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Quasi-Static Ankle/Tibia Loading

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Quasi-Static Ankle/Tibia Loading

Twelve quasi-static tests have been performed on six Calmen (right and left legs of Calmen* 46-51, respectively), at Calspan. This procedure attempts to identify the injury mechanisms involved in ankle fractures that have been found to be quite common in frontal automobile impacts.

Figure 1 shows the setup for this test. Two basic tests have been performed. Calmen 46 and 47 were axially loaded with the subjects' feet at 0° flexions. Calmen 48-51 were axially loaded with the feet at 20° dorsi flexions. This was accomplished by fastening a 20° wedge on the face of the impactor.

In all tests the Calspan Linear Impactor was used in a quasi-static mode. The impactor was pumped at a non-specific rate with the trigger in the open position. This allowed the impactor ram to apply an increasing force on the subject's foot (dependent on the pressure pumped into the system). Impactor load cell and displacement readings were measured throughout the event and recorded on an X-Y plotter.

Figures 2-12 show the force-displacement curves for both the right and left legs of Calmen 46-51, respectively.

Table 1 is a summary of the Calmen tested in each of the quasi-static loadings. Table 2 is a summary of injuries.

Calman 46 was loaded axially along the tibia. The results of this test revealed injuries that are similar to those sustained in a jumping type accident. (Mostly crushing type injuries). In order to more closely simulate leg injuries in a frontal crash, the loading point was moved closer to the toes. A line was drawn between the heel and ball of the foot. The bisection of this line was the loading point for Calmen 47-51.

*Calmen (Calman) is a generic term used to identify a human cadaver used in research at Calspan. The number is serial,i.e., Calman 46 (CM46) is the 46th cadaver studied at Calspan.

