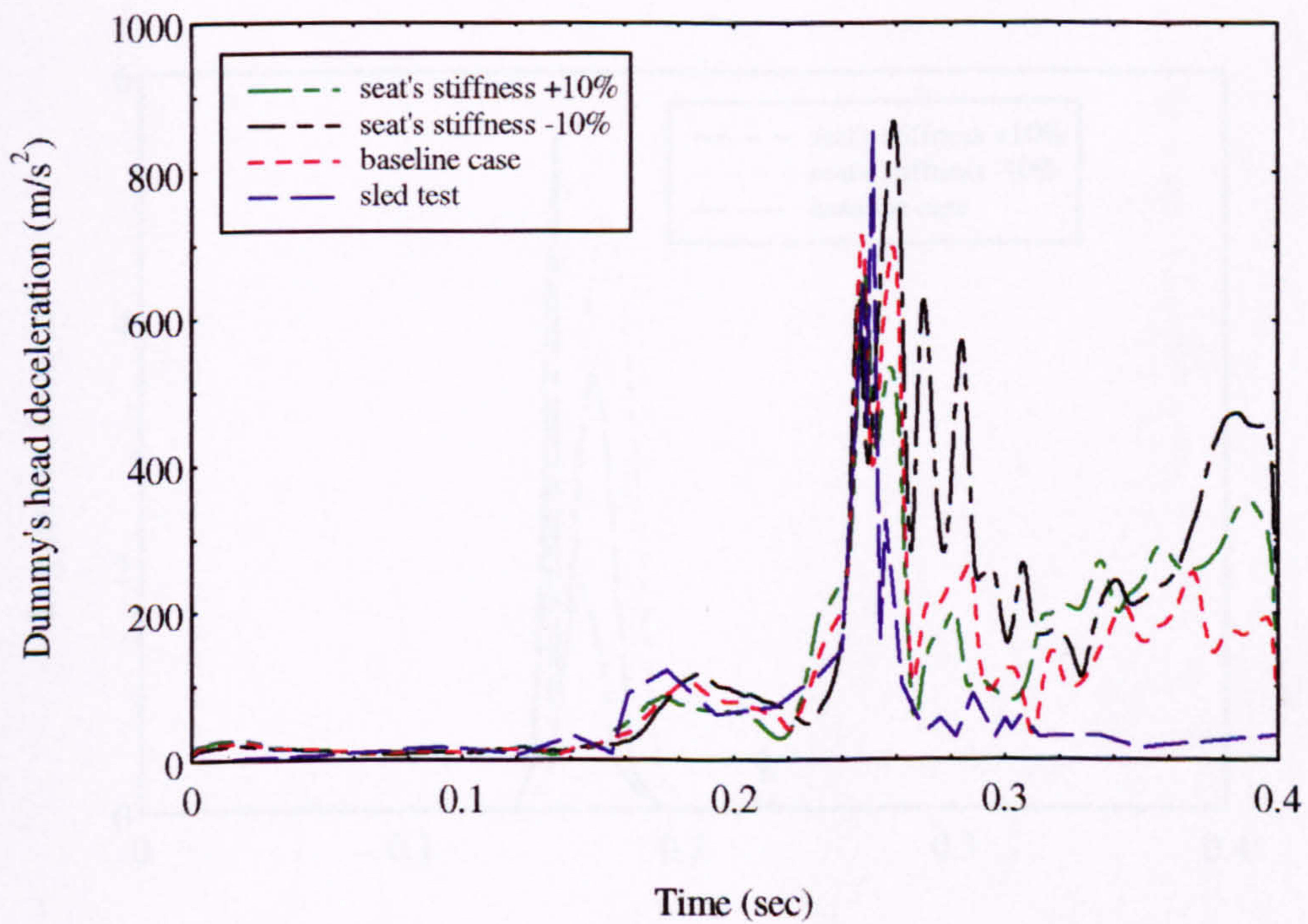


Figure 7.7 : The head's deceleration-time history of the models studying cushion stiffness.

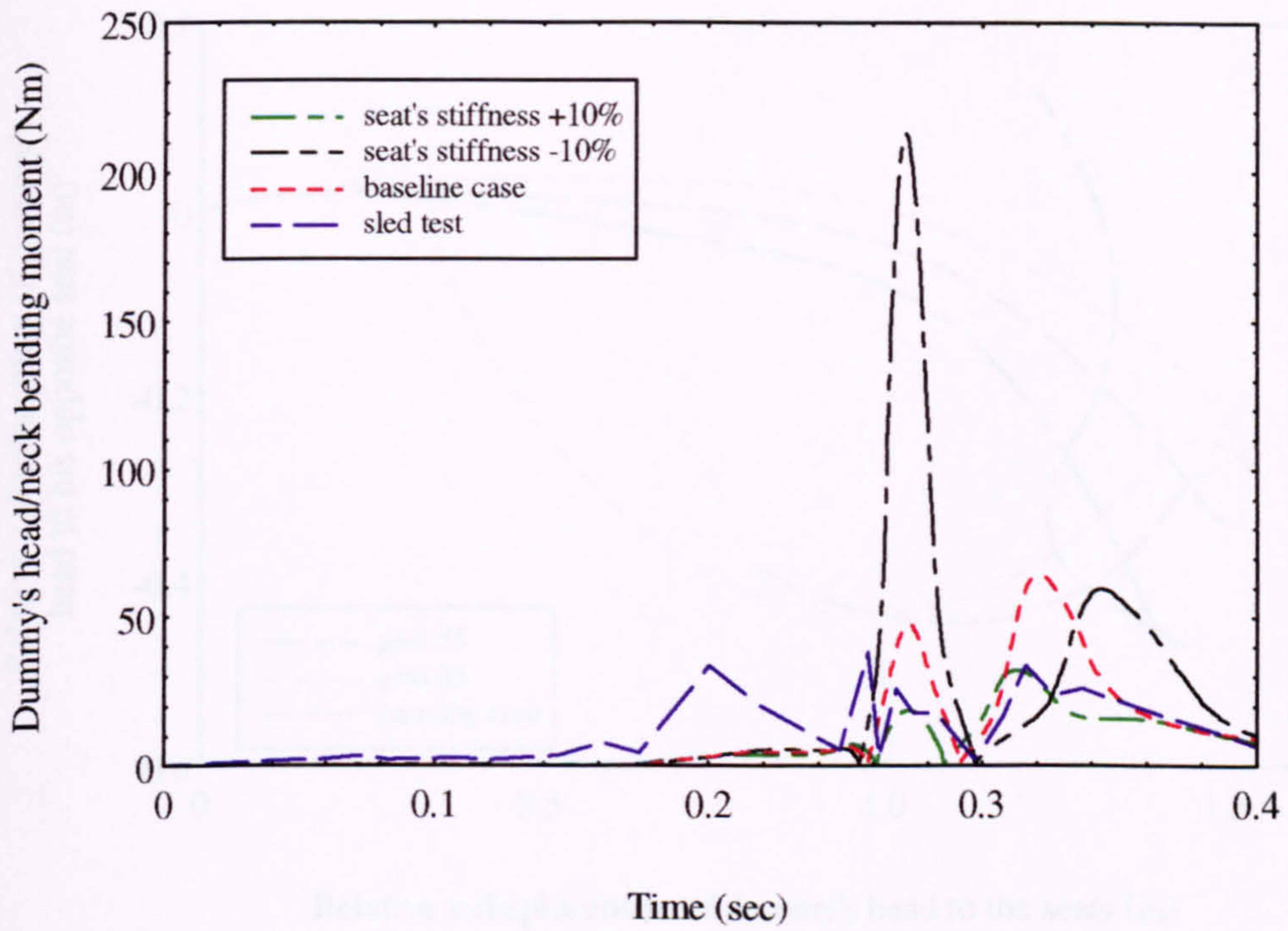


Figure 7.8 : The head/neck moment-time history of the models studying cushion stiffness.

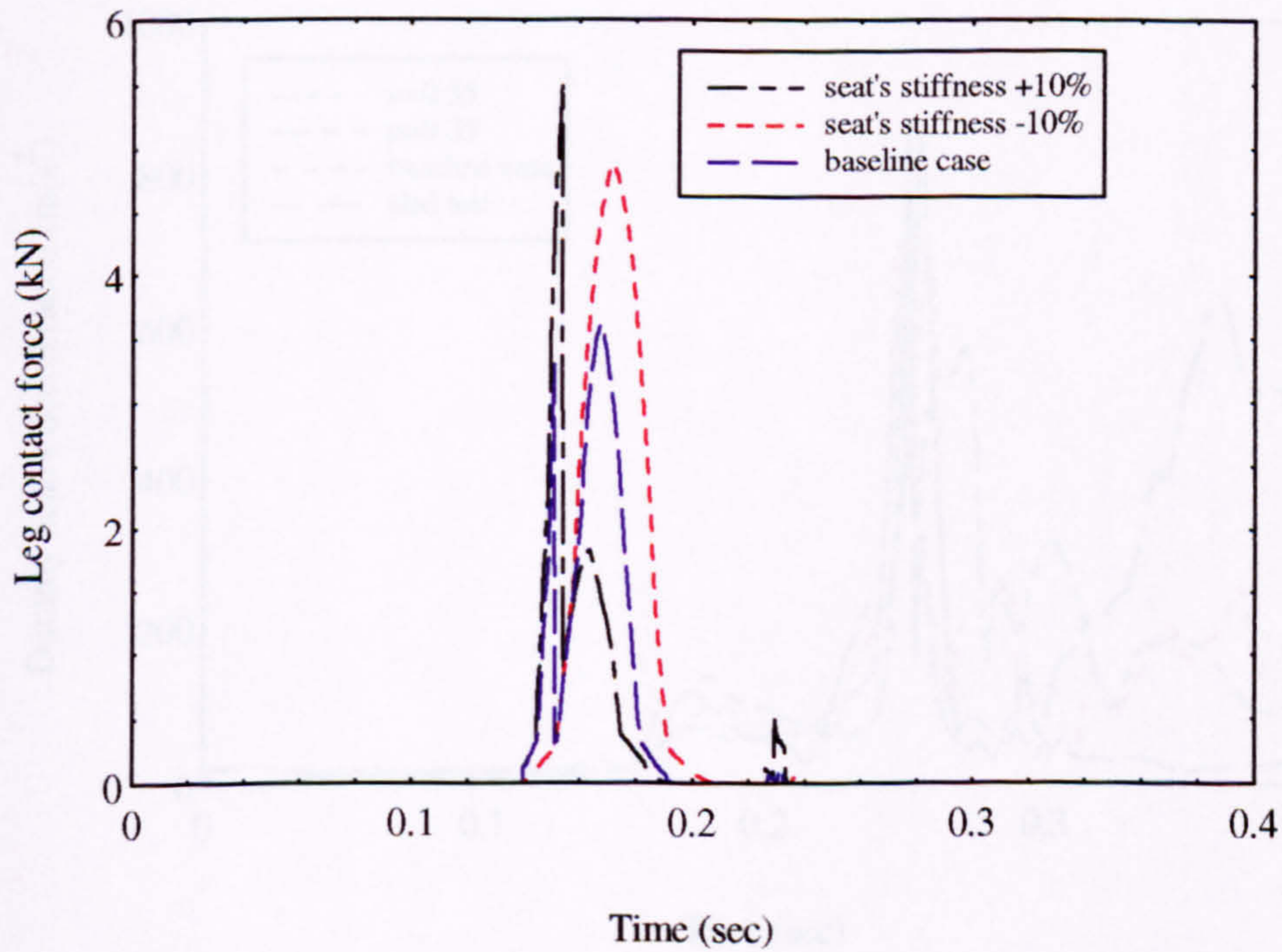


Figure 7.9 : The leg contact force-time history of the models studying cushion stiffness.

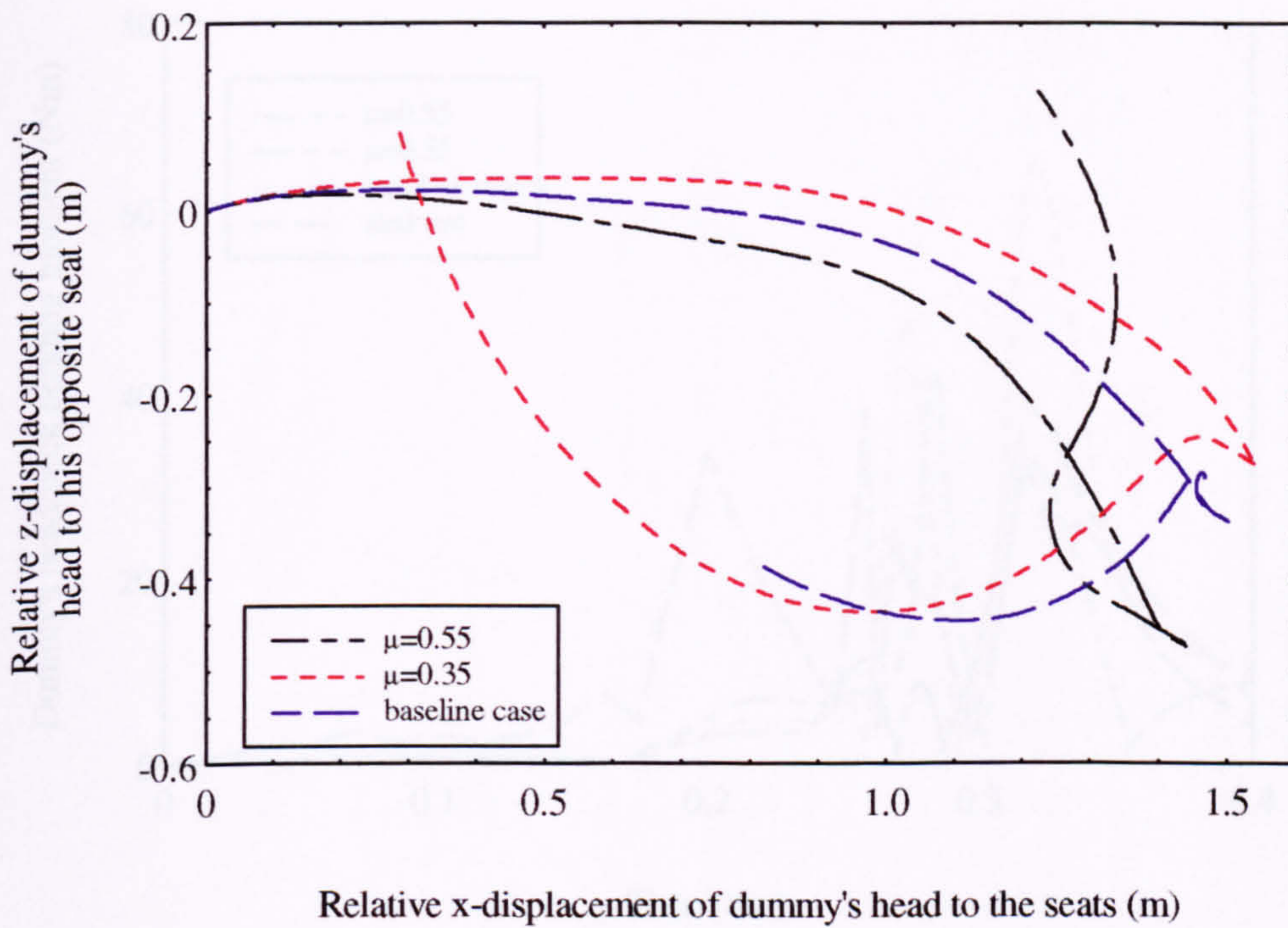


Figure 7.10 : The head's trajectories of the models studying contact friction.

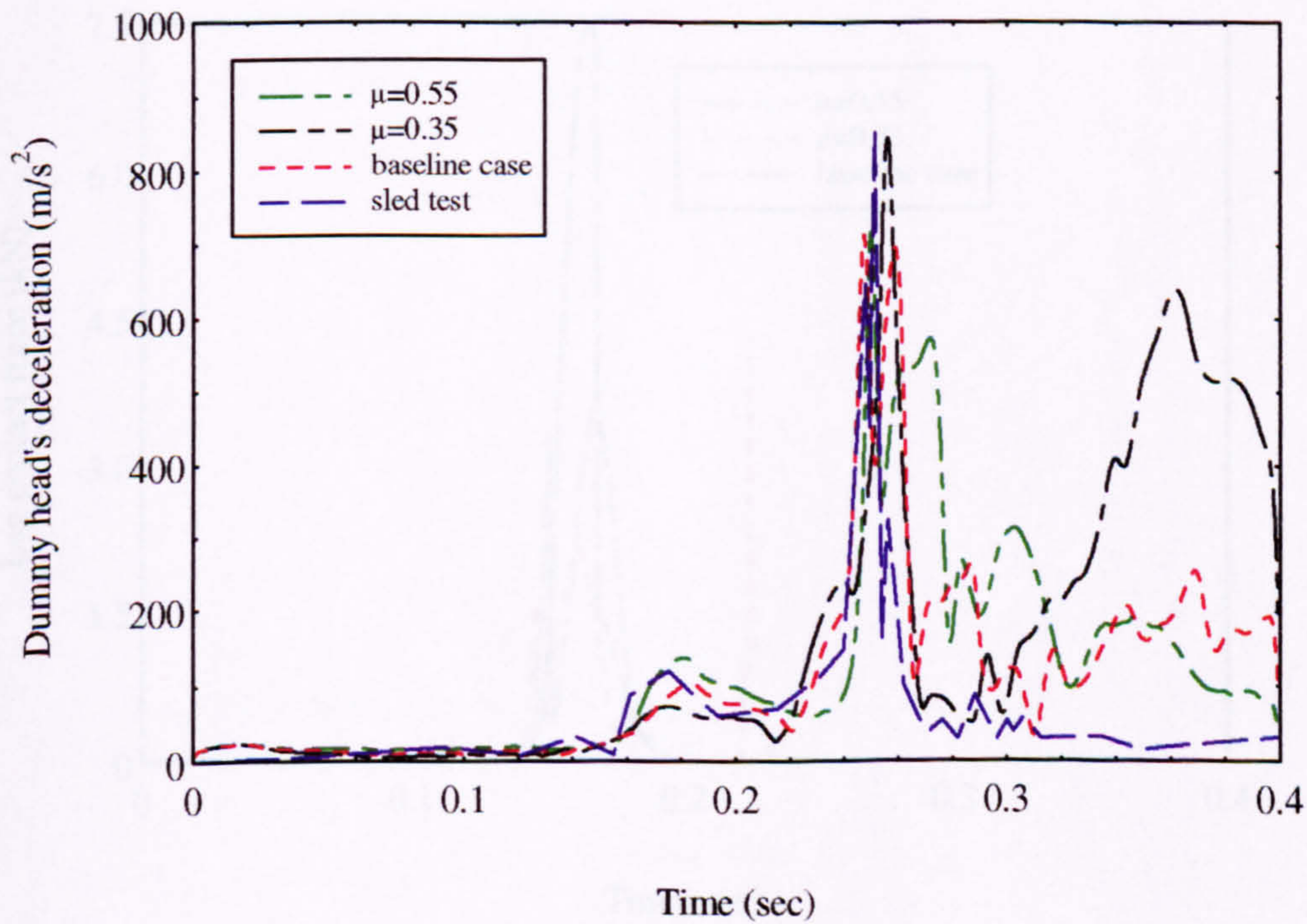


Figure 7.11 : The head's deceleration-time history of the models studying contact friction.

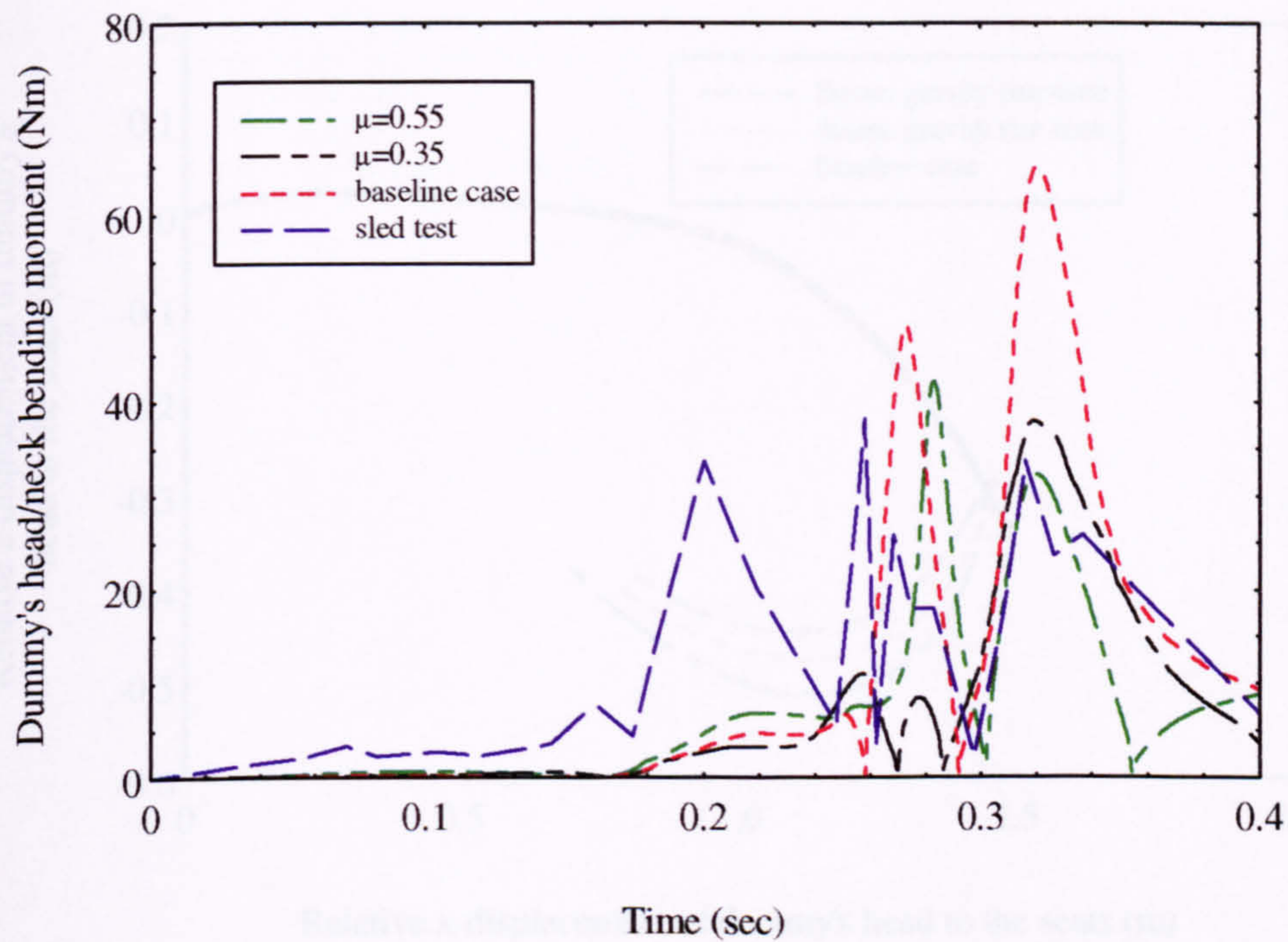


Figure 7.12 : The head/neck moment-time history of the models studying contact friction.

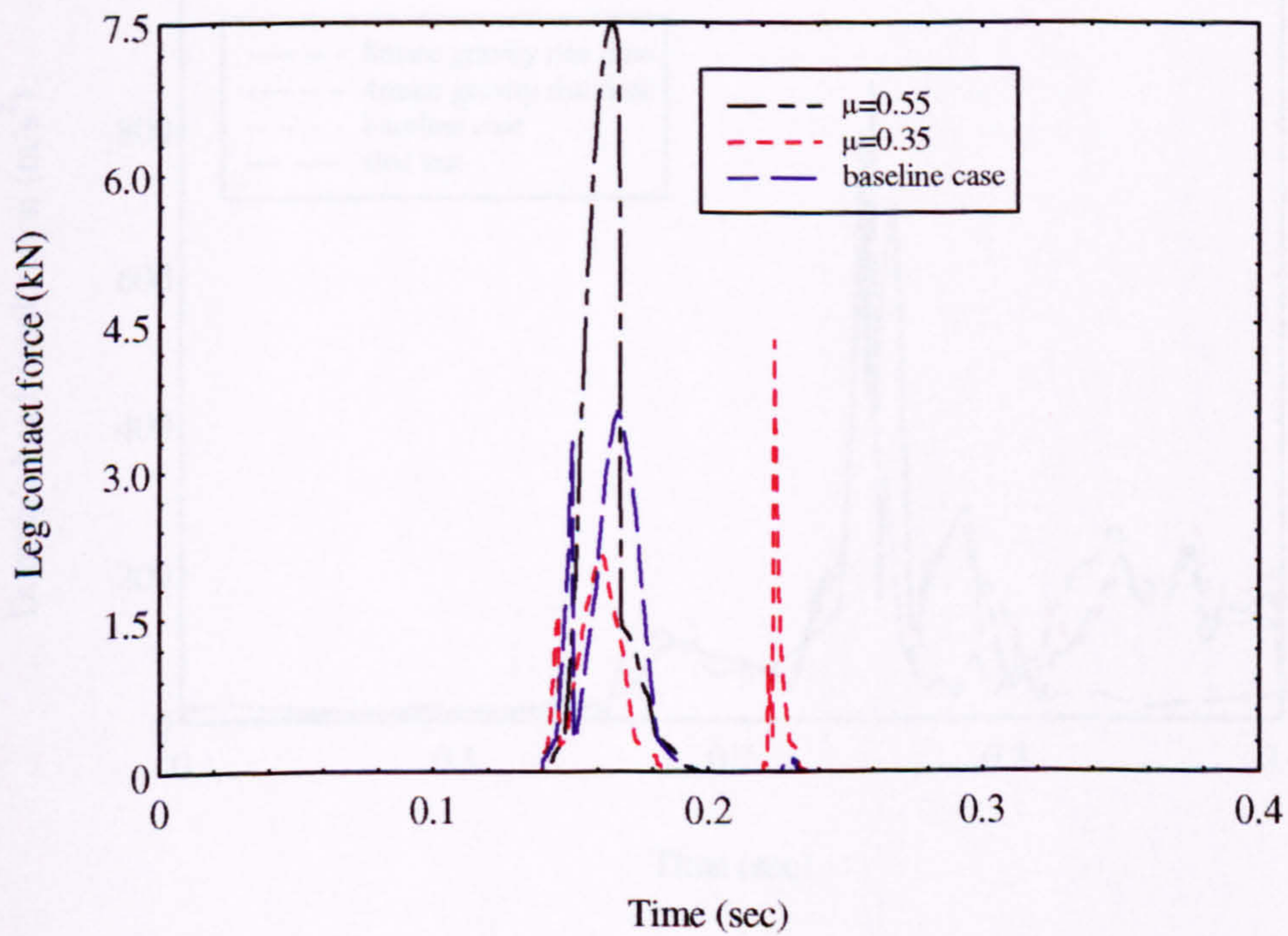


Figure 7.13 : The leg contact force-time history of the models studying contact friction.

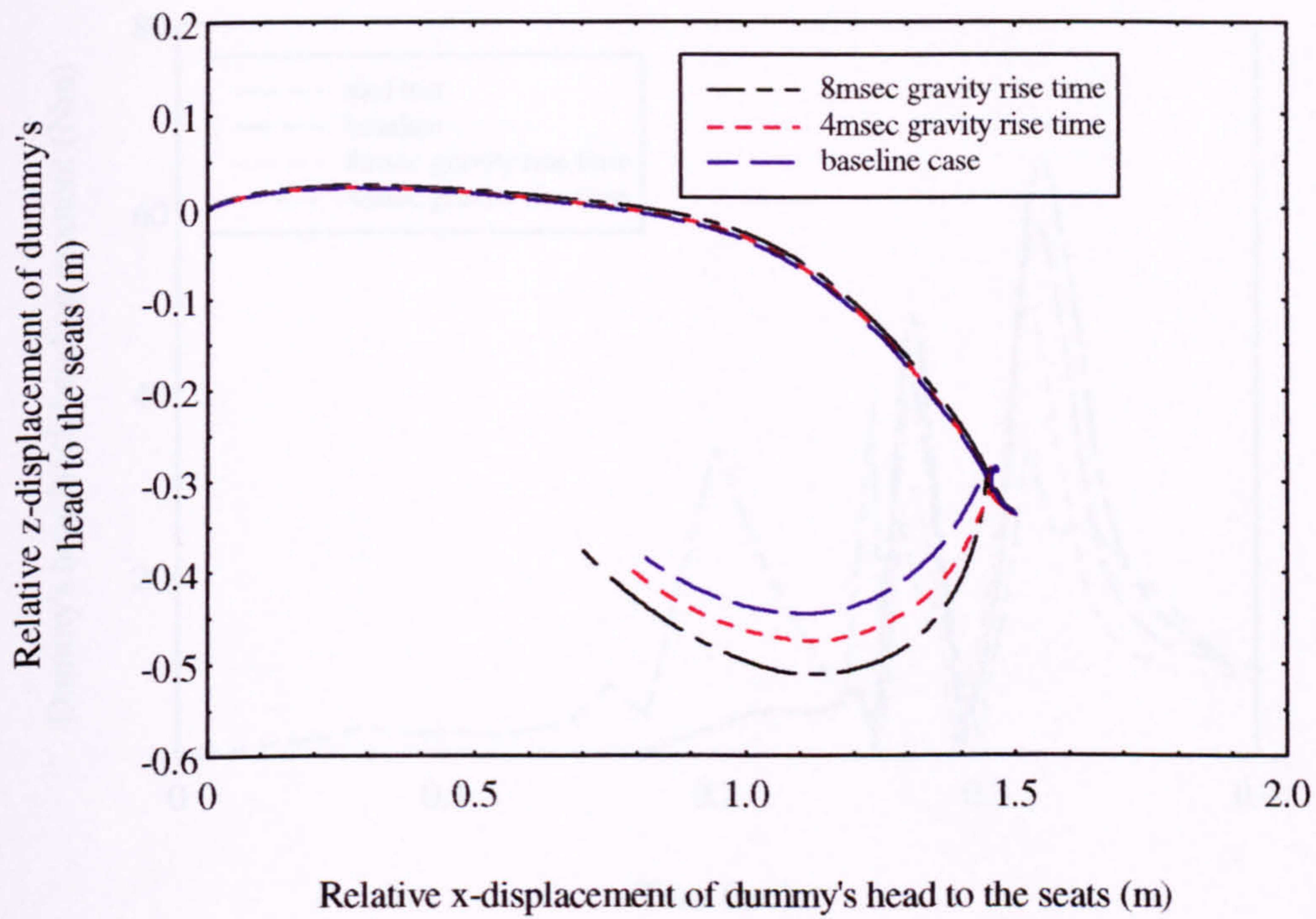


Figure 7.14 : The head's trajectories of the models studying gravity rise time.

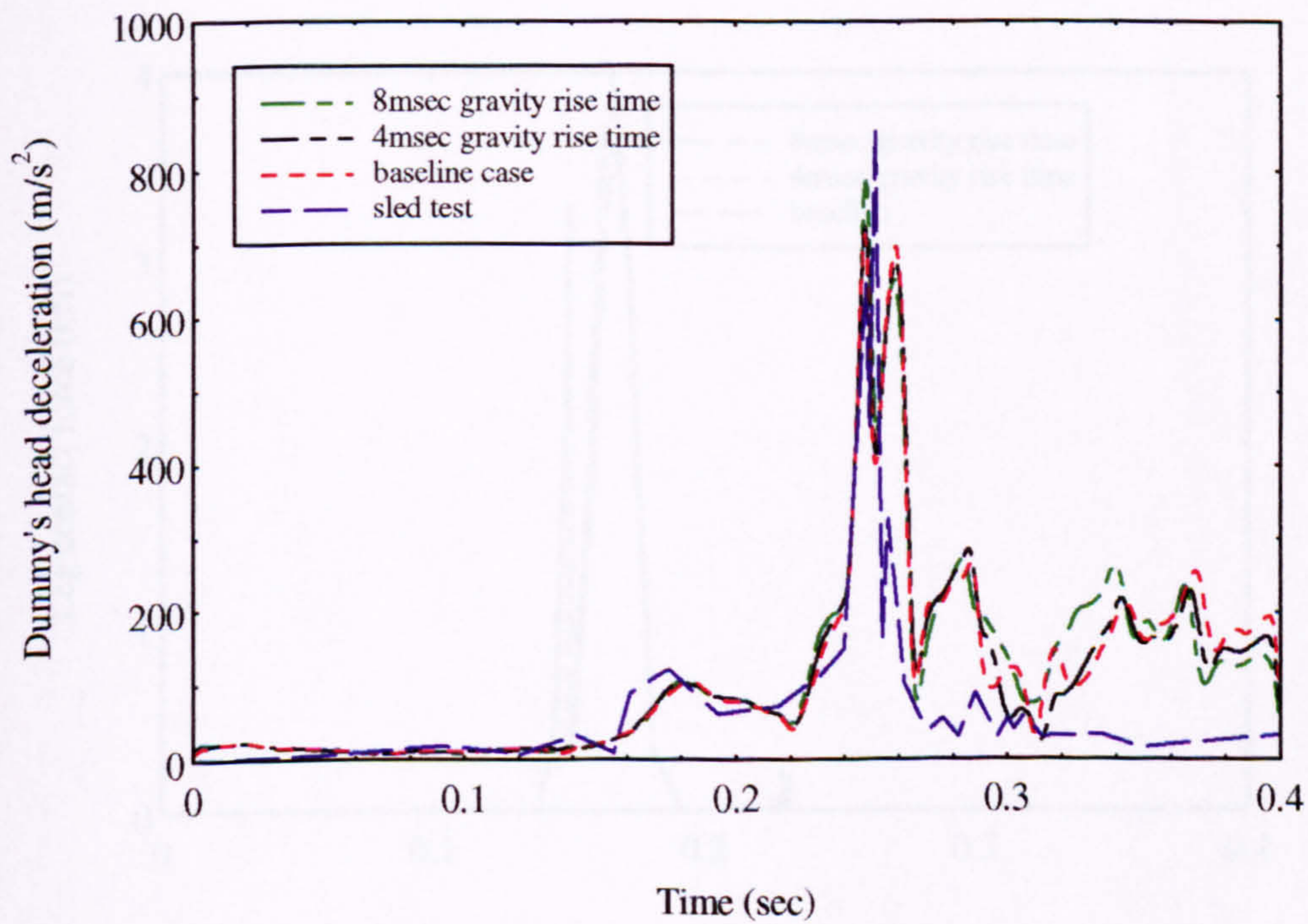


Figure 7.15 : The head's deceleration-time history of the models studying gravity rise time.

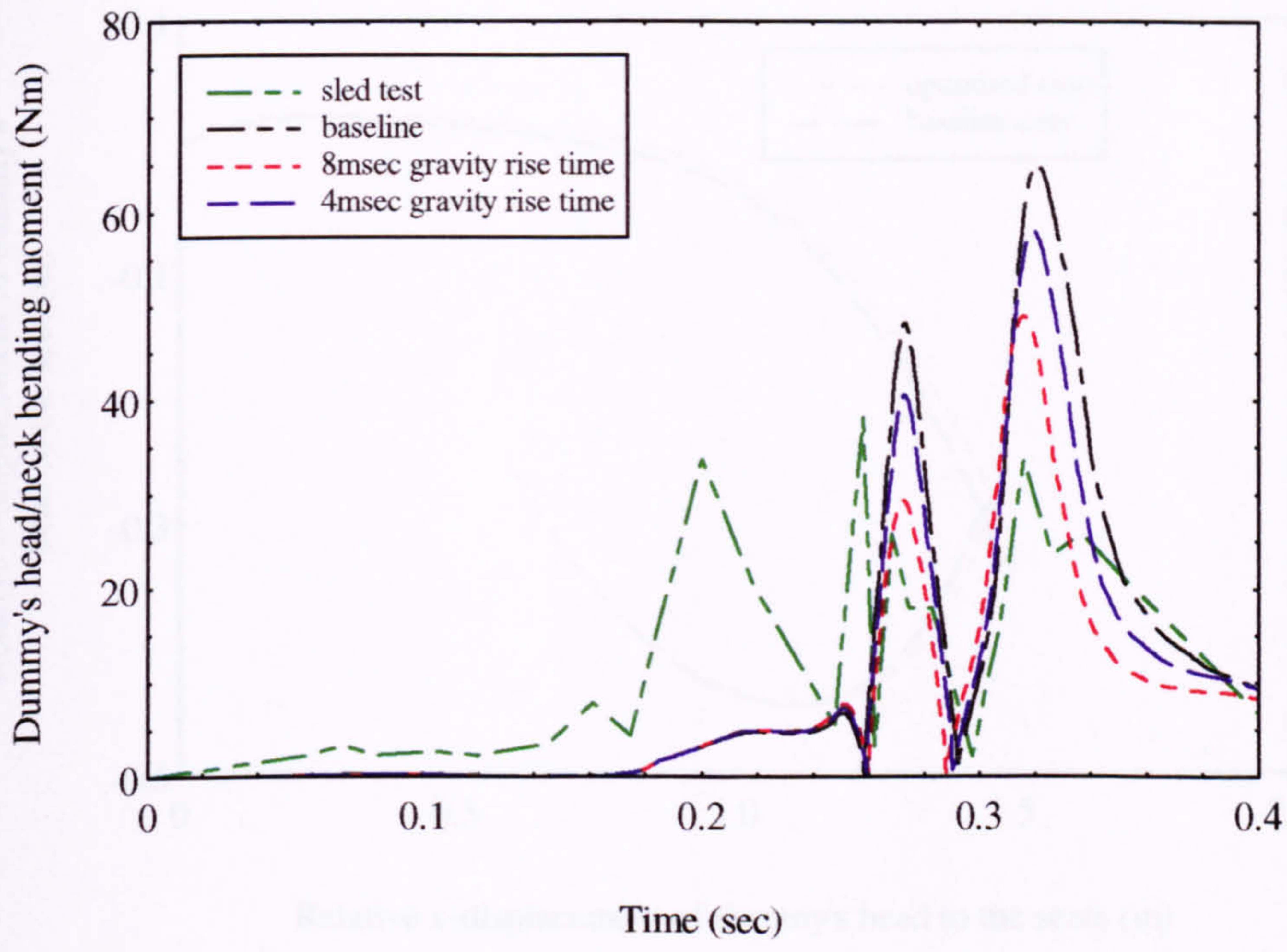


Figure 7.16 : The head/neck moment-time history of the models studying gravity rise time.

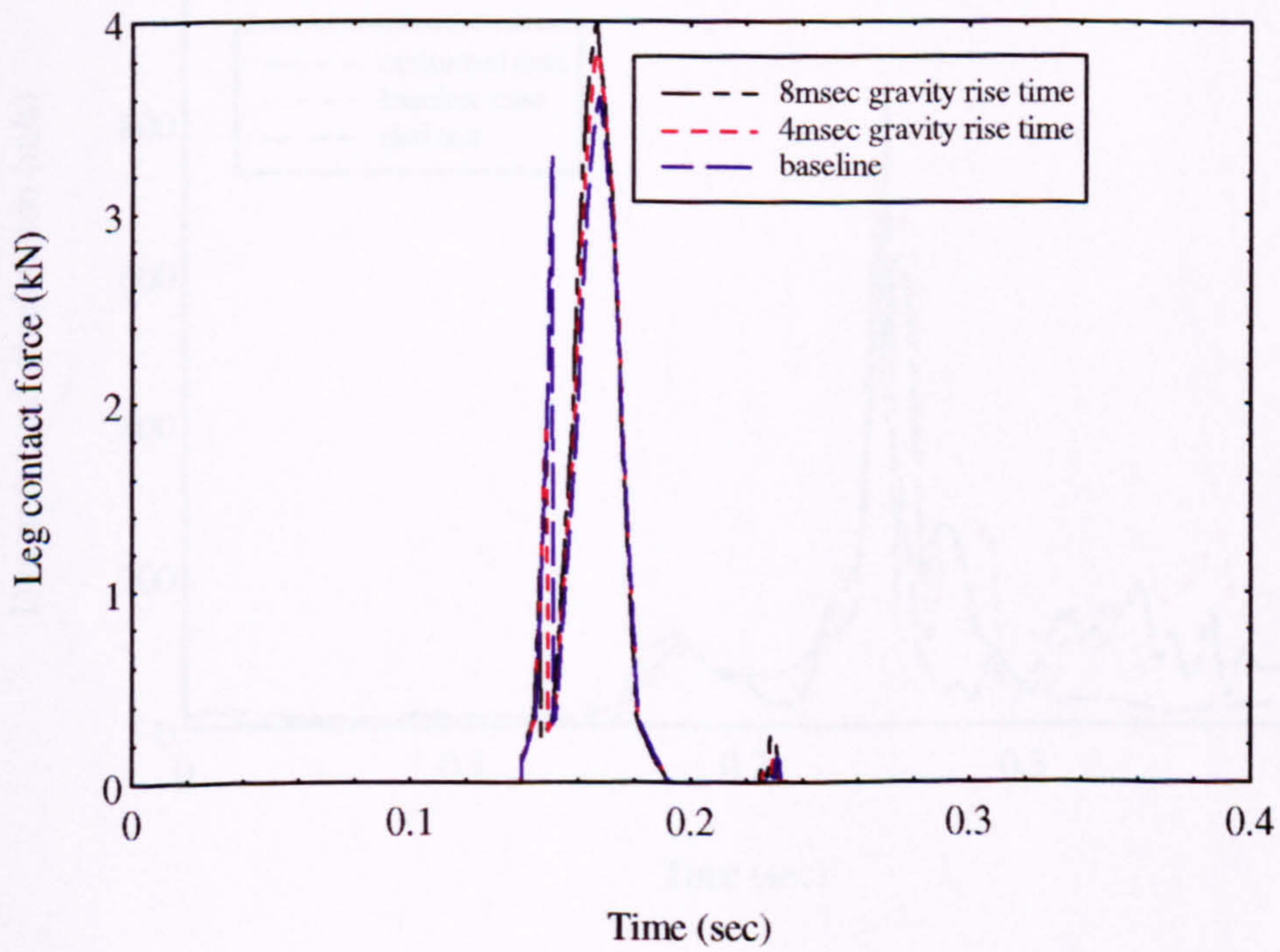


Figure 7.17 : The leg contact force-time history of the models studying gravity rise time.

