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STUDIES ON THE TESTING AND ANALYSIS OF TRACK TANK-TRACK SHOES

FRED GOLDBERG, DIANE J. CHINN, and ROBERT L. BRADY

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STUDIES ON THE TESTING AND ANALYSIS OF T156 TANK-TRACK SHOES*

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December 1987

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Conceptual designs of two laboratory test systems, one for testing full-size tank-track shoes, a second for testing coupons are described. Both systems are capable of simulating the various loading scenarios experienced during tank maneuvers. Details of tests performed with the M1 tank at Yuma Proving Ground to evaluate the T156 pads are presented. A frame-by-frame analysis of movies taken of these tests was made and the results are discussed. A laboratory test system was built at LLNL to duplicate the testing performed by The Aerospace Corporation on the T142 shoes. A description of this LLNL test system together with some preliminary results obtained on testing T156 shoes are presented. Some apparent differences in the response of the T156 and T142 shoes are shown to exist. Recommendations for future studies are made.

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INTRODUCTION

In April of 1985 a project was initiated at the Lawrence Livermore National Laboratory (LLNL) to develop a test facility capable of simulating the conditions experienced by tank-track shoes during tank maneuvers. Effort was directed primarily to the evaluation of the T156 shoes for the Abrahms (M1) tank. Of major concern was the unusually rapid degradation of the shoe pads that occurred under the various loading and terrain conditions encountered in the field. The project evolved into three main tasks: (1) design and develop laboratory test systems for testing full-size pads and scaled-down test coupons, (2) perform tests with the M1 tank at Yuma Proving Ground, and (3) analyze the results obtained for the T156 shoes while the M1 tank is driven over a ramp containing various obstacles and relate these results with those reported for the T142 shoes (M60), similarly tested at Yuma.

PROPOSED LABORATORY TEST SYSTEMS SIMULATING SERVICE CONDITIONS

A preliminary conceptual design of a laboratory test system was developed for testing various sample configurations with loading conditions that would simulate service behavior. The design was based on movies and field measurements made in a previous series of tests on the M60 performed at Yuma. The movies showed the distortions developed in the pads on driving the tank over one of several steel bars (obstacles) bolted on to a ramp, with each bar having a different shape, while the field measurements yielded information on pad temperature and track tension.[1,2] In the ramp tests, recording of the pad deformations was made possible by having the steel bars set on a Plexiglas window inserted into a cutout in the ramp and focusing a movie camera on a mirror placed below the ramp at 45° to the window.

On April 22, 1985, a meeting was held at LLNL to evaluate the proposed design. In attendance were A. L. Alesi, R. E. Singler, and A. I. Medalia representing the Army Materials Technology Center (AMTL), G. Rodriquez from Ft. Belvoir R&D Center, and A. Goldberg, D. R. Lesuer, and T. Lo from LLNL. Dr. Lo, who was responsible for much of the early design input, described several alternative design concepts as well as the test and analysis methodologies to be used with any of these systems. At this meeting the representatives from AMTL requested that the test system should be capable of testing full-size pads. Following a number of design iterations and discussions with AMTL personnel, our final conceptual design was presented on October 24, 1985, to representatives from the Army Tank-Automotive Command (TACOM), AMTL, and the

Keweenaw Research Center (KRC). In addition, we presented a conceptual design of a laboratory test system for testing scaled-down coupons, representative of track-pad configurations, simulating service conditions.

FIELD SIMULATION TEST SYSTEM FOR TESTING FULL-SIZE PADS

Figure 1 shows the design concept that was presented at the October 24 meeting for testing full-size pads. The test system incorporates three track shoes with the center shoe setting on an obstacle of a specific geometry. This shoe is loaded through a sector of a wheel sectioned off from an M1 tank roadwheel. The motion of the roadwheel is developed through a four-bar grasshopper loading system having needle pivot-bearing connections. This type of loading system will minimize the wear that would otherwise occur if conventional bearing connections were to be used. The corresponding components shown in both front and side views in Fig. 1 are identified by the same letters in the two views. Major features of this test system are described in the following discussion.

A vertical load, simulating the weight on a pad during the operation of the tank, is applied through a vertical actuator. The load path goes from A to J as indicated in both views of Fig. 1. The load can be maintained constant or programmed to be continuously varied with time. A horizontal hydraulic actuator, which is displacement controlled, oscillates the roadwheel across the shoes. At the two extreme ends of a stroke, the roadwheel rests on one of the outside shoes with the load being removed from the center shoe. The elevation of the horizontal actuator, which fixes the lever-arm ratio LM/HM shown in Fig. 1, and thereby the movement of the roadwheel, is adjusted to meet the required stroke length and load frequency.

Predetermined track tensions across the obstacle are developed by two hydraulic actuators, one on each end of the shoe assembly. The absolute and differential track-tension values are synchronized with the location of the roadwheel using a programmable controller. The elevation of the shoe assembly is adjustable to allow either the replacement or free movement of the obstacle under no-load conditions. The obstacle is positioned through a screw-drive system, which is powered by a 1/2 HP motor. The location of the obstacle is programmable, such that its position can be changed at the end of any predetermined sequence of loading cycles during a test. A single obstacle is indicated in the conceptual design shown in Fig. 1. An optional feature, however, of varying the obstacle geometry during a test can readily be included in the system. For example, a bar-shaped section with four sides, each having a different obstacle geometry, could be supported on a rotatable shaft. The rotation of the shaft would be

programmed to expose the different obstacle geometries at various times during the test. This should allow a closer simulation of some tank-driven scenario, as compared to that obtained using a single obstacle.

The drawings in Fig. 1 indicate the use of only a single row of three shoes. The actual tank track, however, consists of track shoes linked in parallel pairs. This double-shoe arrangement of T156 pads is illustrated in Fig. 2. On a flat surface, the loading in the double-shoe configuration is symmetrical across the two corresponding pads and, therefore, they maintain a horizontal position. By contrast, in using a single row of shoes, the load distributions are non-symmetrical and non-uniform; furthermore, they vary as the roadwheel rolls across a shoe. In this case, the shoe will not remain horizontal during a test, and some slight wobbling of the test system and the shoe will occur. Such wobbling could increase the total amount of deformation during a loading cycle and correspondingly increase the heat-generation rate. Changing from a single-row to a double-row system would result in doubling the load requirements with a corresponding increase in the structural requirements and, possibly, in the hydraulic requirements. A cursory estimate indicates a cost of somewhat over $100,000 for the proposed single-row system. This estimate is based on using existing hydraulic facilities and load actuators; this system should be capable of developing loading cycles of up to about five hertz. Higher frequencies are attainable with larger hydraulic capacities.

FIELD-SIMULATION TEST SYSTEM FOR TESTING COUPONS

The conceptual design of the system for testing coupons, which was also presented at the October 24 meeting, is based on utilizing two existing test machines. Each machine contains a 2000-pound MTS load actuator with an hydraulic system capable of producing a cyclic loading frequency of about 60 hertz over a displacement of one inch. By interconnecting the two machines at right angles, one vertical and the other horizontal, the corresponding loading and/or displacement directions (normal and shear) can be simultaneously obtained. Following the design concepts proposed for the large test system, various degrees of sophistication can be built into the test system depending on the type of information required (e.g., simulating the rocking motion of a shoe). Various sizes of regular-shaped and/or pad-shaped coupons would be tested and the results compared with those obtained from full-size pads tested on the large test facility. This would yield valuable scaling information. This information would result in a more cost-effective test program by using the coupon test machine for evaluating experimental pad materials and pad designs.

Further effort on the development of the two test systems was delayed, pending evaluation of the test system at KRC by TACOM and AMTL. The test system at KRC was designed and built by The Aerospace Corporation for testing full-size pads for TACOM. The durability of this system, its frequency limitation, and the ability to simulate the load-and-wear conditions experienced during tank maneuvers were important factors to be evaluated prior to continuing work on our two test systems. At the present time, these questions are still to be resolved.

YUMA PROVING GROUND TESTS

On September 11 and 12, 1985 tests were carried out at the Yuma Proving Ground with the M1 tank to evaluate the performance of T156 pads. The tests consisted of two parts: (1) documenting the deformations and temperatures of the pads with the tank driven over various obstacles installed on a ramp, and (2) documenting the tank motions and pad deformations while the tank was being driven over a paved road. Pads with various formulations were being evaluated in the road tests. The second part of these tests was to include cross-country traverses, but this was canceled due to the overheating and failure of a pair of pads that had been improperly installed in the tank track. Both phases were performed by LLNL and Yuma Proving Ground personnel; also participating was A. L. Alesi of AMTL.

Phase 1 was to be evaluated by LLNL and phase 2 by AMTL. The observations were largely documented on 16-mm film, taken at 200 frames per second; stills were also taken using 135 and 120 film. Temperature measurements were made with a device whereby a thermocouple could be injected into a pad to a controlled depth, typically about 1/2 inch deep.[1]

Figure 3 shows the experimental setup for the ramp experiments, with the movie camera being prepared for recording the pad deformations when the tank is driven over the ramp. The ramp contains a Lexan window about 1.25 inches thick. A mirror, set below the window at an appropriate angle, permits both the side and roadside surfaces of a preselected pad to be photographed as the tank passes over the ramp. The tank is prevented from tilting by having the other track climb onto a wood beam of similar height as the ramp, namely, 11.5 inches high. The Lexan window alone represents an obstacle-free, smooth terrain. Three different obstacle configurations were simulated by using a 2 x 2 inch bar, a 2 x 2 inch angle, and a 5/8-inch diameter bolt with its head machined to a 1-inch diameter hemisphere. Figure 4a shows the setup with the angle obstacle and the corresponding severe distortions inflicted on the pad. The distortions

caused by passing over the bolt can be seen in Fig. 4b; the bolt is screwed into and projects out from the bar obstacle. The hole produced by the bolt is shown in Fig. 4c. The bar and angle obstacles are bolted down on to the ramp over the center of the window, individually, for the corresponding test. The distortions induced by the bar alone were considerably less than those illustrated in Fig. 4.

Prior to some of the tests, the temperature of the pads was raised by having the tank driven along the pavement. Unfortunately, mechanical problems with the tank limited the maximum temperature that was reached. The highest temperatures measured were 43 and 71 C on the surface and in the interior of a pad, respectively. The pad selected for testing was then marked with a grid , the final surface and interior temperatures were measured, and the test was run. Figure 5a shows a template being fitted over a pad on which a grid will be developed by spray painting. The grid, after removing the template, is shown in Fig. 5b; it consists of 3/32-inch squares on 3/16-inch centerline spacings. Figure 6a shows a temperature being taken with the thermocouple injector; the thermocouple is injected into the pad by triggering a source of compressive gas (air or nitrogen). A surface-temeprature measurement being taken is shown in Fig. 6b.

A total of 19 test runs were performed over the ramp, involving various pad temperatures, tank speeds, and obstacles; these were all documented on cinema and still film. Similarly documented were the road tests on the asphalt pavement, which were being performed directly for AMTL. Figure 7 shows the setup for photographing the road tests. A considerable amount of rubber debris resulting from abrasion and cutting of the pads, especially during turning of the tank, was observed on the asphalt pavements. An example of this debris can be seen in Fig. 8. Proofs and selected prints from eight rolls of still films together with copies of the cinema films were sent to AMTL. The ramp movies had been edited, provided with subtitles, and combined into a single reel for AMTL; movies on the road tests were subjected to only minor editing and were combined into a second reel.

The analysis of the deformed pads, which is based on changes in the grid spacings that result from the various loading sequences, requires a knowledge of the constitutive relations of the pad material for tension, compression, and shear. Laboratory tests to obtain this information and the follow-up finite element analysis of the grids are pending the availability of additional funds from AMTL. Also proposed under this funding was the laboratory testing of T156 pads using the obstacles from the ramp tests. A number of pads have been received for this purpose. With the limited funds remaining, however, the

decision was made to direct our efforts towards comparing, where possible, the relative performance between the T156 and T142 shoes.

ANALYSIS OF CINEMA FILMS ON T142 AND T156 SHOES AND PADS

By analyzing cinema films made by LLNL of ramp tests performed with the M60 tank, The Aerospace Corporation (TAC) attempted to evaluate the role of the tractive forces on the degradation of the T142 pads.[3] A frame-by-frame analysis of the LLNL film of the side views, giving the shoe movements, and of the bottom views, giving the grid displacements was reported by TAC. To obtain a comparison in the performance between the two types of pads, a similar analysis was made on some of the runs performed with the T156 pads. Furthermore, with this information, together with the track-tension data that were obtained on the M60 in field tests[2] and with input of the data to be obtained from laboratory tests (described below), estimates were to be made on the track tensions for the M1.

In the side-view analysis, the relative movements of the two pins in a shoe are used to obtain the bounce (vertical deflection), pitch (fore-to-aft angulation), and longitudinal displacement as the track wheels pass over a shoe. The three parameters are illustrated in Fig. 9. The results reported by TAC[3] are reproduced in Fig. 10. The corresponding results for the T156 shoes are presented in Figs. 11-16 and 17-21 for some of the ramp and the asphalt-road tests, respectively. The data are normalized so that the first point corresponds to where the center of the first roadwheel was directly above the shoe. In the following, we present some preliminary observations of the analysis.

Comparing the curves in Fig. 11 with those in Fig. 12, with the tank traversing over the Lexan surface, the bounce and pitch are seen to be greater at the slightly lower of the two tank speeds. The corresponding speeds were estimated to be 1.5 and 3.3 mi/h, respectively. The speeds are based on the assumption that each cycle along a curve corresponds to the passage of a roadwheel. Slow and fast speeds of about 4 and 34 mi/h, respectively, were estimated for the asphalt-road tests. Note that for Figs. 18-21 measurements were made on successive film frames, while for the other figures every tenth frame was used. Although there is a significant difference in velocity between the slow and fast road speeds, no definitive differences in trends are indicated between the two speeds. For example, the pitch patterns at the high speed may be somewhat either more negative (Figs. 19-21) or more positive (Fig. 18) relative to the pitch behavior obtained at the slow speed (Fig. 17), while the bounce patterns at the high speeds are either similar (Fig. 19-21) or show larger positive displacements (Fig. 18) compared to

the corresponding results obtained at the low speed. Both bounce and pitch generally exhibit greater displacements for the tank driven over the Lexan surface compared to the corresponding displacements obtained for the asphalt tests.

The longitudinal displacement curves indicate that the displacement rates during the asphalt tests are considerably more uniform than those obtained during the Lucite and obstacle tests. For example, compare Fig. 17 (asphalt) with Figs. 11 and 12 (Lucite), which relate to similar tank speeds and number of frames. The Lucite curves show a significant initial period of relative slow displacement rates. By contrast, relatively uniform displacement rates are exhibited by the asphalt tests; and, these rates would appear to be independent of the tank speed. Note, that in comparing Figs. 18-21 (fast speed) with Fig. 17 (slow speed), the ratios of the number of frames to the tank speed between the fast and slow runs are both equal to about nine.

The bounce, pitch, and longitudinal-displacement results obtained for the T156 obstacle tests (Figs. 13-16) are not significantly different from those described in the above for the Lexan tests (Figs. 11 and 12). Several trends, however, may be pointed out. The pitch tends to become more positive as the roadwheels pass over a shoe, indicative of the shoe rotating from back to front over the obstacle as the shoe moves forward (longitudinal displacement). (Note that a positive pitch indicates that the leading edge of the shoe is lower than its trailing edge; this is of opposite sign to that used by TAC.) Both bar and angle obstacles initially show large negative pitches (Figs. 13 and 16). By contrast, both the bolt, which projects from the bar, and the short angle obstacle, which extends only over part of the pad, initially show a predominantly positive pitch (Figs. 14 and 15). It appears that the embedding of an obstacle, such as the bolt head or the corner of the angle section, into the rubber pad favors the positive rotation of the shoe (as seen facing the right side of the tank). There are no apparent systematic trends between bounce and obstacle. The continuous decrease (more negative) in bounce shown by the long angle obstacle is attributed to a combination of the obstacle bending and embedding into the pad as the roadwheels traverse over the shoe. The initial erratic bounce behavior developed by passing over the bar obstacle could result from the raised elevation of the track at the bar as a roadwheel first contacts the shoe. For all four obstacles, the bounce amplitude becomes less or more negative relative to the initial amplitude. Additional ramp tests over obstacles were run and photographed, but the corresponding film frames had not been analyzed. An analysis of the tank with the T142 shoes being driven over obstacles on the ramp was not presented in the report by TAC.

Grid measurements, made on the roadside surface of a T142 pad driven over Plexiglas, were also reported by TAC. (Plexiglas was used in the first series of ramp tests performed by LLNL at Yuma Proving Ground.) Their results are reproduced in Fig. 22, which show the changes in the longitudinal distance between alternate grid lines along a line near the middle of the pad as the roadwheel traverses the pad. Measurements were taken at seven different locations from the front (trailing edge) to the rear (leading edge) of the pad. The analysis indicated that relatively low surface strains were developed over most of the pad starting with the leading edge; however, significant longitudinal tensile strains (approximately 20 percent) were obtained near and at the trailing edge.

The grid measurements of films taken of two T156 pads, with the tank being driven over the Lexan surface at two relatively slow speeds, estimated at 2.4 and 5.2 mi/h, are shown in Figs. 23 and 24, respectively. Measurements were taken at three positions along a longitudinal line at the center of the pad (A-A in Fig. 5b), namely, the leading edge (bottom), center, and trailing edge (top). The top graph in each figure gives the screen units normalized relative to the zero readings for each of the three positions. The differential normalized readings between these positions are plotted in the corresponding bottom graph (1000 screen units correspond to about 5.5 inches). The zero readings were taken at about the point of initial contact between roadwheel and pad. At the slower of the two speeds, the trailing-edge side exhibits strains that are positive relative to the zero readings, consistent with the results from TAC, whereas, the leading-edge side exhibits both positive and negative relative strains, similar in magnitude to the above strains. At the faster speed, the relative strains are all positive with the strains at the leading-edge side being generally greater than those at the trailing-edge side and, therefore, it would appear that these results are inconsistent with the results reported by TAC. A maximum strain of about 9 percent over a 3-inch length was developed (relative to the zero readings) on the T156 pads. This compares to the 15 percent over a 1/2-inch length for the T142 pad. The tank speed, which was not reported for the corresponding TAC analysis, the roadwheel load, the pad configuration, and the pad orientation are certainly important factors that must be considered in comparing the behavior of the two different pads. Several additional Lexan-surface tests were performed, but the corresponding film frames were not analyzed.