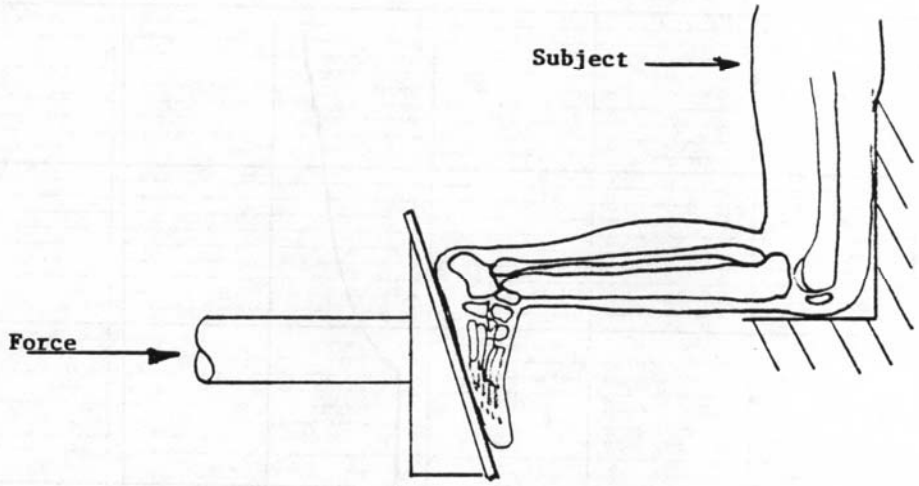

Figure 1 QUASI-STATIC ANKLE TIBIA LOADING

Figure 2 CALMAN 46

AXIAL FORCE VS. DEFLECTION RESPONSE OF RIGHT LEG

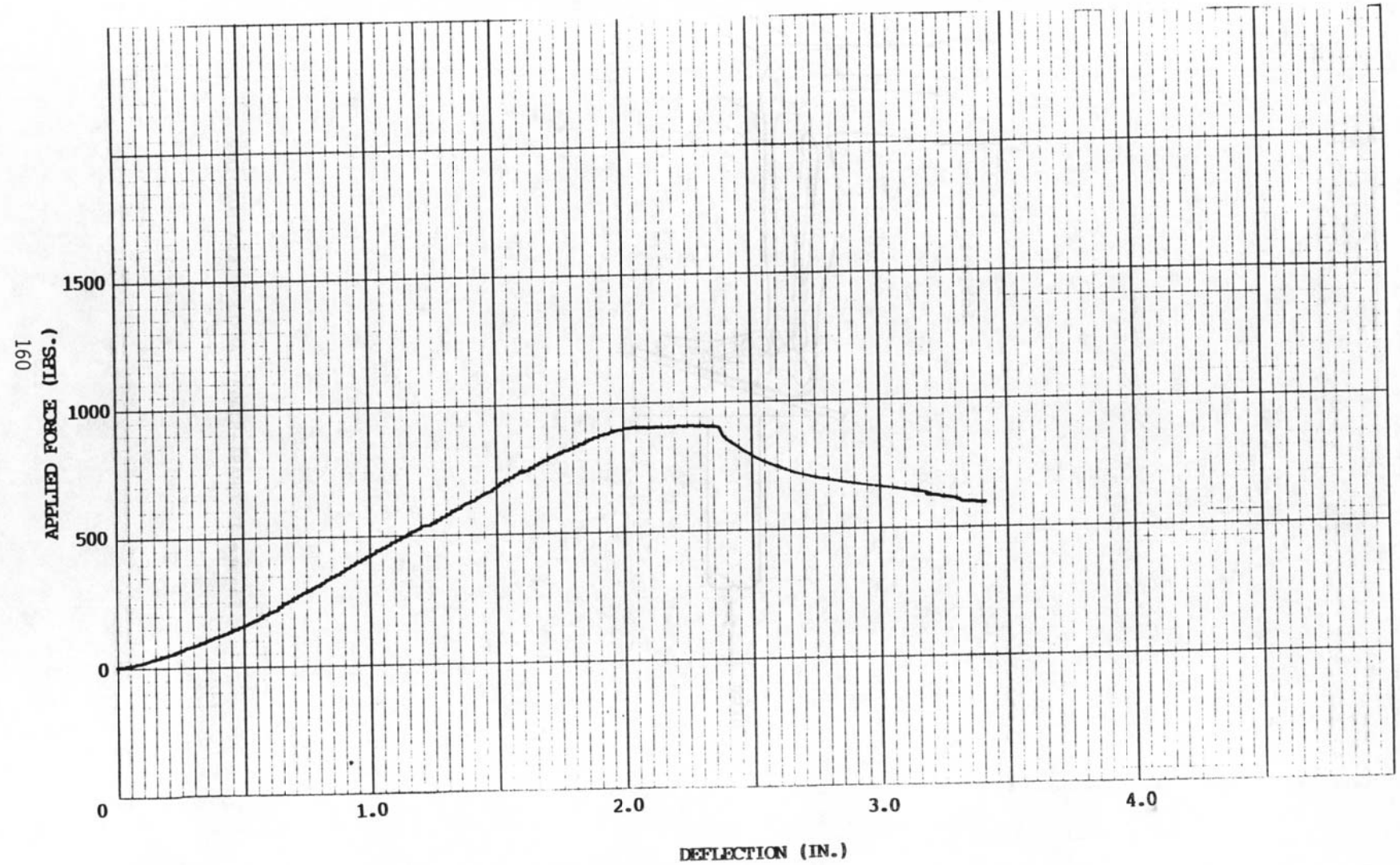

Figure 3 CALMAN 46

AXIAL FORCE VS. DEFLECTION RESPONSE OF LEFT LEG

