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COMPARABILITY OF PENDULUM AND SLED TESTS.

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Introduction.

Cadaver tests are conducted in order to study the effect of impact on the human body under controlled conditions. The data collected from these tests are then analysed with a view to arriving at an injury measure for frontal impact tests by relating the reported AIS (Abbreviated Injury Scale) values to the cadaver response variables and cadaver anthropometric characteristics. The National Highway Traffic Safety Administration (NHTSA) cadaver test data base contains frontal thoracic impact test data from the following two types of impact tests;

- Pendulum or Cannon tests.
- Sled tests.

The data from these two types of tests are analysed together as a group. It is not intuitively obvious if the data from these two kinds of tests can be lumped together and analysed. So, this study was undertaken to compare the response of an appropriate model of the human thorax to simulated pendulum and sled tests. A mathematical representation of the Lobdell model [1] was used in this study.

Method.

Figure 1 is a schematic representation of the Lobdell model used in this study. Accompanying the schematic representation of the model is a set of ordinary differential equations which describe, mathematically, the dynamics of the physical model.

The model was exercised and the responses studied under the conditions prevailing in the following types of tests:

- Pendulum Tests. Blunt Impacts from pendulums with masses of 52 and 100 pounds having impact velocities of 15, 20, 25 and 30 mph. Tables 1 and 2 depicts the results of these tests.

- Sled Tests with Zero Offset. A sled starting from rest with the model resting against it was given a square acceleration pulse of 20 G until end velocities of 10, 15, 20 and 25 mph were reached. After achieving the required end velocity, the sled and the model continued to travel at a uniform velocity. The response of the model to these conditions is tabulated in Table 3. Figure 2 illustrates the initial conditions for this test.

- **Sled Tests with Variable Offsets.** The model and the sled were started from rest. The sled was given a square acceleration pulse of 20 G and traveled through offset distances of 5, 10 and 15 inches before it made contact with the model. After making contact, the sled and the model were accelerated together at 20 G until end velocities of 10, 15, 20 and 25 mph were reached. The thorax and the sled continued to travel at uniform velocity thereafter. Table 4 potrays the effect of these conditions on the model. Figure 3 depicts the initial conditions for tests involving variable offsets .

The model was solved subject to the initial conditions as outlined above using a Hamming predictor-corrector scheme. The fouth order Runge-Kutta scheme was used to start off the solution procedure.

Results.

Figure 4 shows a comparison of the value of the maximum accelerations seen at the spinal mass for different end velocities in four different tests. In Fig. 4 and subsequent figures, the legend "Sled Test with Zero Acceleration" refers to tests wherein the thorax was placed at a predetermined offset distance from the sled and the sled was given a square acceleration pulse. During the time the sled traversed the offset distance, it attained the desired end velocity and continued to travel uniformly at this velocity. The sled made contact with the thorax after traversing the offset distance, thereafter, the sled and the thorax travelled at the end velocity.

As Fig. 4 indicates, the maximum spinal acceleration at any pendulum end velocity within the test range matches fairly well with the maximum spinal acclelerations seen during the sled tests at end velocities which are 5 mph slower than the pendulum end velocities. A similar pattern is seen when the maximum chest compressions are compared at various end velocities in Fig. 5.

Maximum sternal accelerations in the four tests at various end velocities are compared in Fig. 6. It can be seen that the maximum sternal acceleration does not depend upon the mass of the pendulum (for the pendulum masses used in these tests) and is a function only of the end velocity. Also, the maximum sternal acceleration at any pendulum end velocity matches well with the maximum sternal acceleration in a sled test when the sled has the same end velocity as the pendulum. The same pattern is seen in Fig. 7 which shows a comparison of the relative velocities between the sternal and the spinal masses in the four tests for various end velocities.

CONCLUSIONS.

