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National Highway
Traffic Safety
Administration

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Final Report

Evaluation of the BioSID and EuroSID-1

Volume I: Padded Wall Comparison Tests BioSID, EuroSID, and SID

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16. Abstract

In July 1989, the NHTSA initiated a project to evaluate the BioSID and compare its dynamic responses with those of the SID. This comparison was conducted in two phases. The first phase was a series of side impact sled simulations with a variety of padded loading surfaces. These sled tests were conducted with each of three dummies - SID, BioSID, and EuroSID-1. The second phase of the project compared crash test responses of the BioSID and SID. Additional evaluations included the repeatability and reproducibility of the BioSID's response and the durability of the production version dummy. The BioSID's dynamic responses were also compared to the International Standards Organization's recommendations for side impact dummies. Finally, preliminary calibration requirements for the BioSID were established.

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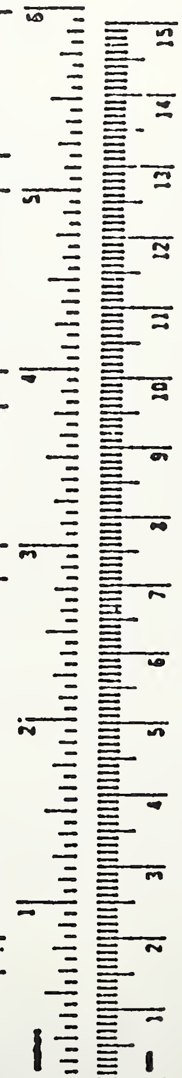
METRIC CONVERSION FACTORS

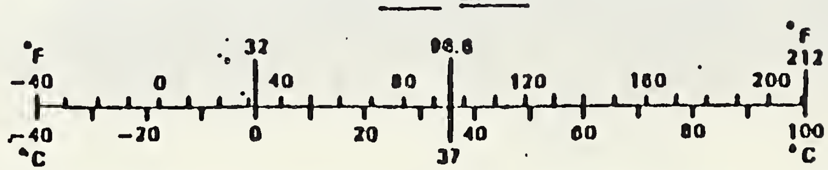
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric ton	t
		VOLUME		
tsp	teaspoons	5	milliliters	mL
Tbsp	tablespoons	15	milliliters	mL
in^3	cubic inches	16	milliliters	mL
fl oz	fluid ounces	30	milliliters	mL
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	5/9 (after subtracting 32)	degrees Celsius	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric ton (1000 kg)	1.1	short tons	
		VOLUME		
mL	milliliters	0.03	fluid ounces	fl oz
mL	milliliters	0.06	cubic inches	in^3
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5 (then add 32)	degrees Fahrenheit	°F



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Department of Transportation
National Highway Traffic Safety Administration

TECHNICAL SUMMARY

Report Title:	Date:
Evaluation of the BioSID and EuroSID-1 Volume I: Padded Wall Comparison Tests - BioSID, EuroSID-1, and SID	July 1991
Report Author(s): David S. Zuby, TRC, Inc.	

The National Highway Traffic Safety Administration (NHTSA) issued a rule in 1990 which requires full scale crash tests to evaluate side impact protection of passenger cars. The rule instituted the use of the NHTSA Side Impact Dummy (SID) as a human surrogate to evaluate the risk of human injury in these crash tests. Two alternative dummy development efforts were in progress at that time. The EuroSID-1 is the result of a two year effort to improve the original EuroSID which the NHTSA has previously evaluated. More recently, General Motors (GM) initiated the development of a side impact dummy, the BioSID. The BioSID concept was realized through efforts by the Society of Automotive Engineers (SAE) and First Technology Safety Systems, Inc. (formerly Humanetics), a supplier of anthropomorphic test devices (ATD).

In July 1989, the NHTSA began a research project to evaluate the BioSID and compare it with the SID. A comparison of the dummies' dynamic responses was the main objective of this program. The first phase of this comparison was accomplished through a series of side impact sled simulations, which also included the EuroSID-1 responses. The second phase of the project compared crash test responses of the BioSID and SID. Since the NHTSA had not previously examined the BioSID, additional tests were conducted to assess repeatability and reproducibility, and establish preliminary calibration requirements. The complete test program represented a significant number of tests with the BioSID, so an appraisal of the dummy's durability was also possible. This final report describes procedures and results of the tests and analyses conducted as part of this project. The report is divided into six volumes which each describe a different aspect of the project.

VOLUME I	"Padded Wall Comparison Tests: BioSID, EuroSID-1, and SID"
VOLUME II	"Analysis of the SID and BioSID Side Impact Crash Tests"
VOLUME III	"BioSID Calibration Data Analysis"
VOLUME IV	"BioSID Repeatability and Reproducibility"
VOLUME V	"BioSID Durability Analysis"
VOLUME VI	"Comparison of the Dynamic Responses of the BioSID s/n 01 & 02 to the ISO Guidelines for Side Impact Dummy Response"

Padded Wall Comparison Tests

The dummies' responses were compared through a series of controlled 32 km/h side impact simulations. Each dummy was subjected to a series of rigid and padded wall impacts on a HYGE sled. The seat and wall configuration was similar to that used by the University of Heidelberg for side impact cadaver testing. The stiffness of the impacted surface was varied in the padded wall tests over a range that was thought to include stiffnesses which the dummies would likely encounter in the crash environment. This was accomplished by using a 3" thickness of various padding materials to cover the rigid wall of the Heidelberg sled buck. The rib, spine, and pelvis accelerations, rib deflections, the Thoracic Trauma Index kernel (TTI(d)), and the Viscous Criterion (V*C) measured by the applicable dummies under the various conditions were compared.

All three dummies produced similar TTI(d)/stiffness relationships for the soft and medium stiffness pads (crush strength < 414 kPa). Although the lowest TTI(d) for each dummy was recorded with a different padding material, the particular materials were relatively close together in the overall range of stiffnesses. The minimum TTI(d) responses for SID, BioSID, and EuroSID were recorded for materials with crush strengths of 131 kPa, 103 kPa, and 65.5 kPa, respectively.

Rib displacement could not be used to distinguish the different padding conditions with any of the three dummies. The SID was not designed to measure deflection and the BioSID and EuroSID deflection measurements did not display acute sensitivity to the range of wall stiffnesses presented in this test matrix. The EuroSID deflection measurements indicated that the full rib stroke of the dummy was approached in every test. The BioSID rib deflection measurements did not indicate that the ribs' deflections were physically obstructed, yet the range of peak deflections produced in these tests was relatively small.

The viscous criterion values indicated by the BioSID and EuroSID-1 did distinguish between the various padded surfaces. The lowest V*C recorded for both dummies was produced by a padding material which represented a crush strength of 221 kPa.

Finally, the pelvis responses of the three dummies were similar. The lowest pelvis acceleration response for all three dummies was measured in impacts with a material of crush strength 221 kPa.

<u>Analysis of Side Impact Crash Tests</u>

The NHTSA conducted five side impact crash tests with the BioSID in vehicles identical to those which the NHTSA had recently recorded crash responses of the SID. The five vehicles were a 1987 2-dr Nissan Sentra, a 1988 4-dr Ford Taurus, a 1988 4-dr Hyundai Excel, a 1987 4-dr Chevrolet Cavalier, and a 1988 4-dr Toyota Tercel. Additionally, the results of crash tests sponsored by the Motor Vehicle Manufacturer's Association (MVMA) were considered. The MVMA conducted its tests with a 1990 4-dr Pontiac 6000 in both baseline and padded door configurations. All of the crash tests were conducted in accordance with the crash test procedures described in the upgraded FMVSS 214.

Inspection of the crash test data indicated that the shapes of the driver rib acceleration histories of the BioSID and SID were similar, while those for the passenger were more frequently different. The shapes of the BioSID spinal and pelvic acceleration histories were generally very similar to those of the SID, for both driver and passenger. Furthermore, the velocities calculated from acceleration measurements indicated that both dummies experienced similar velocity exposures, in both seat positions.

The differences between the SID and BioSID TTI(d) and pelvis acceleration responses were evaluated with a two-way analysis of variance. The analysis of driver seated dummy responses showed that at a significance level of 10% (α=0.10), the null hypothesis (H_0: The SID and BioSID produce the same TTI(d) and peak pelvis acceleration) could not be rejected. The P-value for driver TTI(d) was 10.63% and the P-value for the driver pelvis accelerations was 69.62%. The rear seat passenger data resulted in rejection of the same H_0. The P-values for the rear seat passenger TTI(d) and pelvis acceleration responses were 0.01% and 0.13%, respectively. Despite the similarity of responses for driver seated SID and BioSID, a similarity between rear seated passenger SID and BioSID responses was not observed.

<u>BioSID Calibration Data</u>

Although GM and the SAE had proposed a calibration procedure for the BioSID, calibration response requirements did not exist. Preliminary calibration response requirements were established prior to the NHTSA crash testing, using calibration response data that had been collected during the Padded Wall Sled Test Comparison phase of this project. A greater number of dummies and calibration sites will be needed to establish final calibration requirements.

Analysis of the calibration data for the BioSID which existed preceding the NHTSA crash tests suggested that the dummies' calibration responses were both repeatable and reproducible to within tolerances generally accepted for ATD performance. In fact, a coefficient of variation less than 5% was calculated for many of the calibration responses. The proposed preliminary calibration responses were specified as the smaller range of either $\pm 10\%$ or $\pm 3\sigma$ about the average response. Although the $\pm 3\sigma$ corridors had a smaller range than the $\pm 10\%$ corridors, nearly all of the data used to establish the $\pm 3\sigma$ corridors could considered valid calibration data.

BioSID Repeatability and Reproducibility

Repeatability and reproducibility are properties associated with the capability of a human surrogate test device to produce similar responses when exposed to separate but similar dynamic environments. Specifically, **repeatability** has been defined as the ability of a single device to produce similar responses when exposed to replicate environments; and **reproducibility** as the ability of multiple replicate devices to produce similar responses. The repeatability and reproducibility of the early production BioSIDs were evaluated through a series of five sled tests with each of two padded wall configurations. The reliability of the reproducibility assessment, however, is limited by the small sample of only 2 dummies. The reproducibility of the BioSID will be more accurately known as more dummies become available.

Repeatability of the BioSID, in this analysis, was evaluated by calculating the coefficient of variation for each of the considered responses using data from several tests. The calculated C.V. were compared to a value of 6%, which was established in the FMVSS 214 FRIA as an acceptable level of repeatability for the SID. This level of variability is comparable to the Hybrid III, and does not sacrifice sensitivity for FMVSS testing. The coefficients of variation which were calculated for the BioSID's thoracic rib accelerations and displacements and the spine and pelvis accelerations were less than 6% for all but a few responses. The repeatability of the TTI and V*C were not affected by these few responses, as the C.V. for both injury criteria were also less than 6%.

A perfunctory assessment of the BioSID's reproducibility was made by an examination of the coefficients of variation that were calculated by combining data from several tests with both dummies. Coefficients of less than 8% were considered acceptable because the same level of reproducibility had been established for the SID in the FMVSS 214 FRIA. The coefficients of variation which were calculated for the thoracic rib accelerations and displacements and the spine and pelvis accelerations were less than 8% except for a few responses. The reproducibility of the TTI and V*C were not affected by these few responses, as the C.V. for both injury criteria were within the acceptable range.

Durability of BioSID

A record of durability and serviceability of the BioSID devices was kept throughout this project. The dummies numbered s/n 01 & 02 were subjected to a fairly aggressive testing program and only suffered minor failures. The level of fatigue experienced by those components which have been replaced seemed reasonable given the vigor of the program. The fatiguing and component failures which were observed were considered minor because none had significantly effected the performance of the dummies. With minor exceptions, calibration responses were very consistent which suggested that the dummies' performances were not affected by the observed fatigue and component failures. It was concluded that the BioSID displayed durability commensurate with the durability of other human surrogate test devices in the field of automotive occupant safety research.

Comparison of the BioSID s/n 01 & 02 Dynamic Responses
with ISO Recommendations for Side Impact Dummy Response

Several of the tests conducted in this project were similar to those described in the International Standards Organization's (ISO) guidelines for side impact dummy response. The lateral head drop and the lateral shoulder impact calibration tests, as well as the 27.4 km/h rigid wall and 37 km/h APR padded wall sled tests were conducted in accordance with the ISO recommendations. These four tests were used to check the BioSID's dynamic response with respect to the ISO recommended response for side impact dummies.

The lateral head impact response and the padded wall pelvis force response of the BioSID met the ISO recommendations. The maximum shoulder displacement for the shoulder impact was within one standard deviation of the recommended response. The remaining responses examined in this analysis did not meet the ISO recommendations.

1.0 INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) issued a Rule in 1990, which requires that side impact protection of passenger cars be evaluated by full scale crash testing. The rule instituted the use of the NHTSA Side Impact Dummy (SID) as a human surrogate to evaluate the risk of human injury in these crash tests. Two alternative dummy development efforts were in progress at that time. The EuroSID-1 is the result of a two year effort to improve the original EuroSID (1), which was previously evaluated by the NHTSA (2). The EuroSID was designed and developed by a group of European research laboratories working together under the auspices of the European Experimental Vehicle Committee. More recently, General Motors (GM) initiated the development of a another side impact dummy, the BioSID (3). The BioSID concept was realized through an effort by the Society of Automotive Engineers (SAE) and 1st Technology Safety Systems, Inc. (formerly Humanetics), a supplier of anthropomorphic test devices (ATD).

In July 1989, NHTSA began a research project to evaluate the BioSID and EuroSID-1, and to compare them with the SID. A comparison of the dynamic responses of the BioSID, EuroSID-1 and SID was conducted as a part of this program. The dummies' responses were compared through a series of controlled 32 km/h side impact simulations. Specifically, each dummy was subjected to a series of whole body accelerations on a side impact HYGE sled buck. The apparent strength, or stiffness, of the impacted surface was varied in these tests. The stiffness range was thought to be representative of what the dummies would likely encounter in the crash environment. The rigid side wall of the HYGE sled buck was covered by a 3" thickness of various padding materials to achieve the various stiffnesses. The rib, spine, and pelvis accelerations, rib deflections, the Thoracic Trauma Index Kernel (TTI(d)), and the Viscous Criterion (V*C) measured by the three dummies under the various conditions were compared.

The 3" padding thickness was believed to be a realistic thickness for actual padding countermeasures in automobiles. However, there are significant differences between these test conditions and the actual crash environment. Therefore, the results of these tests should not be construed as an evaluation of the efficacy of the various padding materials as side impact countermeasures. The materials described here were used as tools to evaluate the three side impact dummies. It was useful to measure the dynamic force/deflection properties of the various materials to provide a basis for comparison and selection. The results of the dynamic force/deflection testing with the candidate padding materials are also reported.

2.0 PADDING SELECTION TESTS

Several padding materials were surveyed as candidates for the side impact sled tests with the three side impact dummies. Materials ranging in stiffness from very soft to nearly rigid were desired to test the full range of the dummies' capabilities. Ideally, a single padding material formulation available in various densities would have been chosen to ensure that dummy response differences resulted only from stiffness differences. Unfortunately, it was necessary to use a variety of material formulations to achieve the desired range of stiffnesses.