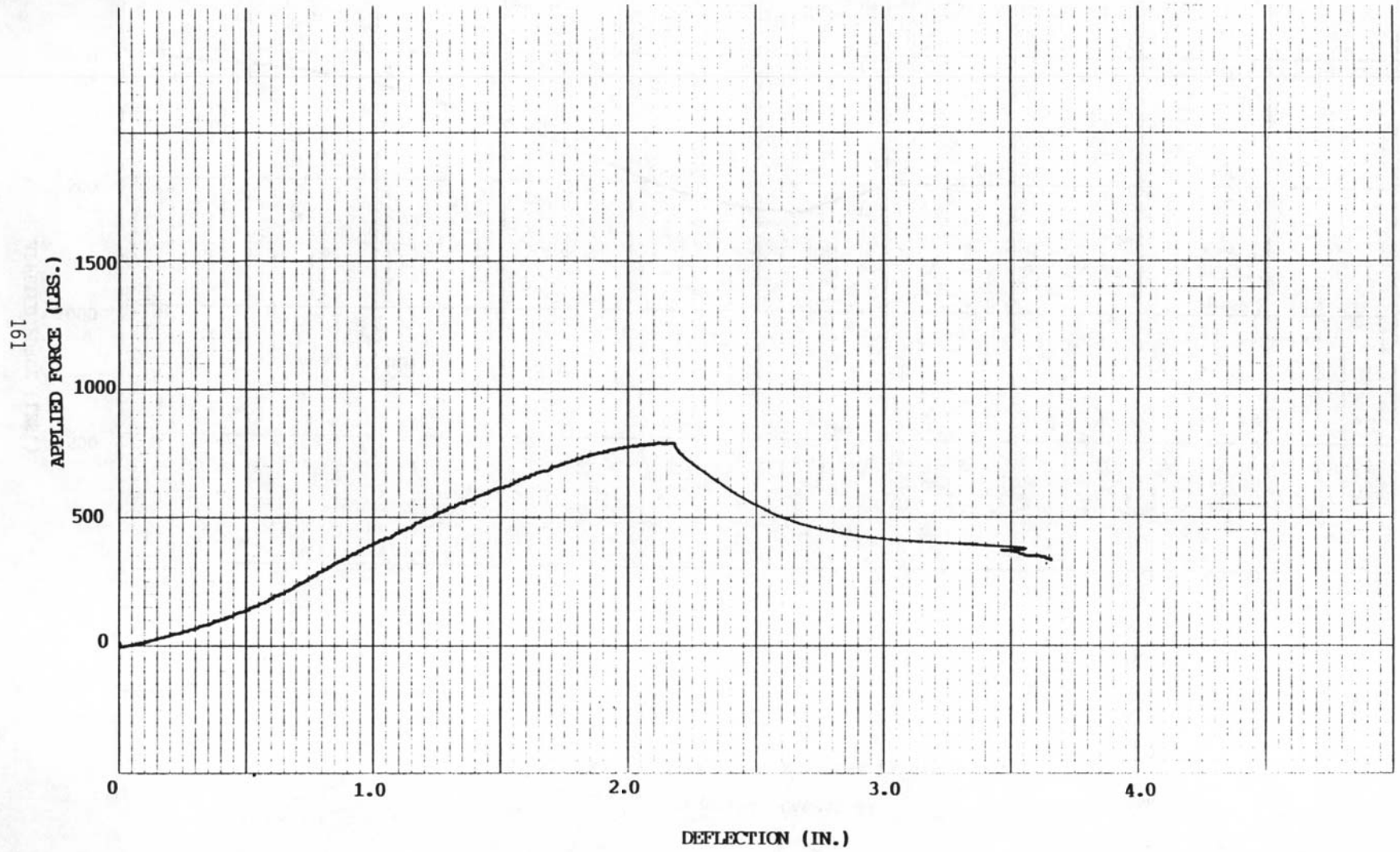

Figure 4 CALMAN 47

AXIAL FORCE VS. DEFLECTION RESPONSE OF RIGHT LEG

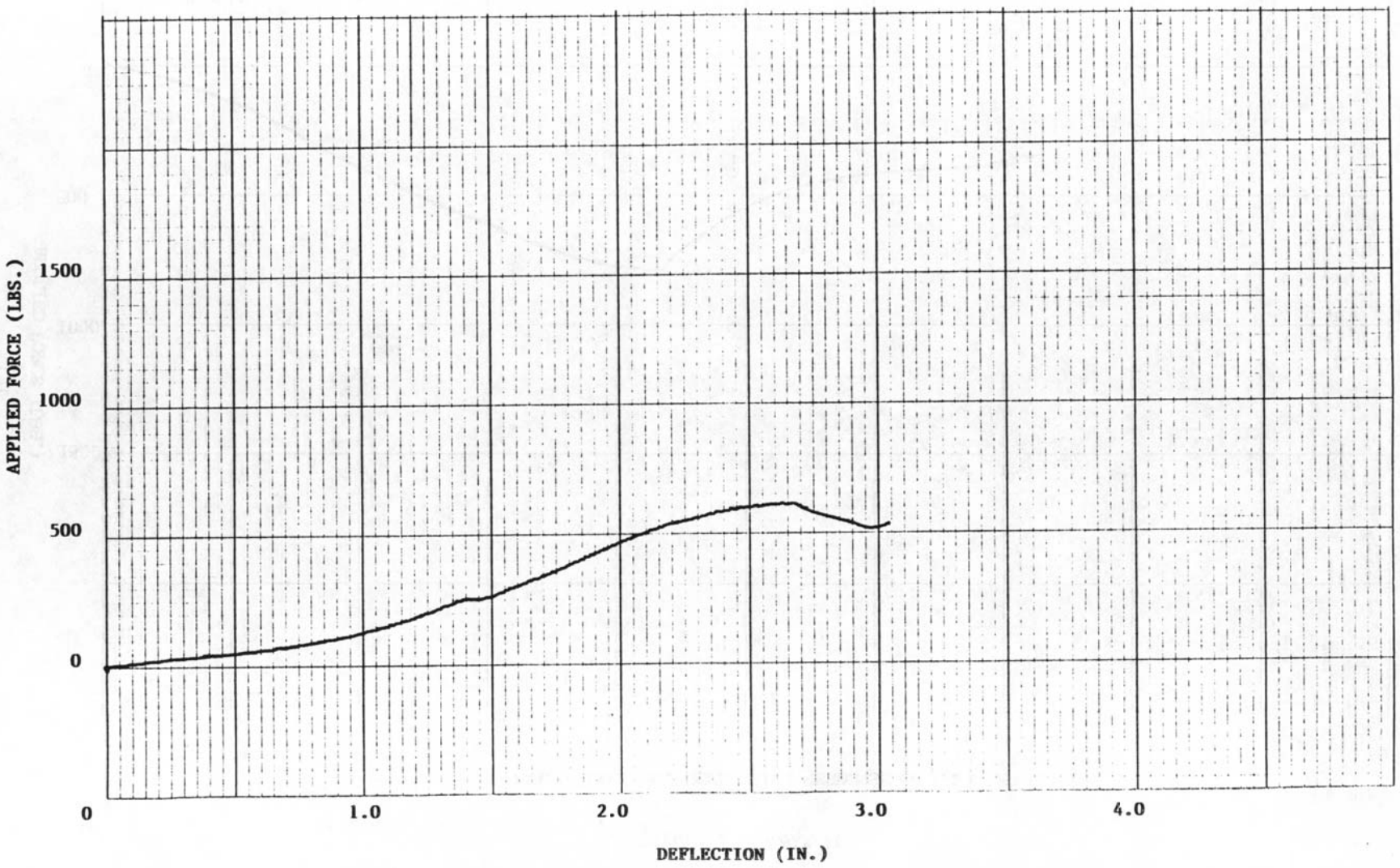

Figure 5 CALMAN 47

AXIAL FORCE VS. DEFLECTION RESPONSE OF LEFT LEG

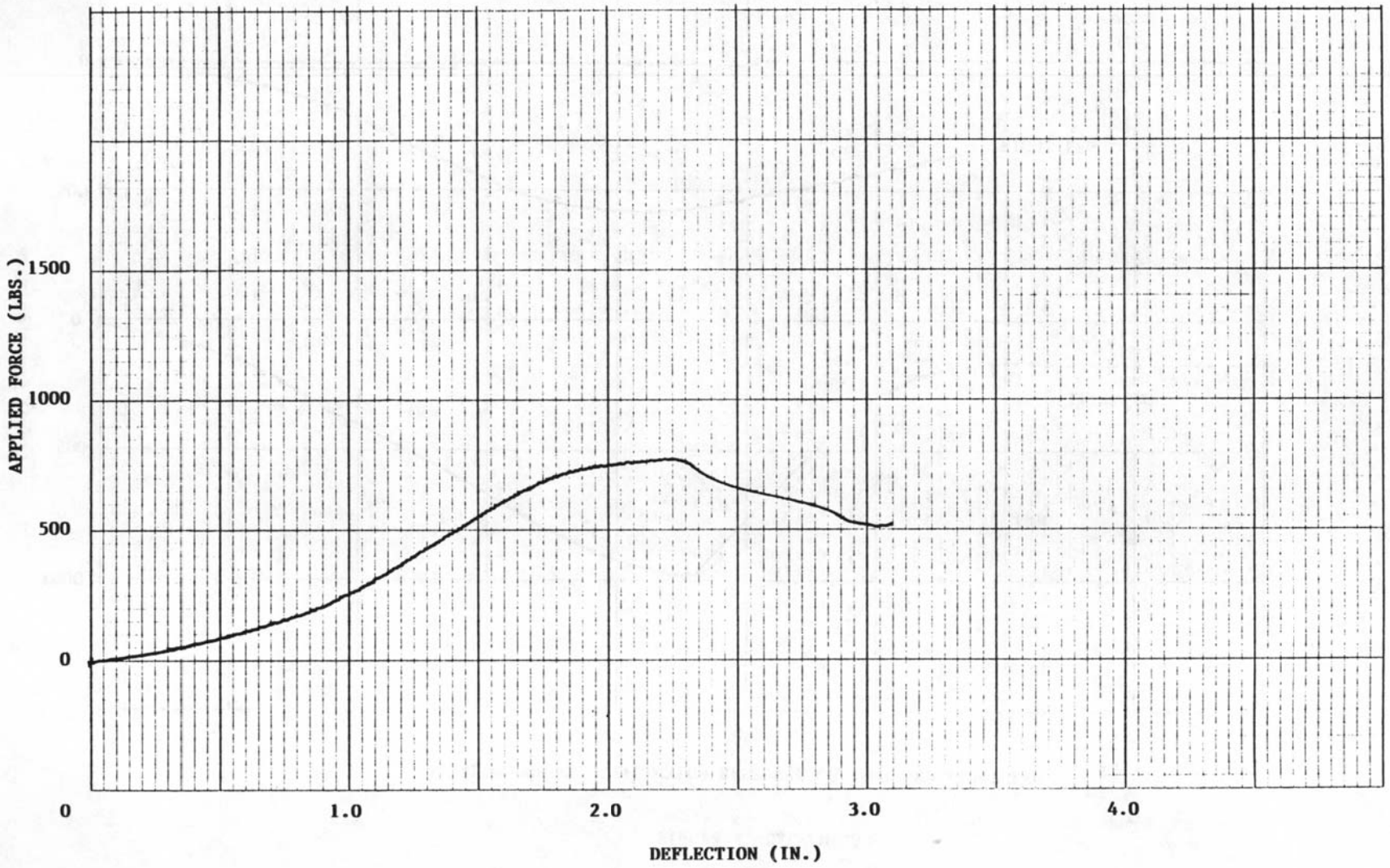

Figure 6 CALMAN 48