On comparing the observations made for the T156 shoes tested on Lexan with those reported for the T142 shoes similarly tested on Plexiglas by TAC, the following points may be noted. On the average, the bounce and pitch amplitudes of the T156 are nearly

twice and three times as great, respectively, as those shown for the T142. The longitudinal (horizontal) movements of the T142 are predominantly backwards; by contrast, the corresponding T156 movements are in the direction of tank motion. The T156 shoe develops considerably larger displacements than those obtained with the T142 shoe. The maximum surface strains on the two types of pads appear to be of the same order of magnitude; however, based on the limited analysis available it is not clear how to interpret the similarities or differences in the strain distribution relative to the leading and trailing sides of the pads. Certainly, the tank speed, the load, the track configuration, the pad configuration, the shoe-to-track linkage, and the terrain or obstacles, all affecting the shoe movements (pitch, bounce, and longitudinal) are the important variables that determine the deformation of the pads. The influence of some of these variables could be evaluated in the laboratory with the appropriate testing system. A laboratory test facility was developed by TAC to evaluate, under controlled conditions, the amount of coupling between the pitch, bounce, and longitudinal displacements of the T142 shoe as a function of offset loading and loading rate. The offset loading would simulate the roadwheel rolling over the shoe. The results of these tests are presented in the report by TAC[3]. To be able to compare more closely the response of the two shoes it was decided to develop a somewhat similar test facility at LLNL. This system would also be able to provide information on the response of the pads to various controlled loadings, although not necessarily attempting to simulate any field scenarios.

LABORATORY TEST SYSTEM DEVELOPED AT LLNL BASED ON THE SYSTEM USED AT THE AEROSPACE CORPORATION (TAC)

The test system used by TAC[3], which was built around an existing compression test machine, was developed to simulate the action of a roadwheel rolling over a shoe. In this system the track shoe is placed on a platform set on rollers supported on the test bed. The bounce, pitch, and horizontal longitudinal displacement are measured with the load applied on the roadwheel side of the shoe set at various offsets from the vertical center. The load-indentor surface in contact with the shoe was machined as a flat to give the approximate contact area of a roadwheel under full static load. The rolling friction forces in this system were unknown and, therefore, could not be duplicated in any system that we might build. In the LLNL design an attempt was made to minimize the magnitude of any unknown forces, as well as to incorporate, where feasible, the facility to simulate field conditions. It also was desirable to be able to film the deformation of the pad while it was being loaded. To eliminate the rolling friction and

facilitate filming, the LLNL test system was designed such that the shoe being tested rests on a free-swinging platform, which is supported by four hanger rods. A working assembly drawing of the system, to which some additions were subsequently made, is shown in Fig. 25. Photographs showing several views of the constructed system, which includes these additions, are presented in Fig. 26. In the following, the main features of the system and the results of some exploratory tests are described.

Referring to Figs. 25 and 26, the loading platform with the four supporting hanger rods are suspended from a frame, which is supported by a tee-slot table attached to the load actuator (ram) of the test machine. The hanger rods pivot at both ends with the upper ends being connected to any one of the five positions shown. This is done to obtain centered or off-centered loading on a pair of pin-connected track shoes. Because of the asymmetric footprint of the T156 shoe and the decision to incorporate an M1 dual roadwheel unit in the load train, a pair of shoes are used, in contrast to the single T142 shoe used by TAC. Both shoes rest on a thick Lucite window allowing the roadside face and sides of a grid-marked pad to be photographed by means of a mirror tilted at 45 degrees to the pad surface. Provisions were initially made to photograph only one pad. The load is applied on the roadwheel side of both shoes through the roadwheel, which is attached to the fixed crosshead of the test machine. The system is instrumented, with output to a computer-controlled data-acquisition system, to obtain pitch, bounce, longitudinal displacement, compression, and shear.

In the initial evaluation of the test system, we noted that during off-center loading there was a tendency for the track shoe to slip or kick out from under the applied load. A number of runs with different off-center distances showed that the load at which this occurred decreased with an increase in this distance. This tendency is due to the unconstrained horizontal force vector, which is then free to move the "frictionless" platform swing. The tilting of the shoe also allows the contact loading surface to slightly shift upwards along the roadwheel circumference, which further aids such slippage and eventual kick-out. Off-center loading limitations were also noted by TAC investigators when they replaced their flat-surface loading indentor with one having a cylindrical surface. The frictional forces associated with the use of a sliding platform, undoubtedly, made these limitations less restrictive in their tests. A similar behavior would be expected in the field if the tank track belt were parted with the elimination of the tension forces between the corresponding severed links.

The slippage problem was addressed by partially constraining the movement of the platform through two parallel sets of Belleville dished spring washers, with each set

inserted along a rod placed between the platform and test-machine column and supported by this column, as can be seen in Fig. 26. A clip gage and two load cells, the latter being attached to the end of each rod that is closest to the platform, allows the platform displacement and restraining force to be measured. The system is adjustable at the other end of the two rods to allow some initial preset unrestrained movement of the platform, which provides an initial space between the platform and load cells, as seen in the closeup view of Fig. 26c. This view also shows the platform-displacement clip gage located at the underside of the platform.

The track pins protruding out from the shoes are connected together at each end by a bar. A clip gage is mounted at each end of the two bars giving a total of four such gages. These gages measure the vertical movement (compression) between the track pins and the Lucite window on which the pads rest. A bar with two of these gages can be seen in Fig. 26c. The clip-gage assembly seen near the center of this bar is designed to measure the horizontal movement between one end of the pins and the window. Assuming that no slippage occurs between pad and window, this movement corresponds to the gross shear between the surface of the pad and a plane approximating a plane through the center of the pins. With zero offset loading, this gross shear should be zero. The presence of any gross shear under zero offset would indicate some unevenness in the system (pad surfaces, roadwheel surfaces, shoe-assembly warpage, test-system misalignment) and/or slippage. To identify the presence of any slippage, the Lucite window was marked with two pairs of parallel lines intersecting at right angles. A measure of any slippage can then be obtained by comparing the relative positions between these reference markings and the lines in the grid pattern on the rubber in the cinema record taken of the test. The superposition of the reference markings and grid lines can be seen in the mirror reflection in Fig. 26b.

SOME PRELIMINARY TEST RESULTS

An exploratory test run was made using vertical loading of the roadwheel assembly with zero offset from the center of each pad. The primary purpose for this test was to evaluate the adequacy and viability of the data and the data-acquisition system. Figure 27 shows the loading and unloading hysteretic compression loops recorded for each of the four clip-gage locations. The shoe assembly was loaded to 13,000 pounds (6,500 pounds on each pad). The average of the four loops are shown in Fig. 28. The variations obtained between the four locations , especially during the early stages of loading, are probably due to the unevenness in the surfaces of both pads and in the slight warpage of

the double-shoe assembly. Figure 29 shows the compression data of Fig. 27 plotted as a function of time. The measurements on gross shear, which under the zero offset-loading conditions should have indicated zero deflection, are shown in Fig. 30. The negative displacement followed by a positive displacement suggests that the non-zero data are due to some unevenness of the system. It was readily apparent that the major source for this behavior was the uneven rubber surfaces and, especially, the warpage found to exist in the two-shoe assembly. Figure 31 shows the horizontal displacement of the support platform in which the Lucite window rests. This should correspond to the longitudinal displacement of the shoe, which should be zero under the present loading conditions of zero offset. A maximum displacement of 0.008 inch is obtained at about a 2,000-pound load, which corresponds closely to the load where there is an apparent discontinuity in each of the curves in Fig. 27 and where the reversal occurs in Fig. 30. This correspondence and the zig-zag behavior of the curve in Fig. 31 again suggest the presence of warpage and surface unevenness in the two-shoe assembly as being the major sources for the unexpected results obtained with zero-offset loading.

There was no evidence that any slippage had occurred. Figure 32 contains views of three frames from a video tape of the test prior to loading, on reaching maximum load, and after unloading as shown in views a, b, and c, respectively. Comparisons between before and after the loading cycle show that slippage is negligible, if at all, since the surface (central region) returned to its original position on the Lucite window. Evidence of slight surface deformation can be see at the maximum load when the relative positions of the reference and grid lines of the loaded pad and the pad prior to loading are compared. As might have been expected, the maximum gross shear was relatively small, less than one percent (over about 1.3-inch thickness of the pad), compared to the associated compression deformation of nearly 25 percent.

It should be noted that the center of contact of each roadwheel along with the center of the pad on the roadwheel side of a loaded shoe are both offset significantly from the center of the roadside surface of the pad. We received a number of T156 shoes; however, only one pair of shoes arrived assembled with the original pins and rubber bushings. Therefore, it was decided to defer use of these shoes until evaluation of the test system was completed. Additional pins had to be made for use with the remaining shoes. These pins, however, were machined (oversize) to provide a tight fit without any rubber inserts. The warpage in the pad assembly, which is largely due to the unevenness in the binocular tubes, would normally be accommodated by the rubber bushings. Thus, the response to the loading may be different for the different pin assemblies. The results reported here are for shoes connected without any rubber inserts.

A comparison can be made between the LLNL and TAC results for the vertical stiffness of the two different pads tested under zero-offset loading. The T142 pad was loaded in 1,000-pound increments at a displacement rate of 0.01 inch/minute with a three-minute holding period between loading steps. The approximate vertical stiffness that we calculated from the data reported for the center of the T142 pad in the TAC report are as follows:

Load range (lbs)	Stiffness (lbs/in.)
2,000 - 4,000	33,000
4,000 - 6,000	67,000
6,000 - 8,000	100,000
8,000 - 10,000	200,000

By contrast, excluding the initial portion of our data, an average value of 48,000 pounds/inch, which is essentially constant (from 2,000 to 13,000 pounds for two shoes) is obtained for the T156 shoes. The loading conditions, however, were different from those reported by TAC; a constant stroke-displacement rate of 0.12 inch/minute was used at LLNL.

Further evaluation of the test system, especially involving offset loading, duplicating the test parameters used for the T142, and extending the matrix of test conditions had to be postponed pending receipt of additional funding from AMTL.

RECOMMENDATIONS FOR FUTURE STUDIES

The frame-by frame analysis of the remaining field tests on the T156 shoes and pads should be completed in order to obtain additional data to either support or modify the conclusions that were based on only a portion of the available information.

The constitutive relations for tension, compression, and shear of the triblend-rubber pad should be obtained. Having the constitutive material-property relations together with the strains obtained from the deformed grid pattern would allow for a meaningful determination of the stress state in the pads.

Compression tests should be performed on the T156 shoes under controlled laboratory conditions with the three obstacles used in the field tests. The results obtained would then be compared with those obtained from the field tests. A grid pattern would be applied to the pads so that a finite element analysis could be performed and verified. Furthermore, a detailed comparison could then be made between the T156 and T142 pads in predicting their response to various loading conditions. Test parameters would be extended to include a wide range of loading and unloading rates as well as a range of temperatures.

Testing directed towards duplicating the tests reported by The Aerospace Corporation should be continued with expansion of the test matrix to cover a wider range of loading rates than were used for the T142 pads. Comparing these results for the two types of pads will facilitate the analysis of the T156 field tests in which track-tension data were not obtained.

There are two main sources of tension acting on a shoe, namely, the track pretension and the induced rocking action of the shoe. This results in a net differential tension across the shoe. A horizontal loading unit could readily be incorporated into the test system that was built at LLNL, which would enable simulating the tensions generated across a tank pad while testing for the various parameters addressed in this report. This added loading unit would consist of a closed system of adjustable tension and compression rods. The system would move in concert with the shoe movements. The concept for this unit was illustrated in a letter to AMTL dated September 26, 1986.

We highly recommend further consideration in the development of a laboratory facility, which is described in the early part of this report, that would contain both the coupon tester and the track-shoe tester capable of simulating various field scenarios.

We also recommend the development of a test system having the capability to simulate various field terrains and a corresponding study to evaluate the serious problem of abrasion experienced during tank maneuvers in the field. In addition to developing an understanding of the abrasion mechanisms that occur under different terrain and loading conditions, we propose evaluating the degradation of various mechanical properties caused by such abrasion. Furthermore, the synergism that is likely to develop between abrasion and other degrading sources such as cut growth, fatigue crack propagation, cyclic deformation, and hysteretic heating should be studied.

ACKNOWLEDGMENTS

The conceptual designs, which were developed by Ian Murray, are based largely on the various tank-loading scenarios analyzed by Ting-Yu Lo. David Hiromoto, Stephen Santor, Bennie Walker, and Dr. Lo contributed greatly in the preparation and execution of the field tests. The tedious frame-by-frame analysis of the movies was performed by Mary LeBlanc. The assembling of the laboratory test and data-acquisition systems and the corresponding testing were performed by Scott Preuss and Roberto Sanchez. We especially want to express our appreciation to Anthony Alesi of AMTL for supporting this work, for the many valuable discussions held with him, and for his involvement in the field tests. We also wish to acknowledge the important participation of Yuma Proving Ground personnel in the field tests. Finally, we want to thank Dr. Donald Lesuer for his patience, his support, his participation in numerous discussions, and reviewing the draft of this report.

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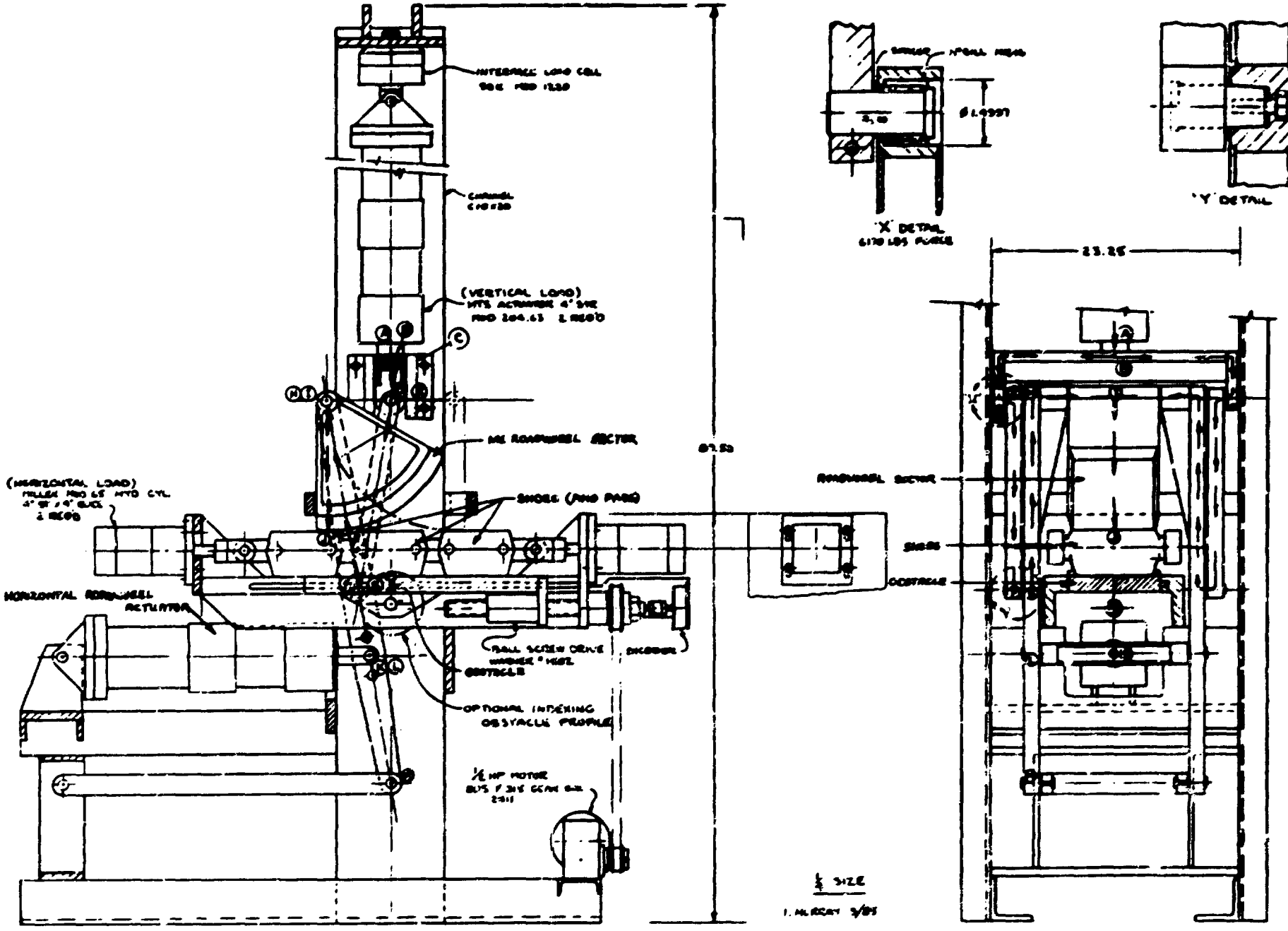


Fig. 1. Schematic concept for a laboratory test system for testing full-size pads, simulating loading and obstacle conditions experienced during tank maneuvers.

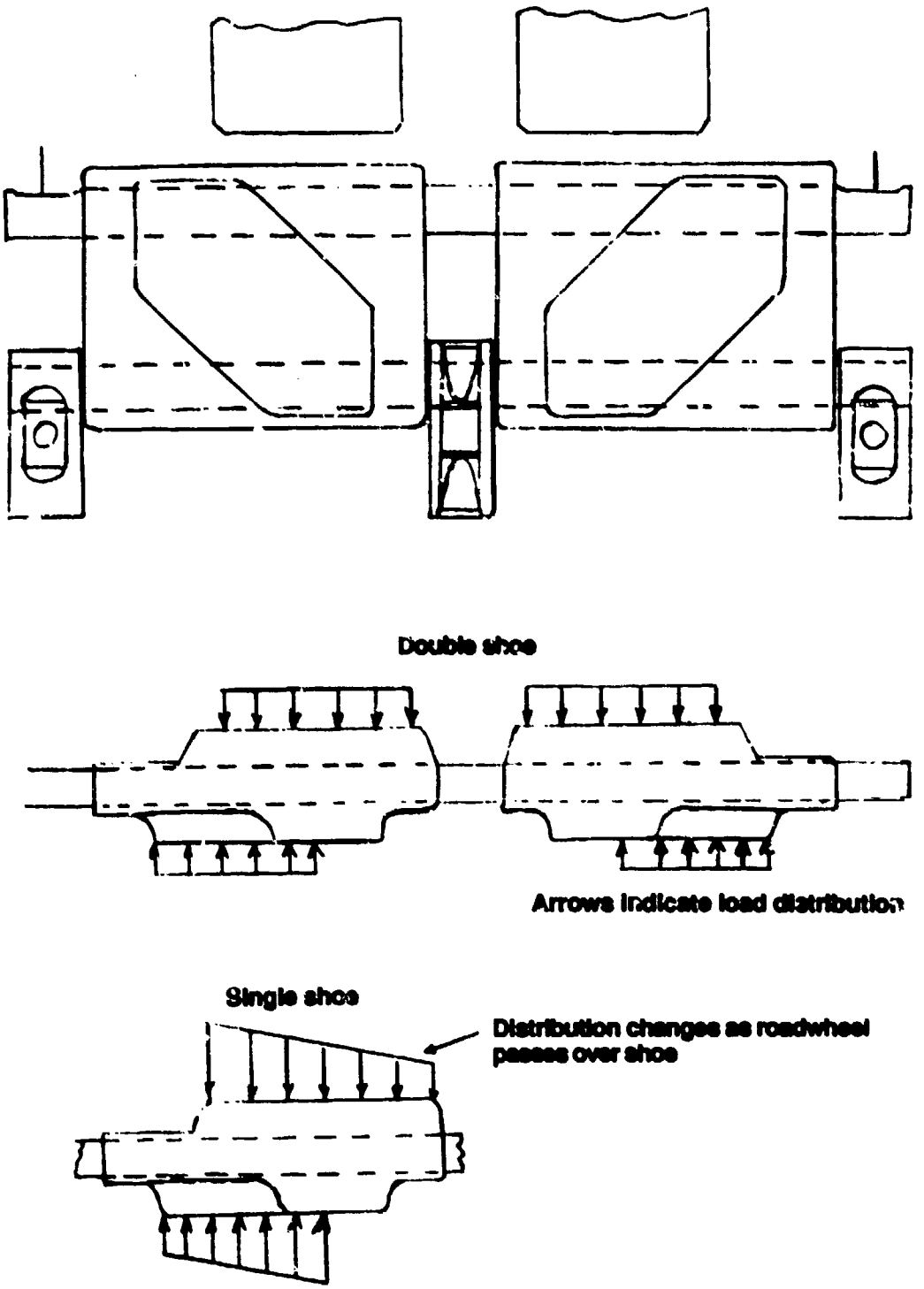


Fig. 2. Illustrating the difference in loading symmetry between a double and single configuration for the T156 shoes.