The dynamic force/deflection characteristics of the padding materials were measured for conditions similar to the sled test environment. The results of such tests were useful for comparing the materials and selecting appropriate padding for the sled tests. The measured force/deflections, however, do not define the absolute characteristics of these materials or indicate efficacy as an actual side impact countermeasure.

2.1 Procedure

The materials that were tested in this survey of padding materials are listed in Table 1. Uniform samples, measuring 178 mm x 165 mm x 152 mm deep, were fabricated from most of the materials for this survey testing. Some of the materials were only available in smaller quantities, therefore, 178 mm x 102 mm x 152 mm deep were used. As the materials were only available in thicknesses ranging from 25 mm to 102 mm, several layers were necessary to form the 152 mm sample depth. Samples made from more than one layer were glued together with an aerosol automotive trim adhesive.

These tests were meant to simulate a loading similar to the dummy loading in the 32 km/h sled tests described later. The 27.2 kg mass of the impactor was chosen to match the upper body (head, upper torso, & arms) mass of a 50th percentile ATD (4). The impactor's rigid face, which contacted the entire surface of the padding samples, measured approximately 178 mm x 165 mm. The impact velocity was approximately 32.2 km/h. Each sample was mounted to a rigid load plate with its center aligned with the impactor face. The impact force was measured by two Interface Model 1210-LT load cells located behind the load plate. The deflection of the sample was measured with a linear potentiometer attached to the ram. The data were collected through the multiplex data acquisition system (MDAS) at VRTC, digitized by a TransEra 7000 at a frequency of 8000 Hz, and subsequently transferred to VRTC's VAX mainframe for additional processing. The force data were digitally filtered in accordance with SAE Recommended Practice for Data Class 180. The force measured by both load cells was added to calculate the total crush force. The total crush force and the

TABLE 1 -- Padding Materials Tested as Candidates for Side Impact Sled Testing

Material Specification	Density Tested	Manufacturer
ARCEL 310	1.5 - 3.0 pcf	ARCO Chemical Co.
ARCEL 512	2.5 - 4.0 pcf	ARCO Chemical Co.
ARPAK 4322	2.3 pcf	ARCO Chemical Co.
ARPRO 3313	1.5 pcf	ARCO Chemical Co.
ARSAN 601	1.0 pcf	ARCO Chemical Co.
DYTHERM (Grades M214N2, M208N2)	1.5 - 4.0 pcf	ARCO Chemical Co.
ETHAFOAM 220	2.2 pcf	DOW Chemical Co.
ETHAFOAM LC 200	1.9 pcf	DOW Chemical Co.
ENSOLITE Type AAC	4.9 pcf	Uniroyal Rubber Co.
Floral Arranging Foam	1.9 pcf	Foliage Co. of America
Synthetic Foam Rubber	1.0 - 2.0 pcf	Unknown

impacted area of each sample was used to calculate the average crush strength. The deflection measurements were normalized to the sample depth and are reported as percent of sample depth.

2.2 Results

Figures 1-3 show the crush strength/compression curves that characterize the 32 km/h dynamic force/deflection properties of the tested materials. The average crush strength for the 10% - 60% range had previously been used at VRTC to classify padding materials. The crush strength/compression curves in Figures 1-3 were approximately linear for this range. Therefore, as an abbreviation of this convention, each material was classified for later reference by its crush strength measured at 35% (53 mm) compression. Table 2 lists the tested materials with their characteristic strength.

TABLE 2 -- Results Material Survey Testing

Test Number	Number of Layers For 152 mm Depth	Specimen Type	Crush Strength At 35%
43	3	Synthetic Foam Rubber 1.1 pcf	14 kPa
42	3	Synthetic Foam Rubber 2.0 pcf	21 kPa
51	3	Ethafoam LC 200 1.9 pcf	103 kPa
39	3	Ethafoam 220 2.2 pcf	117 kPa
46	2	ARSAN 601 0.9 pcf	131 kPa
48	2	ARPAK 4322 2.3 pcf	152 kPa
40	6	Ensolite Type AAC 4.9 pcf	179 kPa
41	6	Floral Foam 1.9 pcf	200 kPa
45	2	ARCEL 310 1.6 pcf	200 kPa
47	2	ARPRO 3313 1.5 pcf	200 kPa
28	3	ARCEL 310 1.5 pcf	220 kPa
50	1	DYTHERM M208N2 1.5 pcf	241 kPa
29	3	ARCEL 310 2.0 pcf	269 kPa
44	2	ARCEL 512 2.2 pcf	269 kPa
32	3	ARCEL 512 2.5 pcf	324 kPa
30	3	ARCEL 310 2.5 pcf	352 kPa
33	3	ARCEL 512 3.0 pcf	365 kPa
31	3	ARCEL 310 3.0 pcf	414 kPa
49	2	DYTHERM M208N2 2.5 pcf	469 kPa
34	3	ARCEL 512 3.5 pcf	490 kPa
37	2	DYTHERM M208N2 3.0 pcf	558 kPa
35	3	ARCEL 512 4.0 pcf	565 kPa
38	2	DYTHERM M214N2 4.0 pcf	848 kPa

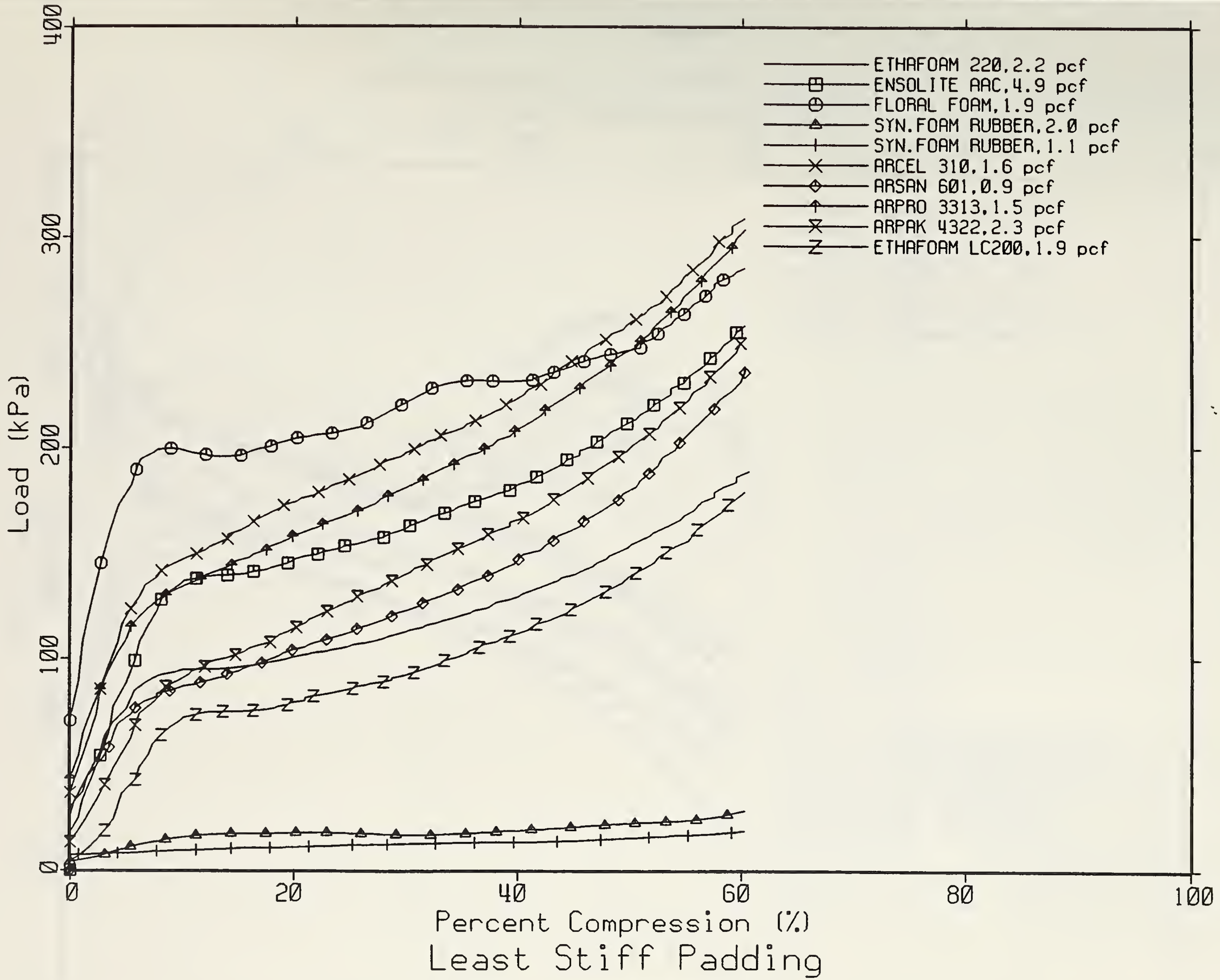
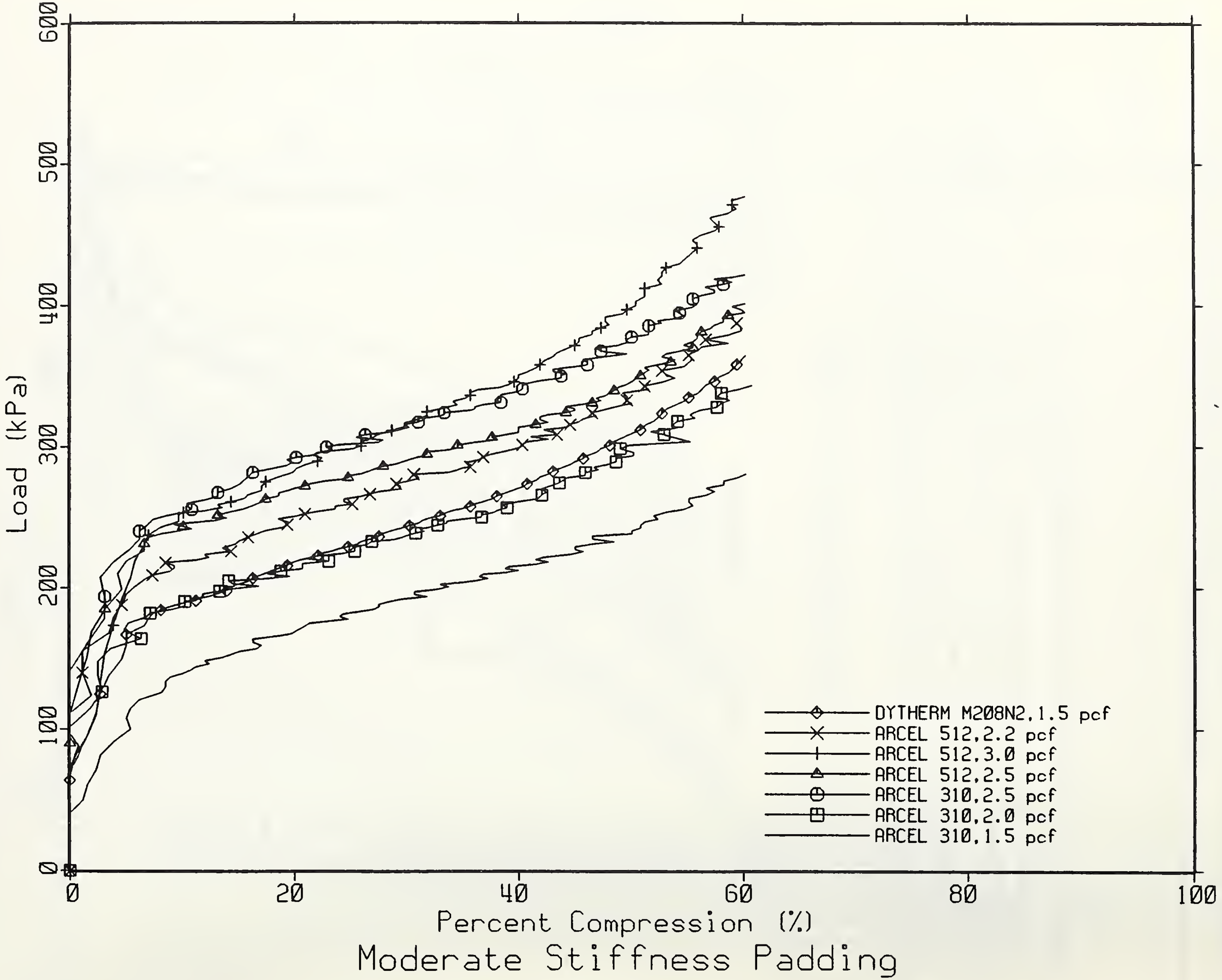
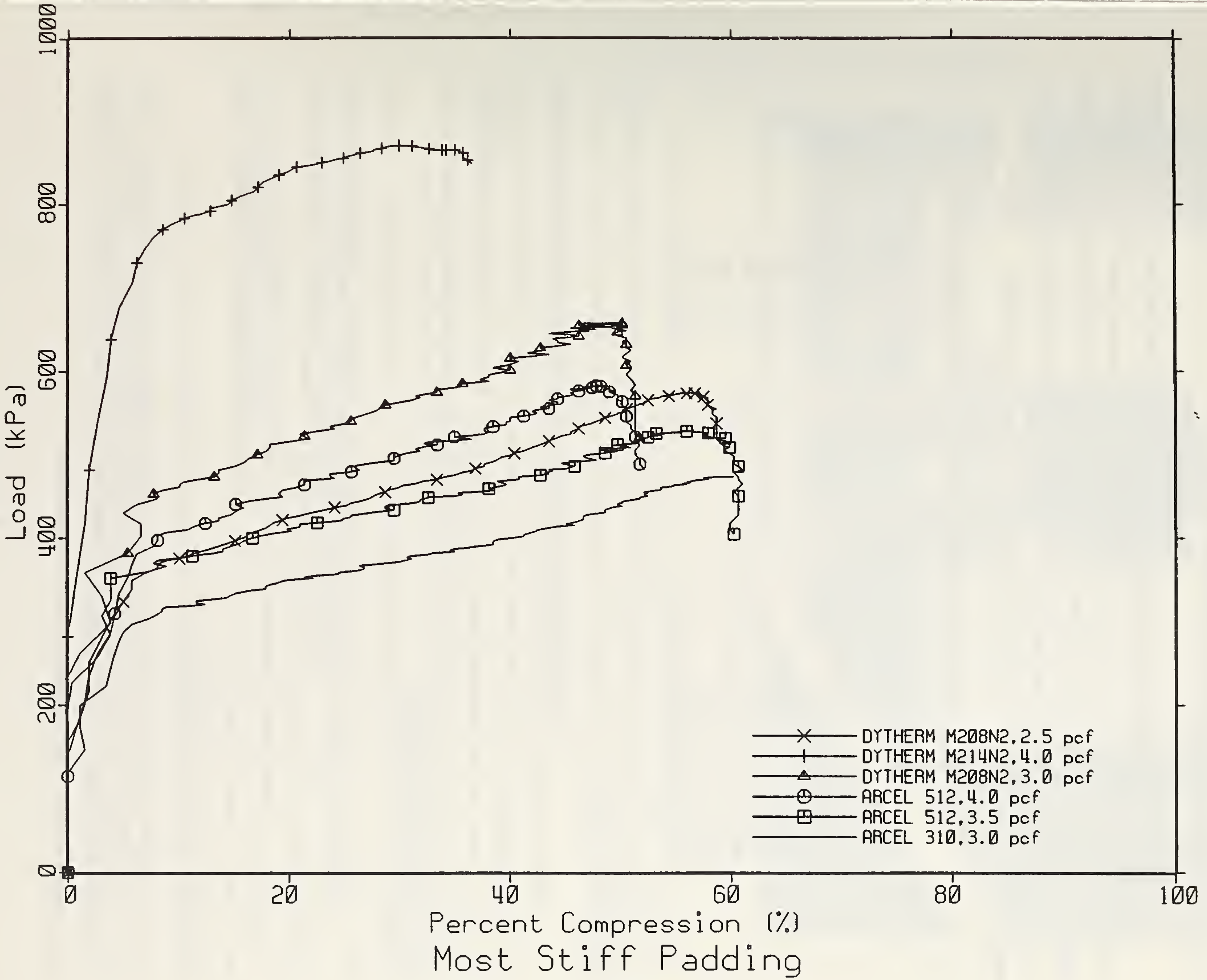

