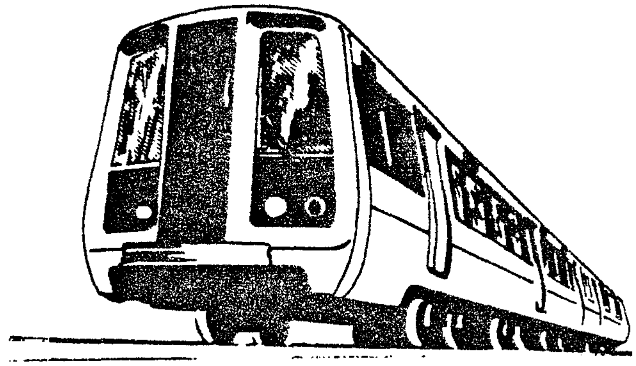
# TECHNICAL NOTE

U.S. Department of Transportation
**Urban Mass Transportation Administration**



TRANSPORTATION TEST CENTER

UMTA/TTC/TN-82/04

## MARTA "C" CAR: TRUCK PRIMARY SUSPENSION STIFFNESS


### SUMMARY

This technical note records the modification process, test setups, and findings of the Truck Primary Suspension Stiffness investigations on the Metropolitan Atlanta Rapid Transit Authority (MARTA) "C" Car. Rubber suspension parts have been modified in several stages of MARTA transit car testing. Data are included here for vertical, longitudinal, and lateral stiffness tests of primary bushings in all stages of modification.


### INTRODUCTION

MARTA has experienced problems with ground carried vibrations caused partially by the 16 to 20 Hz resonance of the primary suspension system of the cars. The MARTA "C" car truck primary suspension stiffness modifications were done to investigate the effect of reduced stiffness of the primary suspension on ground carried vibration levels. At the Transportation Test Center (TTC), Wilson, Ihrig and Associates, Inc., conducted an evaluation of ground vibrations before and after spring rate changes in the car suspension were made. Engineers of Boeing Services International, the TTC Operations and Maintenance Contractor modified the primary suspensions and established the stiffness parameters at all stages in the experiment. Only the TTC activities are reported here. Ground vibration data are reported in Groundborne Vibration Tests with MARTA C-Car.[1]

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[1] Saurenman, Hugh J., Groundborne Vibration Tests with MARTA C-Car, Final Report, November 16, 1981. Wilson, Ihrig, and Associates, Inc., 5776 Broadway, Oakland, CA 84618 U.S.A.

## BUSHING CONFIGURATION

Two classes of original bushings were used for the experiment:

- New, unmodified elastomer primary suspension bushings, and
- Used bushings, drilled near the horizontal joints (both top and bottom) for earlier experiments on MARTA "A" and "B" Cars. (See Figure 1).

The used bushings were included in this test so that earlier investigations of longitudinal stiffness under the MARTA Curving Program[2] might compliment the findings of this investigation.

The A-truck (used) bushings were modified through three stages. The top bushings were thoroughly frozen, and 3/4" diameter evenly spaced holes were drilled in the middle portions. These 3/4" diameter holes (shown in Figure 2) did not provide sufficient reduction in vertical spring rate and were enlarged to 1" diameter in a second attempt to reduce the stiffness. The final modification necessitated removing the connecting elastomer material between the holes as shown in Figure 3.

Once the final modification configuration was established and tested, all the top bushings of both trucks were modified as shown in Figure 3. The entire procedure may be summarized thus:

| Bushing Configuration | Truck Stiffness Measurement Vertical | Lateral | Longitudinal |
|---|---|---|---|
| Unmodified | A | A | A |
| Modification 1<br>3/4" Diameter Holes | A | | |
| Modification 2<br>1" Diameter Holes | A | | |
| Modification 3<br>1" Wide Slots<br>(Tested before field run) | A | | B |
| Modification 3<br>1" Wide Slots<br>(Tested after field run) | A&B | A&B | A&B |

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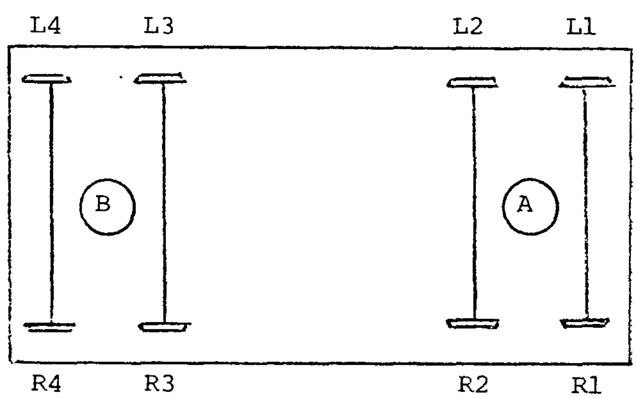
[2]Mutter, H. et al, Metropolitan Atlanta Rapid Transit Authority Transit Vehicle Engineering Tests. FRA/TTC-81/05, NTIS PB82 126392.

## DETERMINATION OF SPRING RATES

The supposition of the test planners was that removal of elastomer material from the primary top bushings would greatly reduce vertical stiffness and change lateral and longitudinal stiffness in similar degrees. Thus, before modification of the MARTA "C" Car bushings took place, preliminary measurements were taken to establish spring rates.

All stiffness tests were performed on a stationary car for which truck and wheel nomenclature are diagramed below.




The weights for the MARTA "C" car testing were as follows for all spring rates.

| Test Weights | A-Truck | B-Truck | Total |
|---|---|---|---|
| AW0 | 42,760 | 41,620 | 84,380 |
| AW2 | 51,080 | 49,640 | 100,720 |
| AW3 | 60,100 | 58,620 | 118,720 |

Spring rates were determined by the following methods.

Vertical Stiffness Test Setup. Each corner of the truck was incrementally relieved of its vertical loading by a hydraulic jack placed under each journal. A 20 kip load cell in series with the hydraulic jack measured the incrementally applied load per wheel. The signals were fed to a digital multimeter and strip chart through a signal conditioner. The vertical deflection of each journal housing with respect to the wheel was measured with dial gages.

Longitudinal Stiffness Test Setup. The rear axle wheels of the A-truck were supported on an air bearing table with the front axle wheels supported at the same height by blocks on the rails. The pneumatic brake cylinders of the rear axle wheels were operated at controlled air pressure from the shop air line to provide the required longitudinal load, and the pneumatic lines of the front axle brake cylinders were disconnected. A pressure regulator in the shop air line, capable of varying the air pressure in the range 30 - 75 psig, provided the longitudinal load increments. A 10 kip load cell in series with one of the active brake cylinder pistons measured the applied longitudinal load when coupled with a digital multimeter and strip chart recorder through a signal conditioner. Two dial gage indicators mounted between the truck side frames and trailing wheelset measured the longitudinal displacement. Air pressure for the active brake cylinders was adjusted in increments of approximately 10 psig over the 30 - 75 psig range and the corresponding dial gage readings were recorded. The digital multimeter output was scaled to indicate the applied longitudinal force directly in pounds. In this test it was assumed that the active tread-brake cylinders were equal in longitudinal force.

Lateral Stiffness Test Setup. A suitable bracket was fixed to the third rail pickup arm of the side frame for applying lateral force by a hydraulic cylinder reacted by a parallel rail support. A load cell in series with the hydraulic cylinder was connected to a digital multimeter and strip chart recorder through a signal conditioner and amplifier to record the applied force. An LVDT (Linear Variable Displacement Transducer) was fixed between the wheel and side frame to record the magnitude of the side frame deflection on a strip chart. A dial gage was fitted between each wheel and side frame to measure the displacement of the side frame with respect to each stationary wheel. The maximum lateral load applied was 4,000 lbs in 500 lb increments. Corresponding readings were taken of the lateral displacements to provide the stiffness curves.

## VERTICAL STIFFNESS TESTS

Original Bushings. The primary suspension bushings were relieved of the vehicle loading at 2,000 lb increments using the jacking procedure described earlier. An additional dial gage mounted between the wheel rim and rail was used to detect any rotation of the wheel during the jacking process. Figure 4 shows the vertical deflection of the journal versus the magnitude of the load relieved until wheel liftoff load was achieved. To provide the second half of the characteristic, the wheel was incrementally reloaded by releasing the jacking load under the journal and recording the corresponding variation of vertical deflection. The above test was conducted at AW2 loading with a total car weight of 100,720 lbs (the A-end being 51,080 lbs and the B-end being 49,640 lbs). The "local" vertical spring rate, expressed as lbs per inch, was determined by dividing the incremental load value by the corresponding incremental vertical deflection. This was assumed to be the spring rate prevailing at a wheel load corresponding to the midpoint of each increment.

In Figure 5, the vertical spring rate of the original primary bushings for the full unloading and loading cycle is shown. In actual practice, it is highly improbable that the dynamic load transfer on a wheel could reach such extreme proportions. During operation of a transit car, the dynamic load transfer on each wheel could be in the range of ±20% of the static wheel load. The reasons may be superelevation of the track during curve negotiation or dynamics of the wheel itself. For the analysis of the above static test data, the region corresponding to ±20% of actual static wheel load is of interest. For the AW2 loading, the average static wheel load (A-truck) was 12,800 lbs. Thus, the normal load variation on each wheel under actual operating conditions would be between 10,000 and 15,000 lbs.

As the maximum static wheel load during the above test was about 13,000 lbs, only the spring rate at a wheel load of 11,000 lbs could be evaluated. In view of this fact, the spring rates were compared for the unloading mode corresponding to the wheel load of 11,000 lbs for the later stages of modification. The spring rates were measured over the load range of ±20% of the static load. To establish the spring rate in the +20% region, the car was loaded to the AW3 level by adding extra weight of 12,000 lbs on the A-truck, as discussed in detail later in this section. The vertical spring rate of the original bushings at a wheel load of 11,000 lbs during the unloading half cycle was found to be 180,000 lbs/inch.

First Modification. In consultation with Wilson, Ihrig and Associates, Inc., modifications (Figure 2) were carried out on the four top halves of the rubber bushings on the A-truck, which had already been modified under the MARTA Curving Program. Eight new 3/4" diameter holes were drilled in the middle portion of each top bushing. These bushings were assembled in the A-truck and the vertical stiffness tests were repeated.

Figure 4 shows the vertical stiffness characteristic for the modified bushings. The corresponding reduction in vertical spring rate against wheel load is shown in Figure 5. The vertical spring rate corresponding to a wheel load of 11,000 lbs was found to be 97,000 lbs/inch as compared to 180,000 lbs/inch for the original bushings.

Second Modification. As the reduction in vertical stiffness was not sufficient, the 3/4" diameter holes were enlarged to 1" diameter holes. The modified bushings with eight 1" diameter holes in each bushing were reassembled in the A-truck, and the vertical spring rate tests were repeated with the car loaded at an AW2 level. Figure 6 shows the vertical stiffness characteristic for the second stage of modification. The test was carried out over the full load range as well as a reduced load range to demonstrate the non-linearity of the system. Figure 7 presents the vertical spring rates corresponding to actual wheel loads.

The vertical spring rate during the unloading mode at a wheel load of 11,000 lbs was found to be 90,000 lbs/inch. During partial unloading down to a wheel load of 8,000 lbs, and subsequently, loading up to 12,000 lbs, the vertical spring rate of the modified bushing was observed to be 72,000 lbs/inch (in the loading mode), at a mean wheel load of 11,000 lbs. The above results imply that during the actual operation of the car, when the wheel is unloaded in the -20% range, the primary bushings exhibit a stiffer vertical spring rate than in the +20% range. In general, the vertical spring rate of the primary bushings after the second modification was reduced to 90,000 lbs/inch at a wheel load of 11,000 lbs from the 180,000 lbs/inch of the original bushings.

Third Modification (Final Configuration). Because the reduction in the vertical spring rate due to the above modification in the primary rubber bushings was not sufficient, the top bushings were further modified by removing elastomer material between the drilled holes in the middle portion as shown in Figure 3. The A-truck was reassembled with the modified top bushings of the final configuration, and the vertical stiffness tests were repeated as tabulated below.

| Truck | Total Truck Load (lbs) | Wheel Lift-off Load (lbs) | Unloading & Loading Between Wheel Loads of (lbs) | Conditions of Testing | Reference Figures |
|---|---|---|---|---|---|
| A | 51,080 | 14,000 | a. 9,000 & 15,000<br>b. 11,000 & 15,000 | Car traversed back & forth within test bay after assembly of bushings. | 8 & 9 |
| A | 63,080 | 18,500 | a. 9,500 & 18,500<br>b. 10,500 & 18,500<br>c. 12,500 & 18,500 | Car traversed back & forth within test bay after assembly of bushings. | 10 & 11 |
| A | 57,000 | L1 = 14,500<br>R1 = 14,500<br>L2 = 16,300<br>R2 = 12,600 | 8,500 & 14,500 (L1&R1)<br>11,300 & 16,300 (L2)<br>7,600 & 12,600 (R2) | Car was run on Transit Track for 4 hours before this test. | 12 & 13 |

Figures 8 and 9 present the vertical deflection and spring rates under fully unloaded and partially unloaded conditions for the final modified bushings. When the primary bushes were loaded between wheel loads of 9,000 and 15,000 lbs, the vertical spring rate was found to be 50,000 lbs/inch at the wheel load equivalent to 11,000 lbs. When the primary bushes were loaded between wheel loads of 11,000 and 15,000 lbs, the vertical spring rate increased to 60,000 lbs/inch measured at the average wheel load of 12,700 lbs.

Before the final series of vertical stiffness tests was conducted, the top primary bushings of the B-truck were also modified to the final configuration (Figure 3). The car was run for about four hours on the transit track, reaching speeds up to 70 mi/h, which enabled the primary bushings to set properly in the corresponding journals. A final series of stiffness tests, including the vertical spring rate, was performed on all primary bushings in both A- and B-trucks. In addition, the wheel liftoff loads were measured for both trucks, the data being tabulated below.

| Truck | Wheel Location | Wheel Liftoff Load |
|---|---|---|
| A | L1 & R1 | 14,500 lbs |
| A | L2 | 16,300 lbs |
| A | R2 | 12,600 lbs |
| B | R3 & L4 | 15,000 lbs |
| B | L3 & R4 | 14,000 lbs |

The final measured vertical deflection and spring rates of the primary bushings in the A-truck (Figures 12 and 13) averaged between 40,000 lbs/inch and 50,000 lbs/ inch measured over the 10,500 to 14,000 lbs wheel load range.