In this study, an effort was made to compare the effects of sled and pendulum tests on cadavers, by comparing the response of a standard Lobdell model to the appropriate exciting forces. The results of this study suggest that some correlation does exist between the response of the model when subjected to simulated pendulum or sled tests. It was seen that:

- Maximum spinal acceleration at any pendulum velocity matches the spinal acceleration observed during simulated sled tests at end velocities which are 5 mph lower the pendulum end velocities.
- A similar pattern was seen when maximum chest compressions were compared at various end velocities in the sled and pendulum tests.
- Maximum sternal acceleration and maximum relative velocity between the sternal and spinal mass measured at a given pendulum end velocity is approximately equal to the respective variables measured in the sled tests when the sled has the same velocity at impact as the pendulum.

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References.

T. E. Lodell, C. K. Kroell, D. C. Schneider, W. E. Hering and A. M. Nahum. "Impact Response of of the Human Thorax". Presented at GMR Symposium on Human Imapct Response-Measurement and Simulation, 1972.

Table 1. Results of Pendulum Tests.

PENDULUM MASS 52 lbm

PENDULUM VELOCITY mph	STERNAL ACCN G' s	SPINAL ACCN. G' s	MAX REL VEL in/sec	MAX CHEST COMPR. in
15	235.01	16.49	19.44	2.8
20	313.35	23.02	25.92	3.8
25	391.69	29.51	32.4	4.4
30	470.03	35.98	38.85	5.3

Table 2. Results of Pendulum Tests.

PENDULUM TEST MASS 100 lbm

PENDULUM VELOCITY mph	STERNAL ACCN G' s	SPINAL ACCN. G' s	MAX REL VEL in/sec	MAX CHEST COMPR. in
15	235.67	20.03	19.81	3.4
20	314.23	27.6	26.43	4.2
25	392.78	35.13	32.03	5.3
30	471.34	42.65	39.55	6.1

Table 3. Results of Sled Tests.

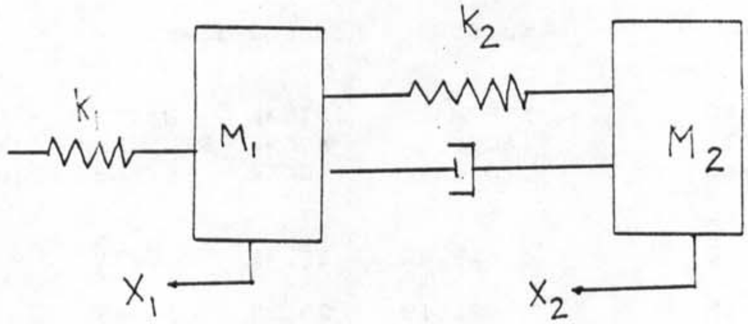
No Sled - Model Offset.

SLED VELOCITY mph	STERNAL ACCN G' s	SPINAL ACCN. G' s	MAX REL VEL in/sec	MAX CHEST COMPR. in
10	19.82	16.71	9.71	3.0
15	21.19	25.25	10.46	3.8
20	23.07	31.9	10.46	4.8
25	23.85	36.03	10.46	5.4

Table 4. Results of Sled Tests.

Sled Tests with Variable Sled-Model Offsets.
Sled Accn. = 0.0 G at Impact

SLED VELOCITY mph	STERNAL ACCN G' s	SPINAL ACCN. G' s	MAX REL VEL in/sec	MAX CHEST COMPR. in
10	157.59	17.16	13.52	3.01
15	236.38	26.87	20.27	4.23
20	315.18	36.53	27.03	5.46
25	393.97	46.16	33.78	6.68



Where :

K 1 = Skin Stiffness (1600 lb/in)

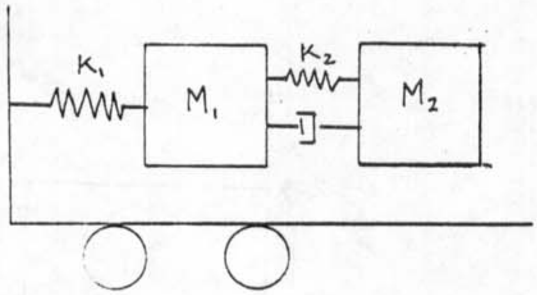
K 2 = Thoracic Stiffness
150 lb/in ((X2 - X1) < 1.25 in.)
450 lb/in ((X2 - X1) > 1.25 in.)

