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Track Train Dynamics

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Association of American Railroads
Research and Test Department

LABORATORY TESTS ON THREE ALTERNATIVE TRACK STRUCTURES

J. CHOROS

REPORT NO. R-614

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AAR Technical Center
Chicago, Illinois

ASSOCIATION OF AMERICAN RAILROADS | RESEARCH AND TEST DEPARTMENT

REPORT BRIEF

Laboratory Tests on Three Alternative Track Structures

R-614

The objective of this study was to determine the structural characteristics of three different track structures, including one that was representative of the conventional track structure used by North American railroads, under various applied loadings and levels of ballast consolidation.

This study is a part of the track strength characterization program whose objective is to quantify the load carrying capacity of the track structure. It is being sponsored by the AAR Research and Test Department, Track Train Dynamics program and Federal Railroad Administration.

The results indicate that **concrete tie track has the highest lateral resistance in the unloaded state.** It was also found that **the lateral resistance is influenced by the applied vertical load,** rather than the type of track structure. The nature of the track structure has an influence on the lateral resistance only when the track is in the unloaded state.

The concrete tie track structure has the highest vertical track modulus, which could increase the dynamic loads experienced by passing vehicles; **wood tie track with elastic fasteners showed a substantial increase in vertical modulus over the conventional track structure.**

The gage widening results indicated that **elastic fasteners are stronger than cut spikes in restraining rail rotation.** Also, the use of elastic fasteners decreases the number of adjacent fasteners that carry any significant portion of the applied load.

Tests were conducted on three different track structures: conventional wood tie track, wood tie track with elastic fasteners, and concrete tie track. All of the track structures were constructed with 12 inches of limestone ballast below the bottom of the ties and 12 inches of shoulder ballast, with a slope of 2:1. Six inches of limestone material were used as subballast. For the two wood tie track structures, 7" x 9" x 8.5' pre-bored and treated hardwood ties were used. Concrete ties similar to those used in the Northeast Corridor were used for the concrete tie track.

Three basic areas of track strength characteristics were investigated in this test program: **lateral track resistance, vertical track modulus, and gage widening restraint.** For the lateral resistance tests, a concentrated lateral load was applied to the test track at the gage line of the rail. Lateral track deflections were recorded for both increasing and decreasing loadings. This was then repeated for different vertical loading environments. This included a vertical load that had been applied to each rail to simulate a single axle loading.

Vertical modulus tests were conducted using both simulated axle and truck loadings. Each of the applied vertical wheel loads were varied from 0 to 40 kips for the axle loadings and 5, 27, and 33 kips for the truck loadings, simulating an empty car, a loaded 70-ton car and a loaded 100-ton car, respectively. Depending on which test was performed, the vertical loads were applied and the corresponding vertical track deflections were measured.

Gage widening tests were conducted by applying a spreading load to both rails and measuring the resulting rail head deflections. These tests were also conducted under various levels of vertical loadings and a number of repeated cycles.

All three parameters were investigated under various levels of consolidation, ranging from 0 (freshly tamped track) to 2 million gross tons. The service load was applied using the track laboratory consolidation vehicle, which was cycled back and forth over the test track. It has the capabilities of applying 0.25 million gross tons in eight hours.

Copies of the AAR Report: "Laboratory Tests on Three Alternative Track Structures" are available from J. G. Britton, Sr., Assistant Vice President, Chicago Technical Center, 3140 South Federal Street, Chicago, Illinois 60616. The AAR report number is R-614; the price is $3.00 for member railroads and $6.00 for nonmembers. Checks should be made payable to the Association of American Railroads. A report list is available upon request.

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13. ABSTRACT

Laboratory track strength characterization tests on three different track structures were conducted. The objectives of these tests were to determine the structural characteristics of each track structure, under various loadings and levels of consolidation, and to compare the findings with the conventional track structure commonly used in the railroad industry. The types of track structures tested were conventional track, wood tie track with elastic fasteners, and concrete tie track. The basic characteristics studied under this program were vertical track modulus, lateral track resistance, and gage widening.

The results indicated that the concrete tie track has the highest vertical modulus, followed by the wood tie with elastic fasteners, and then the conventional track.

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EXECUTIVE SUMMARY

An evaluation of different track structures was conducted at the Association of American Railroads Track Laboratory. Primary concerns in this test series were track strength characteristics under various loadings and levels of consolidation, and comparisons with the different track structures tested. Three different track structures were tested, as follows: conventional North American track, wood tie track with elastic fasteners, and concrete tie track. Strength parameters that were measured were vertical track modulus, lateral track resistance, and gage widening. The loadings varied, depending on the test, from 0 to 40 kips vertical, 0 to 30 kips lateral, and 0 to 20 kips gage widening. The consolidation levels applied to each of the different track structures varied from 0 to 2 million gross tons.

The results from these tests indicate that, under the influence of vertical load and consolidation, there isn't any appreciable difference between the three different track structures in their lateral resistance. In the area of vertical modulus, concrete tie track has the highest modulus, followed by wood tie track with elastic fasteners, then conventional track. Gage widening results indicate that elastic fasteners are stronger than cut spikes.

Summarizing, concrete track would be better in the area of lateral resistance, since its strength in the unloaded state, important in track buckling, is higher. Wood tie track with elastic fasteners could be advantageous over concrete tie track. Concrete tie track has a higher vertical track modulus, which could cause additional vehicle dynamic problems.

ACKNOWLEDGMENTS

This report was prepared as part of the Track Train Dynamics, Federal Railroad Administration, and Association of American Railroads combined efforts in the area of track reliability.

Special thanks are due to Mr. William B. O'Sullivan, Task Monitor, for his valuable assistance and direction during the development of the test plan and the conduct of these tests. Thanks are also due to Mr. Irving Gitlin, Track Laboratory Manager, for his assistance in the conduct of the tests and preparation of this report. Finally, thanks are due to Mr. T. L. Wang, Student Assistant, for his assistance in the data reduction phase of this project.

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1.0 INTRODUCTION

Since early in the history of railroads, crosstie track systems have been considered to be the most optimal track structure. Numerous changes and modifications have been made to this structure in the last 100 years, but the basic concept has remained the same: steel rails on wood crossties, held down with cut spikes and placed on ballast. With ever-increasing demands on rail service for moving bulk commodities, the wheel loads applied to this structure have increased accordingly, and it is believed that this type of structure may be reaching its design limits. Researchers in the past have been able to solve the problems of heavier wheel loads by optimizing the roadbed, the spacing of the crossties, or using heavier rail sections. Numerous papers and reports have been written on the research efforts in the area of track structures, and on new and revolutionary concepts to increase its safe load-carrying capacity. Along with theoretical research, tests have been conducted on some of these concepts and many have already been incorporated into the track structure.

There has also been a limitation as to the type of new track structures that could be tested. This was partially due to the limited amounts of time that a researcher could occupy existing track or take to install a new type of structure in revenue track. Interfacing the existing track structure with the new one was an additional problem to early researchers in this area. Even with these problems, work was done in alternative track structures, such as concrete ties, continuous welded rail, and continuous concrete slab track.

Economics was also a retarding factor in this type of research. The cost of field test installations, such as concrete tie tests, were prohibitive. Continuous concrete slab track is still economically prohibitive, although it has been used in some limited cases. Even if the research was successful, the installation of a new track structure would have been, and still is in many cases, economically unacceptable.

Time was another important factor in this type of research. It would require years to install, monitor, and evaluate the performance of a single test site, dealing with one area of reliability of track and one particular type of alternative track structure.

Some of these problems were addressed in the early 1970's by the Track Train Dynamics program, which concluded that a facility was required where research of this nature could be performed without any interruption from train operations. Two such facilities were built: the Facility for Accelerated Service Testing (FAST), at Pueblo, Colorado and the Association of American Railroads (AAR) Track Laboratory at Chicago, Illinois. At both of these facilities, the cost of new track was reduced, the service loads accelerated, and the problem of unwanted interruptions from regular trains was eliminated, thus making research on new track structures more affordable and less time consuming.

With these facilities available, the AAR, in conjunction with the Federal Railroad Administration (FRA), embarked on a program to test three different types of track structures at the AAR's Track Laboratory. The three track structures were: conventional track, conventional track with elastic fasteners, and concrete tie track. Three tests were conducted on each structure, under various levels of ballast consolidation, and involved vertical modulus tests, lateral resistance tests, and gage widening tests.

One could hardly consider conventional track, with steel rails on wood ties, to be a new type of track structure, but it could be tested to generate baseline data for comparison with the other two types of track structures under identical conditions. Thus, a direct comparison could then be made on the parameters of vertical track modulus, lateral track resistance and gage widening, each as a function of the level of ballast consolidation. With direct comparisons of these parameters for each alternative track structure to those for conventional track, conclusions could be made as to the economic feasibility, long term behavior, and safe operational advantages of each.

The test procedures for each of the three types of track structures and the corresponding test results are described in this report, as well as conclusions drawn from these data.

2.0 TEST PROCEDURES

The procedures for conducting the evaluation tests of the new and existing track structures are described in this section. The type of track structures and the corresponding tests to be conducted on each are given in the overall Test Matrix, shown in Table 1.

2.1 Test Facility and Equipment

The tests for the alternative track systems were conducted at the AAR's Track Laboratory located at Chicago, Illinois. This facility consists of a building measuring 170 x 40 x 20 feet. The test area within this building consists of a section of standard gage track, 45 feet long, with two ramps at 20 degrees from the horizontal at each end. Figure 1 is a schematic diagram showing the track structure and ramps.

Equipment pertinent to these tests included the consolidation vehicle, loading framework, hydraulic systems, and data acquisition system. The vehicle, used to consolidate the track, weighs 131.8 tons and is powered with an on board hydraulic system. This vehicle moves across the test track at approximately 8 mph, thus applying 0.25 million gross tons (MGT) of equivalent consolidation in an 8-hour shift. The loading framework, used to react the hydraulic jacks, consists of an overhead structure and two H-beams running along the length of the track on both sides. The reaction beams on the overhead framework can be moved longitudinally to any location within the central 20 feet of track. Similarly, the vertical loading jacks can be moved in the lateral plane of the track. With this

Table 1

Test Matrix for Evaluating New and Existing Track Structures

	TRACK SYSTEM		
MGT	A	B	C
0.00	I-IV	I-IV	I-IV
0.25	IV	I,IV	I,IV
0.50	IV	I,IV	I,IV
1.00	IV	I,IV	I,IV
2.00	V,VI	I-IV	I-IV

Test Sequence:

I - Lateral Track Resistance Tests
II - Gage Widening Tests
III - Vertical Track Modulus Tests
IV - Dynamic Vertical Track Modulus Tests

Track Configuration:

A - Conventional North American Track - Wood Ties & Cut Spikes
B - Conventional North American Track - Wood Ties & Elastic Fasteners
C - Concrete Tie Track With Elastic Fasteners

<u>Note:</u> For all different track structures, the ballast, subballast and subgrade will remain the same.

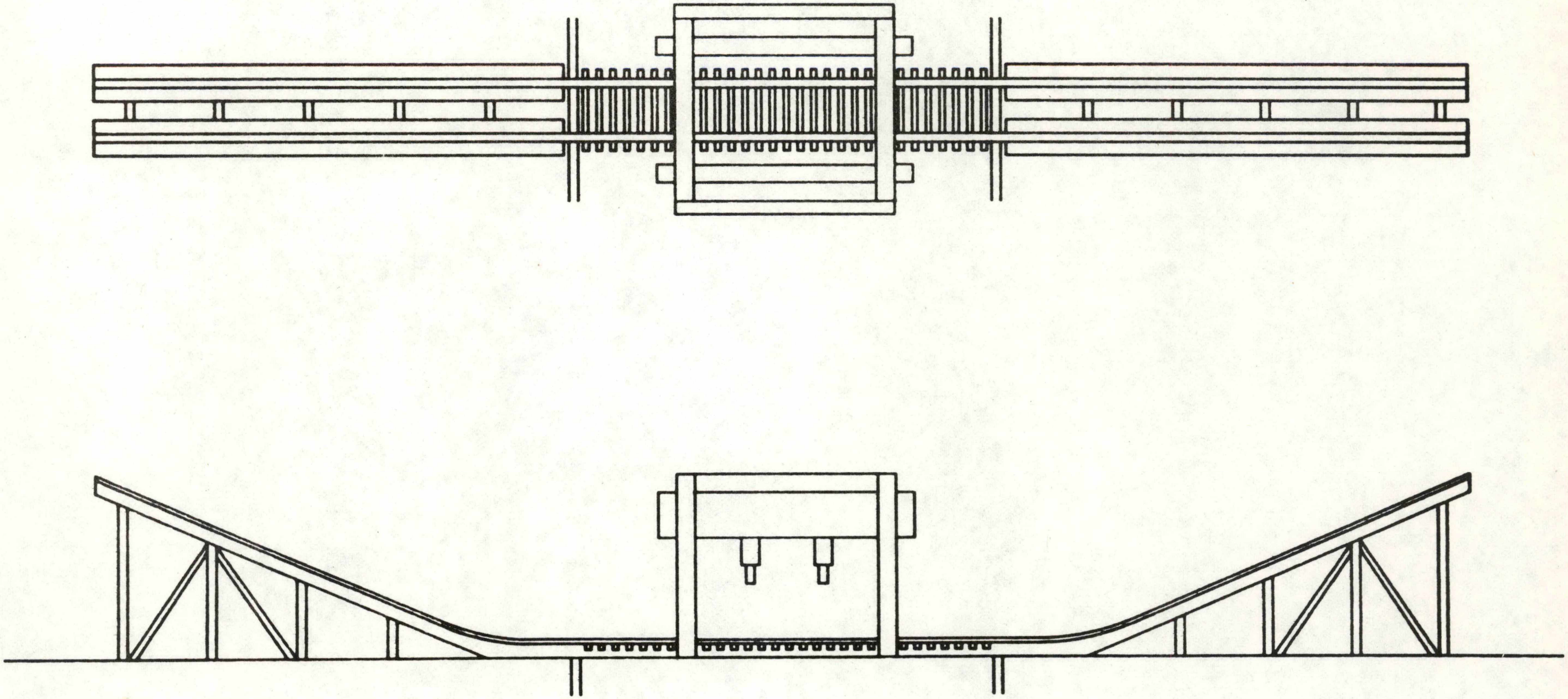

Figure 1. General Schematic Diagram of the Track Laboratory.

arrangement, and the additional capability of moving the lateral loading jack(s) longitudinally along the H-beams, any simulated axle or truck loading, including lateral loads, can be applied to the track at any desired eccentricity. Two hydraulic systems were used to apply the vertical and lateral loads. For the vertical load, an Amsler hydraulic power unit and four jacks were used, each with a capacity of 80 tons. Two lateral jacks with a capacity of 25 tons each were used, powered by a motor-driven hydraulic pump. The data recording system used in this test was a Datum Data Acquisition System with a scan rate of 20,000 samples/second/channel.

A loading bolster was used to maintain the simulated wheel/rail contact geometry. This bolster was constructed using four 36-inch wheel segments attached to the bottom of a rectangular frame, with an attachment for applying vertical and/or lateral loads. Thus, all of the applied loads were transmitted to the rails through the contact point(s) between wheel and rail.

For the gage widening tests, two loading blocks were used to apply the lateral and vertical loads at the gage point of the rail, and at the running point of the rail (9/16 inch from the top of the rail and 9/16 inch to the gage side from the centerline of the rail head), respectively.

2.2 Test Track Construction

The test track was constructed using conventional materials and recommended practices, as outlined in the AREA Manual for Railway Engineering [1].*

2.2.1 Subgrade

The subgrade under the test track consisted of the parent material upon which the laboratory was built and is classified as poorly graded sand (SP) under the USCS classification.