Figures 14 and 15 show the vertical deflection and spring rates of the modified primary bushings in the B-truck. The average spring rate measured at an average wheel load of 11,000 lbs was found to be 50,000 lbs/inch.

## LONGITUDINAL STIFFNESS TESTS

As described in the test procedures, the longitudinal stiffness of the used elastomer primary bushings was measured by floating the rear wheelset of the A-truck on air bearings and applying air brakes while the leading wheelset was supported on stationary blocks on the rails. Figure 16 shows the variation of longitudinal displacement of the floating wheelset versus longitudinal force per bushing. The longitudinal spring rate of the original primary bushings was found to be 165,000 lbs/inch. As expected, hysteresis was observed in the longitudinal spring rate characteristic.

Longitudinal stiffness tests were made again on the final configuration modification. Tests were also made on the B-truck which also had been subjected to final configuration modifications (longitudinal and vertical) similar to those of the A-truck bushings (Figures 1 and 3). The car had been run on the transit track for a few hours before repeating the final longitudinal stiffness tests on both trucks.

Figures 17 and 18 show the variation of longitudinal displacement of the wheelset versus longitudinal force per bushing for the A-truck with an average spring rate of 68,000 lbs/inch. Similar data in Figure 19 indicate a primary bushing longitudinal spring rate of 67,000 lbs/inch for the B-truck.

Figures 16 through 19 also show the longitudinal stiffness for the loading and unloading modes.

## LATERAL STIFFNESS TEST

For analysis purposes, it was assumed that the lateral load transmitted to each primary bushing was equivalent to one fourth of the total lateral load applied to the truck side frame. The lateral displacement of the side frame with respect to the stationary wheels on the rail was plotted against the total load applied to the side frame as shown in Figures 20 and 21 for front and rear axles, respectively. The average measured lateral stiffness of the individual primary bushes varied between 38,000 lbs/inch and 49,000 lbs/inch. The difference in lateral stiffness of the primary bushings is attributed to the lateral load experienced by each bushing not being exactly equal to one-fourth of the total lateral load. There may be some difference in the elastomer material parameters but these are assumed to be minor. Figure 22 shows the average displacement of the side frame with respect to the front and rear axles versus total lateral load applied to the side frame. The resultant average lateral stiffness of the primary bushings is around 44,000 lbs/inch. The average lateral stiffness was calculated in all cases using the formula:

$$K_L = \frac{\text{Total Lateral Load}}{4 \times \text{Average Lateral Displacement}}$$

After the bushings were modified to the final configuration, the lateral stiffness test was repeated up to a maximum lateral load of 5,000 lbs in 500 lb increments for both the A- and B-trucks. Figures 23 and 24 show how the side frame lateral displacement varies with the magnitude of the total lateral load for front and rear axles of the A-truck. The lateral stiffness of the modified bushings <u>increased in magnitude</u> due to the increased compression of the rubber in the middle portion of the top bushing under axle loading as a result of the removal of the elastomer material. This increased compression resulted in increased shear stiffness in the remaining elastomer.

Figures 25 and 26 show lateral displacement of the B-truck side frame as it varies with the applied lateral load.

For both A- and B-trucks, the primary bushings of the rear axles exhibited a greater increase in lateral stiffness than the primary bushings of the front axles. This again is attributed to unequal load sharing of the lateral load between axles. The following tabulation presents the lateral spring rates of primary suspension before and after modifications.

<u>Lateral Spring Rates</u>

| Location of Primary Bushes | Configuration of the Primary Bushings | |
|---|---|---|
| | Before Modification (lbs/inch) | After Modification (lbs/inch) |
| Front axle (A-truck) | 38,000 | 63,000 |
| Rear axle (A-truck) | 49,000 | 105,000 |
| A-truck average | 44,000 | 84,000 |
| Front axle (B-truck) | (not measured) | 66,000 |
| Rear axle (B-truck) | (not measured) | 90,000 |
| B-truck average | (not measured) | 78,000 |

Varied amounts of hysteresis in the lateral direction of the primary suspension before and after modification can be seen in Figures 20 through 26. In general, the lower the magnitude of the lateral stiffness of primary bushes, the higher the amount of hysteresis present in the spring rate characteristic.

## REVIEW

### Vertical Spring Rate

- The modifications in the top primary bushings reduced the vertical spring rate of the primary bushings from the original value of 180,000 lbs/inch to 40,000 lbs/inch measured at an average wheel load of 11,000 lbs.

### Longitudinal Spring Rate

- The modifications in the top elastomer bushings of the primary suspension reduced the longitudinal spring rate of the primary bushings from the original value of 165,000 lbs/inch to 68,000 lbs/inch.

- From the previous study conducted at the TTC under the MARTA Curving Program, it was evident that by removing elastomer material from both top and bottom bushings close to the primary bushing assembly horizontal axis (Figure 1), the longitudinal spring rate could be reduced from 150,000 lbs/inch to 50,000 lbs/inch. From the present study, it is evident that the longitudinal spring rate reduction could be achieved by modification of the top half of the rubber bushings as per final configuration (Figure 3) without any modification to the bottom half.

### Lateral Spring Rate

- Removal of elastomer material from the middle portion of the top half of the primary bushing to reduce the vertical spring rate resulted in certain side effects. The amount of compression of the top half of the rubber bushing for the same wheel load was increased by the modification. Apparently, the reduced thickness of elastomer in the compressed top half of the bushing increased the resistance to lateral shear and resulted in an increased lateral stiffness.

- The average lateral primary spring rate for the A-truck increased from 44,000 to 84,000 lbs/inch, an increase of approximately 90%.

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Data for this report were obtained and analyzed by Britto R. Rajkumar, Principal Engineer, Boeing Services International, Inc., Transportation Test Center, Pueblo, Colorado.

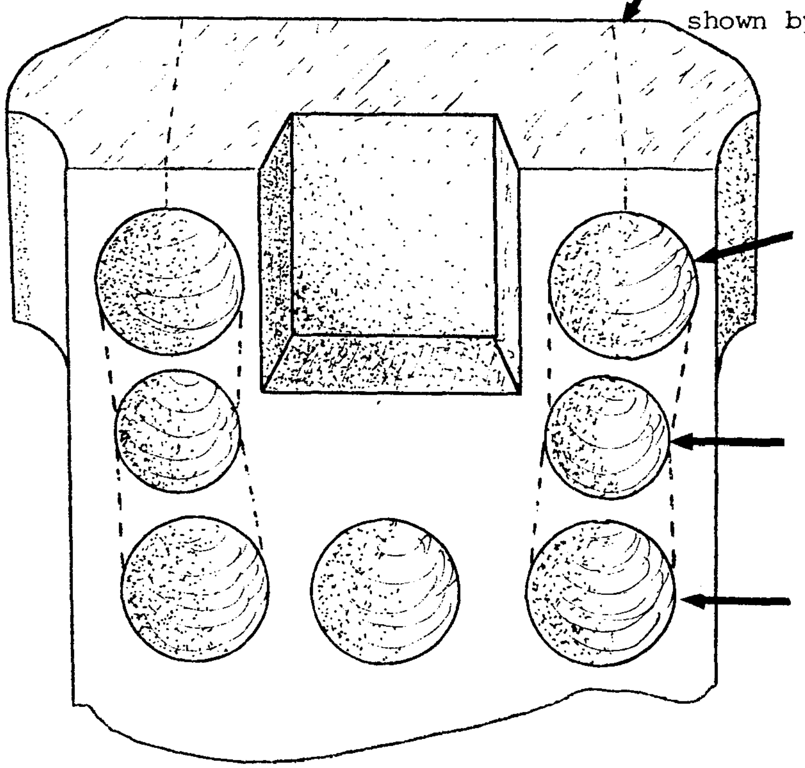



FIGURE 1. TOP HALF MODIFICATION OF BUSHINGS UNDER CURVING PERFORMANCE TESTS OF MARTA "A" and "B" CARS.

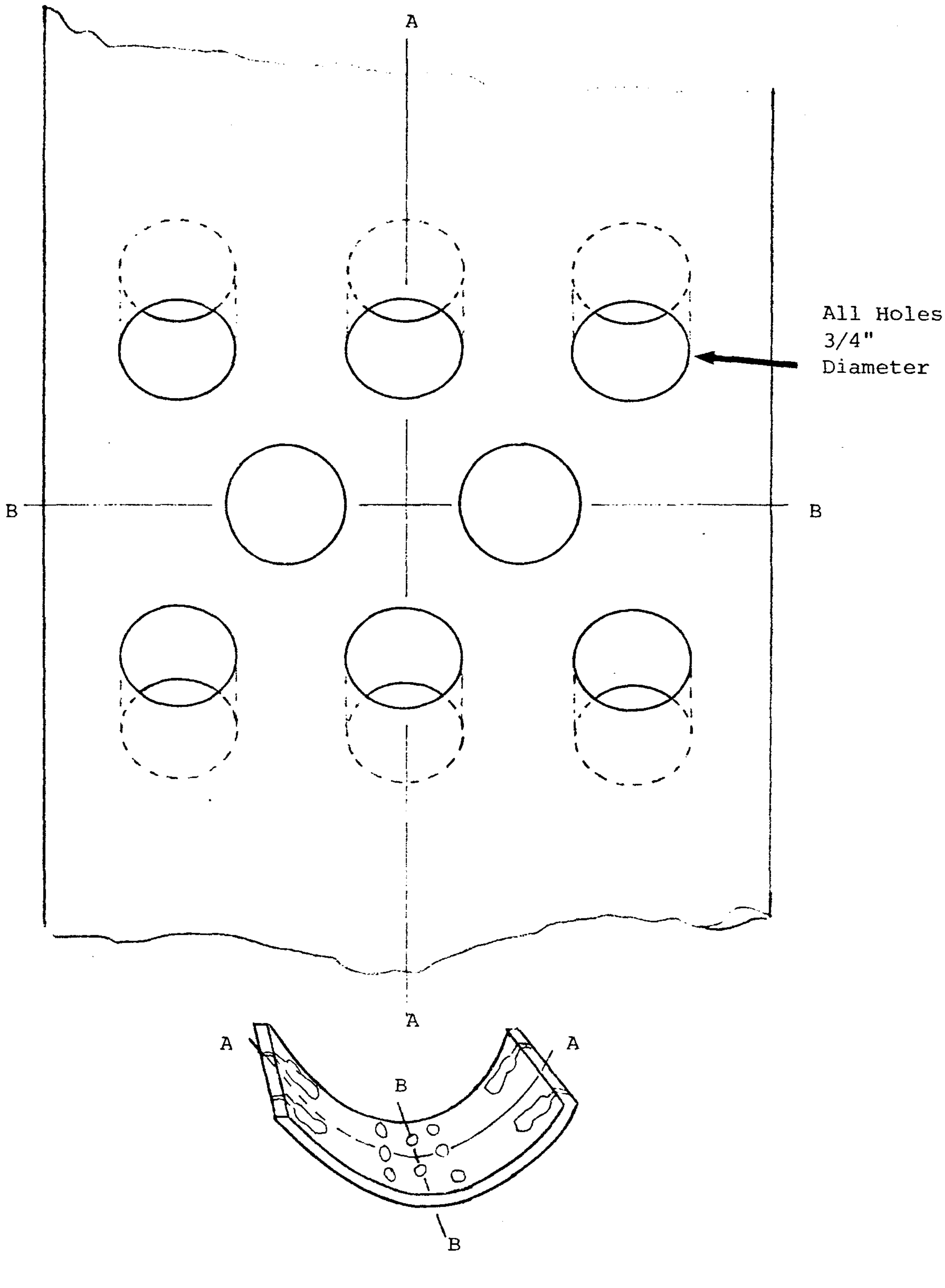



FIGURE 2. FIRST MODIFICATION OF PRIMARY TOP BUSHING.

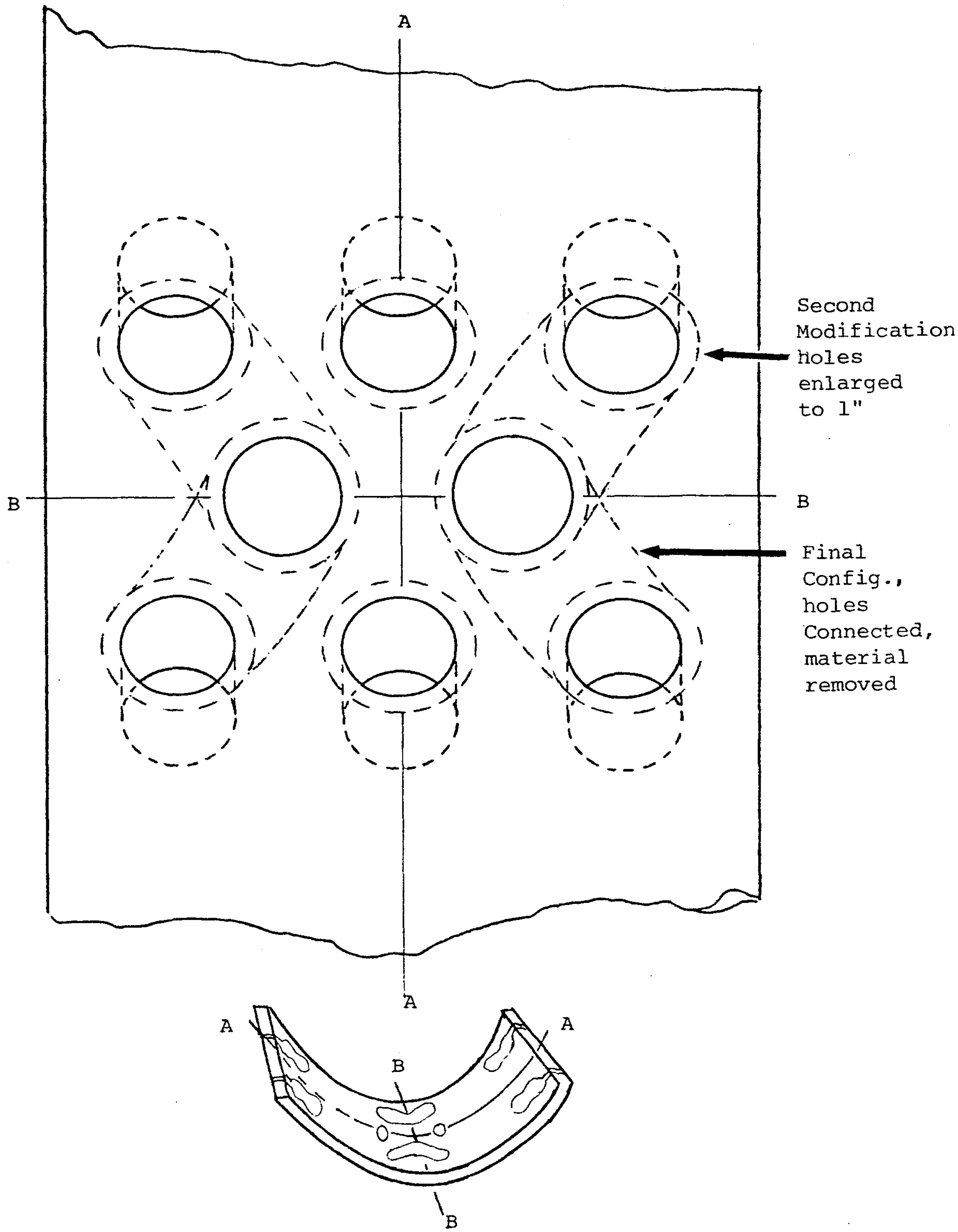



FIGURE 3. SECOND MODIFICATION AND FINAL CONFIGURATION OF PRIMARY TOP BUSHING.