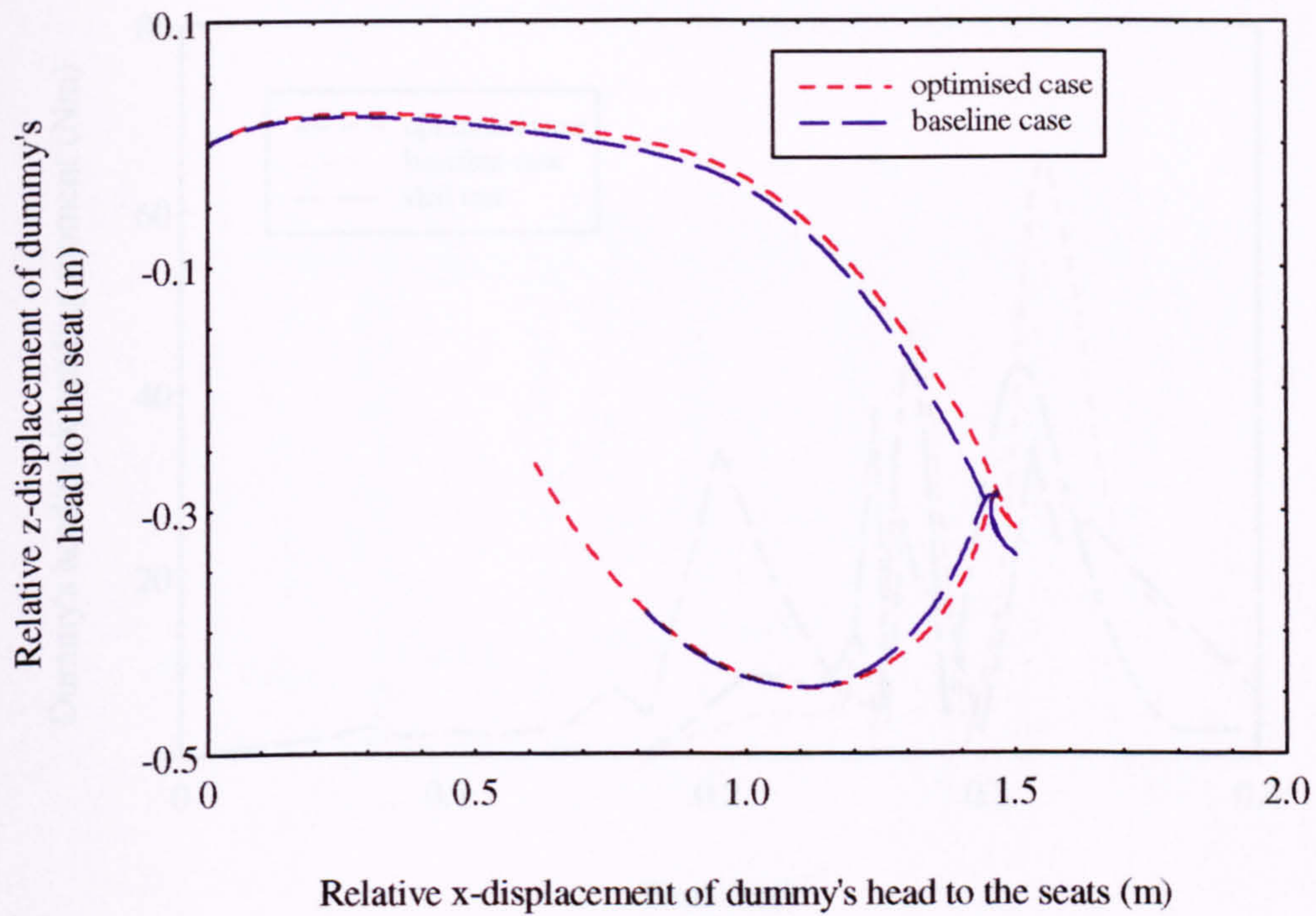


Figure 7.18 : The head's trajectories of the baseline and optimised models.

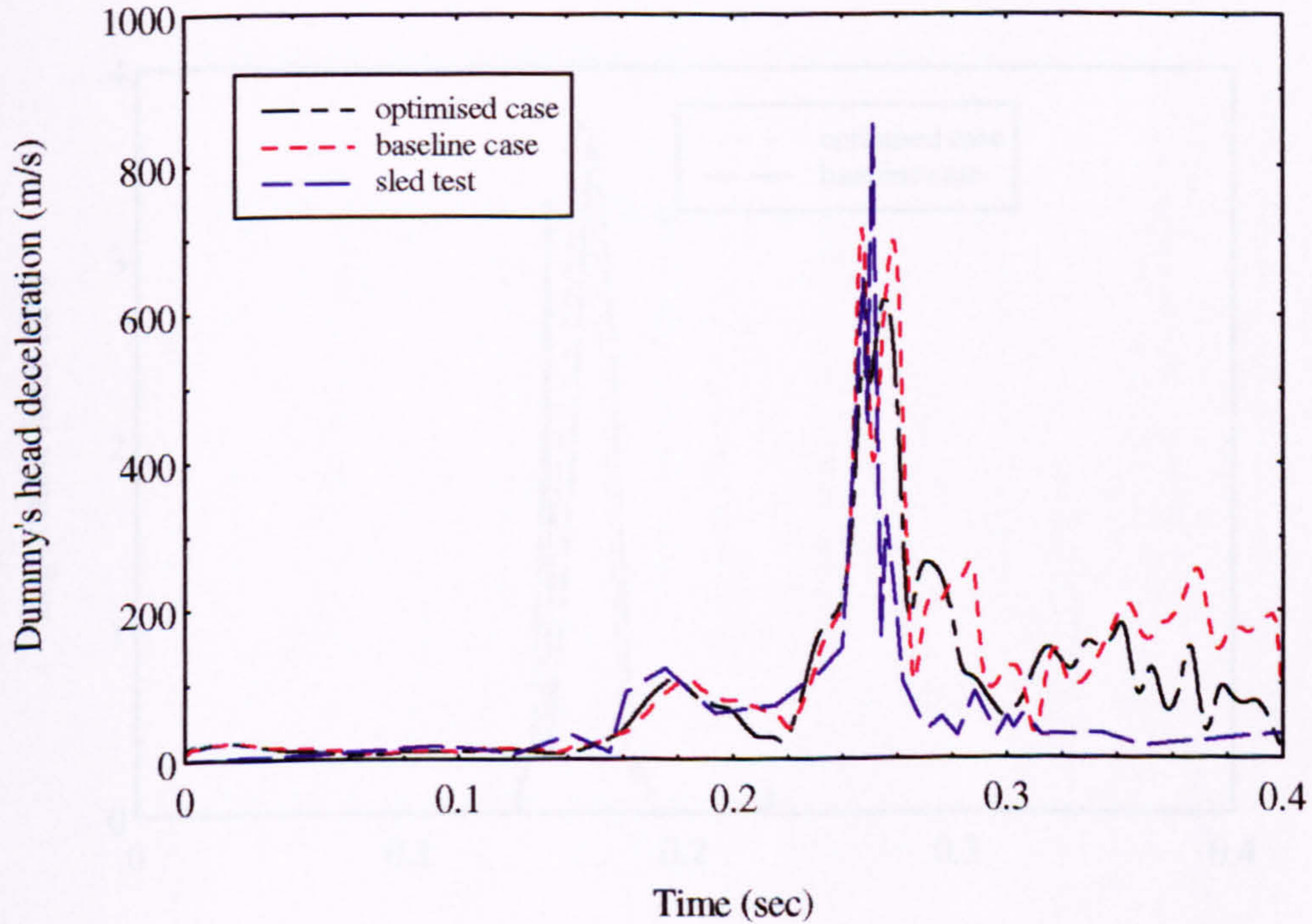


Figure 7.19 : The head's deceleration-time history of the baseline and optimised models.

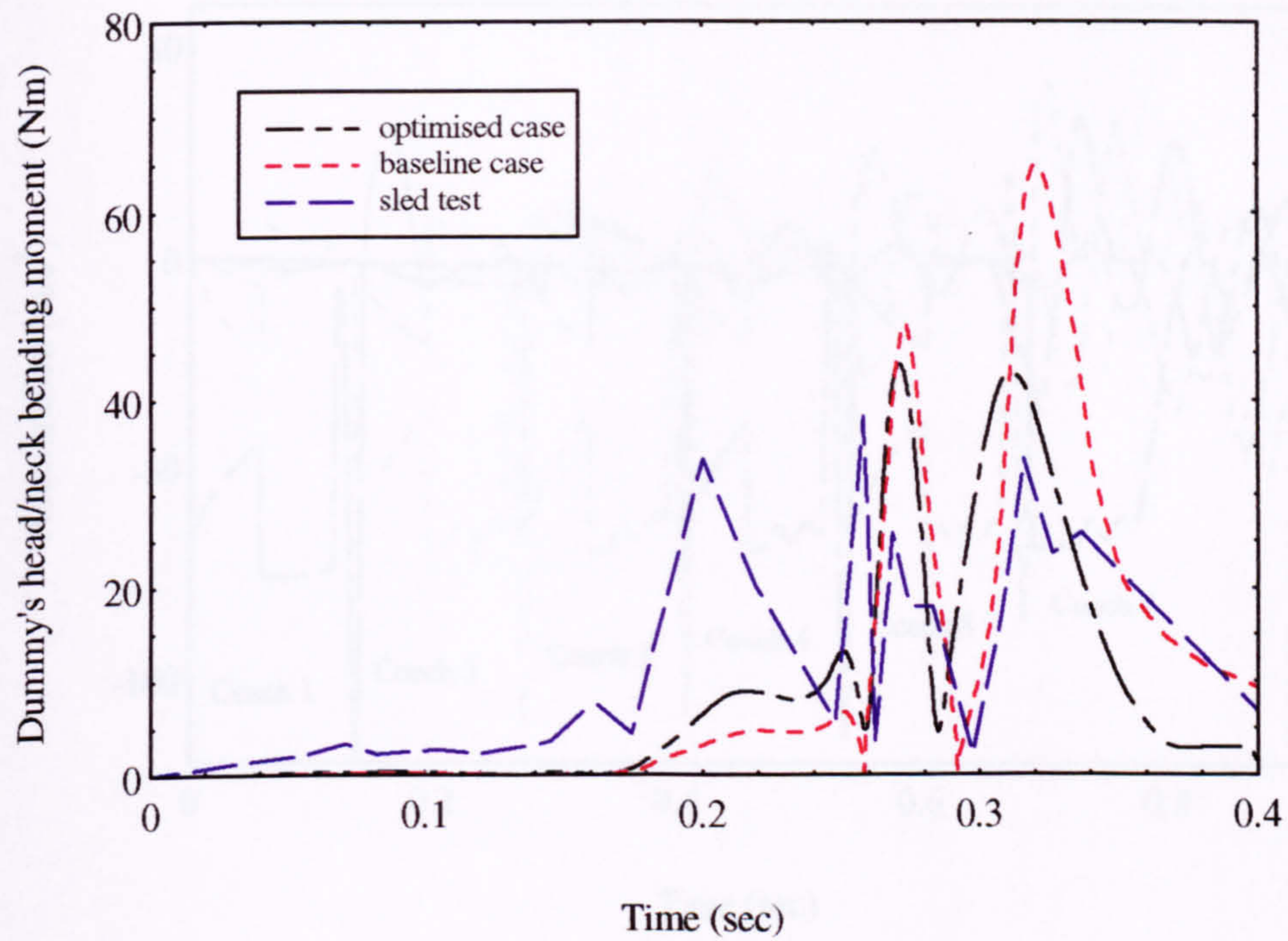


Figure 7.20 : The head/neck moment-time history of the baseline and optimised models.

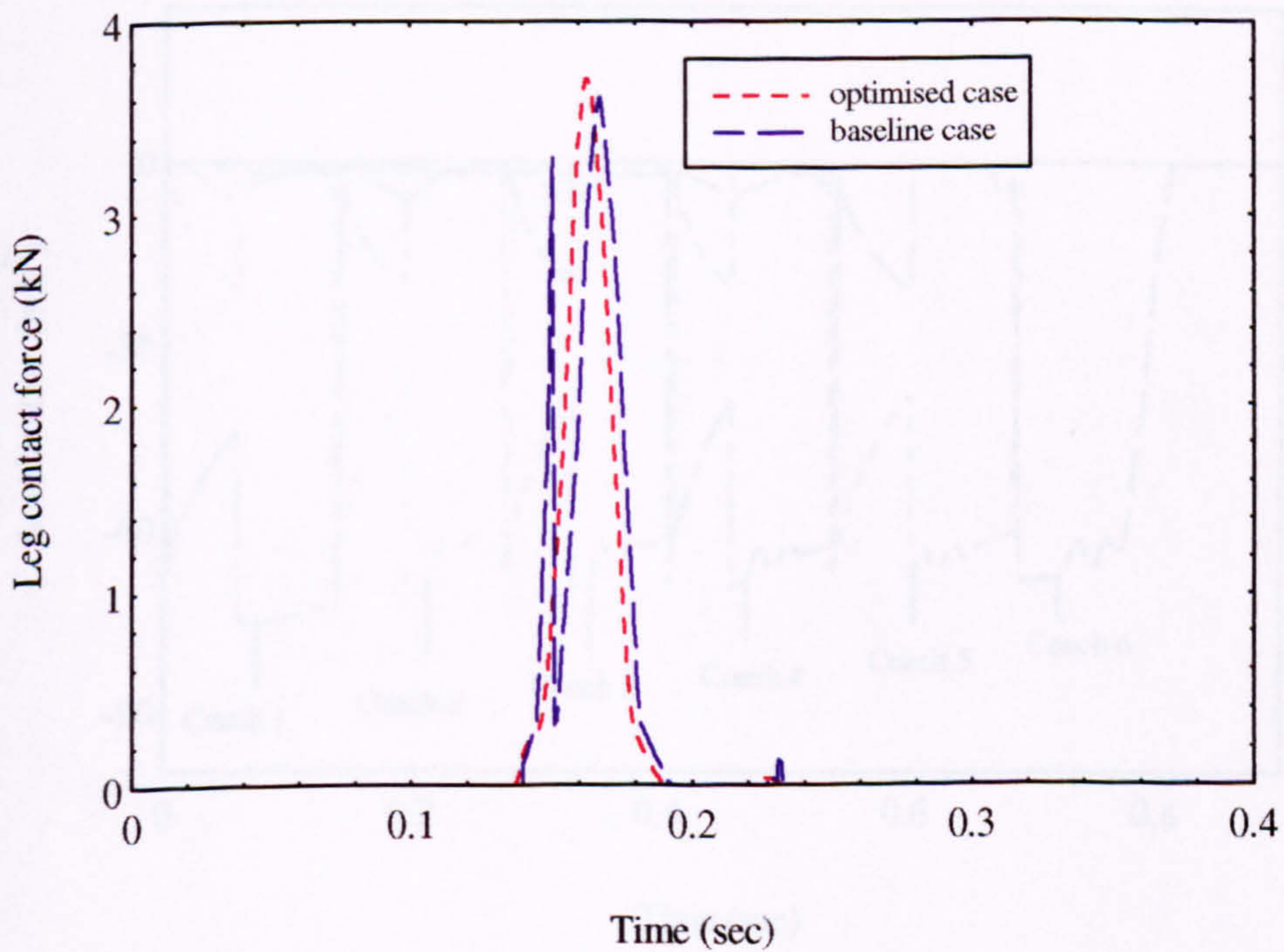


Figure 7.21 : The leg contact force-time history of the baseline and optimised models.

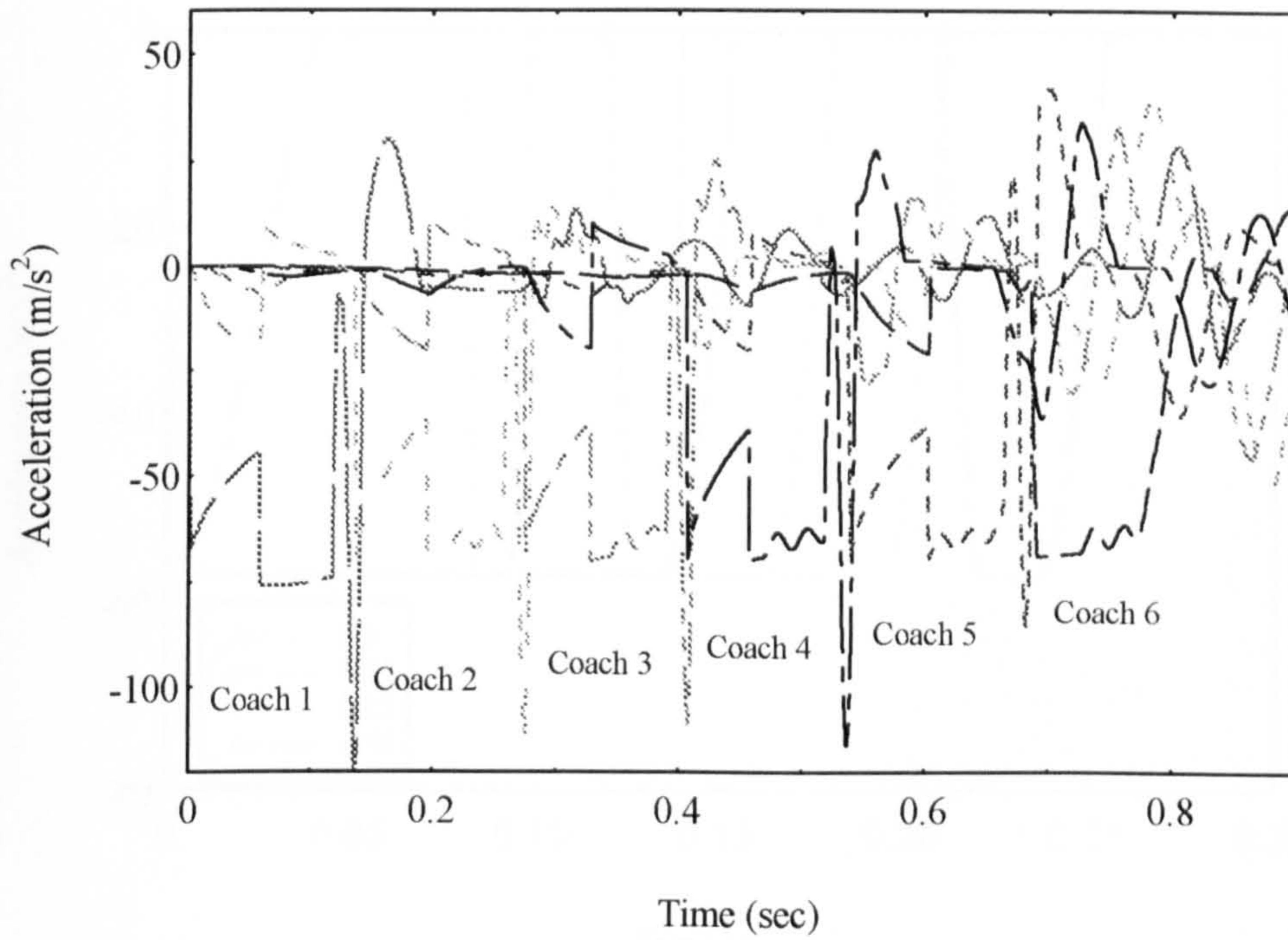


Figure 8.1 : The raw acceleration-time graphs for the coaches in mixn6 (Chapter 4).

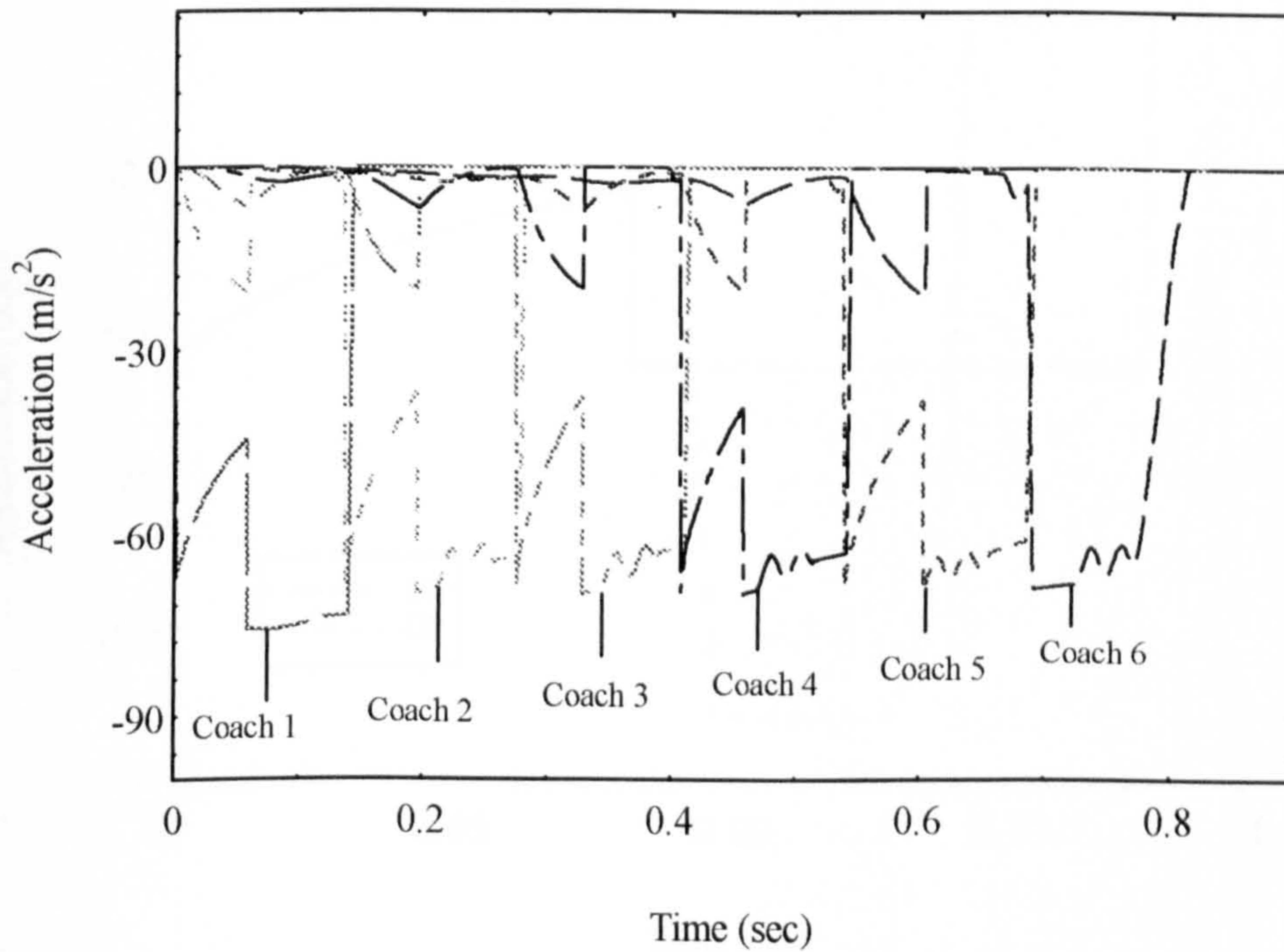


Figure 8.2 : The processed acceleration-time graphs.

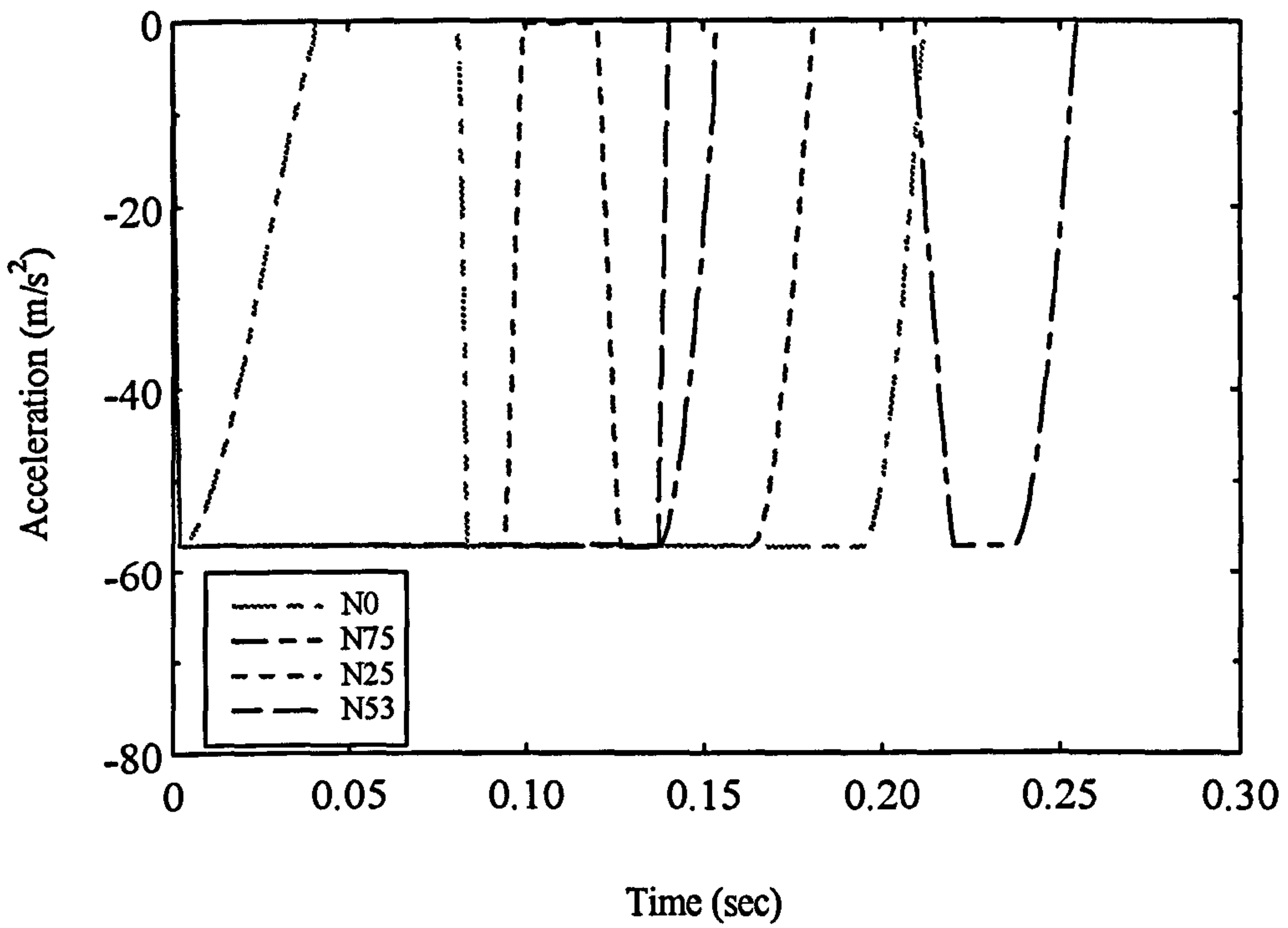


Figure 8.3 : The acceleration pulses in the N-series.