Fig. 3. Camera and ramp setup for testing the T156 shoes. Setup in preparation for response to traversing Lexan-window surface.

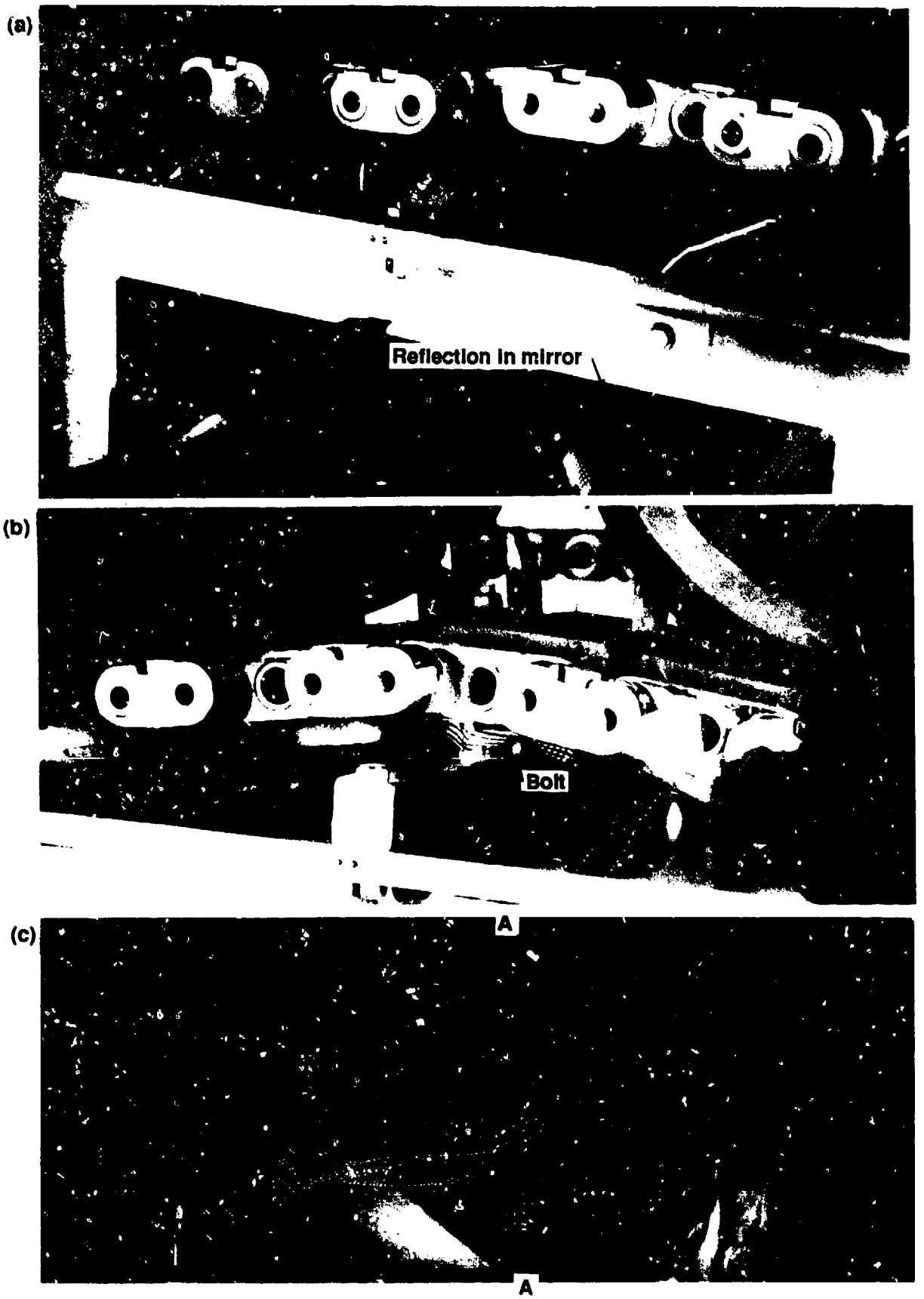


Fig. 4. M1 tank passing over (a) angle and (b) bolt obstacles causing the severe distortion of the grid markings on the pad. View (c) shows the hole formed in the pad by the bolt.

Fig. 5. View (a) shows placing the template on the pad in preparation for spraying. View (b) shows the resulting grid marks.

Fig. 6. Views showing measurements of pad temperatures. In View (a) the thermocouple injector unit contains two duplicate systems in case of malfunction of one. Note hose for pressurized gas supply. Surface temperature is shown being taken in View (b).

Fig. 7. Setup for photographing tests on asphalt pavement. Note guidelines for tank. View (a) shows focusing on tank shoes; (b) shows movies being taken of moving tank.

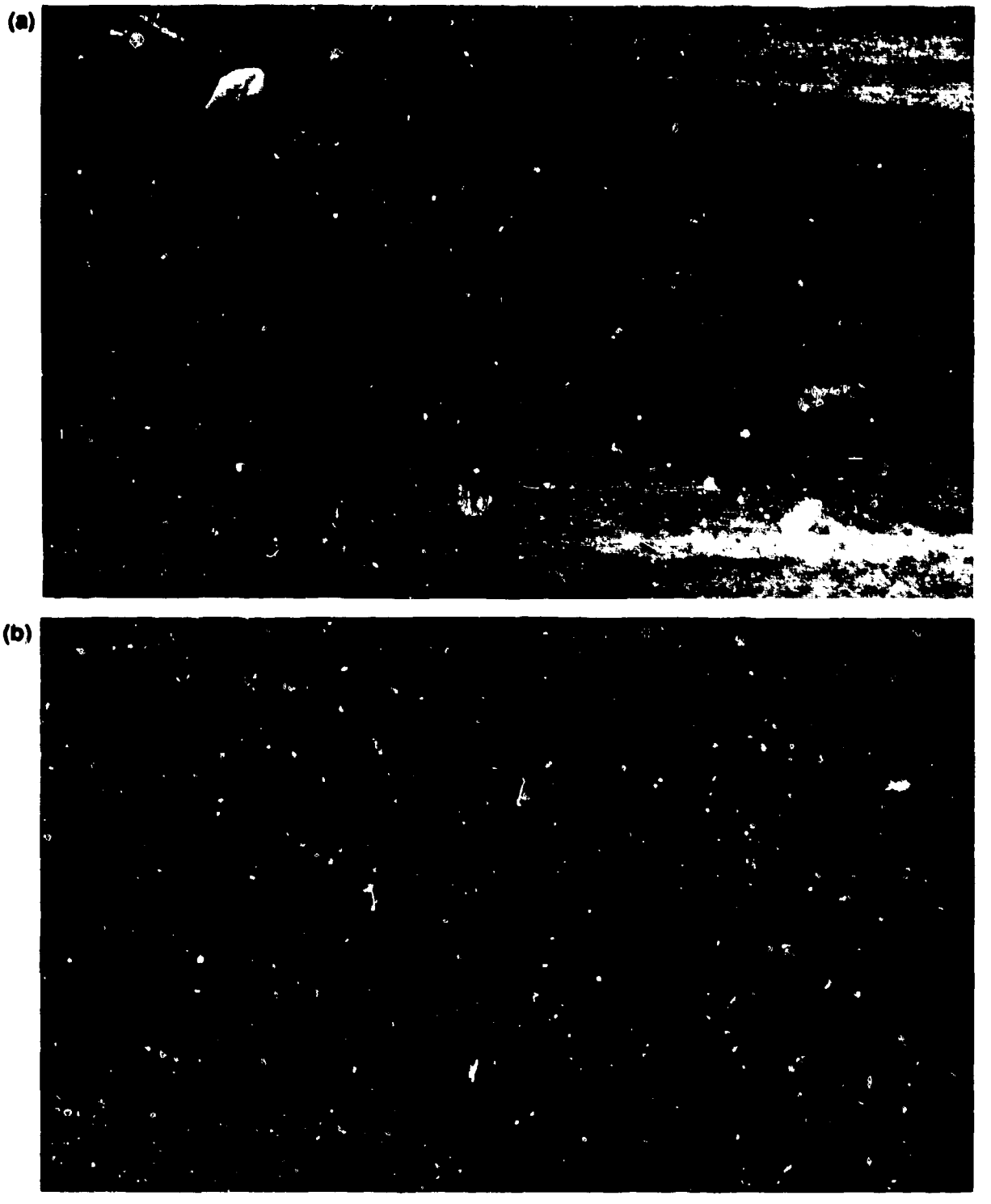
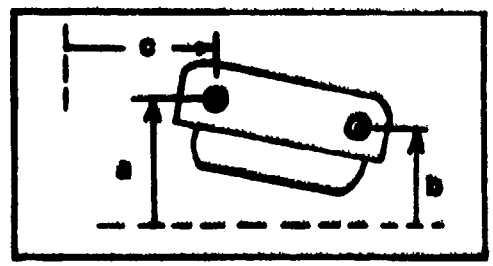


Fig. 8. Views illustrating as-deposited rubber debris and rubber fragments (a) on asphalt road pavement and (b) off the road.

Frame projection on screen of side-view filming of shoe during tank operation



Bounce = (a + b)/2
= vertical deflection

Pitch = a - b
= fore-to-aft angulation

Longitudinal displacement is along "c" direction

Fig. 9. Schematic illustration and definition of bounce, pitch, and longitudinal displacement.

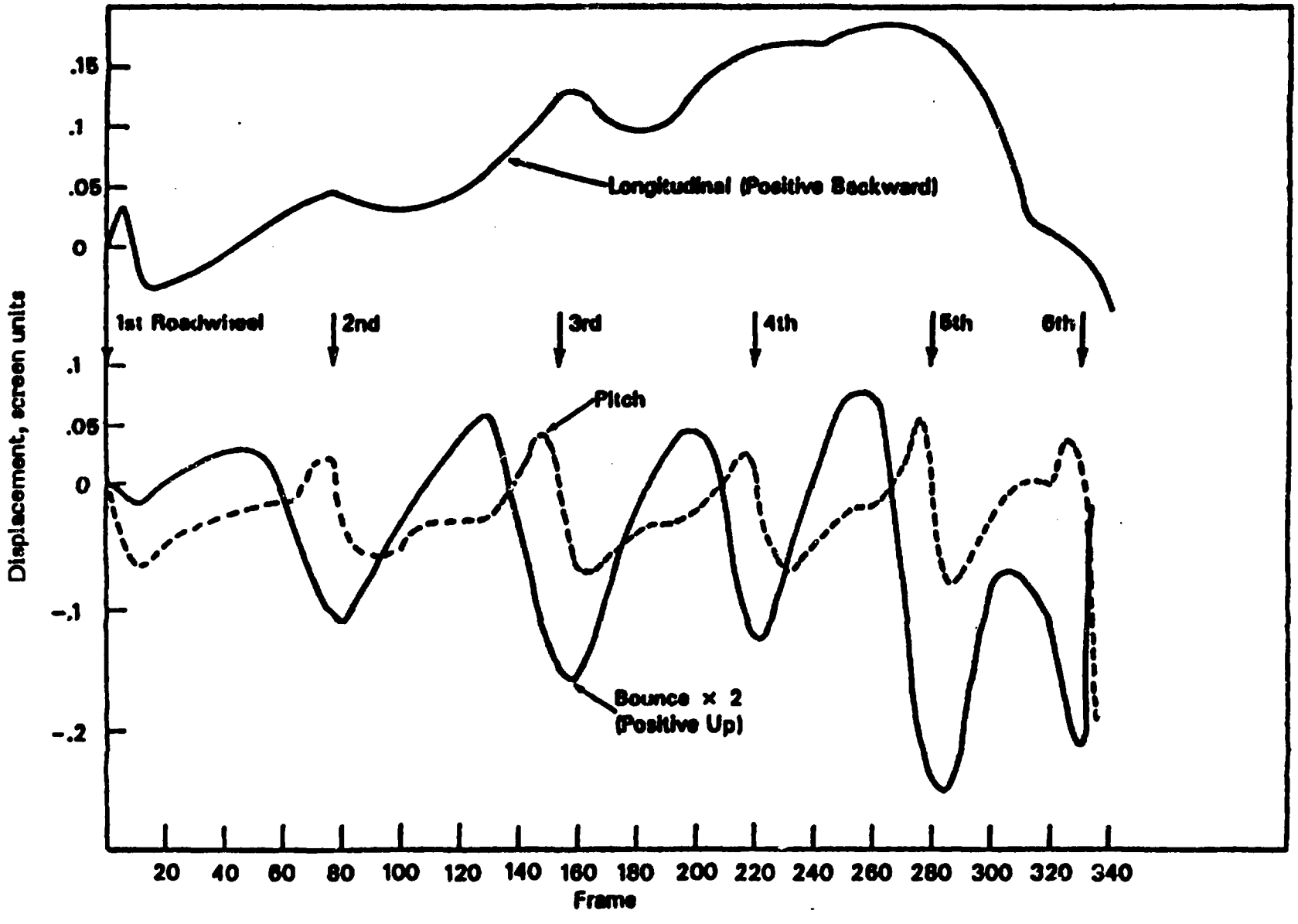


Fig. 10. Longitudinal, bounce, and pitch displacements of T142 track shoes; analysis is from side views. One screen unit corresponds to 12.7 inches or 1.28°. Taken from Ref. 3.

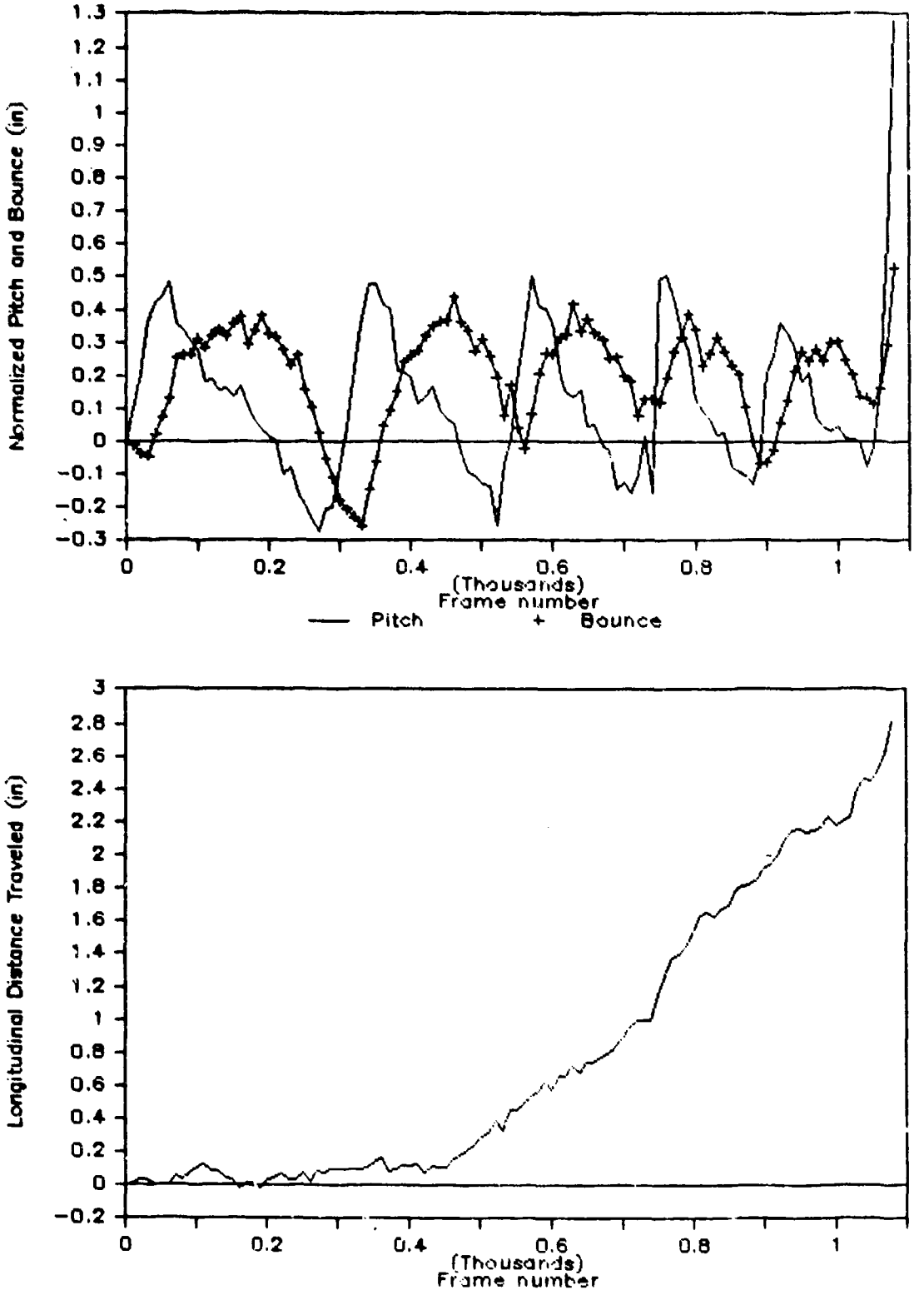
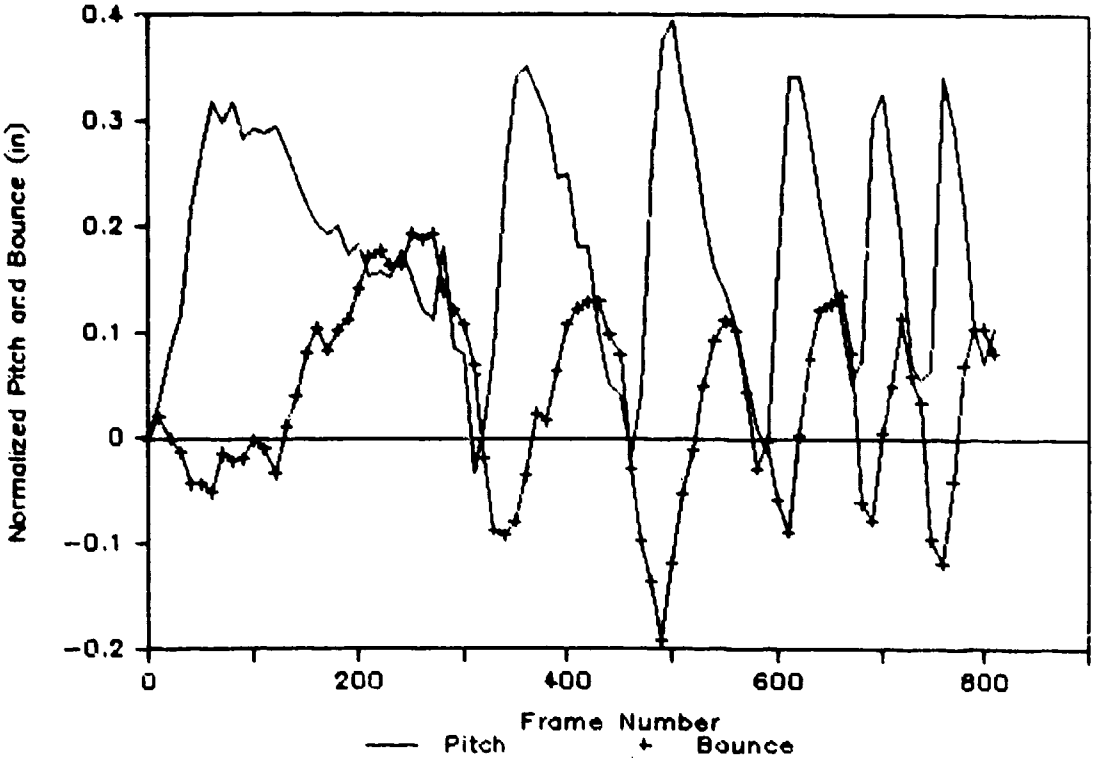


Fig. 11. Ramp test 1A: estimated speed of 1.5 mi/h over ramp with Lexan window surface. Pad temperatures prior to test: 25°C surface, 37°C interior. (Camera speed: 200 frames/sec.)