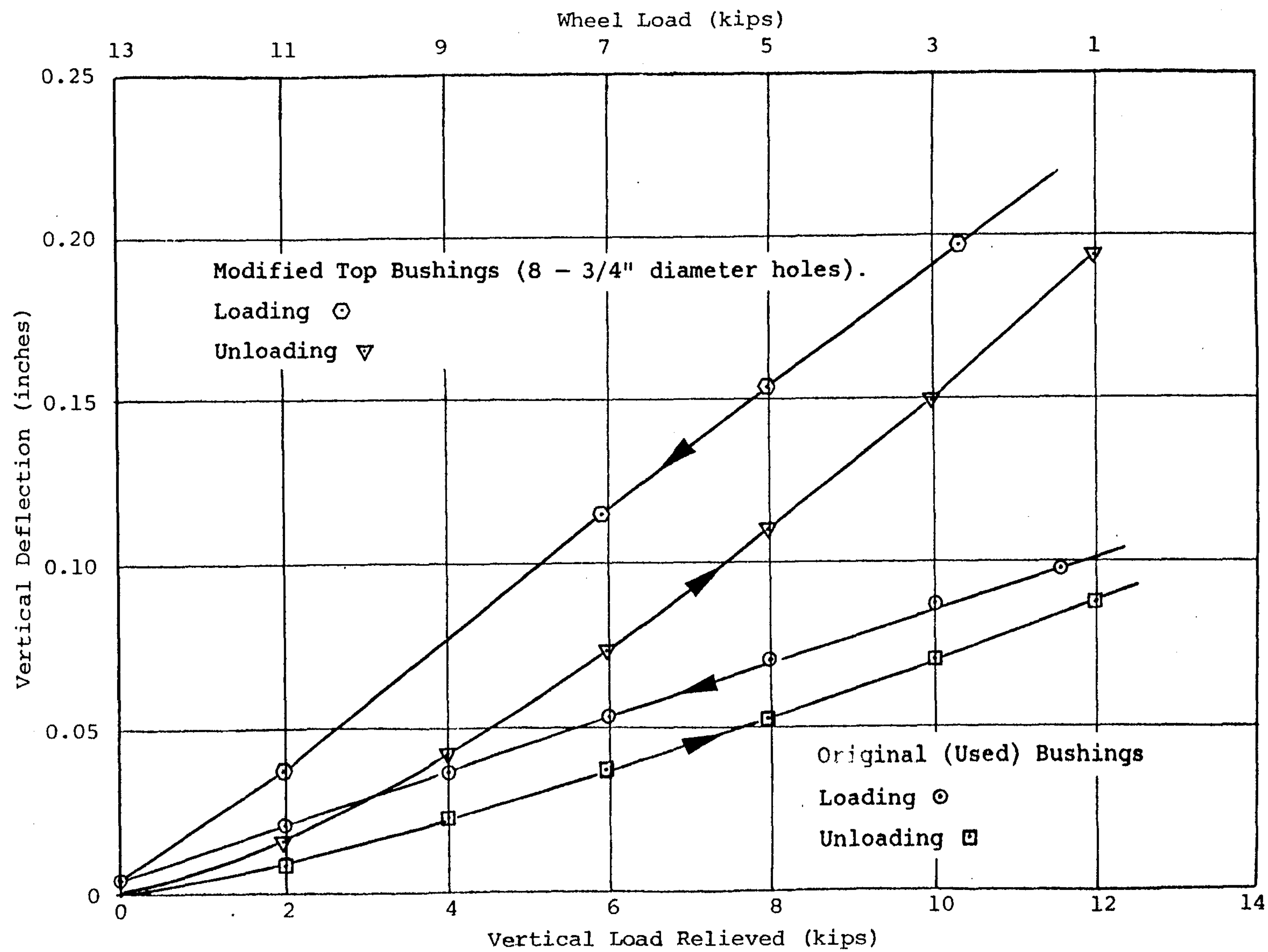



FIGURE 4. VERTICAL DEFLECTION VS WHEEL LOAD, ORIGINAL AND MODIFIED BUSHINGS, A-TRUCK AT AW2 LOADING.

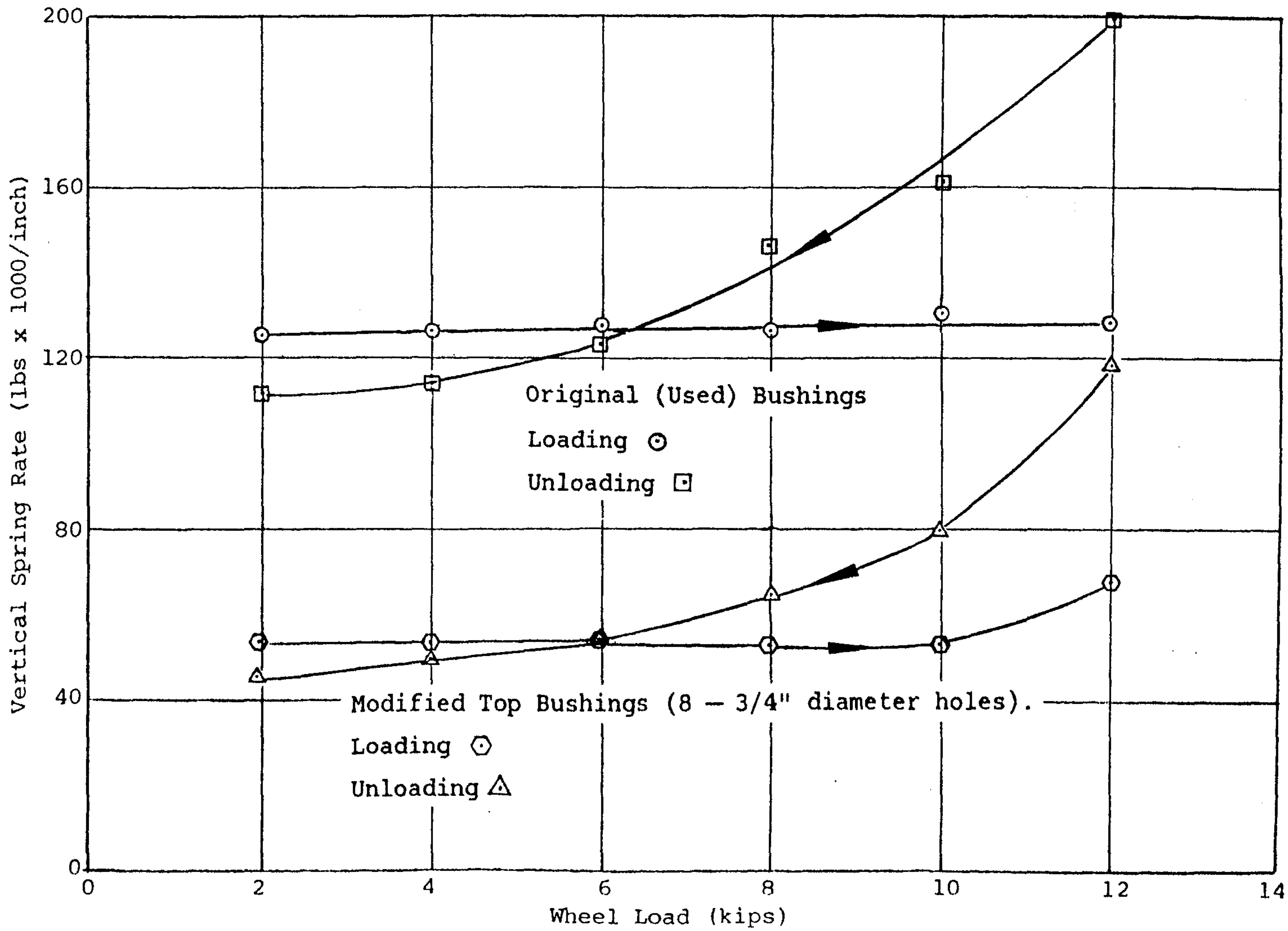



FIGURE 5. VERTICAL SPRING RATE OF PRIMARY BUSHINGS, ORIGINAL AND MODIFIED, A-TRUCK WITH AW2 LOADING.

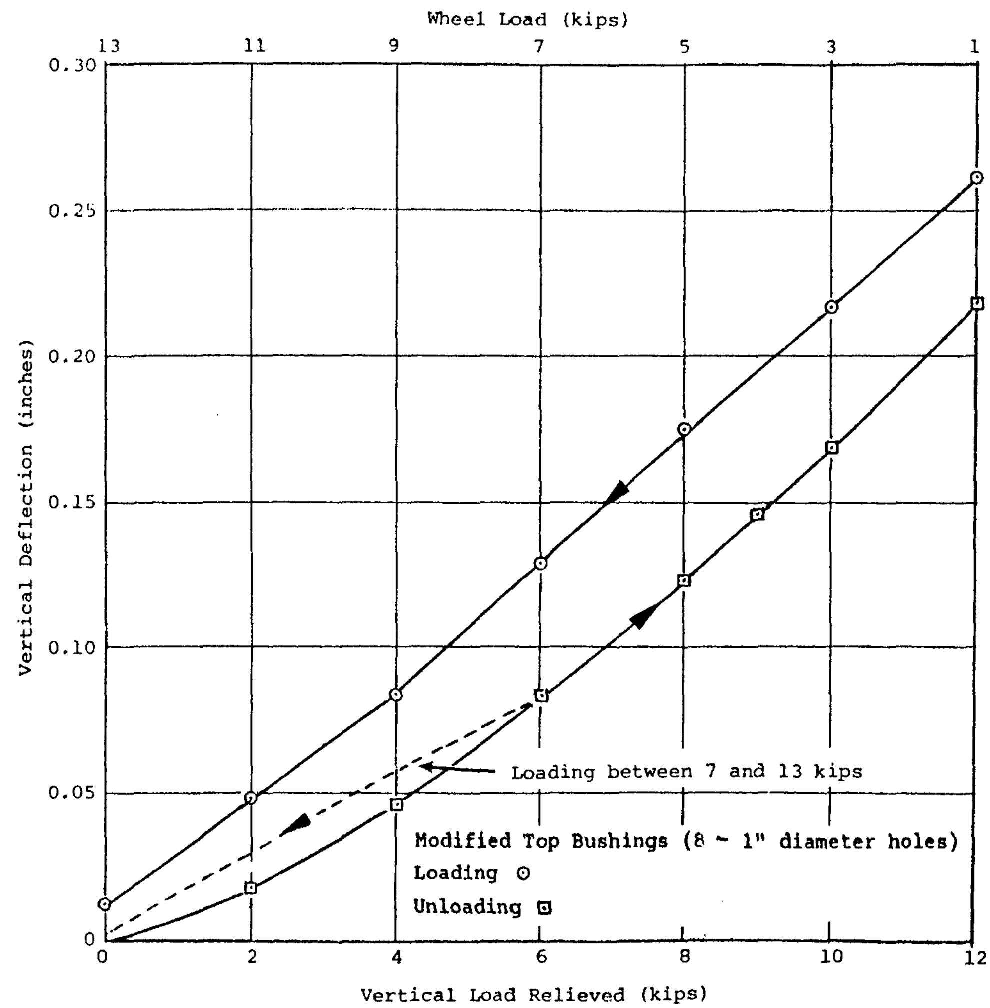



FIGURE 6. VERTICAL DEFLECTION OF MODIFIED PRIMARY TOP BUSHINGS, A-TRUCK AT AW2 LOADING.