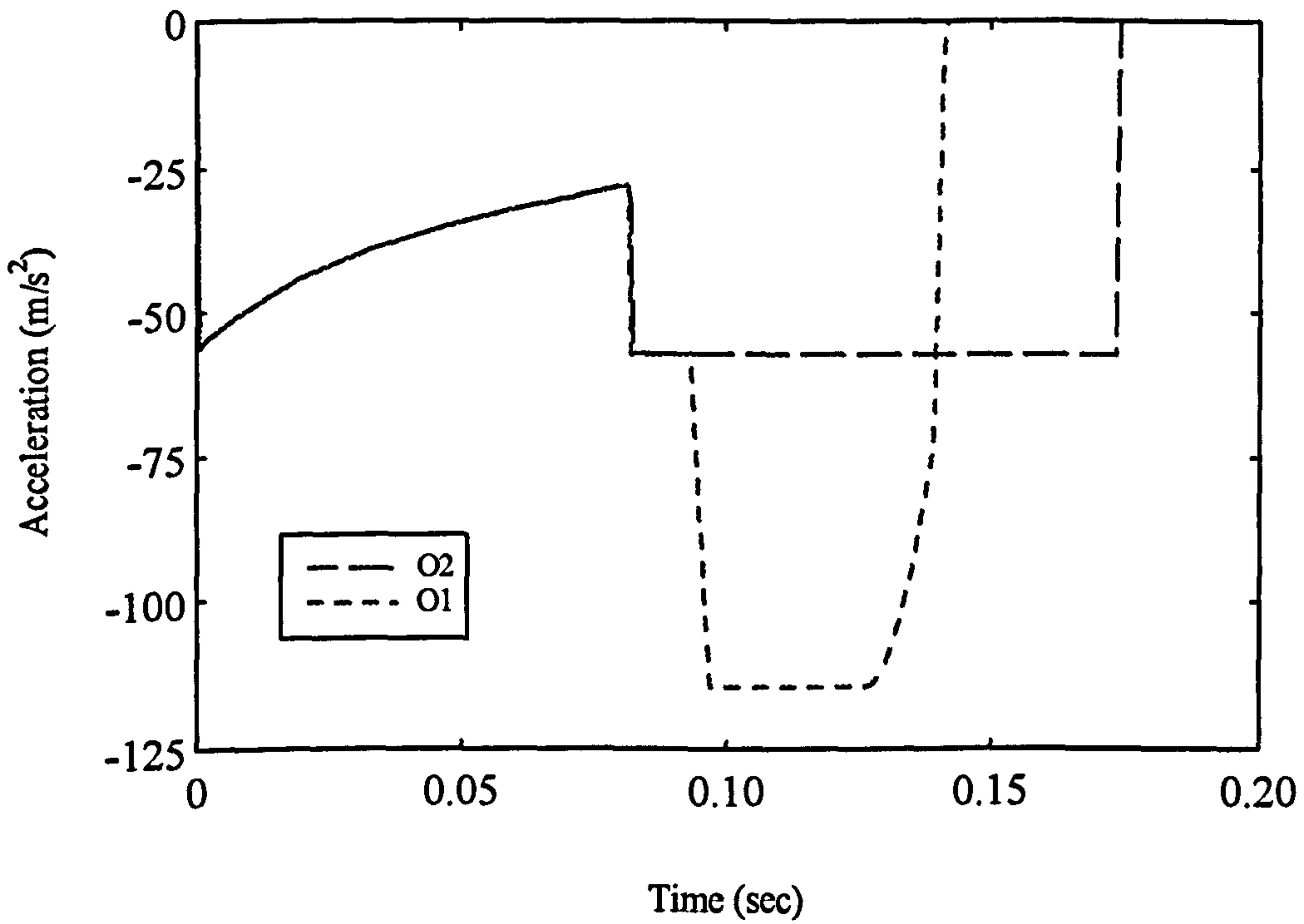


Figure 8.4 : The acceleration pulses in the O-series

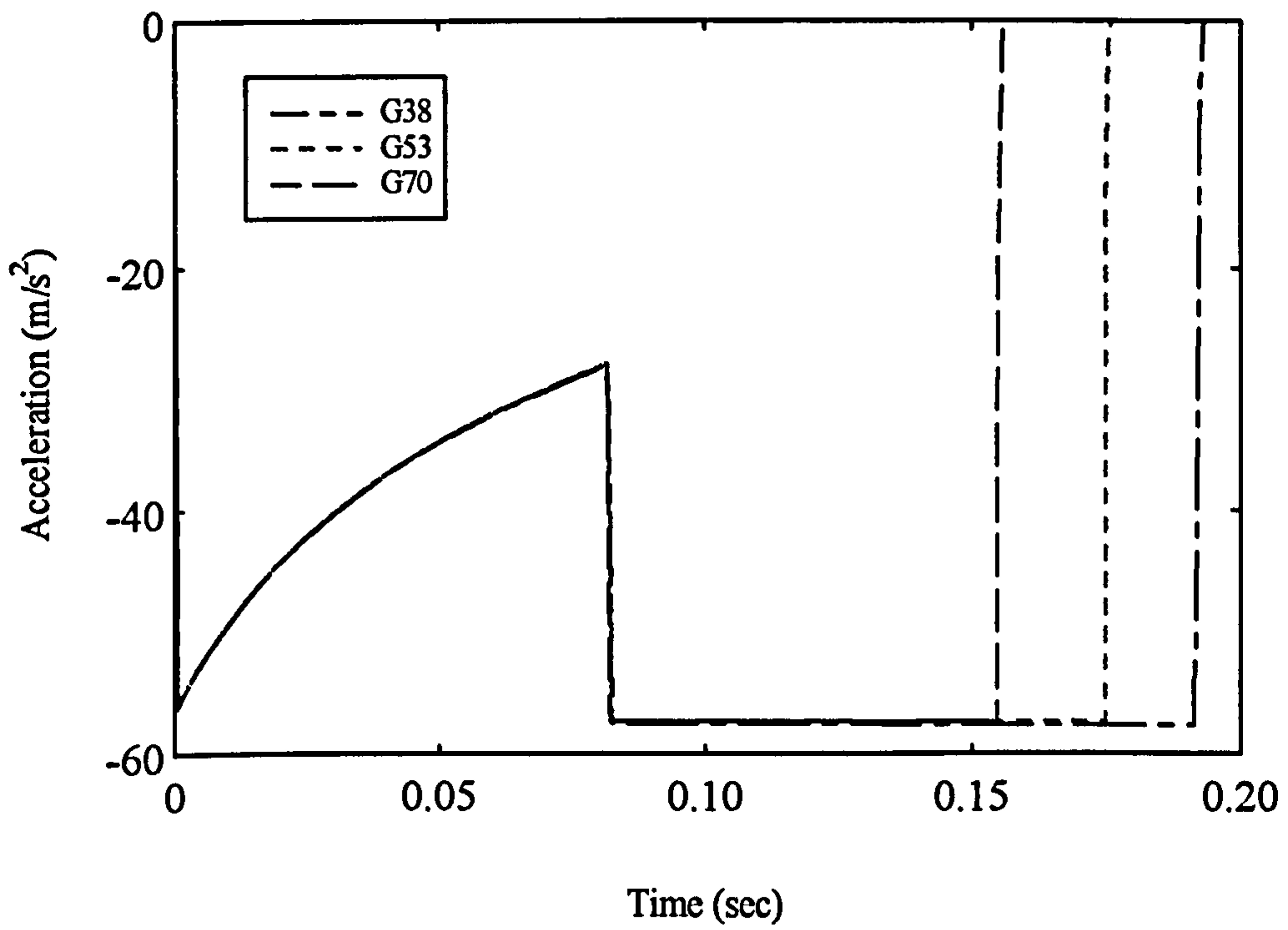


Figure 8.5 : The acceleration pulses in the G-series

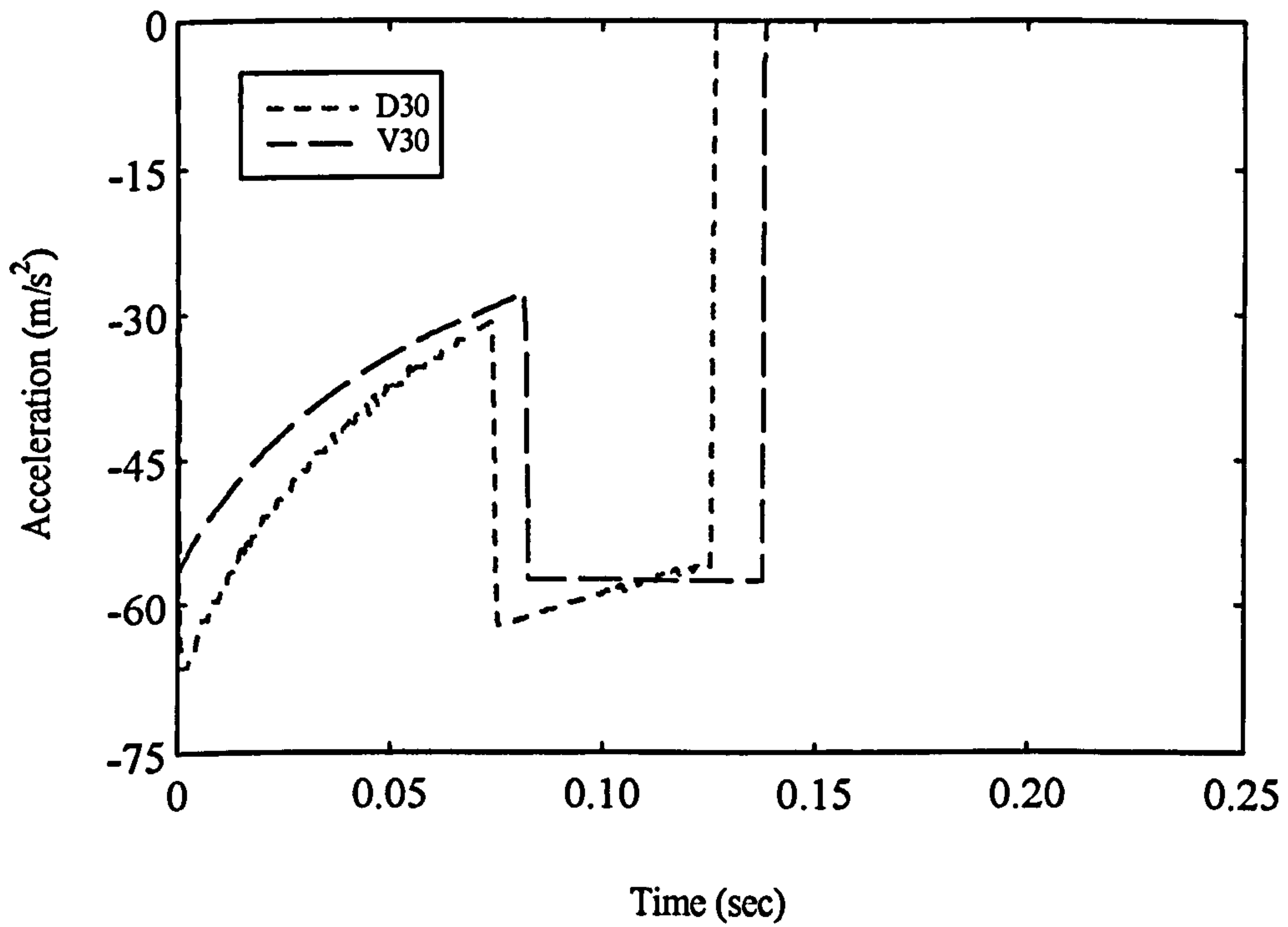


Figure 8.6a : The acceleration pulses in the D-series

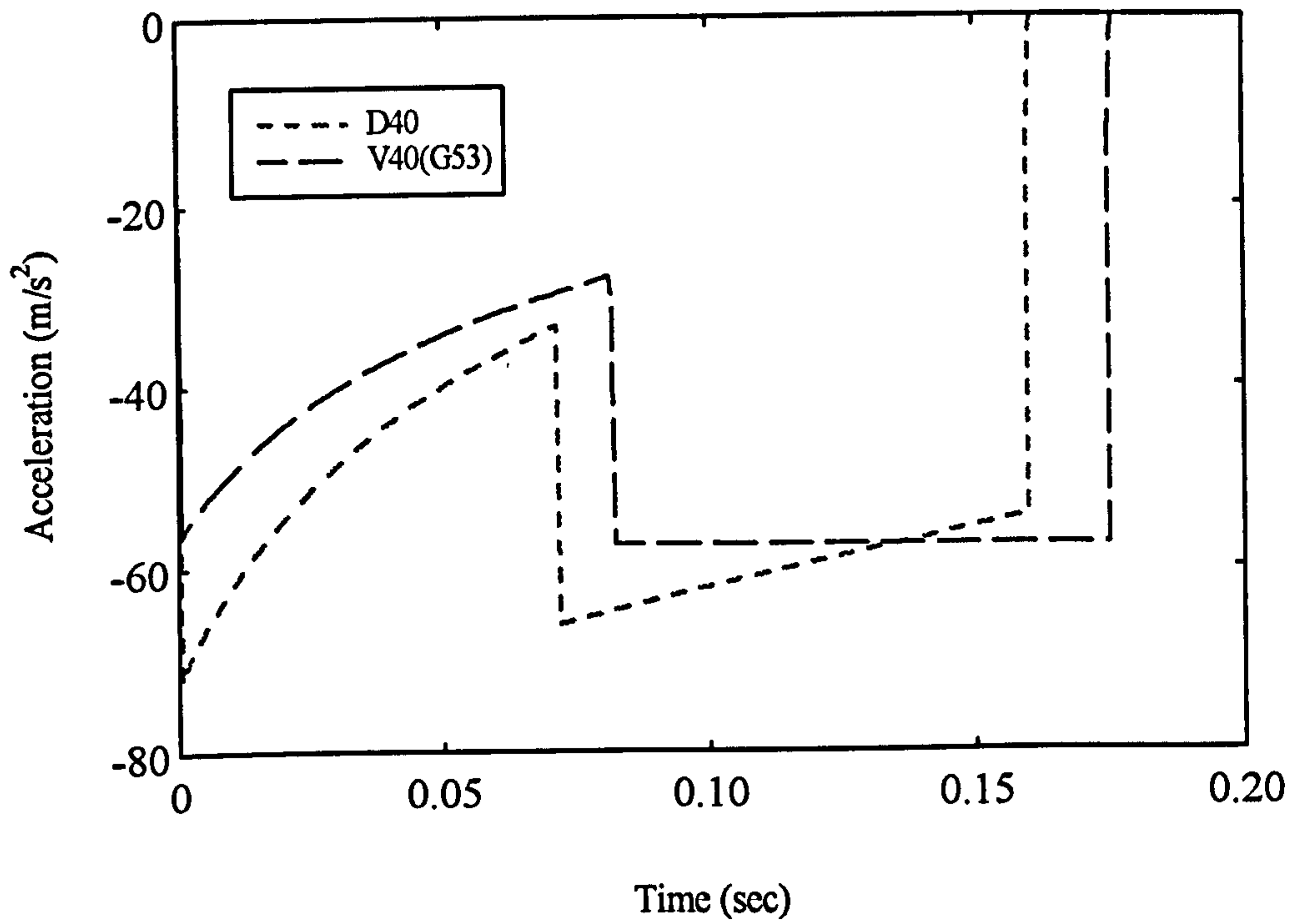


Figure 8.6b : The acceleration pulses in the D-series

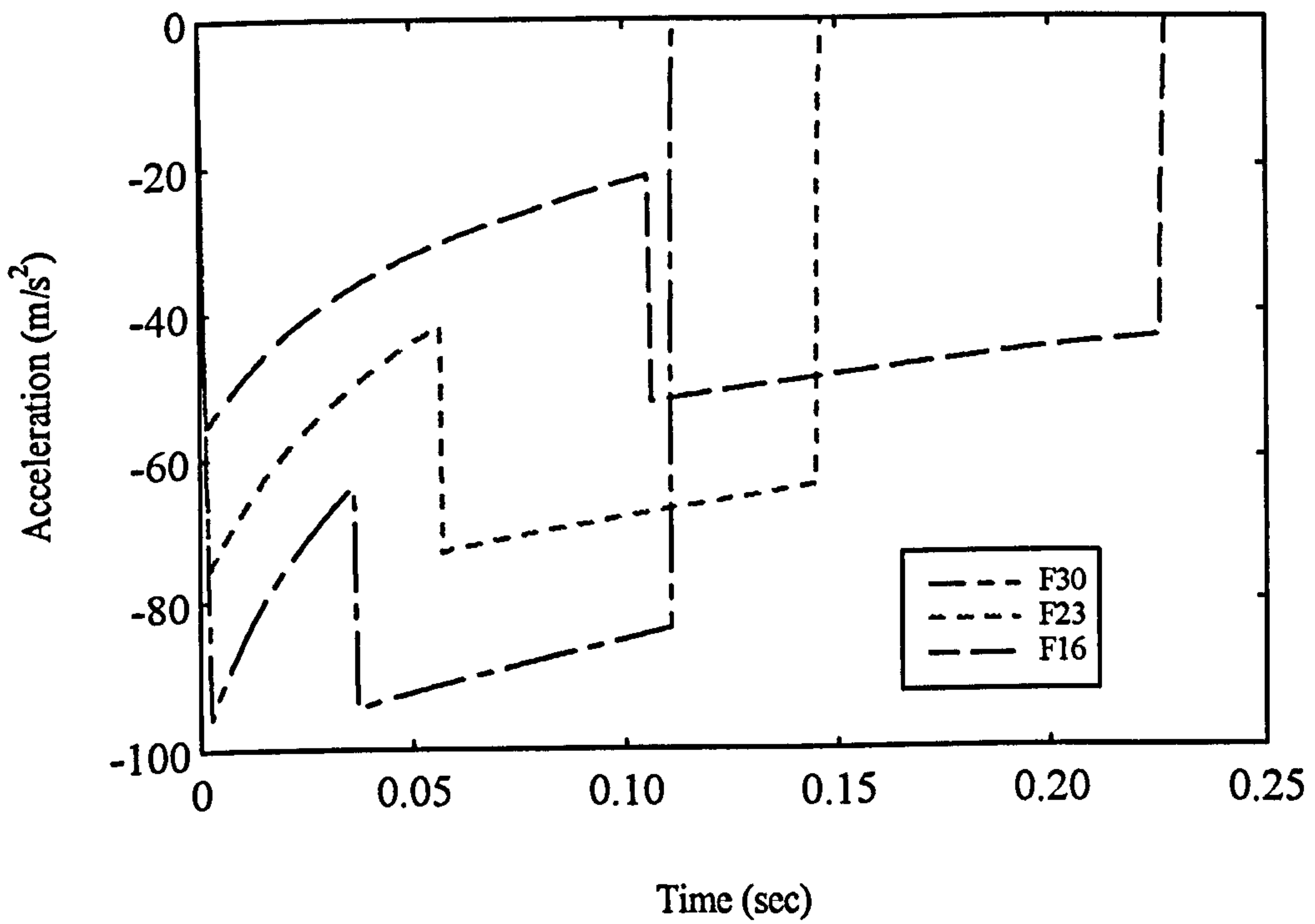


Figure 8.7 : The acceleration pulses in the F-series

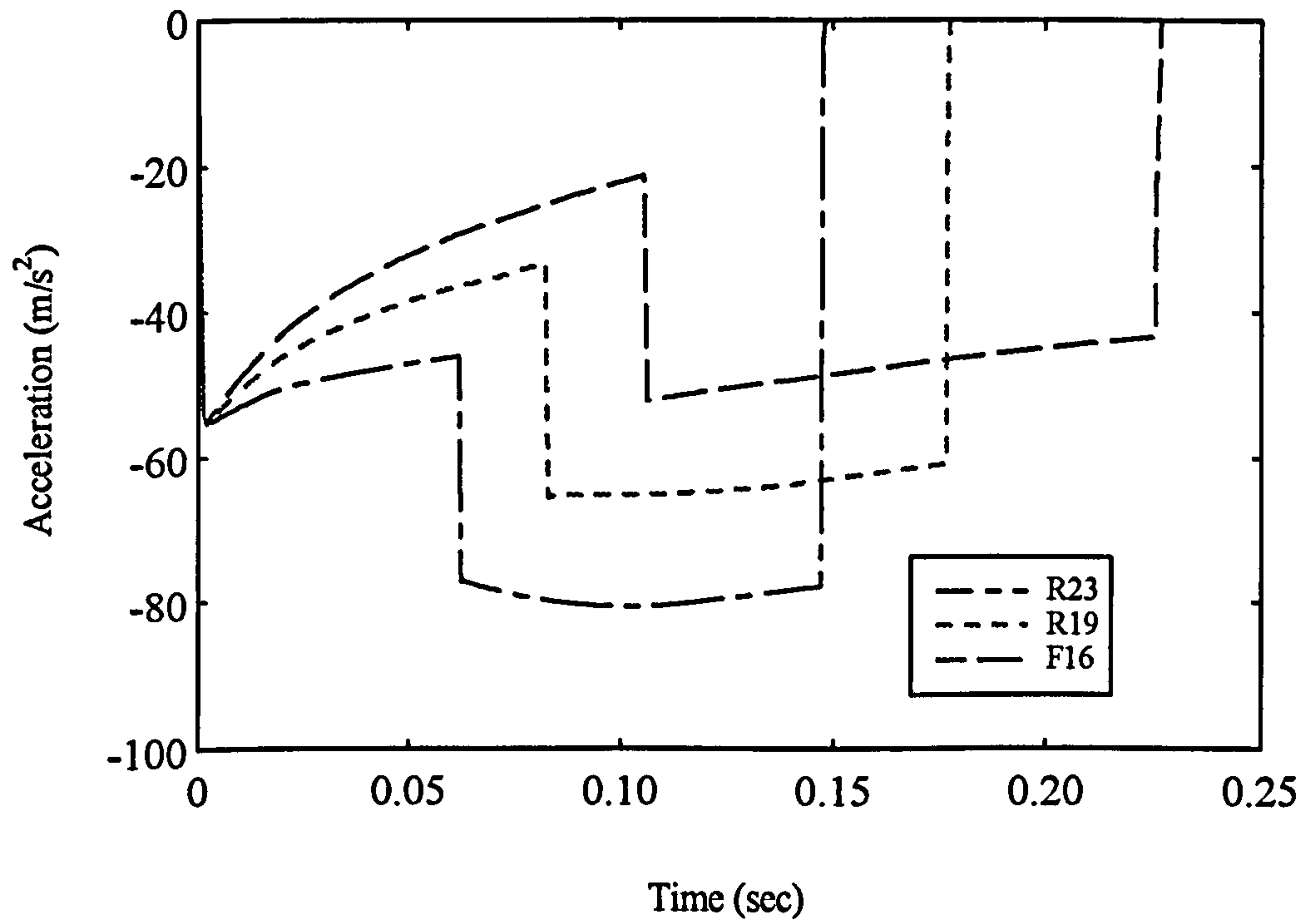


Figure 8.8 : The acceleration pulses in the R-series

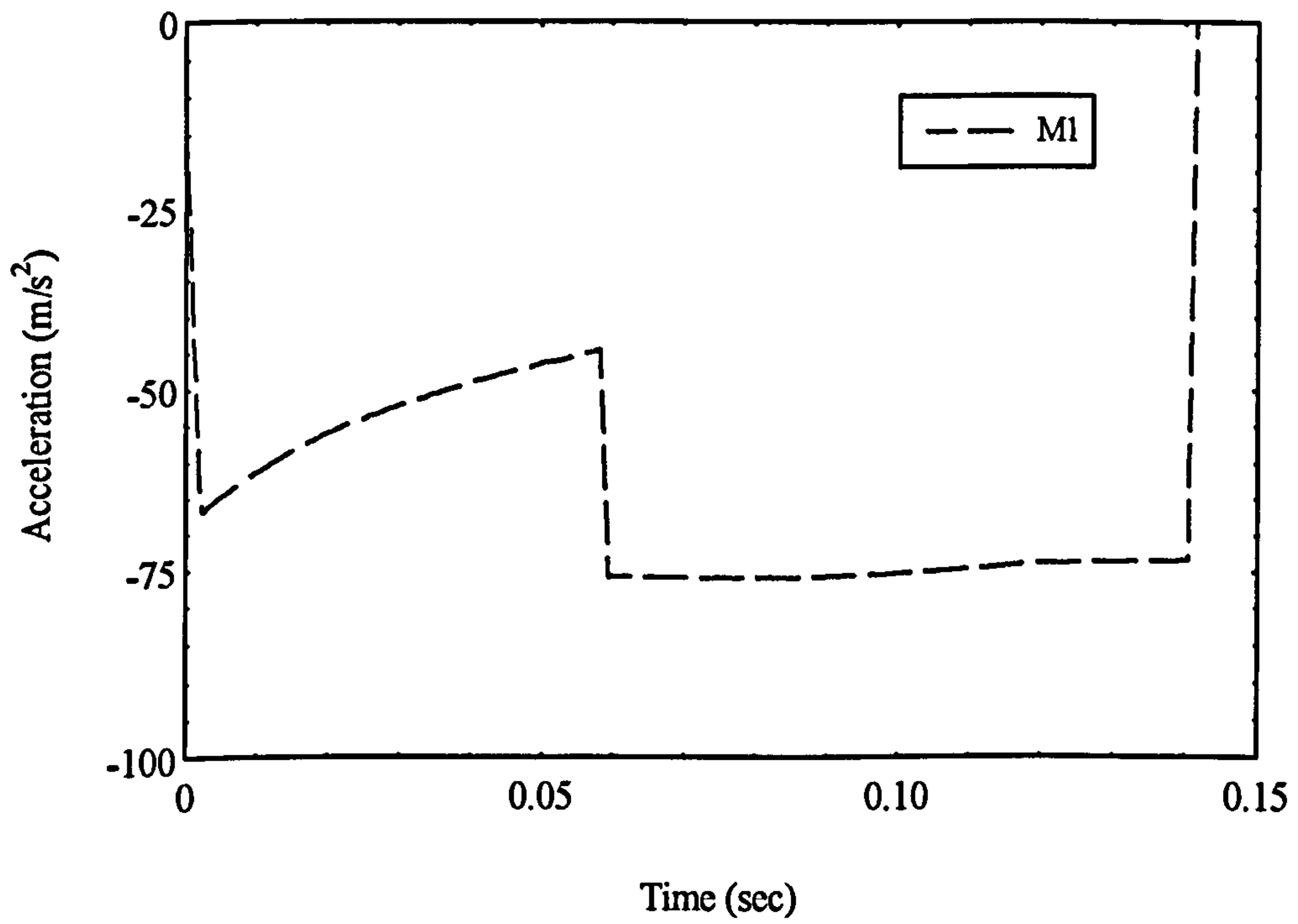


Figure 8.9 : The M1 pulse

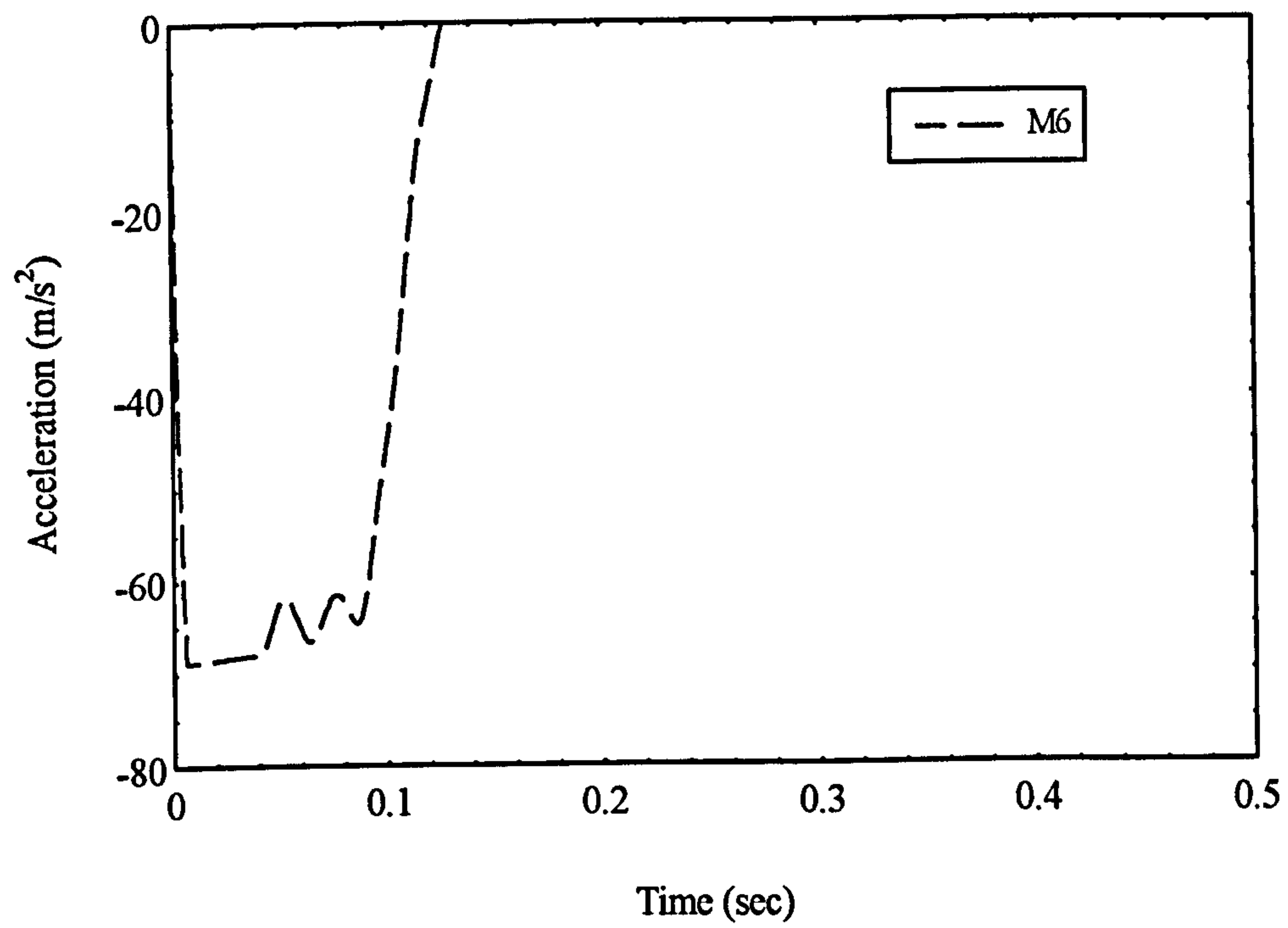


Figure 8.10 : The M6 pulse

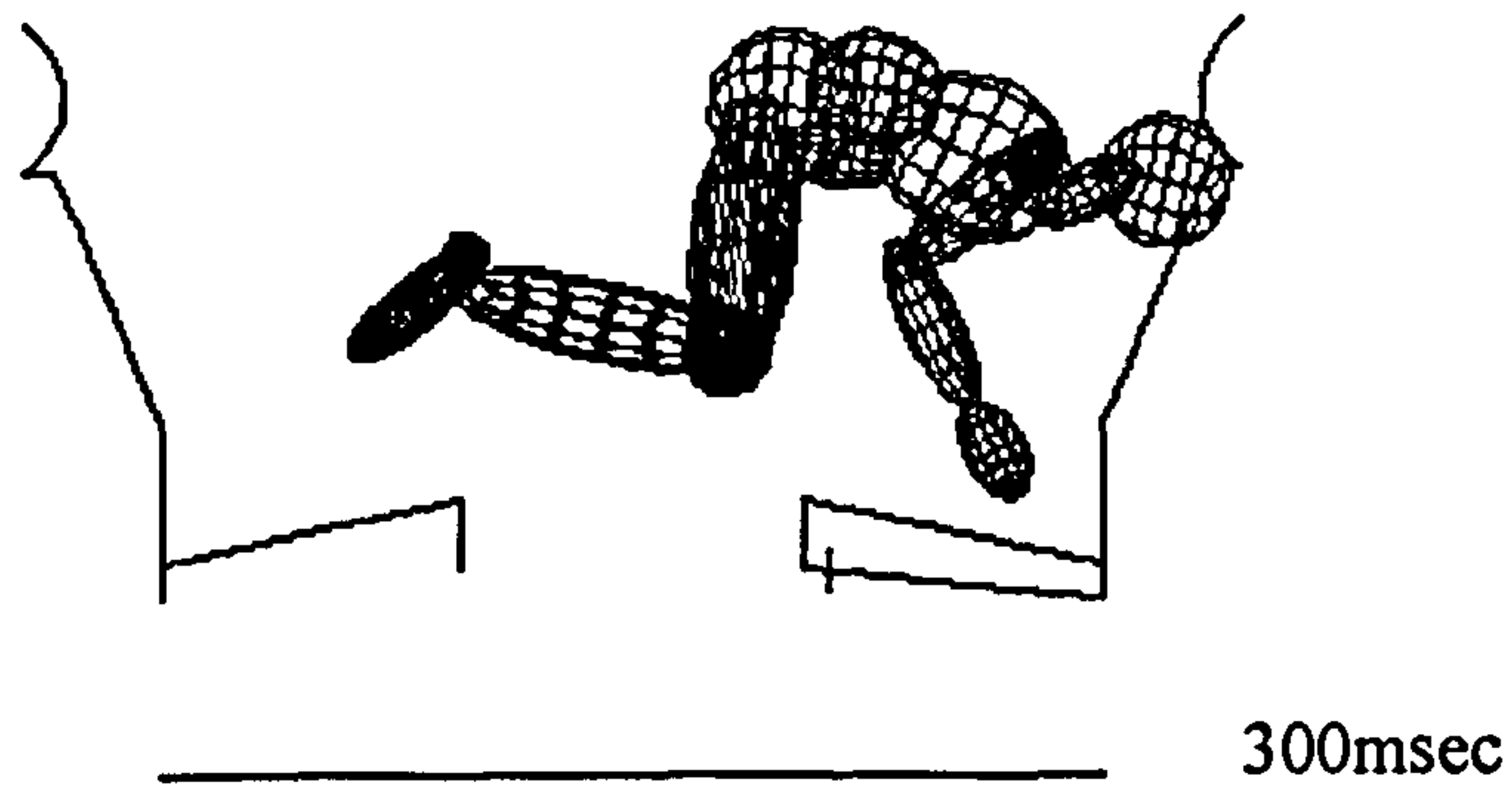
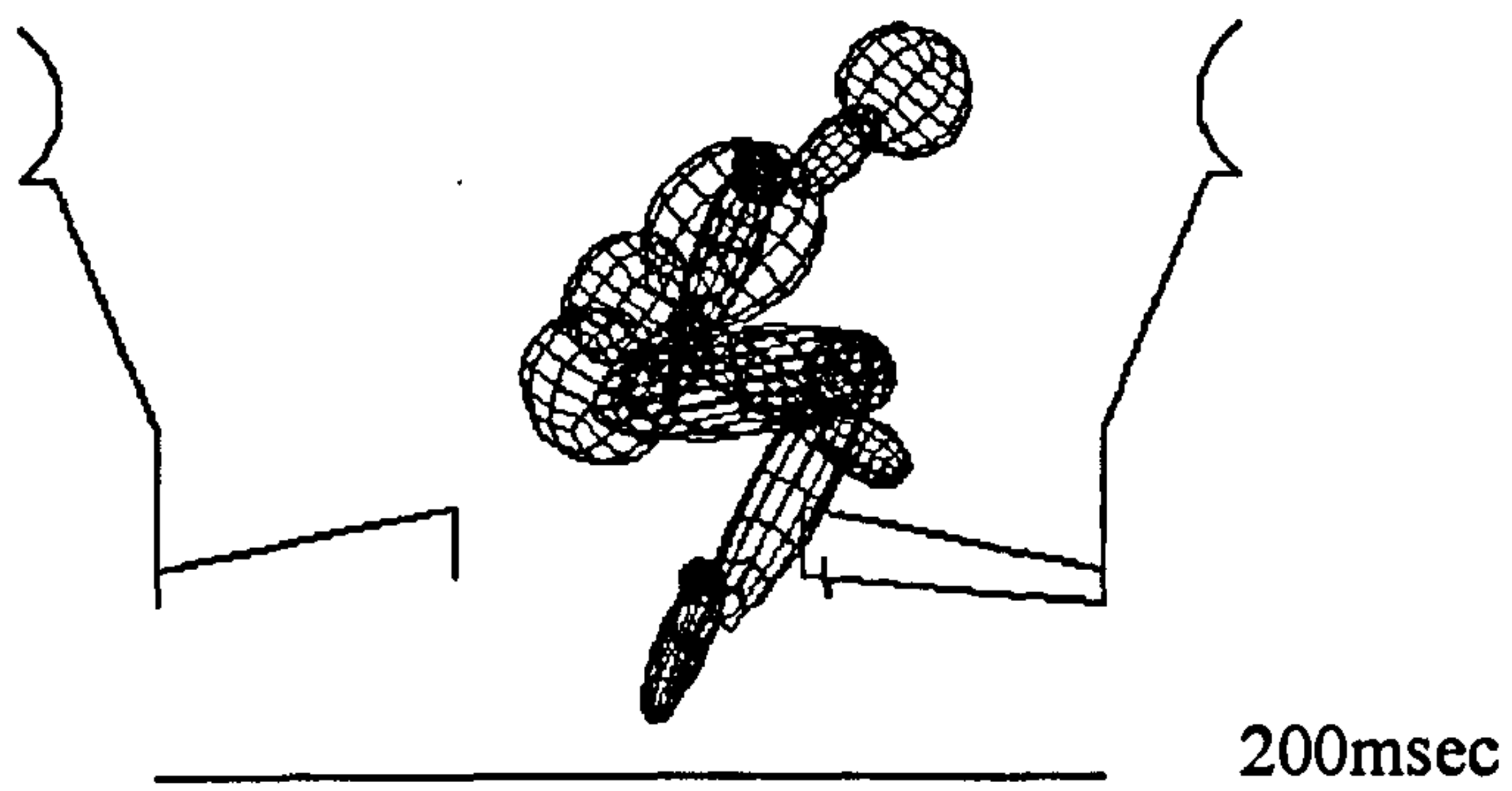
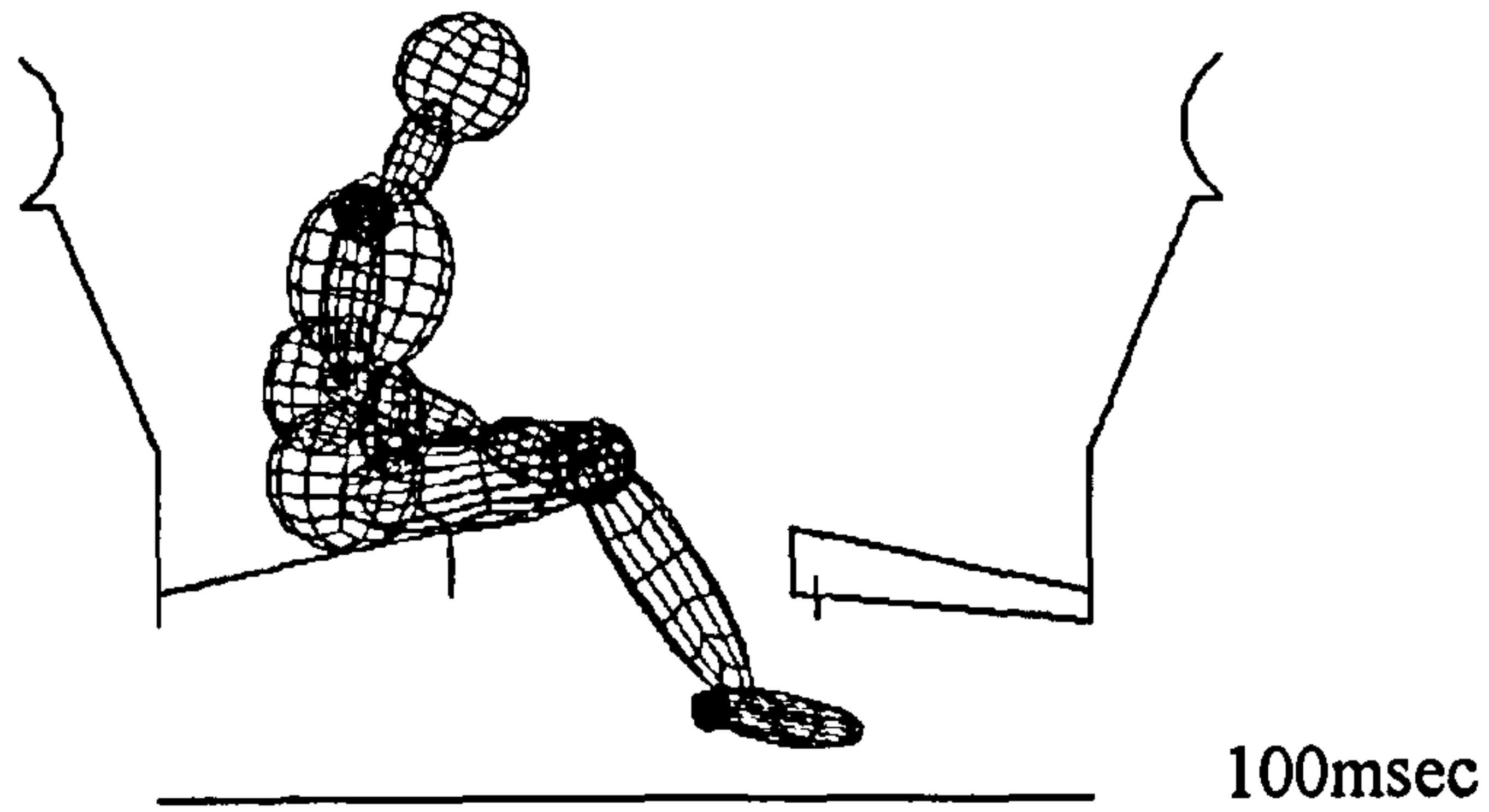
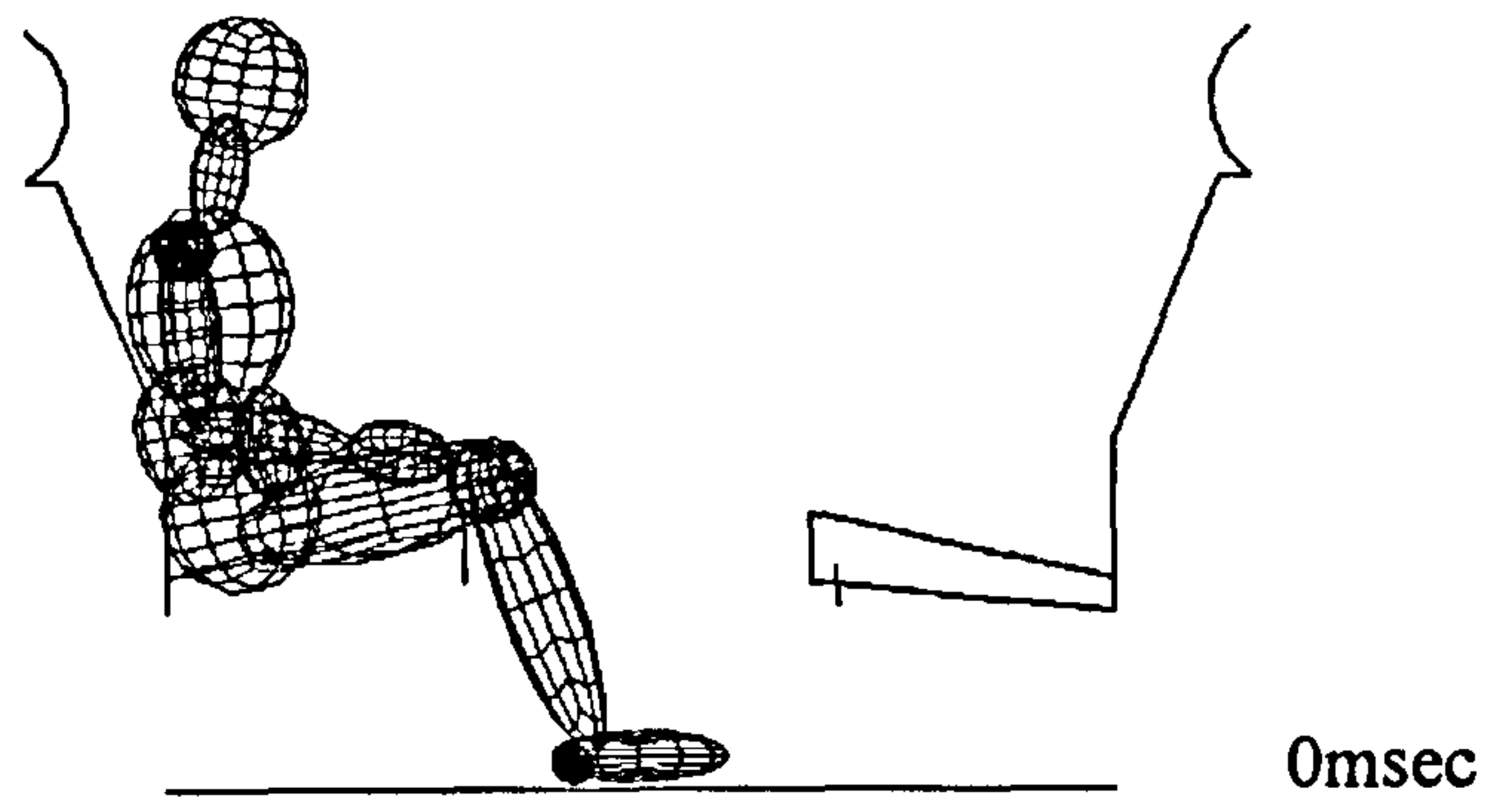


Figure 8.11 : The sequence of animated response in N53.

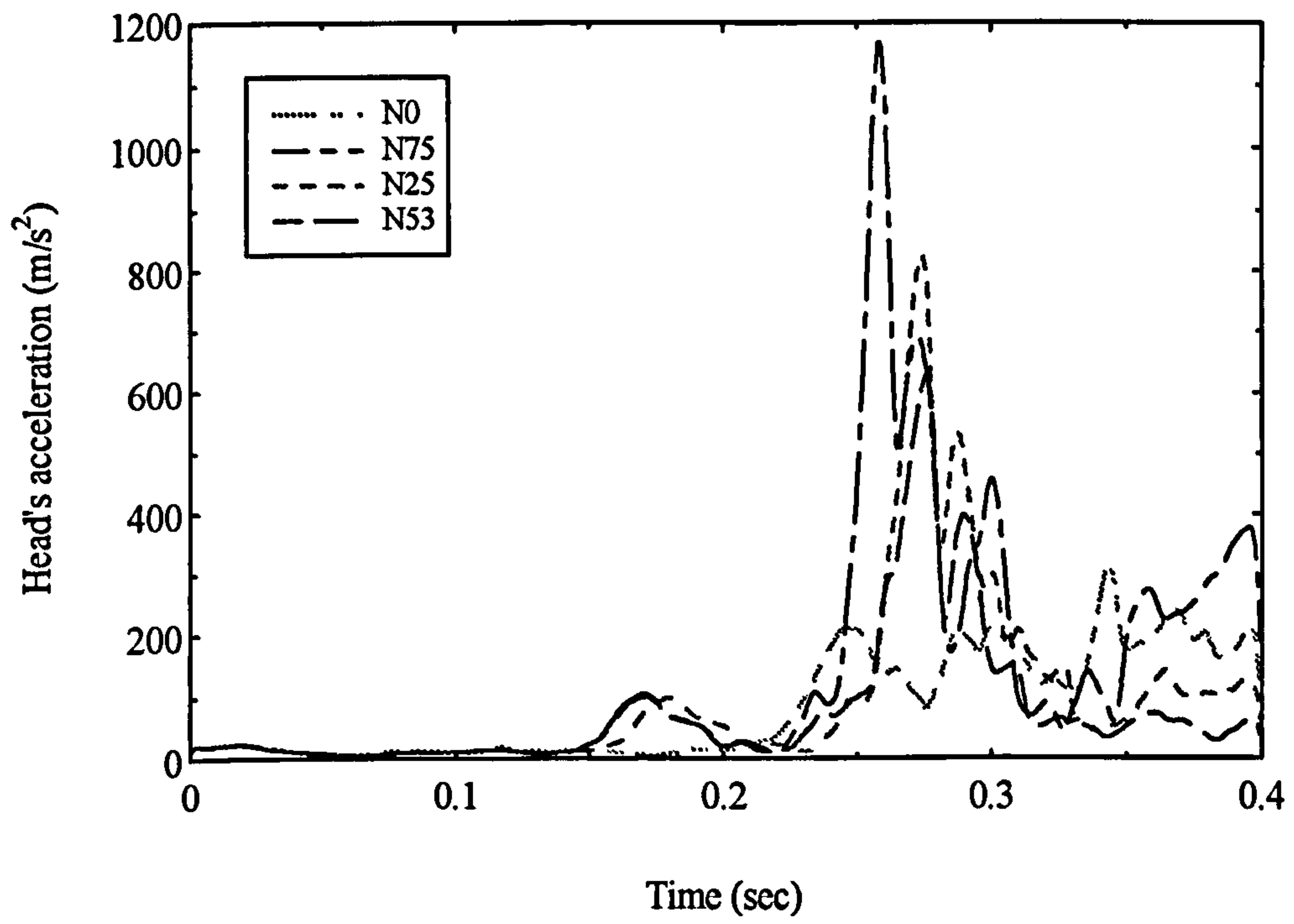


Figure 8.12 : Head acceleration-time history for models in the N-series.