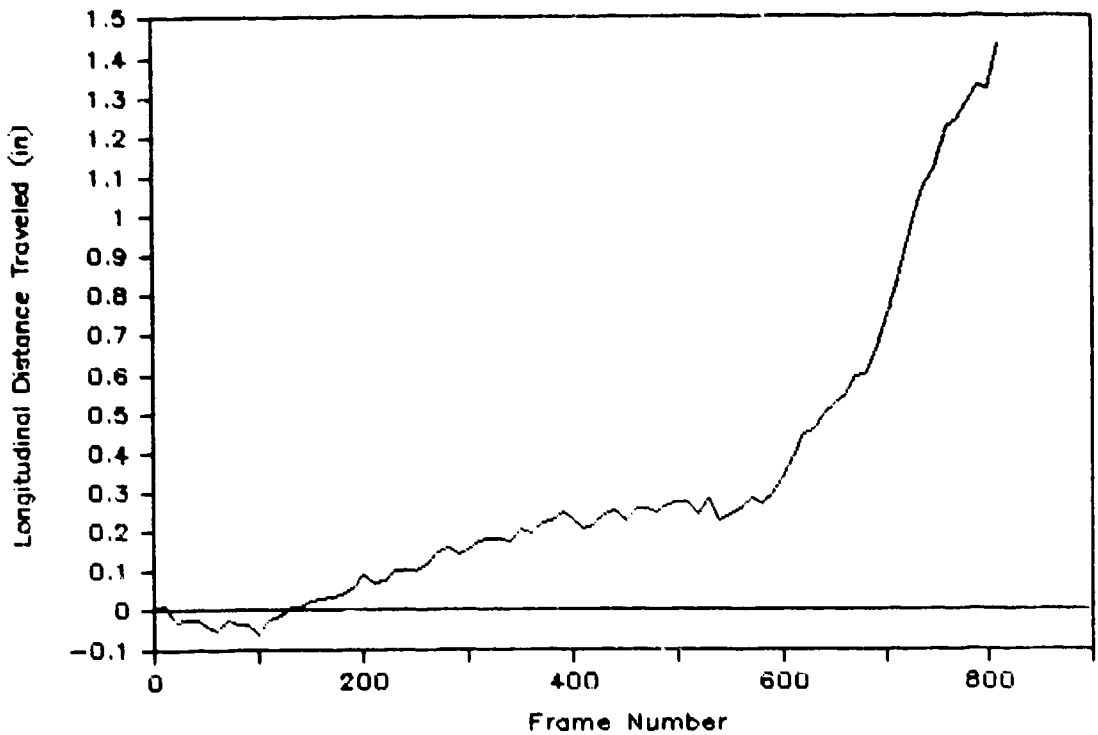


Fig. 12. Ramp test 18: estimated speed of 3.3. mi/h over ramp with Lexan window surface. Pad temperatures prior to test: 27°C surface, 40°C interior. (Camera speed: 200 frames/sec.)

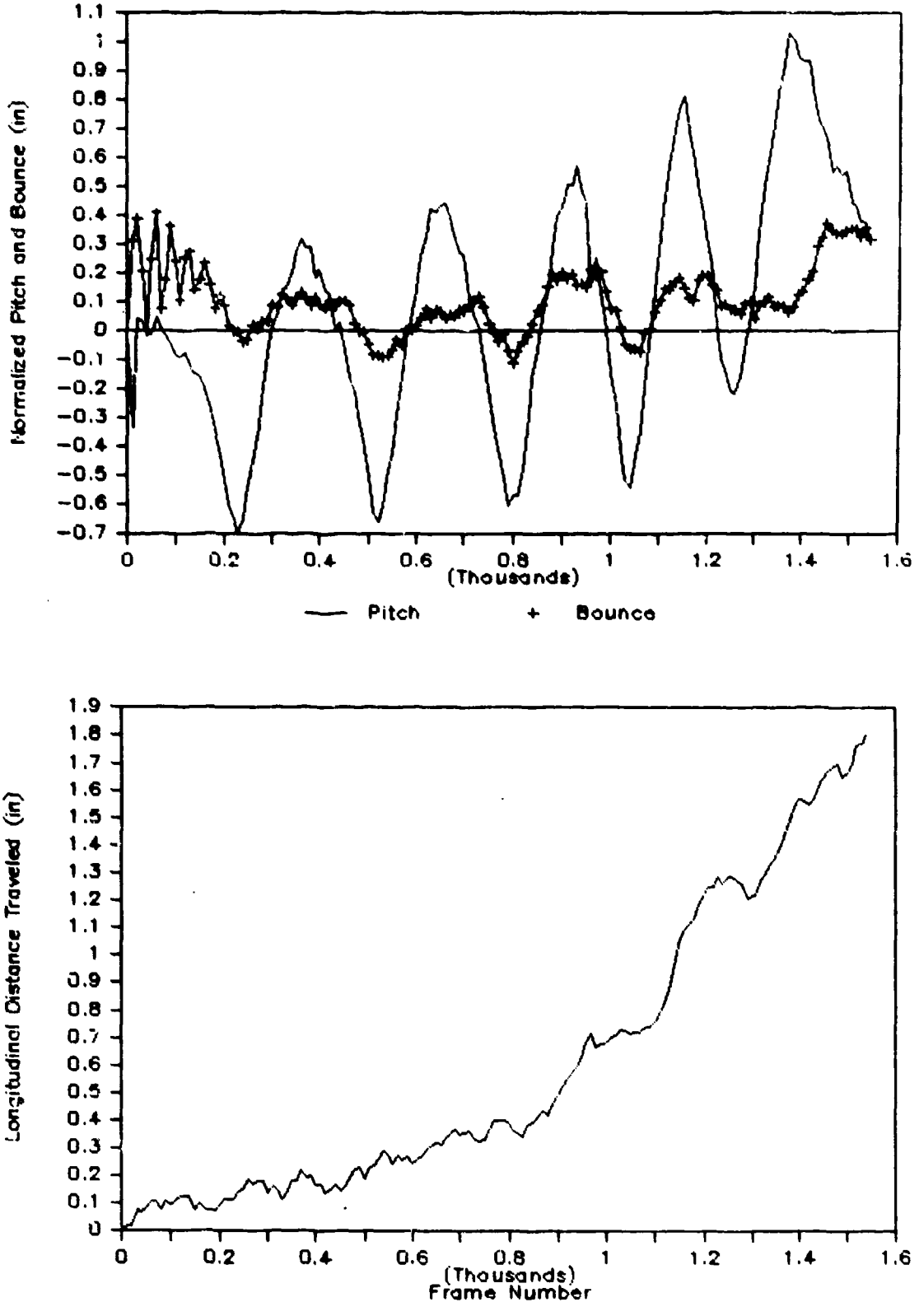
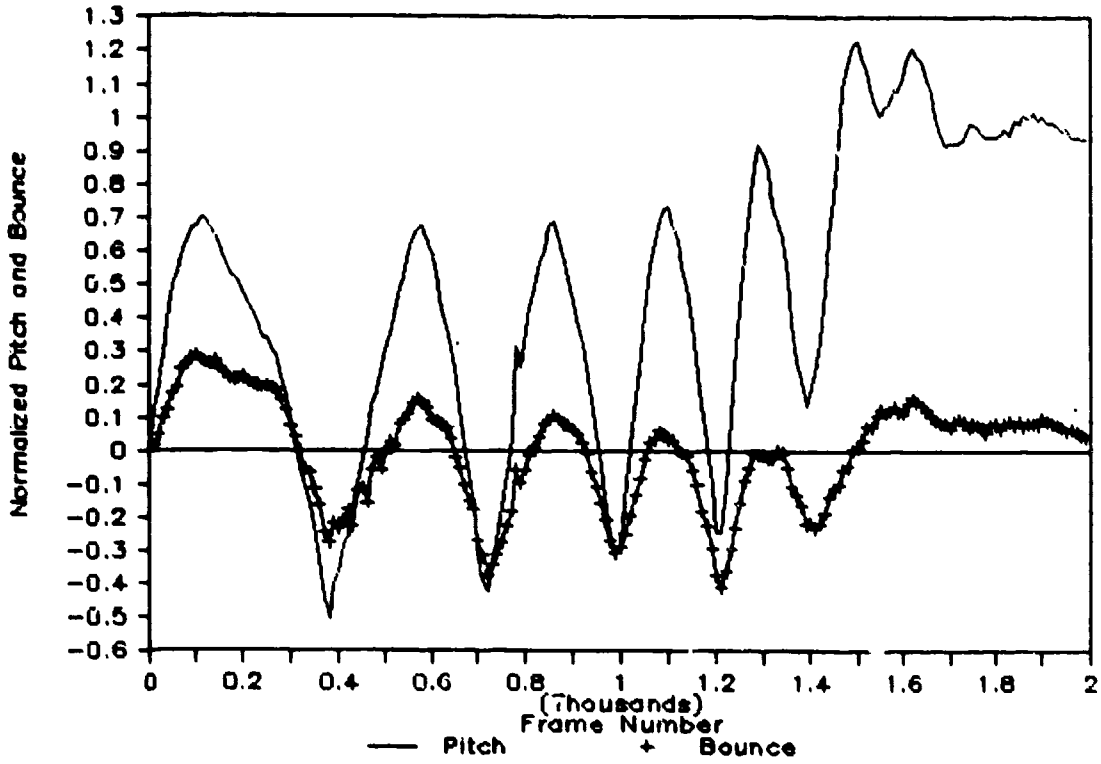


Fig. 13. Ramp test 4B: estimated speed of 1.3 mi/h over ramp with bar obstacle. Pad temperature prior to test: 29°C surface, 40°C interior. (Camera speed: 200 frames/sec.)



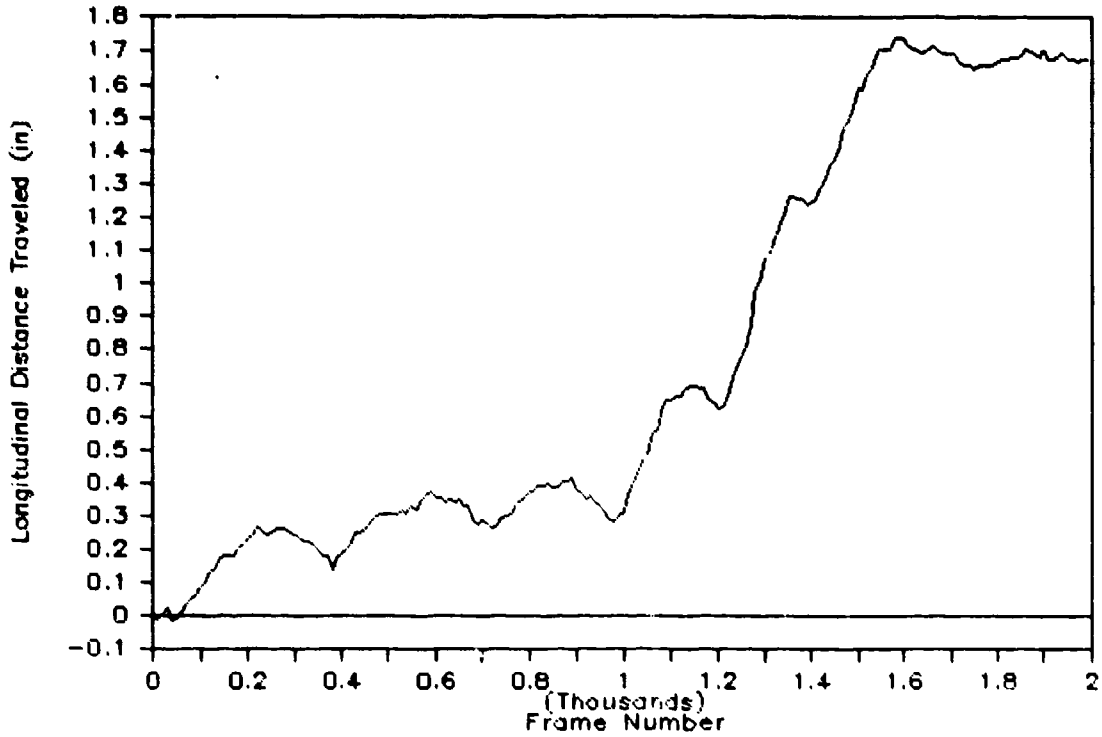


Fig. 14. **Ramp test 5B: estimated speed of 1.2 mi/h over ramp with bolt obstacle. Pad temperature prior to test: 30°C surface, 32°C interior. (Camera speed: 200 frames/sec.)**

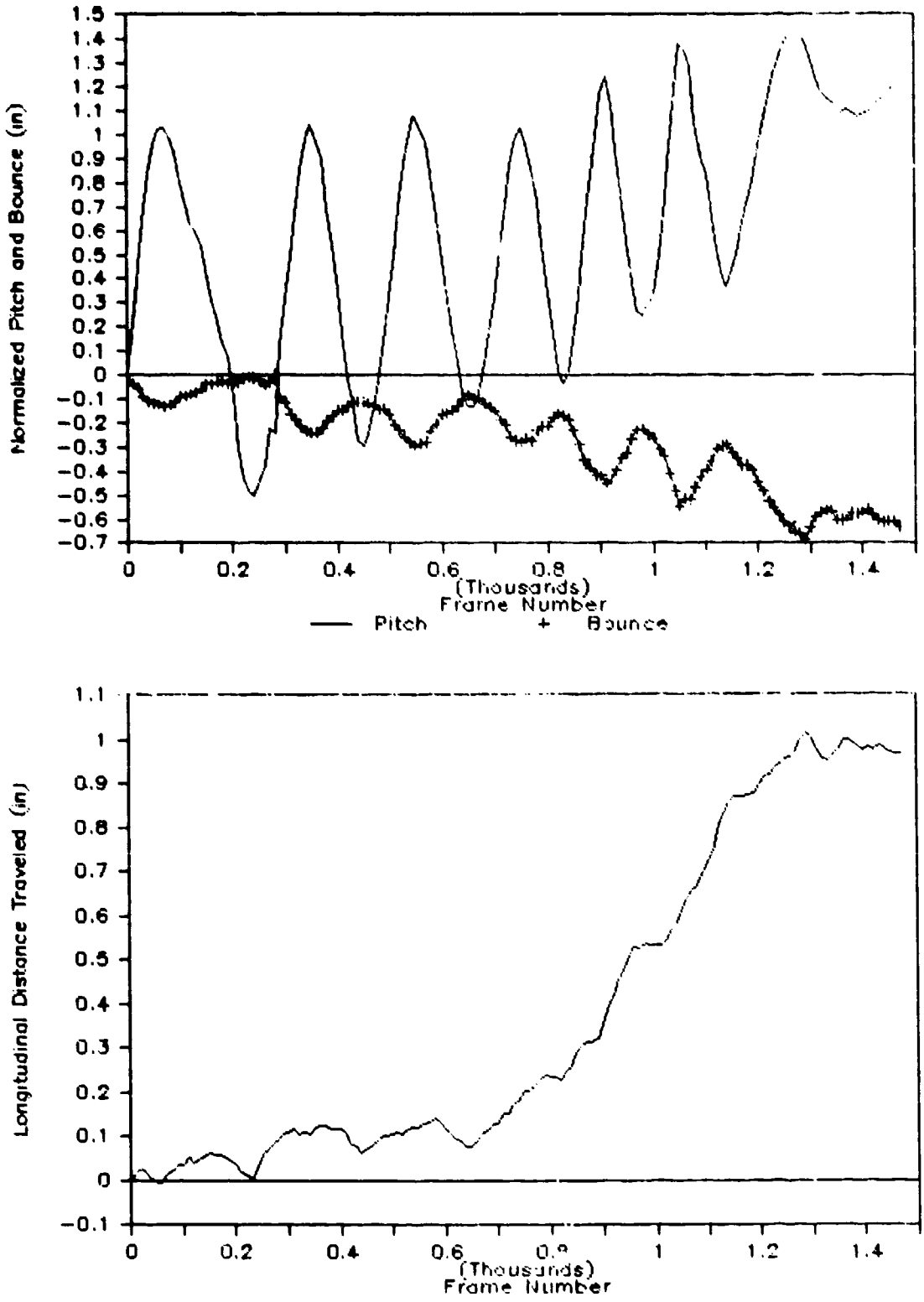


Fig. 15. Ramp test 6A: estimated speed of 1.6 mi/h over ramp with short length of angle obstacle. Pad temperature prior to test: 30°C surface, 32°C interior. (Camera speed: 200 frames/sec.)