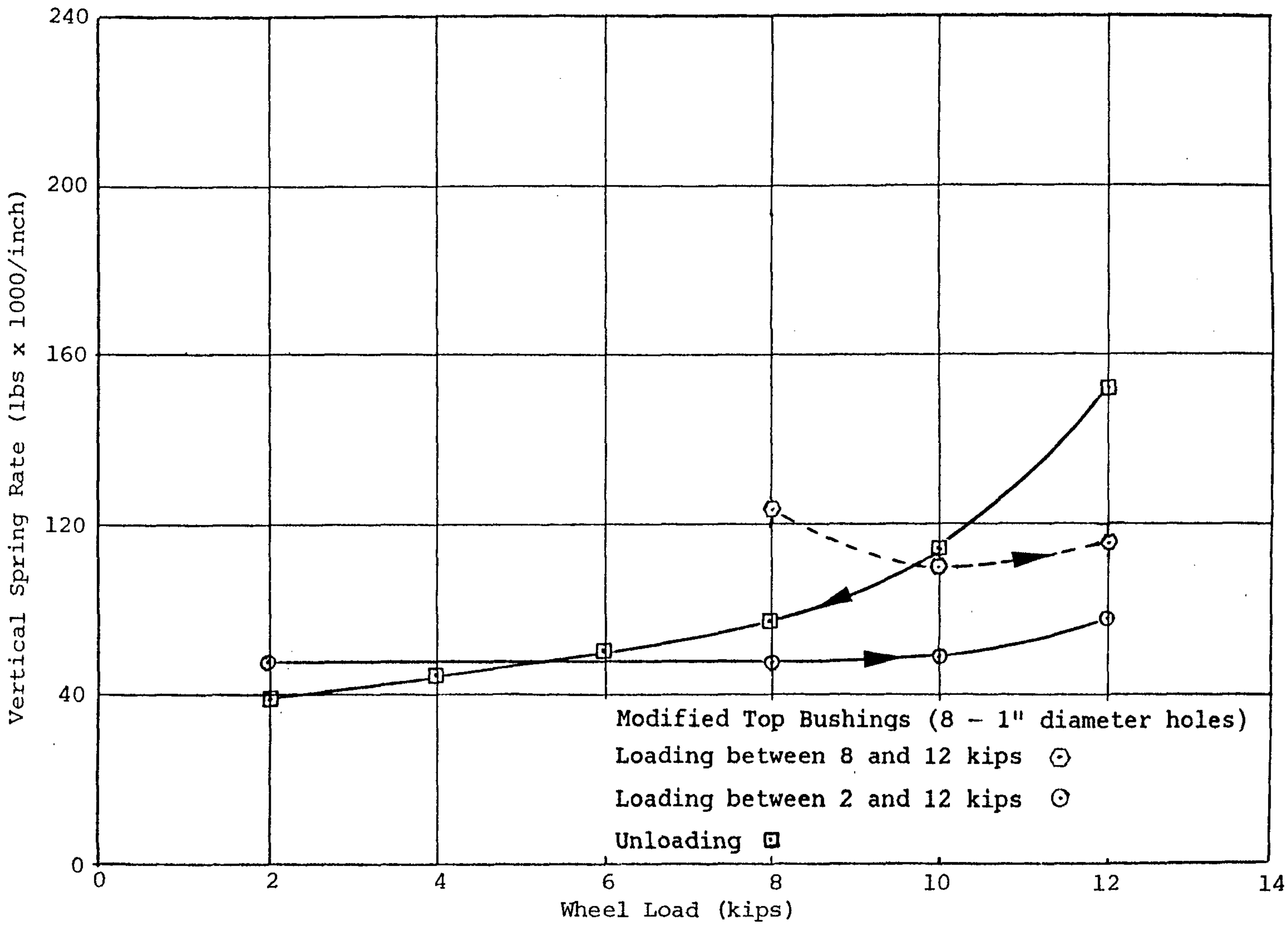



FIGURE 7. VERTICAL SPRING RATE OF MODIFIED PRIMARY TOP BUSHINGS, A-TRUCK AT AW2 LOADING.

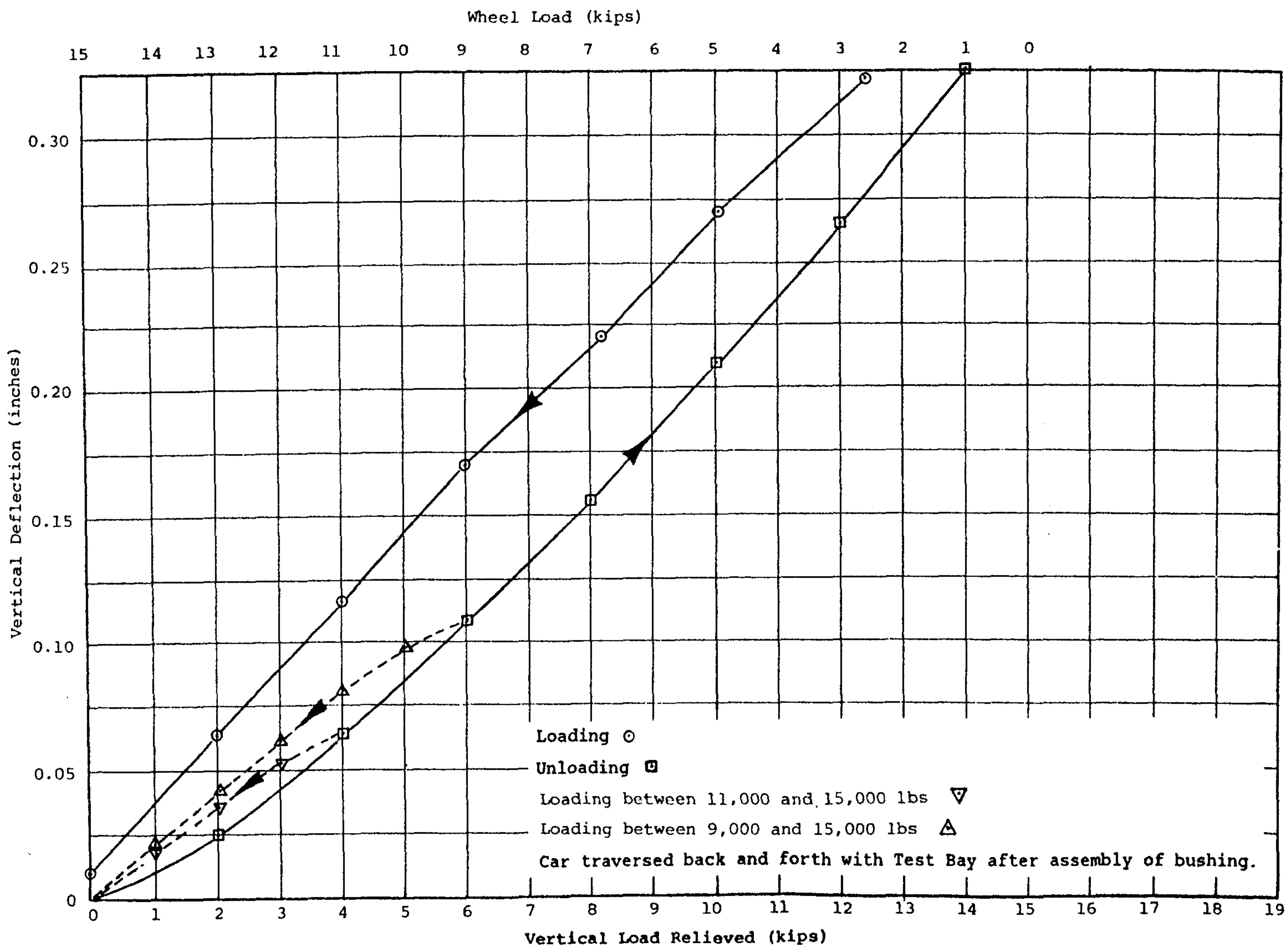



FIGURE 8. VERTICAL DEFLECTION OF FINAL CONFIGURATION BUSHINGS, A-TRUCK UNDER AW2 LOADING.

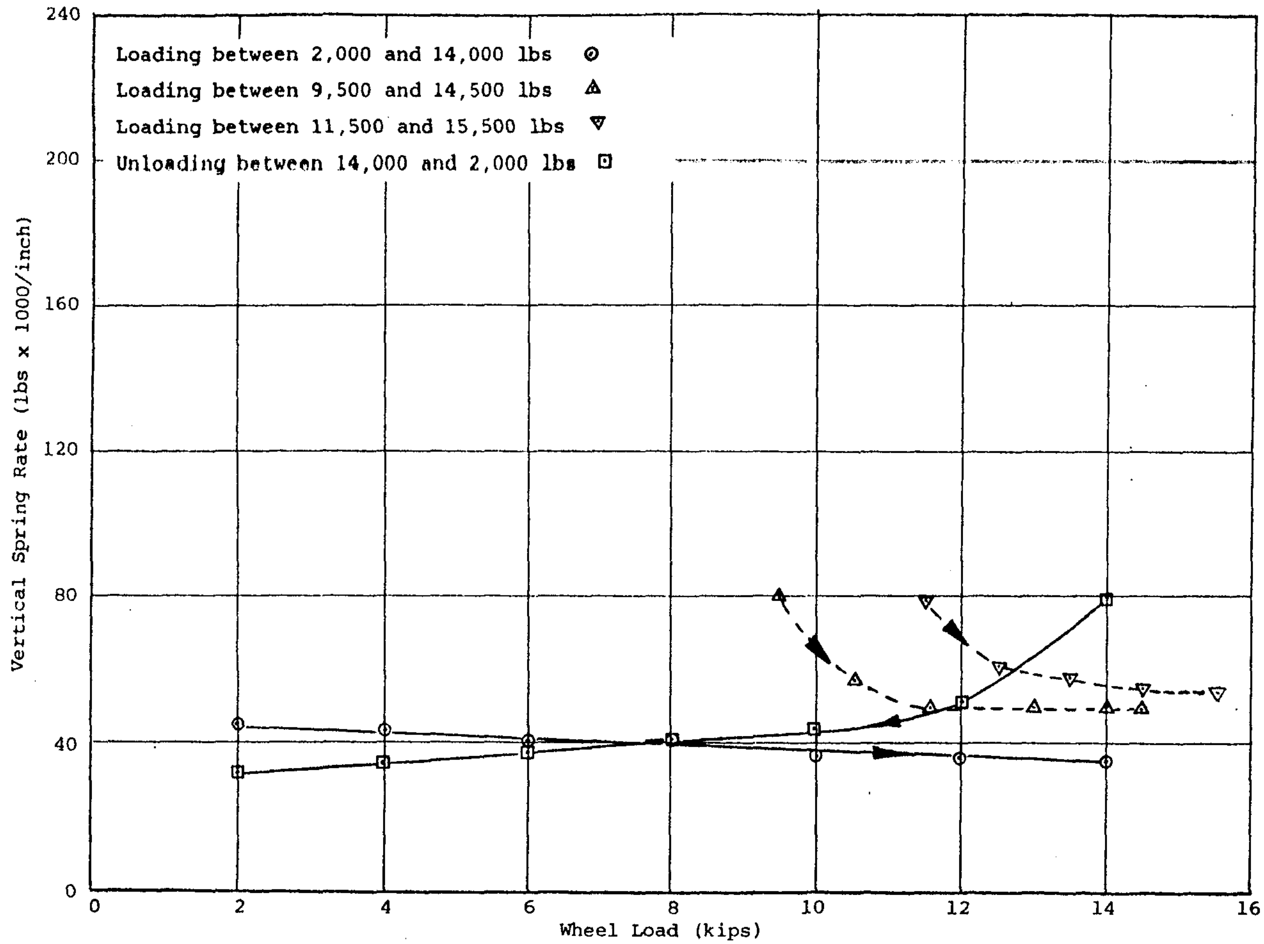



FIGURE 9. VERTICAL PRIMARY SPRING RATE OF FINAL CONFIGURATION BUSHINGS, A-TRUCK UNDER AW2 LOADING.

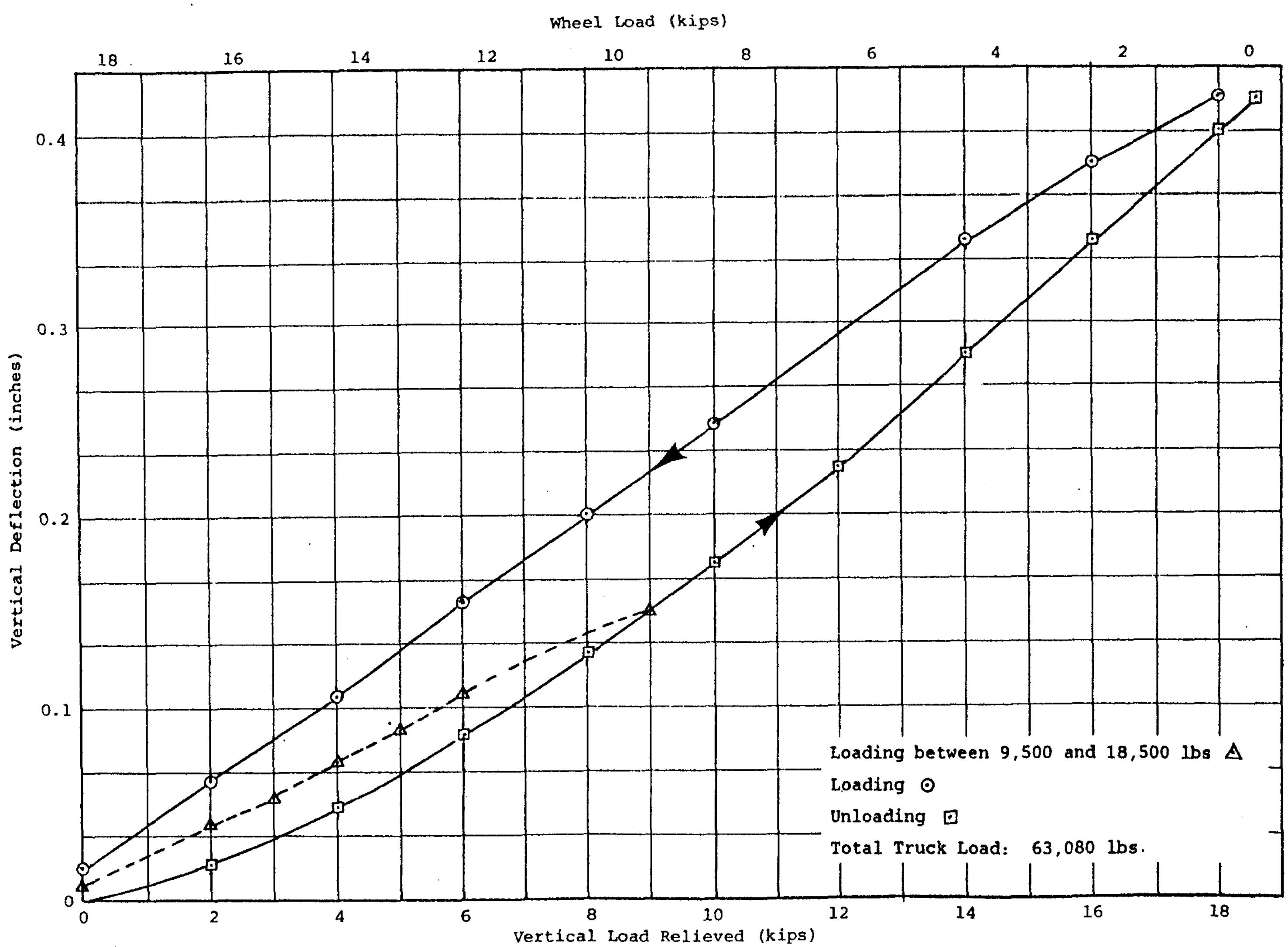



FIGURE 10. VERTICAL DEFLECTION OF FINAL CONFIGURATION BUSHINGS, A-TRUCK (AW3 LOADING).