2.2.2 Subballast

Subballast covered the entire test area to a depth of 6.00 inches. The limestone material used was classified CA-10 under Illinois Department of Transportation Specifications.

2.2.3 Ballast

Ballast material for all three track structural configurations was AREA No. 4 limestone, placed to a depth of 12 inches from the bottom of the ties. The shoulders, with a slope of 2:1, were 12 inches from the end of the ties. Crib areas were filled to the top of the ties.

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*Numbers in brackets [] indicate the references, listed in Section 5.0 of this report.

2.2.4 Track

Three different types of track construction were used for this test: conventional track, conventional track with elastic fasteners, and concrete tie track.

The conventional test track was constructed using 136 RE rail, 7" x 9" x 8'-6" treated hardwood ties, pre-bored spike holes and No. 14 tie plates, 8 punch. The tie spacing used in this track was 19.5 inches, with two cut spikes per plate and without anchors. The total length of the test track was one rail length, 39 feet. It must be pointed out that many Class 1 railroads use different tie spacings, ties sizes, tie plates and rails, but the common denominator for conventional track is steel rails and wood ties with cut spikes.

The conventional track with elastic fasteners was constructed in the same way as the conventional track, with the exceptions of the tie plates and fasteners. Pandrol PR601A Rail Clips were used on treated hardwood ties, along with Pandrol 2847D 16 x 7.50 inch, six punch Tie Plates. Lock spikes were used for the hold down spikes. Tie spacing was the same as for the conventional track, 19.5 inches on centers.

The concrete tie track was constructed using Santa Fe/San Val #SFRT7-SS2 Concrete Ties with Pandrol Fastener PR601A Rail Clips. The spacing for the concrete ties was 26 inches on centers. The fastening system was identical to those used on the Northeast Corridor, including the insulating pads and rail seat pads.

2.3 Lateral Track Resistance Tests

Lateral track resistance tests were conducted for the three different track structures, after various levels of ballast consolidation and under various vertical loads. In all the tests conducted in this sequence, the maximum lateral deflection was limited to two inches. Tests conducted in these test series are given in the Lateral Track Resistance Test Matrix, shown in Table 2.

After each specific test track configuration was constructed, hydraulic actuators were moved over Tie 2S (the instrumentation and measurement configuration are shown in Figure 2) to apply equal vertical loads to each rail and a lateral load to one rail. All loads applied to the track were applied through the loading bolster. Once the loading actuators were in place, the instrumentation was set up. In addition to the three load measurements, vertical and lateral deflection measurements were taken, resulting in a total of 23 channels of data. The lateral displacement transducers were located symmetrically about the loaded tie at every other tie. Vertical displacement transducers were placed at the loaded tie and symmetrically at the next two ties, then at every other tie, for a total of nine channels.

Test procedures were to apply the vertical load and then increase the lateral load at a constant rate, such that the lateral deflection increased at a rate of approximately 0.50 inch/minute, until the total lateral deflection at the loaded

Table 2

Lateral Track Resistance Test Matrix

MGT	TEST
0.00	a,b,c
0.25	a
0.50	a
1.00	a
2.00	a*

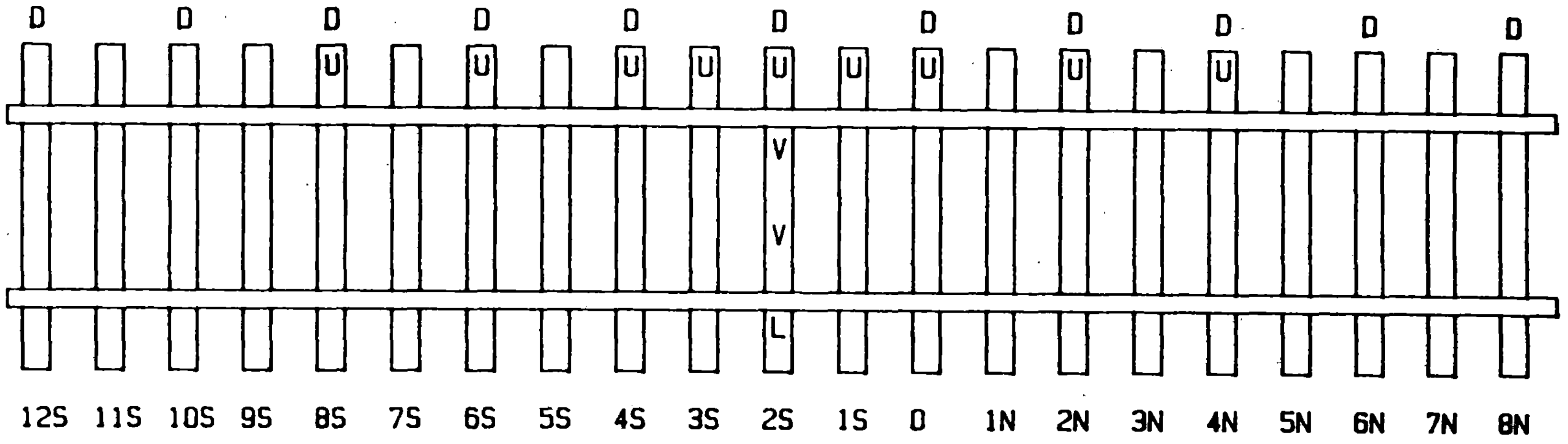
Loading Sequence:

a - Single point lateral load at the rail head with 20 kips vertical

b - Single point lateral load at the rail head with 10 kips vertical

c - Single point lateral load at the rail head with 0 kips vertical

*Note: This test was run for the non-conventional track systems only: wood ties with elastic fasteners and concrete ties with elastic fasteners.



TRACK DATA
RAIL SIZE: 136 RE
TIE SIZE: 7' x 9' x 8.5' HARDWOOD (TREATED)
TIE PLATE: AREA No. 14 - 8 PUNCH
BALLAST: AREA No. 4 LIMESTONE (12 in.)
SUBBALLAST: ILL. SPEC. CA-10 (6 in.)

TEST DATA
D - LATERAL DEFLECTION
V - VERTICAL APPLIED LOAD
L - LATERAL APPLIED LOAD
U - VERTICAL DEFLECTION
(Conventional track only)

Figure 2. Instrumentation Layout for the Lateral Resistance Tests, for the Three Different Track Structures Tested.

tie reached 2.00 inches. The lateral load was then removed, followed by removal of the vertical loads.

Data taken during the test were recorded at a rate of one scan of all channels per second, during both the loading and unloading cycles. Once the track had stabilized after the load was removed, data recording was stopped and preparations for the next test were made.

The track was realigned and reformed after each of the tests was conducted. Tamping was performed manually, due to the instrumentation cabling, which made power tamping impossible. Once this was completed, the next level of consolidation was applied to the track with the consolidation vehicle and the process repeated for all tests shown in the Test Matrix. It should be noted that the subballast and subgrade conditions were not disturbed, or monitored in any way for their level of consolidation.

2.4 Vertical Track Modulus Tests

The vertical modulus tests that were conducted for each of the three different track structures tested are given in Table 3. Two types of tests were conducted for vertical modulus: axle and truck loadings. Instrumentation for these two tests were identical, with the exception of the two extra applied loads for the truck loadings. For the axle loadings, the loads were applied over Tie 2S; for the truck loadings, one axle was over Tie 2S and the other was 70 inches away, corresponding to a

Table 3

Vertical Track Modulus Test Matrix

MGT	AXLE LOADING (kips)	TRUCK LOADING (kips)
0.0	0-40*	5,27,33
0.25	0-40*	
0.50	0-40*	5,27,33
1.0	0-40*	
2.0	0-40*	5,27,33

<u>*NOTE:</u> Axle loads were applied through the loading bolster, using two vertical jacks.

Data were recorded continuously until the maximum load of 40 kips was reached.

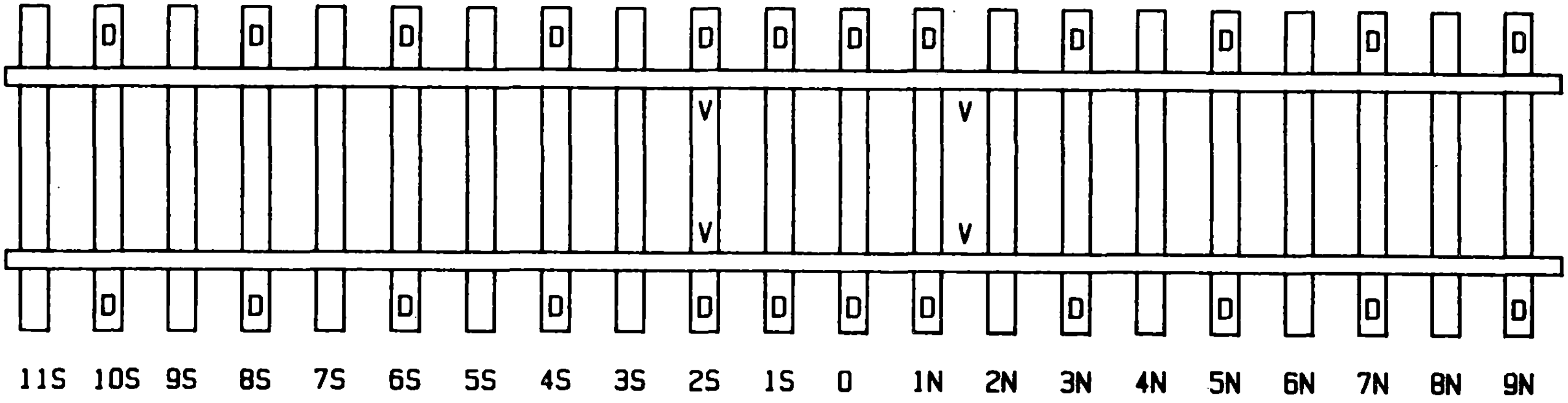
Truck loads were applied throughout the loading bolster, using four vertical jacks, and data were recorded at the truck loadings given above.

standard axle spacing for a 100-ton capacity truck. For the axle loadings, a continuous load was applied up to 40 kips. For the truck loadings, the load was applied up to the maximum value given in the Test Matrix, and then released, followed by the next load increment, until all three truck loading increments were tested. At the completion of the two tests, the consolidation vehicle was used to apply the next level of consolidation. Data for these tests were recorded at a scan rate of one per second. The instrumentation locations within the track are shown in Figure 3.

2.5 Gage Widening Tests

For the gage widening tests, all loads were applied through two loading blocks. These blocks were designed to apply the vertical load to the rail head at locations 9/16 inch from the lateral centerline of the rail and 9/16 inch from the top of the rail, as shown in Figure 4. The west rail was braced with a modified tie plate that was shimmed under the rail head and restrained by two spikes at the tie, thus forming a truss structure that prevented the rail from rotating. This arrangement allowed only the east rail to rotate/translate under gage widening loads; therefore, it was the only rail that was instrumented. The tie plate restraining system for the wood ties is shown in Figure 5.

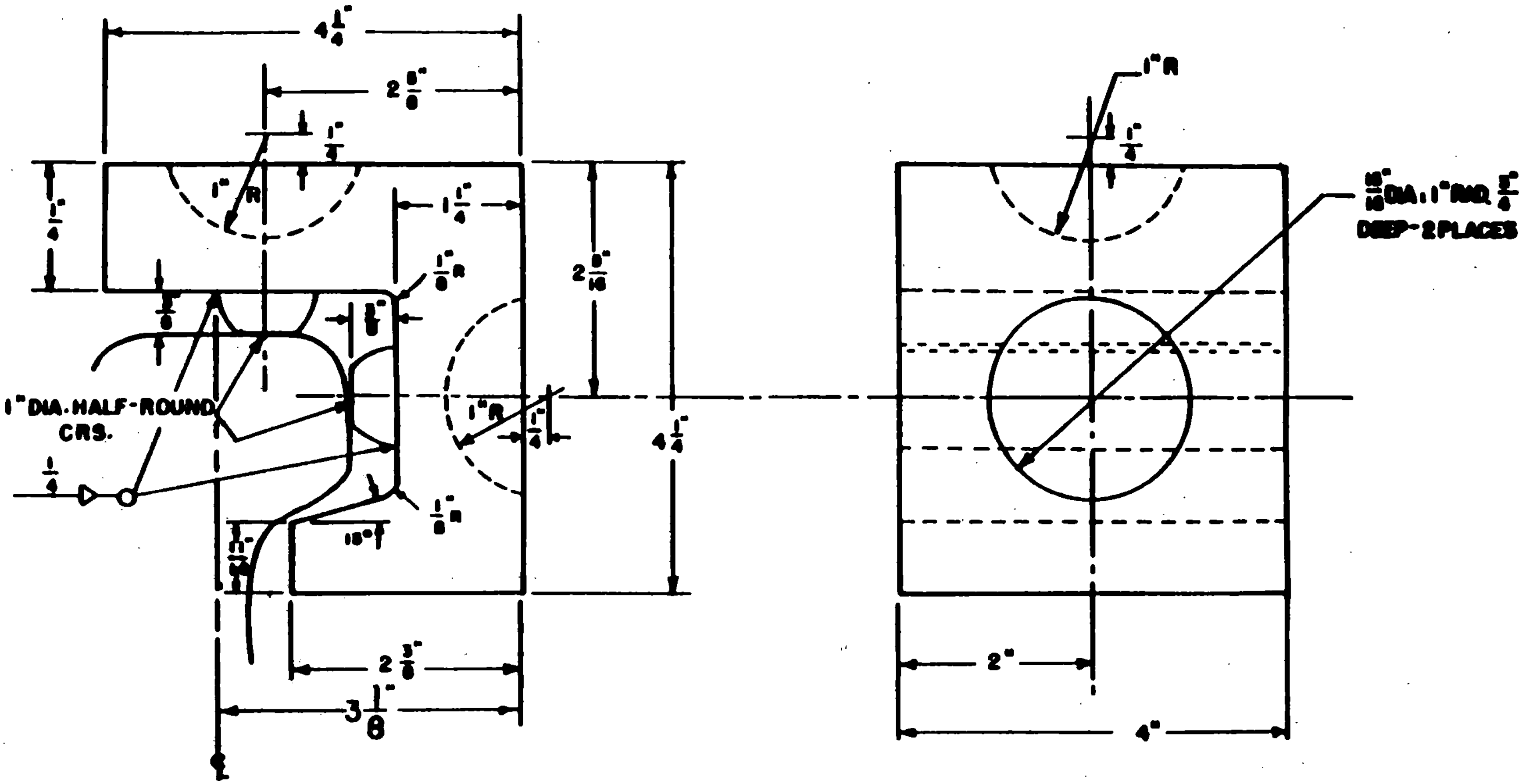
Instrumentation for this test included measurements of the vertical load, lateral load, and rail displacement. Both loads



TRACK DATA
RAIL SIZE: 136 RE
TIE SIZE: 7′ x 9′ x 8.5′ HARDWOOD (UNTREATED)
TIE PLATE: AREA No. 12 - 8 PUNCH
BALLAST: AREA No. 4 LIMESTONE (12 in.)
SUBBALLAST: ILL. SPEC. CA-10 (6 in.)

TEST DATA
D - RAIL DEFLECTION
V - VERTICAL APPLIED LOAD

Figure 3. Instrumentation Layout for the Vertical Modulus Tests with Simulated Axle and Truck Loadings.



Material: Hot or Cold Rolled Steel

Figure 4. Loading Block Used to Apply the Gage Widening Loads During the Gage Widening Tests.