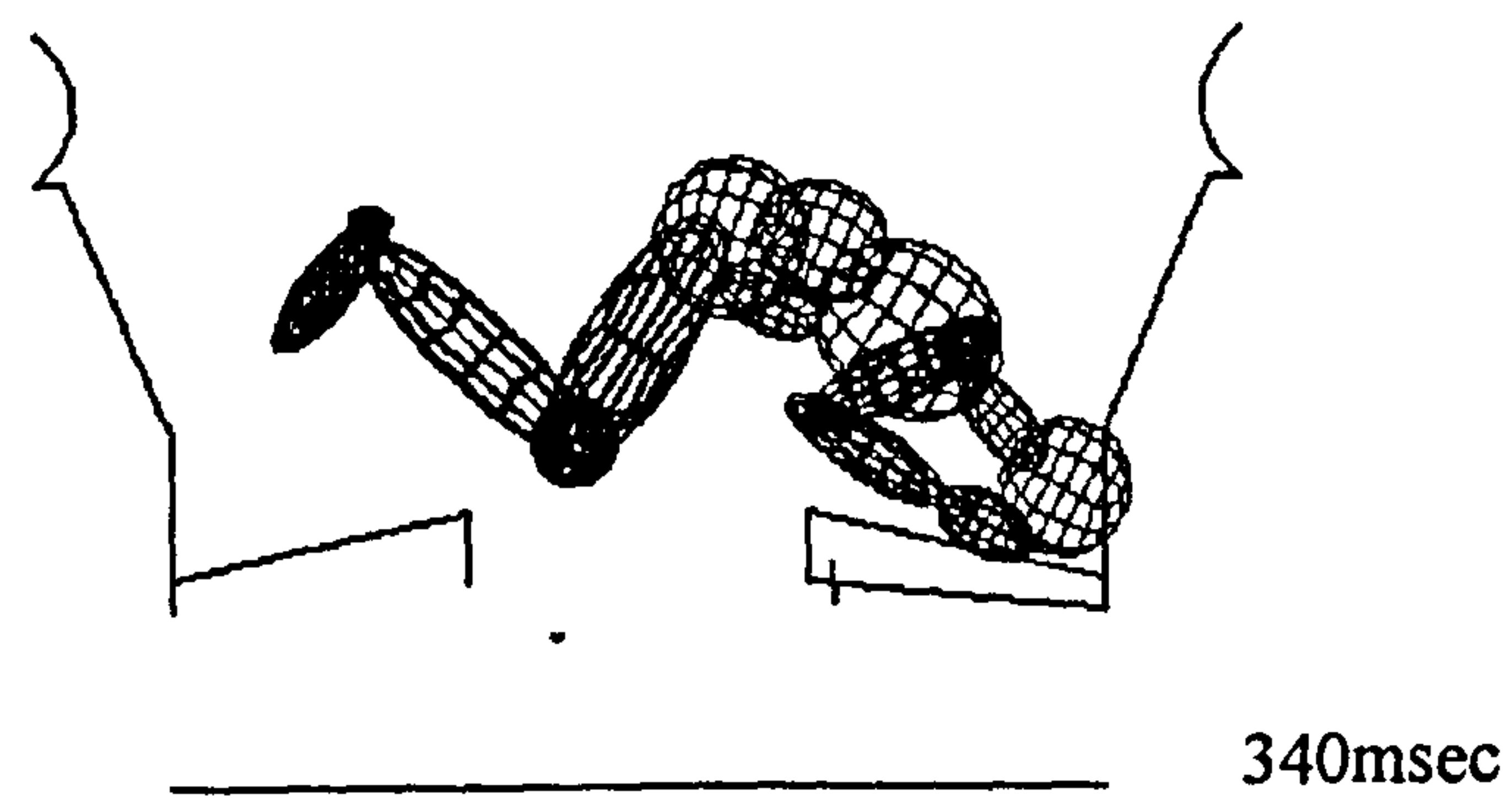
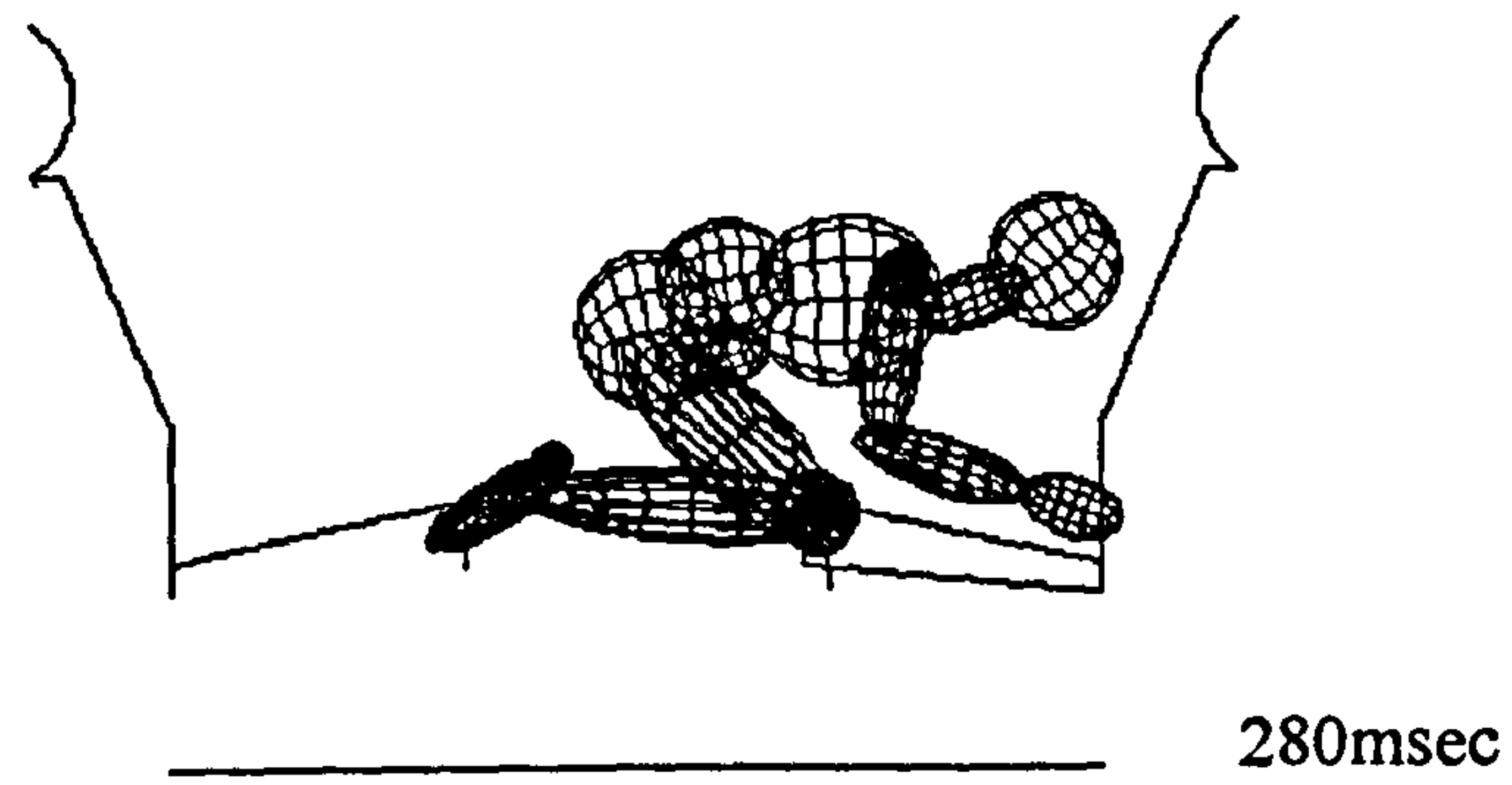
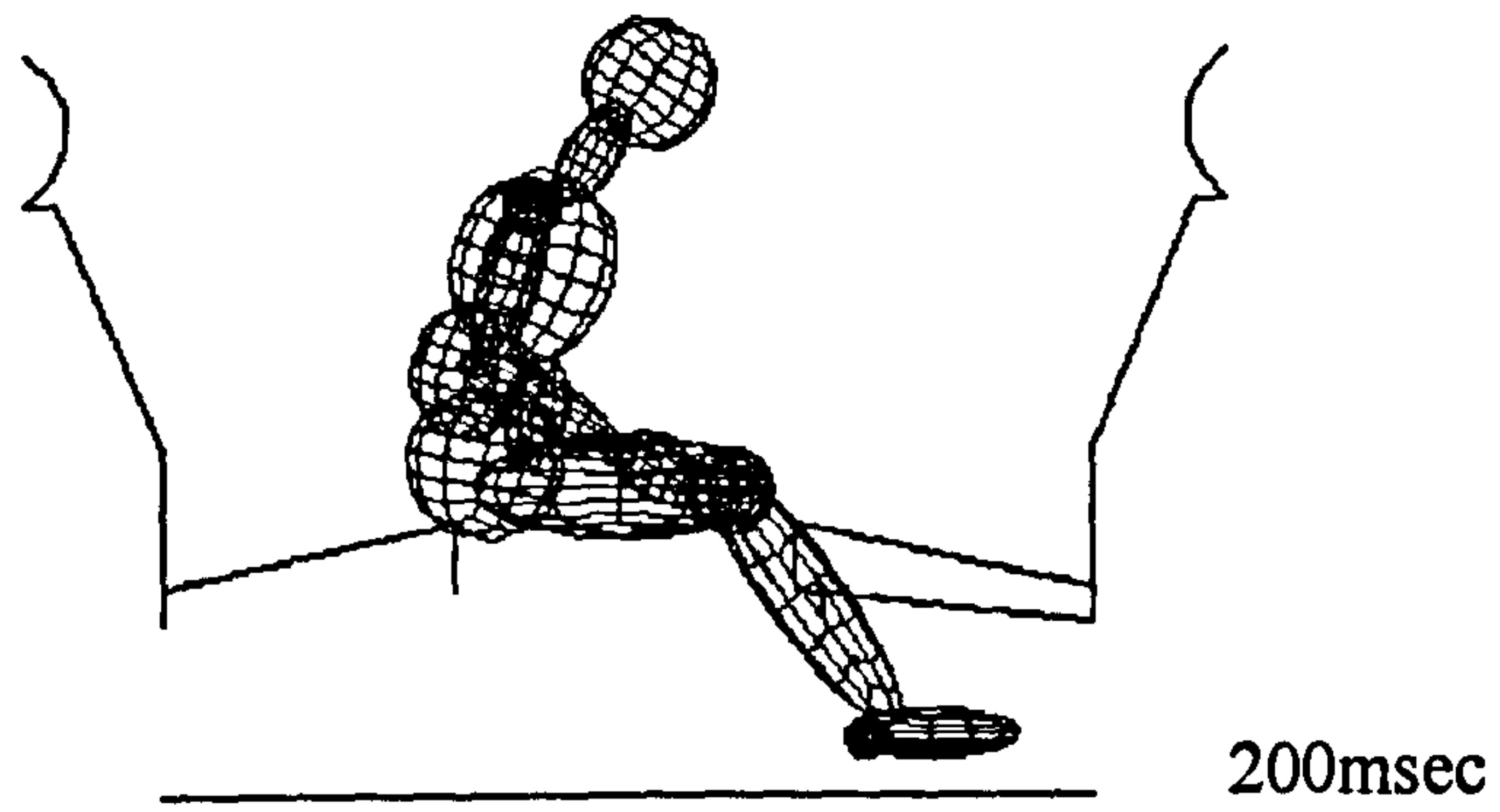
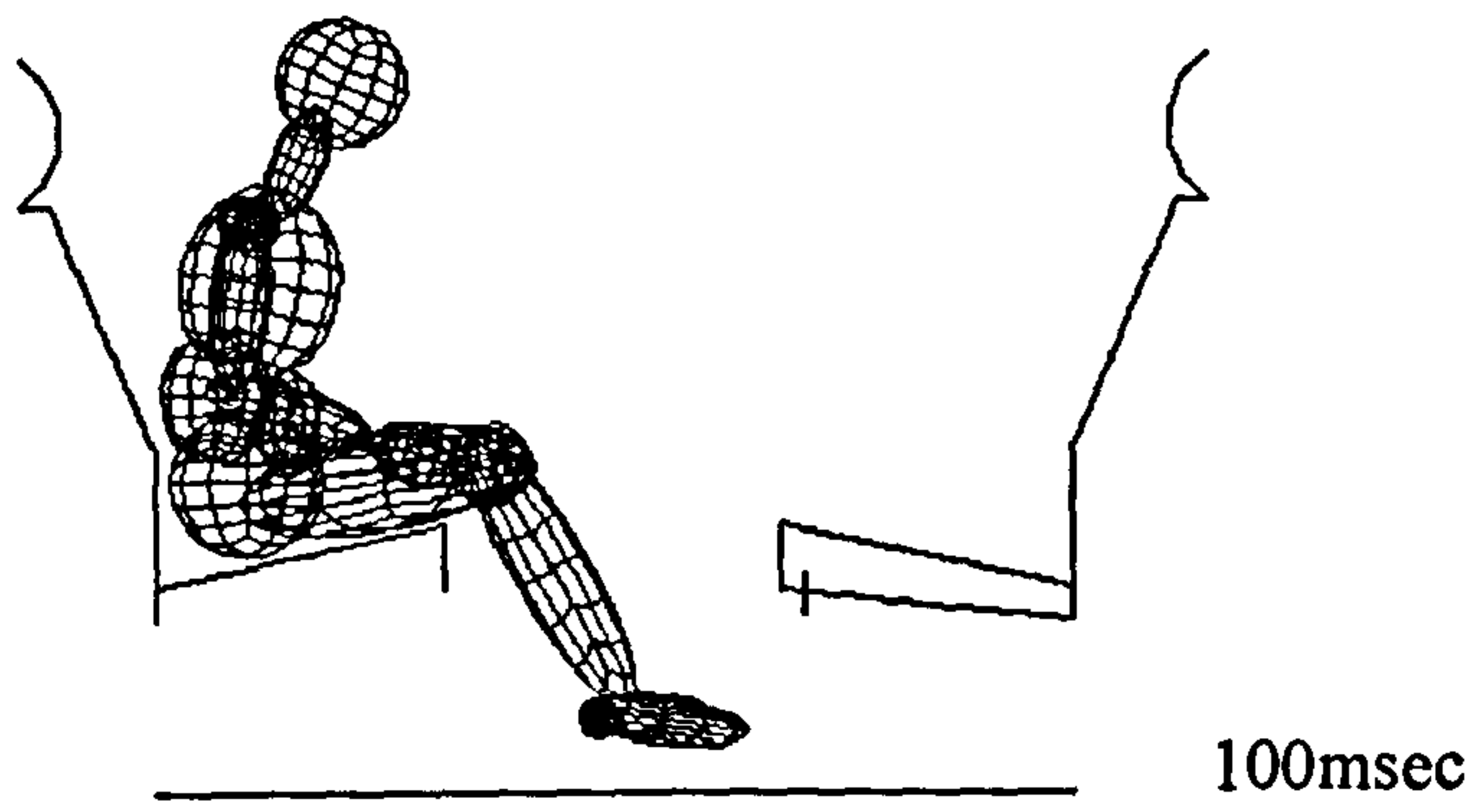


Figure 8.13 : The sequence of animated response in N0.

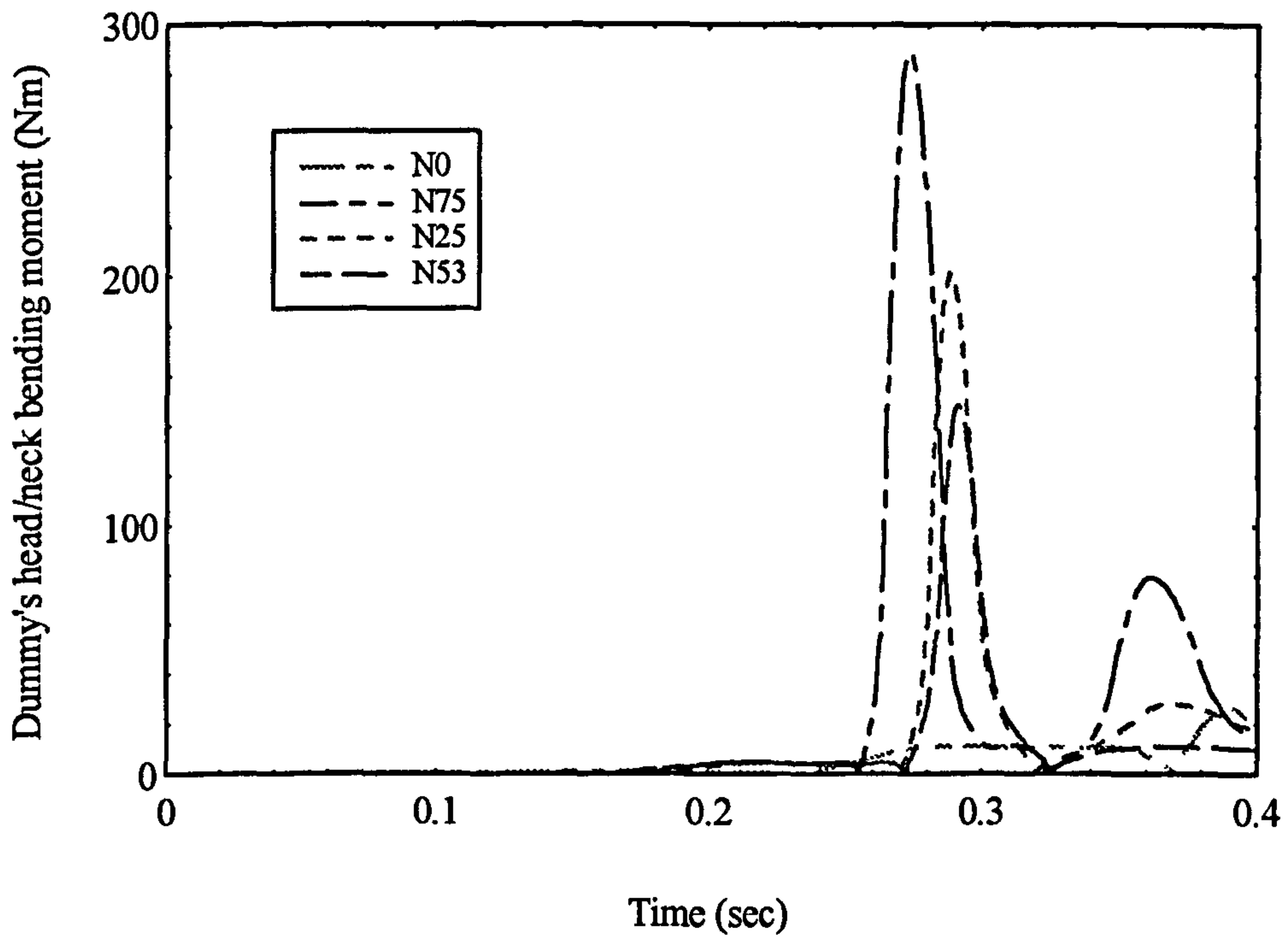


Figure 8.14 : Head/neck bending moment-time history for models in the N-series.

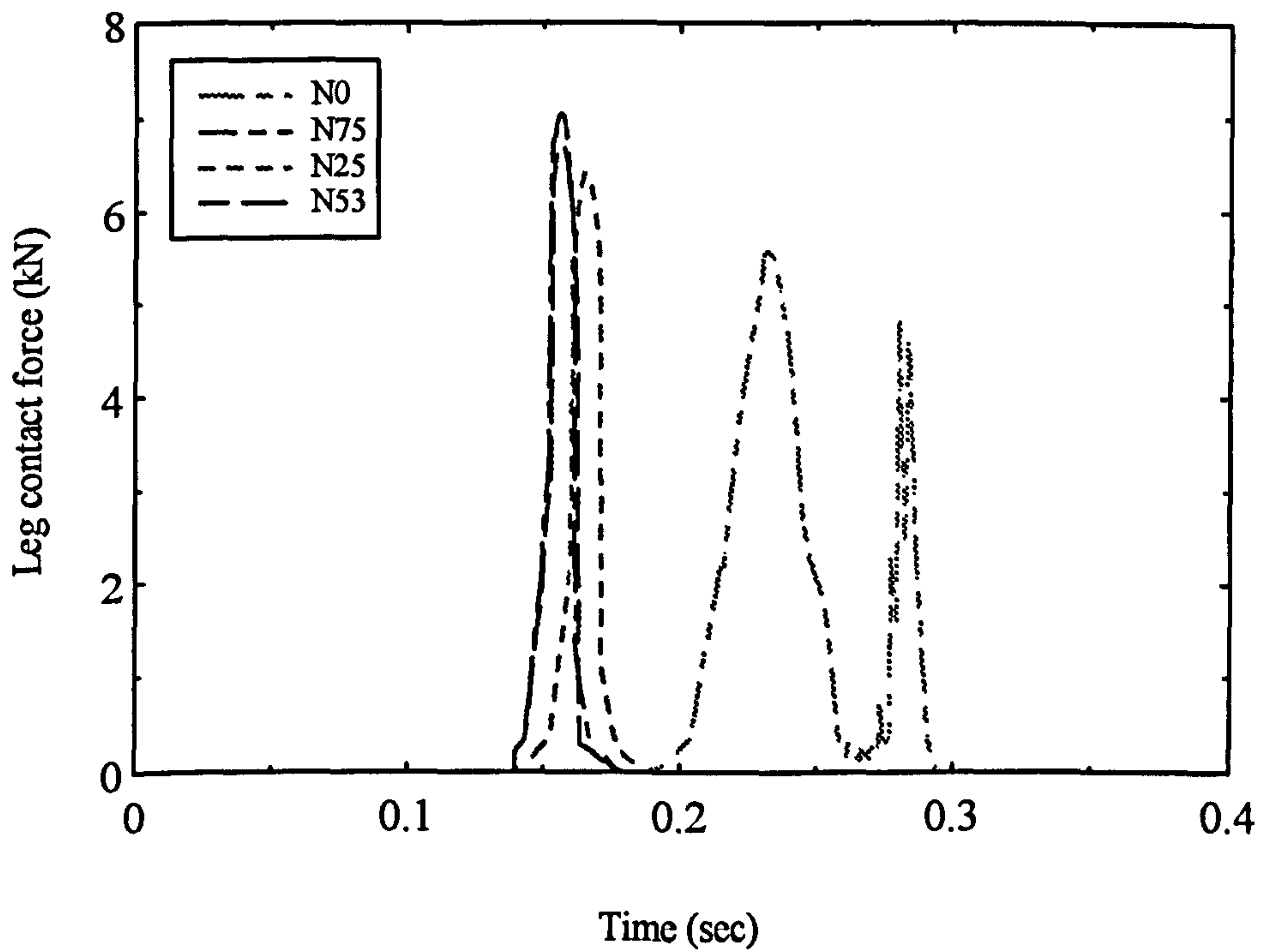


Figure 8.15 : Leg contact force-time history for models in the N-series.

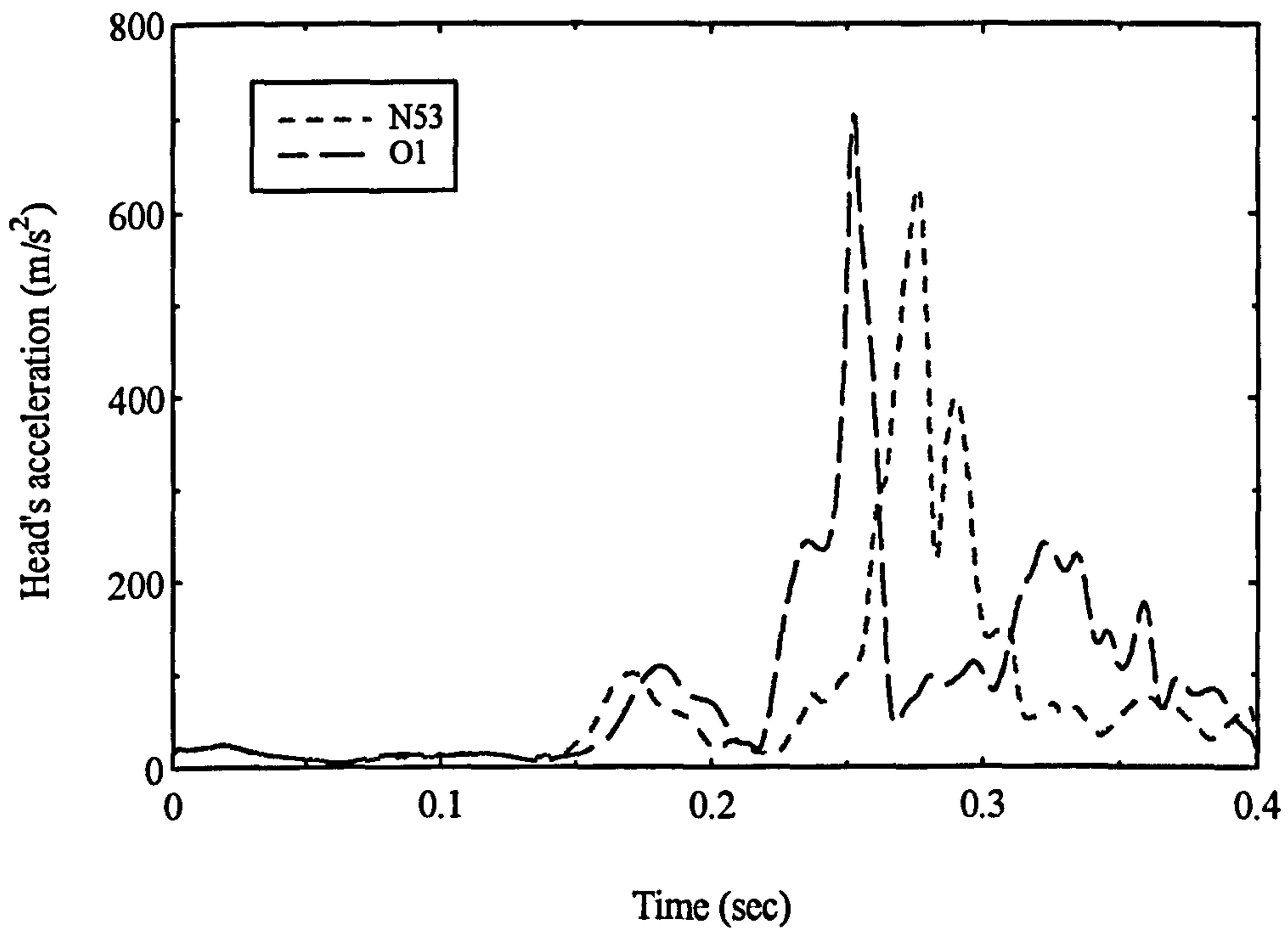


Figure 8.16 : Head acceleration-time history for models in the O-series.

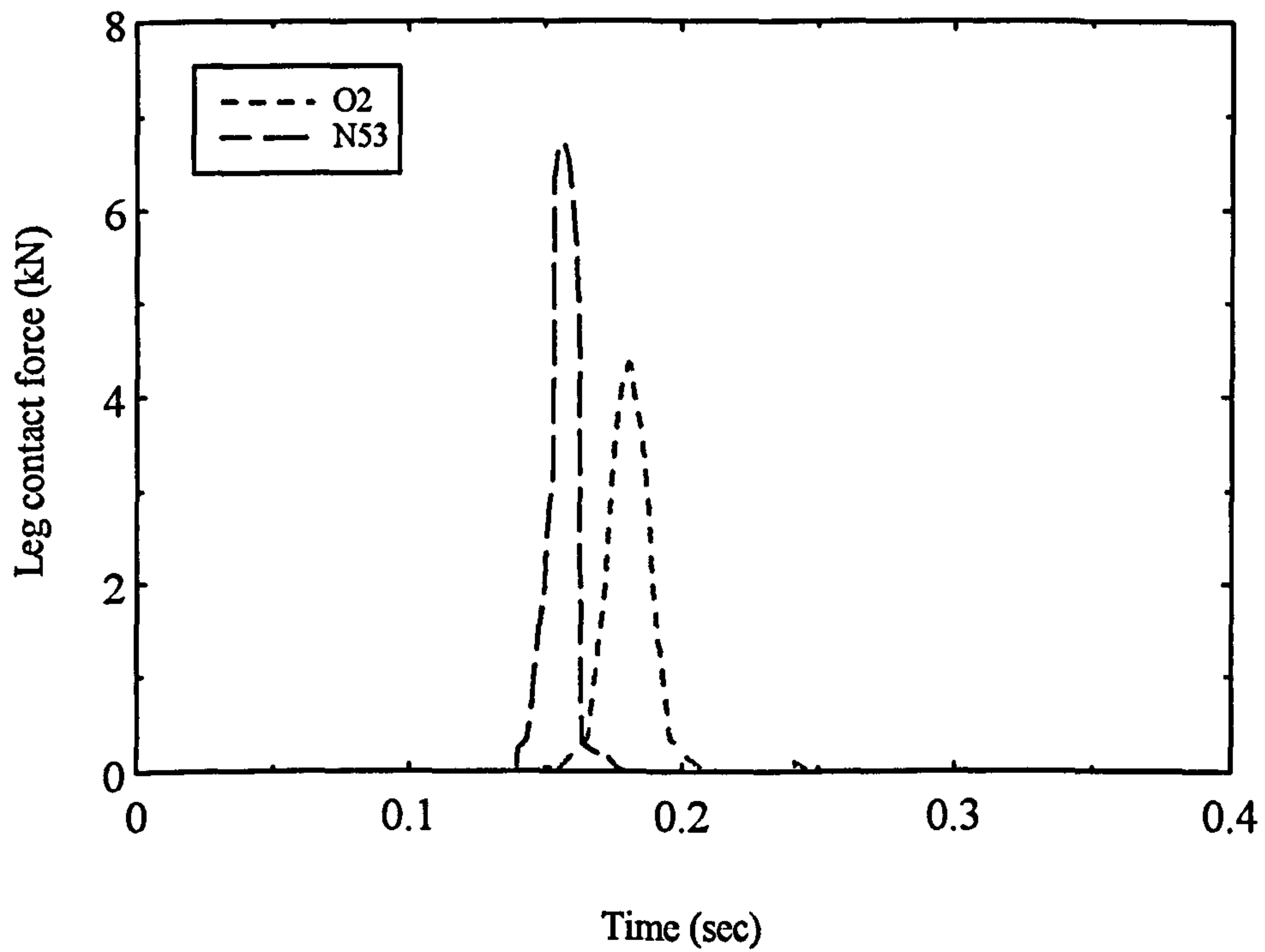


Figure 8.17 : Leg contact force-time history for models in the O-series.

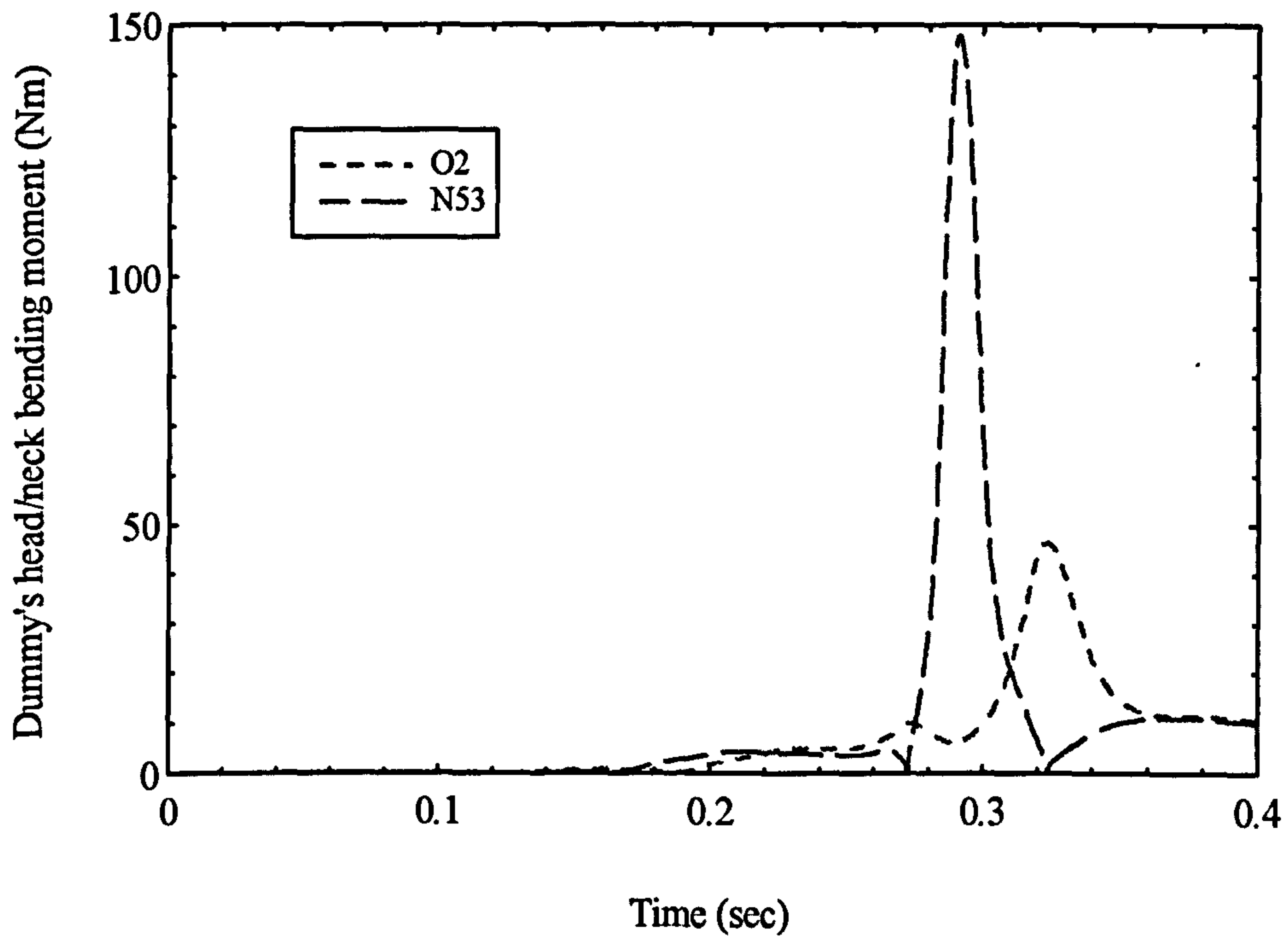


Figure 8.18 : Head/neck bending moment-time history for models in the O-series.

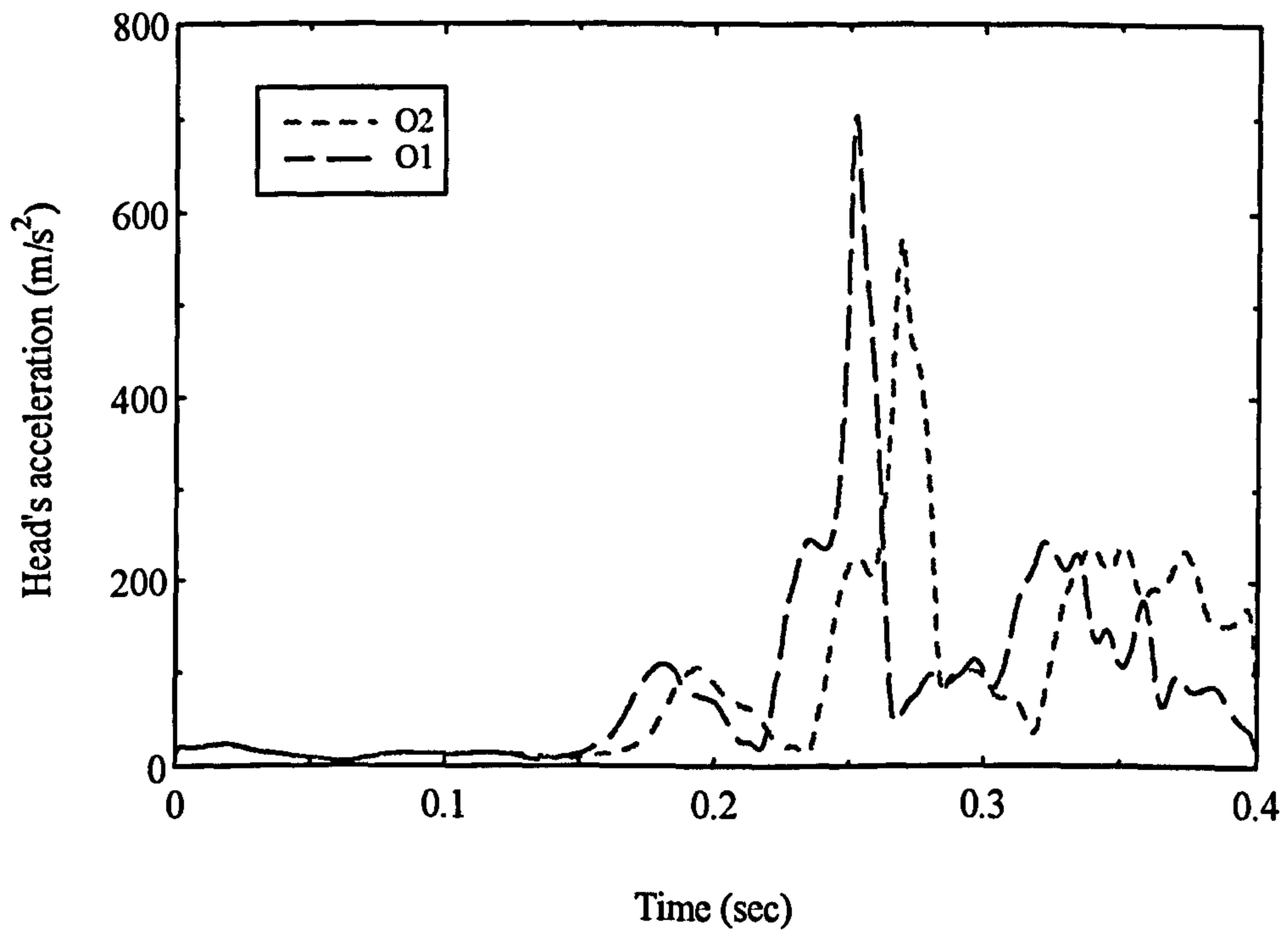


Figure 8.19 : Head acceleration-time history for models in the O-series.

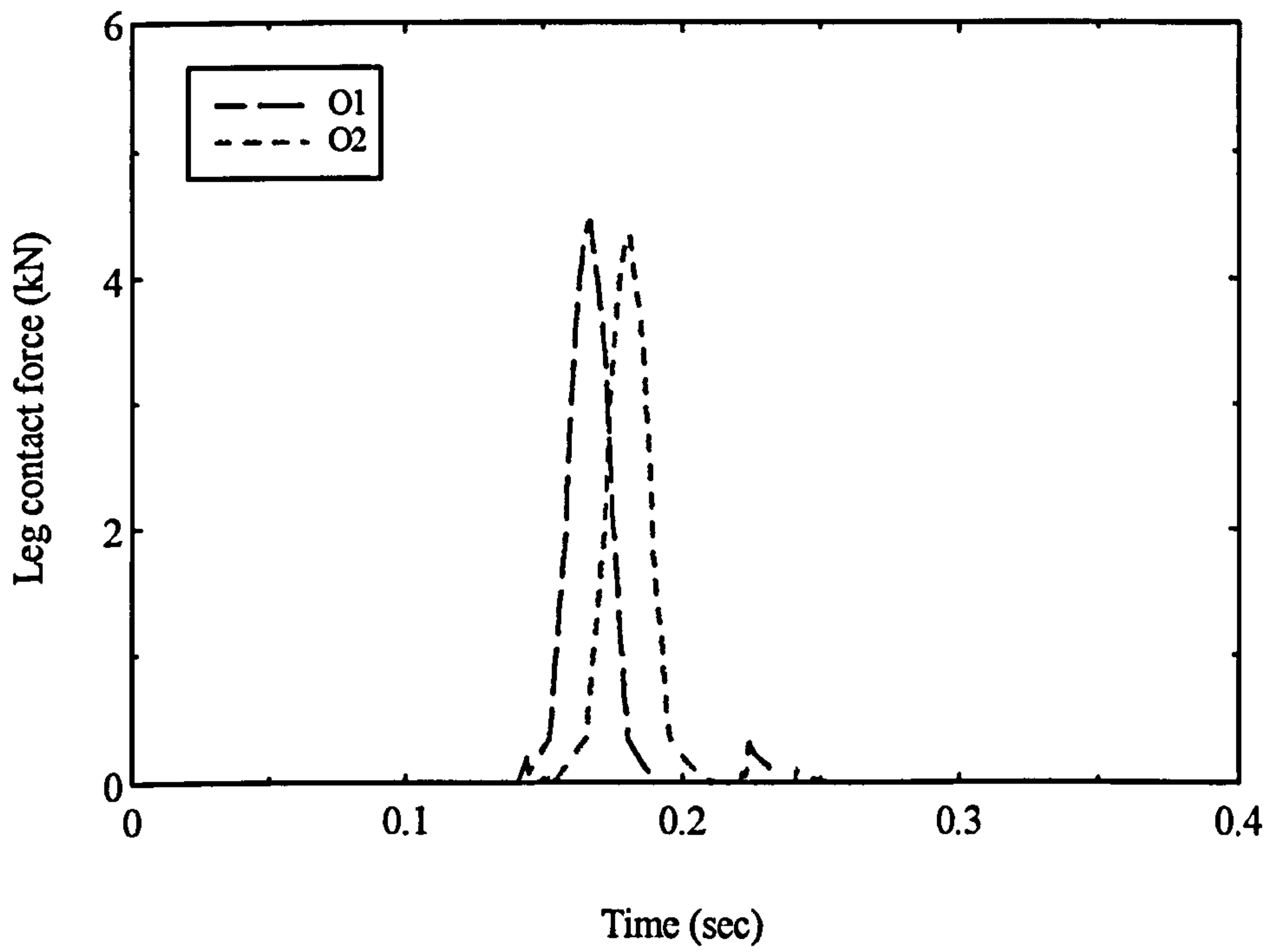


Figure 8.20 : Leg contact force-time history for models in the O-series.

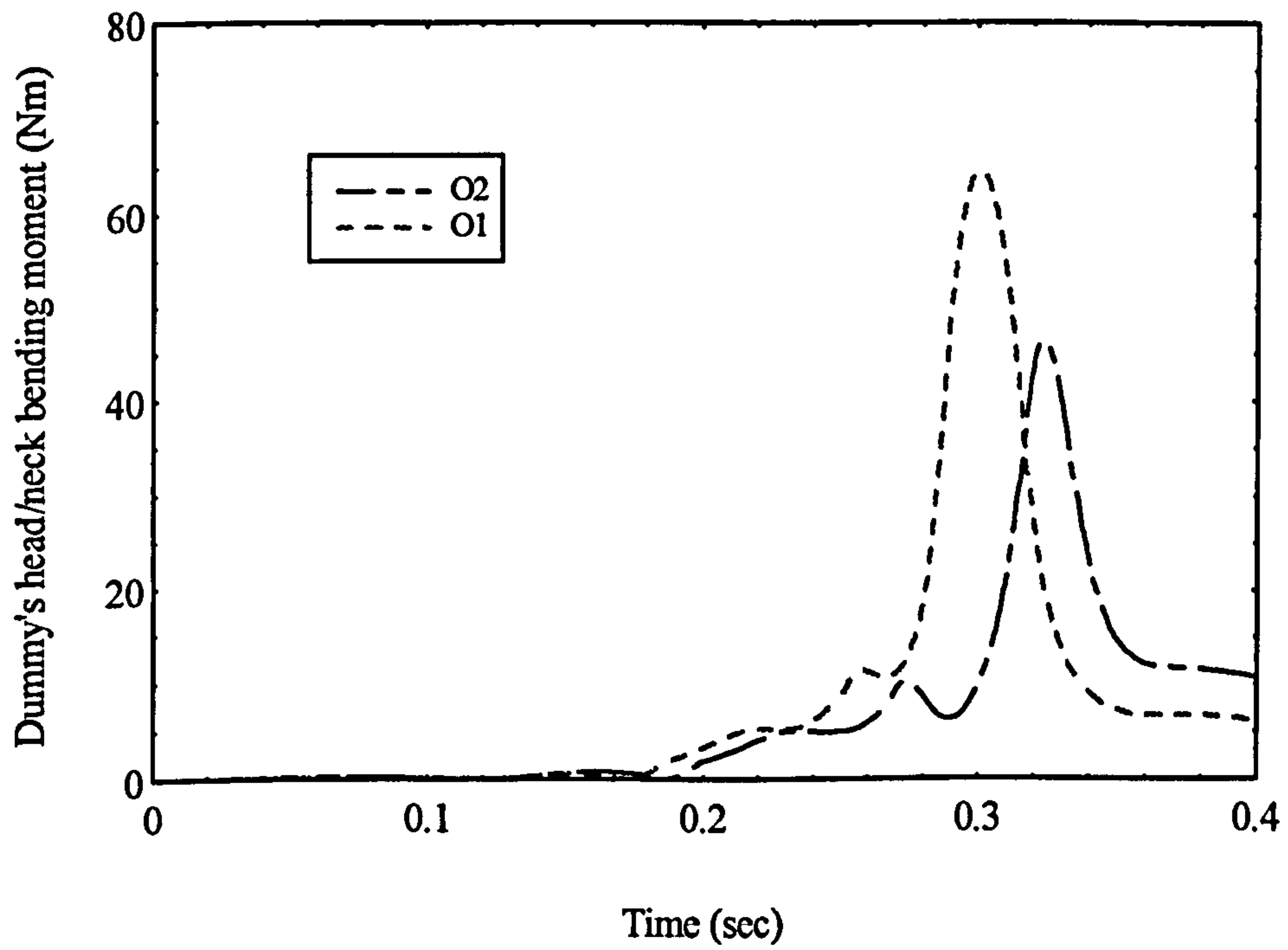


Figure 8.21 : Head/neck bending moment-time history for models in the O-series.