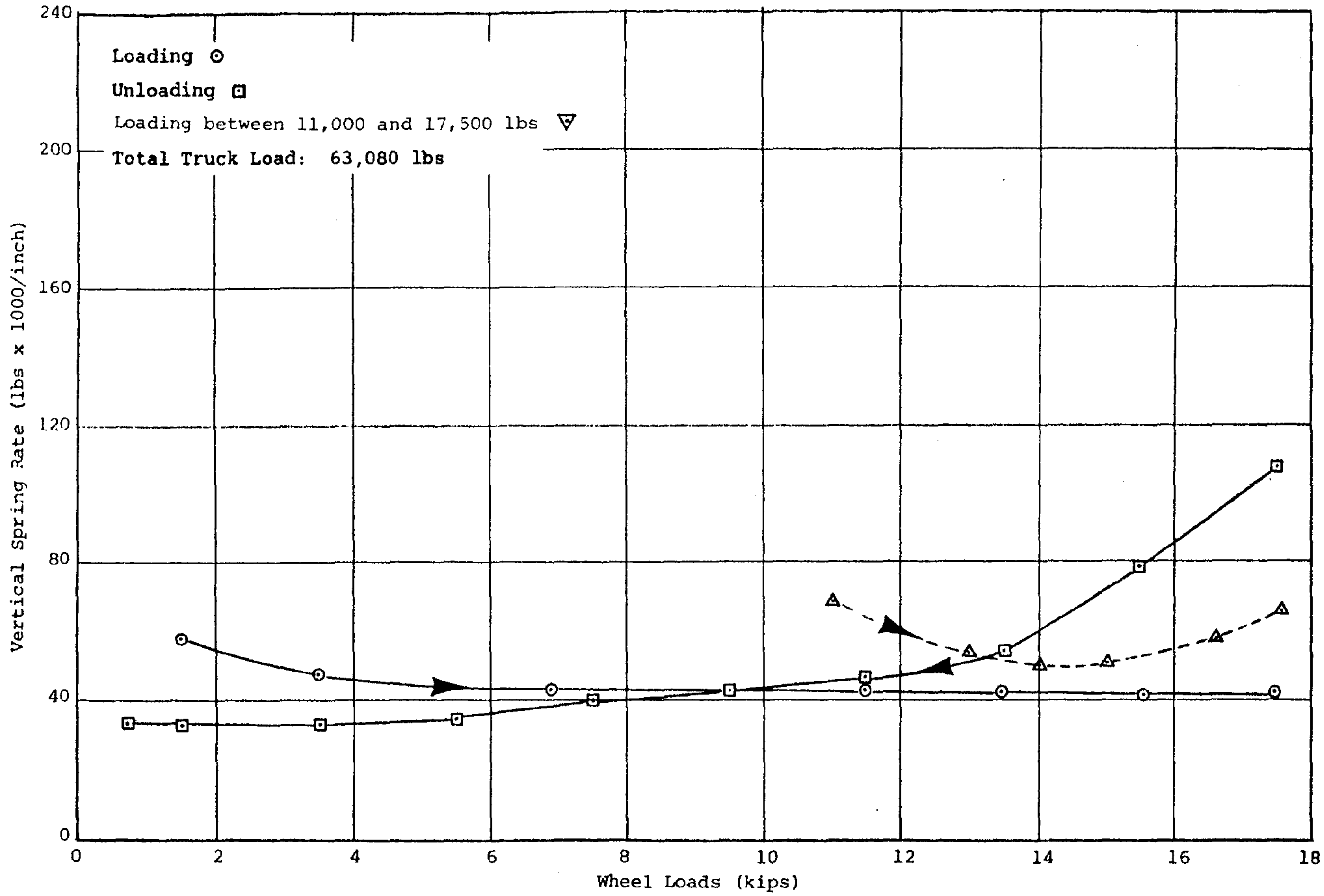



FIGURE 11. VERTICAL PRIMARY SPRING RATE OF FINAL CONFIGURATION BUSHINGS, A-TRUCK (AW3 LOADING).

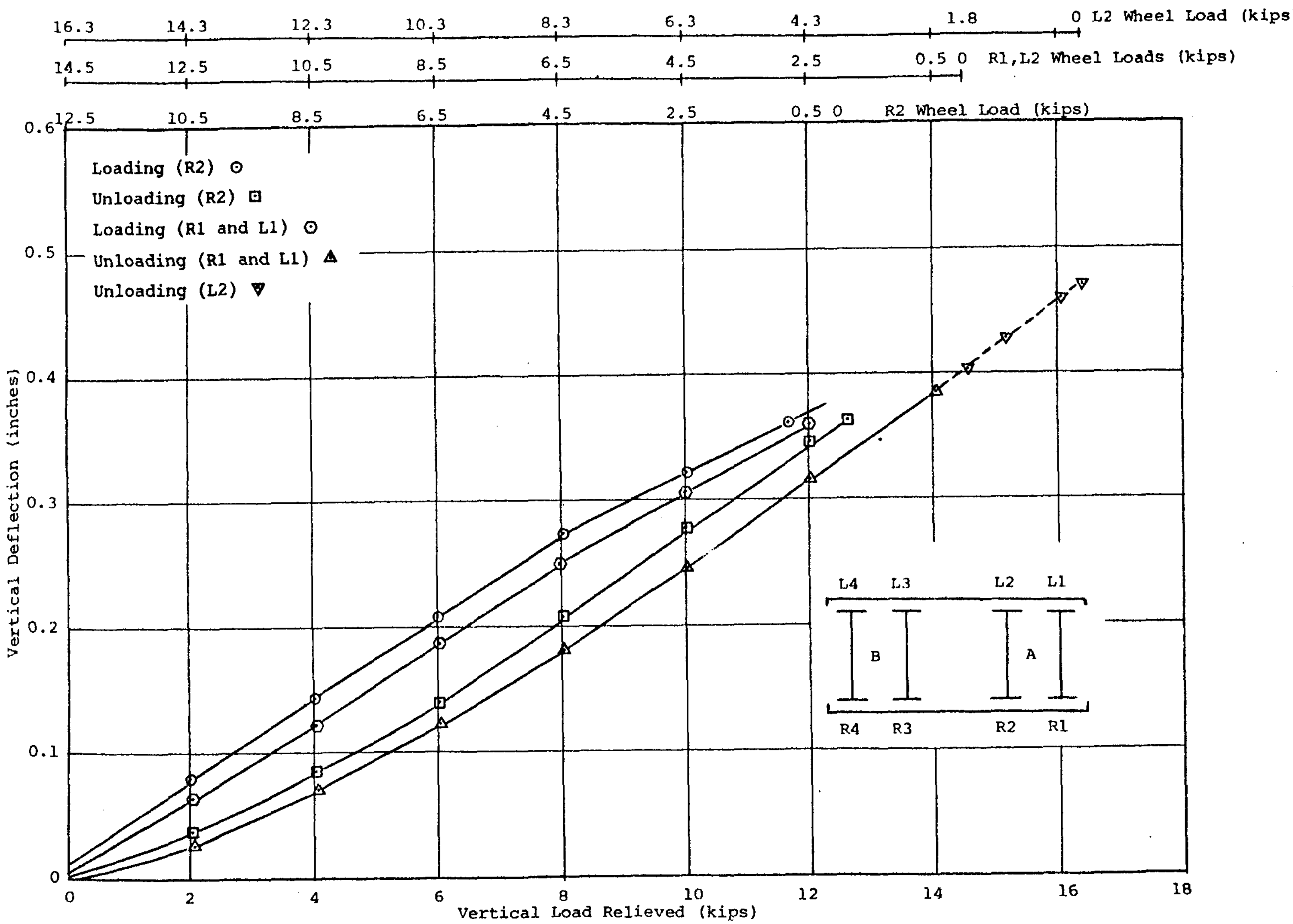



FIGURE 12. VERTICAL DEFLECTION, A-TRUCK AFTER FOUR HOURS RUNNING, AW2 LOADING.

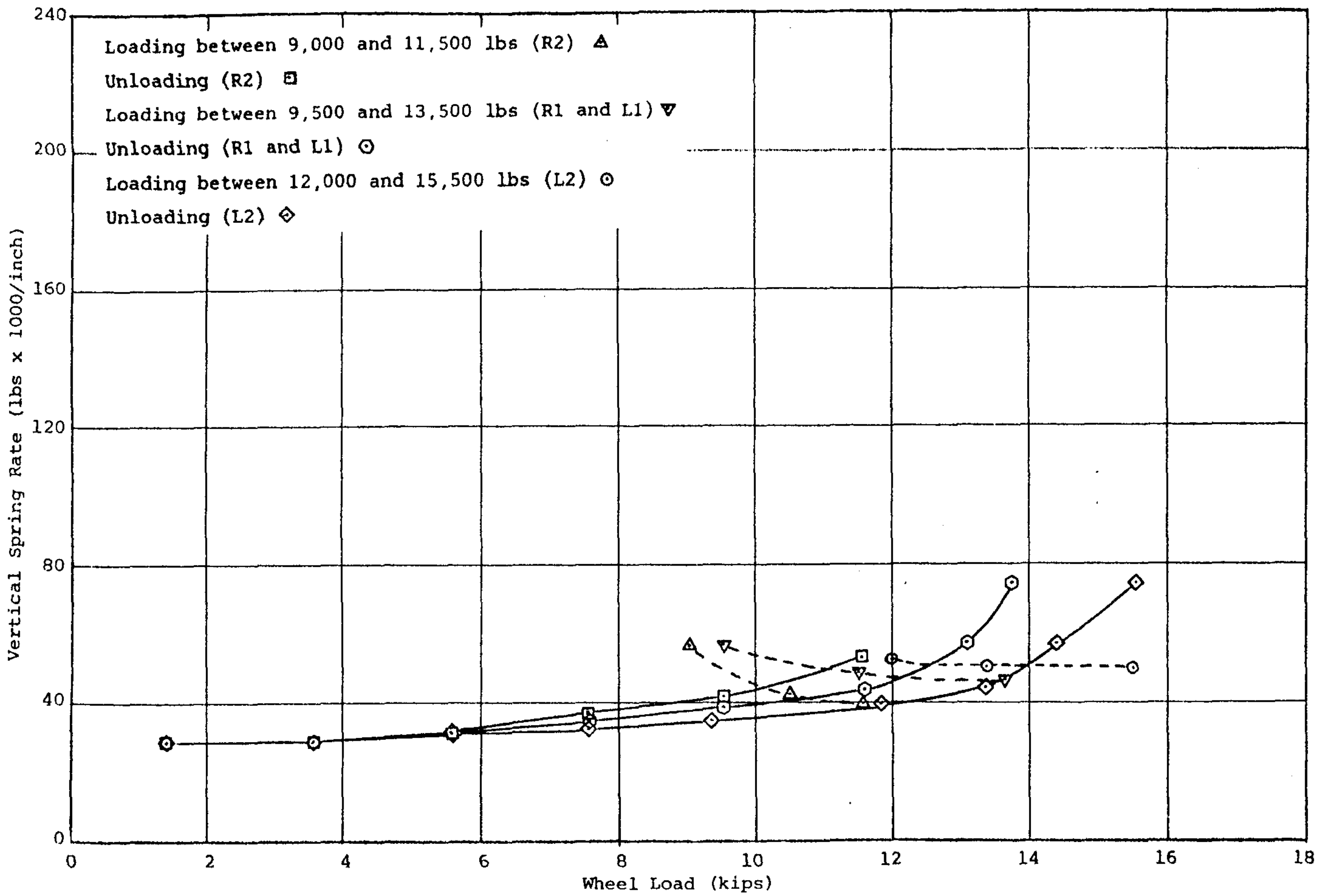



FIGURE 13. PRIMARY VERTICAL SPRING RATE, A-TRUCK AFTER FOUR HOURS RUNNING, AW2 LOADING.