ETHAFOAM 220,2.2 pcf
ENSOLITE AAC,4.9 pcf
FLORAL FOAM,1.9 pcf
SYN.FOAM RUBBER,2.0 pcf
SYN.FOAM RUBBER,1.1 pcf
ARCEL 310,1.6 pcf
ARSAN 601,0.9 pcf
ARPRO 3313,1.5 pcf
ARPAK 4322,2.3 pcf
ETHAFOAM LC200,1.9 pcf
Load (kPa)
0
100
200
300
400
0
20
40
60
80
100
Percent Compression (%)
Least Stiff Padding

FIGURE 1



600
500
400
300
200
100
0
Load (kPa)
0
20
40
60
80
100
Percent Compression (%)
DYTHERM M208N2,1.5 pcf
ARCEL 512,2.2 pcf
ARCEL 512,3.0 pcf
ARCEL 512,2.5 pcf
ARCEL 310,2.5 pcf
ARCEL 310,2.0 pcf
ARCEL 310,1.5 pcf
Moderate Stiffness Padding

FIGURE 2



Load (kPa)
0
200
400
600
800
1000
0
20
40
60
80
100
Percent Compression (%)
Most Stiff Padding
DYTHERM M208N2,2.5 pcf
DYTHERM M214N2,4.0 pcf
DYTHERM M208N2,3.0 pcf
ARCEL 512,4.0 pcf
ARCEL 512,3.5 pcf
ARCEL 310,3.0 pcf

FIGURE 3

3.0 SID, EuroSID, & BioSID COMPARATIVE SLED TESTS

Ten of the materials above were used for a comparative test of the 3 side impact dummies. The materials listed in Table 3 were chosen as representative of the wide range of crush strength for the candidate materials. The dummies were subjected to impact tests on the Heidleberg-style side impact buck (5). In each test, the impact surfaces of the sled buck were covered with 3 inches of one of the materials so that the impact response of the dummies could be measured for paddings with various crush strengths.

TABLE 3 -- Padding Materials Used in Side Impact Sled Testing

Material Type	Crush Strength At 35%
Synthetic Foam Rubber	17.5 kPa
ETHAFOAM LC 200 (drilled)	65.5 kPa
ETHAFOAM LC 200	103 kPa
ARSAN 601 - 1.0 pcf	131 kPa
ARCEL 310 - 1.5 pcf	220 kPa
ARCEL 512 - 2.5 pcf	324 kPa
ARCEL 310 - 3.0 pcf	414 kPa
ARCEL 512 - 4.0 pcf	565 kPa
DYTHERM M214N2 - 4.0 pcf	848 kPa

3.1 Sled Test Procedure

A sled buck, similar to the one used for side impact cadaver tests at the University of Heidelberg, was used for these side impact dummy comparison tests (5). This buck consisted primarily of a bench seat with low friction surfaces and load measuring plates at one end (Figure 4). In each test, the impact surfaces of the sled buck were covered with 3 inches of one of the materials so that the impact response of the dummies could be measured for various paddings.

The direction of motion of the bench seat was parallel with the dummies lateral axis and perpendicular to the load plates. The HYGE sled was accelerated to produce a ΔV of nominally 8.9 m/s. The dummies each were seated in an upright position, approximately 38 cm from the load plates. This initial spacing allowed the sled to reach a constant velocity before the dummy contacted the loading surface. More detailed seating measurements can be found in Appendix A.

In addition to the plate loads, both sled acceleration and padding deflection were measured. The instrumentation common to all three dummies consisted of rib, spine, and pelvis accelerations. Complete instrumentation lists for each dummy can be found in Appendix B.

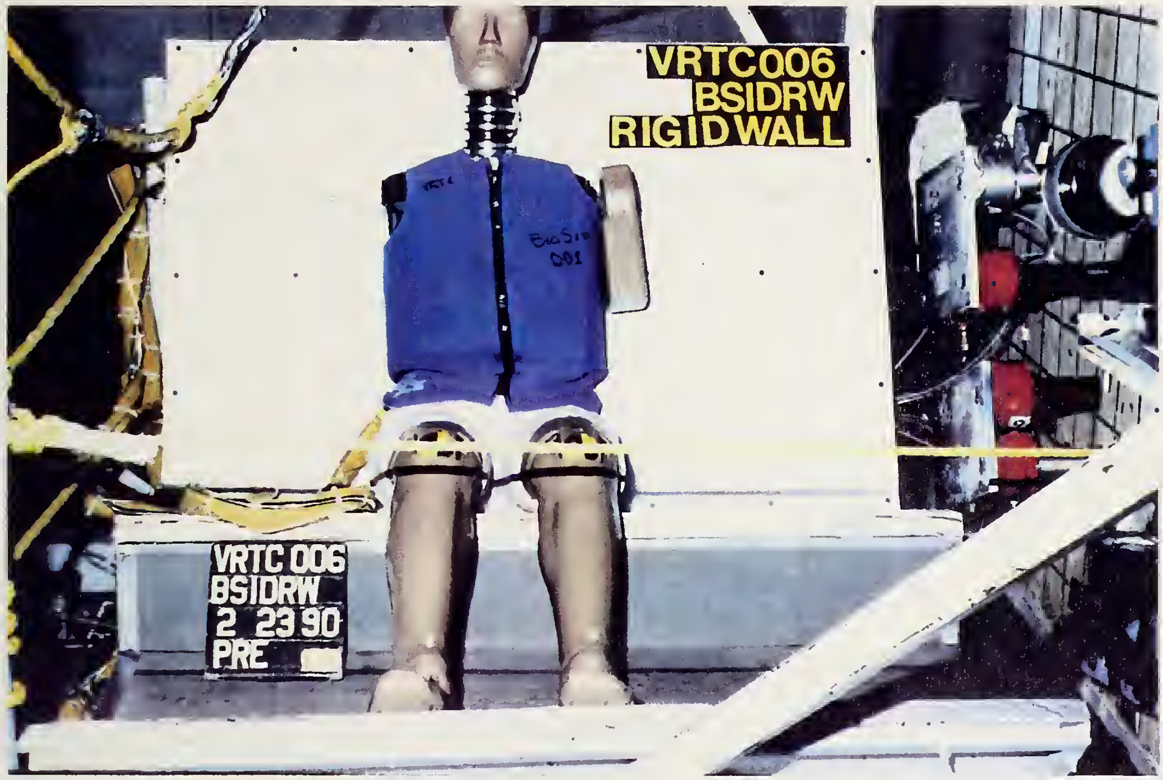


FIGURE 4 -- Side Impact Sled Set-up

Each of the three dummies - BioSID, EuroSID , and SID, was subjected to one test with each of the nine paddings and the uncovered, rigid wall. The BioSID and EuroSID were also tested in an additional "arm-up" configuration with five padded conditions and the rigid wall. The angle between the central axis of the arm and the spine in the "arm-up" position for both dummies was approximately 40°.

3.2 Results

The results of these tests were compared primarily on the basis of various parameters considered to be indicative of thoracic trauma in side impacts. These included peak rib acceleration, peak rib displacement, and peak spinal acceleration. Two injury indices were also calculated - TTI(d) and V*C. In addition to these thoracic parameters, the peak pelvic accelerations were also compared.

3.2.1 Acceleration Response Comparisons

The maximum rib peak accelerations, lower spine (T12) accelerations, TTI(d), and pelvis accelerations could be compared for all three dummies. Figures 5-8 show each of the acceleration parameters plotted against the padding crush strength for each of the three dummies. These plots are all somewhat similar. Each

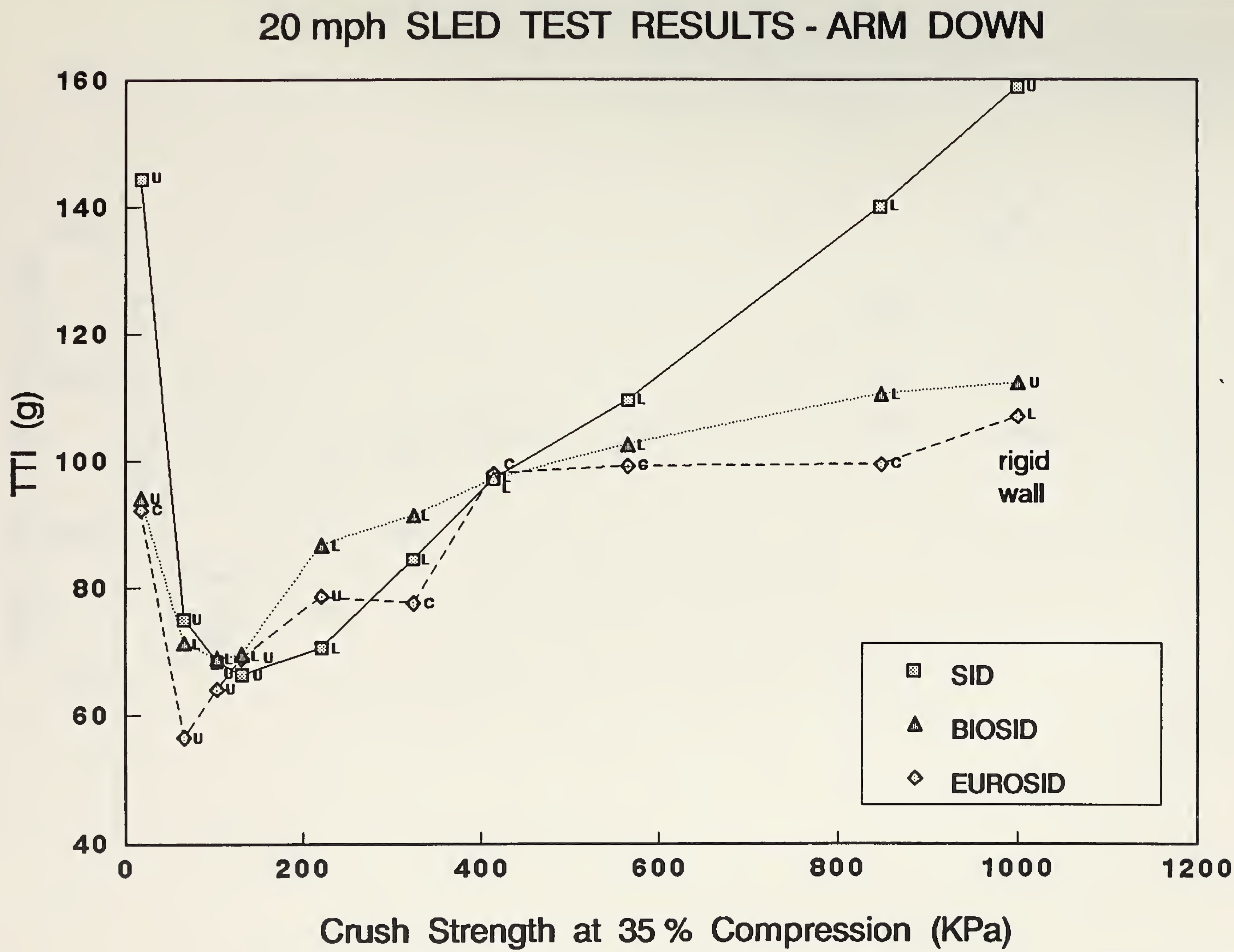

20 mph SLED TEST RESULTS - ARM DOWN
TTI (g)
160
140
120
100
80
60
40
0
200
400
600
800
1000
1200
Crush Strength at 35 % Compression (KPa)
rigid wall
SID
BIOSID
EUROSID

FIGURE 5

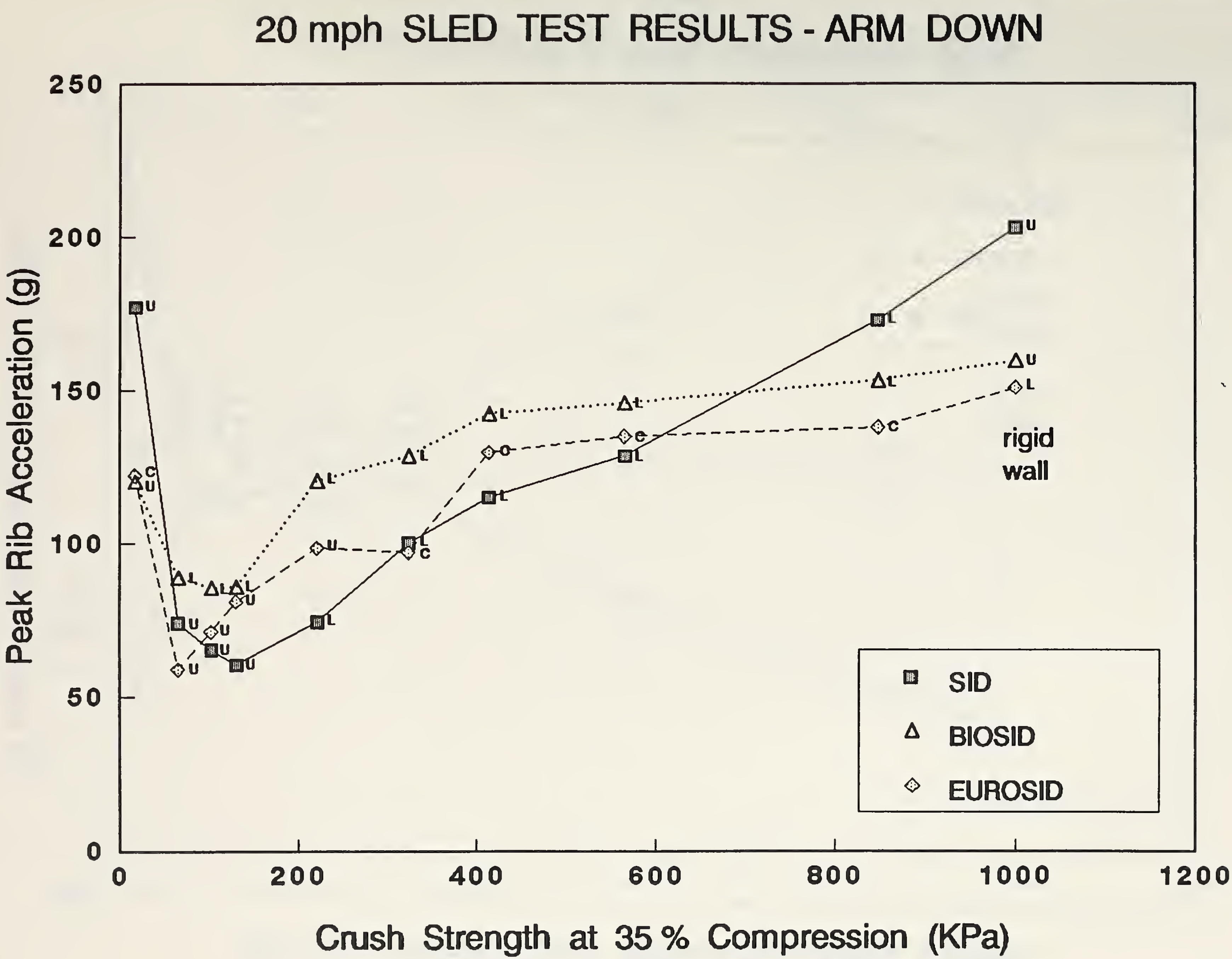

20 mph SLED TEST RESULTS - ARM DOWN
Peak Rib Acceleration (g)
Crush Strength at 35 % Compression (KPa)
250
200
150
100
50
0
0
200
400
600
800
1000
1200
rigid
wall
SID
BIOSID
EUROSID