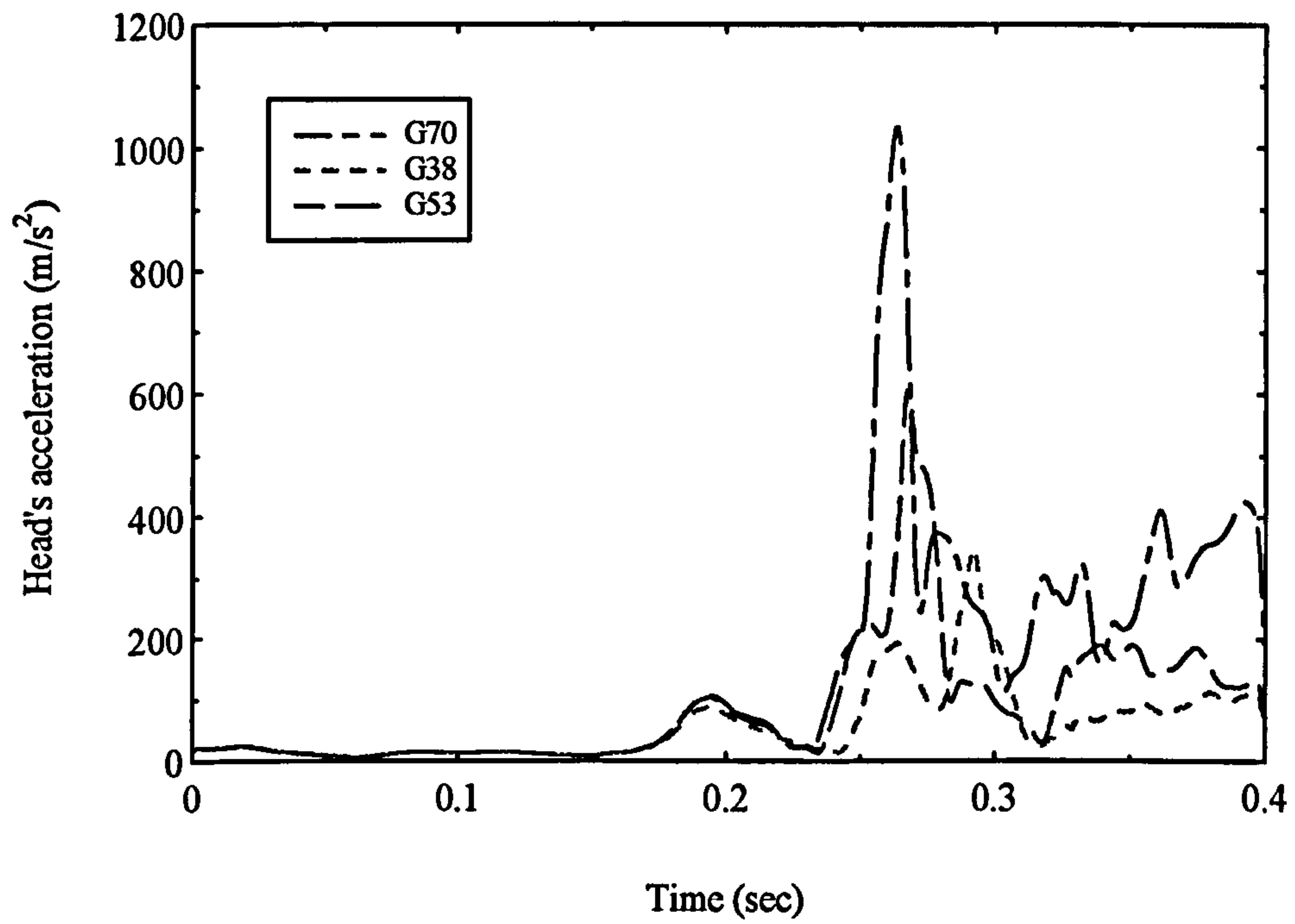


Figure 8.22 : Head acceleration-time history for models in the G-series.

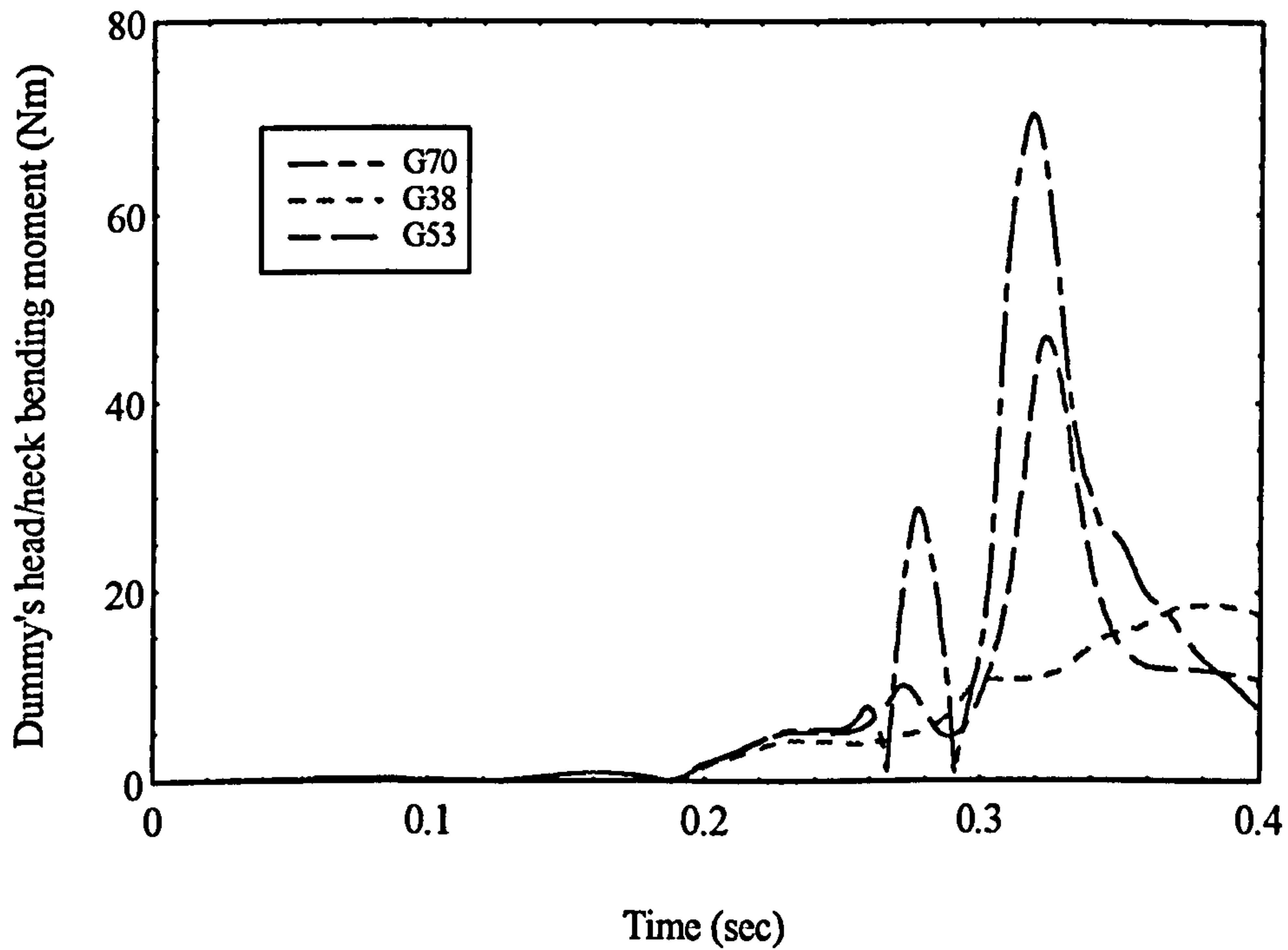


Figure 8.23 : Head/neck bending moment-time history for models in the G-series.

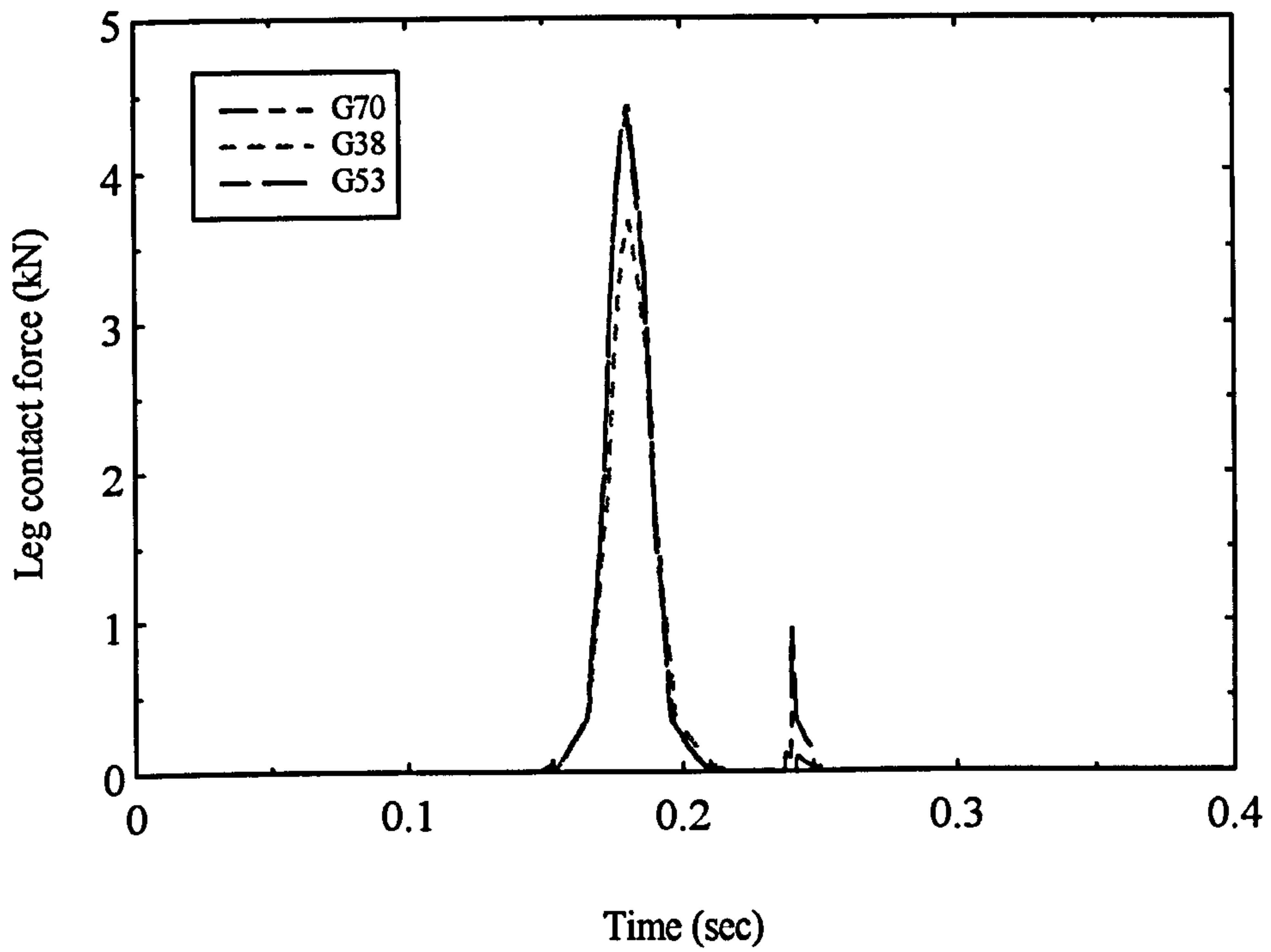


Figure 8.24 : Leg contact force-time history for models in the G-series.

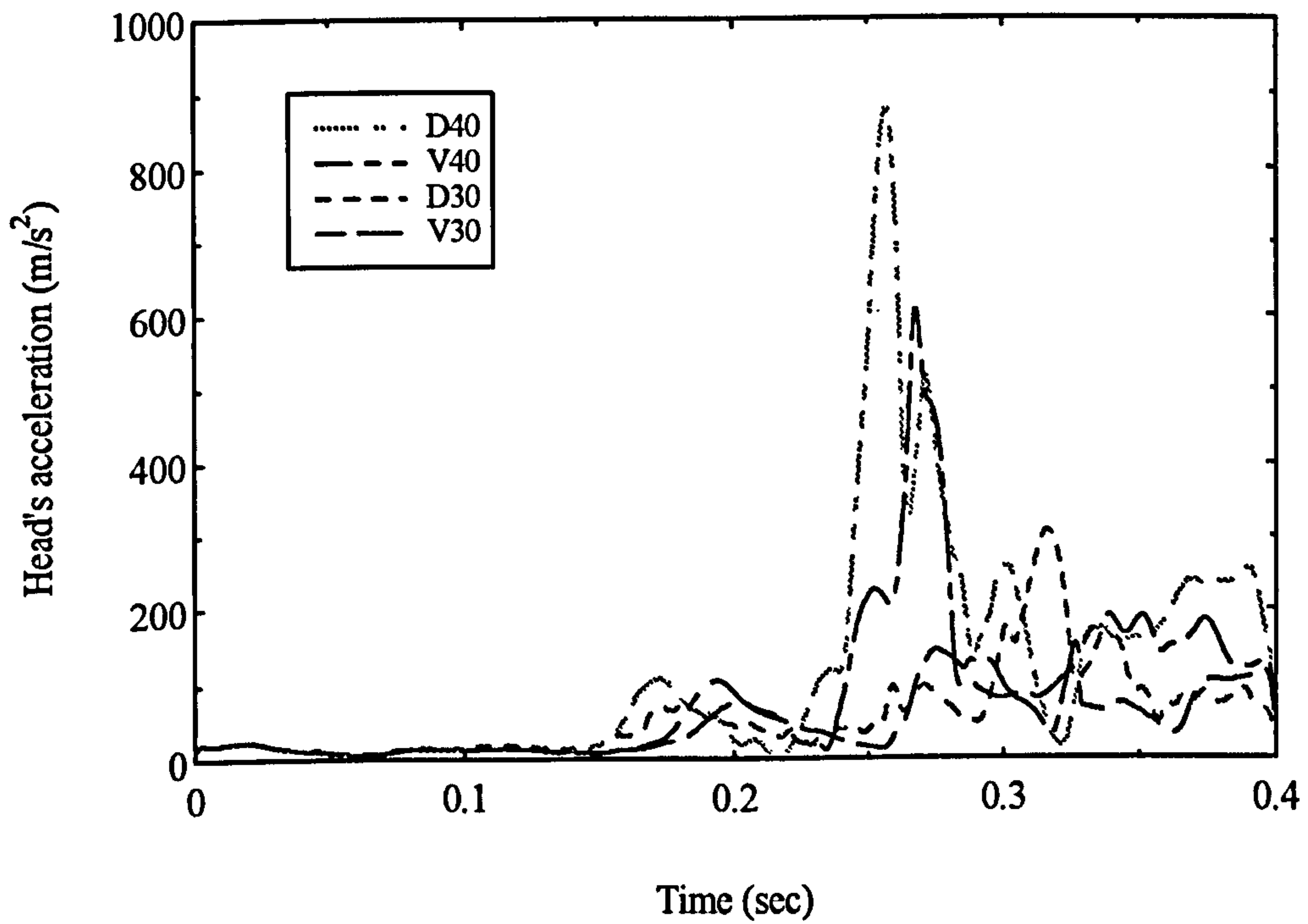


Figure 8.25 : Head acceleration-time history for models in the D-series.

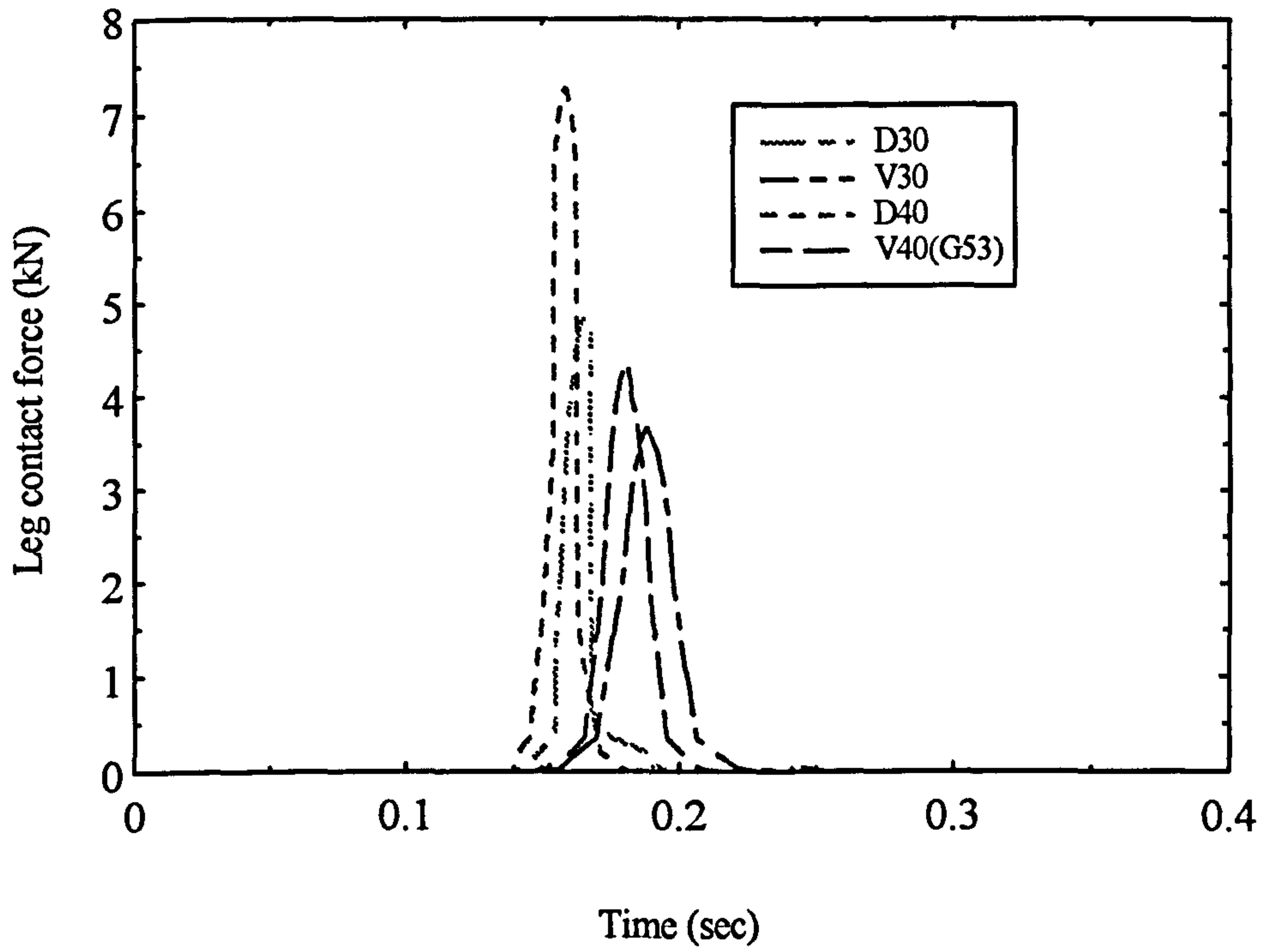


Figure 8.26 : Leg contact force-time history for models in the D-series.

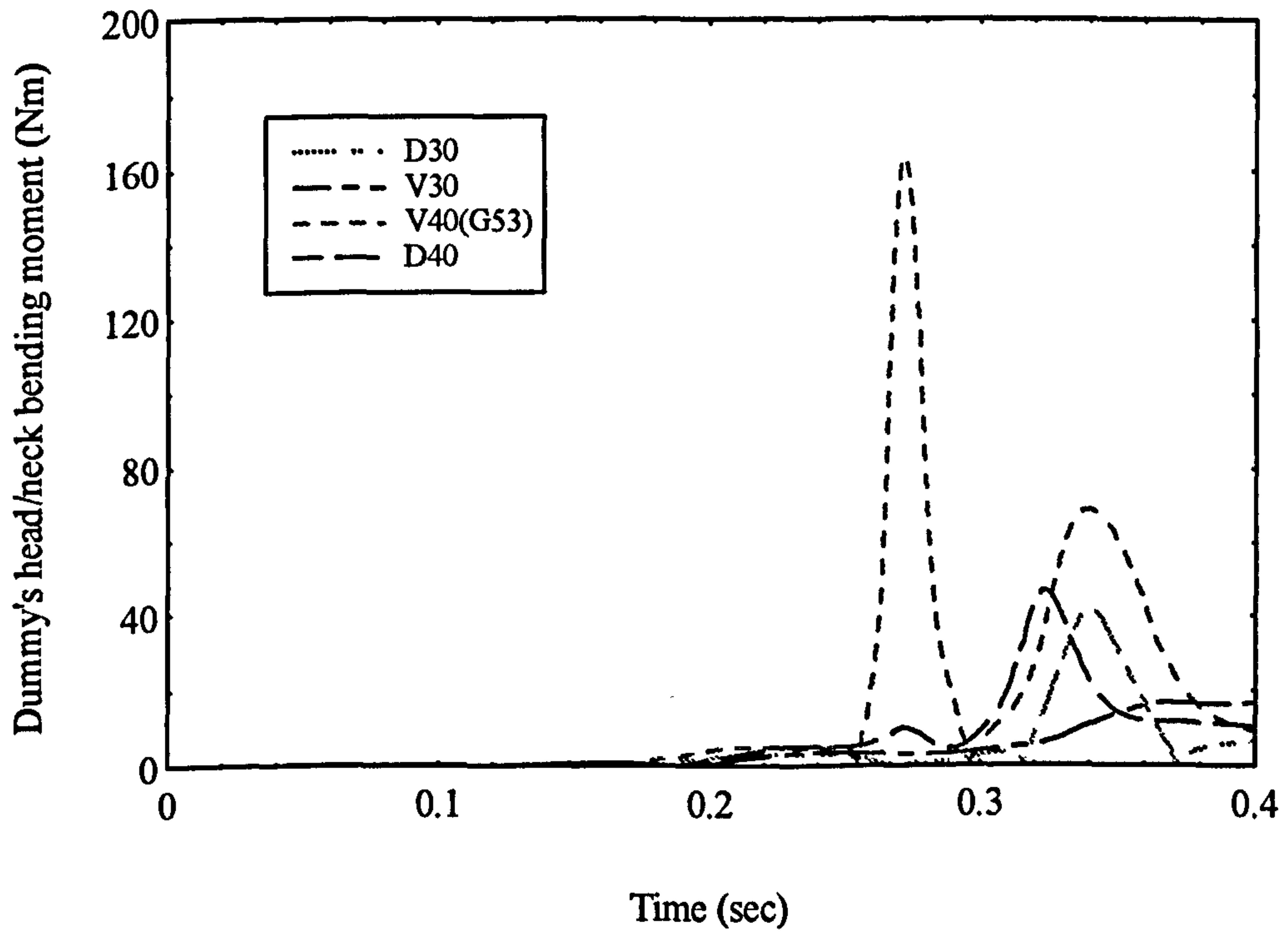


Figure 8.27 : Head/neck bending moment-time history for models in the D-series.

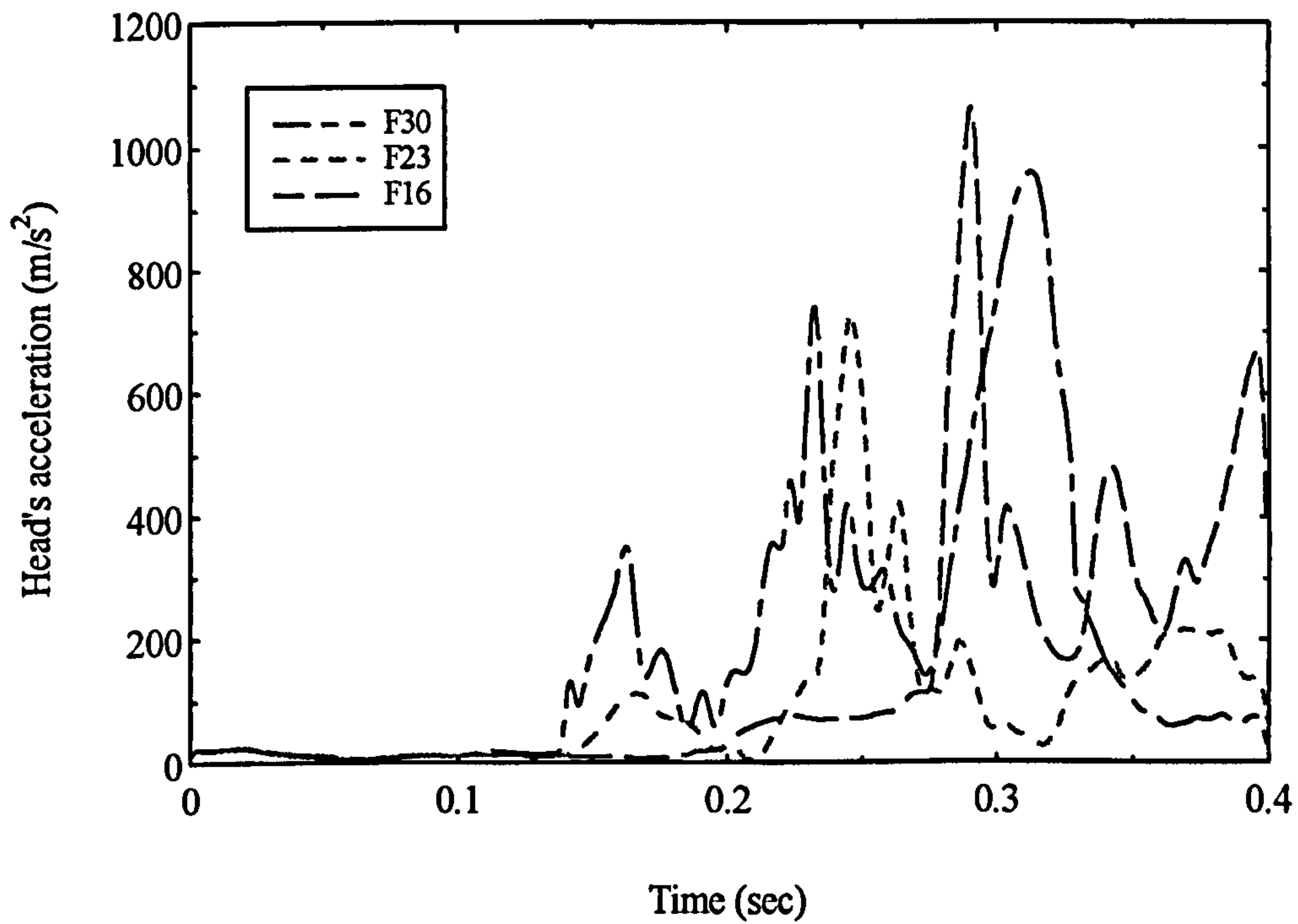


Figure 8.28 : Head acceleration-time history for models in the F-series.

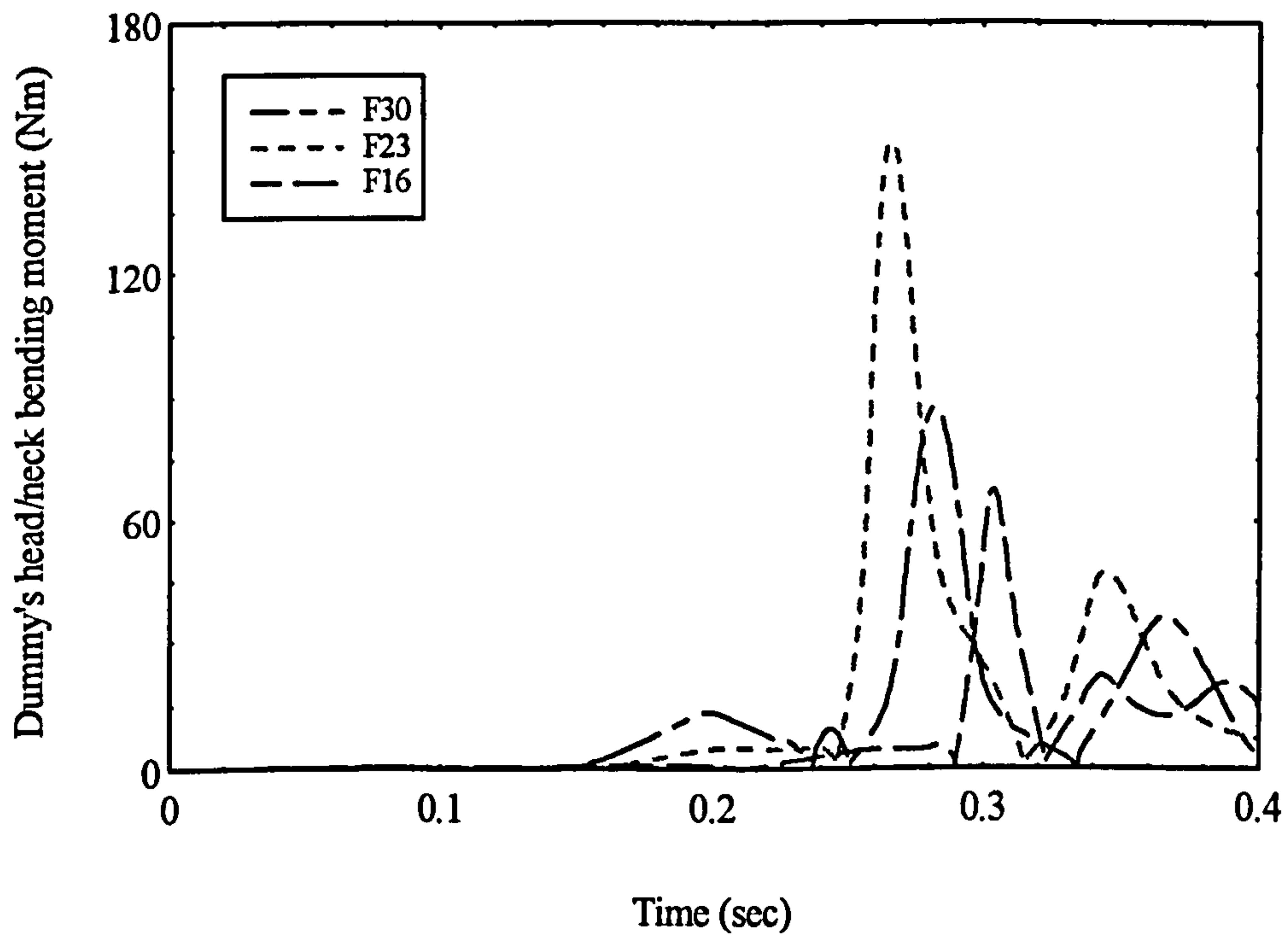


Figure 8.29 : Head/neck bending moment-time history for models in the F-series.

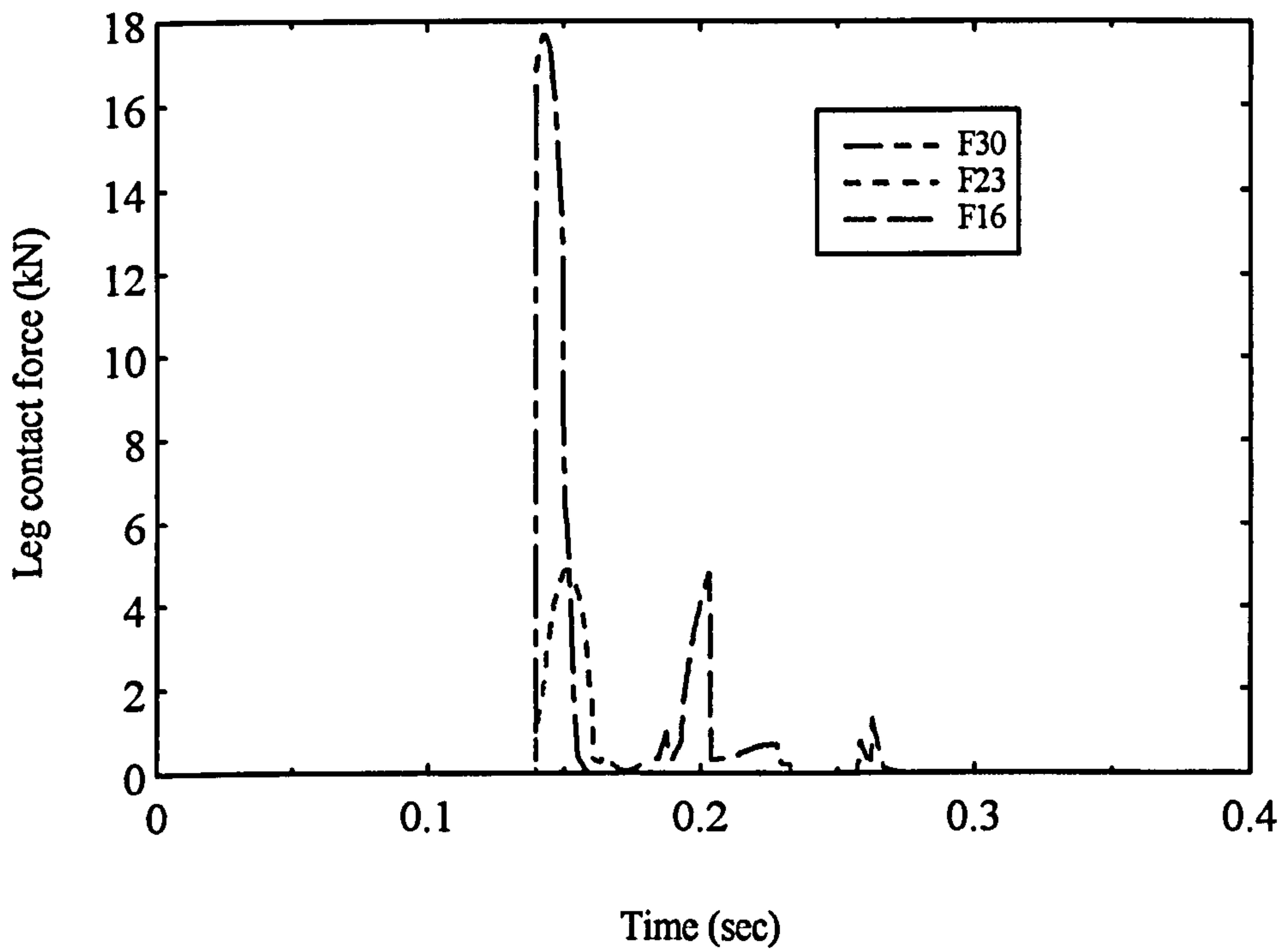


Figure 8.30 : Leg contact force-time history for models in the F-series.

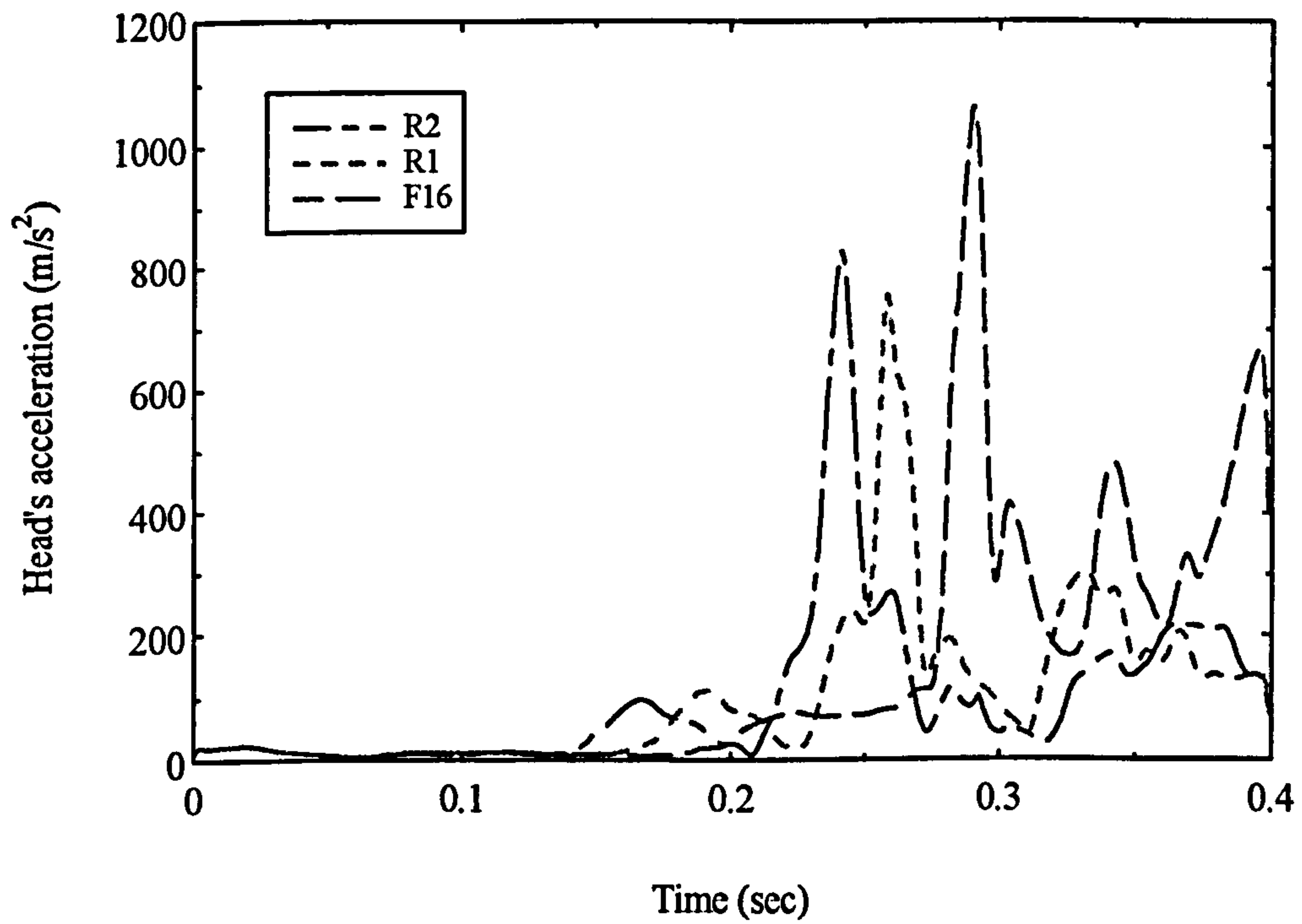


Figure 8.31 : Head acceleration-time history for models in the R-series.

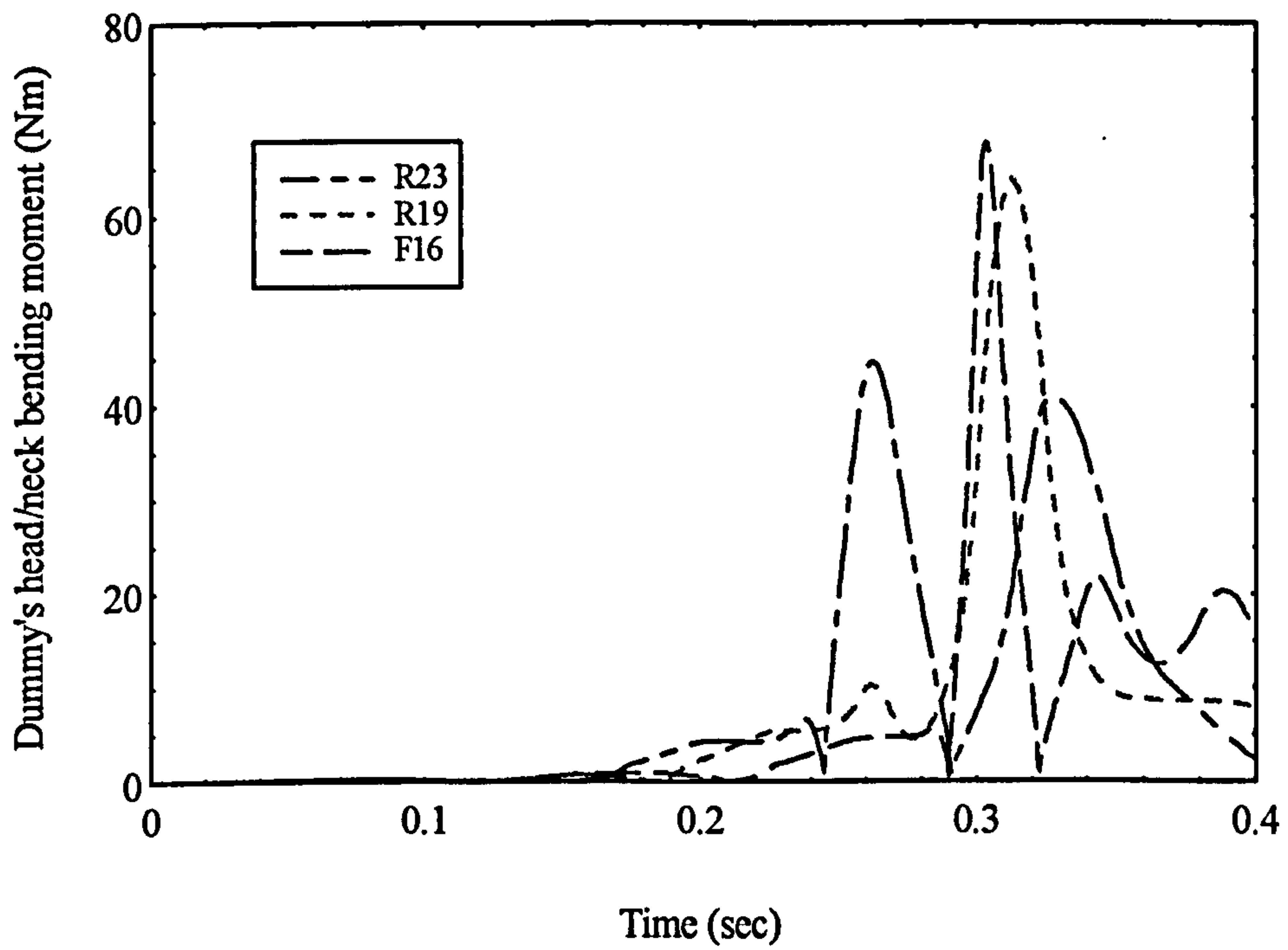


Figure 8.32 : Head/neck bending moment-time history for models in the R-series.