AXIAL FORCE VS. DEFLECTION RESPONSE OF LEFT AND RIGHT LEG

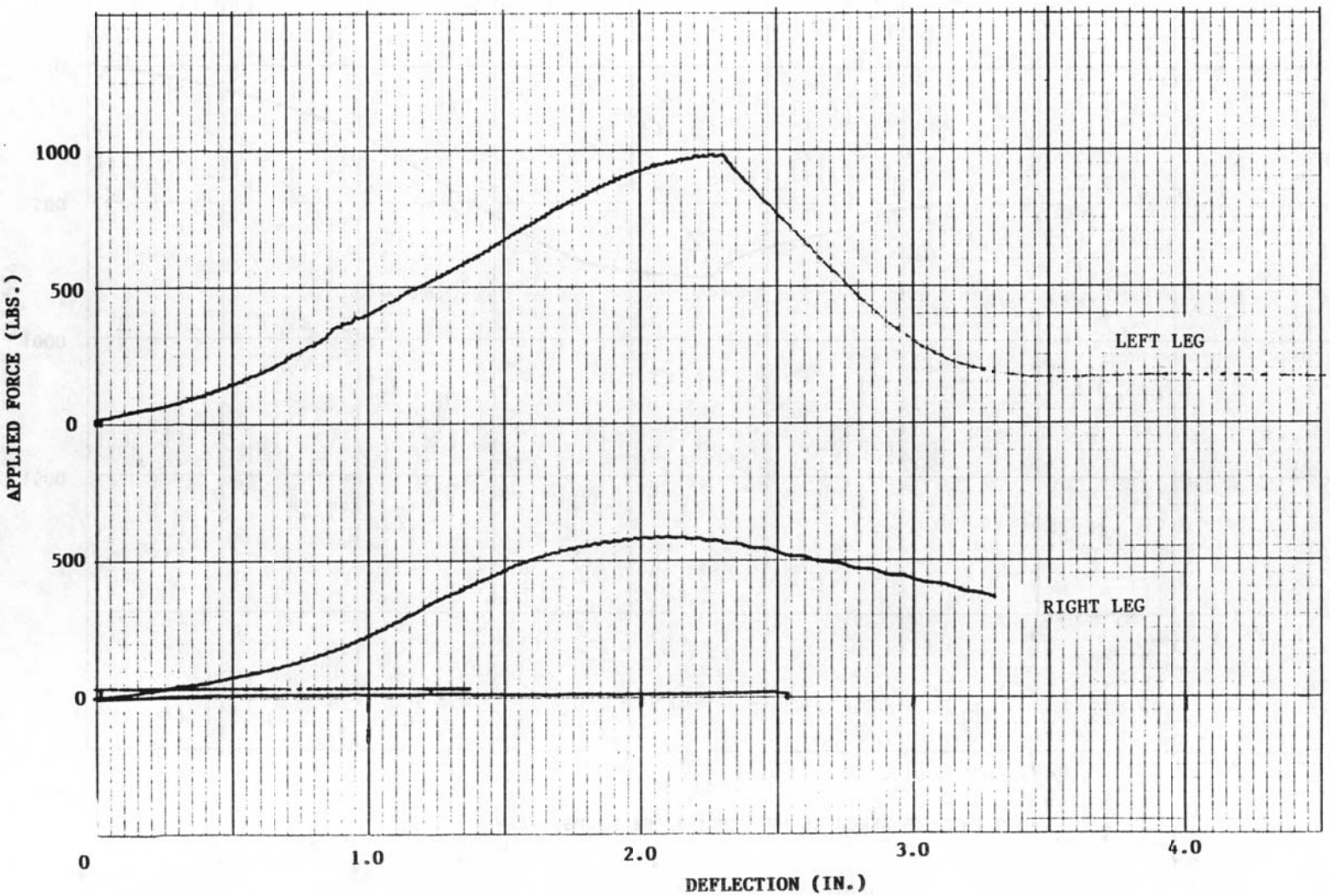

Figure 7 CALMAN 49

AXIAL FORCE VS. DEFLECTION RESPONSE OF RIGHT LEG

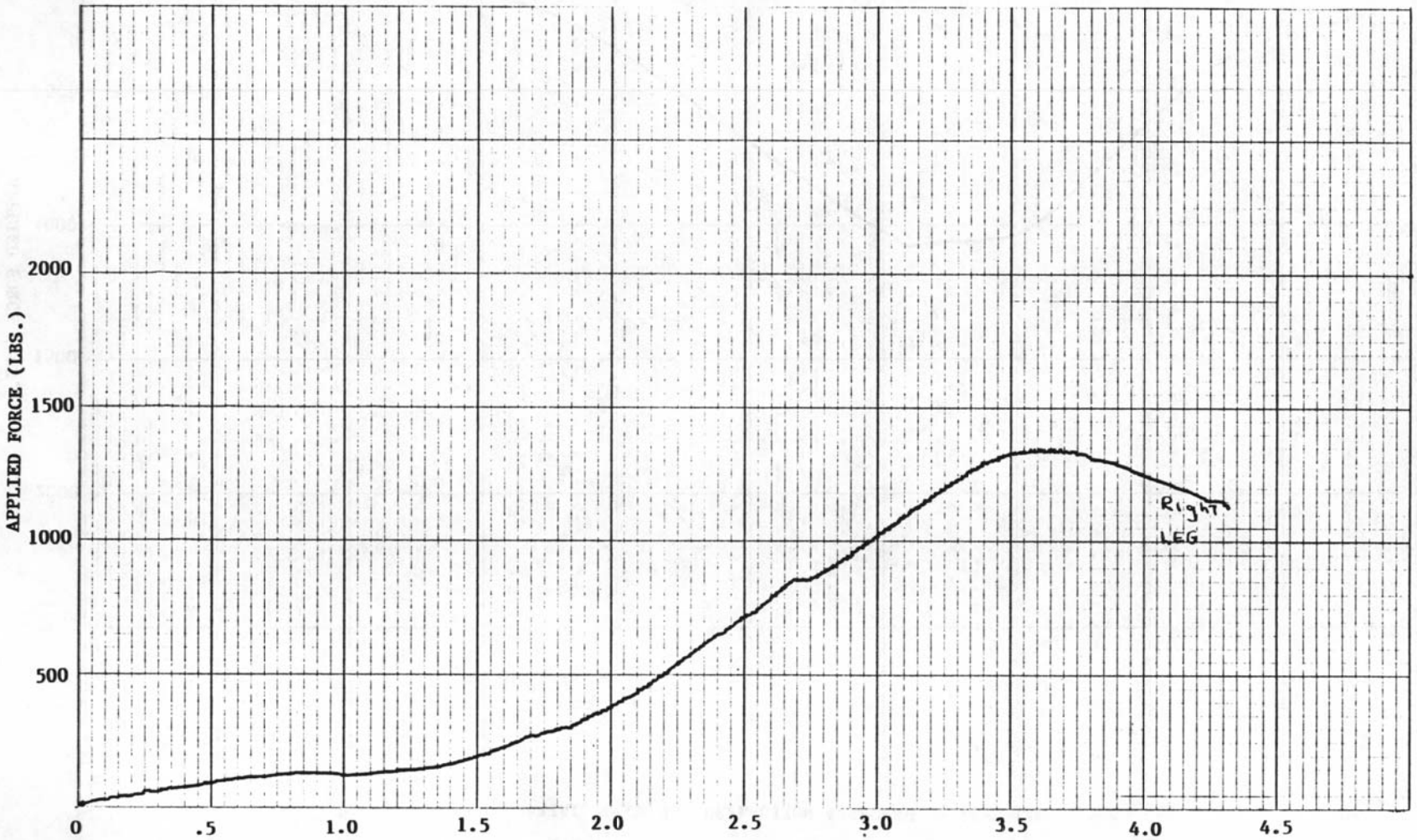

Figure 8 CALMAN 49

AXIAL FORCE VS. DEFLECTION RESPONSE OF LEFT LEG