FIGURE 6

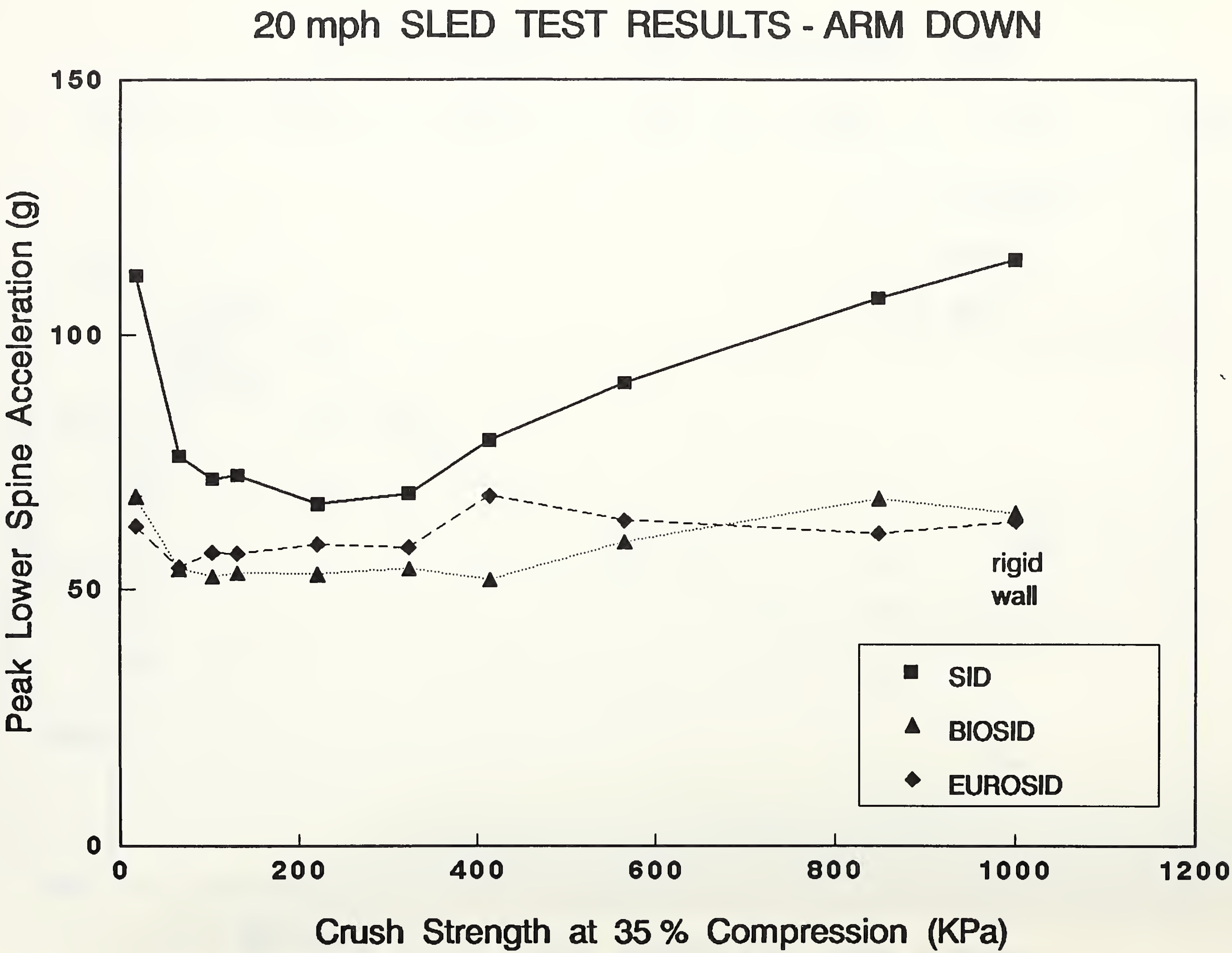

20 mph SLED TEST RESULTS - ARM DOWN
Peak Lower Spine Acceleration (g)
150
100
50
0
0
200
400
600
800
1000
1200
Crush Strength at 35 % Compression (KPa)
rigid
wall
SID
BIOSID
EUROSID

FIGURE 7

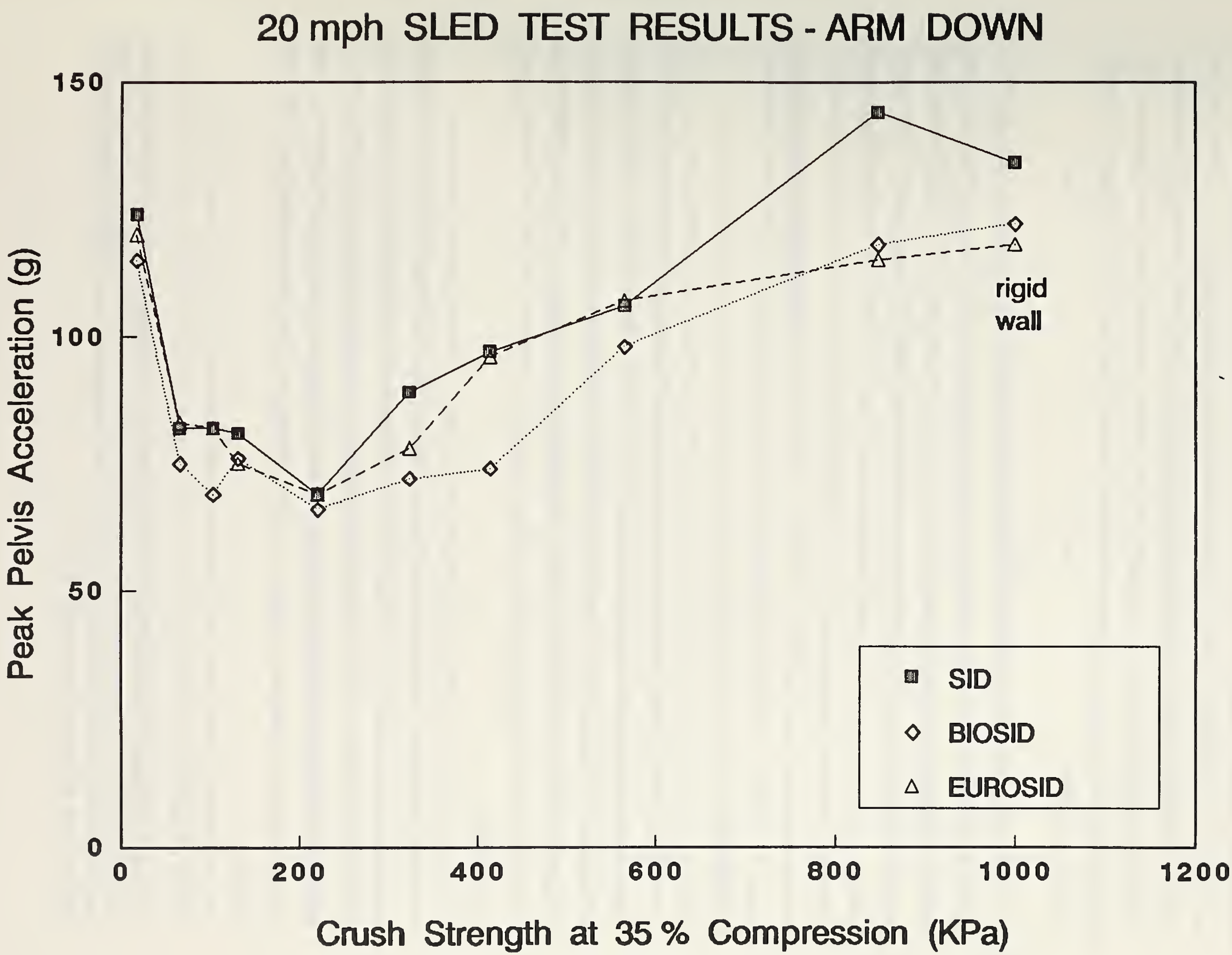

20 mph SLED TEST RESULTS - ARM DOWN
Peak Pelvis Acceleration (g)
150
100
50
0
0
200
400
600
800
1000
1200
Crush Strength at 35 % Compression (KPa)
rigid
wall
SID
BIOSID
EUROSID

FIGURE 8

shows that the measured parameter has a minimum value for padding with a crush strength between 65.5 kPa and 414 kPa. This relationship resulted from the finite depth of the padding samples. The softest pads did not provide enough resistance to gradually accelerate the dummy before the padding became fully compressed. The stiffest materials did not deflect much and impelled the dummy to accelerate over a shorter distance. The pads which produced the lowest acceleration based injury indices provided just enough resistance to gradually accelerate the dummy.

Figure 5 illustrates that the TTI(d) responses of all three dummies were very similar. The symbols U, C and L (Upper, Center, and Lower, respectively) indicate which of the dummies' ribs' accelerations were used in the TTI(d) calculation[1]. The minimum SID response was recorded for the 131 kPa ARSAN surface, the BioSID and EuroSID minimum responses were recorded for the 103 kPa Ethafoam and 65.5 kPa drilled Ethafoam surfaces, respectively. All three dummies produced rigid wall TTI(d)s that were greater than those recorded for the softest padding material. The TTI(d)s produced for all three dummies were most similar for the low and medium strength materials (< 414 kPa). The SID's TTI(d) appeared more sensitive to stiffness changes for the stiffer (> 414 kPa) to rigid surfaces, and were considerably higher than for either of the other two dummies.

The maximum rib peak accelerations for the three dummies (Figure 6) were very similar to their TTI(d) responses. The minimum SID response was observed for the 131 kPa ARSAN surface, the BioSID's lowest peak maximum rib acceleration was recorded with the 103 kPa Ethafoam surface, and the EuroSID again produced its minimum response with the 65.5 kPa drilled Ethafoam material. The peak maximum rib accelerations were very high for the softest padding, averaging about 80% of the rigid wall response for all three dummies.

The lower spine (T12) accelerations (Figure 7) did not appear to be as sensitive to the padding differences as the rib accelerations. The minimum T12 accelerations were recorded with the 221 kPa ARCEL, the 414 kPa ARCEL and the 65.5 kPa drilled Ethafoam for the SID, BioSID, and EuroSID devices, respectively. The ranges of T12 acceleration values (Table 4) indicated that the SID's spinal acceleration was approximately three times more sensitive to padding stiffness than the spinal accelerations of the other dummies.

---

[1] The TTI(d) for the BioSID and EuroSID responses have been calculated using the peak acceleration from the thoracic rib with the greatest peak acceleration. While TTI(d) for the SID was calculated using the larger peak acceleration of only two ribs (upper and lower), the comparisons were considered valid because the impact surface in these tests was essentially flat.

TABLE 4 -- Range of Peak T12 Acceleration - SID, BioSID, EuroSID

Dummy	T12 Acceleration Range (g)	Δg
SID	65 - 112	47
BioSID	54 - 69	15
EuroSID	52 - 68	16

The pelvis acceleration (Figure 8) is also a common indication of side impact severity in simulation tests. Additionally, the upgraded of MVSS 214 imposes limits on pelvis acceleration in crash tests to reduce the chance of pelvis injuries. The peak pelvis acceleration of three dummies was similar for the padded surfaces in these tests. The minimum peak pelvis acceleration was recorded for all three dummies with the 221 kPa ARCEL surface.

3.2.2 Rib Deflection Comparison

The rib displacement and viscous criterion are two other indications of side impact thoracic trauma. The V*C is a displacement based criterion, therefore, like the rib displacement, is meaningless when applied to the SID, which is an acceleration based device. Comparisons between the BioSID and EuroSID were, however, conducted. Figures 9 and 10 show both V*C and peak rib displacement produced by the various paddings. The shapes of the V*C plots for both dummies and the peak maximum rib deflection plot for the BioSID were similar to the shapes of the TTI(d) and peak spinal acceleration versus crush strength plots, respectively.

The maximum rib peak deflections (Figure 9) were not particularly sensitive to the changes in padding properties. The BioSID deflections ranged between 63.7 mm and 69.8 mm, while the EuroSID deflections showed essentially no variation (49.4 mm to 50.4 mm). Measurements of the distance between the rib and spine of the EuroSID suggested that the ribs reached their displacement limit in all of the padded and rigid wall tests. Interior dimensions of the BioSID, however, suggested that its ribs had approximately 10 mm clearance beyond the largest deflection measured.

Figure 10 shows that the V*C responses of the two dummies did not have similar magnitudes, but both resembled the TTI(d) responses of the side impact dummies. The minimum V*C was recorded for the 221 kPa ARCEL material for both dummies. The V*C measured for the BioSID were higher for every condition than the EuroSID responses.