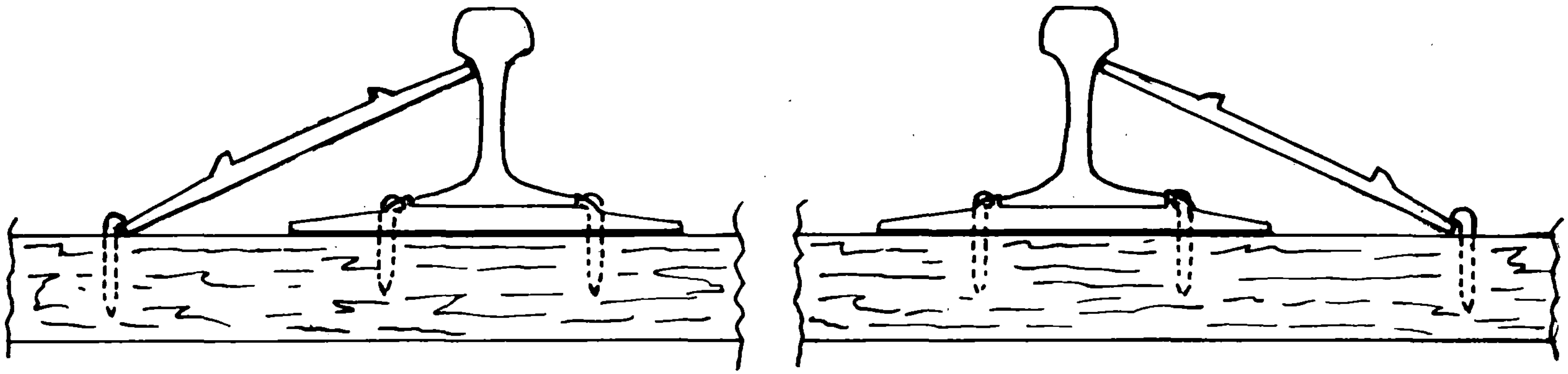


Figure 5. Rail Restraint Mechanism Used in the Gage Widening Tests.

were measured with strain gaged load cells placed between the load actuators and the loading blocks. Deflections were measured with Bourns two and four-inch displacement transducers. The location of the instrumentation with respect to the track is given in Figure 6.

Once the instrumentation, load actuators, and rail bracing were put in place, the vertical load was applied. Without removing the vertical load, a gage widening load was applied at a rate which caused the gage to increase at a rate of approximately 2.00 inches per minute until the rail head, at the load application point, deflected 1.00 inch. The load was then removed at the same rate and the procedure repeated for an additional twenty-four load cycles. Once completed, all loads were removed and the next loading sequence, given in Table 4, was performed, until all of the tests shown in the Test Matrix were completed.

3.0 RESULTS

3.1 Lateral Track Resistance

From the lateral resistance tests, the load deflection curves for each of the three track structures are shown in Figures 7 to 15, for all levels of consolidation and applied vertical loads.

After examining the data for a zero level of consolidation and 0.0, 10.0, and 20.0 kips vertical load (Figures 7, 8, and 9, respectively), two conclusions can be reached. First, at 2.00 inches of lateral tie displacement, the required lateral load

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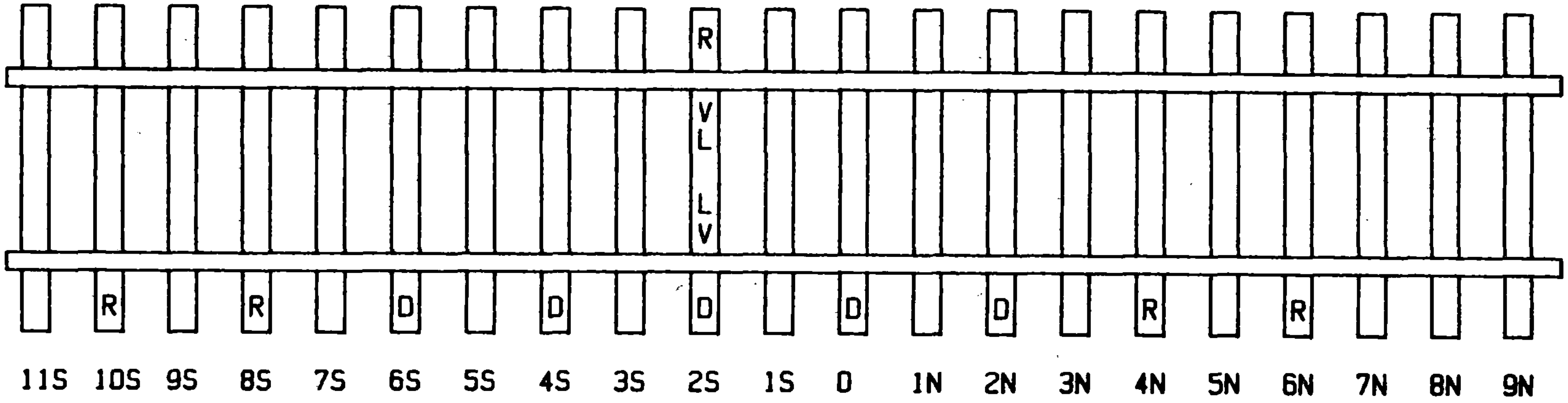

TRACK DATA
RAIL SIZE: 136 RE
TIE SIZE: 7′ x 9′ x 8.5′ HARDWOOD (TREATED)
TIE PLATE: AREA No. 14 - 8 PUNCH
BALLAST: AREA No. 4 LIMESTONE (12 in.)
SUBBALLAST: ILL. SPEC. CA-10 (6 in.)

TEST DATA
D - RAIL TRANSLATION AND ROTATION
V - VERTICAL APPLIED LOAD
L - GAGE WIDENING LOAD
R - RAILHEAD DEFLECTION

Figure 6. Instrumentation Layout for the Gage Widening Tests.

Table 4

Gage Widening Test Matrix

VERTICAL LOAD (kips)	LATERAL LOAD (kips)	NUMBER OF CYCLES
20	14	25
20	**	25
15	10.5	25
15	**	25

**Until maximum deflection is reached (1.00 inch).

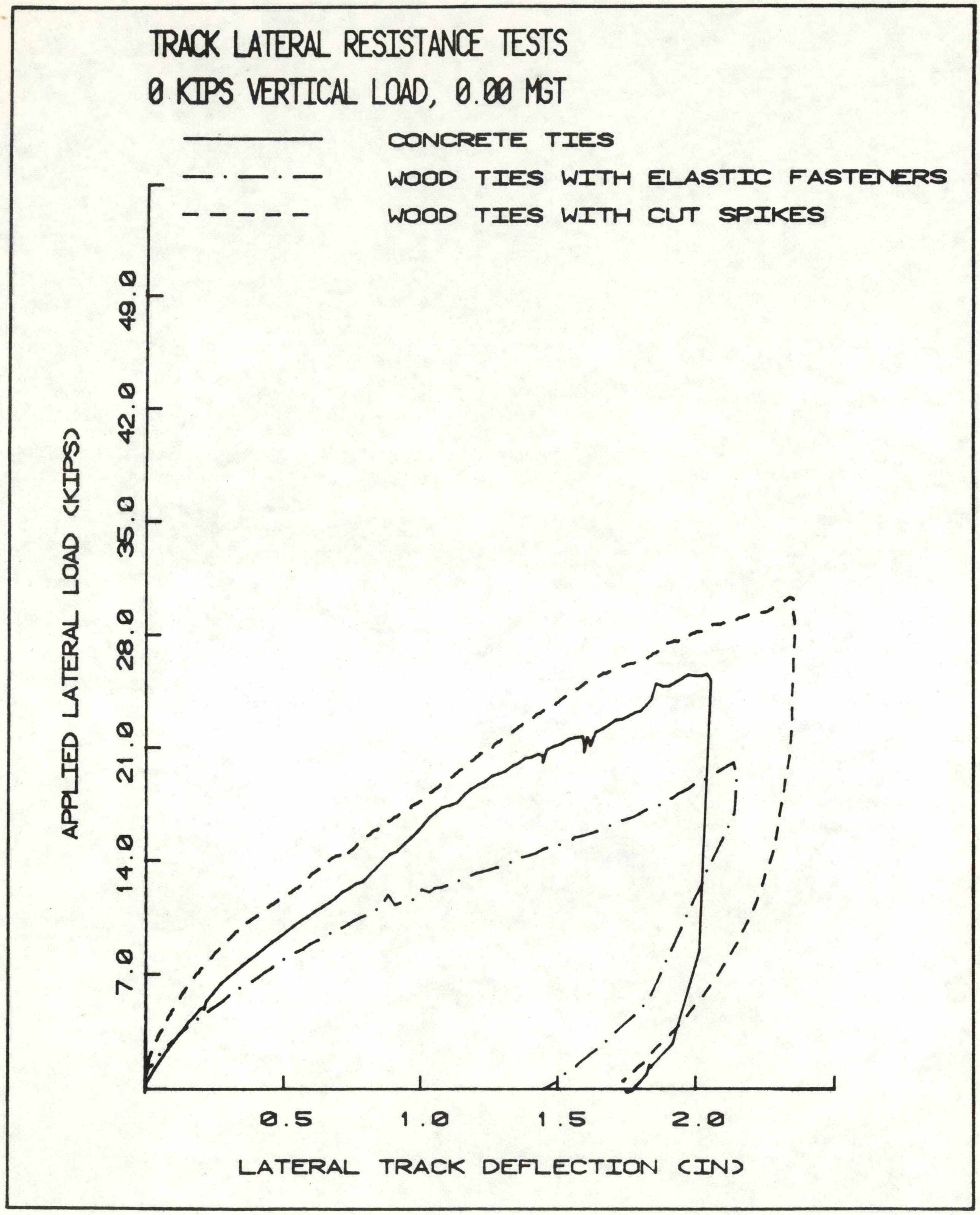

Figure 7. Load Deflection Curves from the Lateral Track Resistance Tests, for 0.0 MGT and a 0.0 Kip Vertical Load.

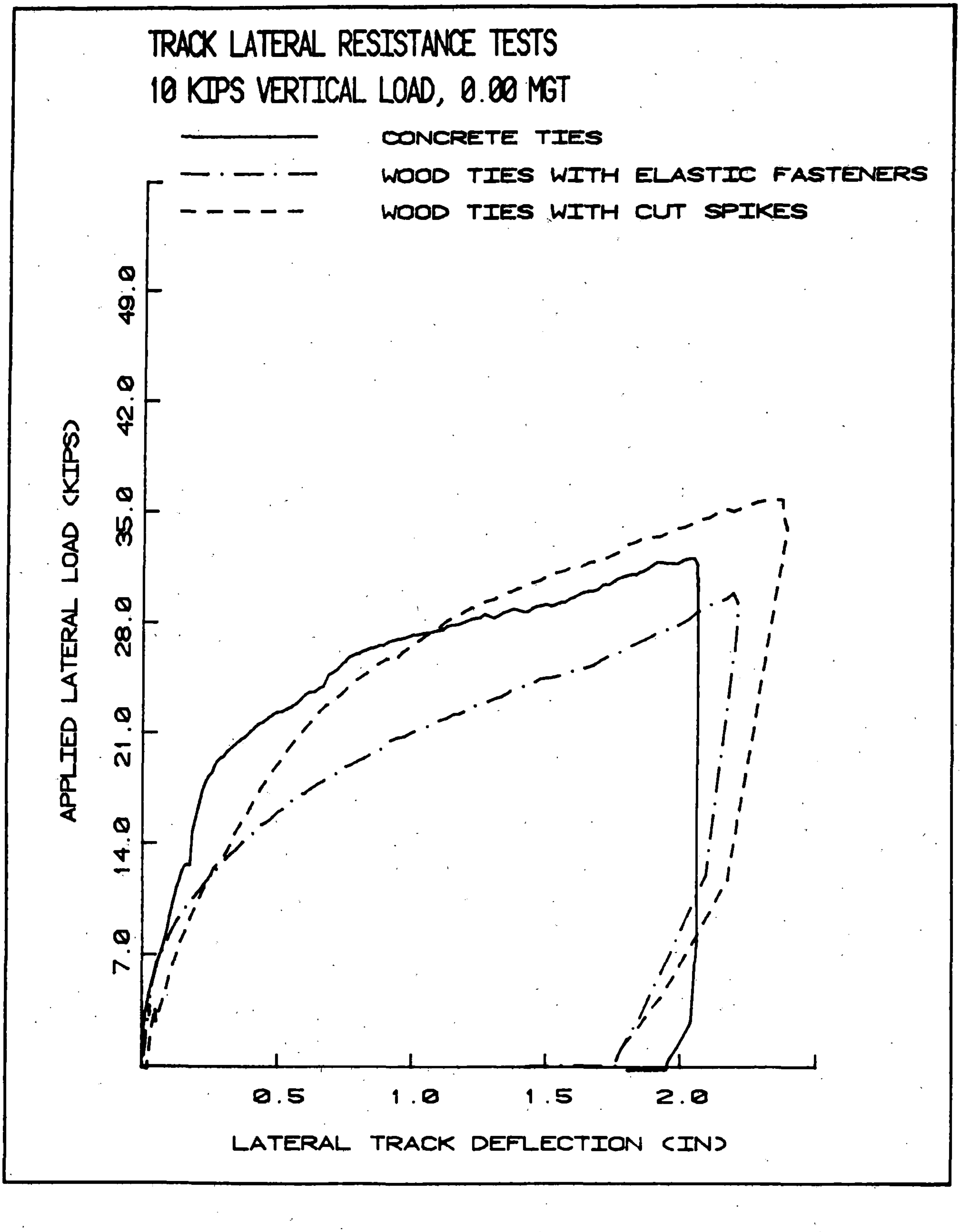

Figure 8. Load Deflection Curves from the Lateral Track Resistance Tests, for 0.0 MGT and a 10.0 Kip Vertical Load.