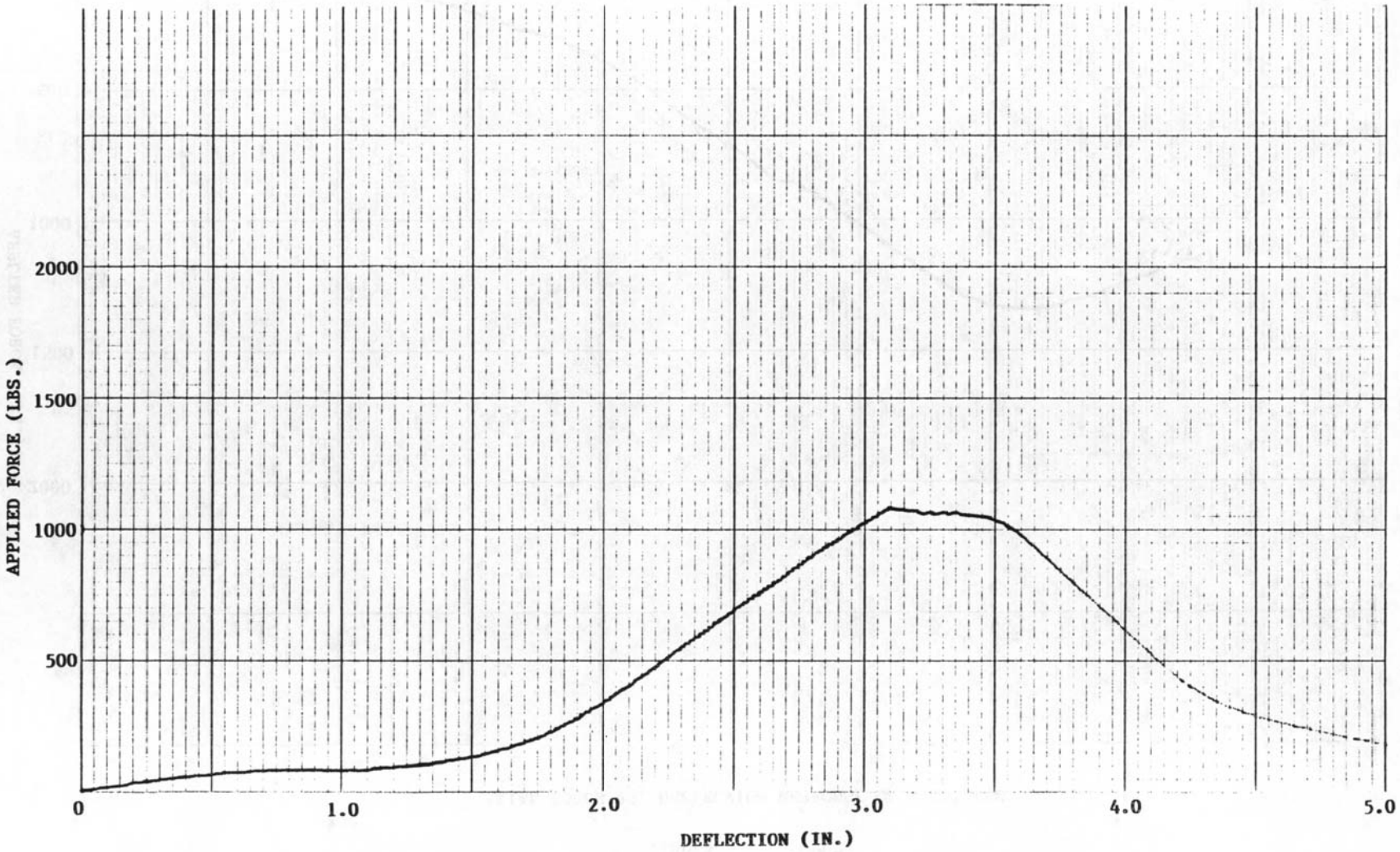

Figure 9 CALMAN 50

AXIAL FORCE VS. DEFLECTION RESPONSE OF RIGHT LEG

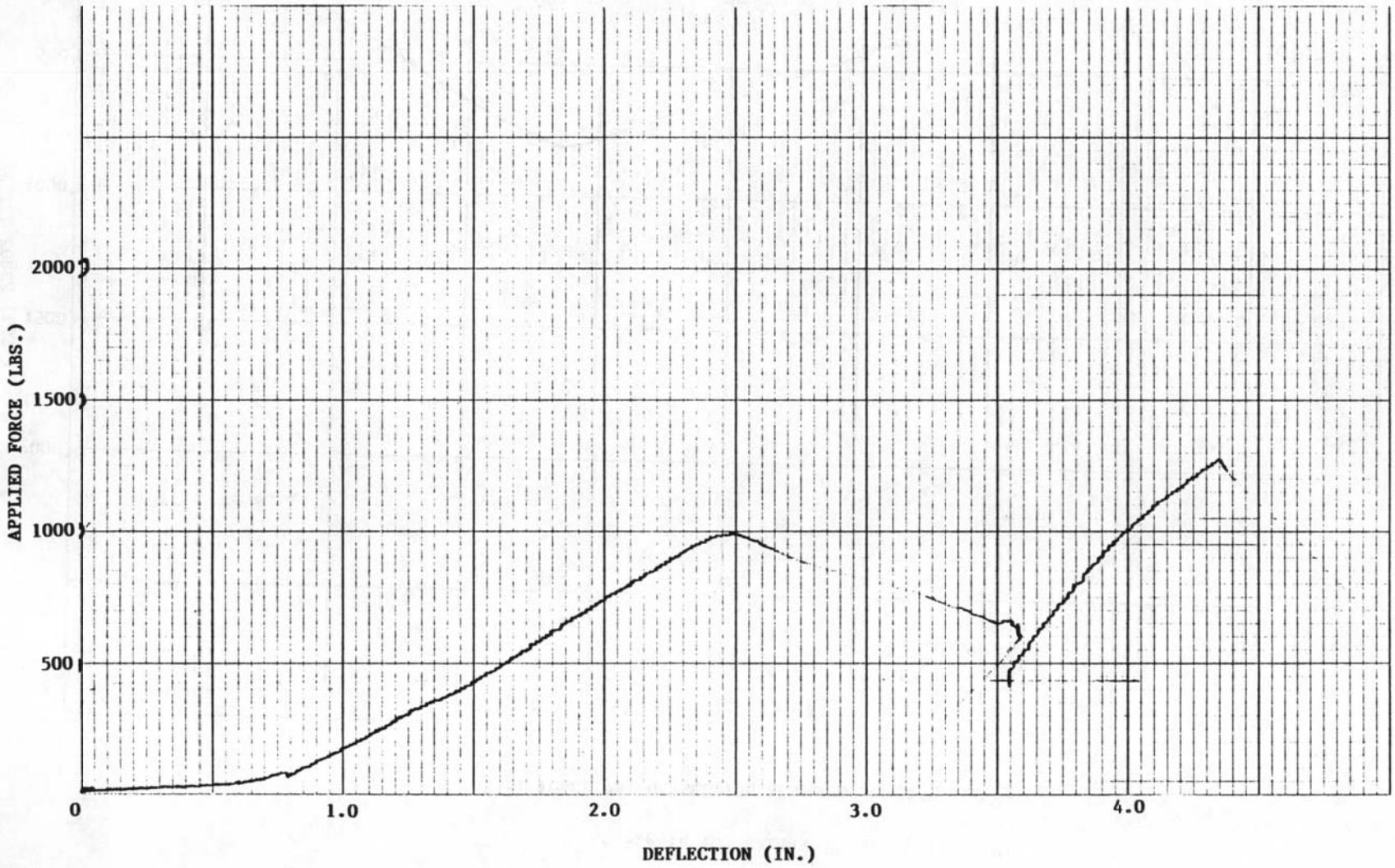

Figure 10 CALMAN 50

AXIAL FORCE VS. DEFLECTION RESPONSE OF LEFT LEG

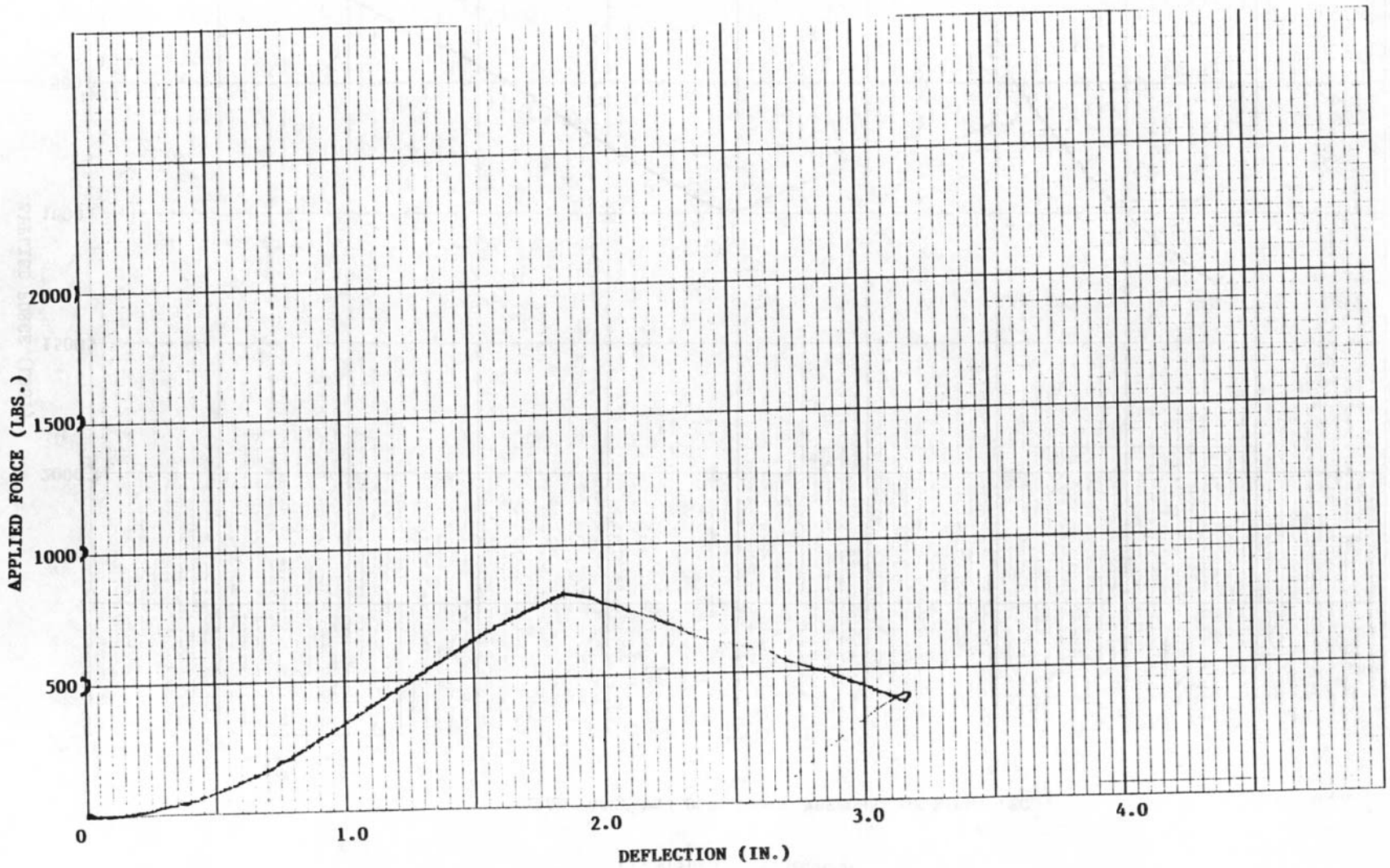