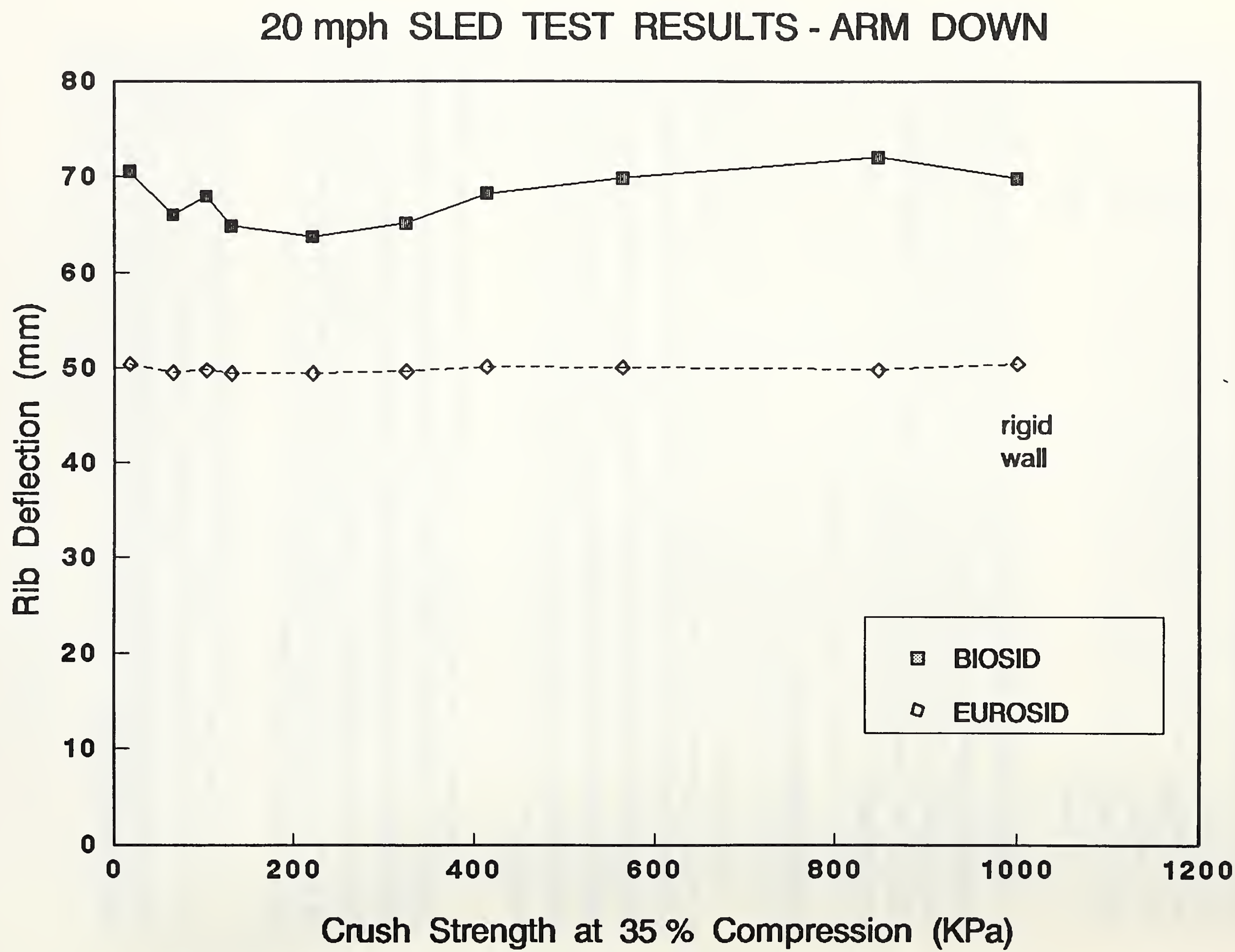
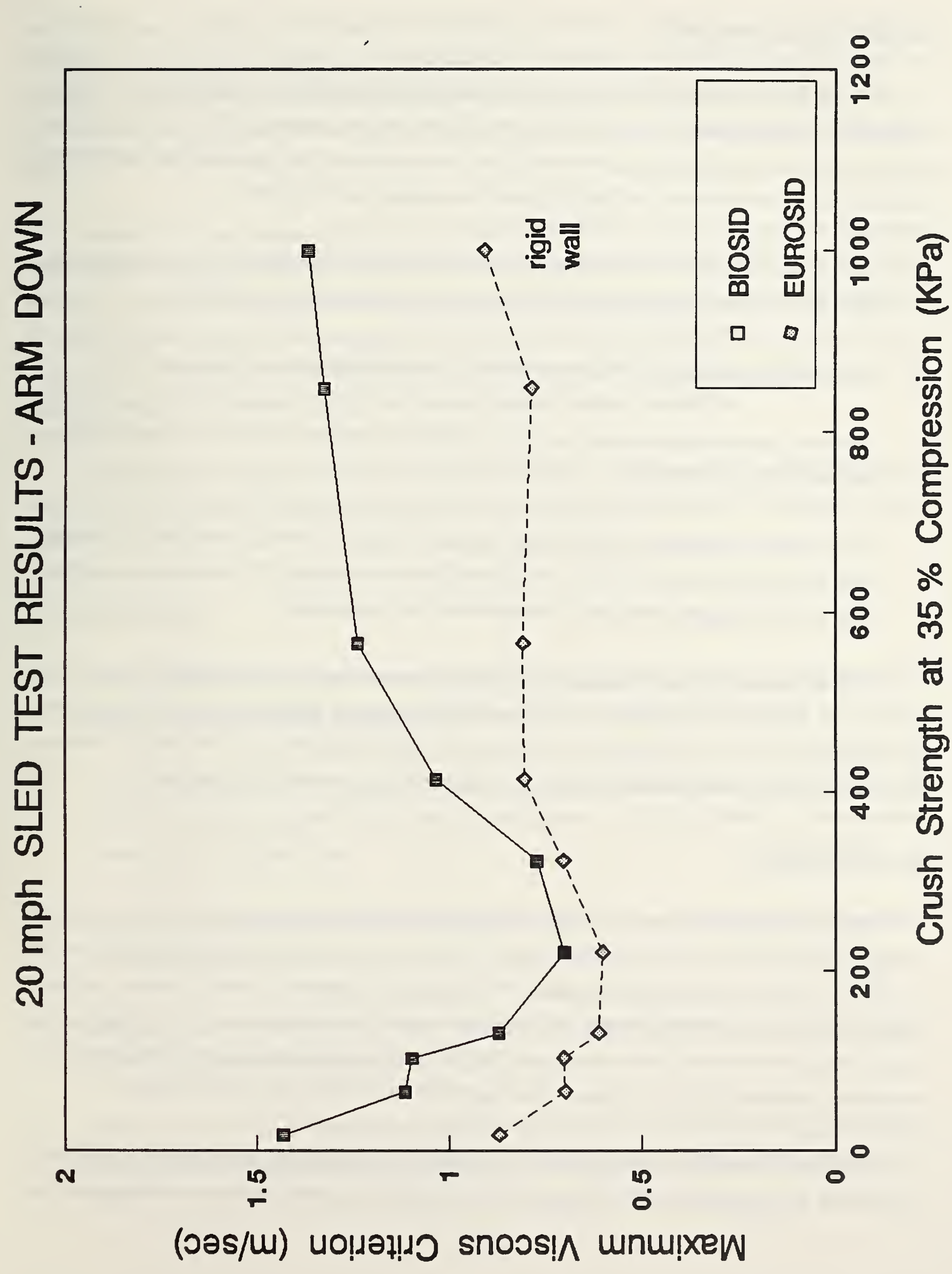

20 mph SLED TEST RESULTS - ARM DOWN
Rib Deflection (mm)
80
70
60
50
40
30
20
10
0
Crush Strength at 35 % Compression (KPa)
0
200
400
600
800
1000
1200
rigid
wall
BIOSID
EUROSID

FIGURE 9



20 mph SLED TEST RESULTS - ARM DOWN
Maximum Viscous Criterion (m/sec)
Crush Strength at 35 % Compression (KPa)
0
0.5
1
1.5
2
0
200
400
600
800
1000
1200
rigid wall
BIOSID
EUROSID

FIGURE 10

3.2.3 Arm Position Comparisons

Several tests, as mentioned above, were conducted with the BioSID and EuroSID in an arm-up configuration. Summary plots of the results of these tests can be found in Appendix C. The results of the arm-up tests could not be meaningfully compared with SID test results, because of the fixed arm-down configuration of the SID. Some observations of the BioSID/EuroSID comparisons are listed below:

-> The arm-up configuration produced higher peak rib accelerations and TTI(d) for both dummies. The difference between arm-up and arm-down was greater for the EuroSID than BioSID.

-> The arm-up configuration produced slightly higher T12 accelerations for both dummies.

-> There was little difference between the pelvis accelerations produced in the arm-up tests and those observed in the arm-down tests.

-> The arm-down configuration produced larger maximum rib peak deflections and higher V*C than the arm-up configuration with the BioSID. The EuroSID experienced higher V*C in the arm-up condition, although the rib displacements did not distinguish the arm configuration.

This last observation may be explained by interaction between the arm and the BioSID's thorax. The BioSID's arm can pivot at the shoulder. Its free end is aligned with the lowest thoracic rib. The maximum rib displacement and V*C were observed at the lowest rib in every arm-down test. The action of the lower end of the arm may have accentuated the displacements of the lower rib in the arm-down tests.

4.0 CONCLUSIONS

All three dummies appeared to be viable test apparatus. The TTI(d) responses of all three dummies distinguished between the different padded surfaces. For the soft and medium stiffness pads (crush strength < 414 kPa), the three dummies produced similar TTI(d)/stiffness relationships. The SID, however, exhibited a greater sensitivity to padding differences for the stiffer materials (crush strength > 414 kPa). Although the same padding material did not produce the lowest TTI(d) for all three dummies, the lowest TTI(d) values were recorded for materials which were relatively close together in the overall range of crush strengths.

Rib displacement did not distinguish itself as a feasible injury parameter for any of these three dummies. The SID was not designed to measure deflection and the BioSID and EuroSID deflection measurements did not display acute sensitivity to the range of wall stiffnesses presented in this test matrix. The EuroSID deflection measurements, in particular, were meaningless at the impact severity level presented in this test program. The full rib stroke of the EuroSID device was approached in every test. The BioSID rib deflection measurements did not indicate that the ribs had bottomed out, yet the range of peak deflections produced by these tests was relatively small.

Application of the viscous criterion to the EuroSID and BioSID, on the other hand, did distinguish between the various padded surfaces. The V*C from the two dummies was lowest for the same padding material. This material was somewhat stiffer than the materials which produced the lowest TTI(d) responses, for any of the three dummies. The minimum V*C for both the EuroSID and BioSID was produced by the 221 kPa ARCEL. The minimum TTI(d) responses for SID, BioSID, and EuroSID were recorded for the 131 kPa ARSAN, the 103 kPa Ethafoam, and 65.5 kPa drilled Ethafoam surfaces, respectively.

Finally, the pelvis responses of the three dummies were similar. The lowest pelvis acceleration response was measured for all three dummies with the same material that produced the lowest V*C response (221 kPa ARCEL).

5.0 REFERENCES

1. Roberts, A.K., "Report on EuroSID 1989," Twelfth International Technical Conference on Experimental Safety Vehicles, Proceedings Volume 1; U.S. Department of Transportation, May 1989.

2. Saul, R.A. and Colvin, J.M., "Evaluation of EuroSID Pre-Production Side Impact Dummy," VRTC-88-0103, The National Highway Traffic Safety Administration - U.S. Department of Transportation, Washington D.C., August, 1988.

3. Beebe, M.S., "What is BioSID ?," SAE Paper #900377, Society of Automotive Engineers, Warrendale, PA; February, 1990.

4. Saul, R.A., "State of the Art Dummy Selection," DOT HS 806 722, National Technical Information Service, Springfield, VA, December 1984.

5. Marcus, J.H., et al, "Human Response and Injury for Lateral Impact," (SAE# 831634), Twenty-Seventh Stapp Car Crash Conference (P-134), Society of Automotive Engineers; Warrendale, PA, February, 1990.

6. Eppinger, R.H., Marcus, J.H., and Morgan, R.M., "Development of Dummy and Injury Index for NHTSA's Thoracic Side Impact Protection Research Program," (SAE#840885), SAE Transactions, Vol.93, Society of Automotive Engineers; Warrendale, PA, 1984.

APPENDIX A

Dummy Seating Measurements

DUMMY SEATING FOR SIDE IMPACT SLED BUCK TESTS

The dummies were seated upright with their shoulders level and their backs against the back of the seat. The dummies were not wearing shoes but did wear pants and a shirt or jacket. The knees were bent and the lower legs were parallel. The dummies' position with respect to the impact surface were described by the following measurements:

SID MEASUREMENTS

Shoulder to rigid plate	483 mm
Dummy CL to plywood wall (measured at the nose & crotch)	927 mm
Knee Spacing	203 mm
Ankle Spacing	203 mm

BioSID MEASUREMENTS

Shoulder to rigid plate	483 mm
Dummy CL to plywood wall (measured at the nose & crotch)	927 mm
Knee Spacing	203 mm
Ankle Spacing	203 mm

EuroSID MEASUREMENTS

Shoulder to impact surface	483 mm
Dummy CL to plywood wall (measured at the nose & crotch)	927 mm
Knee Spacing	203 mm
Ankle Spacing	203 mm

All seating measurements were maintained within $\pm$13 mm of those listed above for all of the side impact padded and rigid wall tests.

APPENDIX B

Dummy Instrumentation

NOTE

There were several potential positions for the spinal acceleration measurements on the BioSID. The T01 and T12 accelerometer positions that were chosen for this work were analogous to the T01 and T12 accelerometer positions of the SID. The T01 spinal accelerometer was mounted on top of the spine/neck bracket adaptor block. The BioSID T12 accelerometer was mounted on the un-struck side of the spine box, opposite the upper abdominal rib. The Table B-1, below shows a comparison of SID and BioSID T01 and T12 locations.