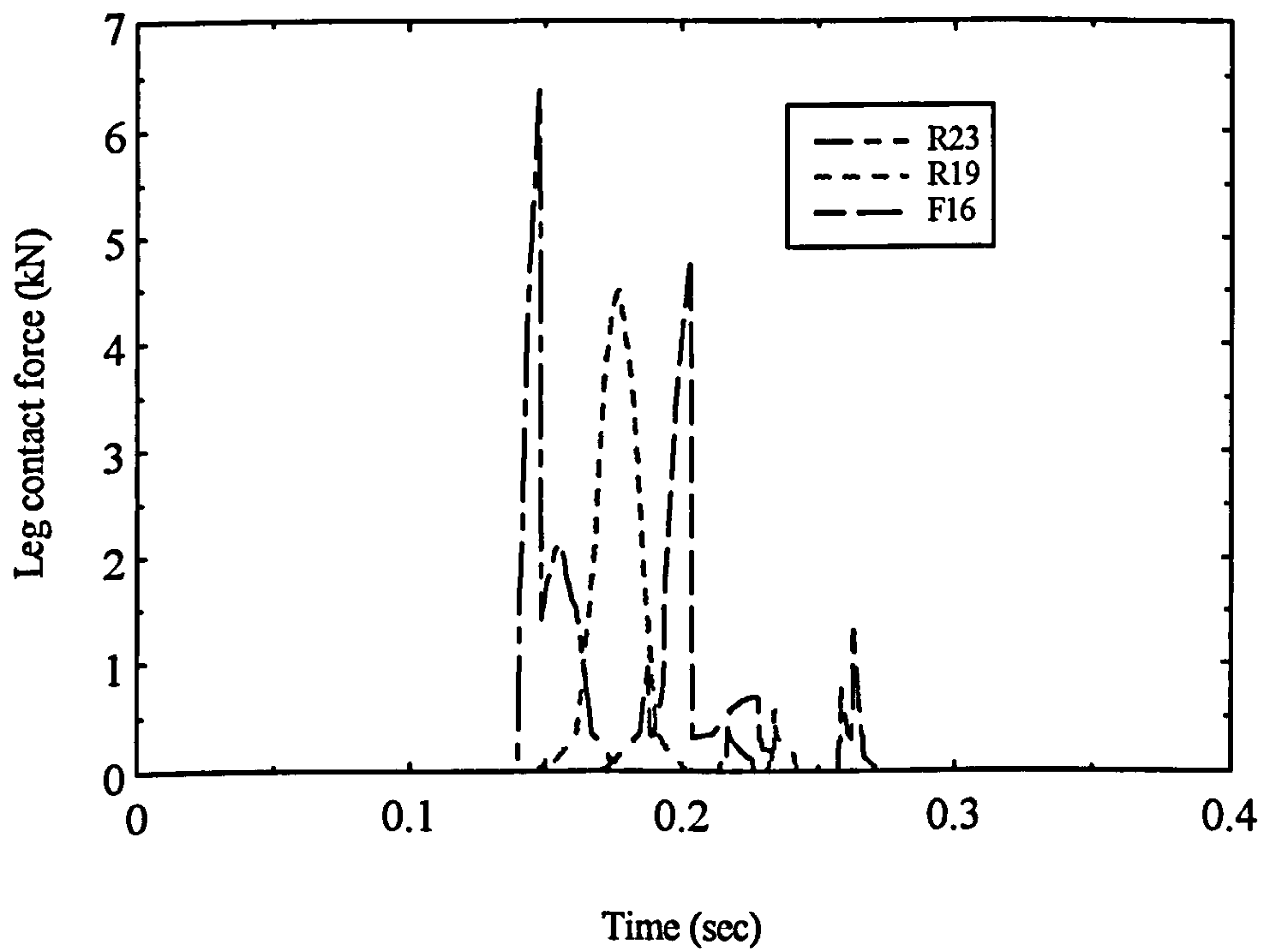


Figure 8.33 : Leg contact force-time history for models in the R-series.

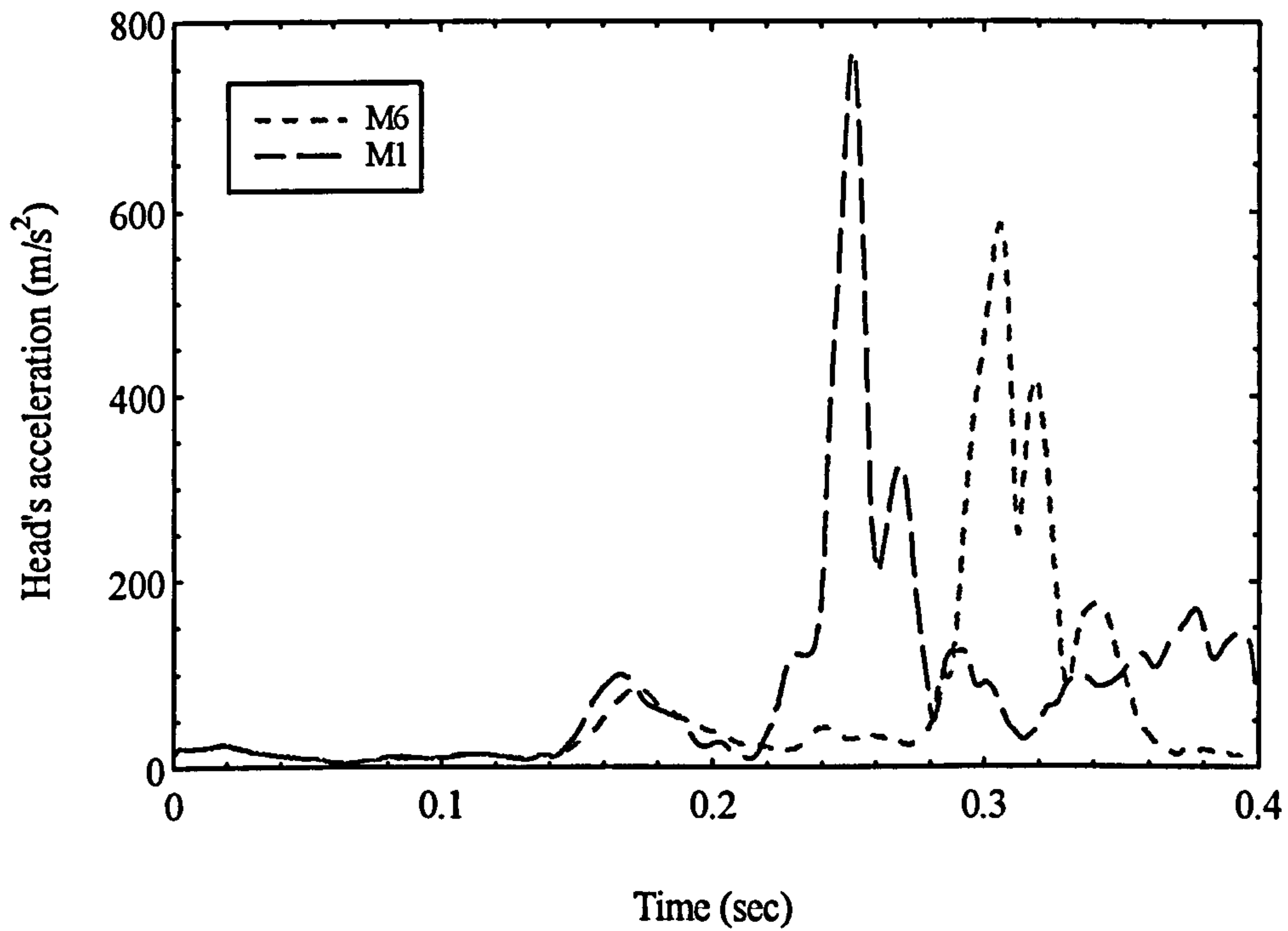


Figure 8.34 : Head acceleration-time history for models in the M-series.

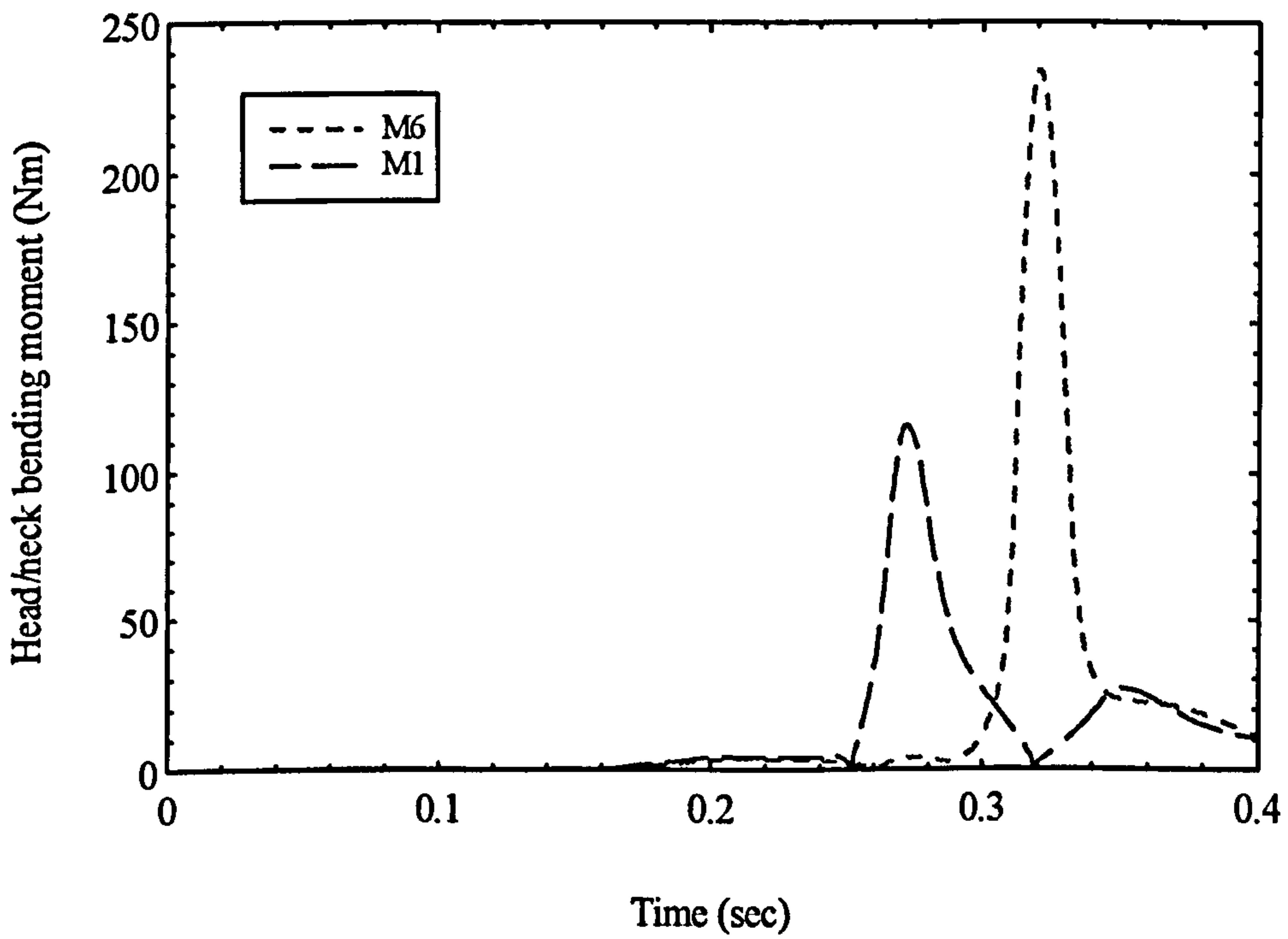


Figure 8.35 : Head/neck bending moment-time history for models in the M-series.

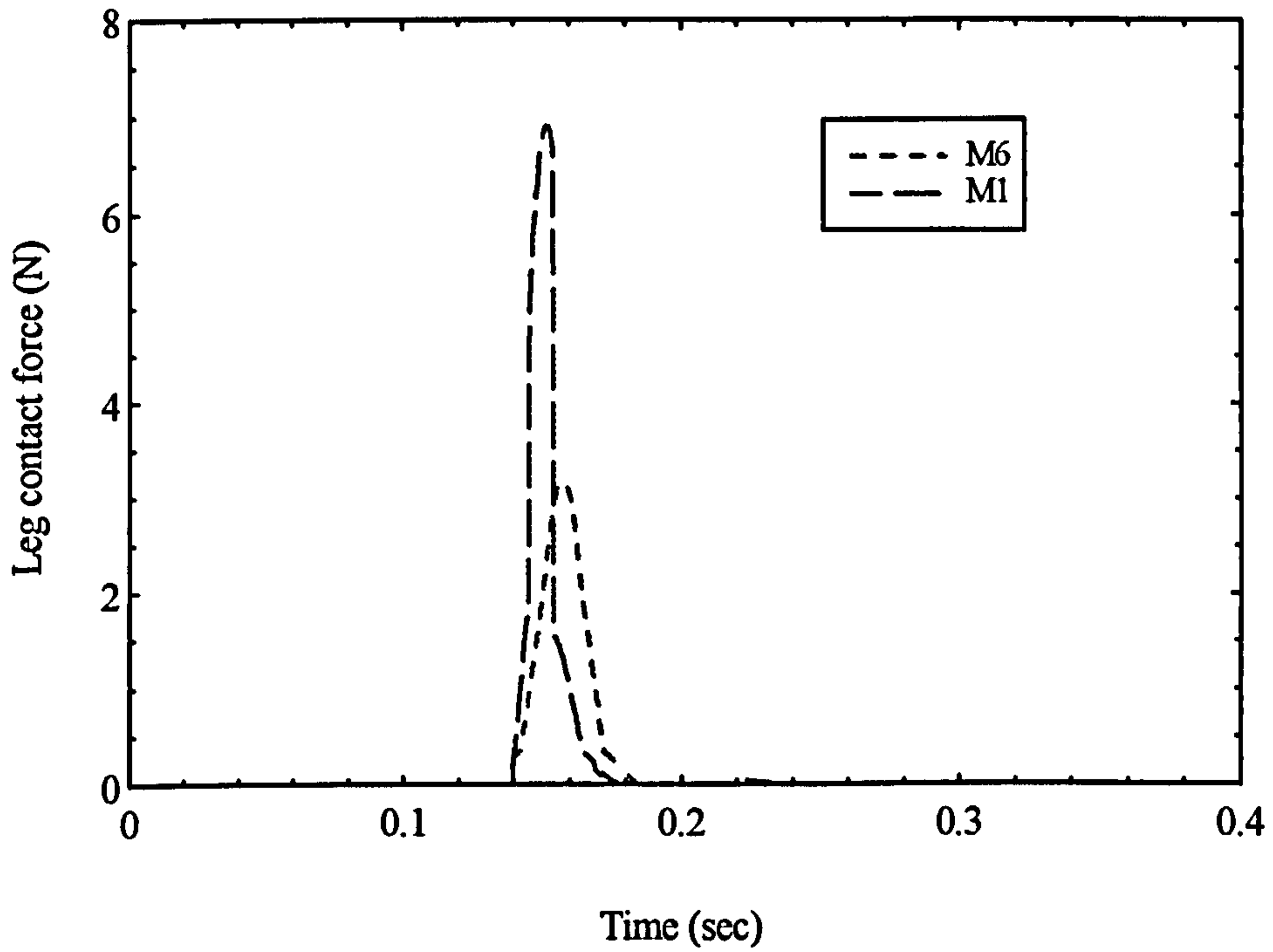


Figure 8.36 : Leg contact force-time history for models in the M-series.

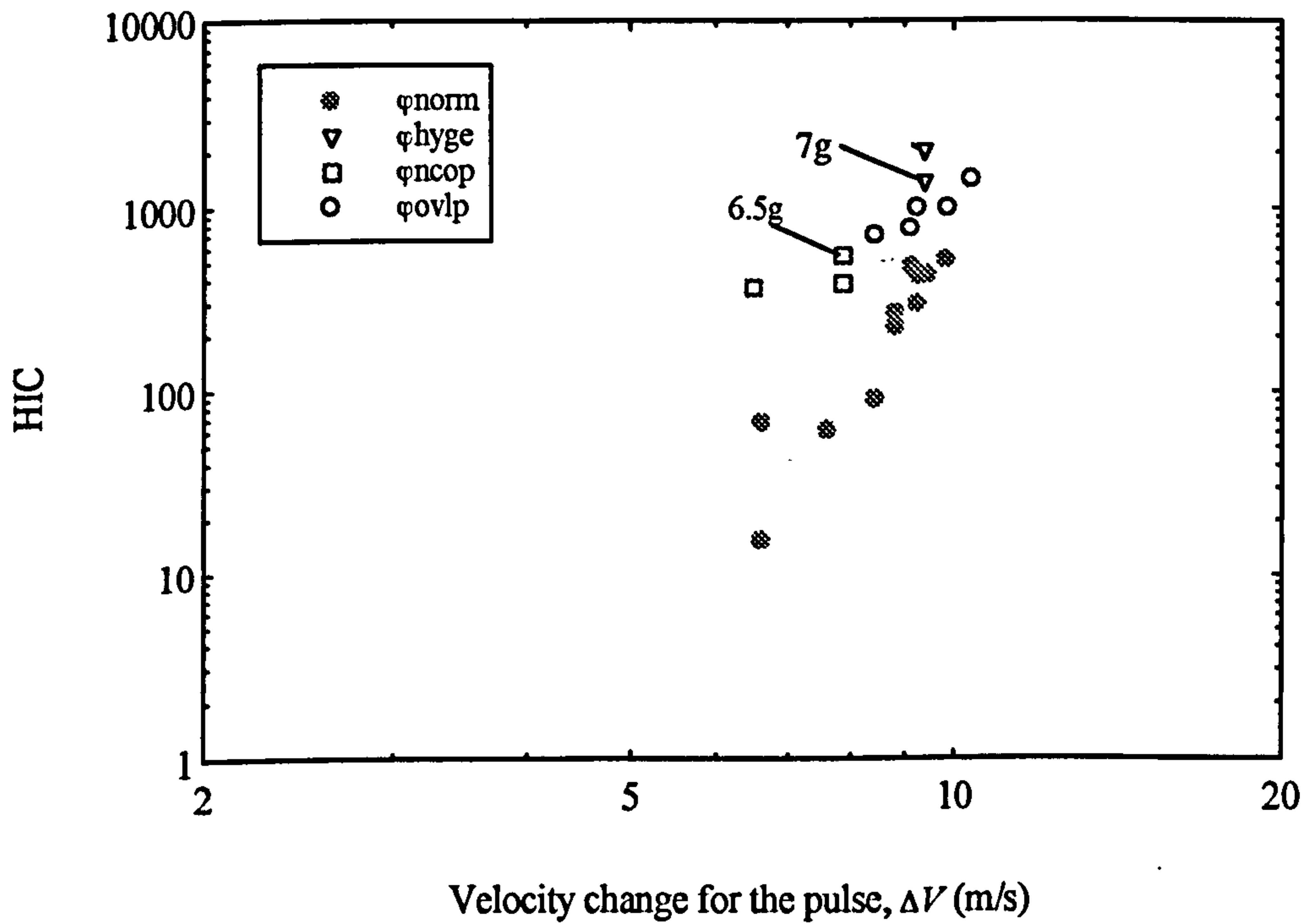


Figure 8.37 : log (HIC) against log (ΔV)

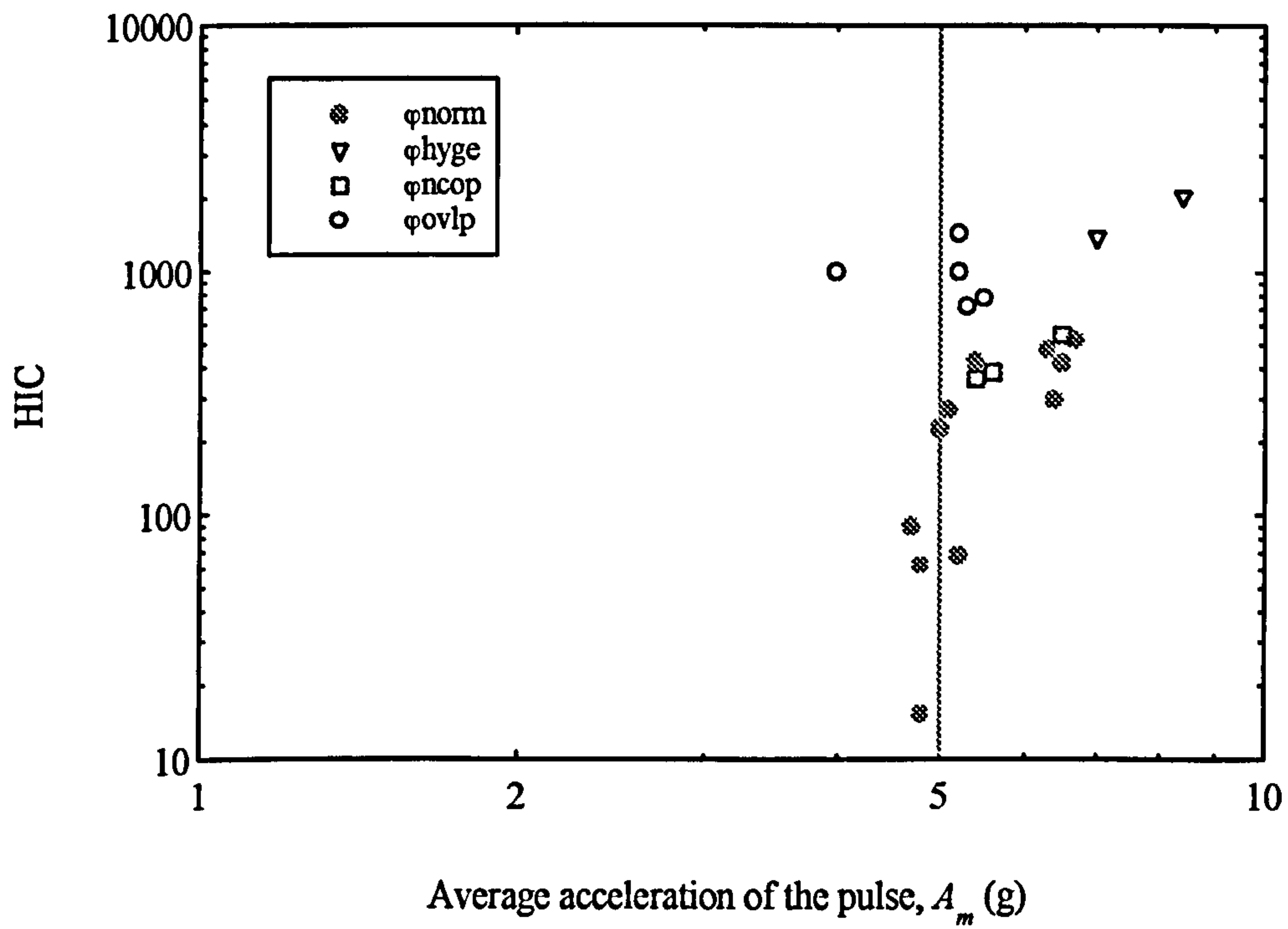


Figure 8.38 : log (HIC) against log (A_m)

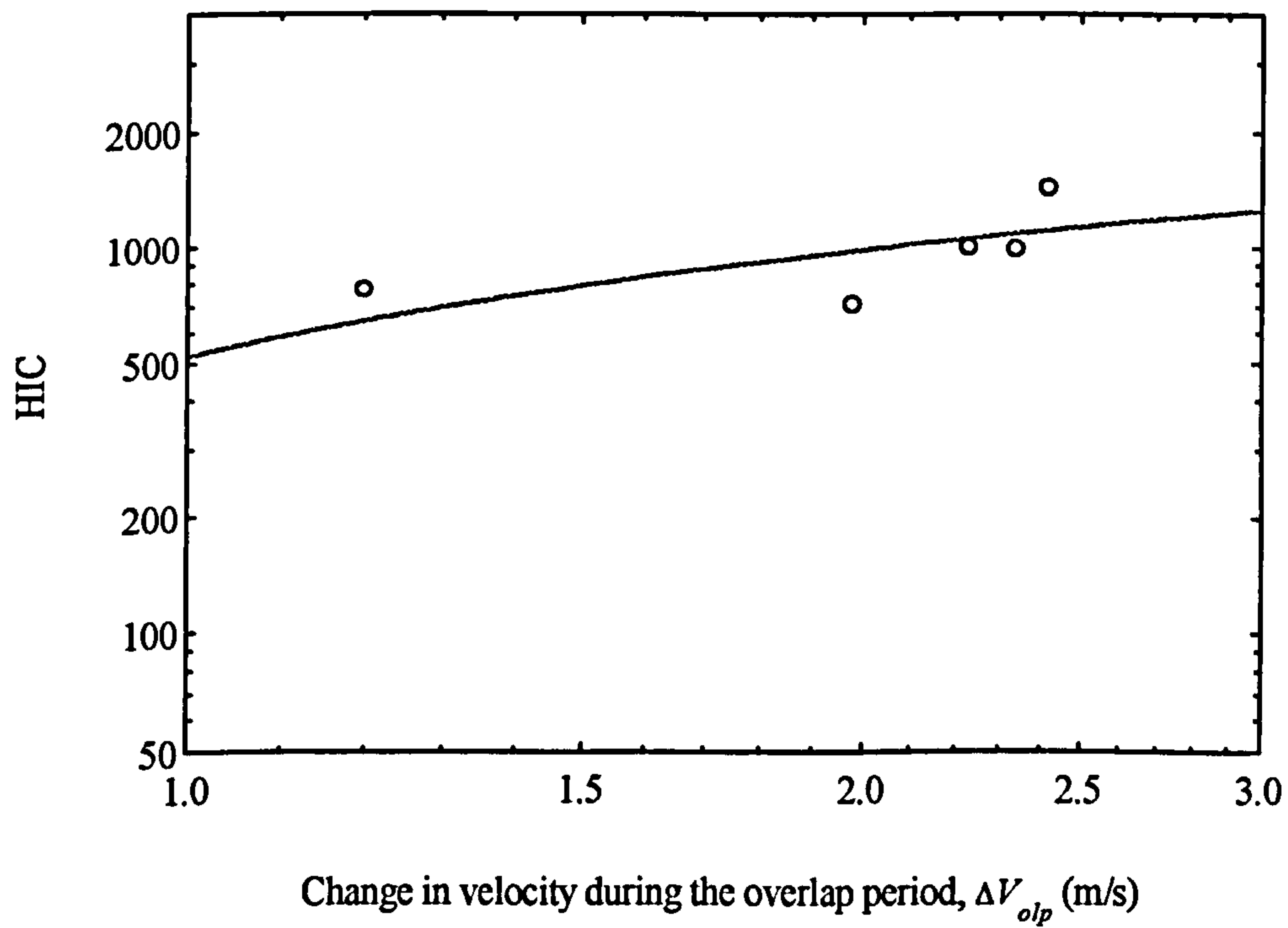


Figure 8.39 : log (HIC) against log (Δv_{ovlp}) for models in ϕ_{ovlp} .

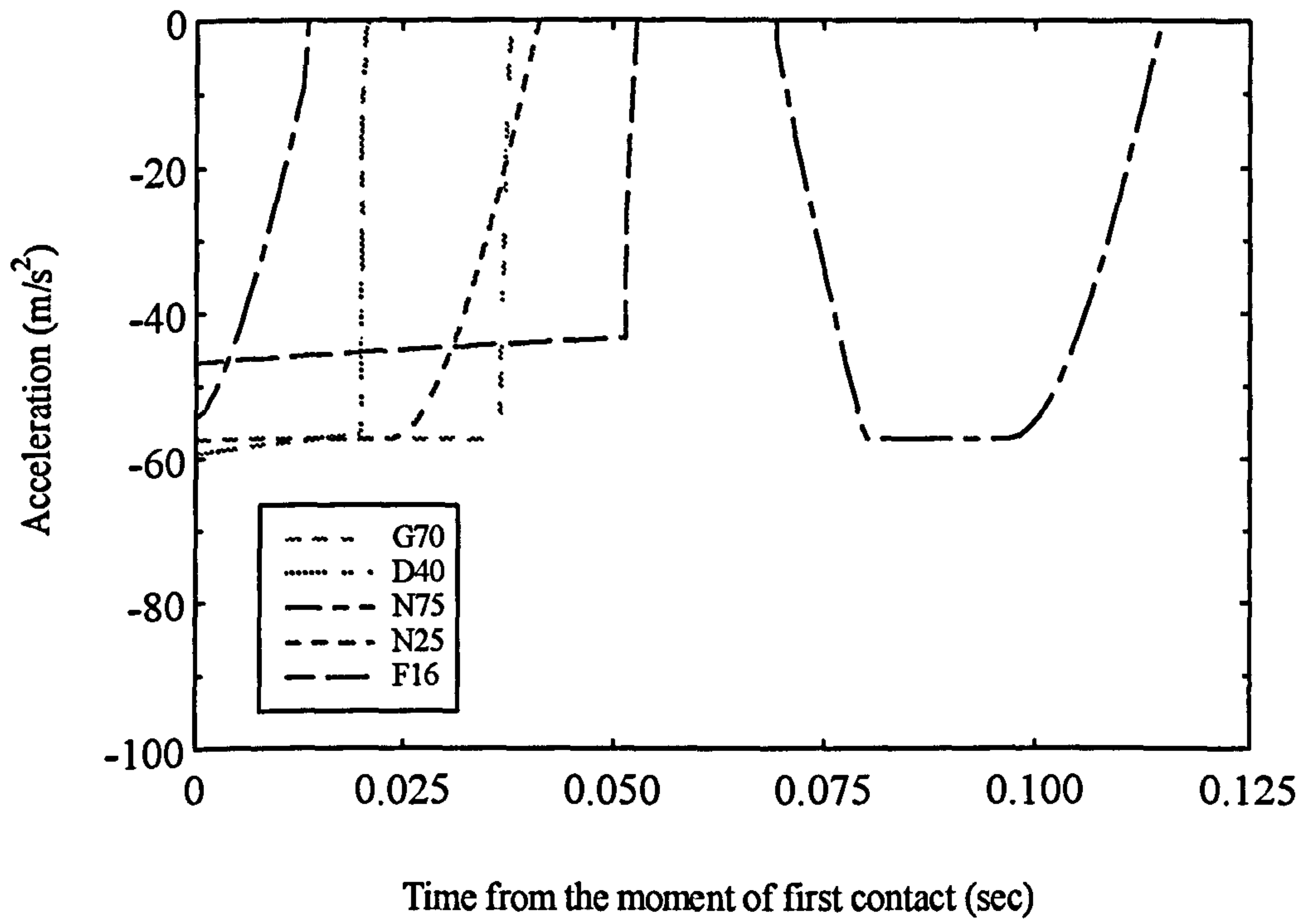


Figure 8.40 : The final portion of the acceleration pulses for models in φ_{ovlp} during the 'overlapped' period.

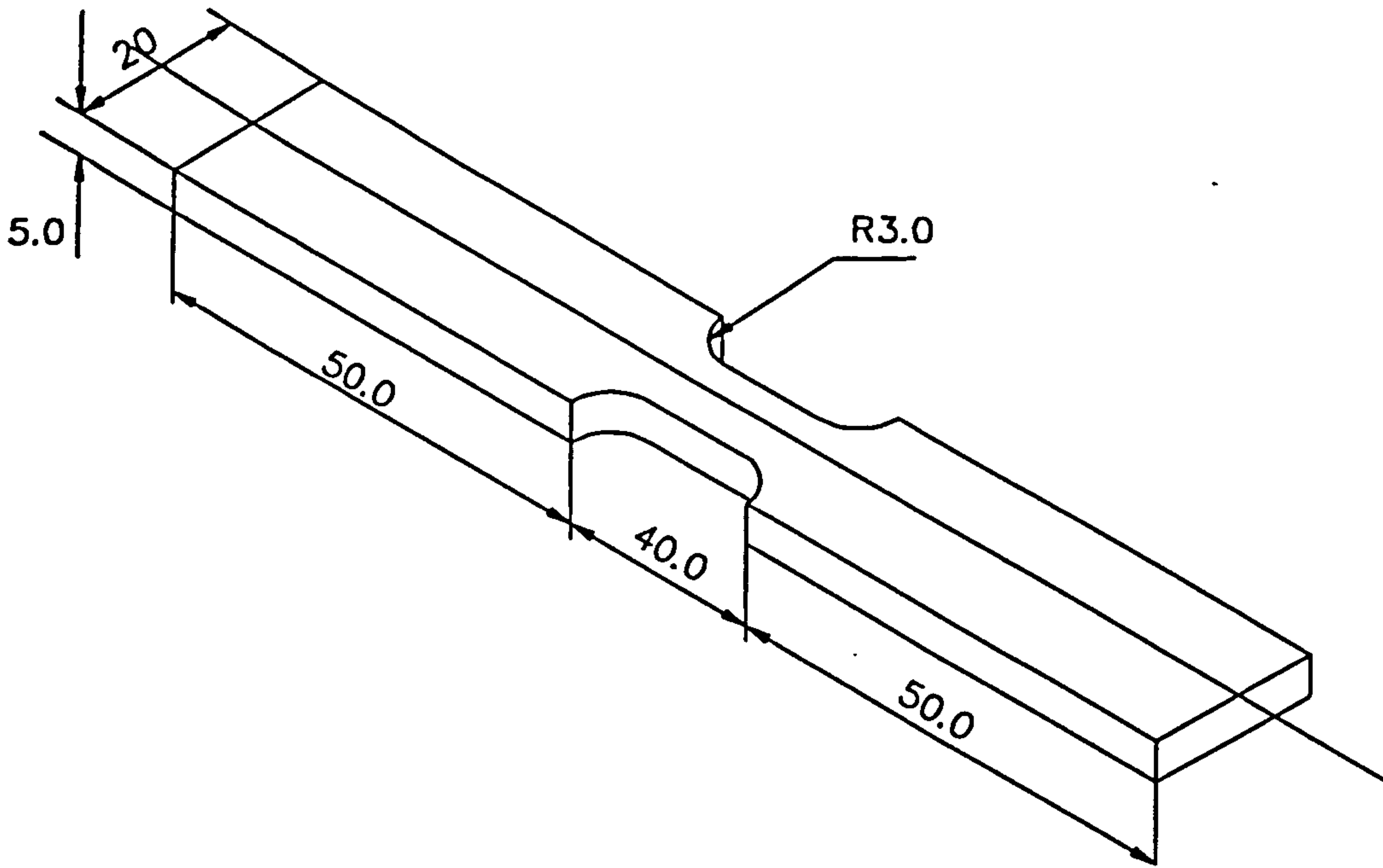


Figure A.1 : The geometry of tensile test specimens (all dimensions in mm).

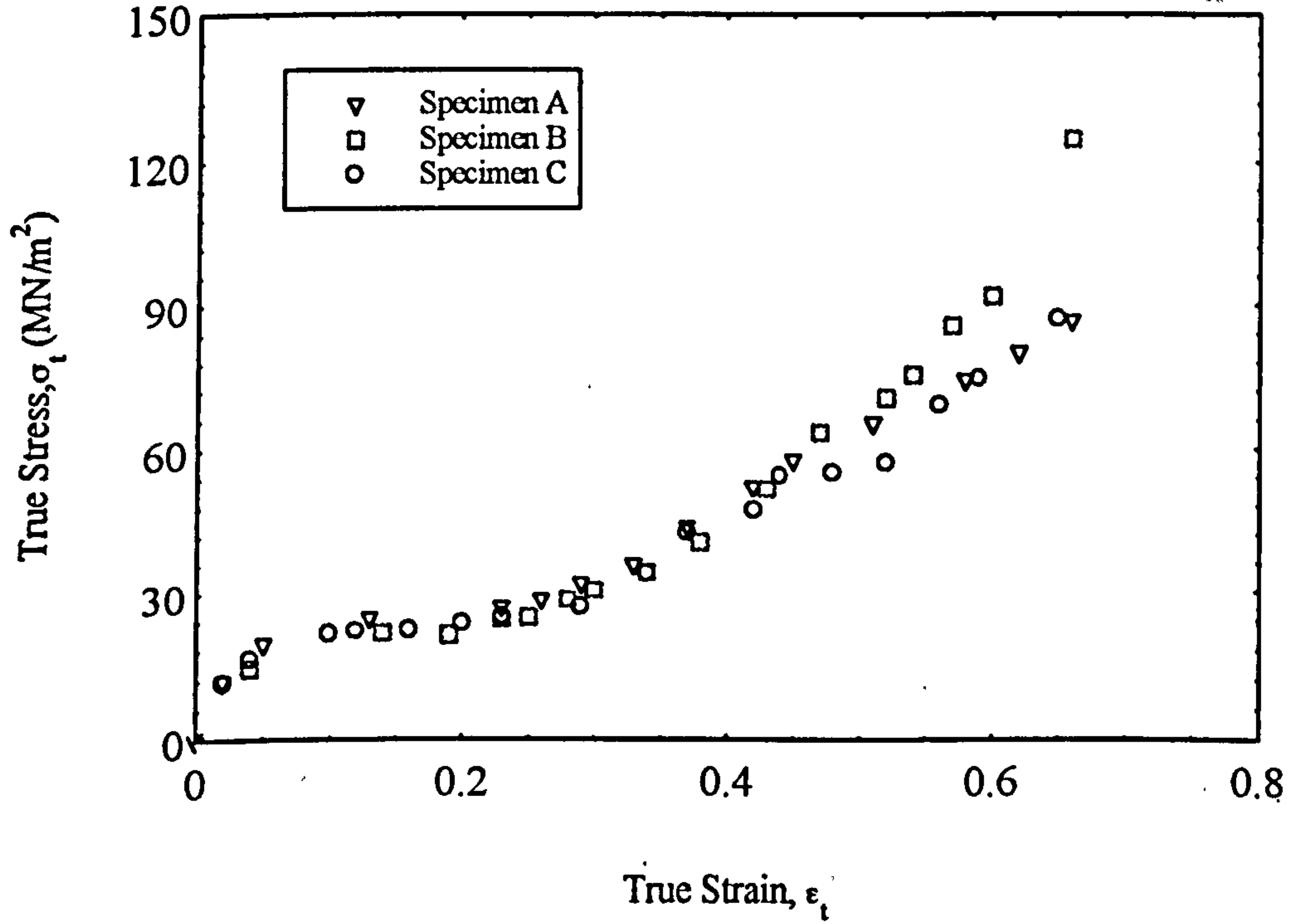


Figure A.2 : The True Stress against True Strain curves for three specimens tested.

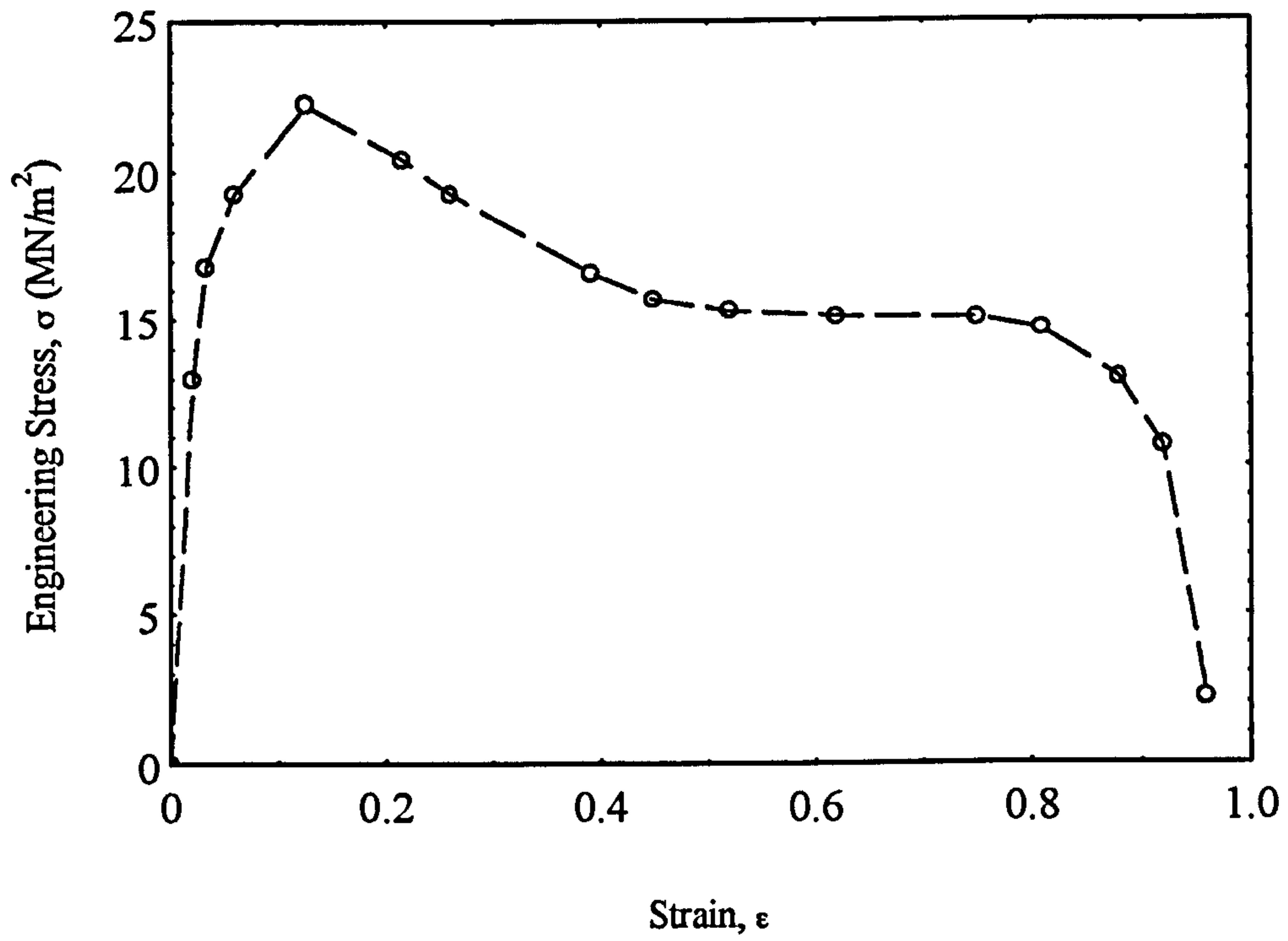


Figure A.3 : The Engineering Stress-Strain Curve for a tested specimen.