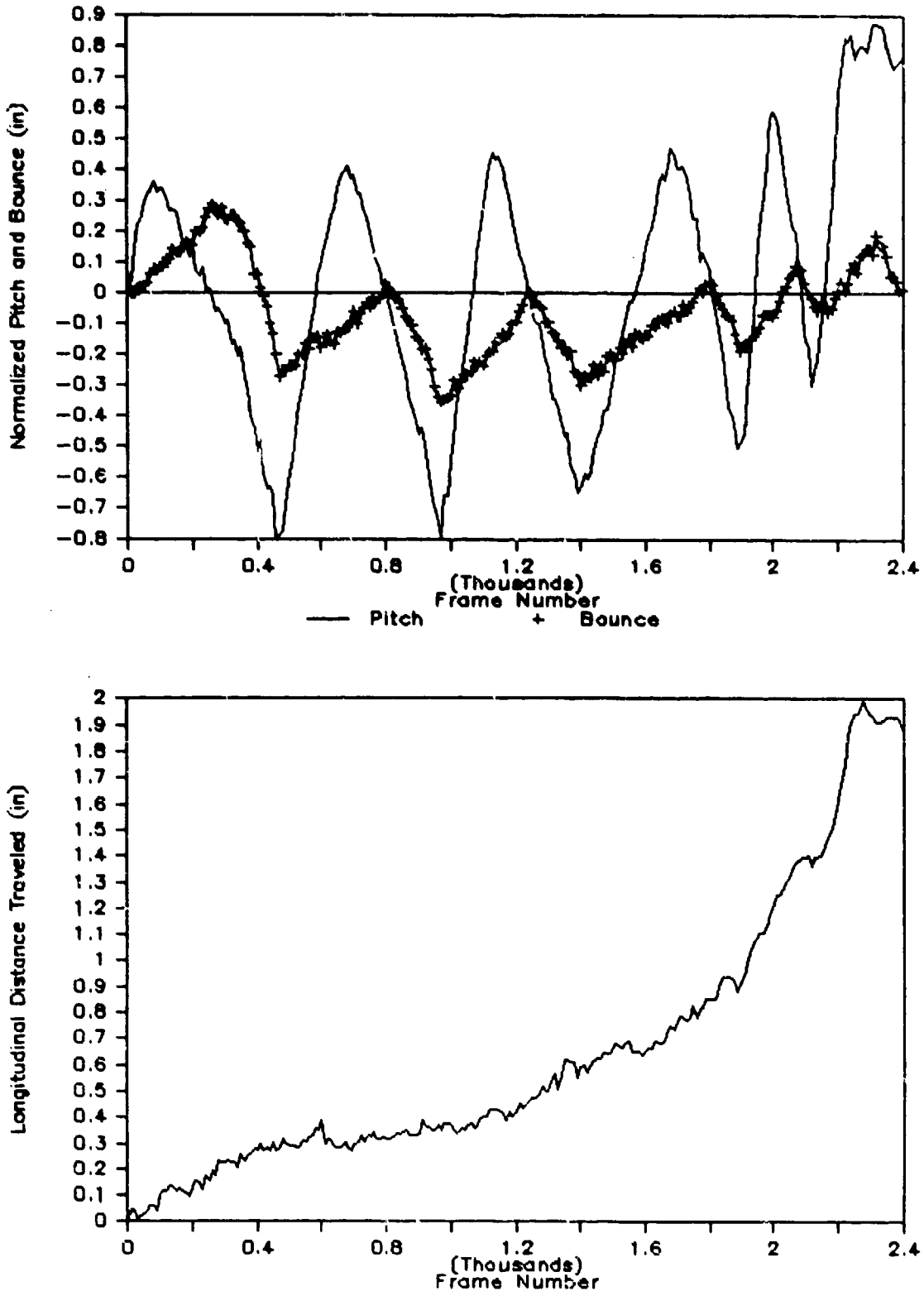
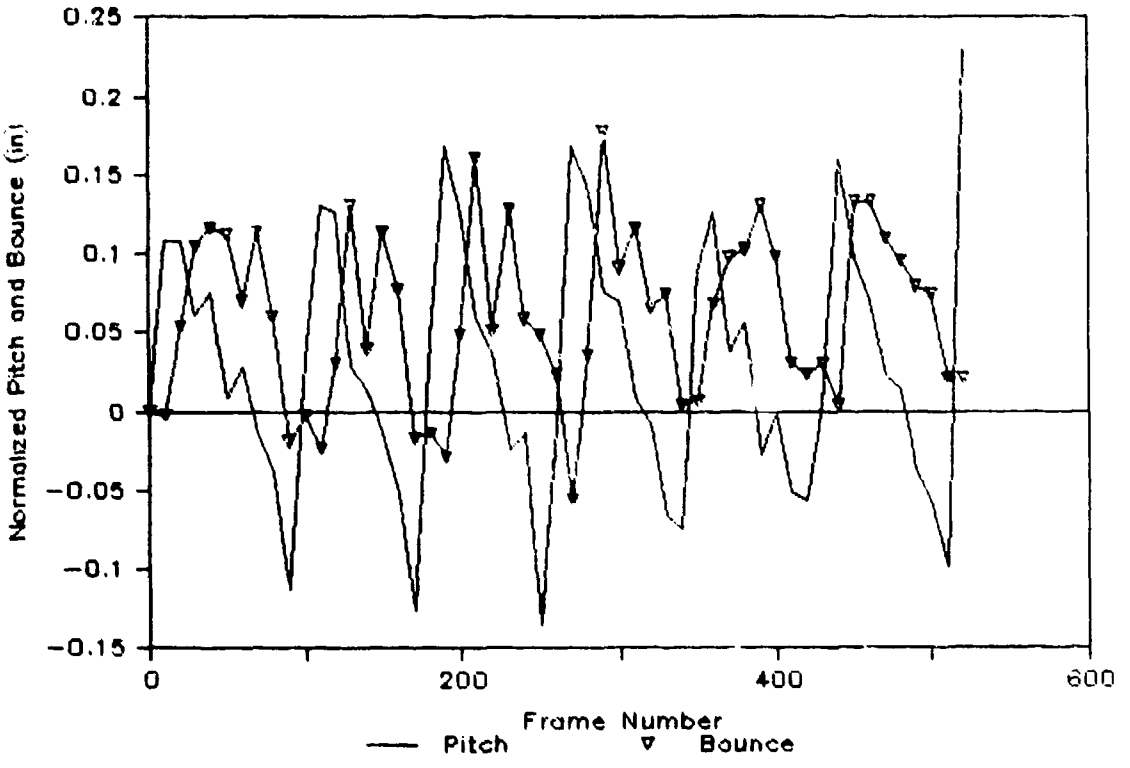


Fig. 16. Ramp test 8A: estimated speed of 0.7 mi/h over ramp with long length of angle obstacle. Pad temperature prior to test: 38°C surface, 56°C interior. (Camera speed: 200 frames/sec.)



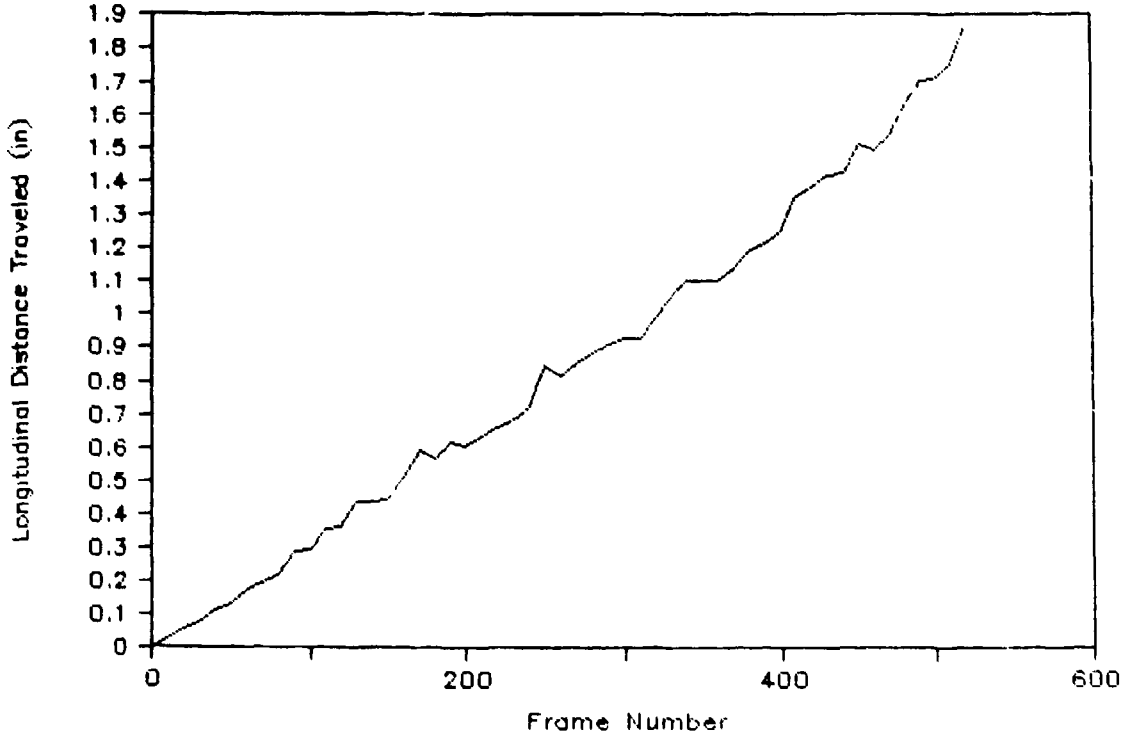


Fig. 17. Road test 1A: asphalt pavement; estimated speed of 3.9 mi/h. (Camera speed: 200 frames/sec.)

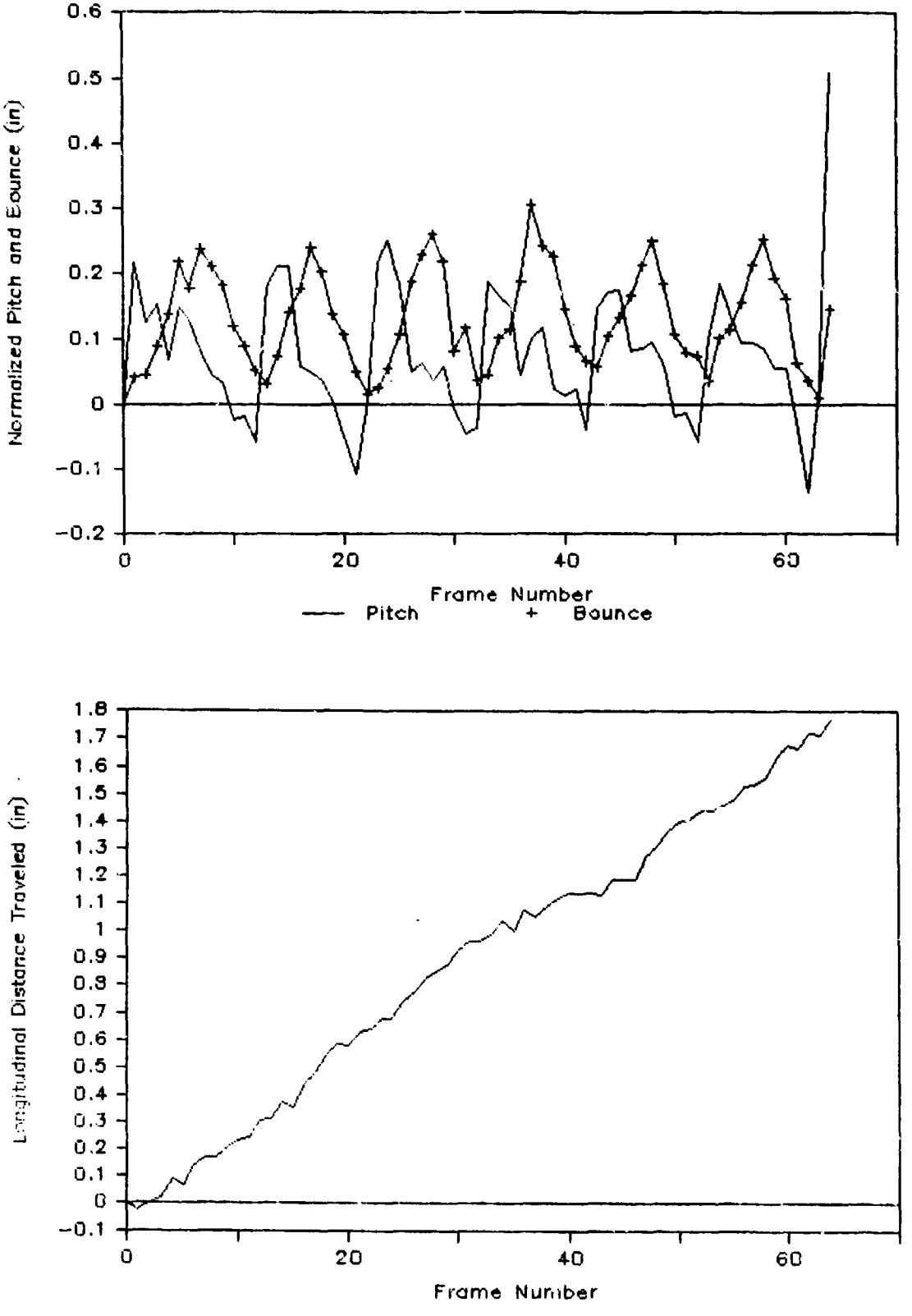
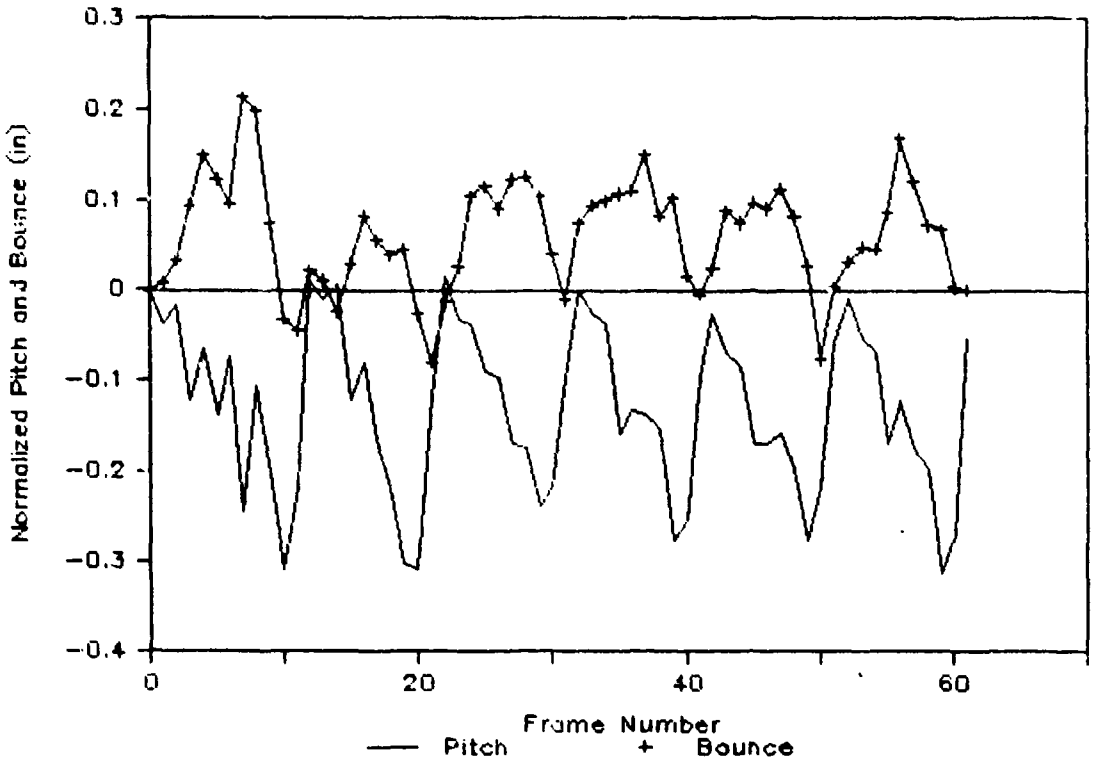


Fig. 18. Road test 1B: asphalt pavement, estimated speed of 33 mi/h. (Camera speed: 200 frames/sec.)



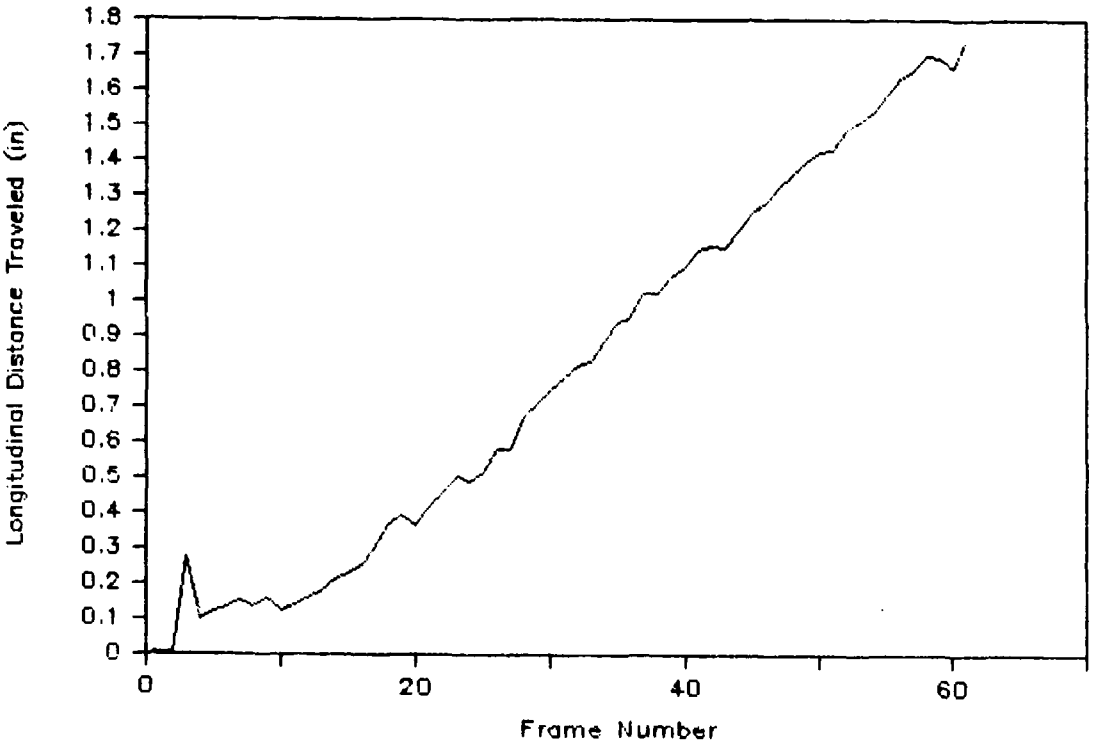
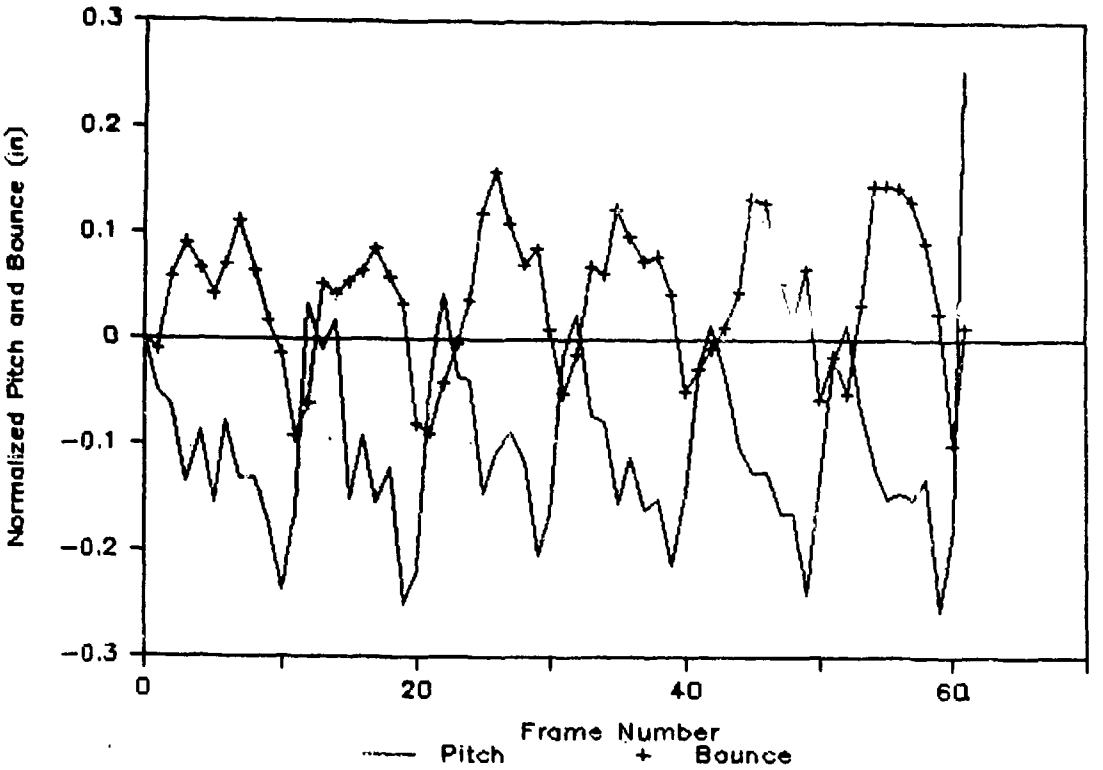


Fig. 19. Road test 2: asphalt pavement, estimated speed of 34 mi/h. (Camera speed: 200 frames/sec.)