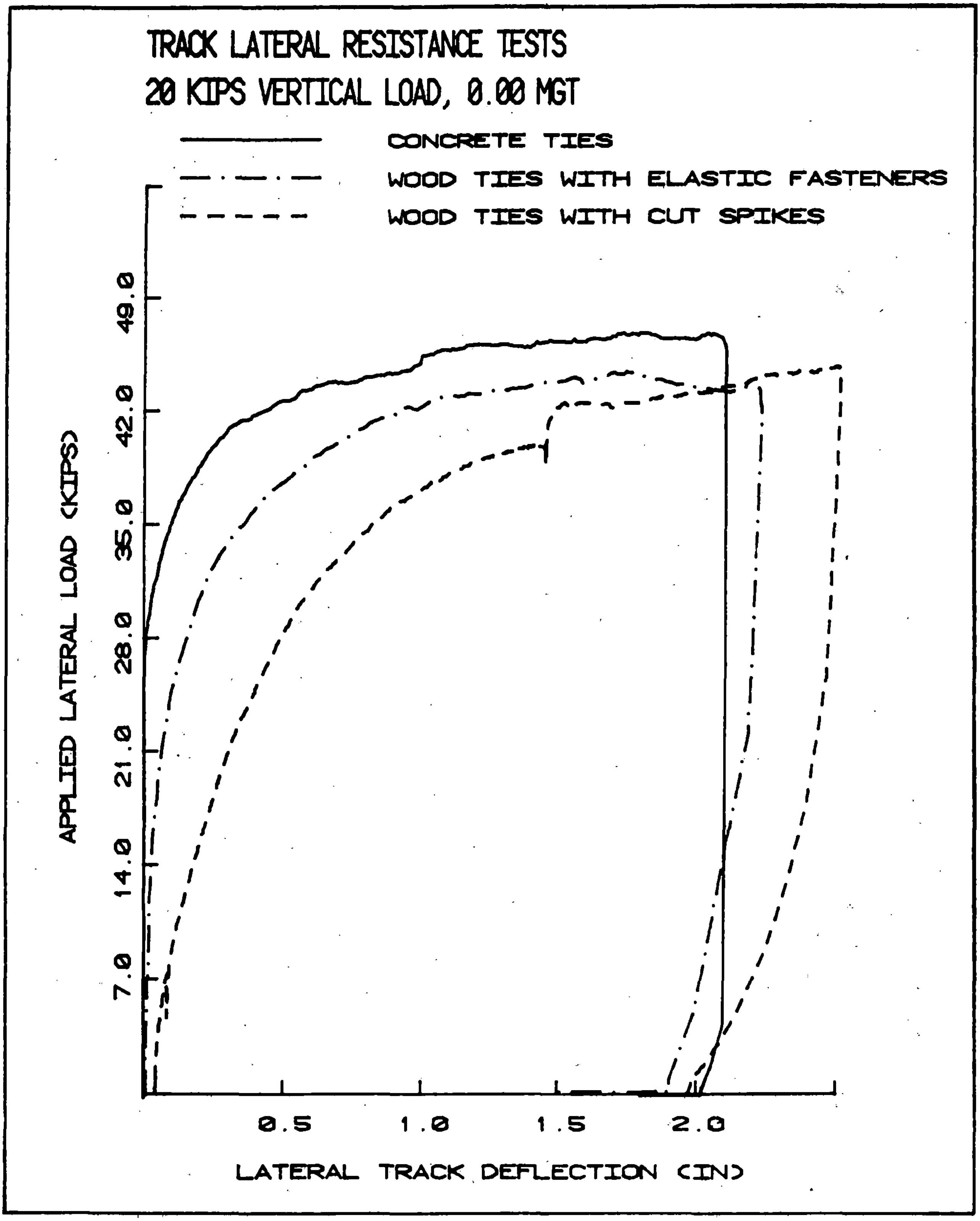

Figure 9. Load Deflection Curves from the Lateral Track Resistance Tests, for 0.0 MGT and a 20.0 Kip Vertical Load.

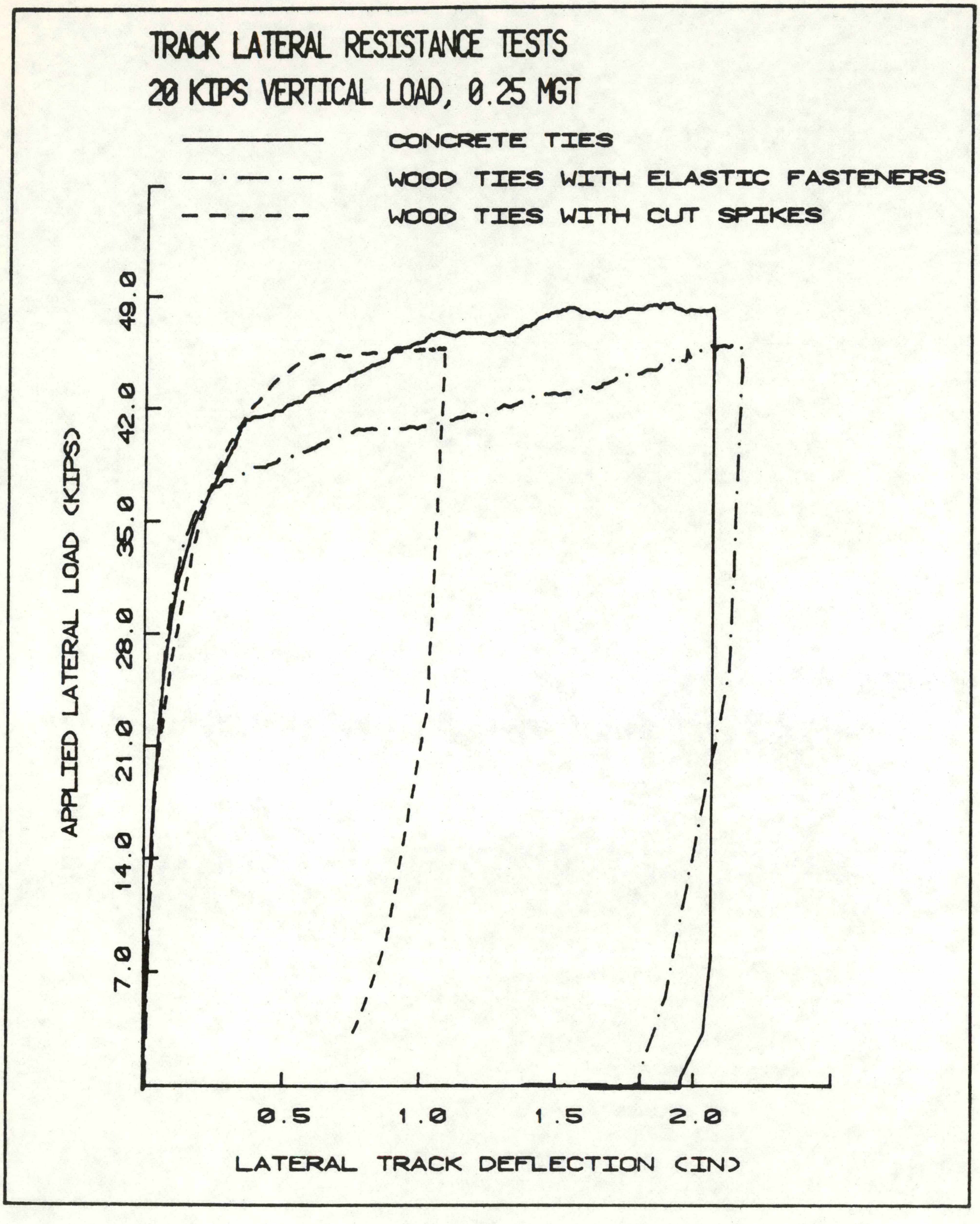

Figure 10. Load Deflection Curves from the Lateral Track Resistance Tests, for 0.25 MGT and a 20.0 Kip Vertical Load.

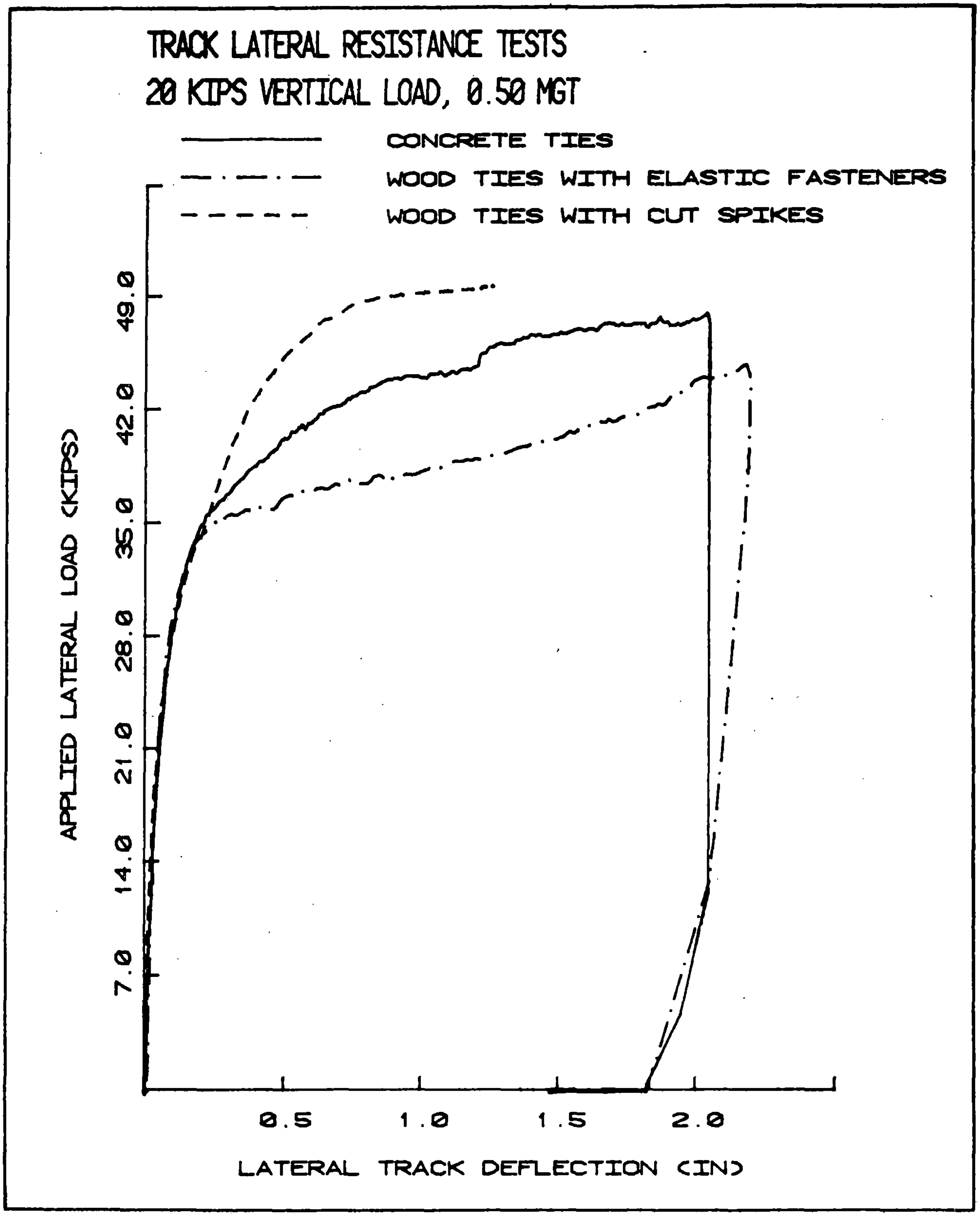

Figure 11. Load Deflection Curves from the Lateral Track Resistance Tests, for 0.50 MGT and a 20.0 Kip Vertical Load.

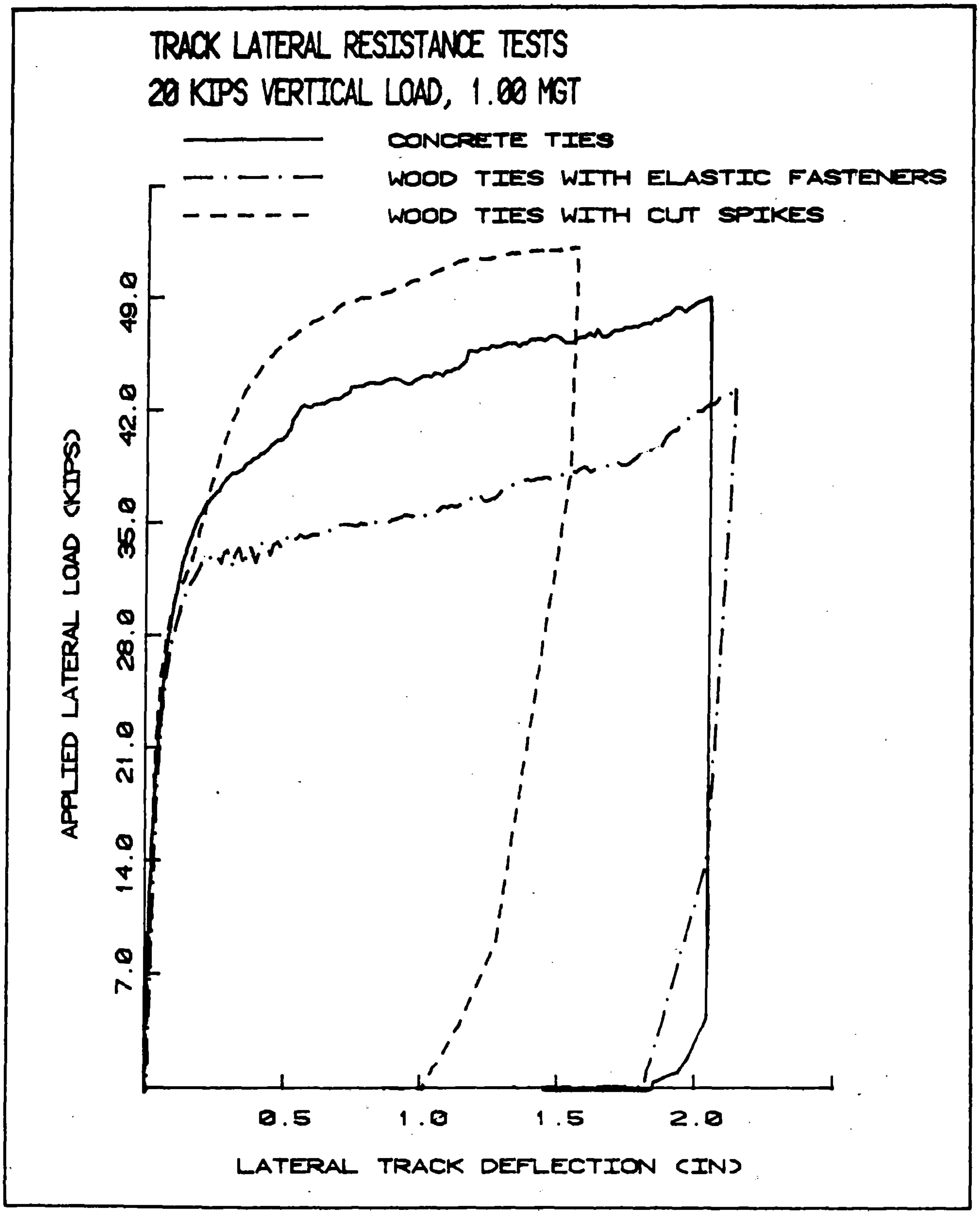

Figure 12. Load Deflection Curves from the Lateral Track Resistance Tests, for 1.00 MGT and a 20.0 Kip Vertical Load.