TABLE B-1
COMPARISON OF SPINAL ACCELEROMETER POSITIONS
FOR THE
SID AND BIOSID
IN AN
UPRIGHT SEATED POSITION

	SID	BioSID
seating surface - to - T01 accel.	575 mm	556 mm
seating surface - to - T12 accel.	330 mm	298 mm

TABLE B-2
SID INSTRUMENTATION

3 head accel. - HEDXG, HEDYG, HEDZG
2 upper rib accel. - LURYG1, LURYG2
2 lower rib accel. - LLRYG1, LLRYG2
4 upper spine accel. - T01XG, T01YG1, T01YG2, T01ZG
4 lower spine accel. - T12XG, T12YG1, T12YG2, T12ZG
3 pelvis accel. - PEVXG, PEVYG, PEVZG
1 thorax displacement - CSTYD

TABLE B-3
BIOSID INSTRUMENTATION

3 head accel. - HEDXG, HEDYG, HEDZG
1 shoulder rib accel. - SHLYG
1 #1 thoracic rib accel. - LURYG
1 #2 thoracic rib accel. - LCRYG
1 #3 thoracic rib accel. - LLRYG
1 #1 abdominal rib accel. - LUAYG
1 #2 abdominal rib accel. - LLAYG
3 upper spine accel. - T01XG, T01YG1, T01YG2, T01ZG
3 lower spine accel. - T12XG, T12YG, T12ZG
3 pelvis accel. - PEVXG, PEVYG, PEVZG
1 shoulder rib disp. - SHLYD
1 #1 thoracic rib disp. - LURYD
1 #2 thoracic rib disp. - LCRYD
1 #3 thoracic rib disp. - LLRYD
1 #1 abdominal rib disp. - LUAYD
1 #2 abdominal rib disp. - LLAYD
1 shoulder load - SHLYF
1 iliac wing load - PILYF
1 pubic symphysis load - PPSYF
1 sacrum load - PSAYF

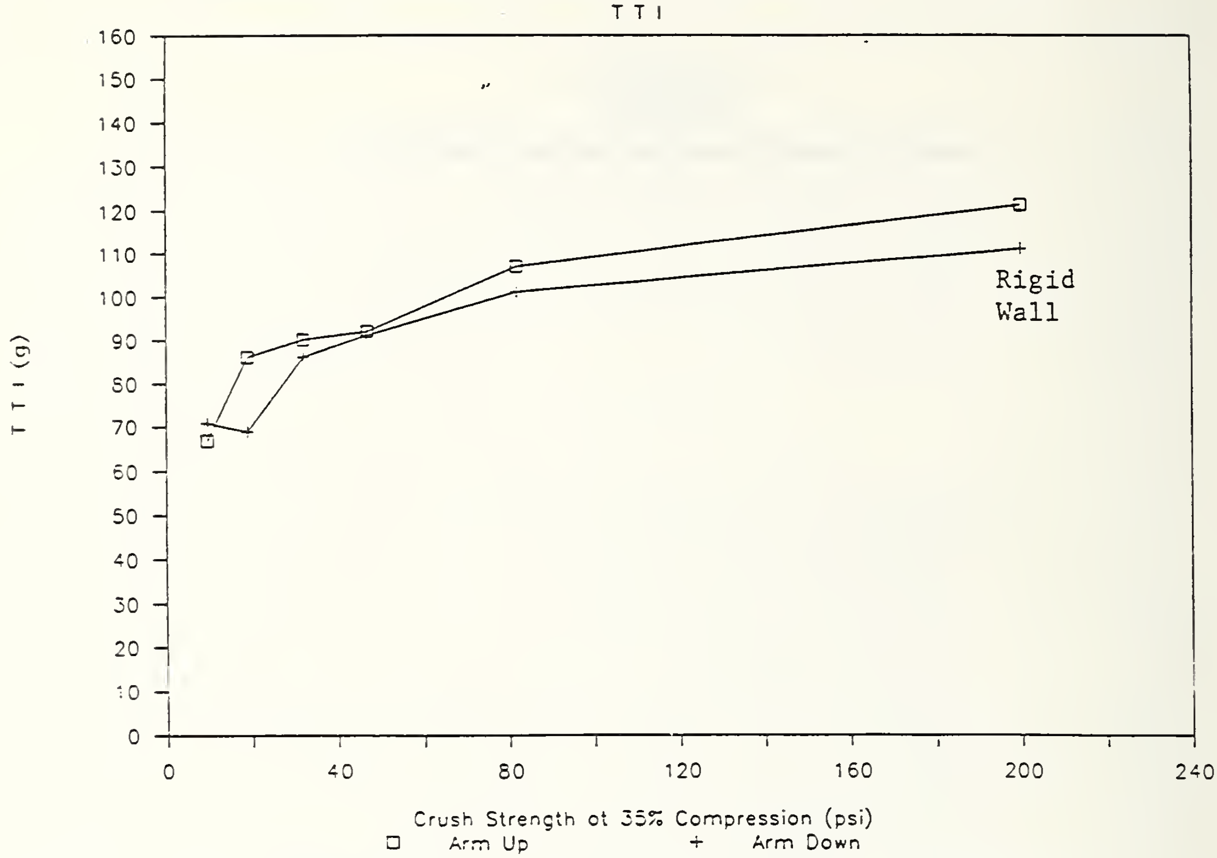
TABLE B-4
EUROSID INSTRUMENTATION

3 head accel. - HEDXG, HEDYG, HEDZG
1 #1 thoracic rib accel. - LURYG
1 #2 thoracic rib accel. - LCRYG
1 #3 thoracic rib accel. - LLRYG
3 upper spine accel. - T01XG, T01YG, T01ZG
3 lower spine accel. - T12XG, T12YG, T12ZG
3 pelvis accel. - PEVXG, PEVYG, PEVZG
1 #1 thoracic rib disp. - LURYD
1 #2 thoracic rib disp. - LCRYD
1 #3 thoracic rib disp. - LLRYD
3 abdominal loads - LFAYF, LCAYF, LRAYF

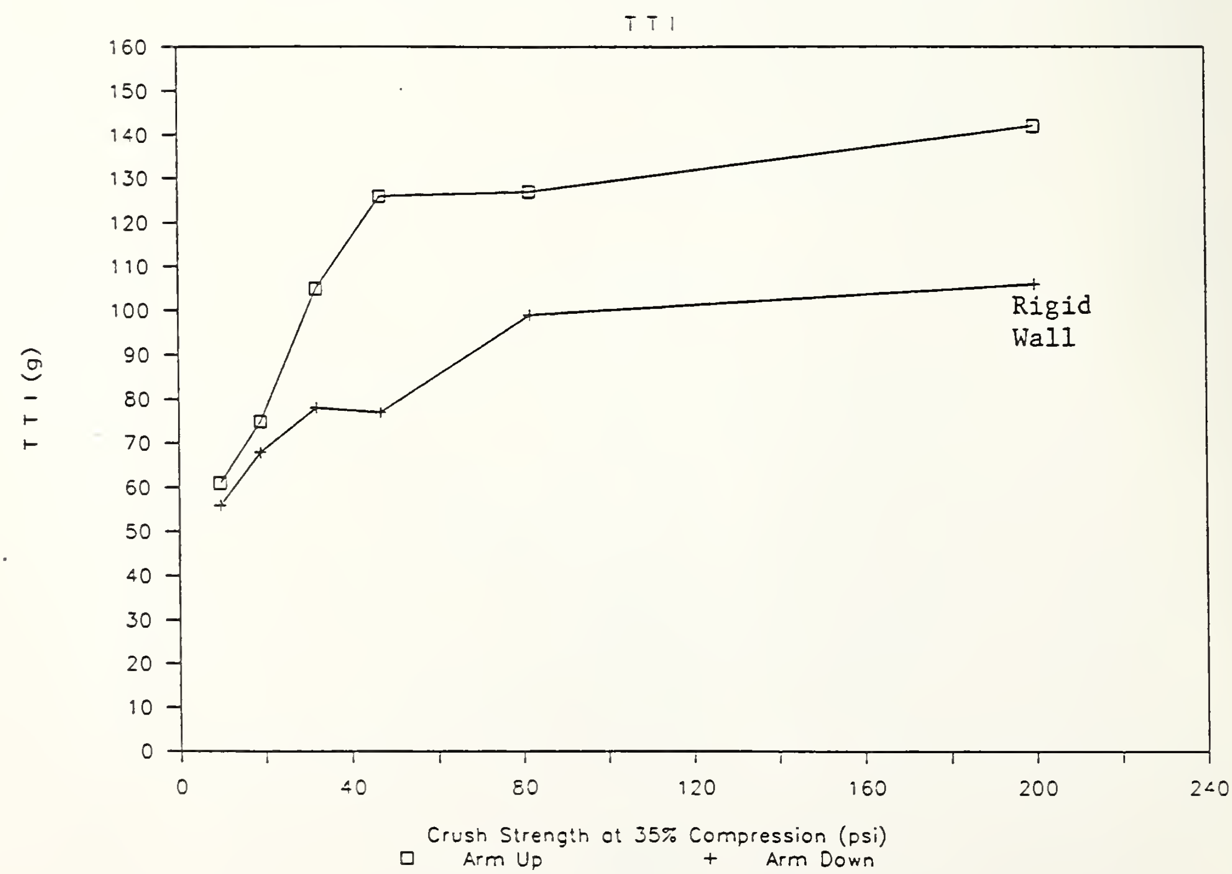
APPENDIX C

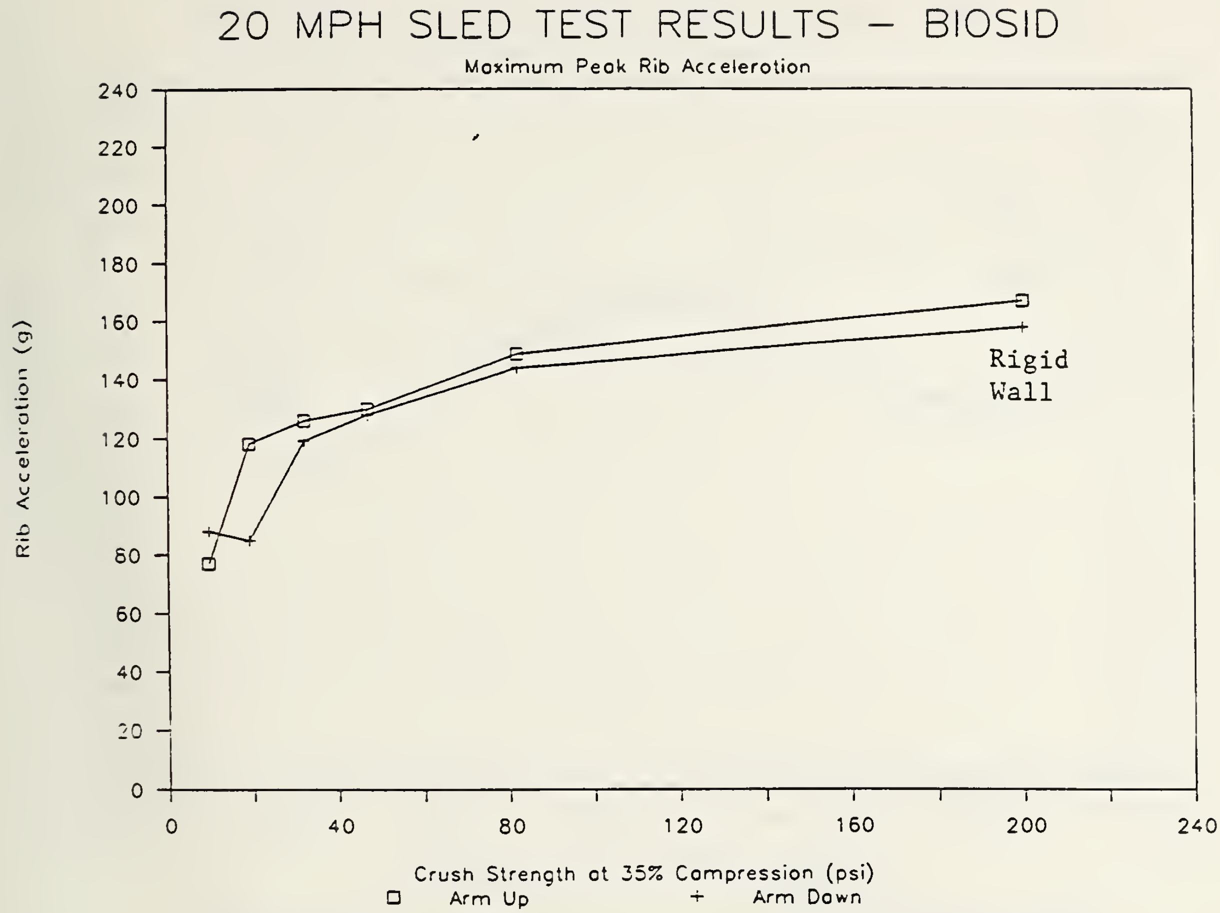
BioSID & EuroSID Arm-Up/Arm-Down Comparisons