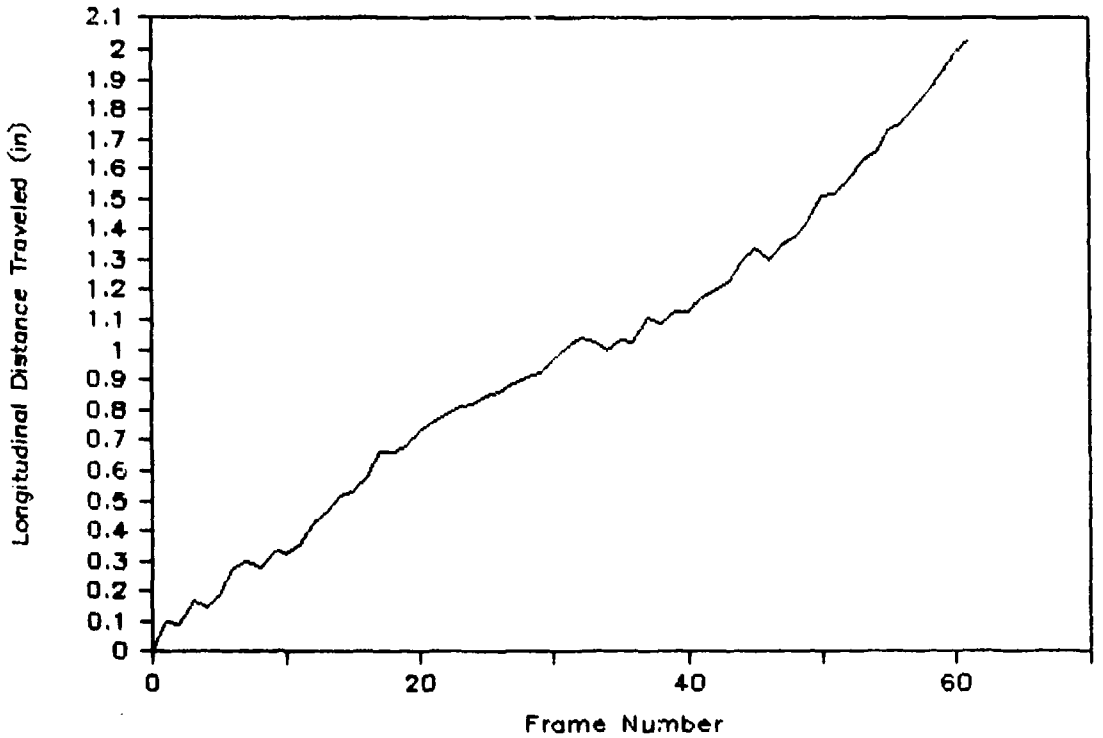


Fig. 20. Road test 3: asphalt pavement, estimated speed of 34 mi/h. (Camera speed: 200 frames/sec.)

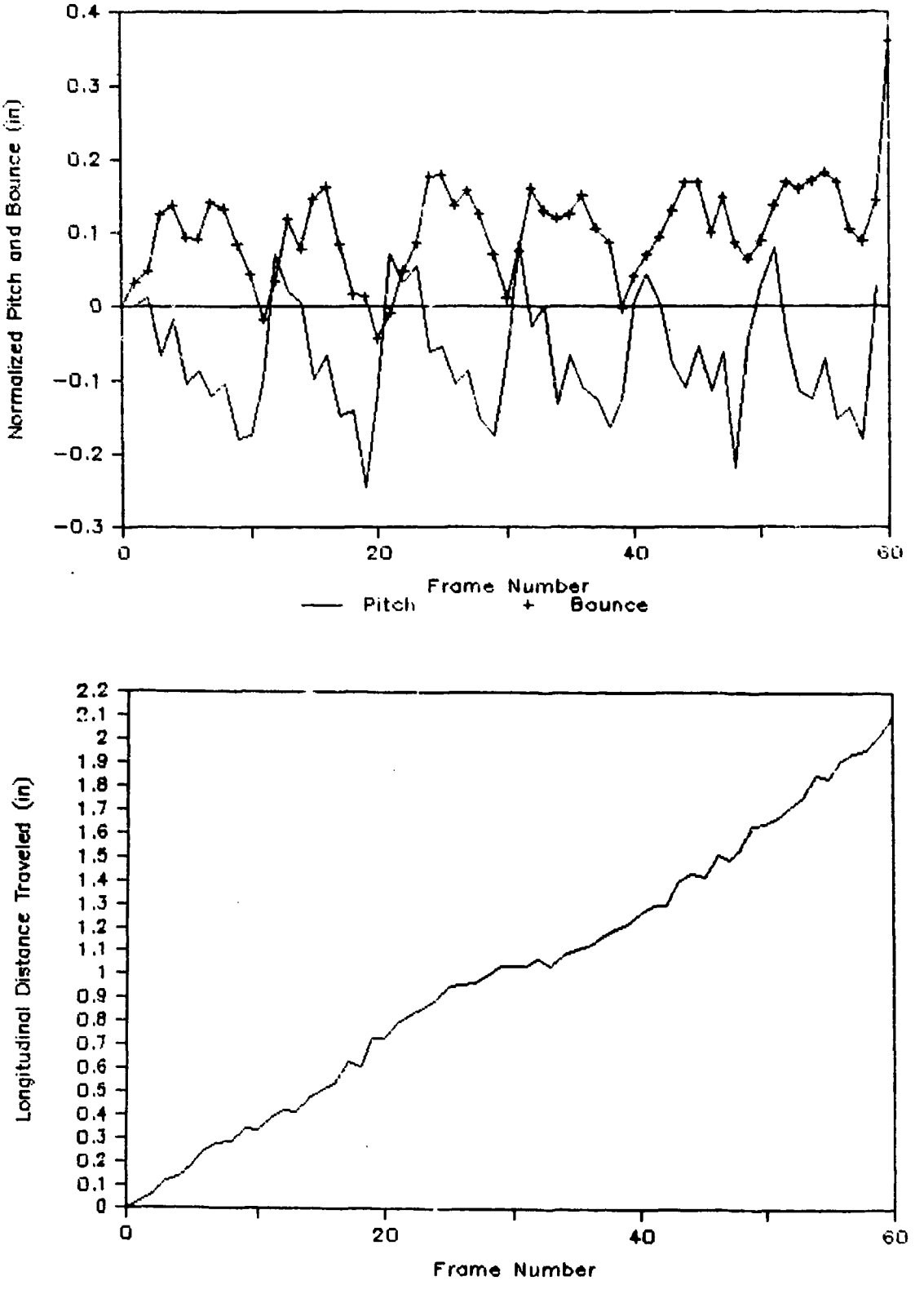


Fig. 21. Road test 1B: asphalt pavement, estimated speed of 33 mi/h. (Camera speed: 200 frames/sec.)

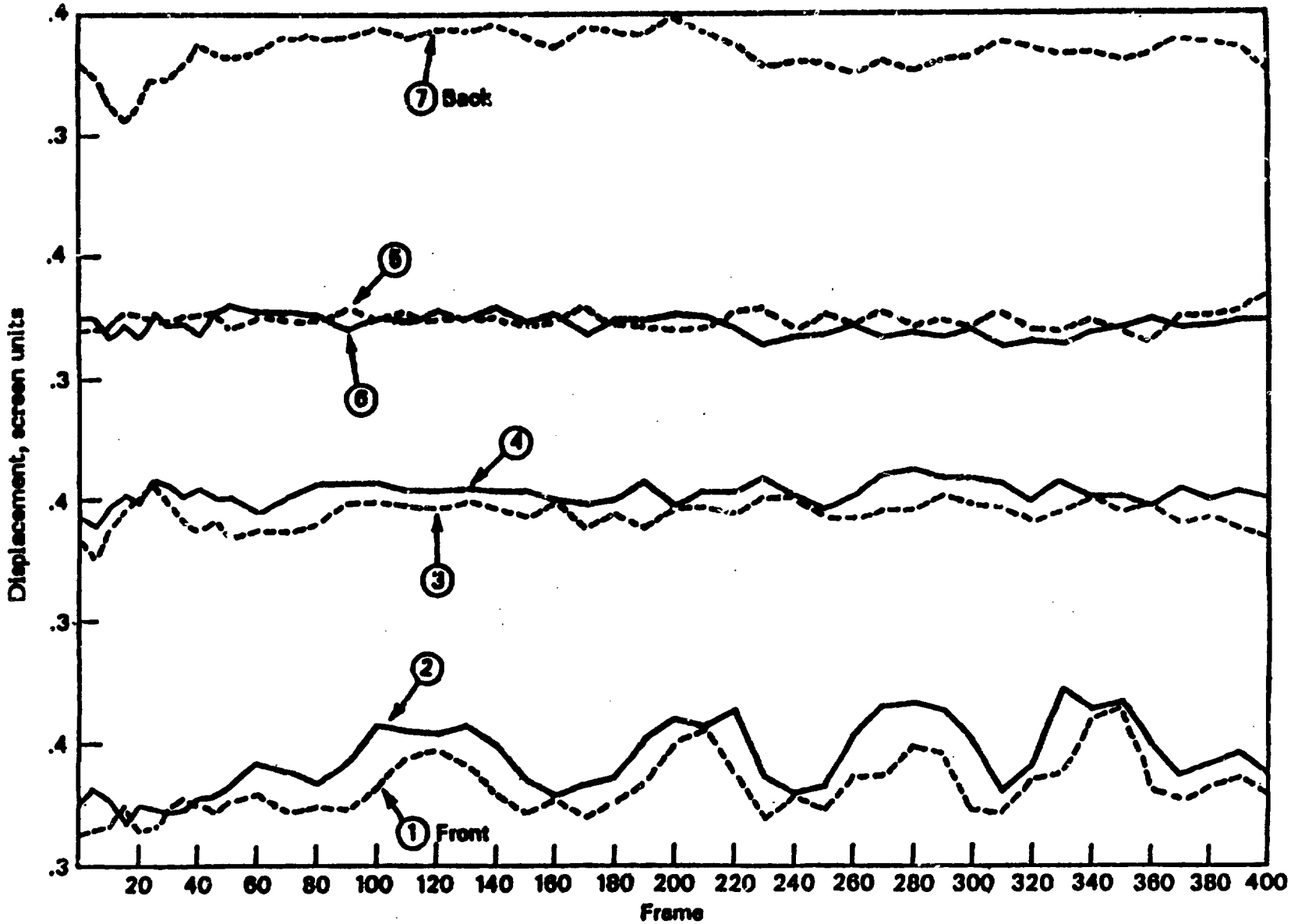
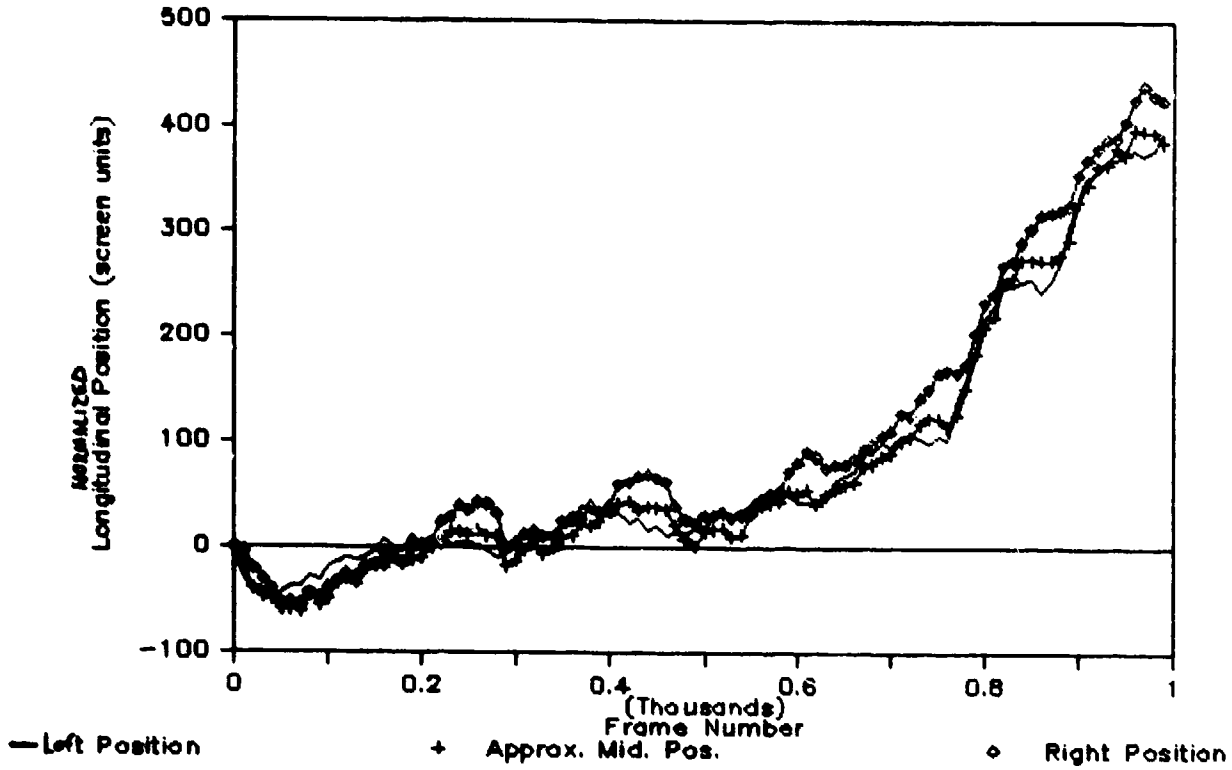


Fig. 22. Changes in longitudinal distance between alternate grid lines on bottom of T142 pad in contact with lucite window during traversing of M60 tank. Measurements taken at 7 locations along a line near the middle of the pad. Location 7 at leading edge and location 1 at trailing edge relative to road wheels. Conversion factor from screen units not given; 1/4-inch grid spacings