Figure 11 CALMAN 51

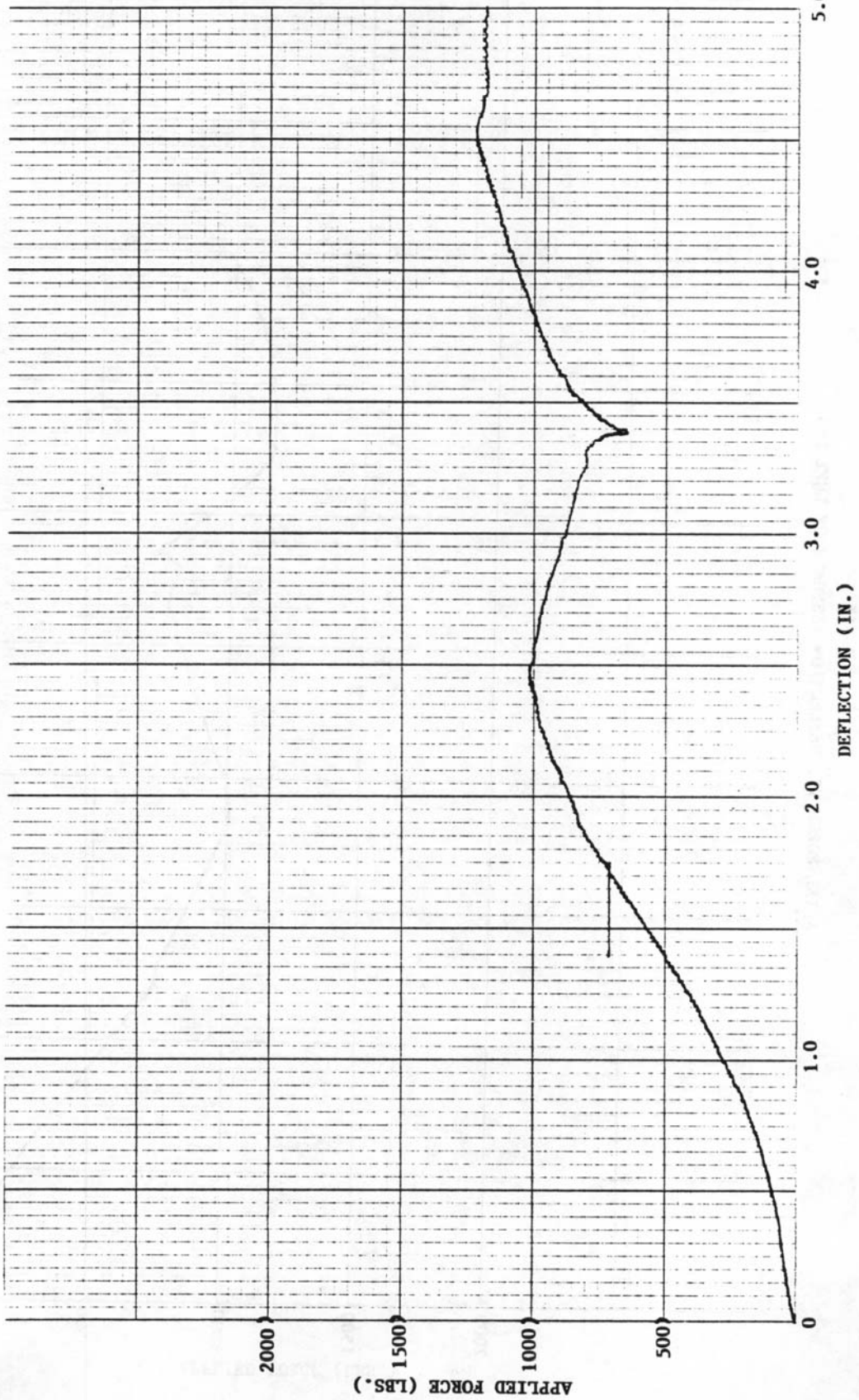

Figure 12 CALMAN 51

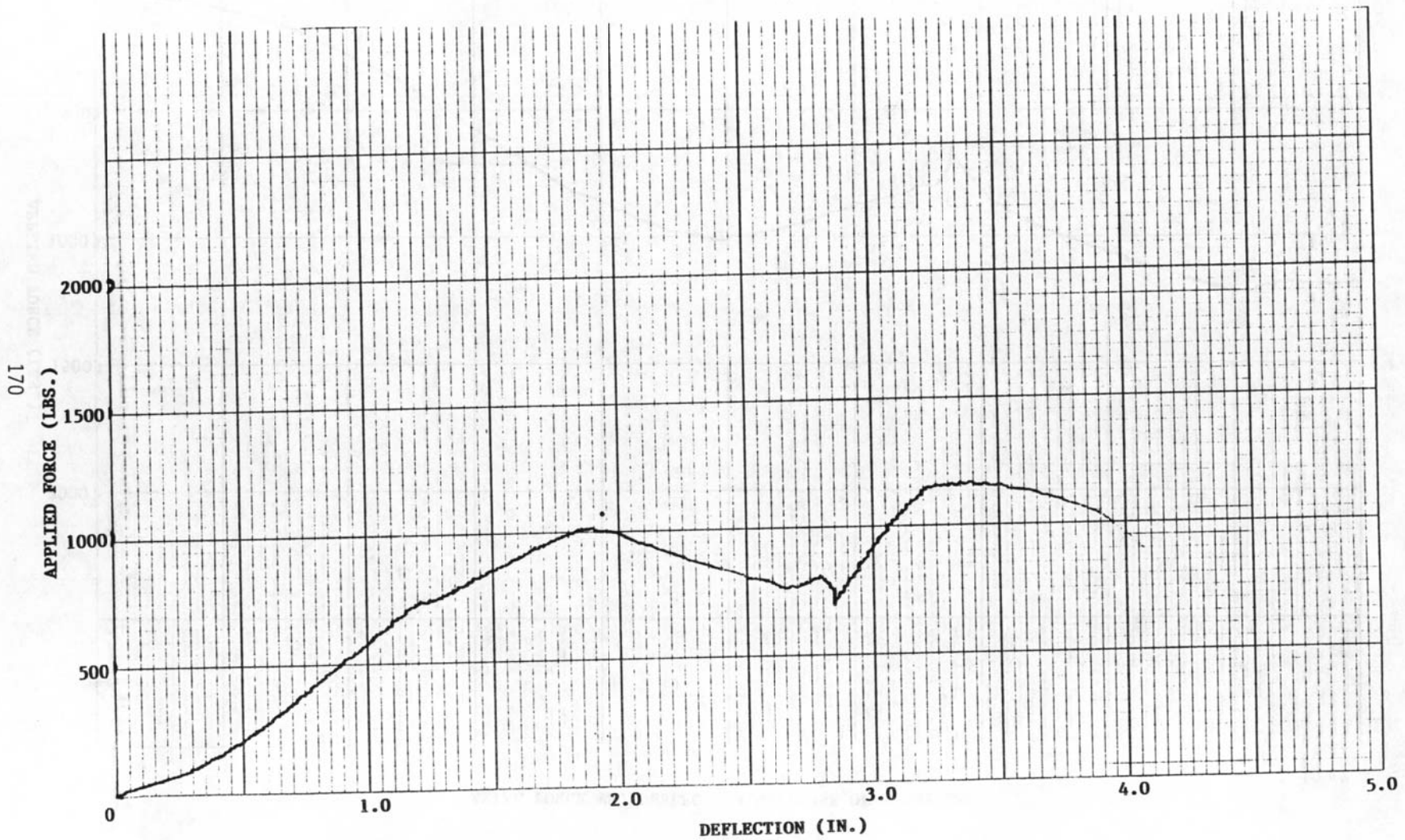

Table 1

SUMMARY OF QUASI-STATIC LEG TESTS

Subject No.	Age (yrs.)	Sex	Ht. (in.)	Wt. (lbs.)	Leg	Foot Angle	Peak Load (lbs.)
46	59	M	68.5	148	Right	0°	900
					Left	0°	800
47	49	M	69.0	200	Right	0°	600
					Left	0°	760
48	74	M	64.0	157	Right	20°	580
					Left	20°	980
49	51	M	71.0	141	Right	20°	1350
					Left	20°	1080
50	74	M	67.0	140	Right	20°	1270
					Left	20°	810
51	69	M	67.0	139	Right	20°	1220
					Left	20°	1150