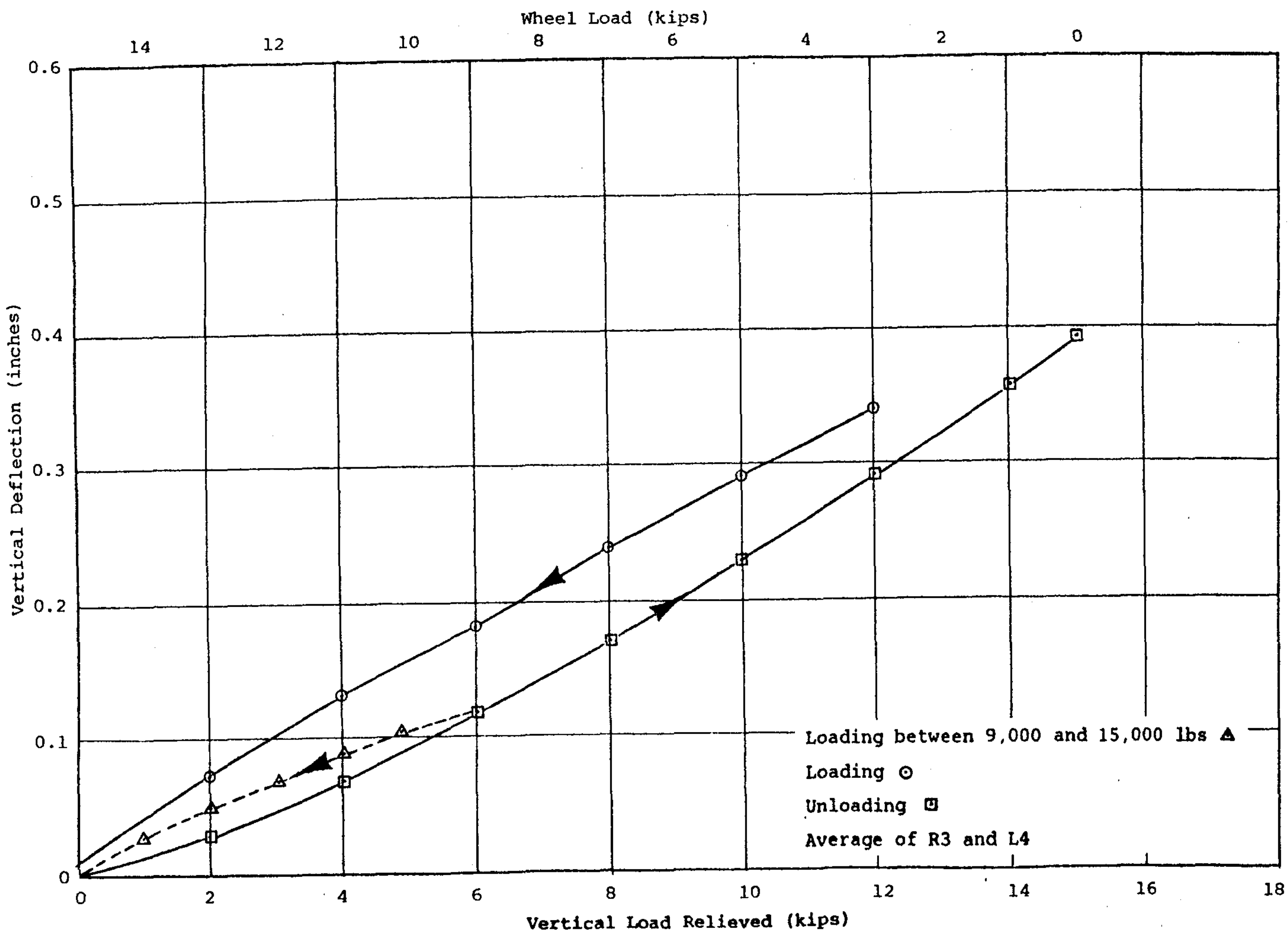



FIGURE 14. VERTICAL DEFLECTION, B-TRUCK AFTER FOUR HOURS RUNNING, AW2 LOADING.

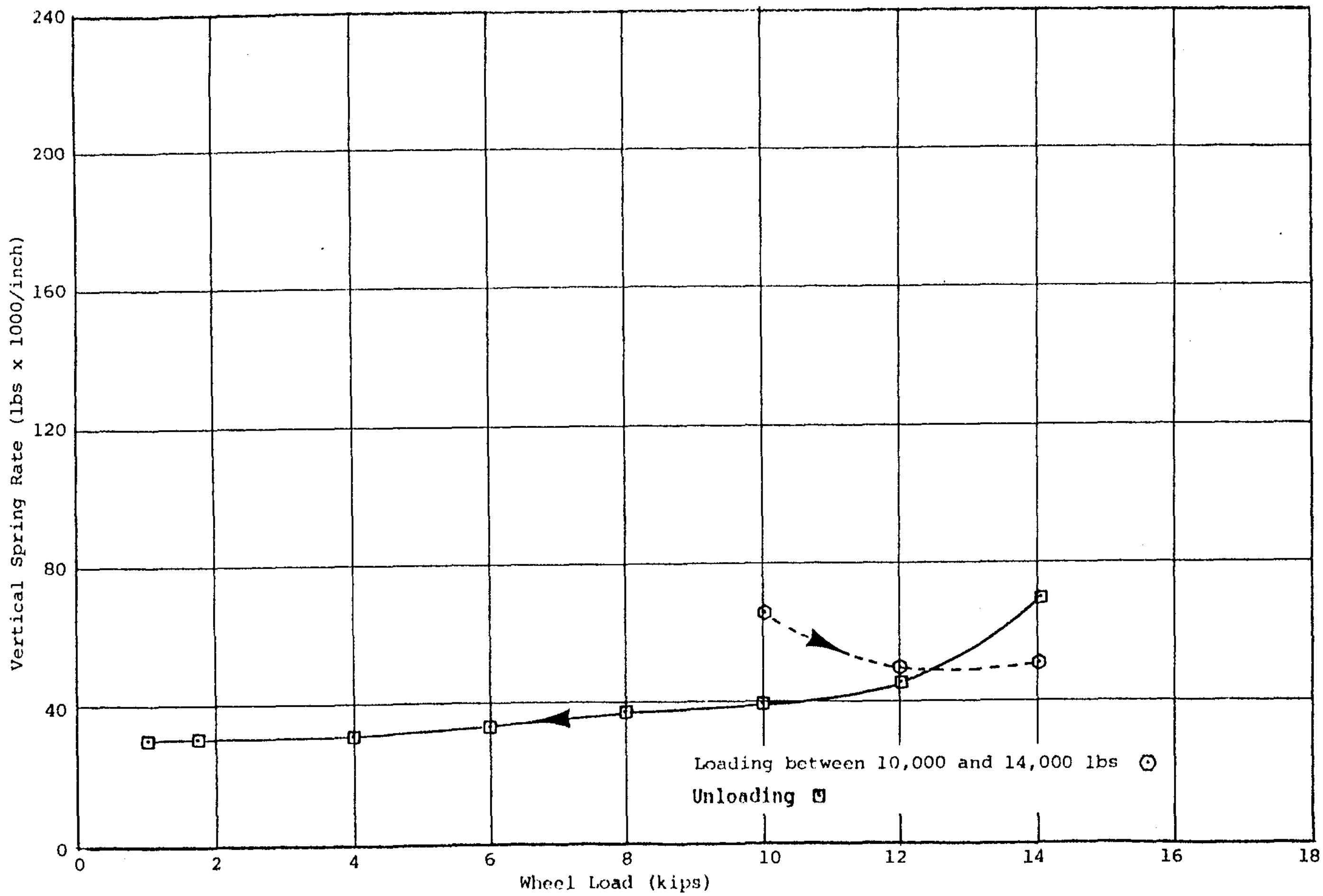



FIGURE 15. PRIMARY VERTICAL SPRING RATE, B-TRUCK AFTER FOUR HOURS RUNNING, AW2 LOADING.

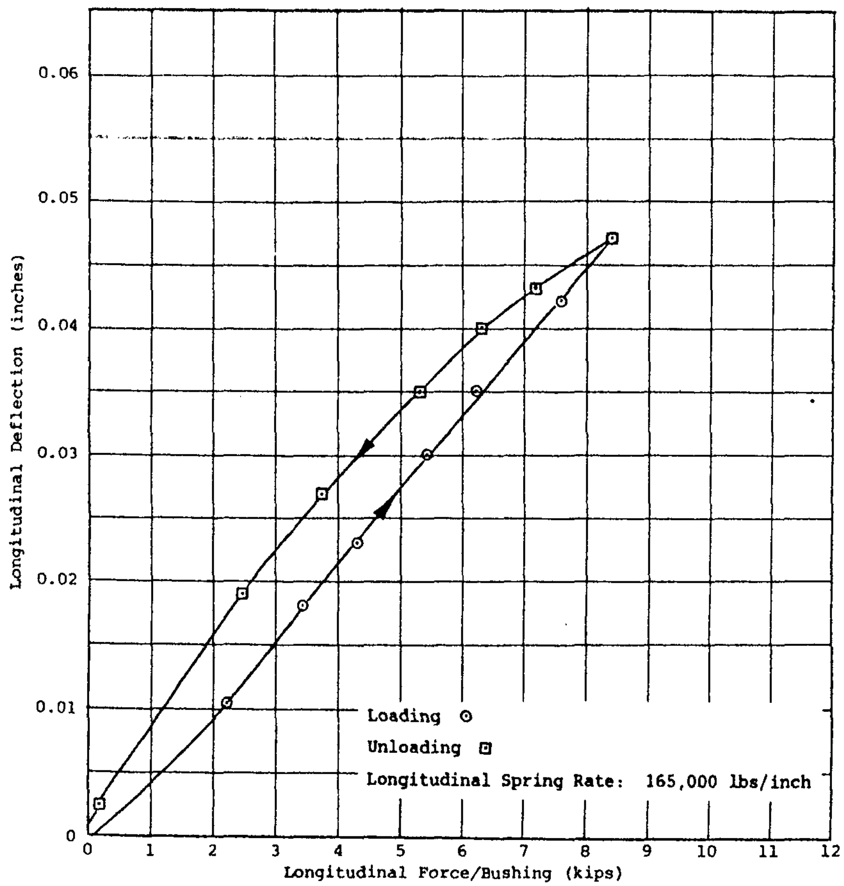



FIGURE 16. LONGITUDINAL DEFLECTION OF ORIGINAL (USED) BUSHINGS A-TRUCK REAR AXLE (L2 and R2 AVERAGE).

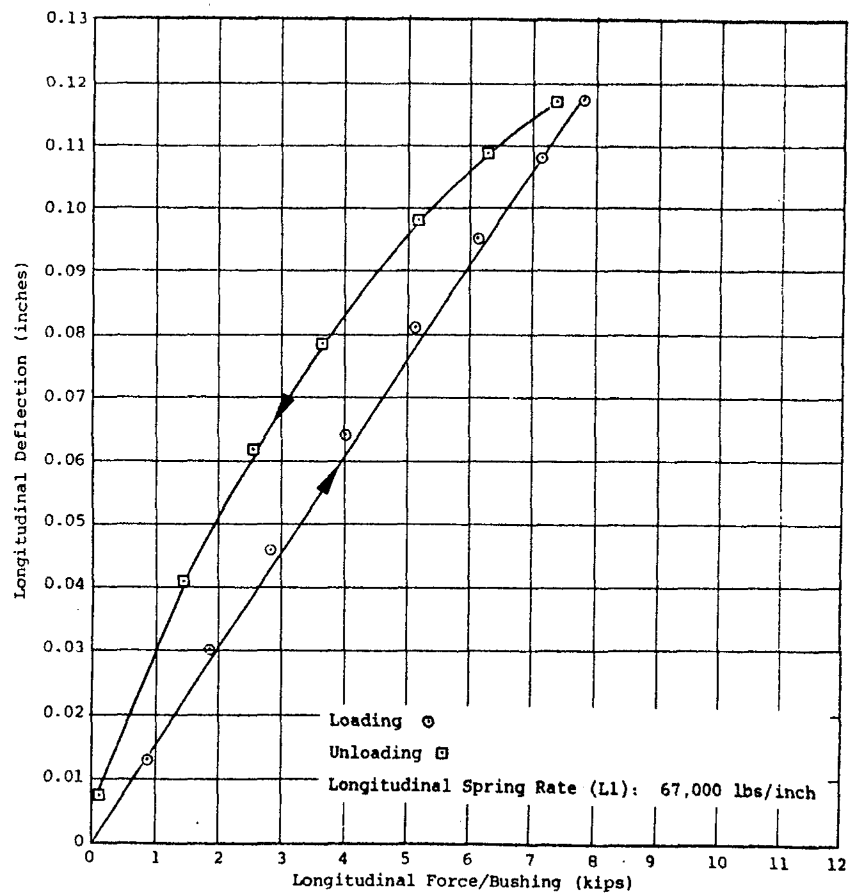



FIGURE 17. LONGITUDINAL DEFLECTION OF MODIFIED TOP BUSHINGS, A-TRUCK FRONT AXLE FLOATING.

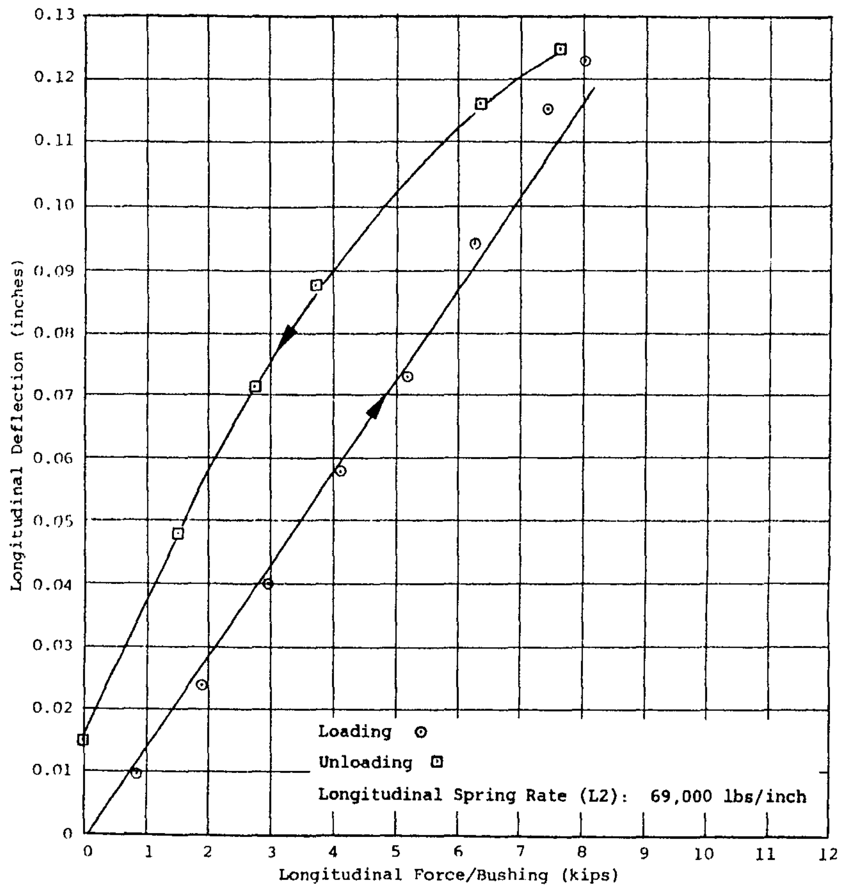



FIGURE 18. LONGITUDINAL DEFLECTION OF MODIFIED TOP BUSHINGS, A-TRUCK REAR AXLE FLOATING.