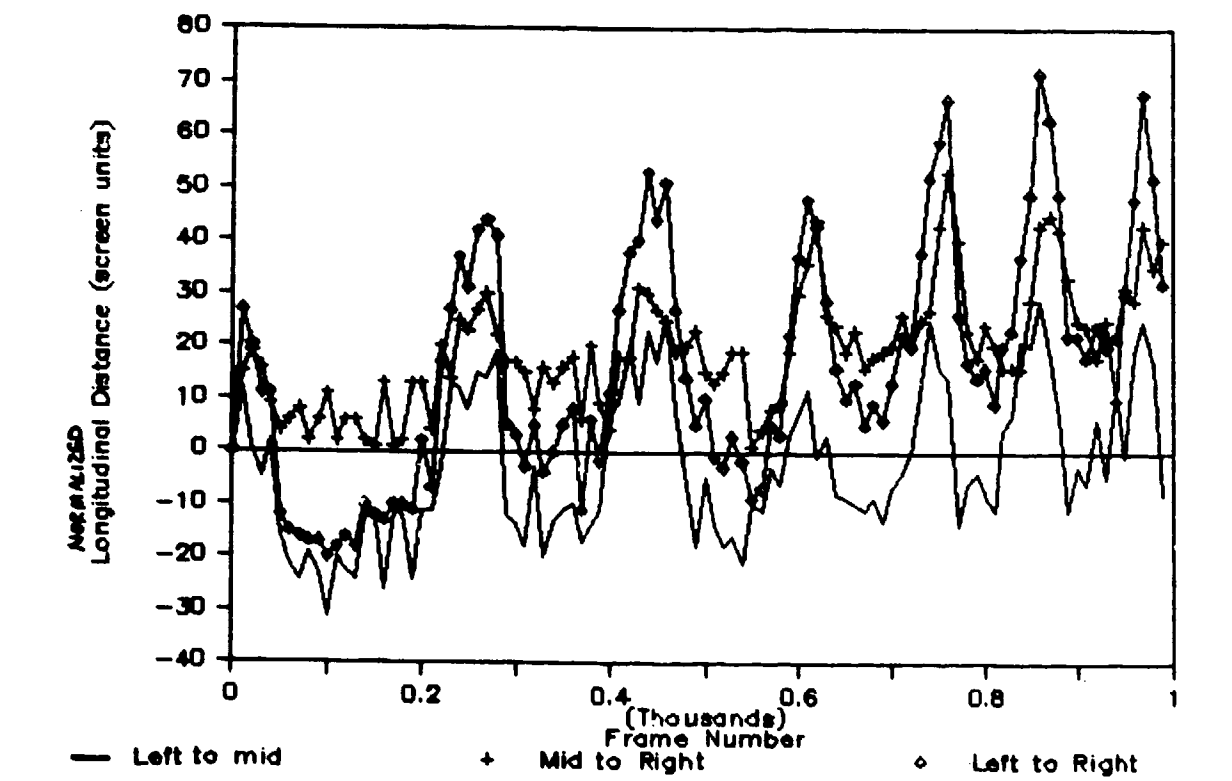
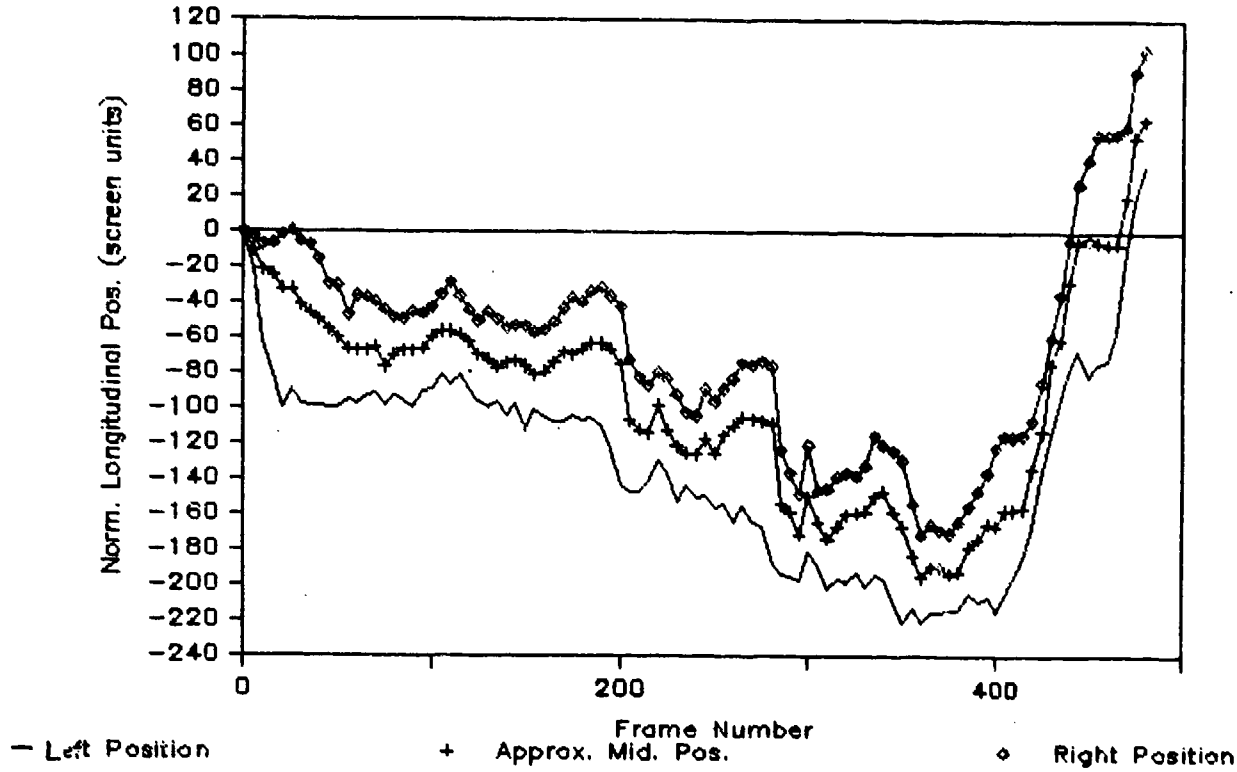


Fig. 23. Ramp test 2A: estimated speed of 2.4 mi/h over ramp with Lexan window surface. Pad temperature prior to test: 29°C surface, 40°C interior. Top plots give actual readings, bottom plots give differential readings. (Camera speed: 200 frames/sec.)



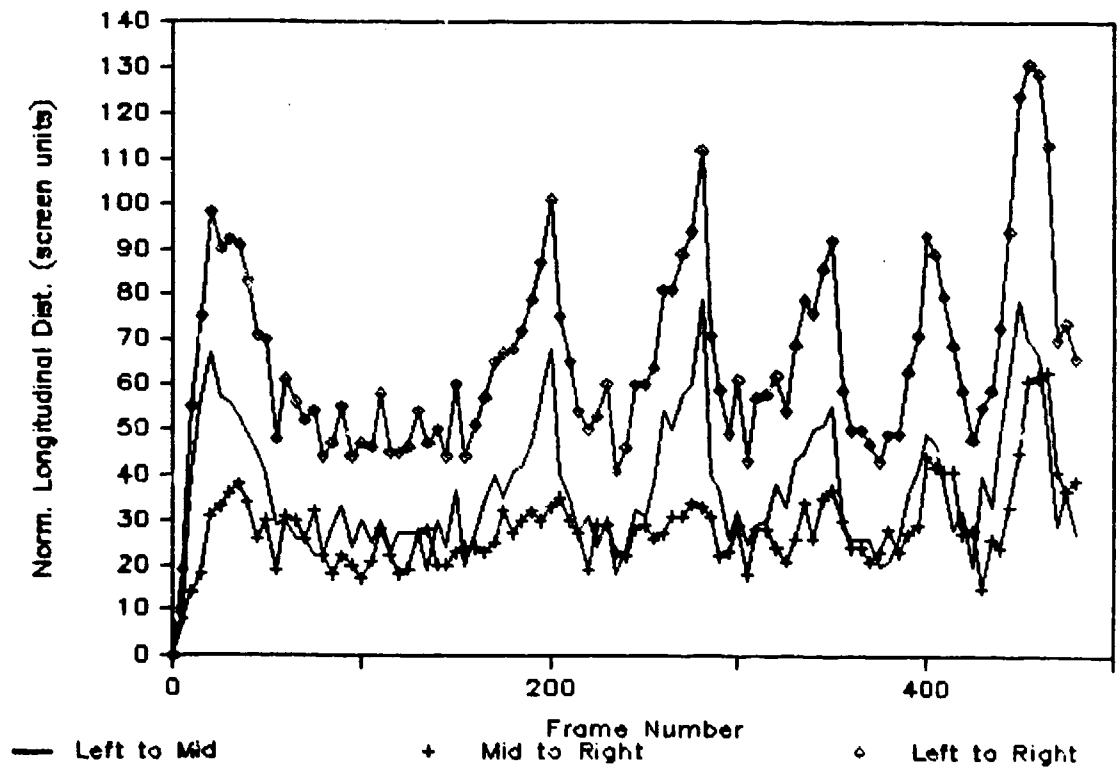


Fig. 24. Ramp test 2A: estimated speed of 3.5 mi/h over ramp with Lexan window surface. Pad temperature prior to test: 29° surface, 40°C interior. Top plots give actual readings, bottom plots give differential readings. (Camera speed: 200 frames/sec.)

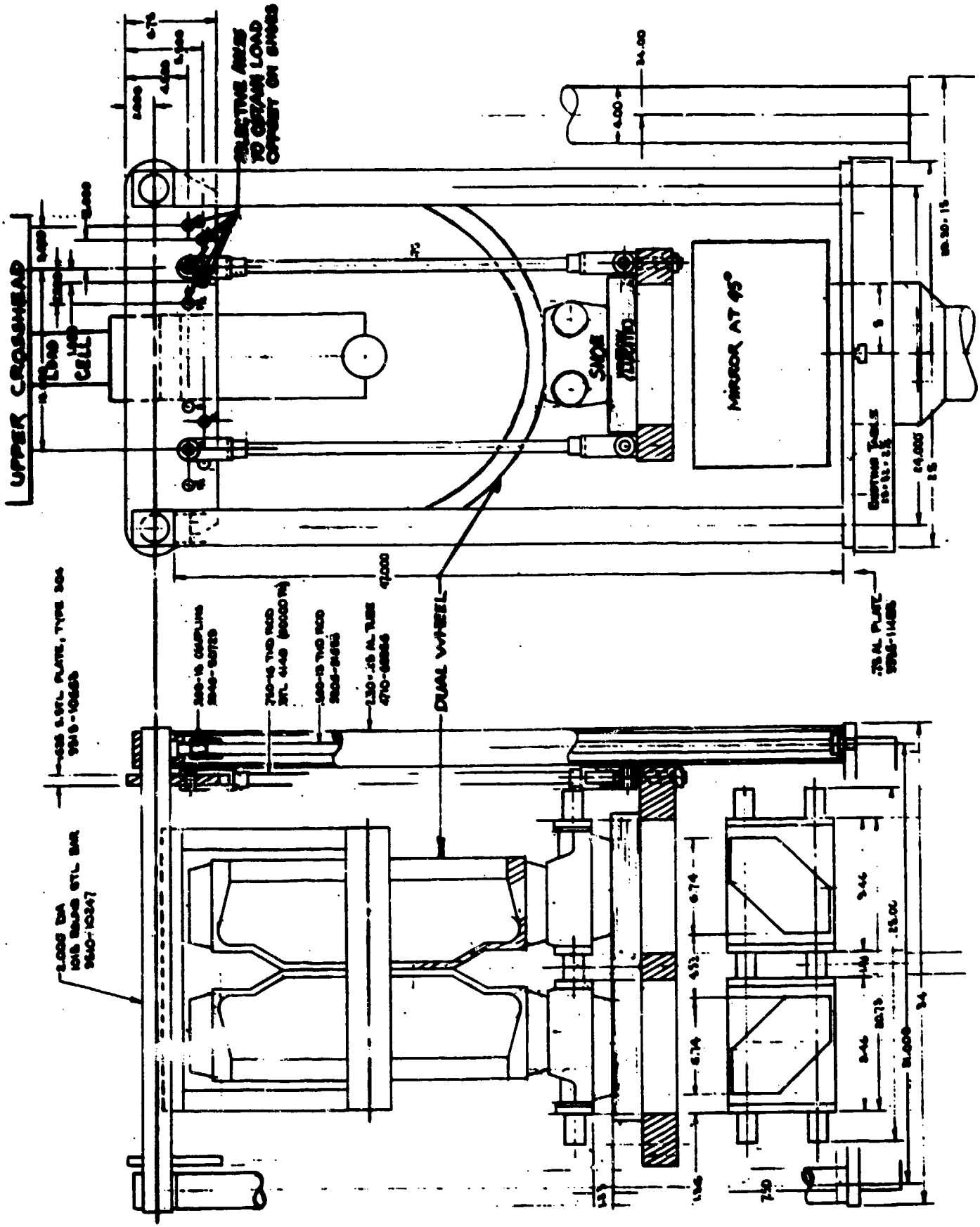


Fig. 25. An assembly working drawing of LLNL test system for evaluating response of T156 shoes to offset loading conditions.

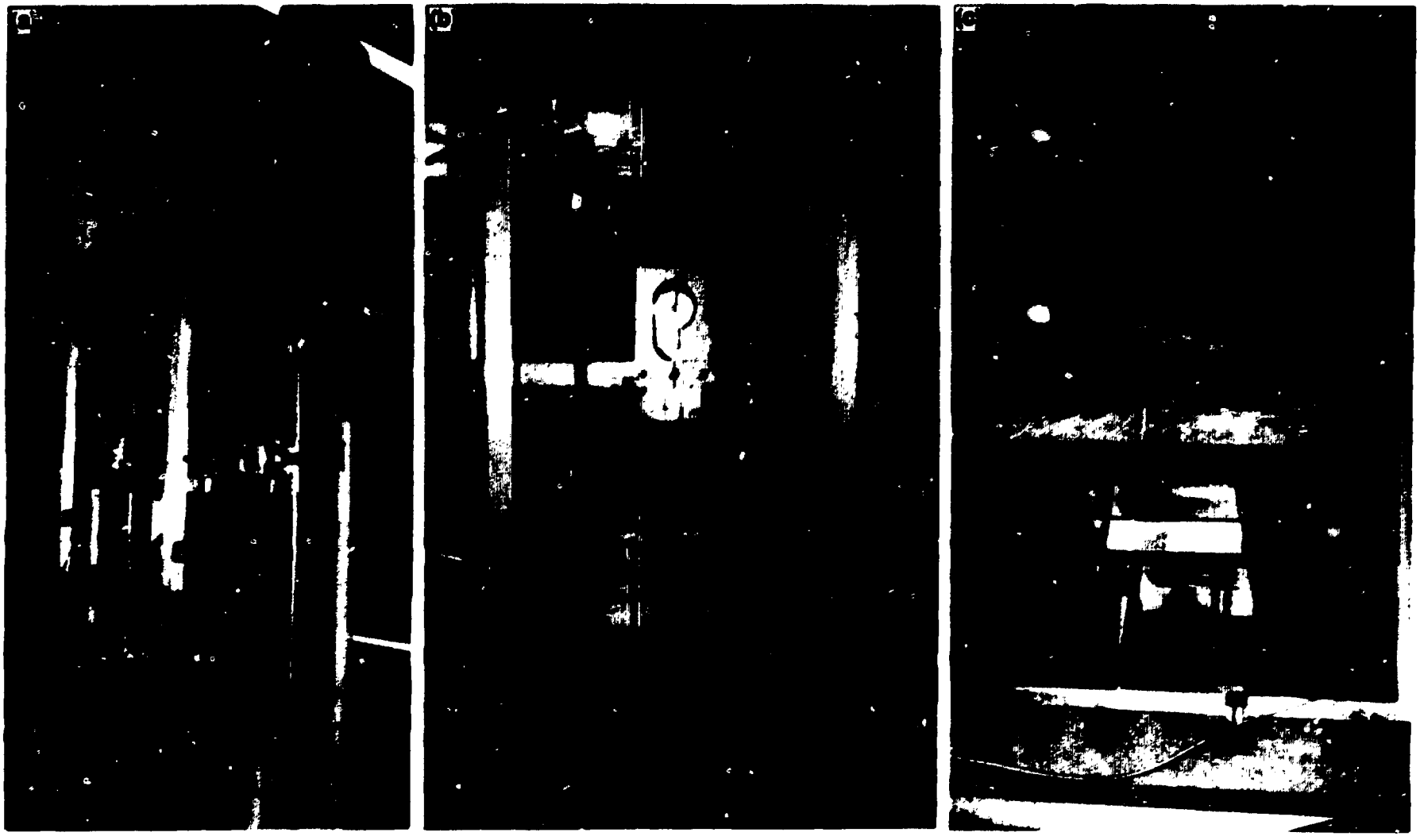


Fig. 26. Photographs of LLNL test system. Refer to text for details on components.

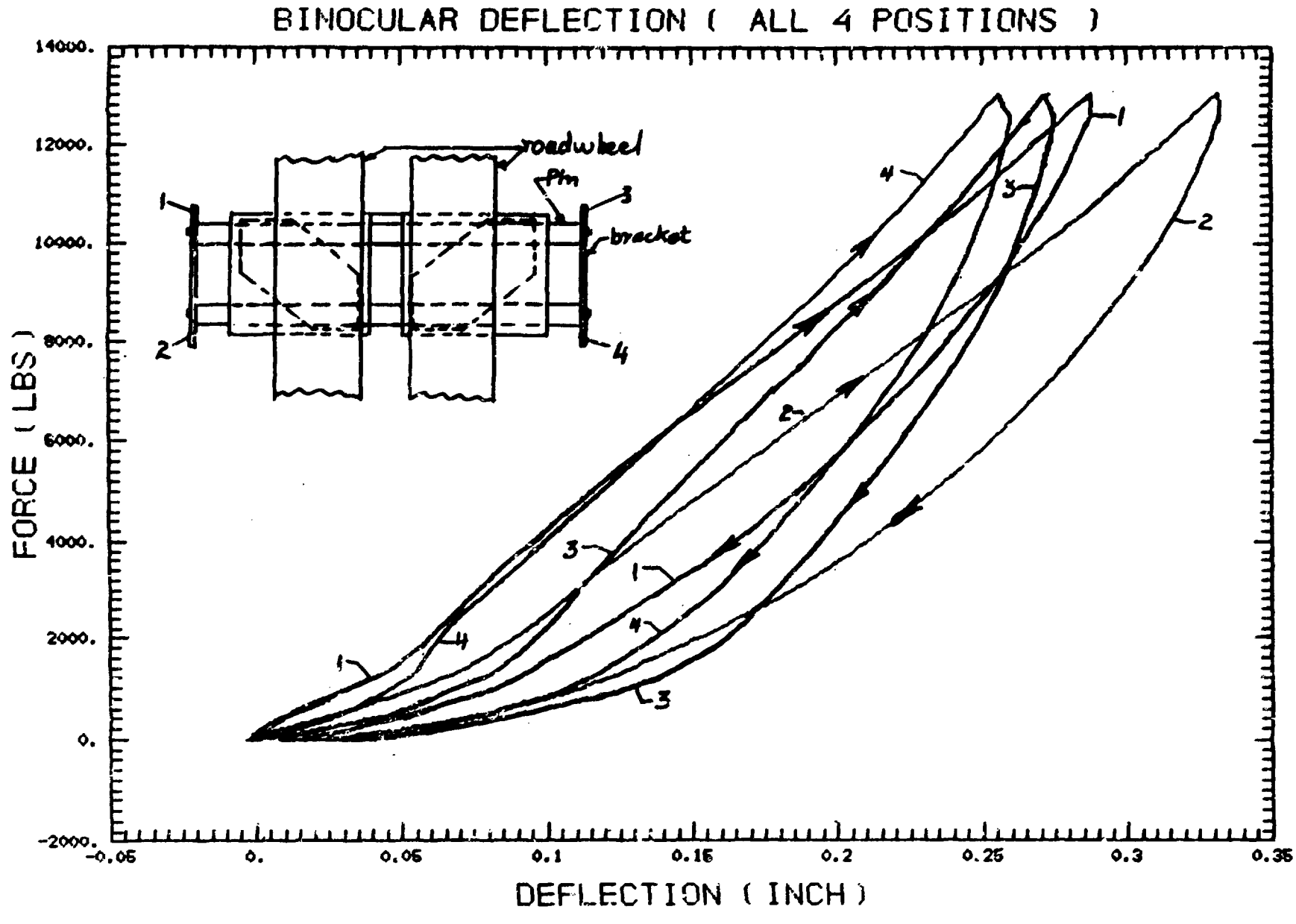


Fig. 27. Hysteretic loading-unloading compression loops of four clip-gage locations (1 through 4) between T156 pins and Lucite window supporting the shoes. (Zero offset loading.)