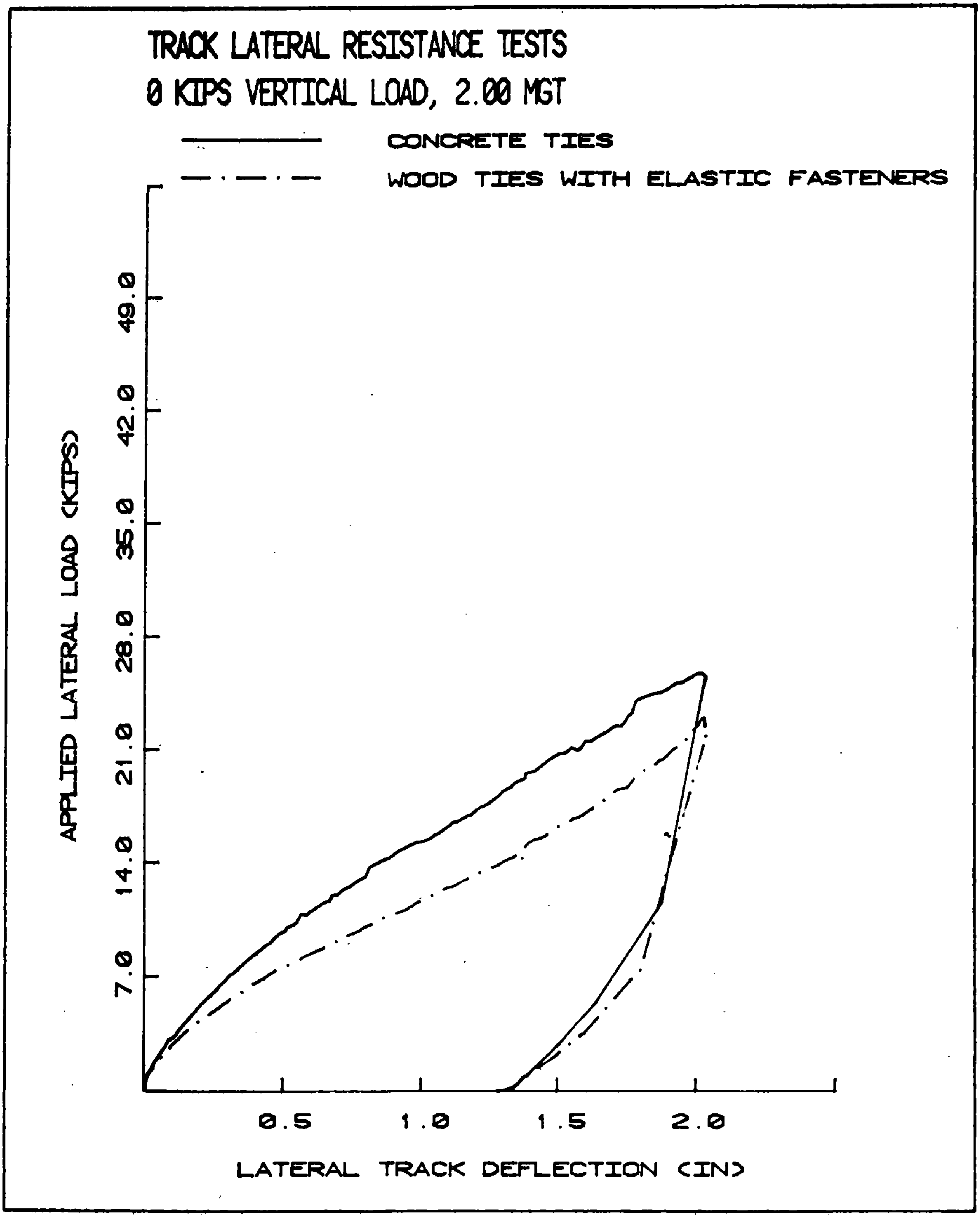

Figure 13. Load Deflection Curves from the Lateral Track Resistance Tests, for 2.00 MGT and a 0.0 Kip Vertical Load.

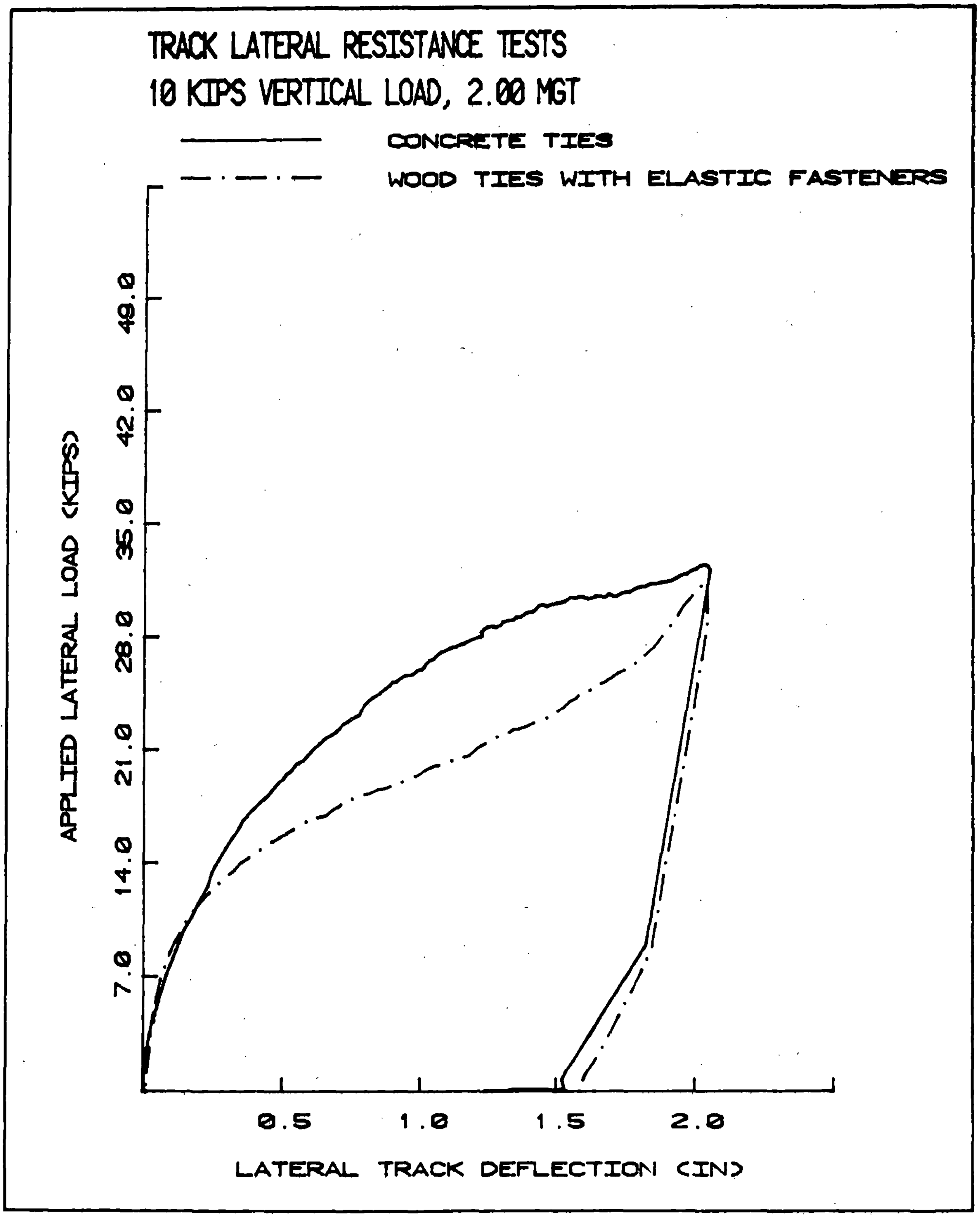

Figure 14. Load Deflection Curves from the Lateral Track Resistance Tests, for 2.00 MGT and a 10.0 Kip Vertical Load.

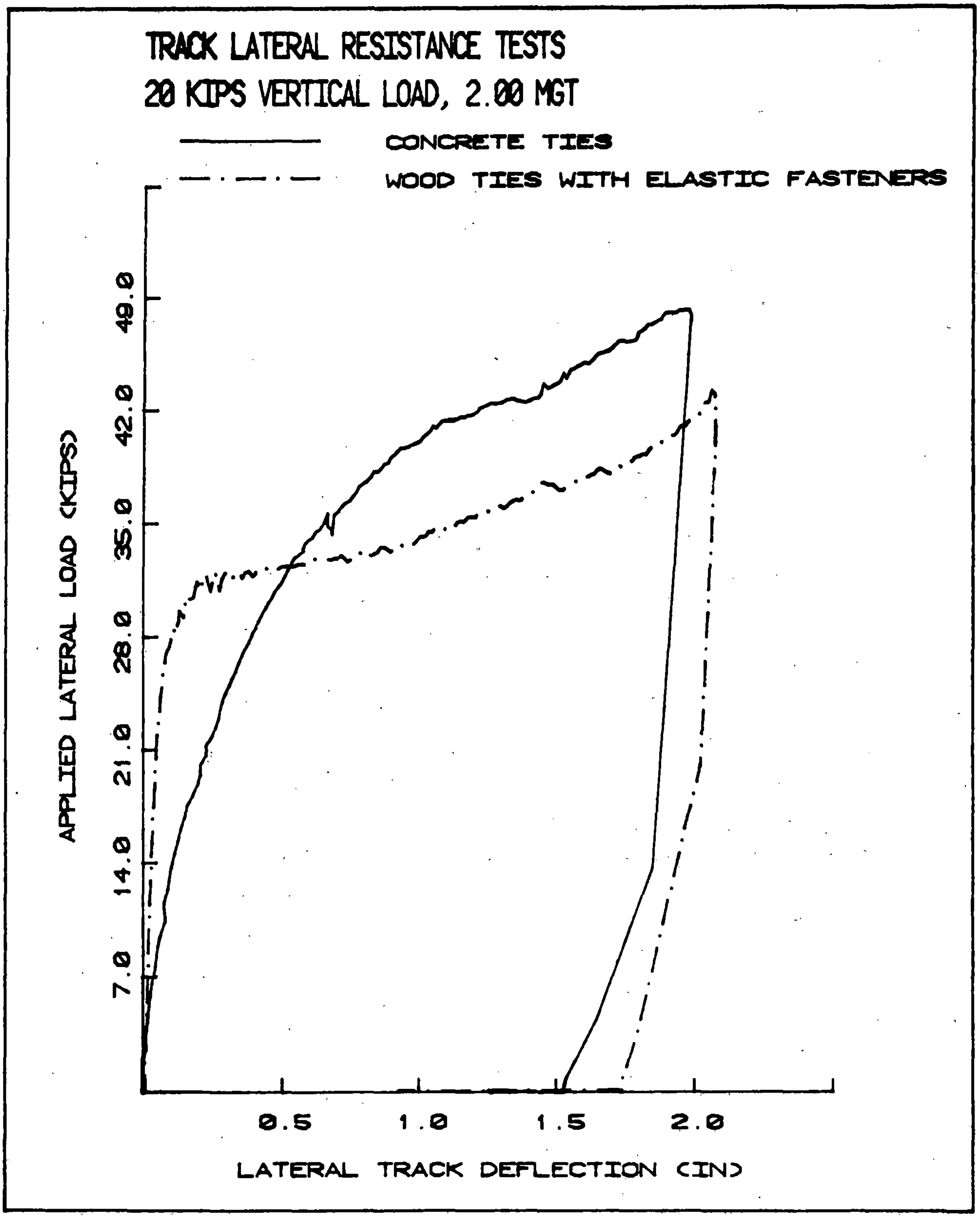

Figure 15. Load Deflection Curves from the Lateral Track Resistance Tests, for 2.00 MGT and a 20.0 Kip Vertical Load.

is higher for the conventional track than the concrete tie track, or the wood tie track with elastic fasteners. With a 20 kip vertical load and without consolidation, however, the concrete tie track requires higher loads for the same displacement. The reversal between the vertically loaded and unloaded lateral resistance would lead one to believe that the track construction or initial conditions are very important, relative to lateral track resistance. Secondly, a vertical load increases the lateral track stiffness, regardless of the level of consolidation or type of track structure, as seen by the deflection curves in these figures.

An examination of all of these figures gives a clear indication that, under the influence of vertical load, the lateral track resistance is bilinear, and it can be approximated with two distinct stiffness values: K1 and K2. Since the determination of these two stiffnesses is highly subjective, as to where the breaking point is chosen, it was deemed appropriate, for comparative purposes, to choose the break point as 0.25 inch of tie displacement, and the end points as 0.0 and 2.00 inches. Using this approach, the lateral stiffnesses were determined and are given in Table 5 for all the tests conducted.

Regarding the concrete tie data, it can be seen that there was a significant increase in K1 (lateral stiffness) as the vertical load was increased from 0 to 20 kips. But once the track started to move in the lateral direction, the lateral stiffness (K2) decreased substantially. K2 also decreased with

Table 5

Summary Of Results from the Lateral Resistance Tests

Levels of Consolidation	Vertical Load (kips)	Concrete Ties		Wood Ties			
		Elastic Fasteners		Elastic Fasteners		Cut Spikes	
		Stiffness (kips/in)		Stiffness (kips/in)		Stiffness (kips/in)	
		K1	K2	K1	K2	K1	K2
0.00 MGT	0	24.992	11.107	20.548	7.567	44.708	10.945
	10	73.588	8.053	48.596	9.025	48.596	13.398
	20	159.532	4.419	130.512	7.637	74.696	15.759
0.25 MGT	20(30)*	151.476	6.781	148.560	4.489	151.476	9.129
0.50 MGT	20(30)*	144.676	7.335	140.232	4.235	148.560	12.304
1.00 MGT	20(30)*	148.008	6.572	129.972	3.841	153.560	10.086
2.00 MGT	0	24.852	11.131	19.716	9.163		
	10	55.400	11.403	49.984	8.863		
	20	92.332	15.388	126.208	4.859		

<u>*Note:</u> For the conventional track with cut spikes, the vertical load was 30 kips.

increasing vertical load, which would indicate that beyond some point in the lateral load deflection curve, there was a lateral load component due to the applied vertical load. Comparing this with the wood tie lateral stiffness, it can be seen that K2 was higher and increased with vertical load on the conventional track.

Figures 10, 11, and 12 show the load deflection curves at three levels of consolidation: 0.25, 0.50, and 1.00 MGT, with a 20 kip vertical load. (Note: For the wood tie track with cut spikes, the vertical load data were obtained from a previous test series, which utilized a 30 kip vertical load.) These figures show that there was practically no difference in K1 for the three track structures tested. The only observed difference was in K2, where the concrete tie track was somewhat stronger than the wood tie track with elastic fasteners. Direct comparisons in this region cannot be made with conventional track, due to the vertical load difference. However, by extrapolation from these results, it would seem that the track stiffness would be lower than that found in the alternative track structures. As indicated in Table 5, K2 is higher for conventional track than the other two track structures, but it must be noted that there is a difference in vertical load of 10 kips.

Figures 13, 14, and 15 are plots of the lateral deflections for 0.0, 10.0, and 20.0 kip vertical loads at 2.00 MGT accumulated tonnage, for the concrete and wood tie track with elastic fasteners. There is an indication from these tests that the initial lateral resistance for concrete tie track (K1) was higher for the 0.0 and 10.0 kip vertical loads, but was considerably lower for the 20 kip vertical load. Looking at the K2 values, there was a minimal change in the concrete tie track with an increase in vertical load, whereas for the wood tie track, the K2 values decreased with increasing vertical loads.

3.2 Vertical Track Modulus

Data from the vertical modulus tests were reduced, using beam-on-elastic-foundation theory [2]. The vertical track modulus was calculated using Equation (1) for single axle loadings, and Equation (2) for truck loadings [3].

$$\mu = \sqrt[3]{\frac{P^4}{64\ EIy^4}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\mu = \frac{\beta}{2y} \sum_{i=1}^{n} P_i \eta_i \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\eta(x) = e^{\beta x} \quad (\cos \beta x - \sin \beta x)$$

$$\beta = \sqrt[4]{\frac{\mu}{4EI}}$$

where P is the applied load (kips)

y is the track deflection under load (in)

μ is the vertical track modulus (kips/in/in)

x is the distance from the applied load (in)

EI is the rail stiffness (kips-in^2)

β is the damping factor.

The results from these tests are given in Tables 6 and 7 for the axle and truck loadings, respectively. For the axle loadings, the vertical modulus was calculated using Equation (1), for a vertical load of 33 kips, for both the loading and unloading cycles. The corresponding vertical modulus for the truck loadings was calculated from Equation (2) and the loads called for in the Test Matrix. In addition to these tables, the vertical track modulus was determined as a function of the vertical load for both the loading and unloading cycles from the axle loading sequence. These results are given in Figures 16 to 20 for five different levels of consolidation: 0.0; 0.25; 0.50; 1.00; and 2.00 MGT, respectively. In these figures, a least-squares method was used to fit a smooth curve through the data points and to eliminate the effect of slack at low loads.