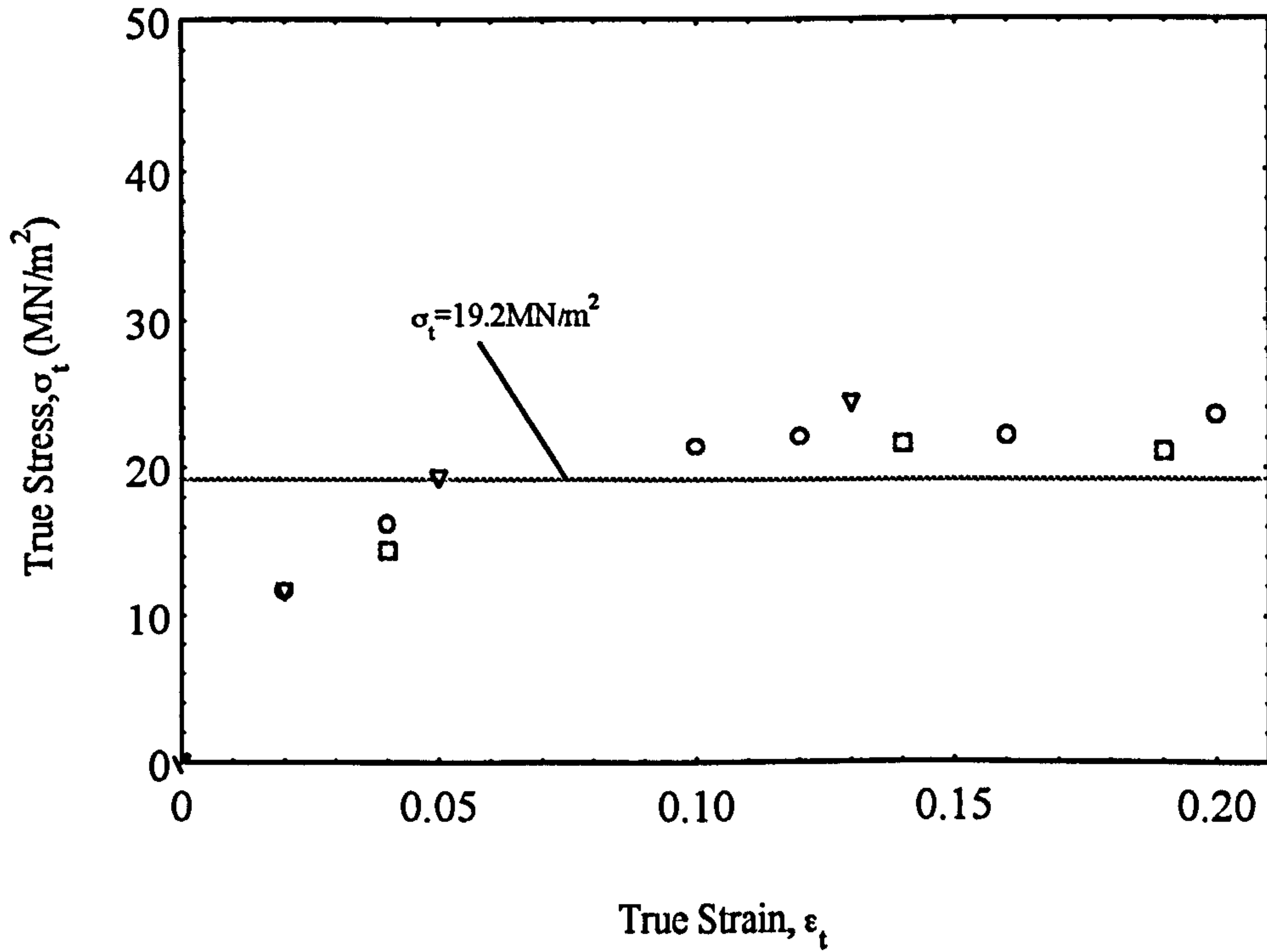


Figure A.4 : The 'plateau' during the early stage of plastic deformation, with a perfectly plastic line fitted as 19.2MN/m^2 .

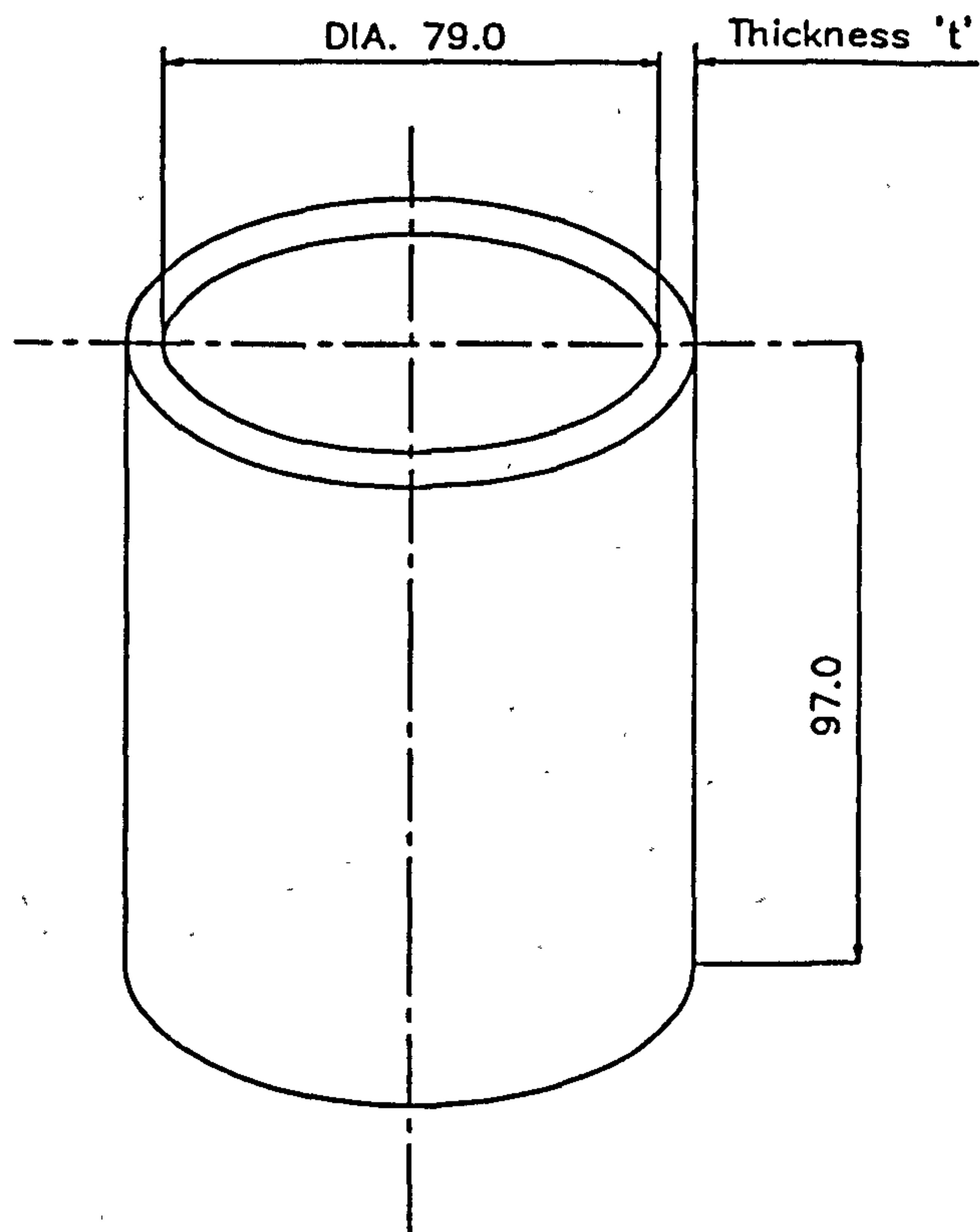


Figure A.5 : The geometry of crush specimens.

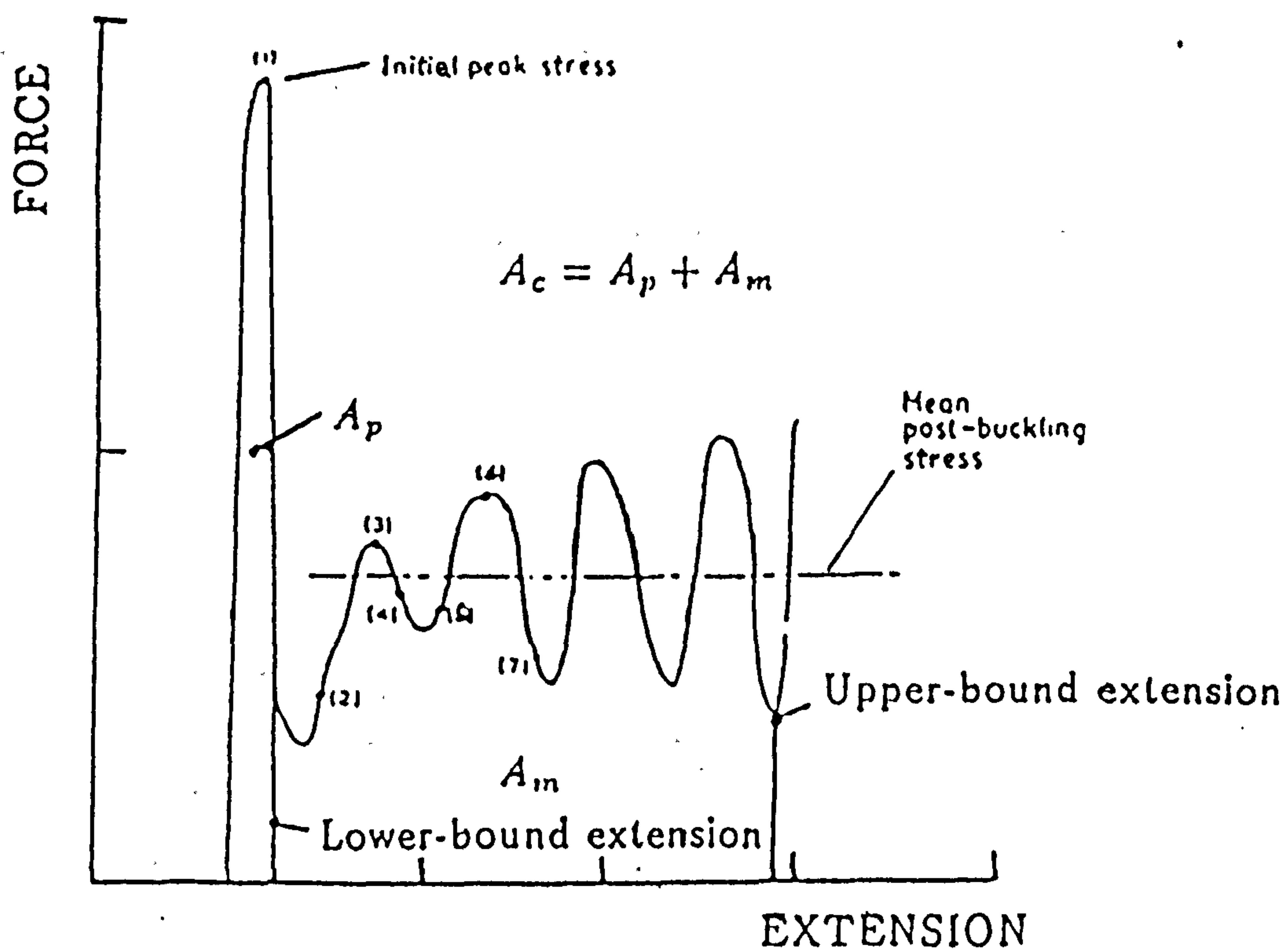


Figure A.6 : The interpretation of mean post buckling load and energy absorbed from an experimental load-deflection graph.

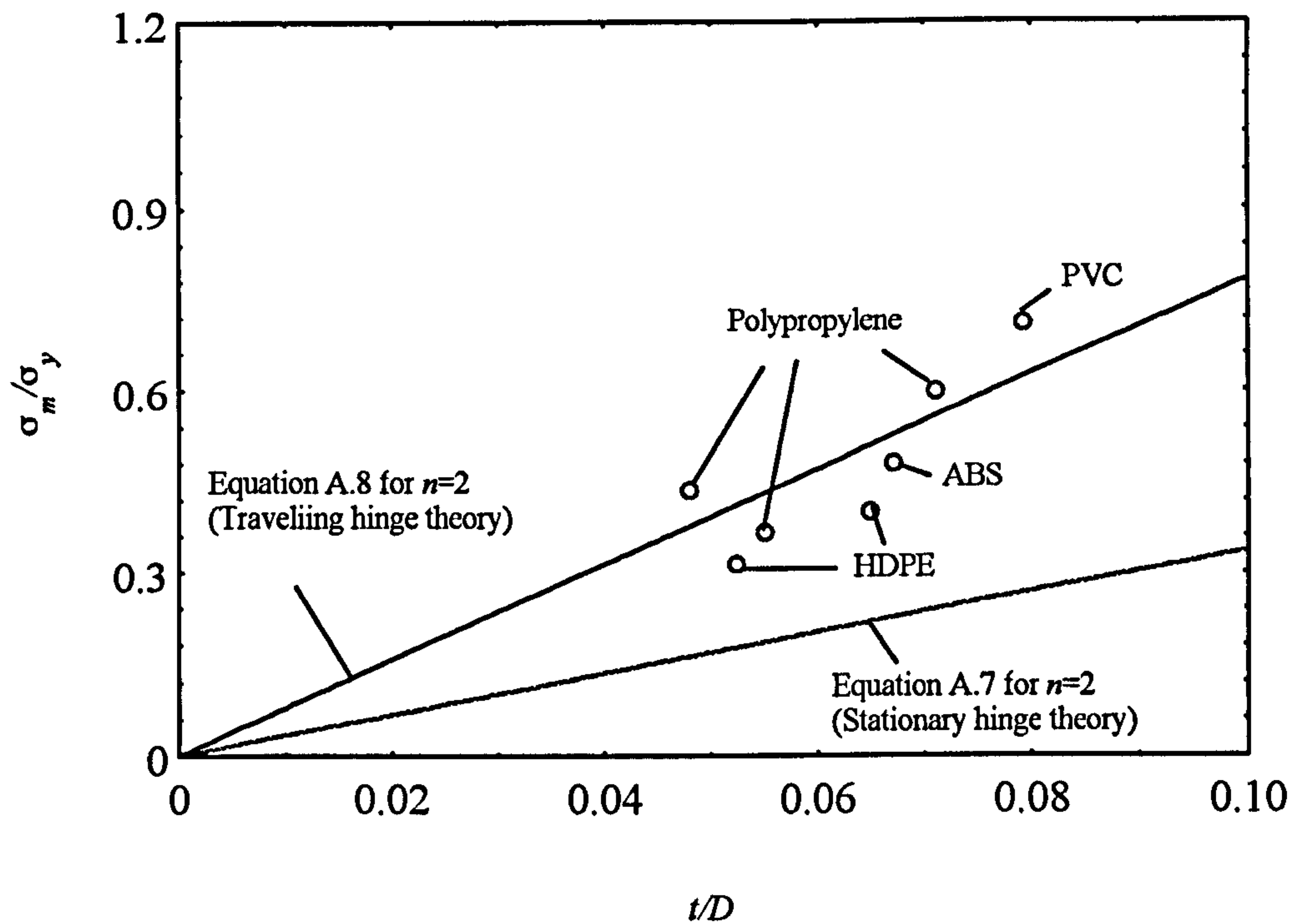


Figure A.7 : Experimental data for various polymeric tubes with $n=2$, with Johnson *et al.* theoretical lines superimposed.

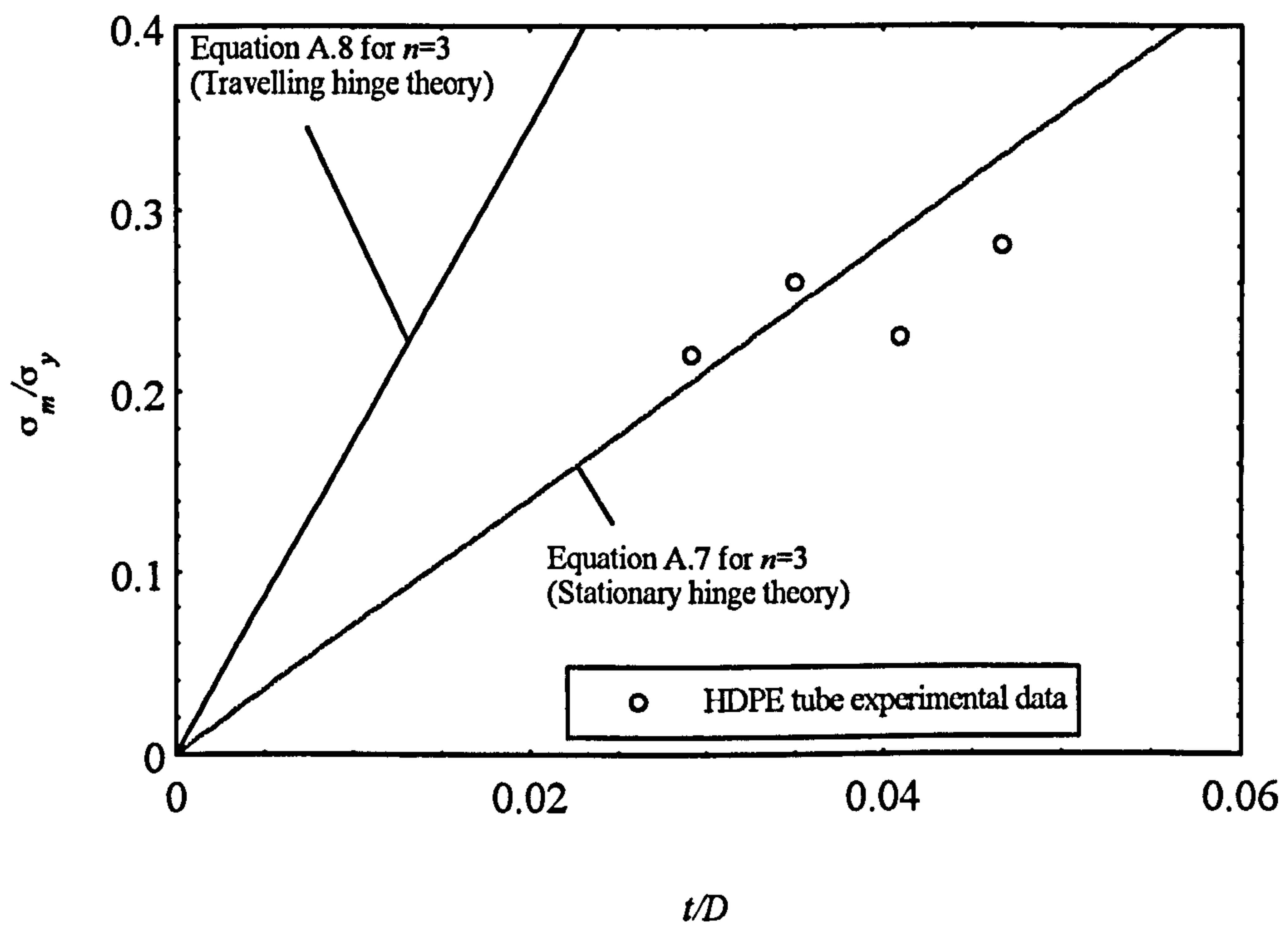


Figure A.8 : Experimental data for HDPE tubes with $n=3$, with Johnson *et al.* theoretical lines superimposed.

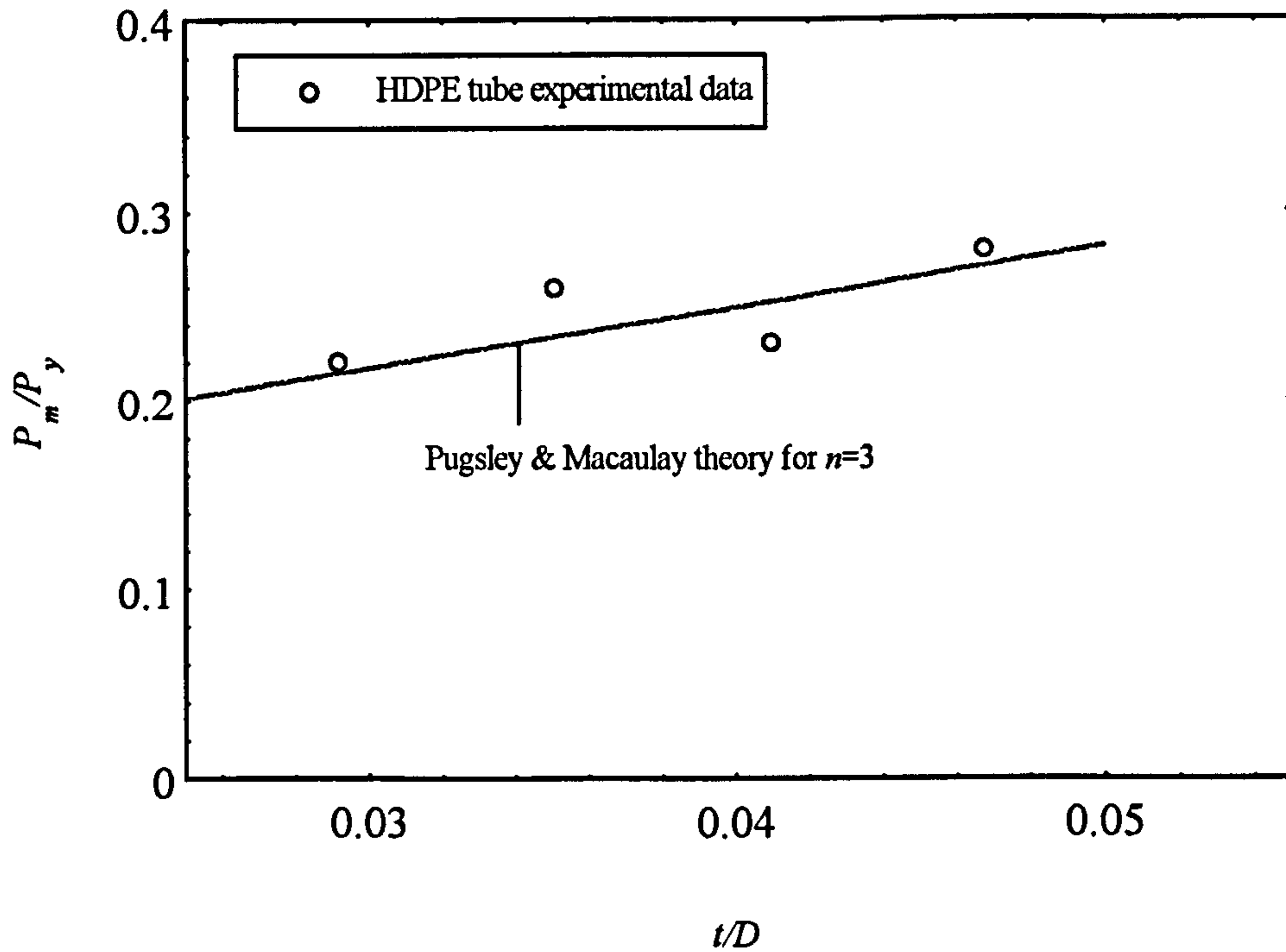


Figure A.9 : Experimental data for HDPE tubes with $n=3$, with Pugsley and Macaulay theoretical line superimposed.

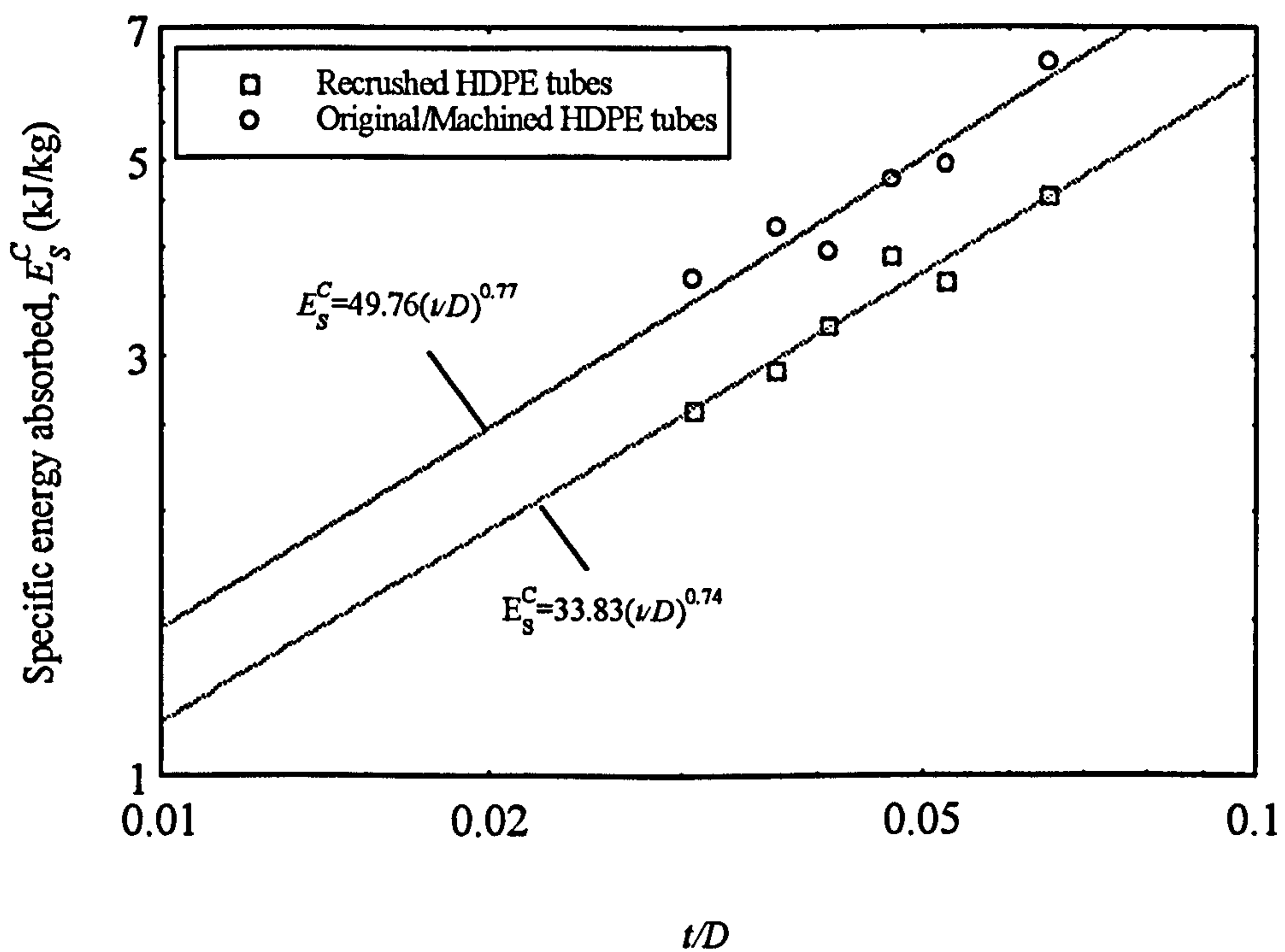


Figure A.10 : The log-log plot of specific energy absorbed against t/D , as recommended by Thornton and Magee [5].

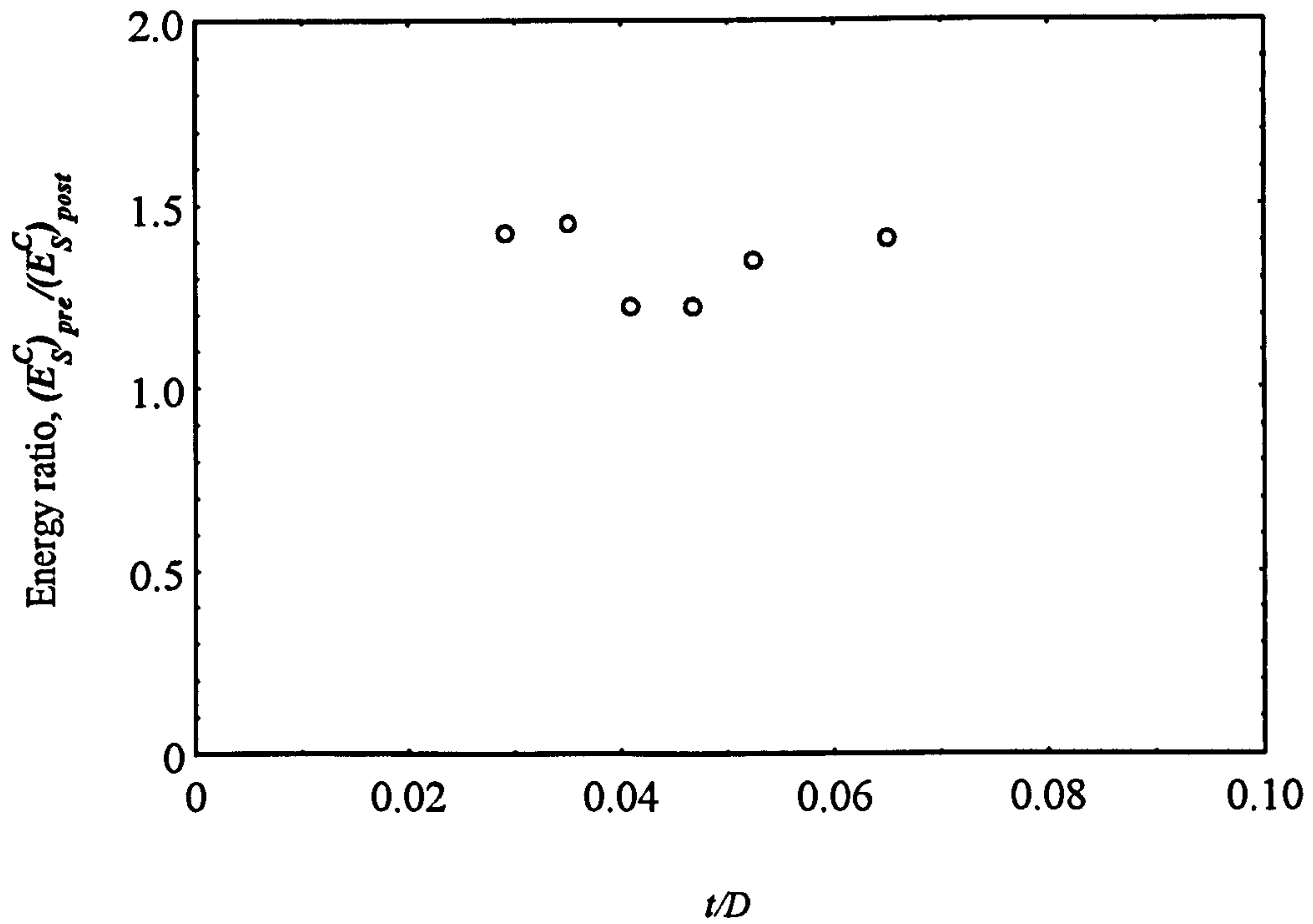


Figure A.11 : Energy ratio against t/D . This graph suggests that the loss in energy dissipation for recycled tubes is independent of t/D of the tubes.

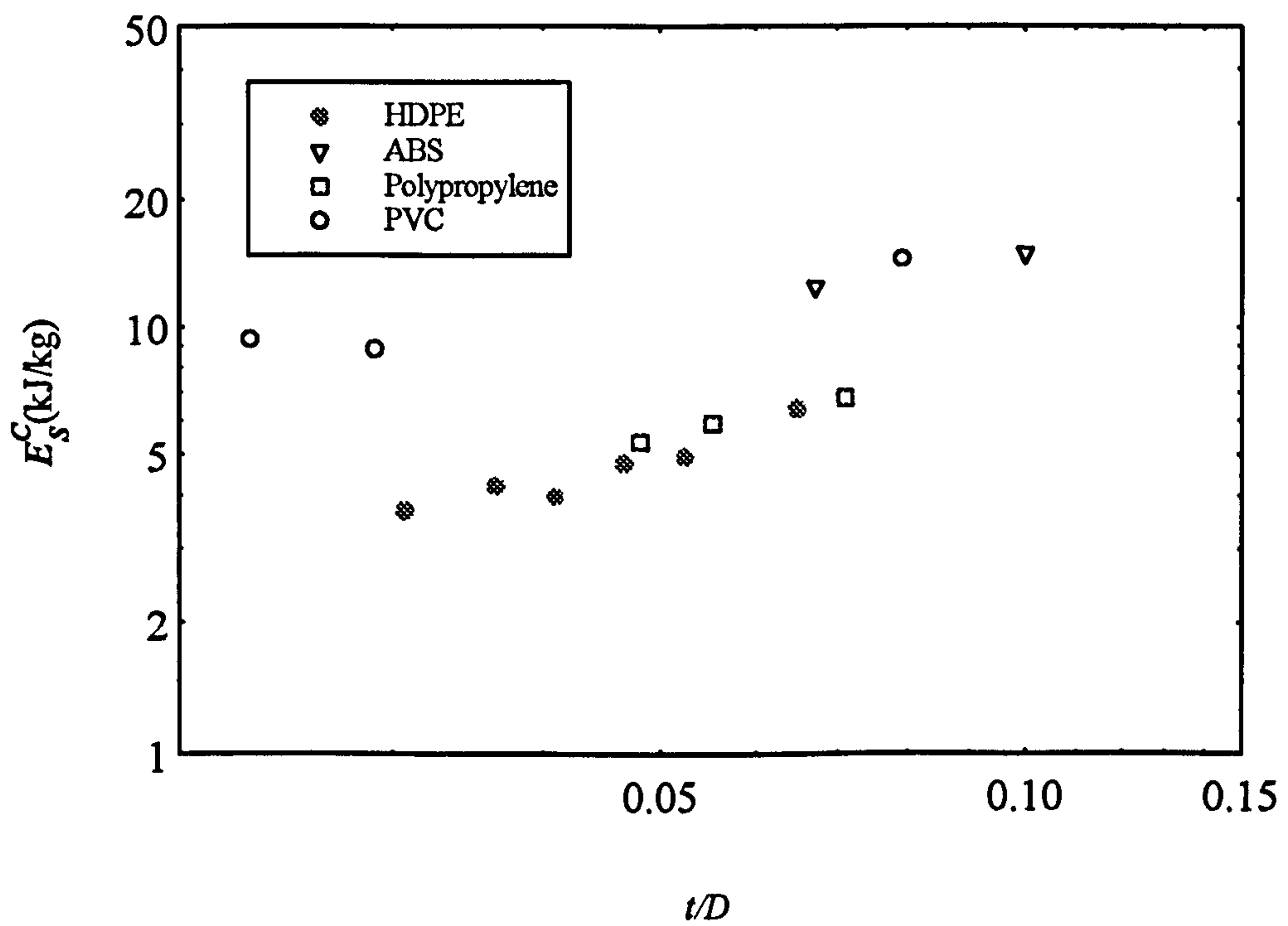


Figure A.12 : The log-log graphs of E_S^C against t/D for various polymeric tubes tested by Morgan [1] and the author.

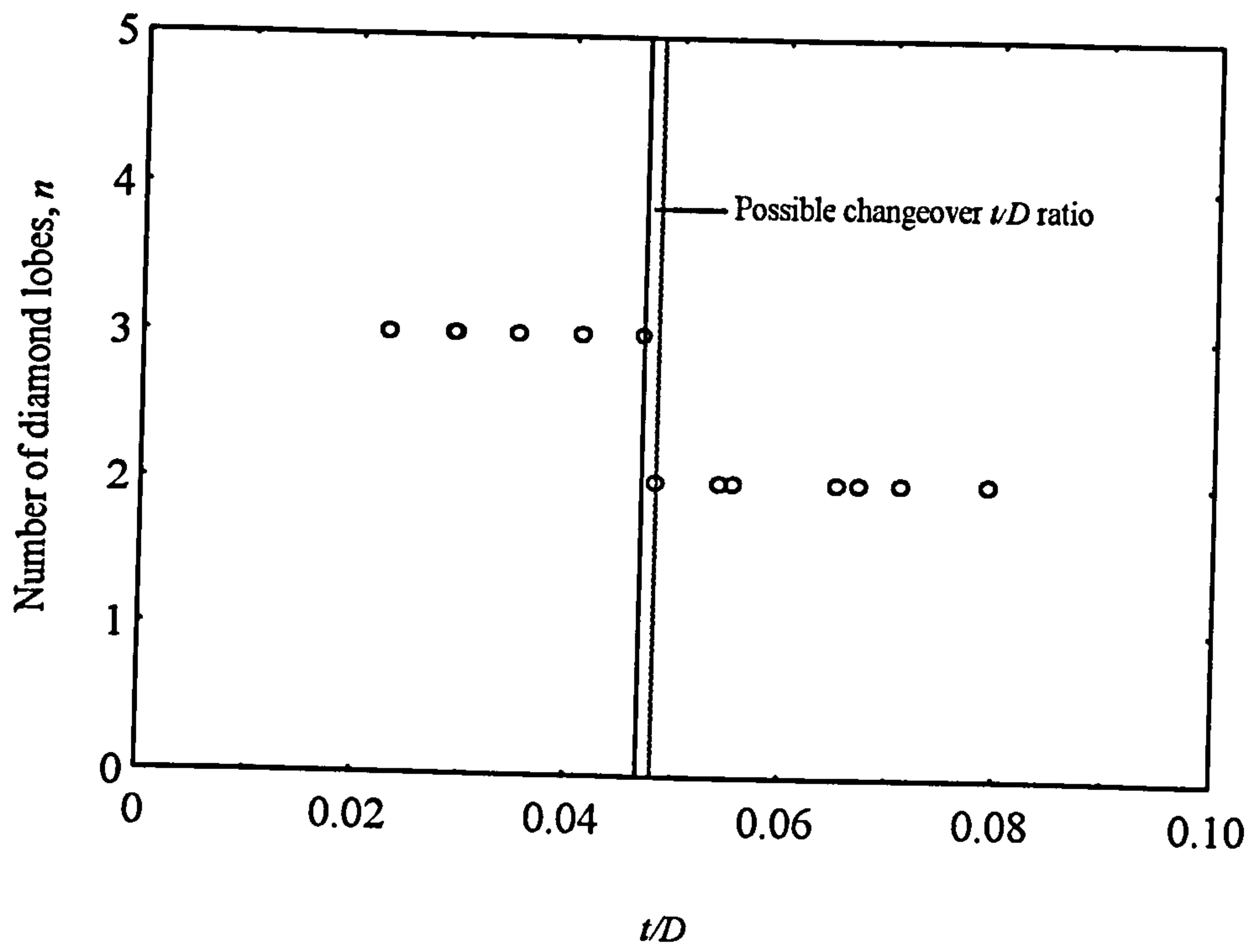


Figure A.13 : Number of diamond lobes against t/D .