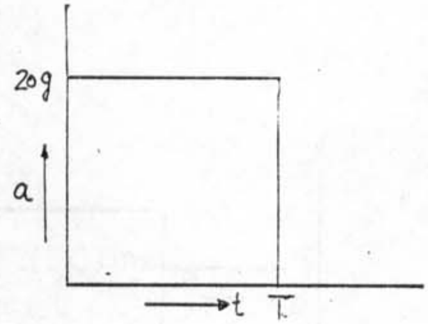
C = Thoracic Damping .
3.0 lb - s/in ((X2 - X1) > 0)
7.0 lb - s/in ((X2 - X1) < 0)

M 1 = Sternal Mass (1.0 lbm)

M 2 = Spinal Mass (60.0 lbm)

Figure 1 : Schematic Representation of Lobdell Model.





Initial Conditions :

Sled Acceleration = 20 G 0 < t < T
= 0 t > T

Velocity (0) = 0

T adjusted to acheive required end velocities of 10, 15, 20 and 25 mph.

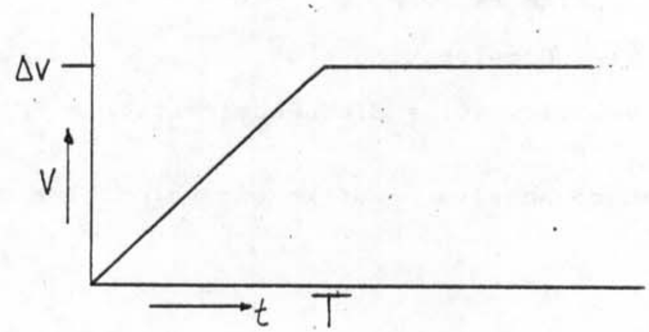
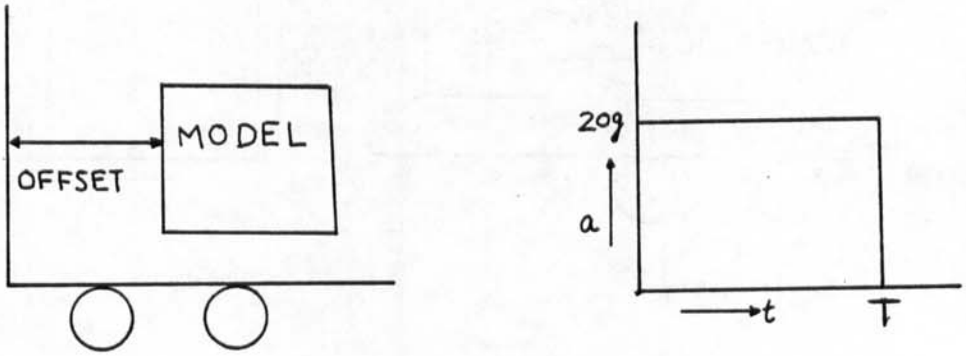


Figure 2: Details of Sled Test with no Offset.



Case 1 : Sled makes contact with model before pulse is over. Let sled make contact with the model at time t, such that;

t = HITTYM

Sled Acceleration = 20 G HITTYM < t < T
= 0 t > T.

Velocity (0) = Sled Acceleration * HITTYM

Case 2 : Sled makes contact with model after acceleration pulse is over.

Sled Acceleration = 0

Velocity (0) = Sled Acceleration * T.

T adjusted to acheive required end velocities of 10, 15, 20, and 25 mph.

Figure 3: Details of Sled Tests with Variable Offsets.