20 MPH SLED TESTS RESULTS – BIOSID

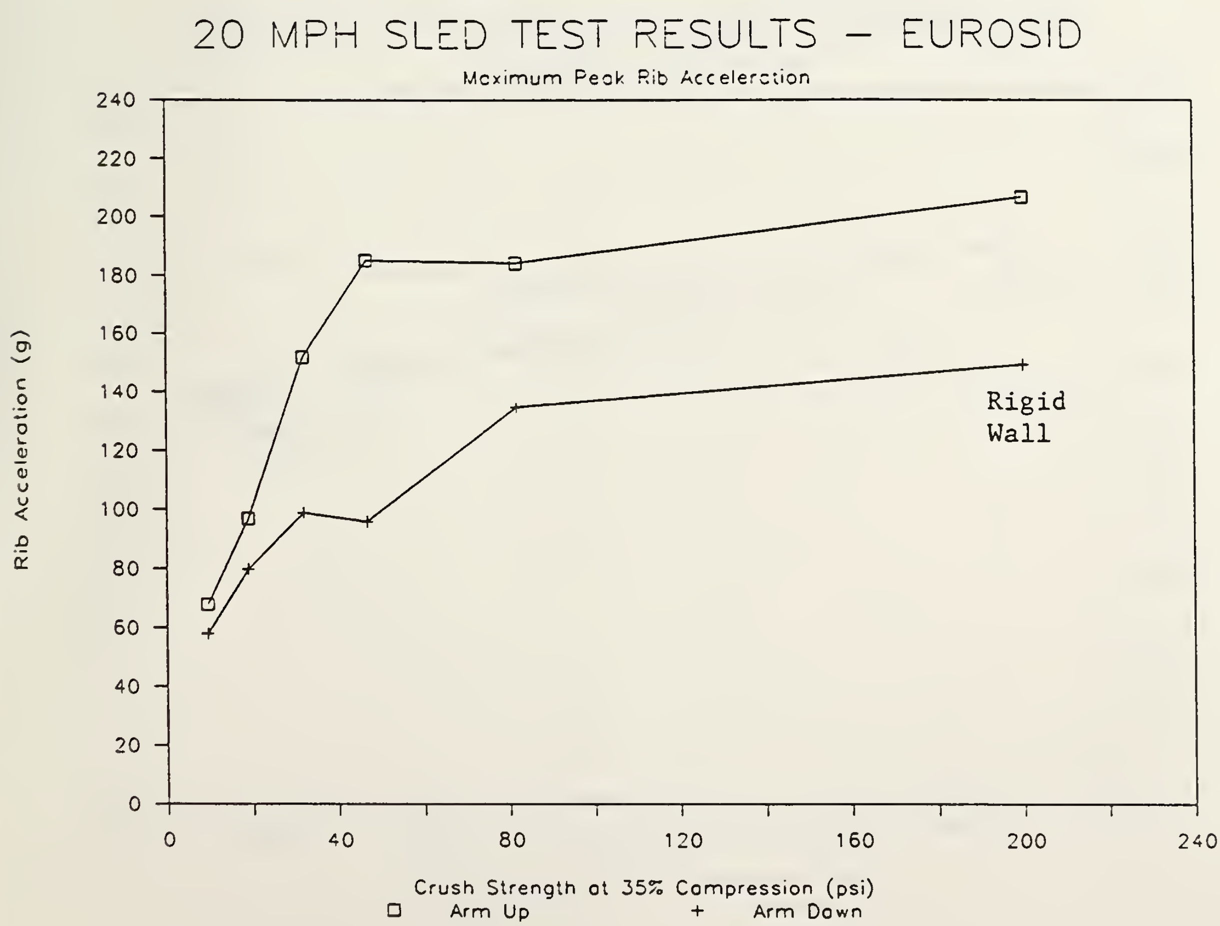


20 MPH SLED TESTS RESULTS – EUROSID



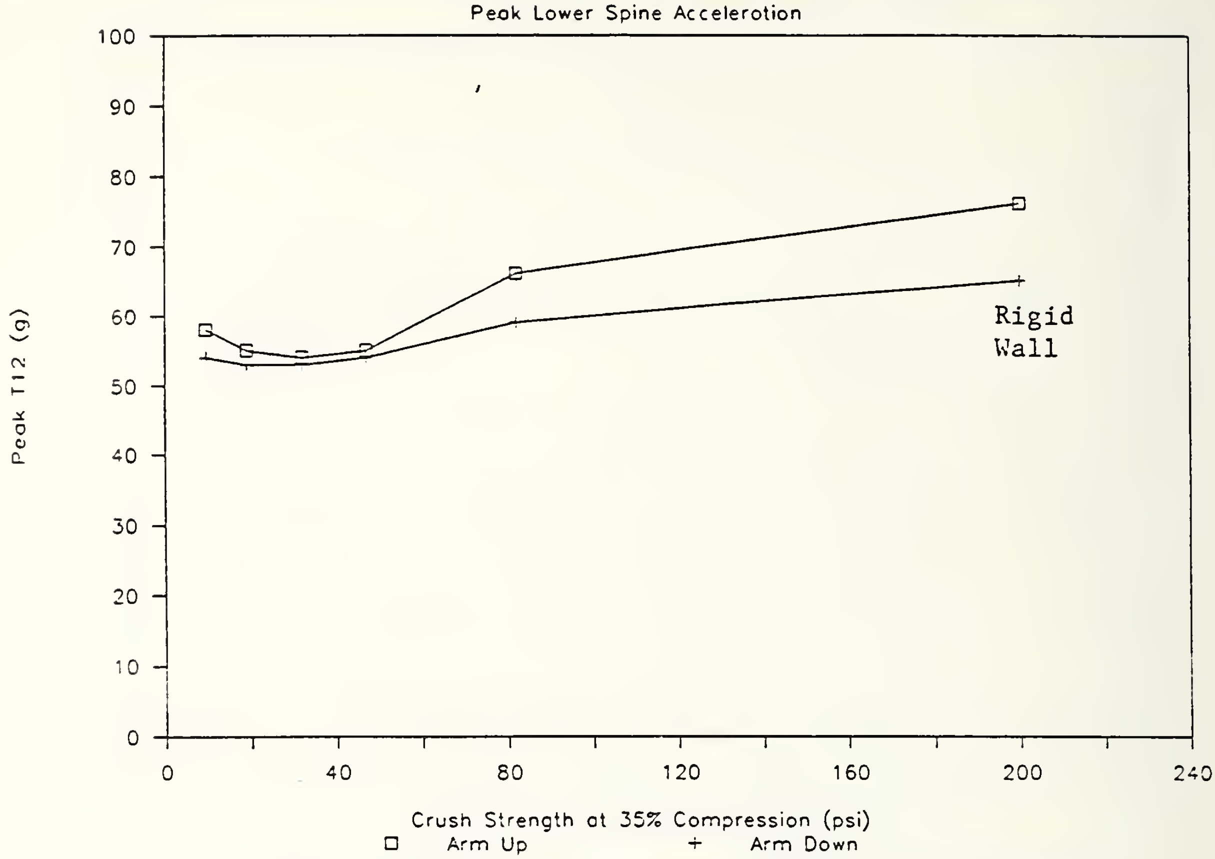


20 MPH SLED TEST RESULTS - BIOSID
Maximum Peak Rib Acceleration
Rib Acceleration (g)
Rigid
Wall
Crush Strength at 35% Compression (psi)
Arm Up
Arm Down

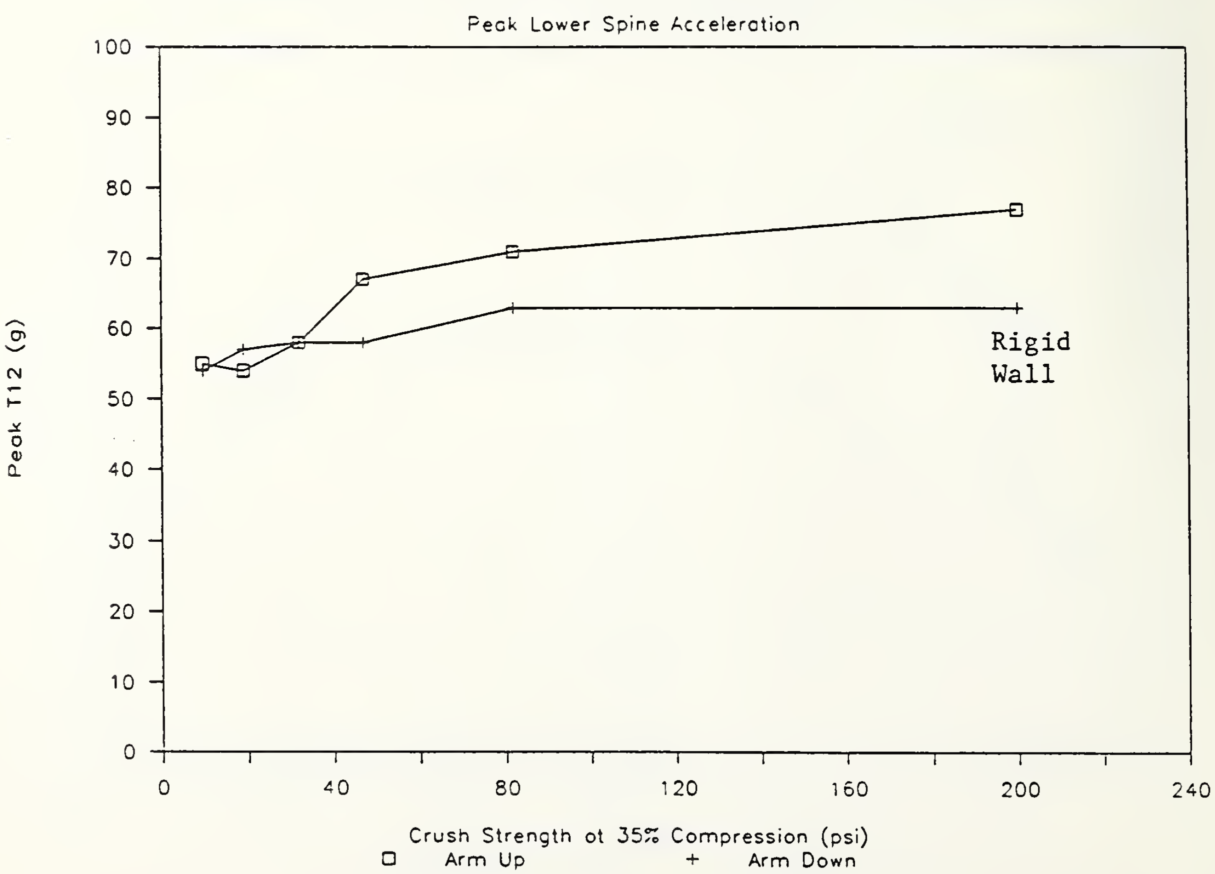


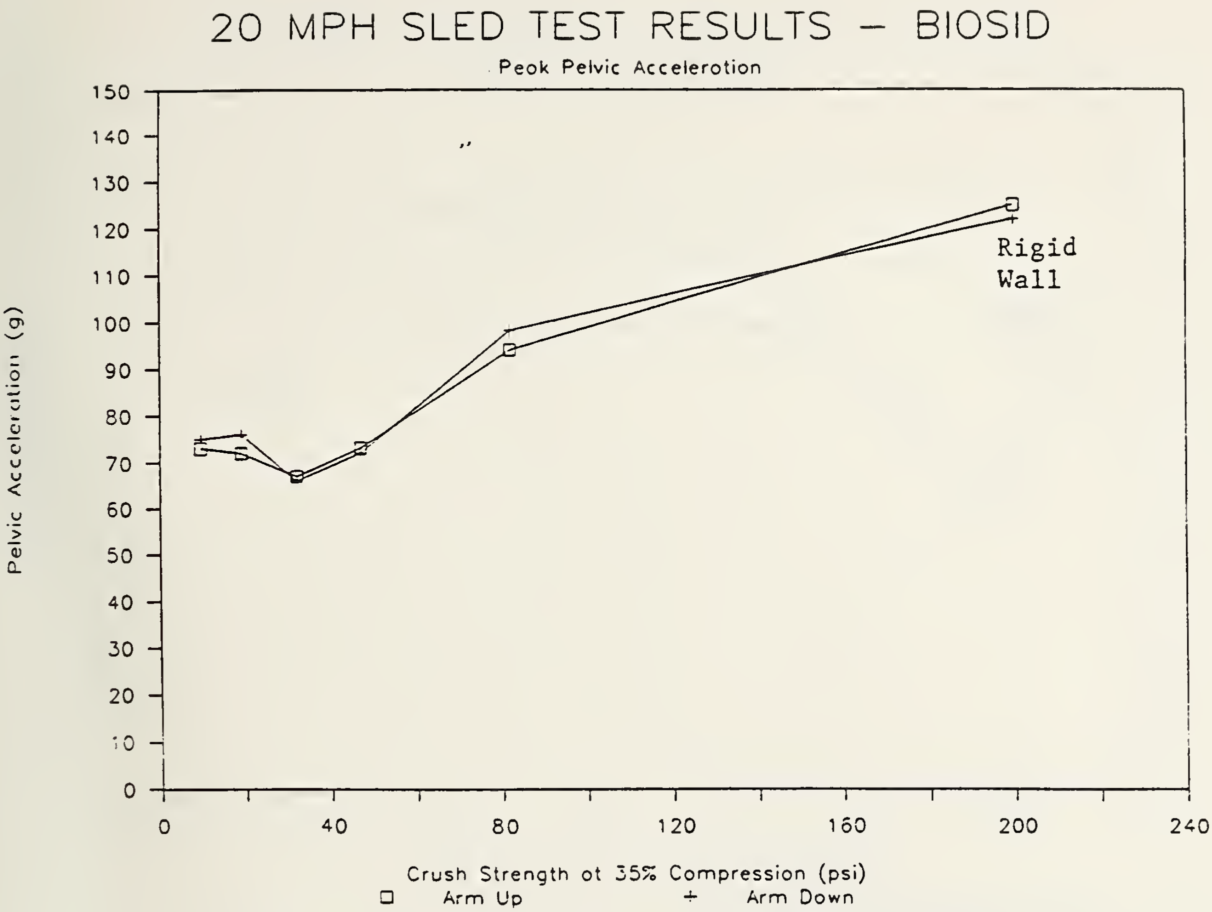
20 MPH SLED TEST RESULTS - EUROSID
Maximum Peak Rib Acceleration
Rib Acceleration (g)
Rigid
Wall
Crush Strength at 35% Compression (psi)
Arm Up
Arm Down