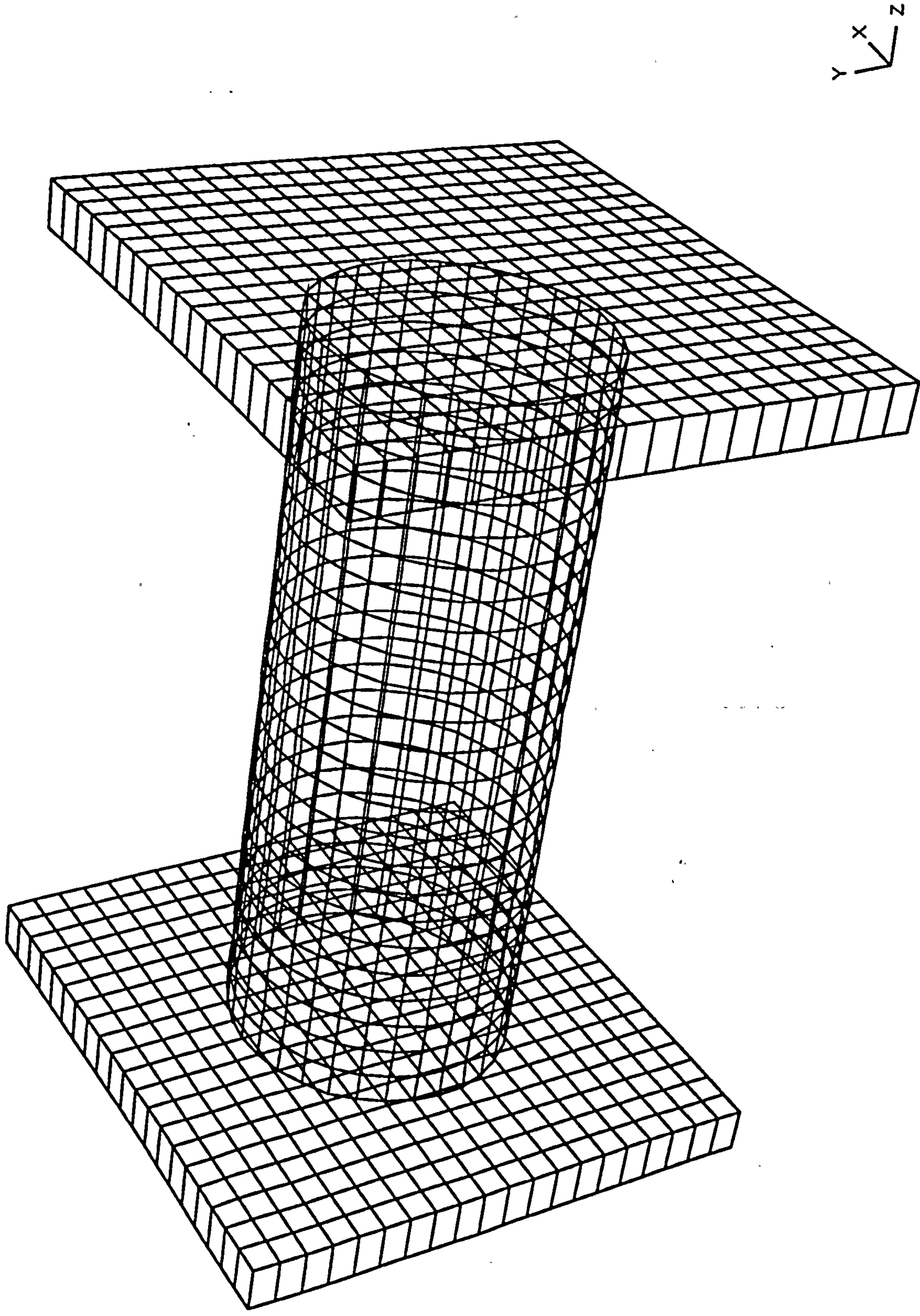


Figure B.1 : The model set-up for HDPE-true and HDPE-bilinear.

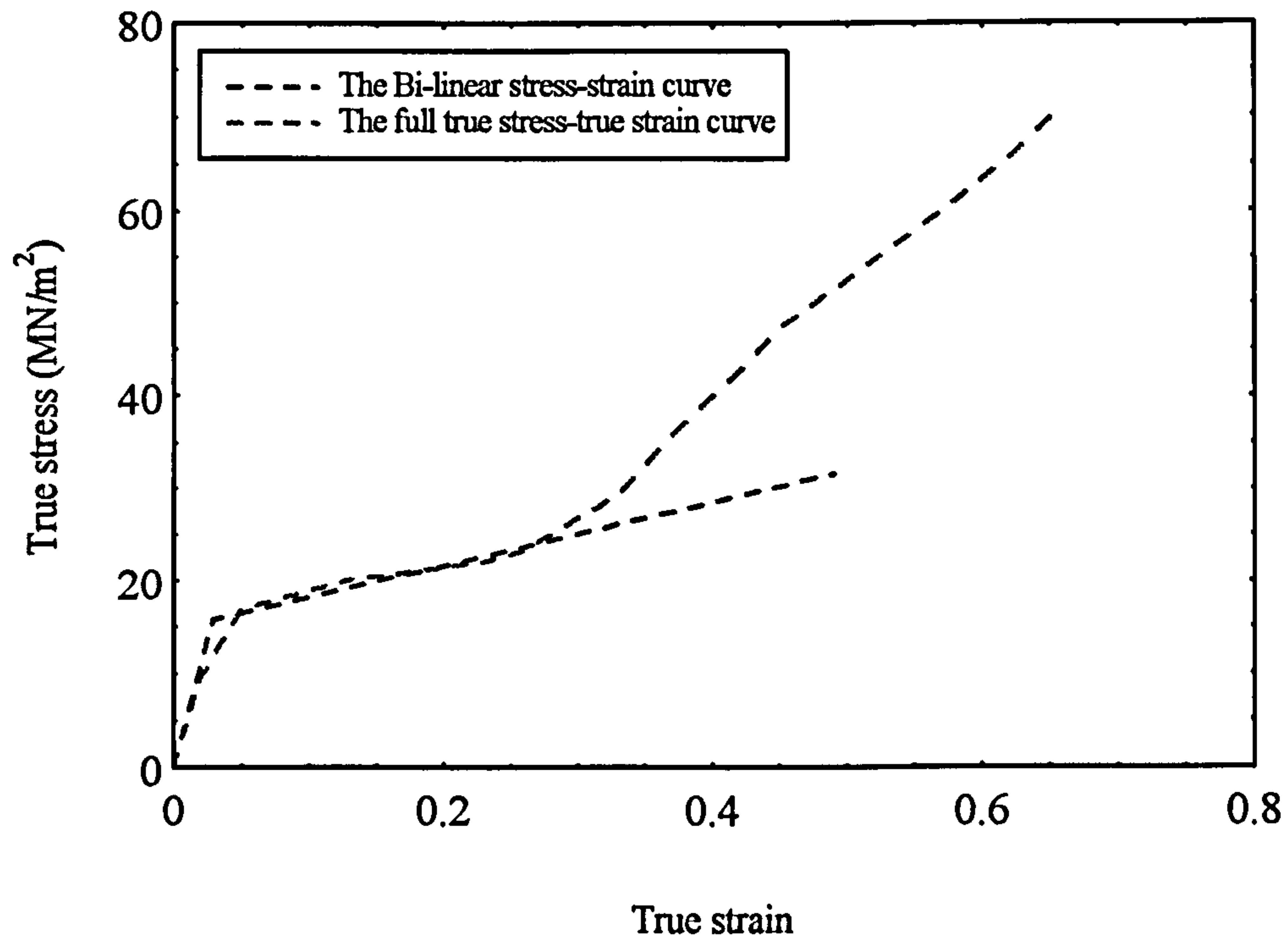


Figure B.2 : The full true stress-true strain curve and its bi-linear simplified curve.

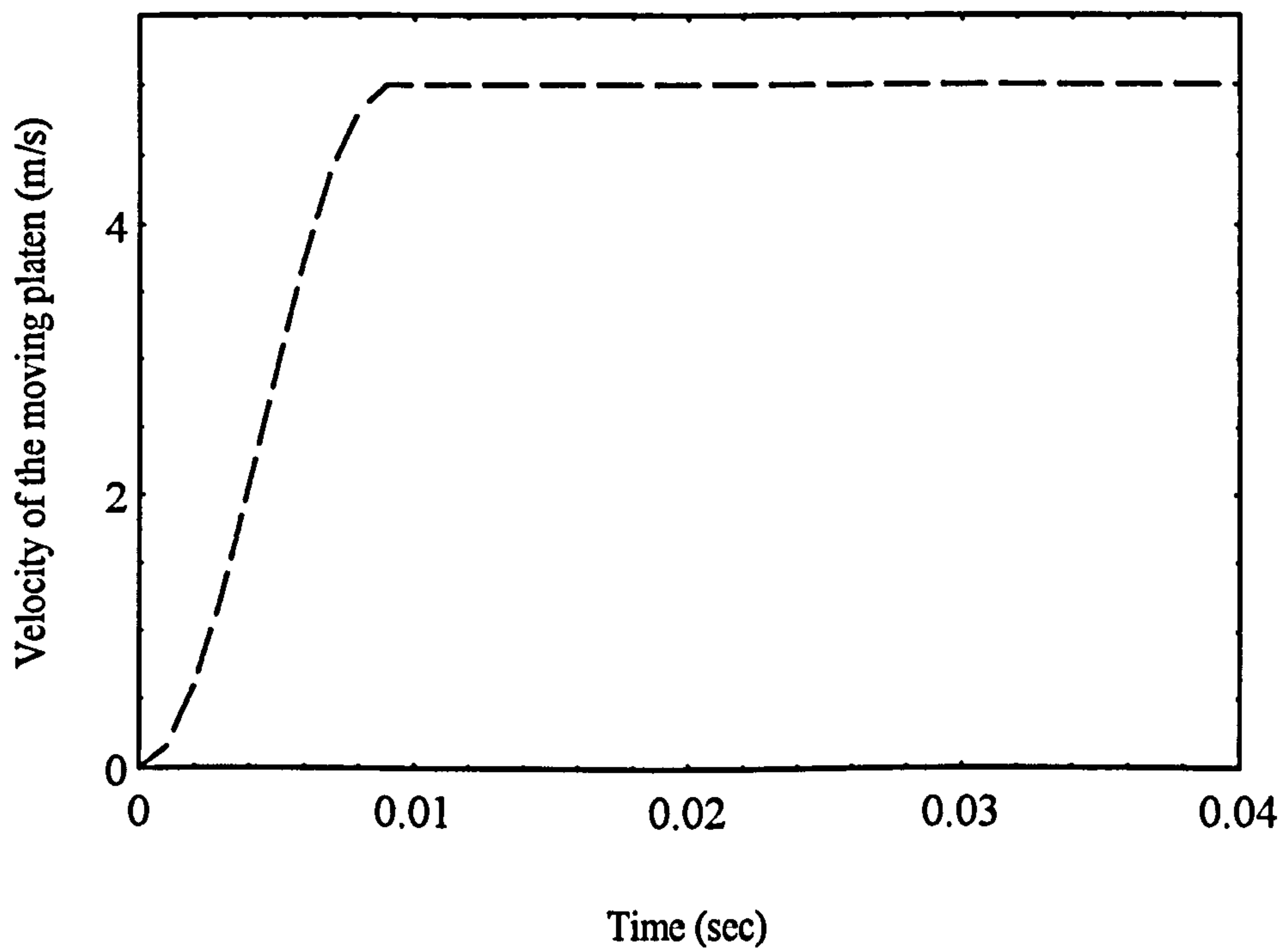


Figure B.3 : The velocity load curve for the moving platen.

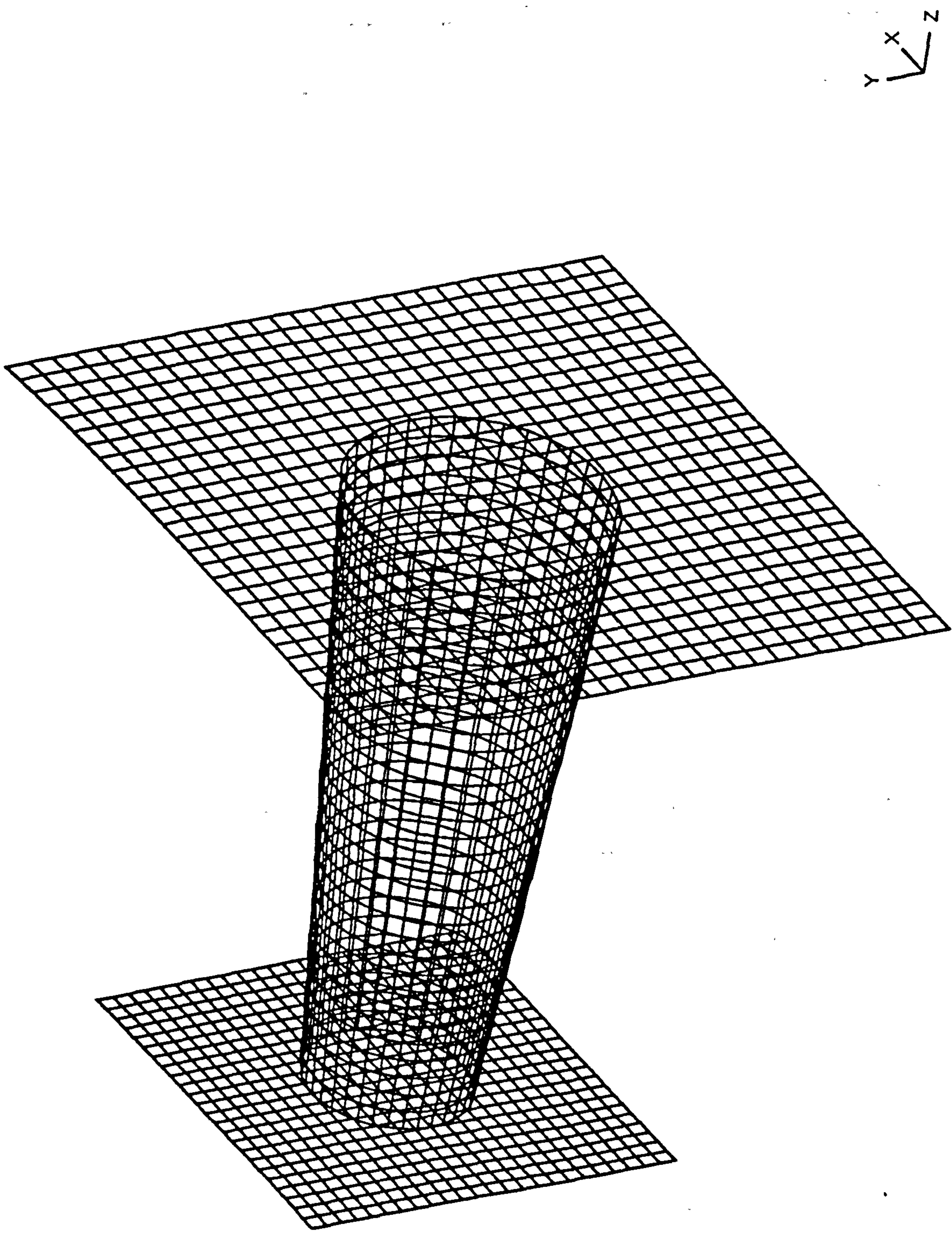


Figure B.4 : The model set-up for PVC-conic.

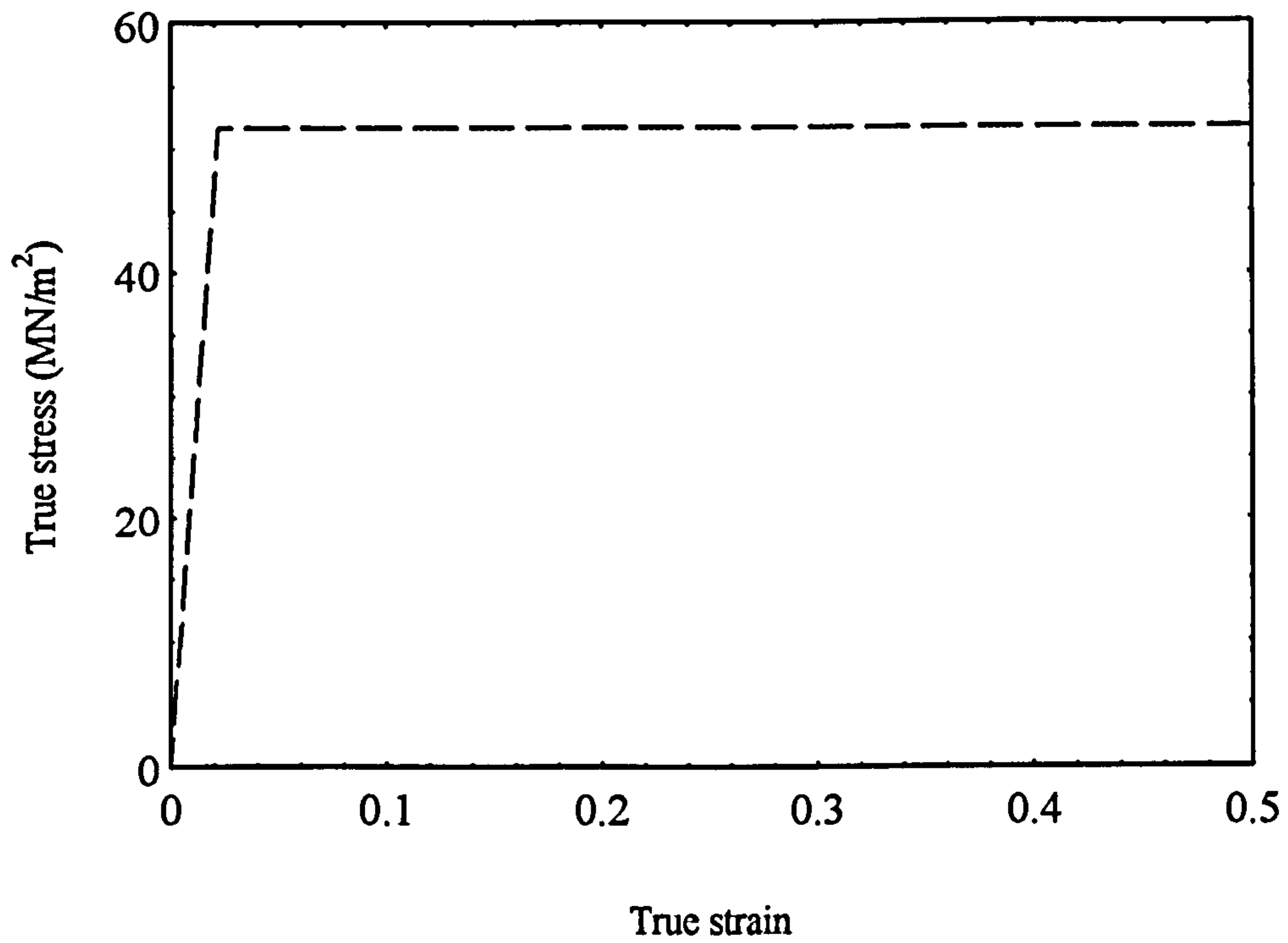


Figure B.5 : The stress-strain curve used in the crushing of the conical PVC model.

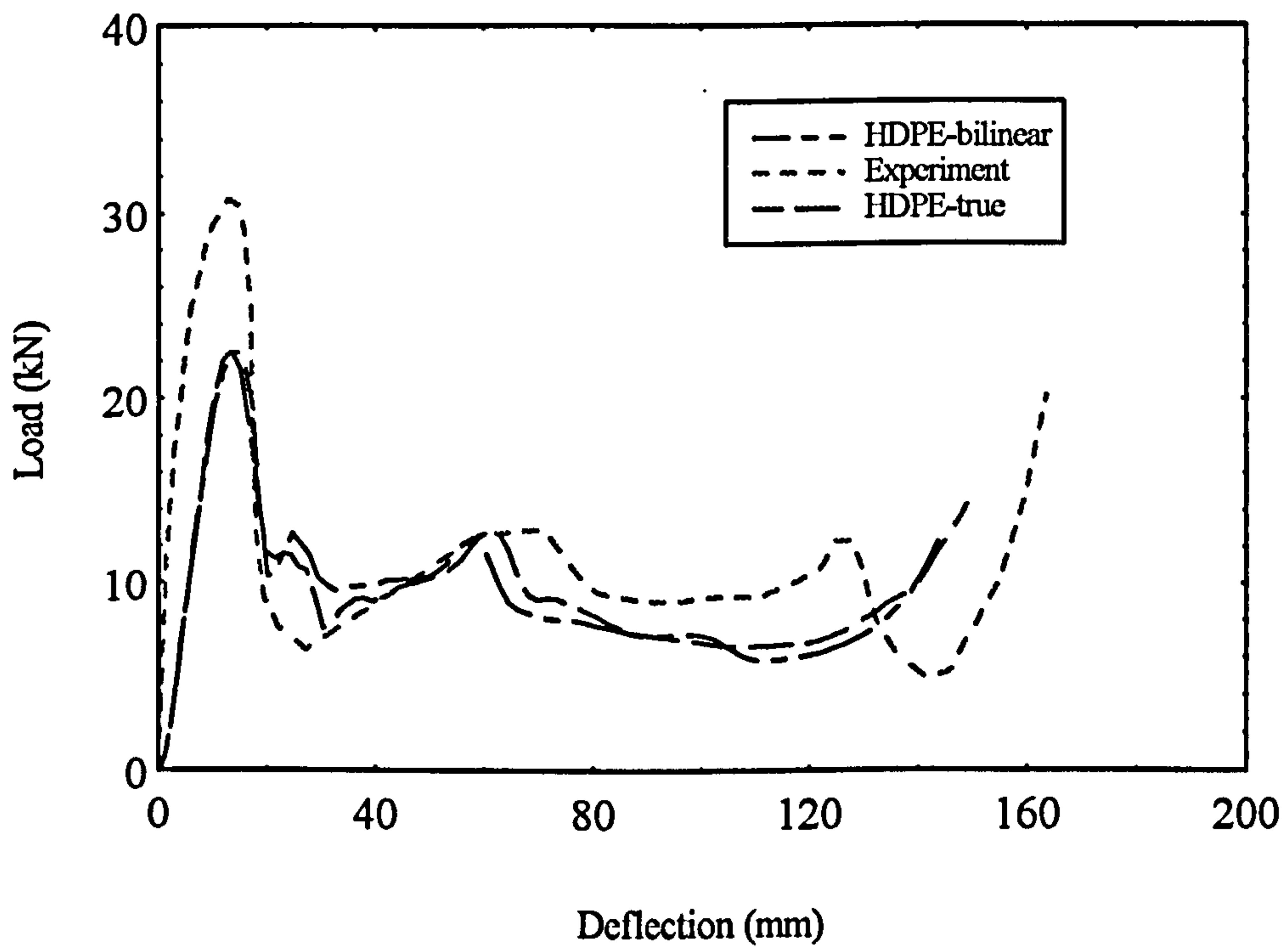


Figure B.6 : The load-deflection results for the crushing of HDPE tubes with $t/D=0.0651$.

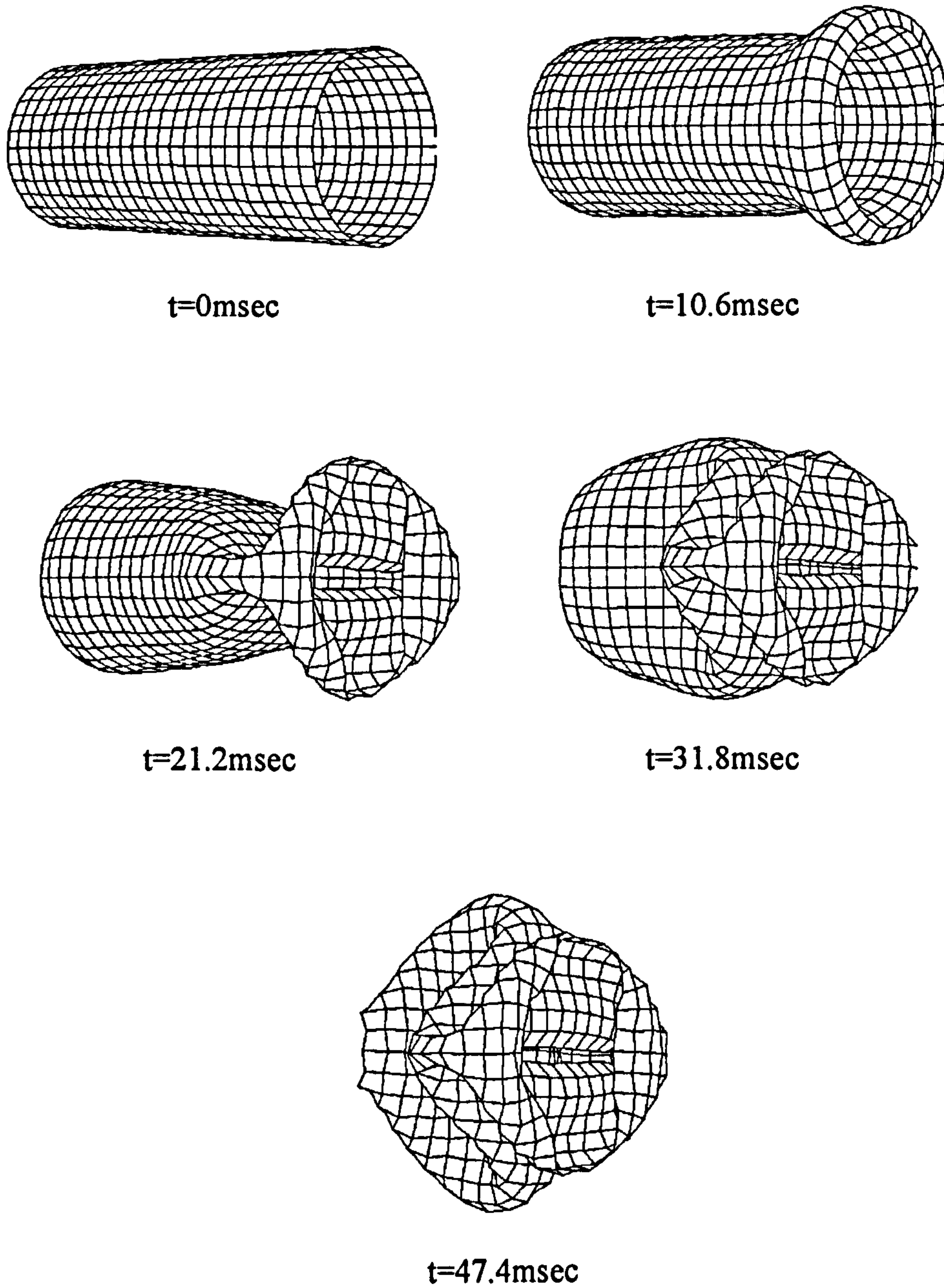


Fig. B.7 : The deformation sequence as predicted by the DYNA3D model HDPE-bilinear.

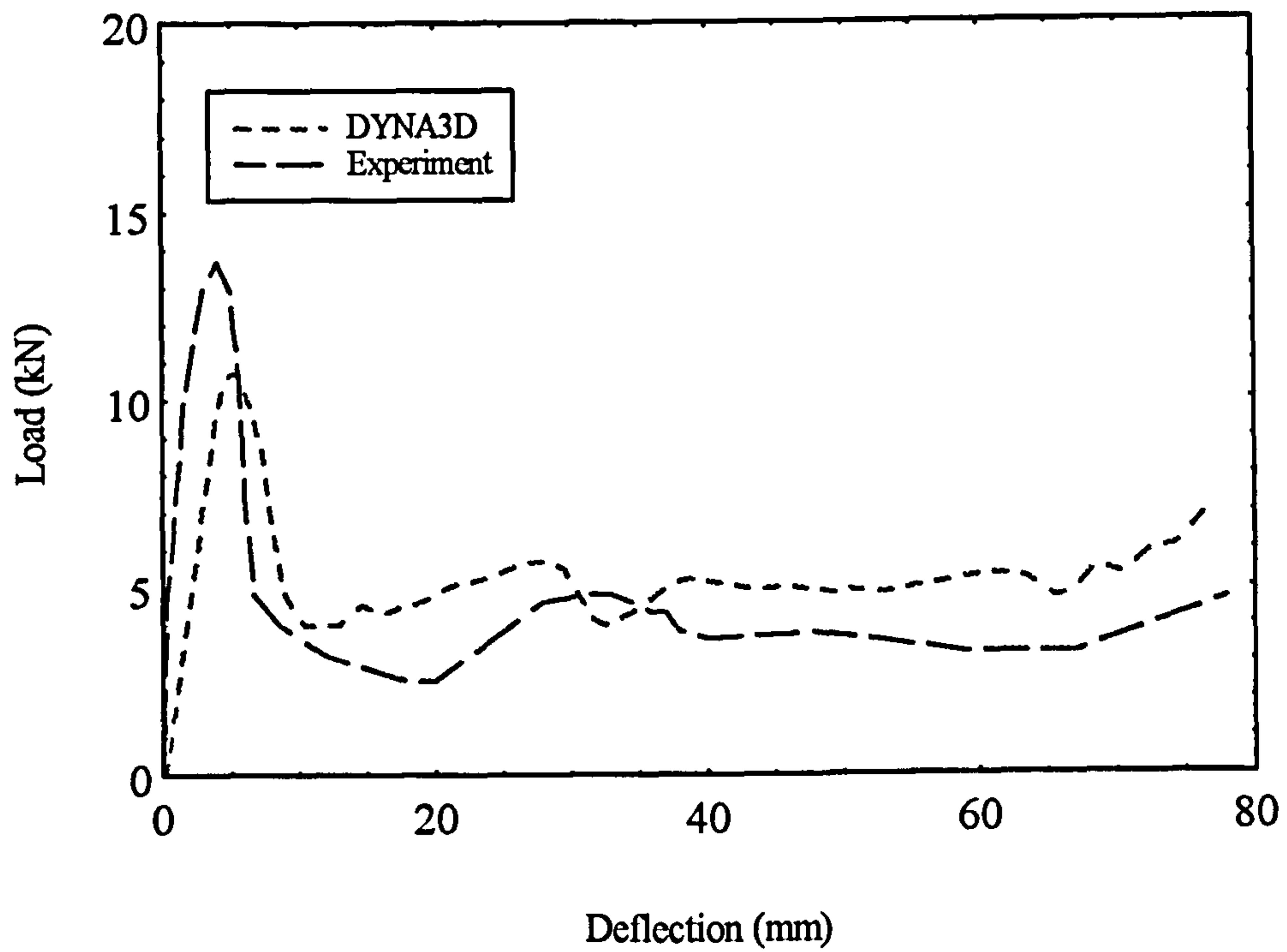


Figure B.8 : The load-deflection results for the crushing of HDPE tubes with $t/D=0.0351$.

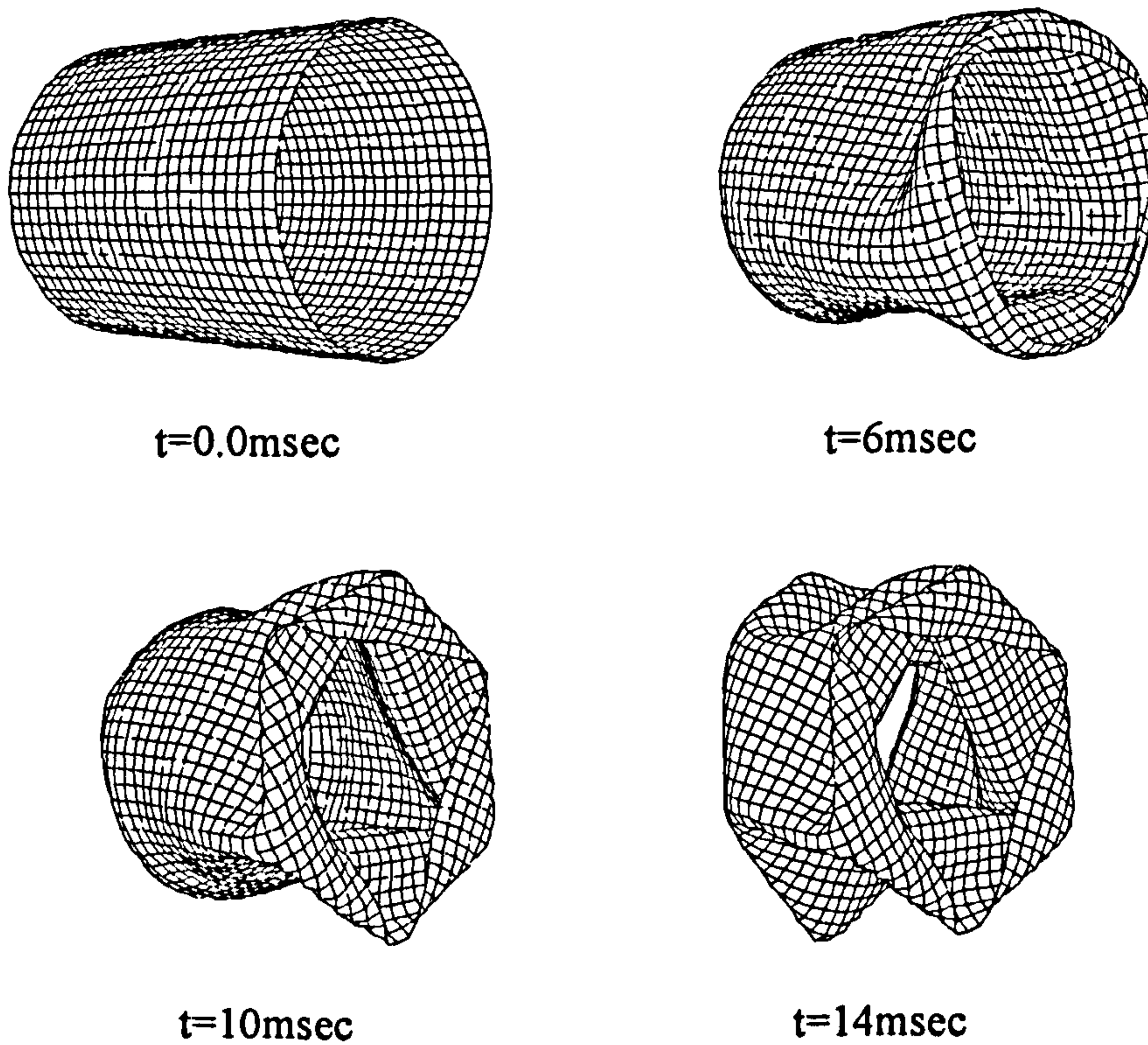


Figure B.9 : The deformation sequence as predicted by the DYNA3D model.

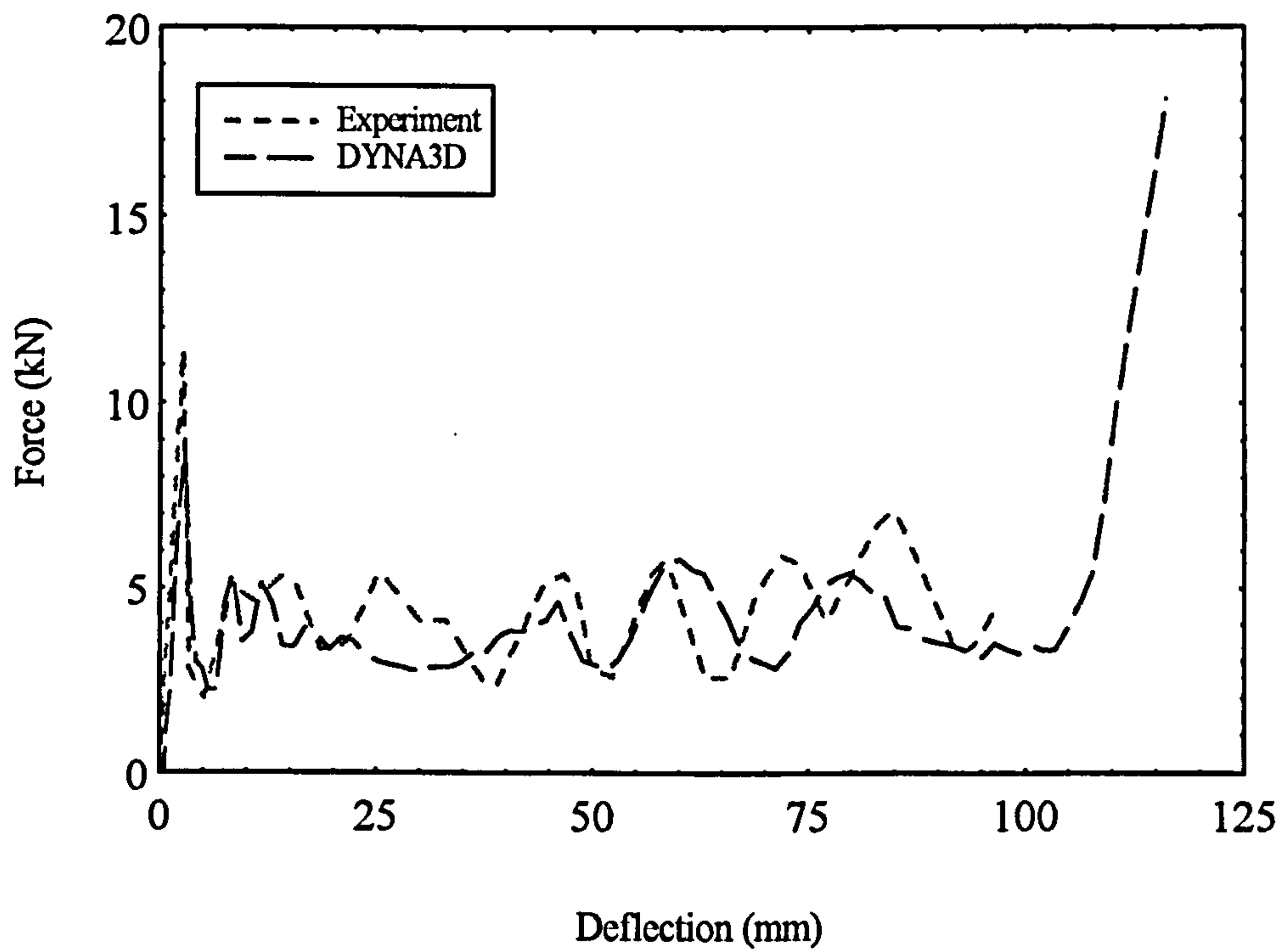


Figure B.10 : The load-deflection results for the crushing of the conical PVC tube.

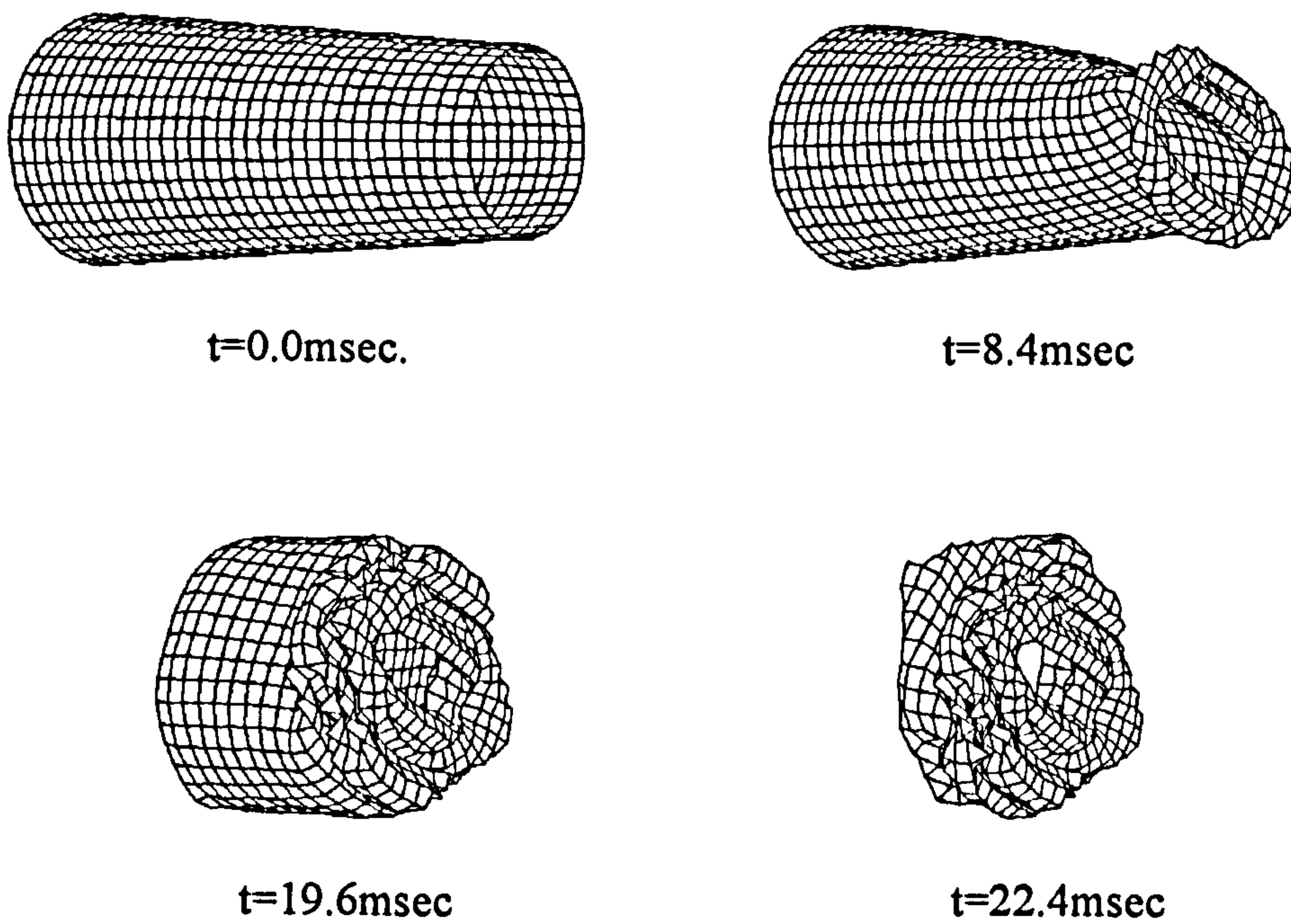


Figure B.11 : The deformation sequence as predicted by the DYNA3D model PVC-conic.