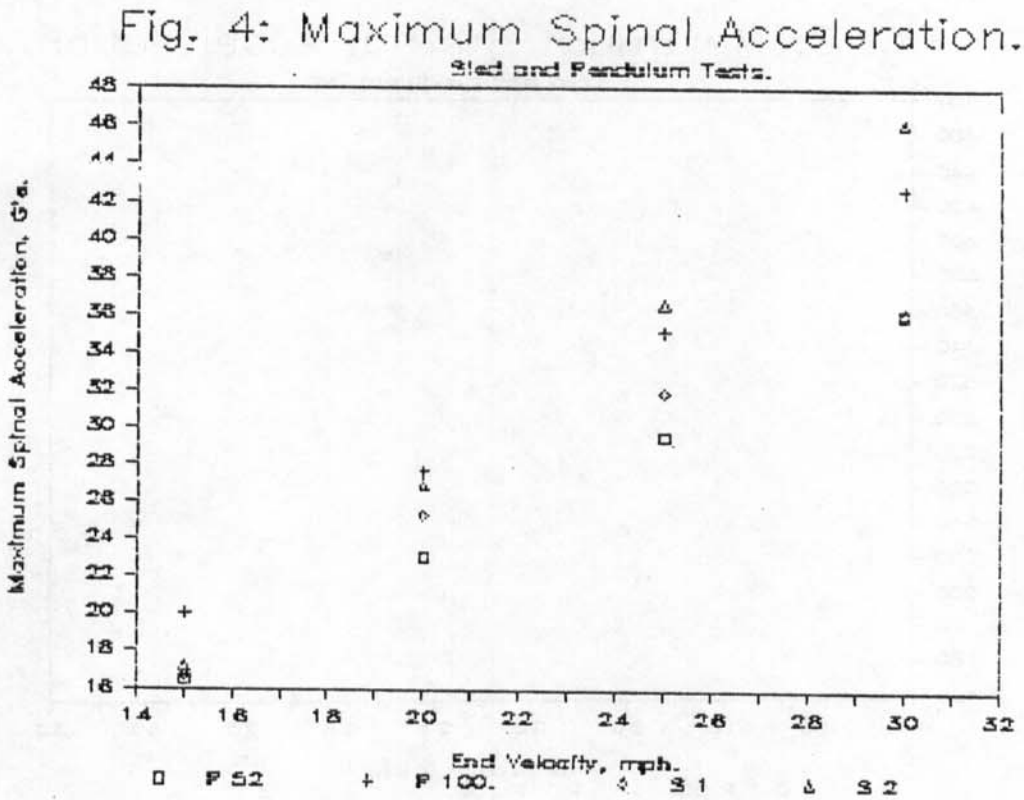


Fig. 4: Maximum Spinal Acceleration.
Sled and Pendulum Tests.
Maximum Spinal Acceleration, G's.
End Velocity, mph.
F 52
F 100.
S 1
S 2