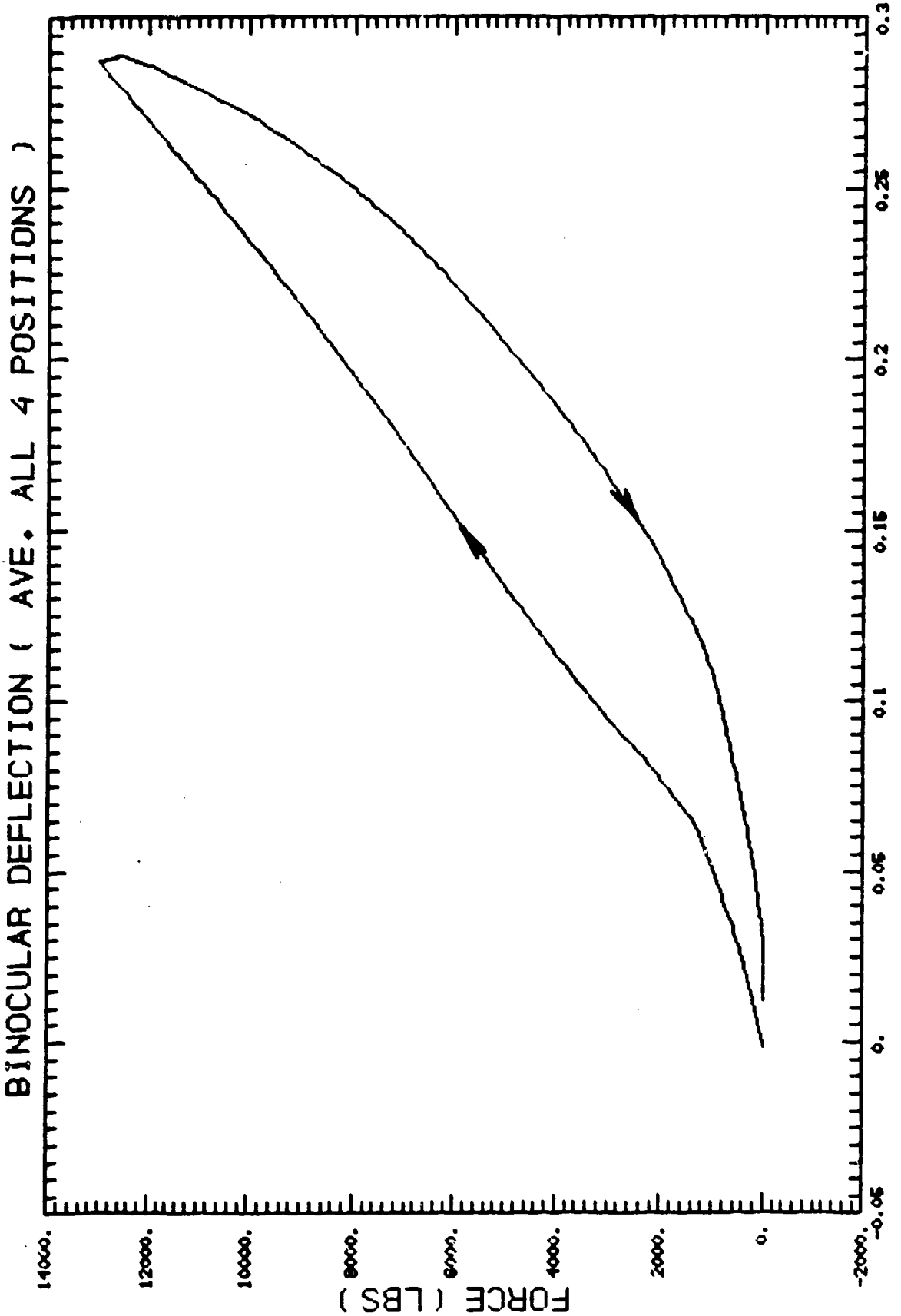


Fig. 28. Average of hysteretic compression loops shown in Fig. 27. (Zero offset loading.)

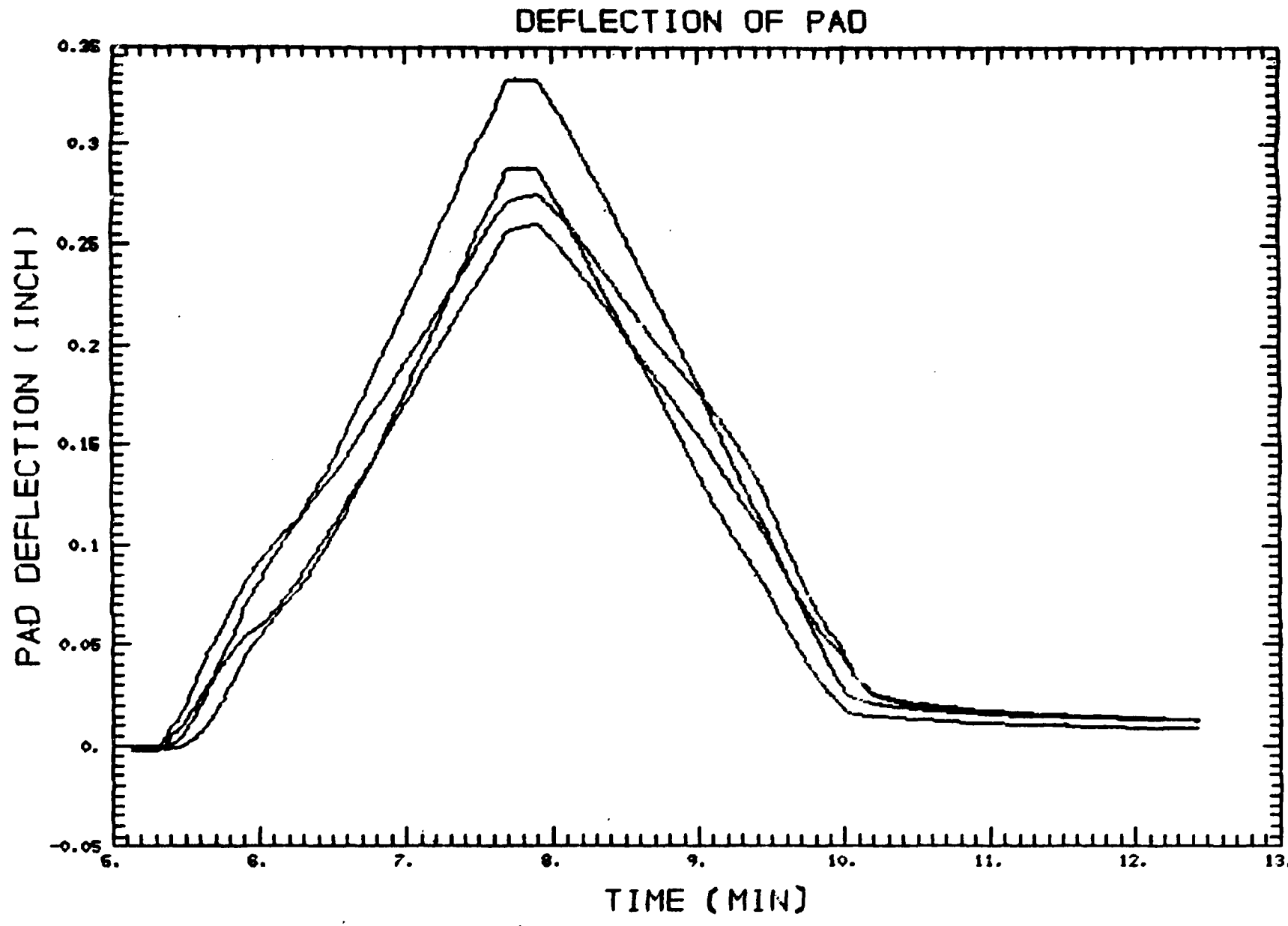


Fig. 29. Compression loading and unloading as a function of time of four clip-gage locations between T156 pins and Lucite window supporting the shoes. (Zero offset loading.)

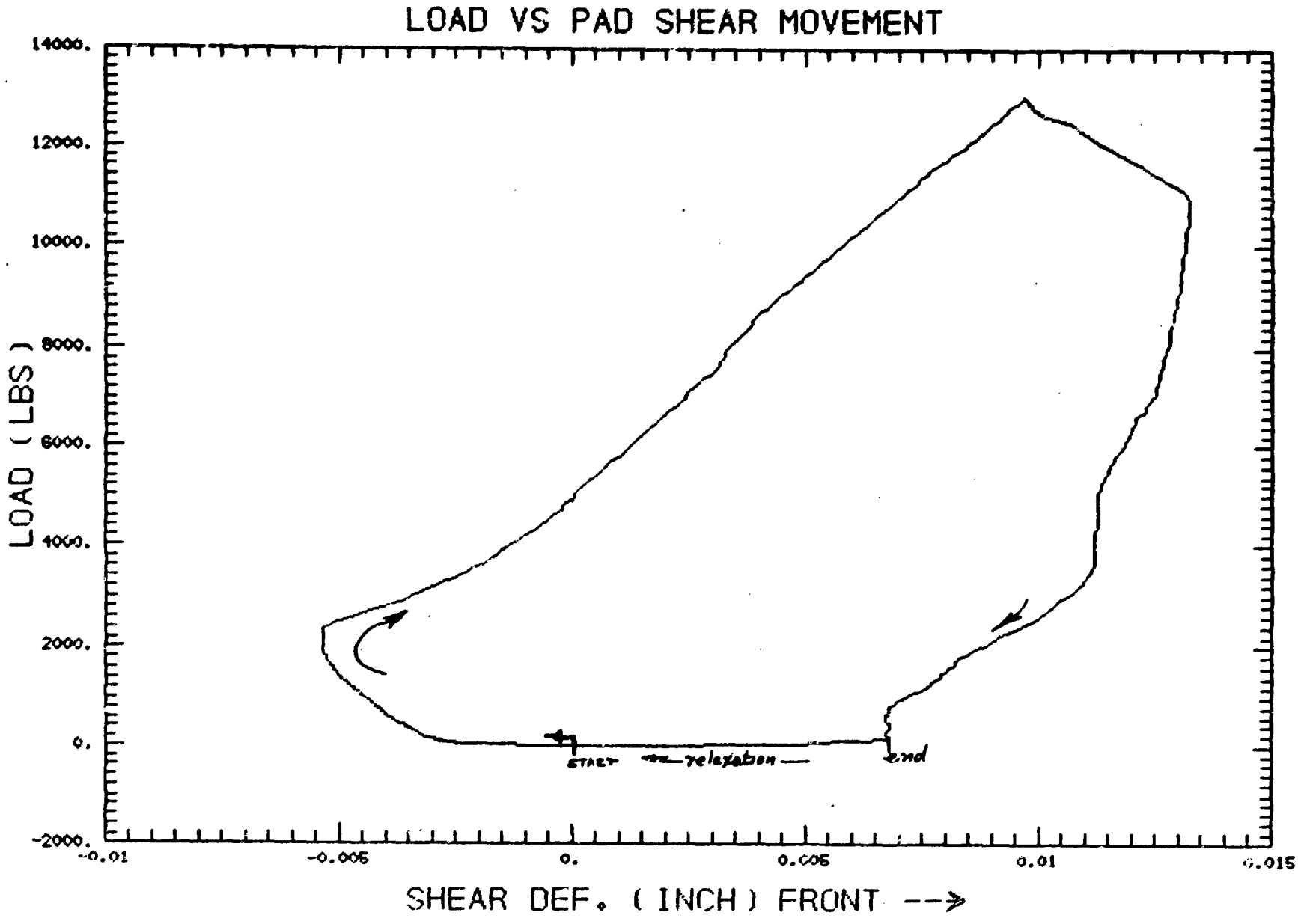


Fig. 30. Gross-shear deformation measurements taken near position 4 of Fig. 27. (Zero offset loading.)

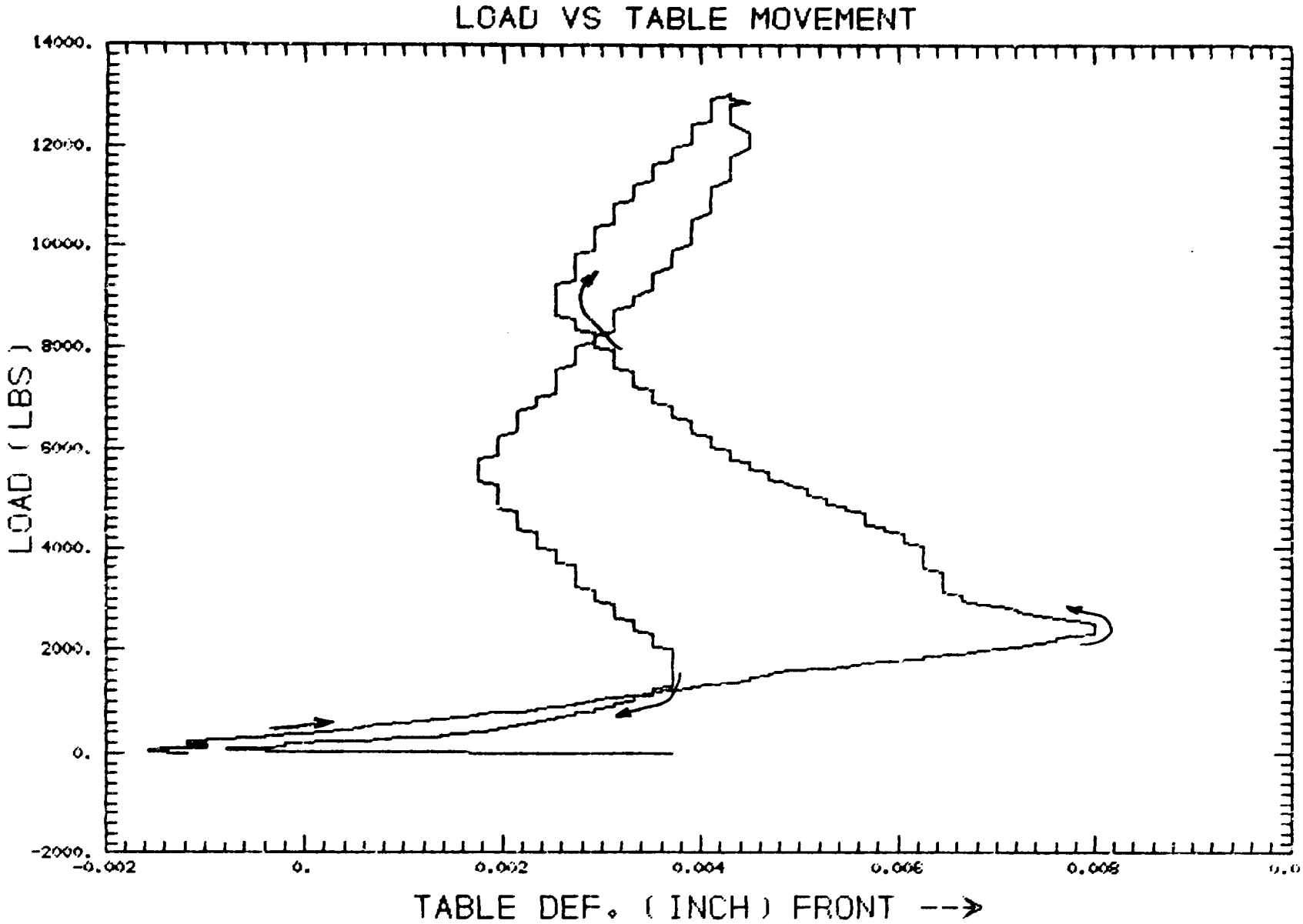


Fig. 31. Longitudinal (horizontal) displacement of the support platform swing during loading and unloading which should correspond to the shoe-assembly displacement. (Zero offset loading.)

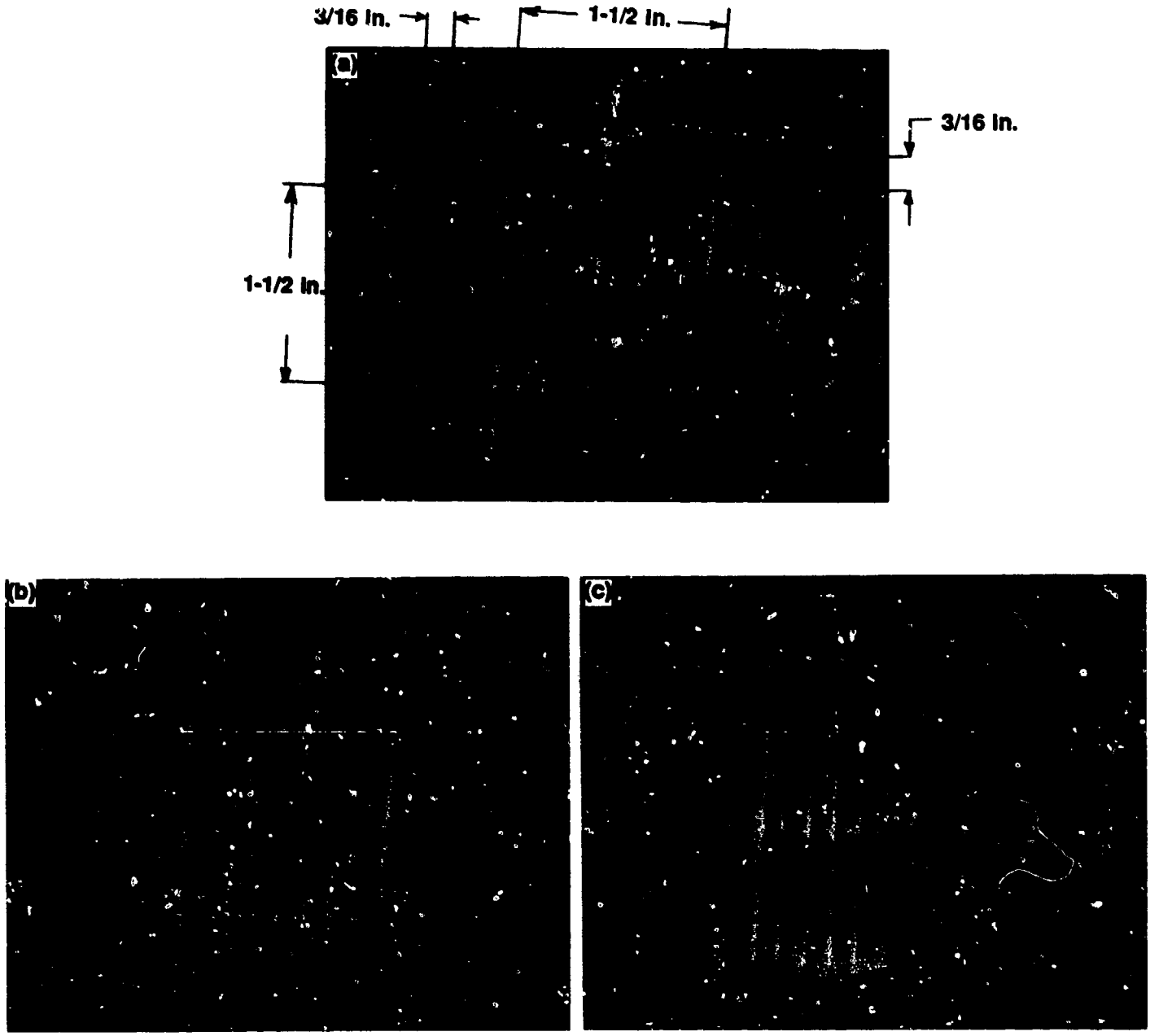


Fig. 32. Photographs of video tape containing a record of laboratory test. Views show pad surface supported on lucite window. View (a) prior to loading; (b) after unloading; (c) maximum load of 13,000 pounds (6,500 pounds per pad). Corresponds to tank motion from right to left. Compare changes in relative positions of marks (two sets of parallel lines at 90^{o}) inscribed on window with grid marks on pad.

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