Comparing the vertical moduli, as determined from the axle loadings (shown in Table 6) for the three different track structures tested, it can be seen that the concrete tie track was approximately two times stiffer than the conventional track, whereas the wood tie track with elastic fasteners was approximately 1.5 times stiffer. As the service loads increased, i.e., higher values of accumulated MGT, these ratios seemed to remain the same. As shown in Table 7, listing the vertical moduli from truck loadings, it can be seen that for light loads (5 kips), this ratio did not hold. This was attributed to slack in the track, which in the truck loading environment required a somewhat higher load before it could be

Table 6

Vertical Track Modulus for Simulated Axle Loadings

Levels of Consolidation	Loading Condition	Vertical Track Modulus (kips/in/in)		
		Test A	Test B	Test C
0.00 MGT	Loading	10.565	8.195	4.757
	Unloading	9.527	6.968	4.098
0.25 MGT	Loading	11.423	8.203	4.132
	Unloading	10.129	7.224	3.767
0.50 MGT	Loading	8.256	6.534	
	Unloading	7.768	5.679	
1.00 MGT	Loading	8.061	6.534	5.460
	Unloading	7.328	5.979	4.574
2.00 MGT	Loading	9.887	6.217	
	Unloading	8.843	5.789	

<u>Note:</u> Test A for concrete ties and elastic fasteners.

Test B for wood ties and elastic fasteners.

Test C for wood ties and cut spikes.

Table 7

Vertical Track Modulus for Simulated Truck Loadings

Levels of Consolidation	Truck Loading (kips)	Vertical Track Modulus (kips/in/in)		
		Test A	Test B	Test C
0.00 MGT	5	5.066	4.472	4.470
	27	8.835	7.696	4.838
	33	9.968	8.236	4.947
0.50 MGT	5	5.390	3.825	
	27	7.705	6.336	
	33	9.319	6.670	
2.00 MGT	5	5.057	4.084	
	27	8.388	6.438	
	33	8.544	6.735	

Note: Test A for concrete ties and elastic fasteners.

Test B for wood ties and elastic fasteners.

Test C for wood ties and cut spikes.

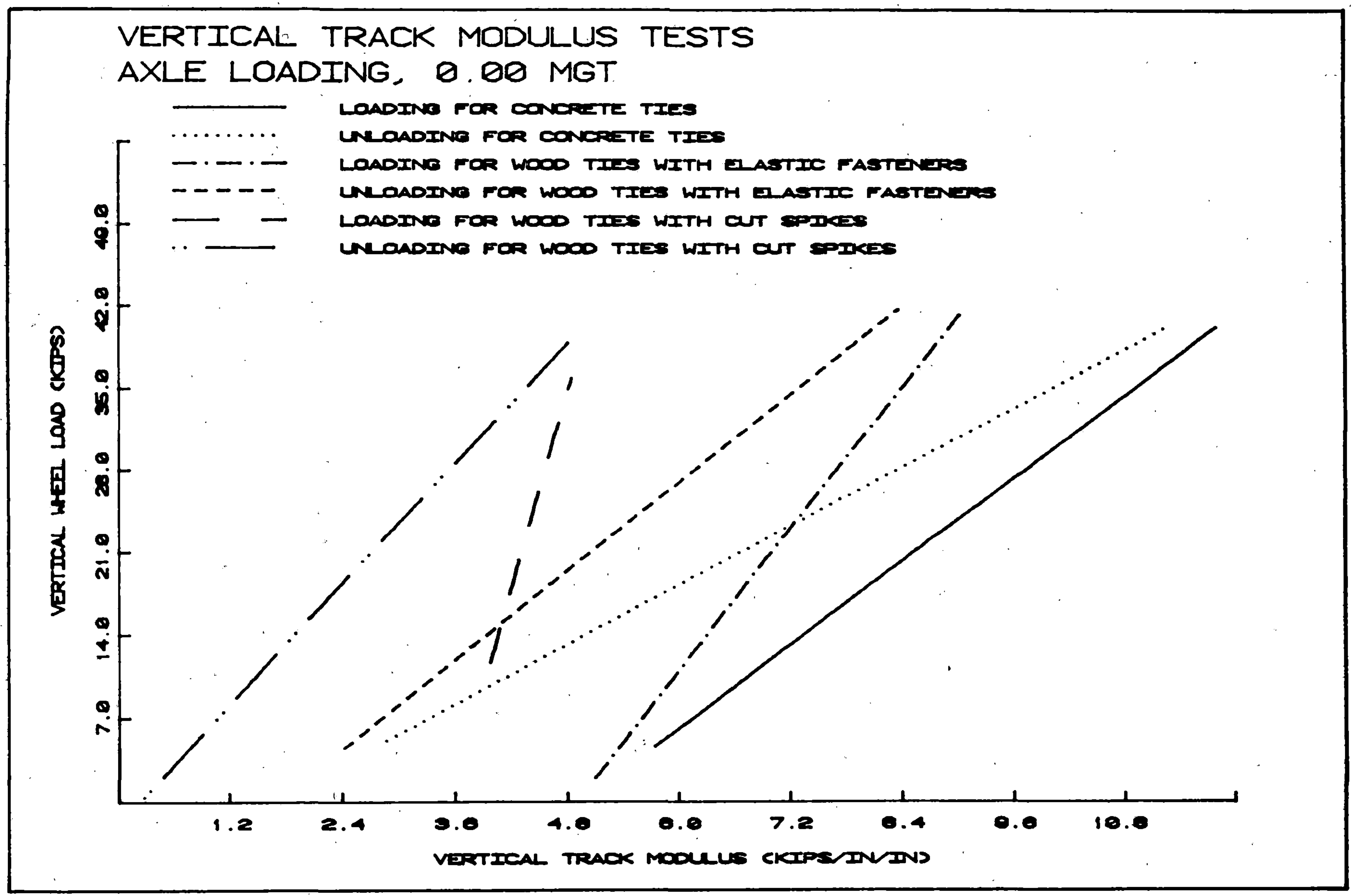

Figure 16. Comparison of the Vertical Moduli for the Different Track Structures, from the Axle Loadings at 0.00 MGT.

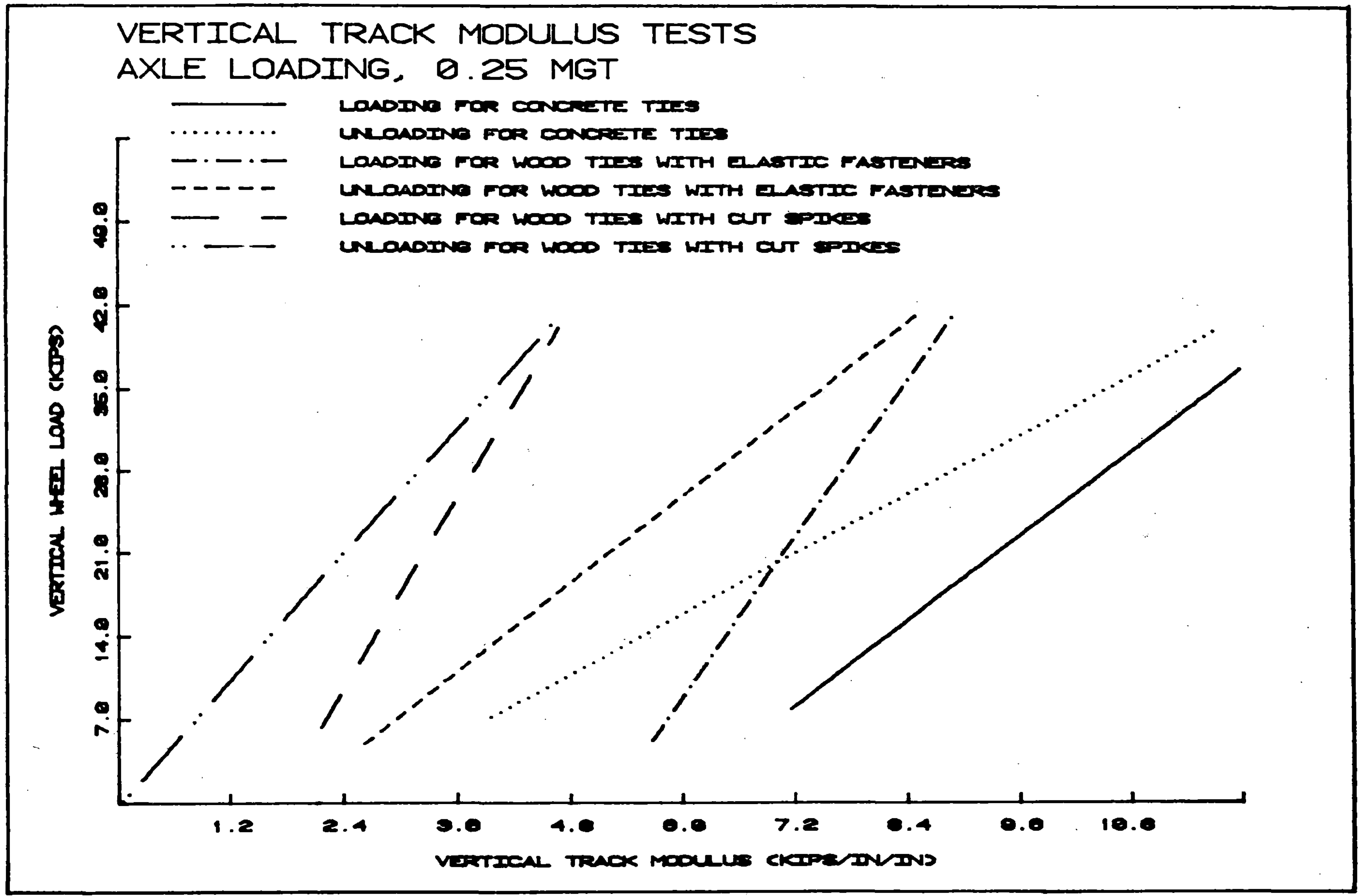

Figure 17. Comparison of the Vertical Moduli for the Different Track Structures, from the Axle Loadings at 0.25 MGT.

[redacted]

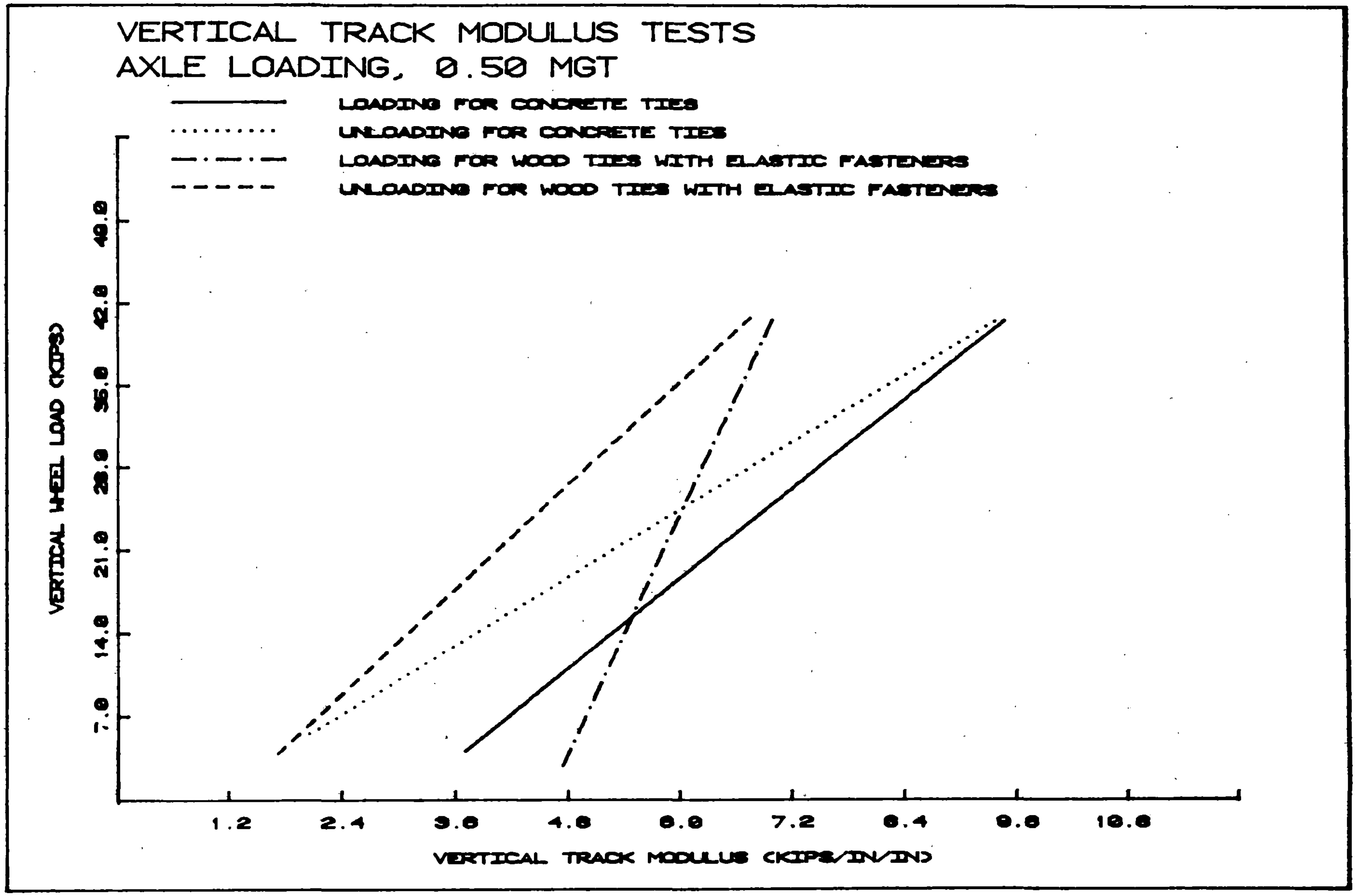

Figure 18. Comparison of the Vertical Moduli for the Different Track Structures, from the Axle Loadings at 0.50 MGT.