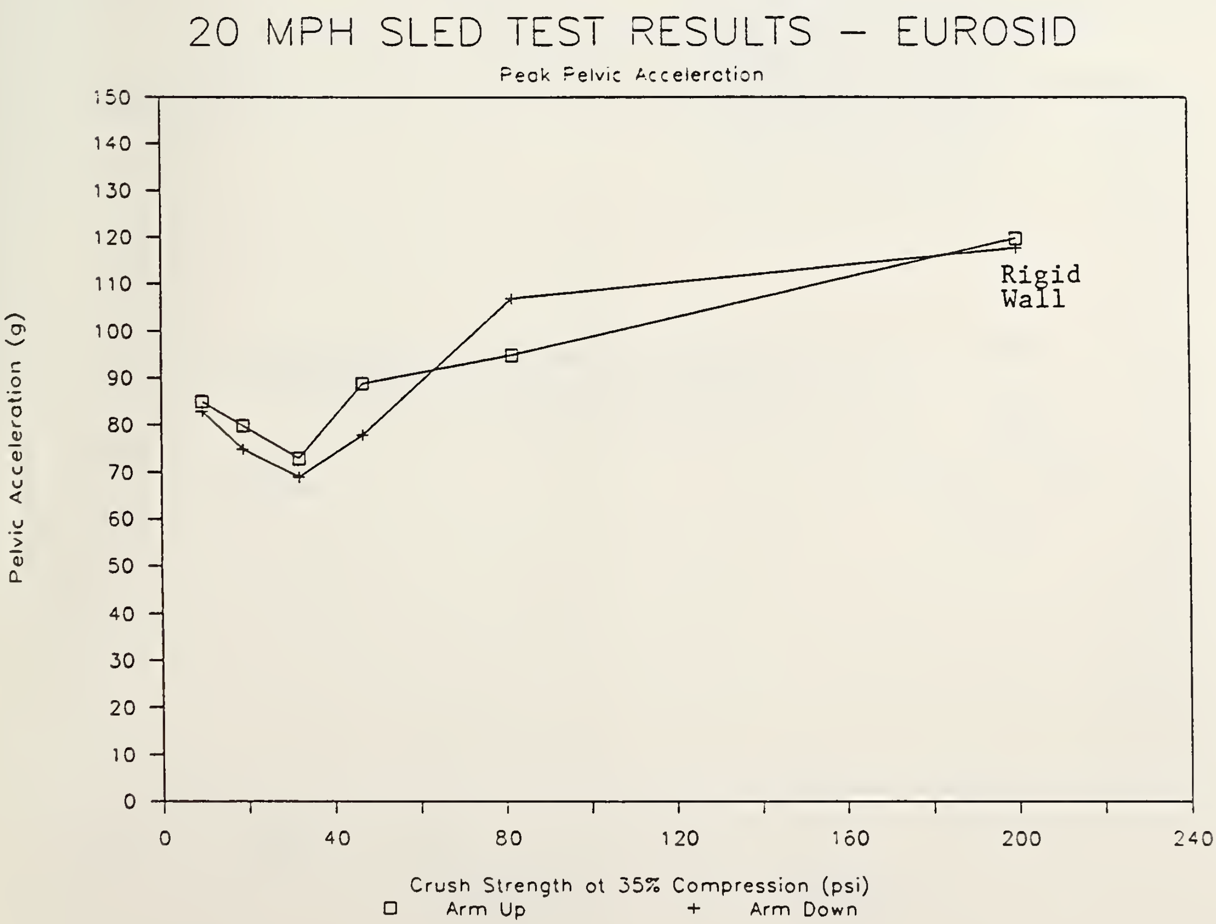
20 MPH SLED TESTS RESULTS – BIOSID

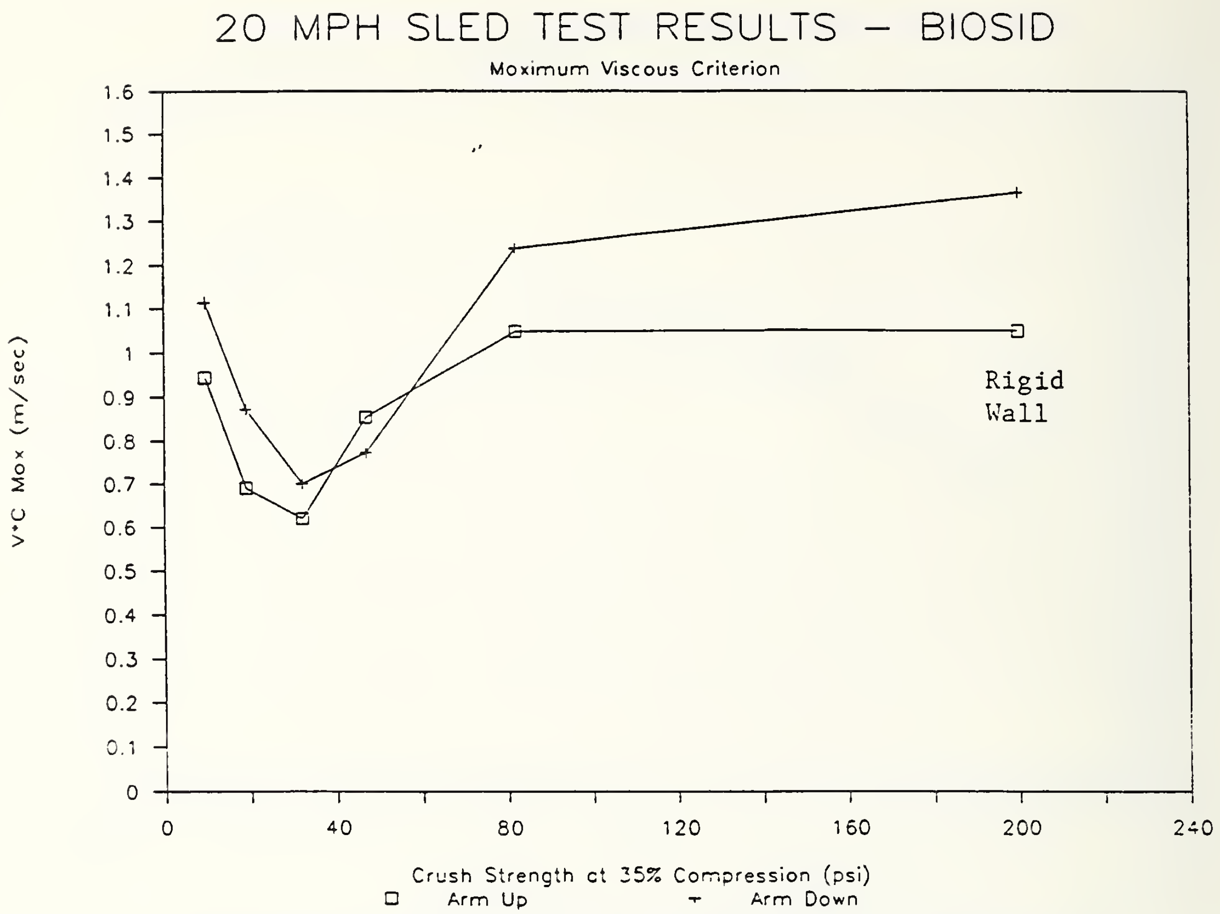


20 MPH SLED TESTS RESULTS – EUROSID

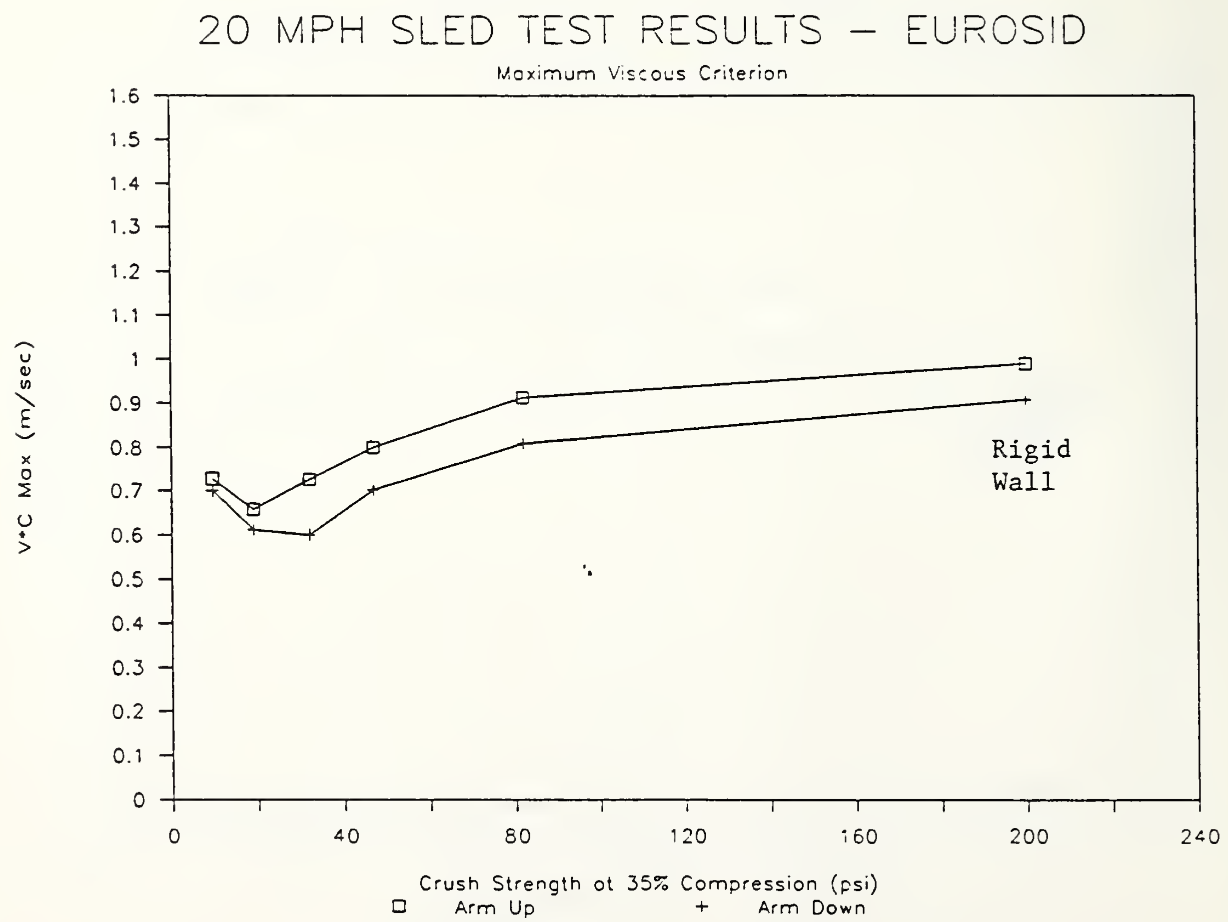



20 MPH SLED TEST RESULTS – BIOSID
Peak Pelvic Acceleration
Pelvic Acceleration (g)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
40
80
120
160
200
240
Rigid Wall
Crush Strength at 35% Compression (psi)
Arm Up
Arm Down

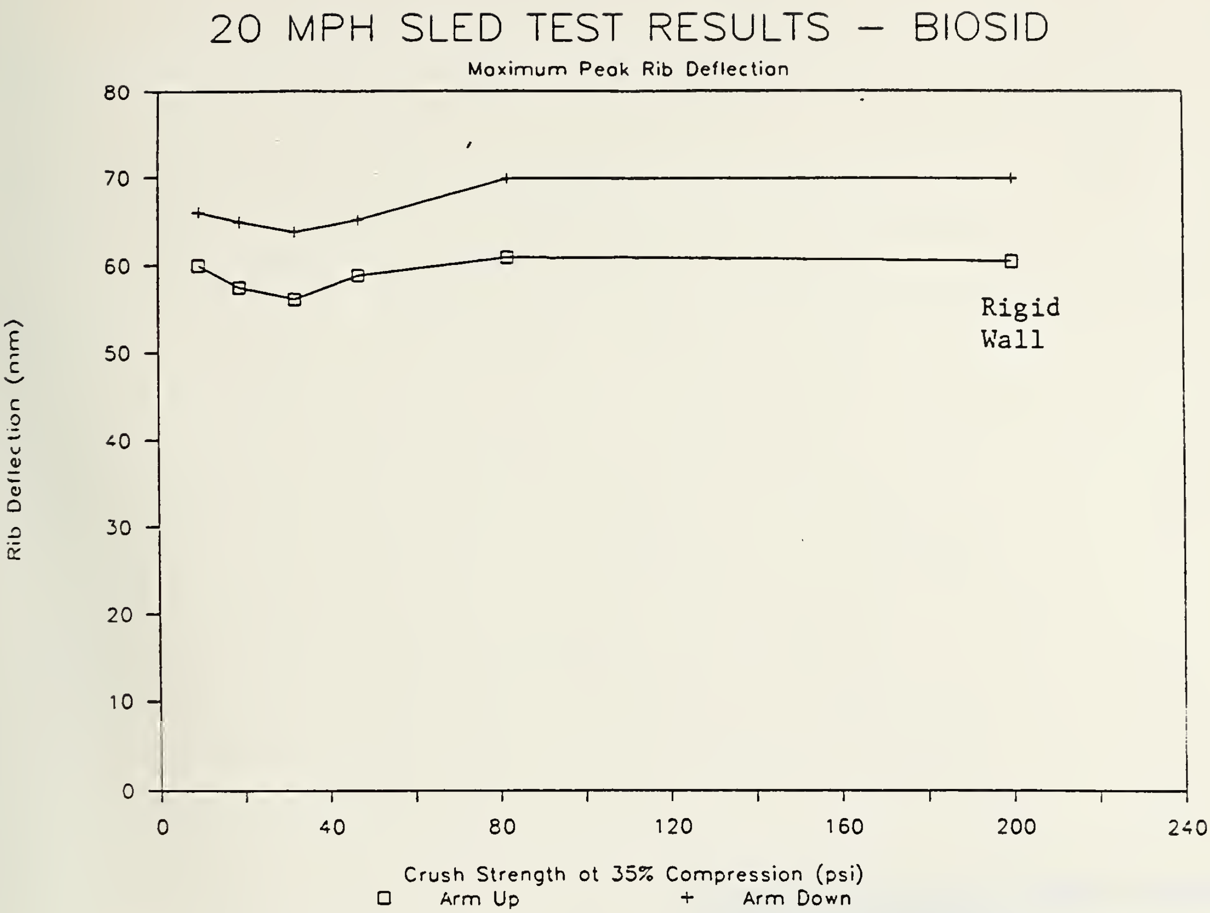

20 MPH SLED TEST RESULTS – EUROSID
Peak Pelvic Acceleration
Pelvic Acceleration (g)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
0
40
80
120
160
200
240
Rigid Wall
Crush Strength at 35% Compression (psi)
Arm Up
Arm Down

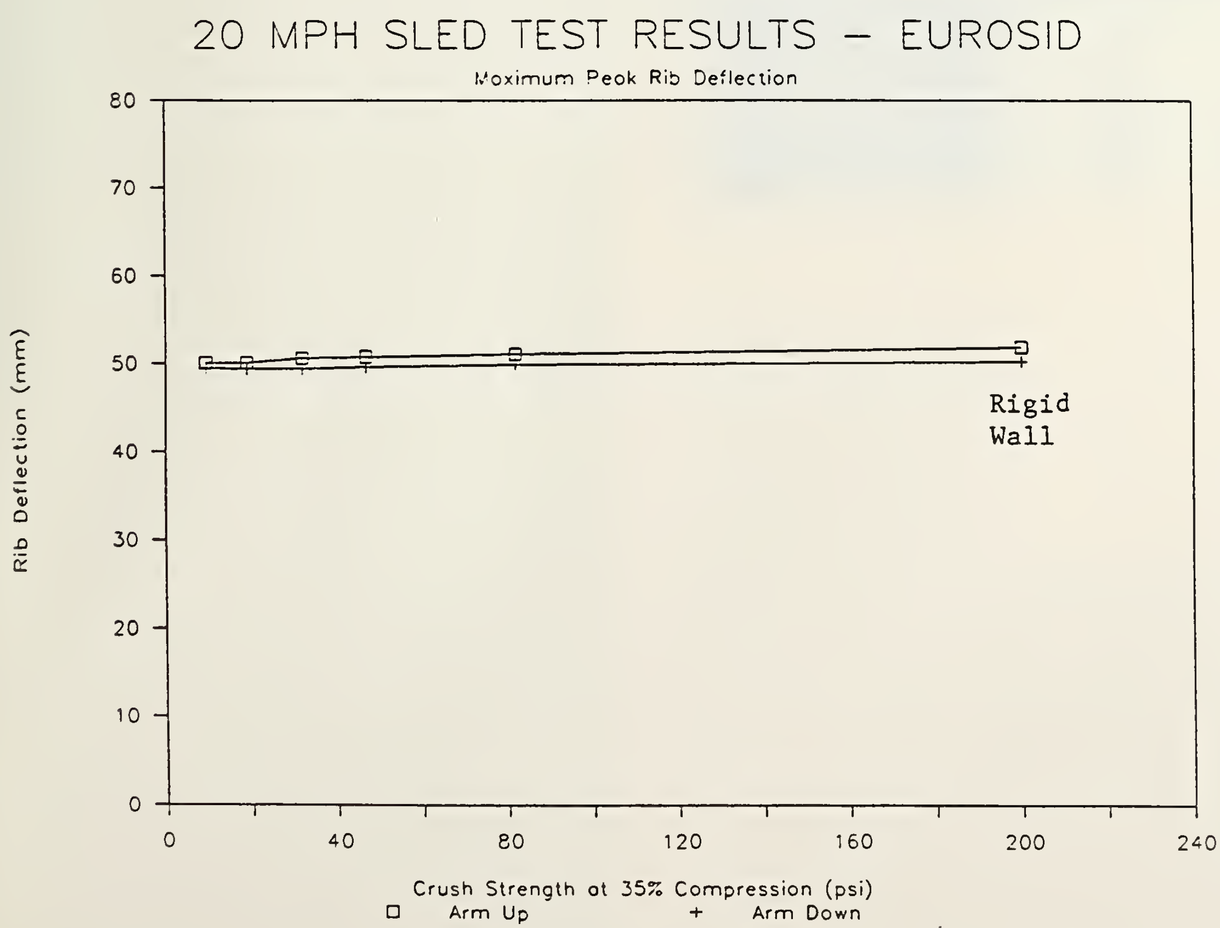


20 MPH SLED TEST RESULTS – BIOSID
Maximum Viscous Criterion
V*C Max (m/sec)
Rigid Wall
Crush Strength at 35% Compression (psi)
Arm Up
Arm Down



20 MPH SLED TEST RESULTS – EUROSID
Maximum Viscous Criterion
V*C Max (m/sec)
Rigid Wall
Crush Strength at 35% Compression (psi)
Arm Up
Arm Down


20 MPH SLED TEST RESULTS – BIOSID
Maximum Peak Rib Deflection
Rib Deflection (mm)
Rigid
Wall
Crush Strength at 35% Compression (psi)
Arm Up
Arm Down


20 MPH SLED TEST RESULTS – EUROSID
Maximum Peak Rib Deflection
Rib Deflection (mm)
Rigid
Wall
Crush Strength at 35% Compression (psi)
Arm Up
Arm Down