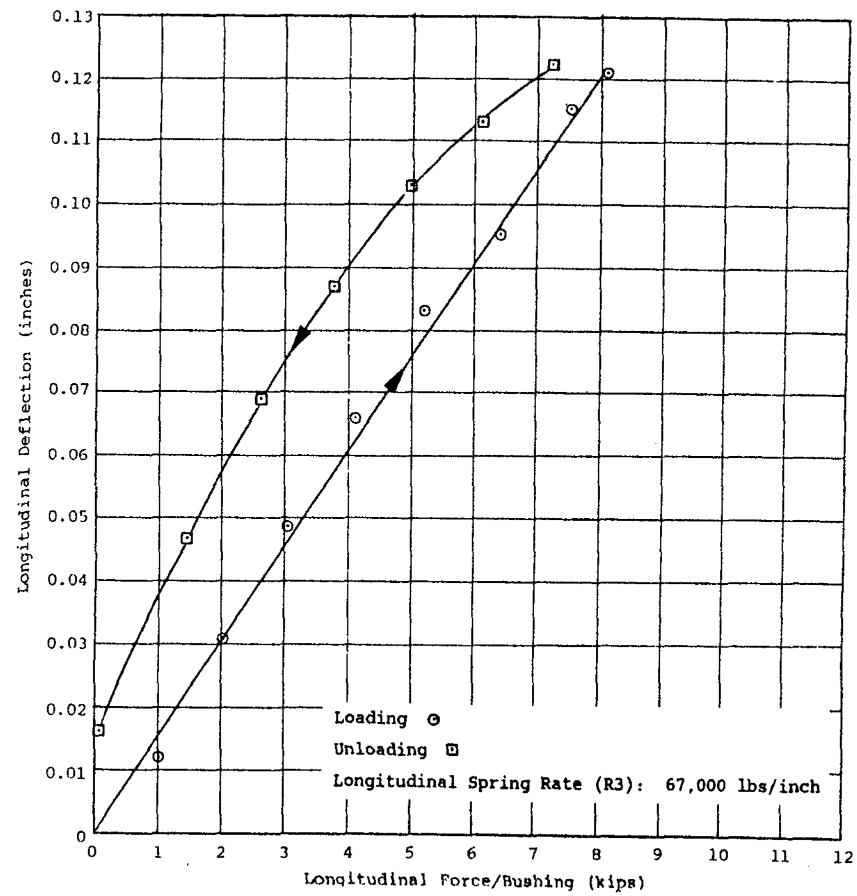



FIGURE 19. LONGITUDINAL DEFLECTION OF MODIFIED TOP BUSHINGS, B-TRUCK FRONT AXLE FLOATING.

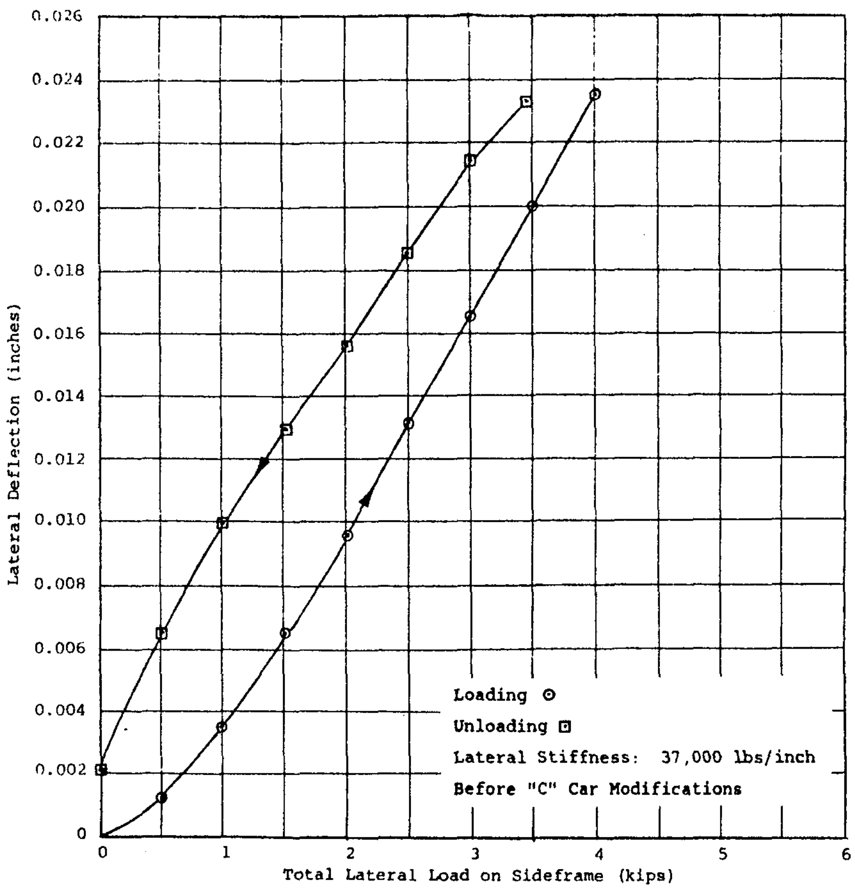



FIGURE 20. LATERAL STIFFNESS TEST, A-TRUCK, LEAD AXLE LEFT (L1).

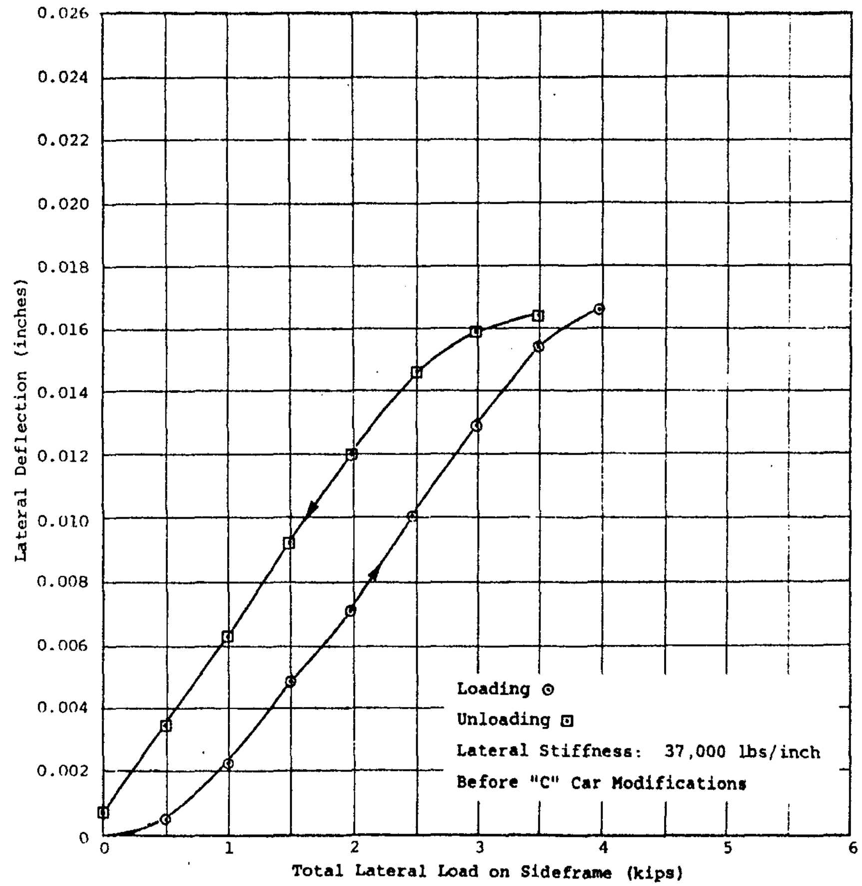



FIGURE 21. LATERAL STIFFNESS TEST, A-TRUCK, REAR AXLE RIGHT (R2).

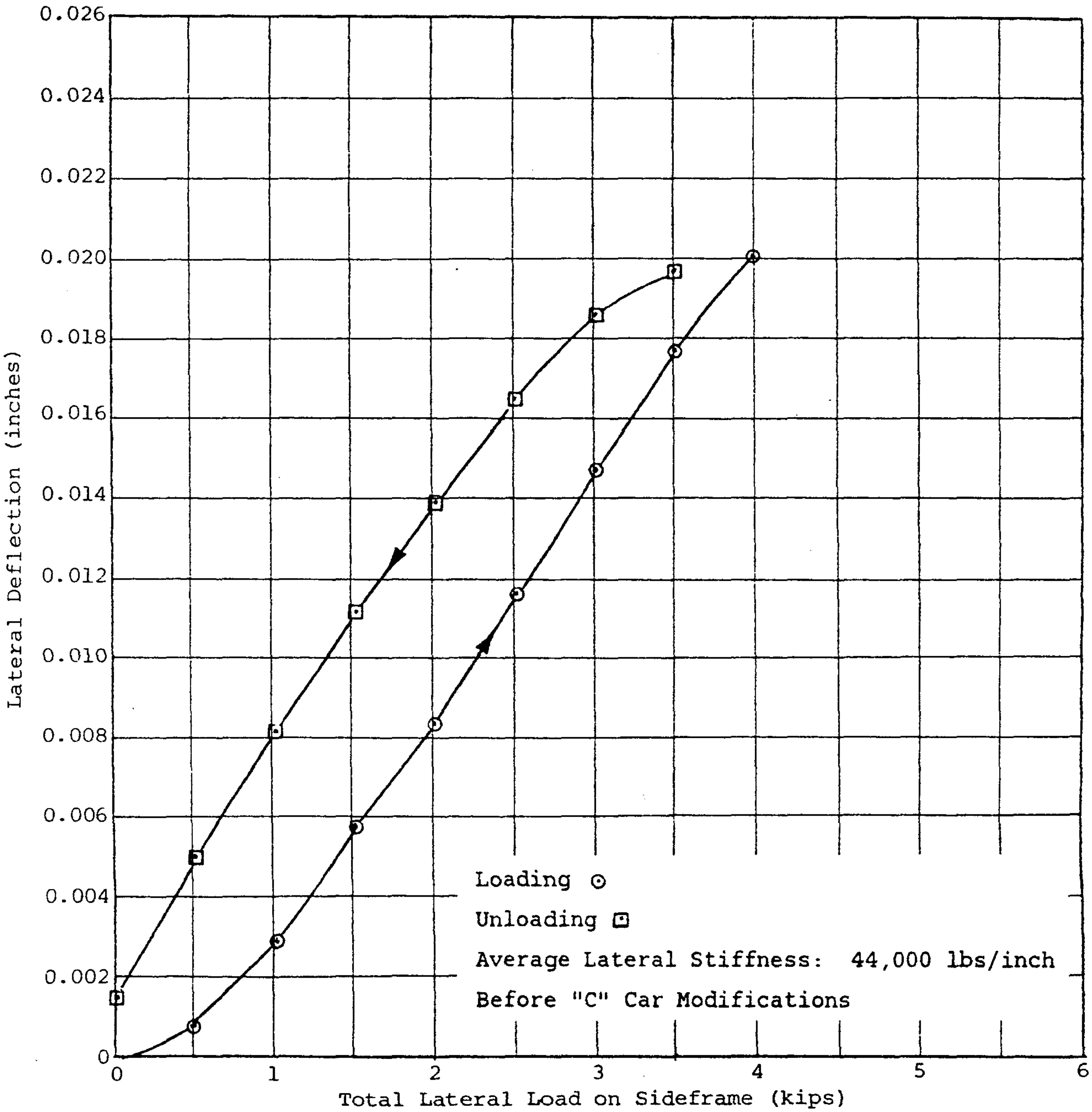



FIGURE 22. AVERAGE DEFLECTION OF SIDE FRAME WITH RESPECT TO L2 and R2.

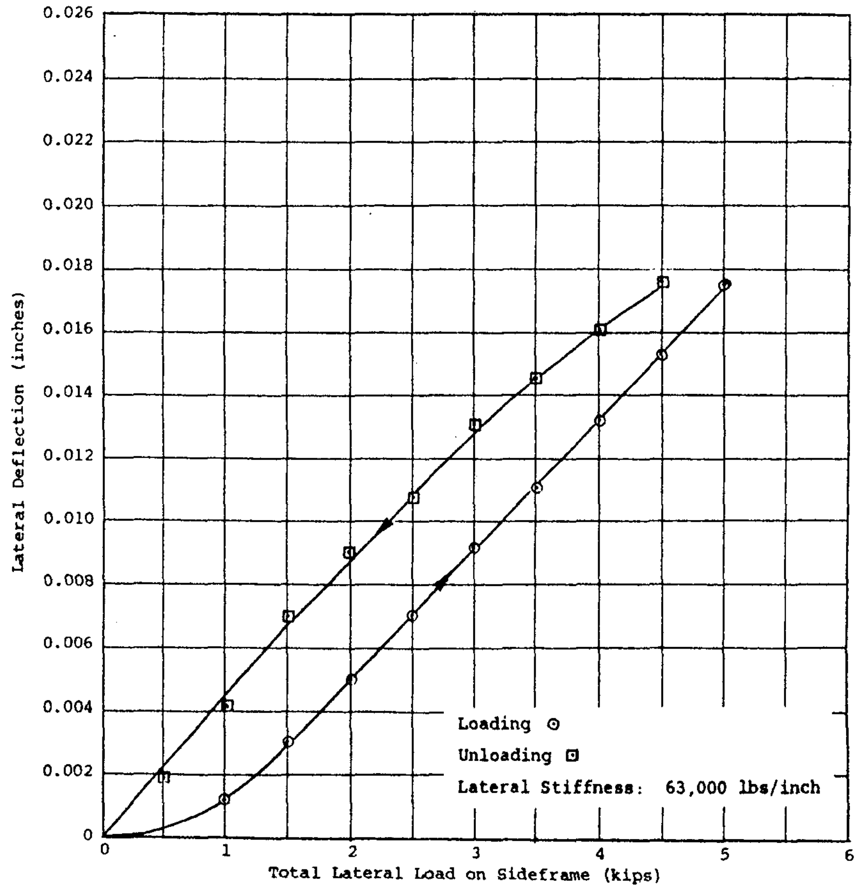



FIGURE 23. LATERAL DEFLECTION OF FINAL BUSHING CONFIGURATION, A-TRUCK LEAD AXLE LEFT (L1).