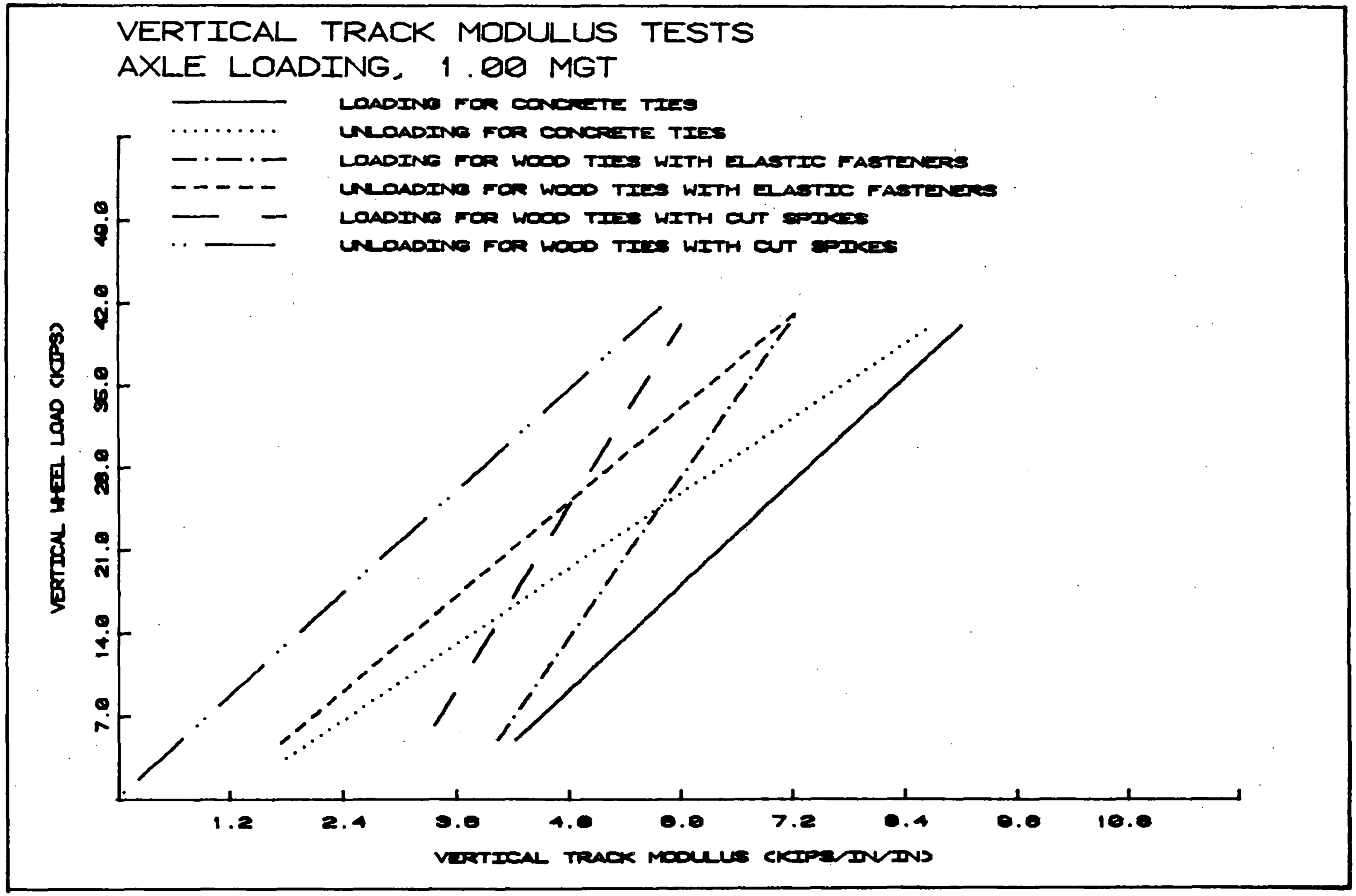

Figure 19. Comparison of the Vertical Moduli for the Different Track Structures, from the Axle Loadings at 1.00 MGT.

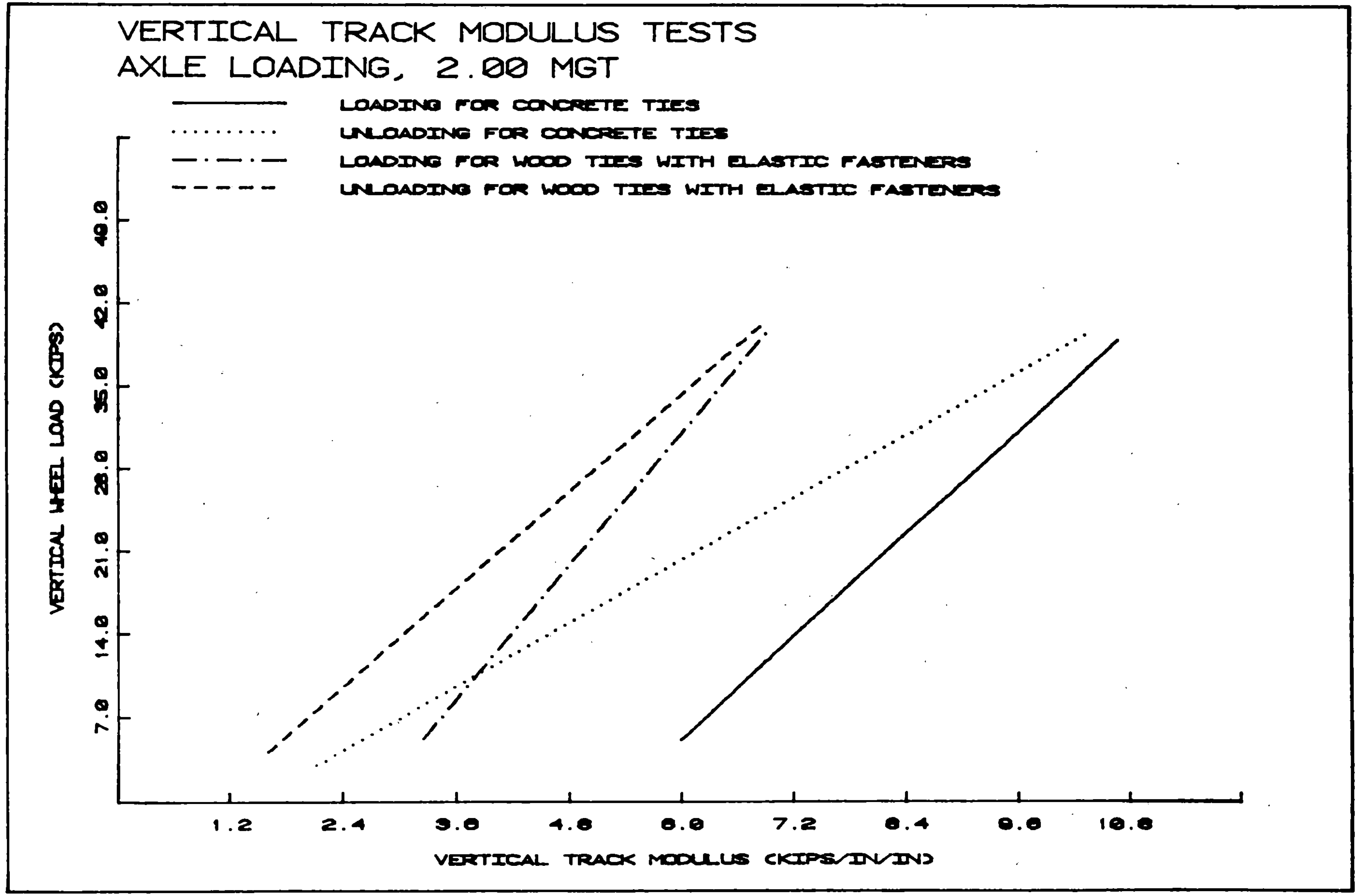

Figure 20. Comparison of the Vertical Moduli for the Different Track Structures, from the Axle Loadings at 2.0 MGT.

overcome. For the 27 and 33 kip loadings, the comparative results agreed with those found using the single axle loadings.

Considering the results from the axle loadings, plotted as a function of the vertical load in Figures 16 to 20, it can be seen that at zero MGT the area enclosed by the loading and unloading cycles from each of the track structures was inversely proportional to the value of the vertical track modulus. This area, which is related to the hysteresis loop between the loading and unloading cycles, is the sum of the energy dissipated by the track structure and the permanent track deformation. These results tend to indicate that the concrete tie track will dissipate less energy than conventional track, and/or it will have less permanent deformation during each cycle. The wood tie track with elastic fasteners falls between the two extremes. This observation seems to hold for all the MGT levels tested, with the exception of 0.25 MGT, where the conventional track had less enclosed area than the other two track structures.

3.3 Gage Widening

The lateral load required to deflect the rail a given amount, as a function of the number of cycles, was determined from the gage widening test data. These results are given in Figures 21 and 22 for rail head displacements, of 0.25 and 0.50 inch, respectively.

The results indicated that for a 0.25 inch rail head

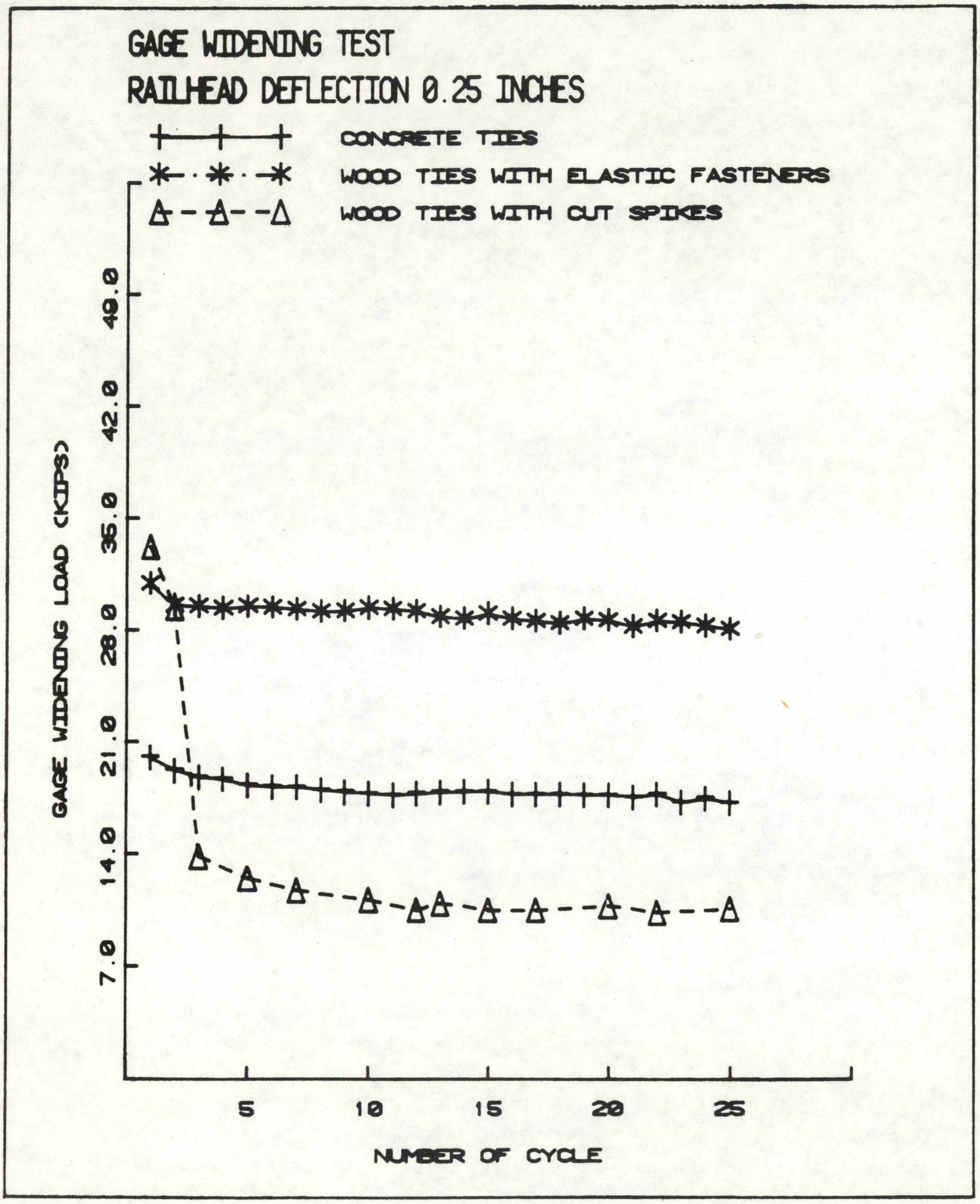

Figure 21. Load Required to Displace the Rail Head 0.25 Inch, as a Function of the Applied Lateral Load, for the Different Track Structures Tested.

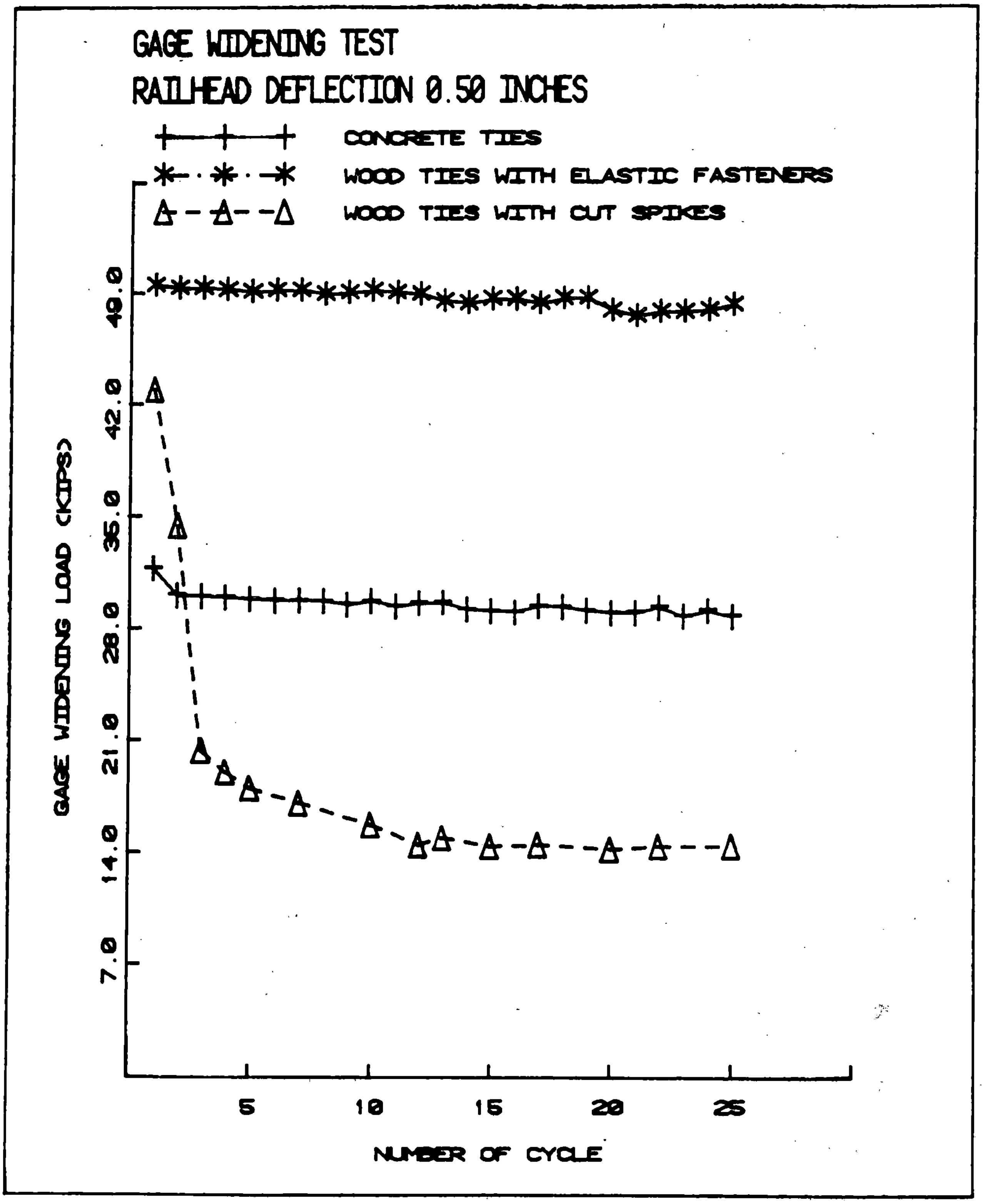

Figure 22. Load Required to Displace the Rail Head 0.50 Inch, as a Function of the Applied Lateral Load, for the Different Track Structures Tested.

deflection, and all three types of track structures, most of the damage occurred during the first cycle of loading. After the initial damage, the lateral load required to displace the rail head stabilized for all three track structures. This initial damage was very apparent for the conventional track and was noticeable for the other two track structures. It could also be seen that the conventional track was "weaker" than the other two track structures, followed by the concrete tie track, and then by the elastic fasteners on wood ties. Once the load stabilized, an additional lateral load was required to reach the same deflection, e.g., compared to wood tie track with elastic fasteners, the values were 2.75 times higher for conventional track and 1.65 times higher for the concrete tie track. Similar results can be seen in Figure 22, for a 0.50 inch of rail head displacement, but with two exceptions. First, for the wood tie track with elastic fasteners there was no initial damage, and second, the lateral load ratios among the different track structures changed to 2.07 for the concrete tie track and 3.44 for wood tie track with elastic fasteners.