Table 2

SUMMARY OF QUASI-STATIC LEG INJURIES

Subject No.	Peak Load (lbs.)	Leg	Injuries
46	900	Right	Ankle: Intracutaneous contusion anterior to lateral malleolus. Peroneous longus and brevis muscles dislodged. Superior peroneal retinaculum torn. Deltoid ligament stretched including tibianavicular and tibicalcaneo part. Ligamentum lacinatum stretched. Medial and lateral tubercle of talus fractured. Cuboid crushed. Entire anterior portion of calcaneous crushed. Knee: No damage.
46	800	Left	Ankle: Skin laceration below medial malleolus. Stetched tendons of tibialis posterior, flexor digitorum longus and flexor hallicis. Deltoid ligament lacerated. Ligamentum lacinatum lacerated. Medial tubercle of talus was avulsed. Cuboid crushed. Entire anterior portion of calcaneous crushed. Knee: No damage.
47	600	Right	Ankle: Tibialis posterior tendon stretched. Anterior articular surface of calcaneous fractured. Abrasion of inferior articular surface of talus. Knee: No damage.

Table 2 (cont'd)

Subject No.	Peak Load (lbs.)	Leg	Injuries
47	760	Left	Ankle: Capsule of ankle torn medial side. Flexor retinaculum torn. Medial part of superior articular cartilage of talus was fractured. Knee: No damage.
48	580	Right	Ankle: No damage. Knee: No damage.
48	980	Left	Ankle: Bleeding in subcutaneous tissue superior to medial malleolus. Flexor retinaculum torn. Tendon of Flexor digitorum longus stretched (strained). Deltoid ligament torn (complete). Tibia fractured and displaced inferior to medial malleolus. Talus fractured on superior lateral articular surface. Calcaneous crushed on the anterolateral portion. Fibula fractured superior to lateral malleolus. Peroneus longus and brevis muscles lacerated. Knee: No damage.
49	1350	Right	Ankle: No damage. Knee: No damage.
49	1080	Left	Ankle: No damage. Knee: No damage.

Table 2 (cont'd)

Subject No.	Peak Load (lbs.)	Leg	Injuries
50		Right	Ankle: Skin laceration medial side, 3.0 inches by 1.5 inches superior to medial malleolus. Complete dislocation of talus. Tibialis posterior tendon showed 2.0 to 3.0 inches of stretch at joint. Flexor digitorum longus tendon showed 2.0 inches of stretch at joint. Ankle joint capsule ruptured medial side. Displaced fracture of malleolus medial side. Flexor retinaculum ruptured (complete). Deltoid ligament ruptured (complete). Flexor hallicis longus tendon torn (complete) away from muscle. Posterior tibial artery and vein ruptured (complete). Lateral surface of talus crushed. Articular cartilage of talus fractured. Talar facet of calcaneous fractured. Displaced fracture of malleolus lateral side. Knee: Anterior cruciate ligament ruptured. Posterior medial part of tibial plateau fractured (bone and cartilage).
50	810	Left	Ankle: Avulsion of medial malleolus with distal part of tibia attached to deltoid ligament (complete). Flexor retinaculum was partially ruptured. Tibialis posterior tendon showed 2.0 inches of stretch. Flexor digitorum longus tendon showed 2.0 inches of stretch. Lateral, inferior facet of talus displayed cartilage fracture. Middle facet of calcaneous displayed cartilage fracture. Undisplaced fracture of malleolus lateral side. Knee: No damage.

Table 2 (cont'd)

Subject No.	Peak Load (lbs.)	Leg	Injuries
51	1220	Right	Ankle: Laceration of ankle medial side. Flexor digitorum longus and tibialis posterior tendons pulled out. Undisplaced fracture of medial malleolus. Fracture (crush) of lateral portion of facet of talus. Flexor hallucis longus stretched. Calcaneous completely crushed. Complete calcaneous crush. Knee: Rupture of anterior cruciate. Fractures of tibial plateau - both sides.
51	1150	Left	Ankle: Loceration of left ankle - medial side. Displaced fracture of medial malleolus. Lacerated deltoid ligament. Posterior tibialis and flexor digitorum longus pulled out. Dislocation of talus. Posterior tibial artery and vein lacerated. Flexor hallucis longus tendon pulled out. Talus cartilage fracture - inferior antero-lateral surface. Medial plantar nerve showed some rupturing. Posterior lateral surface of calcaneous cartilage fractures. Knee: Anterior cruciate ruptured and bucket handle tear medial side. Fractures on medial and lateral sides of the tibial plateau.

Calmen 48-51 had each leg loaded with the foot at a 20° dorsi flexion. At the time this was felt to be more realistic of the orientation of the leg in a frontal crash situation. The loads in all cases were higher with correspondingly more severe injuries. It appears that the flexion of the foot helped to stabilize the ankle joint, slightly, allowing greater loads to be achieved before fracture. Calman 48's right leg did not display injuries due to the low load level applied. Immediate post-test palpation of the right leg failed to indicate injury. For the left leg it was decided to increase the load applied. Consequently, catastrophic failure of the ankle joint resulted.

Calman 49's right and left legs did not display injuries due to the subject slipping out of the test mechanism. For the remaining tests, the subjects' thigh was tethered to the front of the test apparatus by means of automotive belt webbing.

In all cases the force delivered to each foot caused an eversion of the foot to occur. The eversions resulted in the majority of soft tissue injuries to occur on the medial side. The injuries on the lateral side tended to be more of a crushing type due to the compression of the tissues. These tended to be hard tissue injuries.

With Calmen 50 and 51 the loads delivered were higher than the previous tests. Calman 50's right and 51's right and left leg force deflection curves show double peaks (Figures 9-12). It was thought that when the first peak was achieved during the test that no injuries had occurred in the subject. The decision was made to continue to load the foot until fracture had occurred. In all three cases the anterior cruciate ligaments were torn (knee joint). This appears to be associated with the first peak of the curve. The continued loading of the foot eventually lead to catastrophic failure of the ankle joint for both legs of Calmen 50 and 51.

DISCUSSION

PAPER: Quasi Static Ankle/Tibia Loading

SPEAKERS: B. Donnelly, & David Roberts

Q: Unnamed
You mentioned in your introduction that NHTSA has noticed that there is an increase in ankle injuries. I would like to know in which time frame it has increased?

A: If I said that I didn't mean to, I think their interest is recent, I don't think the injuries are.

Q: Okay. Also the injuries that you say they are not typical of what you would get in a car accident is that right?

A: I understand that they're not. Right.