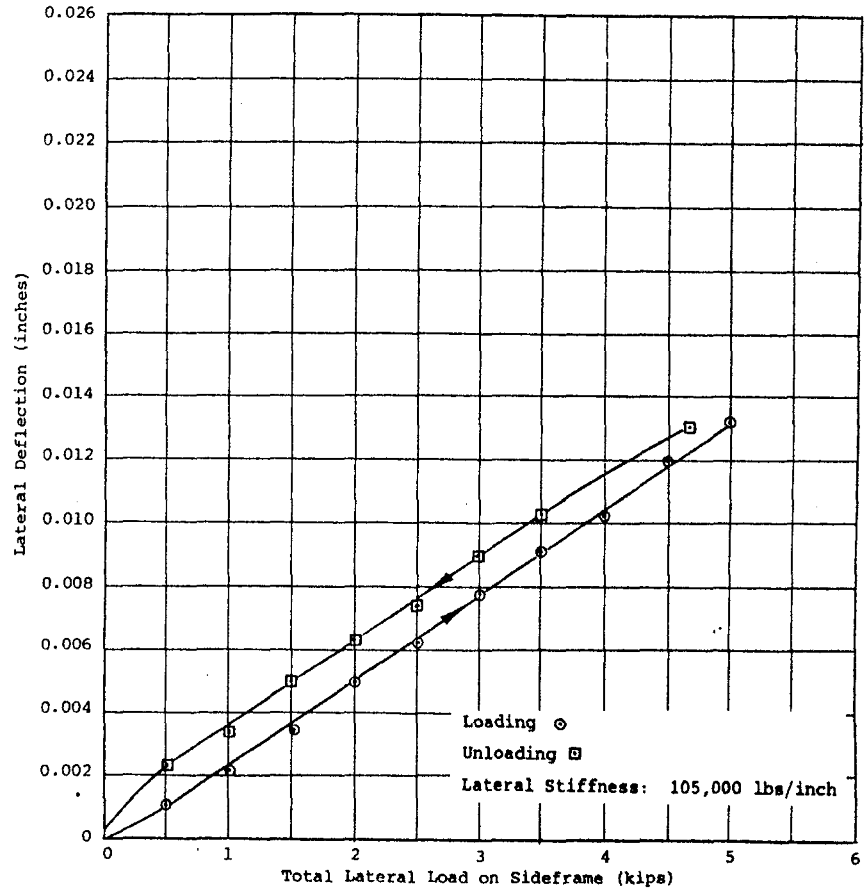



FIGURE 24. LATERAL DEFLECTION OF FINAL BUSHING CONFIGURATION, A-TRUCK REAR AXLE RIGHT (R2).

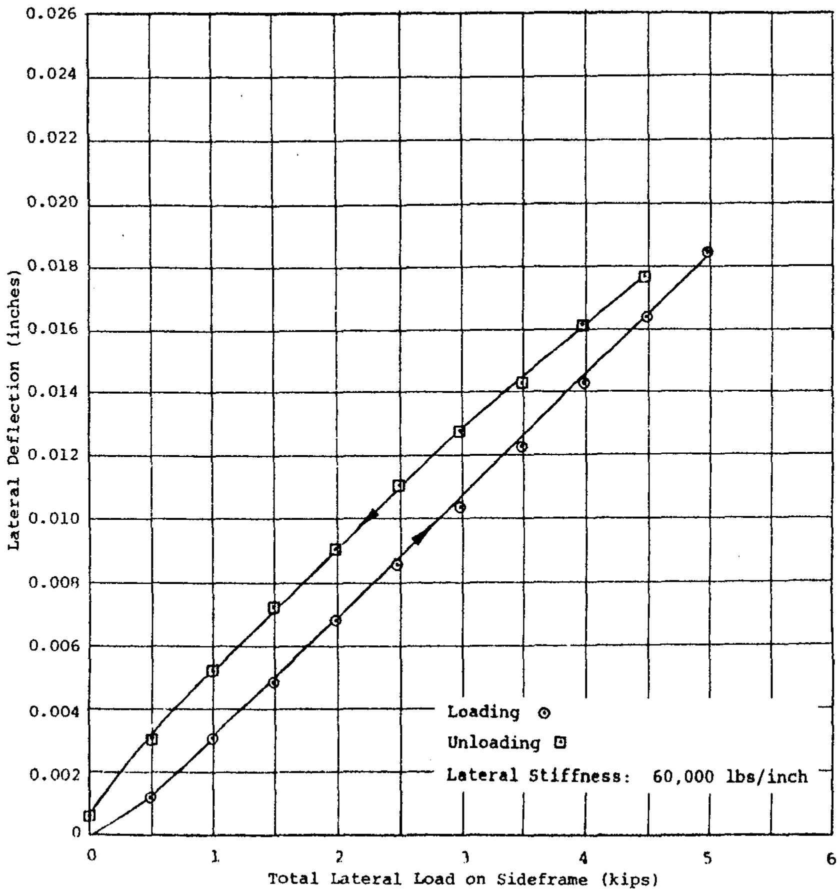



FIGURE 25. LATERAL DEFLECTION OF FINAL BUSHING CONFIGURATION, B-TRUCK FRONT AXLE LEFT (L3).

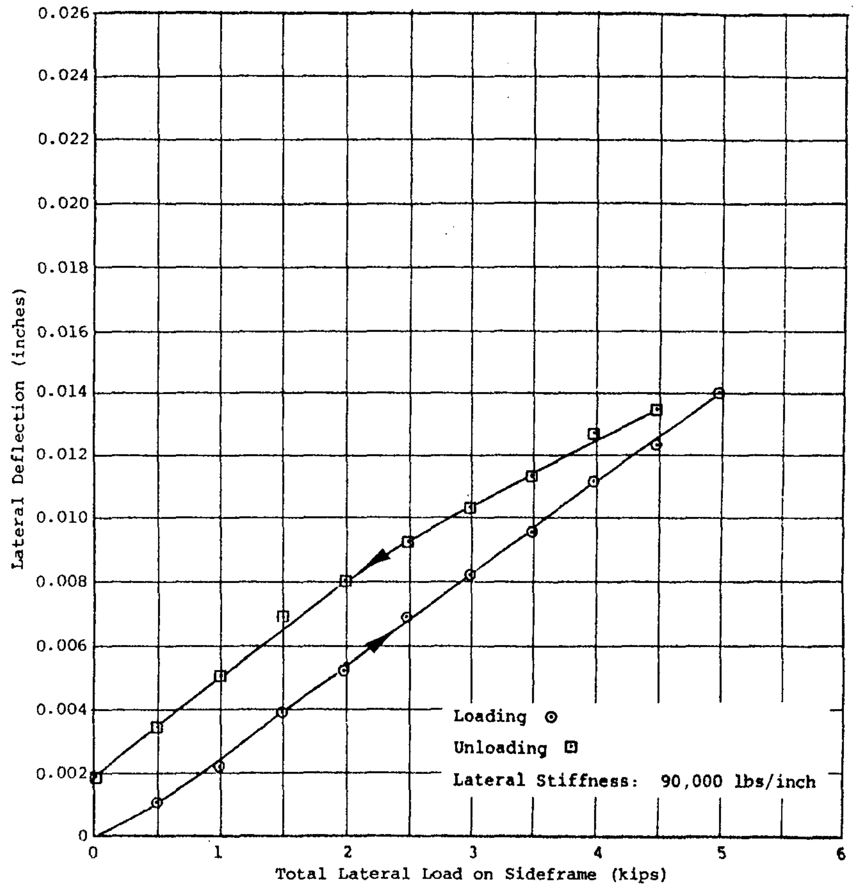
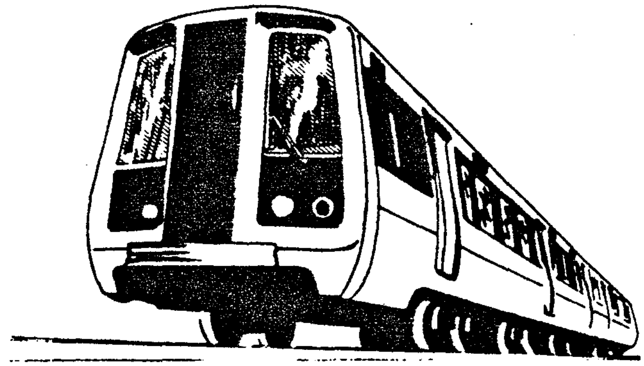



FIGURE 26. LATERAL DEFLECTION OF FINAL BUSHING CONFIGURATION, B-TRUCK REAR AXLE RIGHT (R4).

# TECHNICAL NOTE

U.S. Department of Transportation

**Urban Mass Transportation Administration**



TRANSPORTATION TEST CENTER

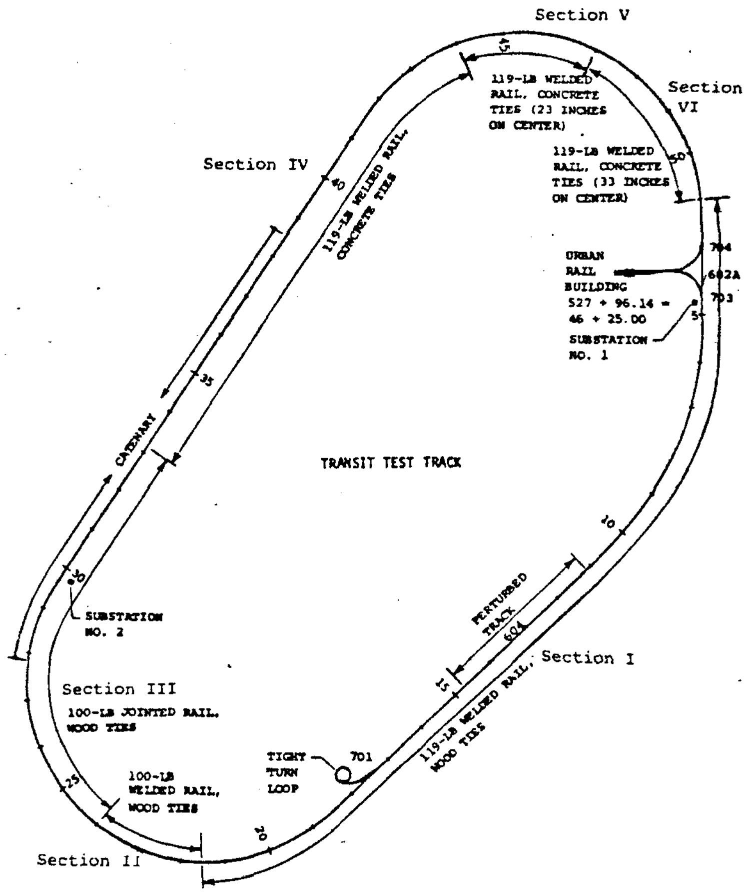
Test and evaluation activities of the Urban Mass Transportation Administration (UMTA) are coordinated through The Office of Technical Assistance in Washington, D.C., and are conducted by The UMTA Program Office at the Transportation Test Center (TTC) in Pueblo, Colorado.

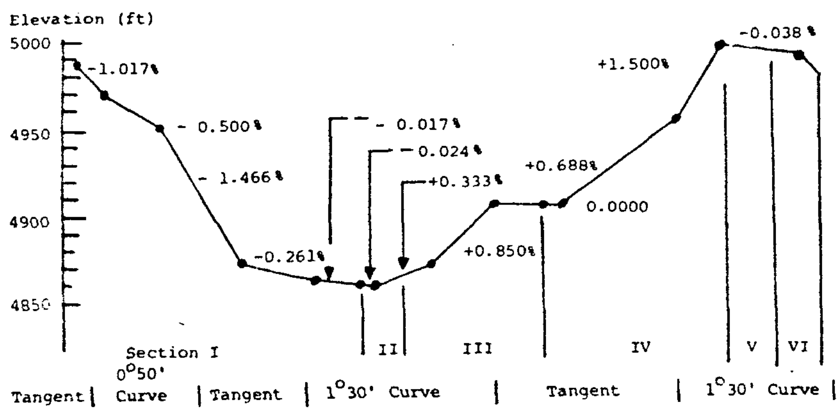
The urban rail transit test facilities at the TTC provide for test and evaluation of urban rail vehicles, subsystems, track, and structural components in an environment that is both safe and free from the scheduling constraints imposed by revenue service operations.

The Transit Test Track (TTT) is a 9.1 mile oval (see next page) designated for sustained 80 mi/h vehicle operation with the exception of the perturbed track section, which is subject to a speed limit based on ride quality test requirements and safety considerations. Power is provided either by a conventional third rail or a section of overhead catenary cable; the third rail was constructed to New York City Transit Authority specifications.

The rectifier station voltage can be varied infinitely from 400 to 1,200 V.d.c. with a current limit of 11,000 A. The stations each feed from one bus to all of the TTT and are designed to operate in several alternate modes, including computer control. Voltage can be controlled at a constant level at the substation, or at the position of the vehicle and held within the above constraints to a constant value at the vehicle regardless of demand or voltage drop through the rails. In alternate modes of operation the test vehicle can be subjected to a voltage profile or a voltage step such as might occur in revenue service at the transition between one substation and another.

The Test Center's technical support capabilities include test management, engineering instrumentation, calibration and electronic repair, photo-optical instrumentation, and data processing. In addition, TTC has the capability to assist users in developing test plans and requirements, and preparing reports.




NOTES:

Track Curvature:

| Sta. to Sta. | | Degree of Curve |
|---|---|---|
| 55.3 | 10.3 | 0° 50" |
| 18.9 | 29.4 | 1° 30" |
| 41.8 | 50.8 | 1° 30" |

Elevation:

Minimum - 4863 ft at Station 22.0.
Maximum - 5003 ft at Station 46.0.

Curve Superelevation:

1° 30' curves are superelevated a maximum of 4.5". The maximum superelevation on the 0° 50' curve is 2".

Tight Turn Loop

150 ft radius.
119 lb AREA Head Hardened running rail.
85 lb ASCE restraining rail installed as per Massachusetts Bay Transit Authority specifications.