The rail head deflection wave shapes are plotted for the three different track structures at three arbitrary load cycles: 1, 10, and 25, in Figures 23, 24, and 25, respectively. These plots show the rail head deflection wave shapes for a maximum deflection of 0.50 inch at the point of loading. Analyzing these results, it can be seen that for the first cycle, the deflection wave shapes were very close to each other for all

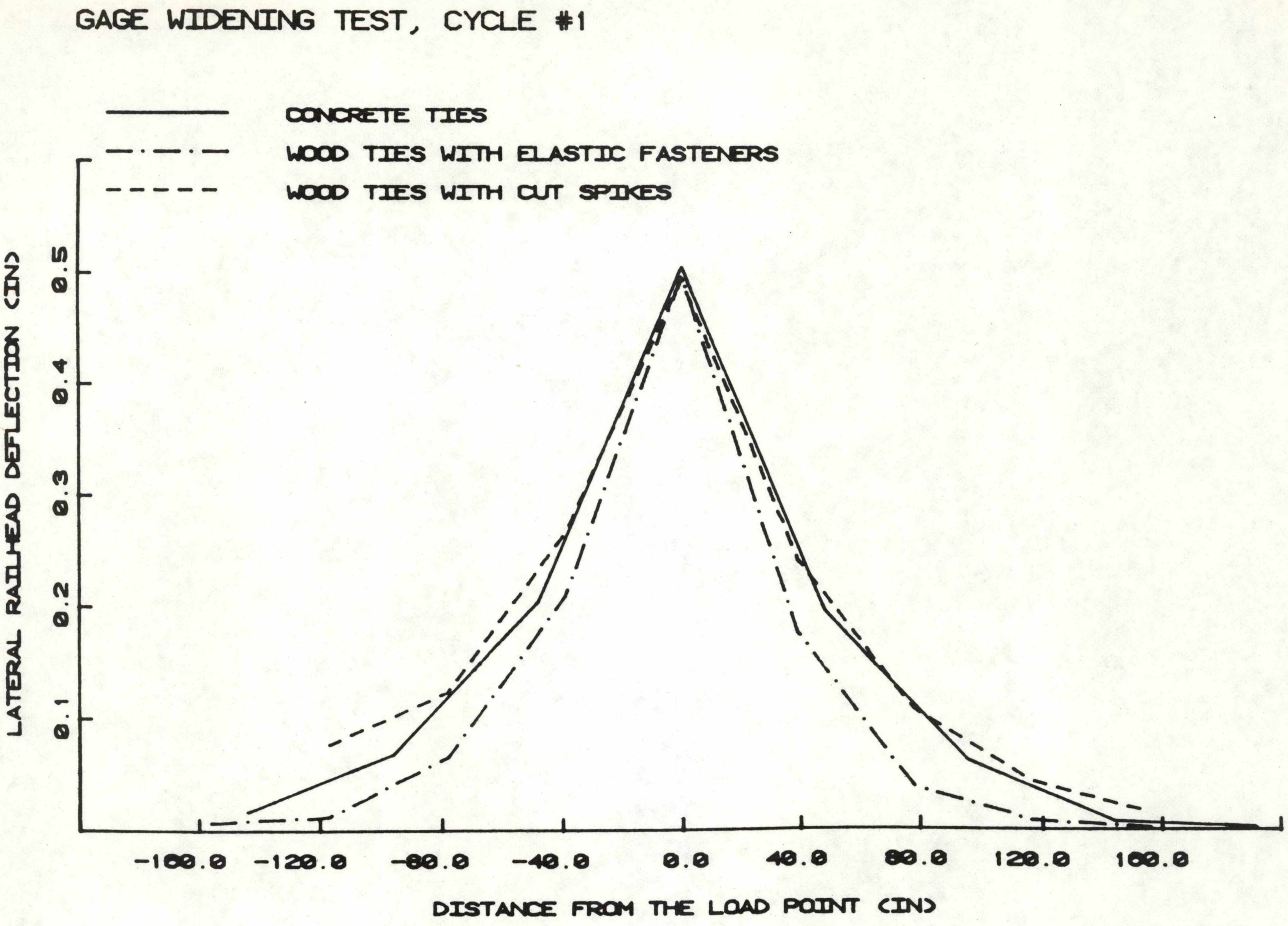

Figure 23. Deflection Wave Shapes for the Three Different Track Structures, Under a Cyclic Gage-Widening Load, After Cycle 1.

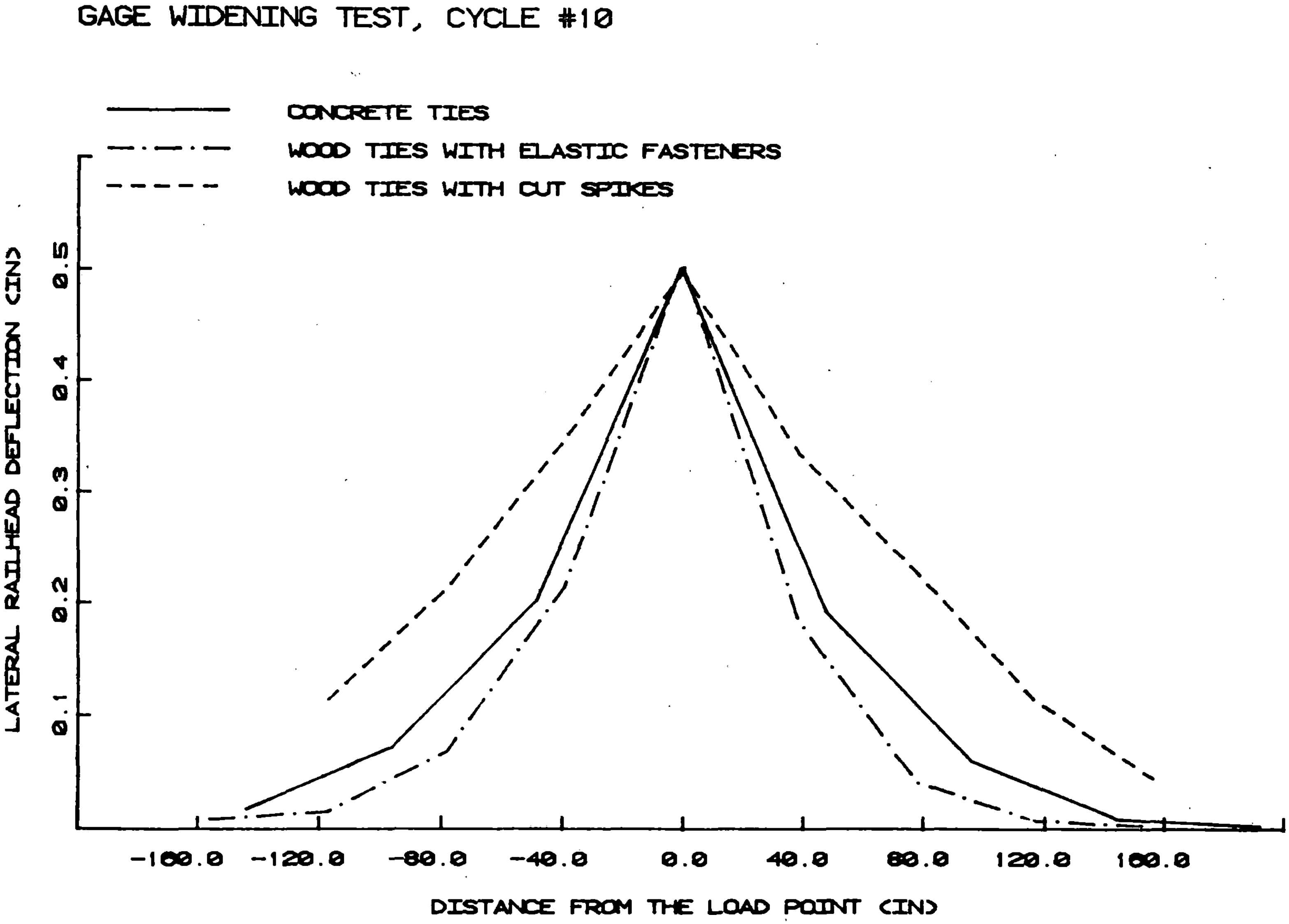

Figure 24. Deflection Wave Shapes for the Three Different Track Structures, Under a Cyclic Gage-Widening Load, After Cycle 10.

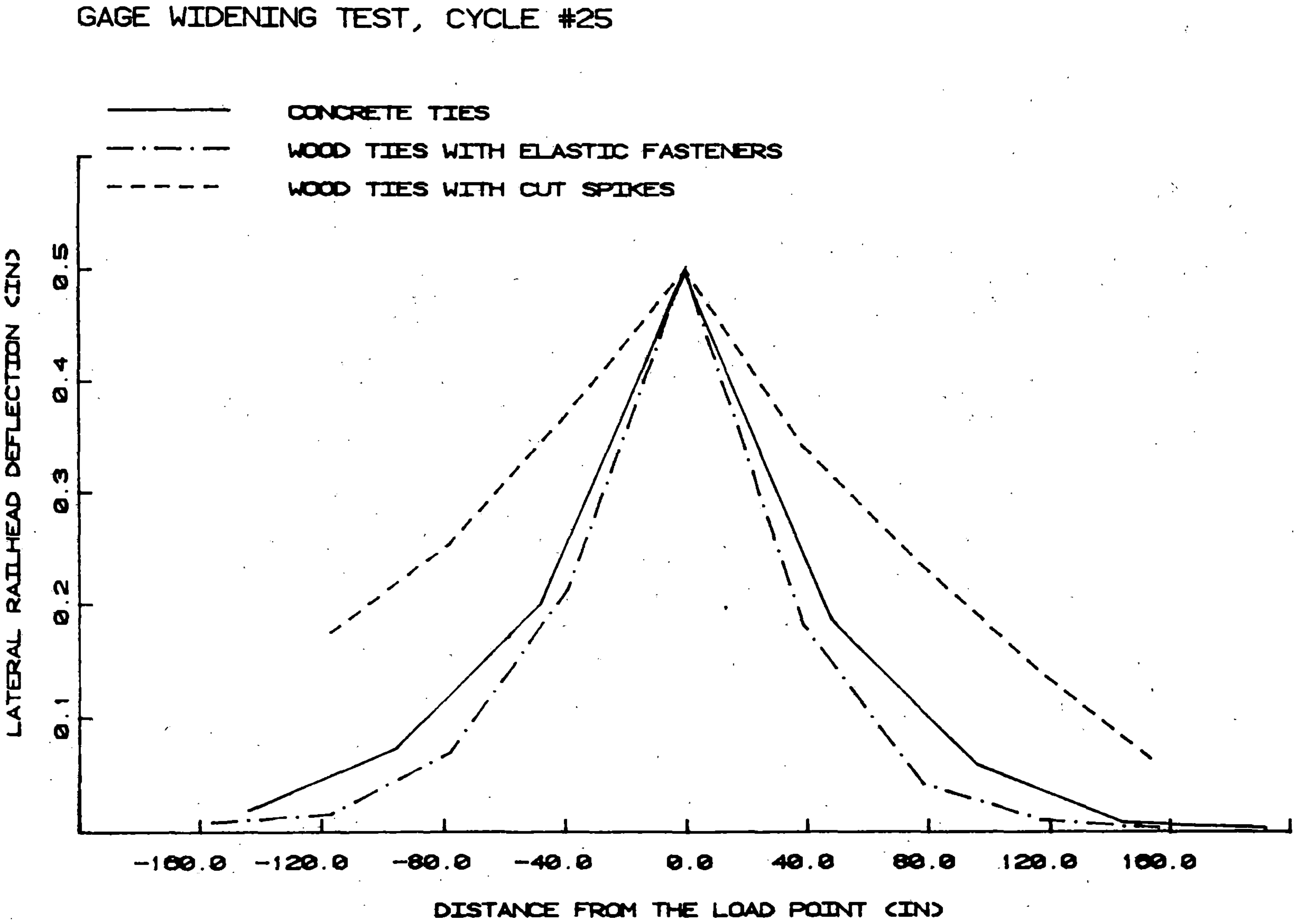

Figure 25. Deflection Wave Shapes for the Three Different Track Structures, Under a Cyclic Gage-Widening Load, After Cycle 25.

three track structures. As the number of loading cycles increased to 10 and then 25 (Figures 24 and 25), the deflection wave shapes for the concrete tie and wood tie track with elastic fasteners remained the same, whereas the wood tie track with cut spikes progressively became wider at the outer regions, i.e., the deflection at a given location away from the applied loading point became larger as the number of loading cycles increased. These wave shapes indicate that conventional track is progressively damaged outwardly from the point of loading with increasing cycles, whereas it shows an elastic behavior for the other two track structures. This is, however, not an indication that progressive damage does not occur in these other two track structures. It is just that the rate of damage is much smaller and cannot be detected for the relatively limited number of cycles used in these tests. Note that the loads given after the test definition in these three figures are the loads required to displace the rail head by 0.50 inch.

4.0 CONCLUSIONS

From results obtained during the lateral resistance tests, it was concluded that under vertical loads and consolidation there were no appreciable differences in the lateral track strength among the three structures tested. In the unconsolidated state, the concrete track was strongest, followed by the wood tie track with elastic fasteners and the conventional track. Finally, with no vertical load, the concrete track had a higher stiffness than the other two types.

The vertical modulus tests indicated that the concrete tie track had the highest modulus. The wood tie track with elastic fasteners showed an increase in modulus, as compared to the conventional track, by a factor of two, and thus, it can be assumed that the premium fasteners increased the vertical modulus of the track structure.

The gage widening tests indicated that the premium fasteners were stronger than cut spikes. Also, there was less progressive damage in the region of the lateral load application. Under track conditions where excessive lateral rail deflections might occur, such as over a failed tie fastener, it would not damage the adjacent fasteners.

These results indicated that, in comparing the three different track structures, the concrete tie track was best in terms of the lateral resistance, since the strength of the unloaded state, (important in track-buckling problems) was higher than the other two. The vertical modulus can be increased by using premium fasteners, and, thus, the wood tie track with elastic fasteners was better in this area. Concrete tie track will have the highest modulus, but it could be so stiff that the resultant dynamic loadings could cause other problems. Wood tie track with elastic fasteners is the strongest track with respect to gage widening.

These results are by no means conclusive, relative to which track structure is optimal, but they do offer a first order approximation as to the characteristics of each type of track. With additional tests to reinforce these data, an engineering decision could then be made as to which track structure would be most appropriate for an existing situation.

5.0 REFERENCES

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~~KRICK, R.~~

~~BANG~~, A. AB

~~KRUCKOW, B.~~ BK

DOBSON, K.

~~RRS-31~~

~~RRS-32~~

File: Bowers

Comments:

An International Government-Industry Research Program
Track Train Dynamics
3140 South Federal Street ′ Chicago, Illinois 60616 / Telephone: (312) 567-3585

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January 22, 1986

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Enclosed is a copy of AAR Report, R-614, "Laboratory Tests on Three Alternative Track Structures." This report presents the results of a study to determine the structural characteristics of three different track structures, and to determine the improvement obtained by using premium fasteners in concrete ties. The results indicate that additional investments in fastening and tie systems do produce a track structure which has substantially different strength characteristics from conventional North American track. This test was sponsored by the Federal Railway Administration as part of the Track Train Dynamics program.

Sincerely,
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A. J. Reinschmidt

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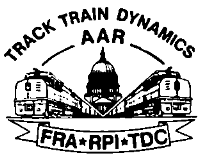
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