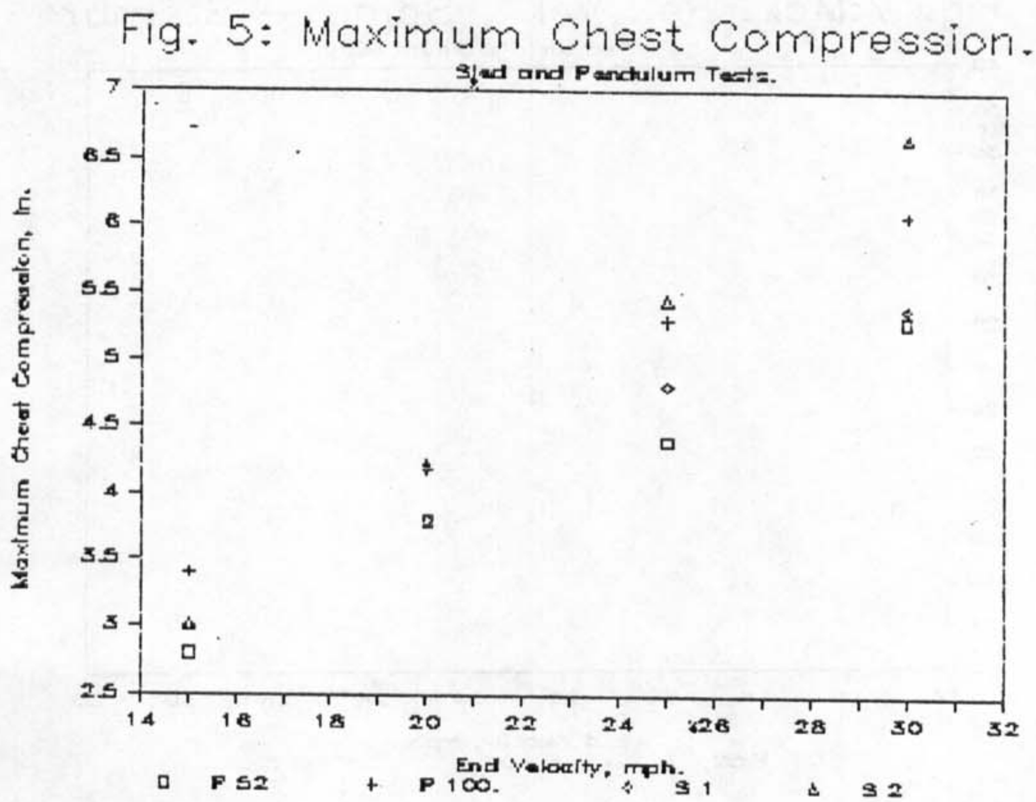


Fig. 5: Maximum Chest Compression.
Sled and Pendulum Tests.
Maximum Chest Compression, in.
End Velocity, mph.
F 52
F 100.
S 1
S 2

Fig. 6: Maximum Sternal Acceleration.

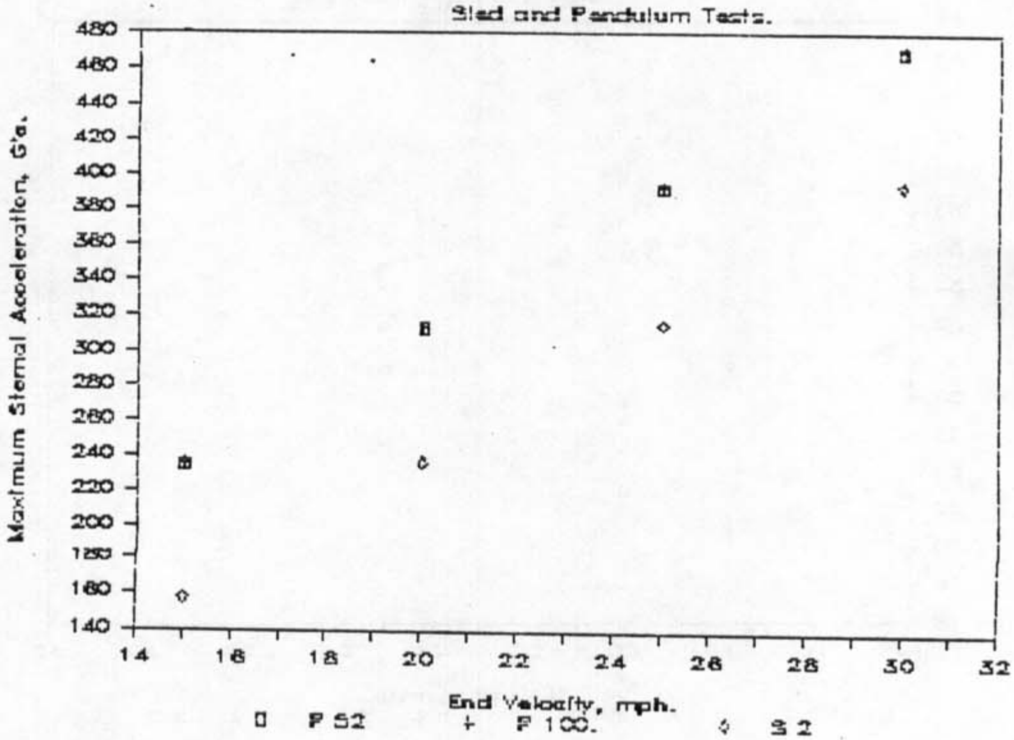


Fig. 7:Max. Rel. Vel. , Spine — Sternum