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EMBANKMENT SUPPORT FOR KANSAS TEST TRACK

ANALYSIS OF EMBANKMENT INSTRUMENT DATA

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16. Abstract

Static and dynamic data collected from the embankment instrumentation at the Kansas Test Track are summarized in this report. The static data included permanent horizontal and vertical deformation measurements, moisture contents, and temperatures taken at intervals between the end of embankment construction in Fall 1971 to the opening of the track for traffic in October 1974. Data were also collected through April 1975 after the track was opened to traffic. Dynamic instrument response was measured at three periods between October 1974 and April 1975. The dynamic data include horizontal and vertical deformations and embankment pressure under traffic loads. The static and dynamic response and performance of each test section are analyzed, and the results are summarized.

The track was closed to traffic in June 1975 because of relatively large track displacements. During the summer of 1976, the embankment was inspected with test pits by others to study the causes of the large displacements. These investigations were observed, in part, by Shannon & Wilson, and observations are presented on performance of embankment and instrumentation.

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EMBANKMENT SUPPORT FOR A RAILROAD TEST TRACK
ANALYSIS OF EMBANKMENT INSTRUMENT DATA

INTRODUCTION

Background

The Federal Railroad Administration of the United States Department of Transportation (DOT) and the Atchison, Topeka, and Santa Fe Railway Company (ATSF) are jointly sponsoring an investigation into methods of providing more stable railroad track structures for present and future operating conditions with high speed trains and heavily loaded cars. ATSF has established a test embankment on a mainline of its system between Aikman and Chelsea, Kansas. The site selection was influenced by the presence of abundant rail traffic, a long straight tangent section, uniform and relatively flat grades, a good performance record under mainline traffic conditions, and other factors. The test segment was considered to be reasonably typical of much of the country's railways, and the uniform soil conditions and gentle terrain were suitable for construction of a uniform test embankment at reasonable cost.

Shannon & Wilson, Inc., under a previous contract to ATSF, designed the embankment for the test structures, developed embankment instrument criteria, furnished instruments, observed and tested the embankment during construction, and installed embankment instrumentation. Previous reports, "Embankment Support for A Railroad Test Track - Design Studies" (Ref. 1) and "Embankment Support for a Railroad Test Track - Construction Report" (Ref. 2), covered the design and construction of the embankment.

The design and construction objective was to provide an embankment that would furnish uniform support of good quality to the test track using native materials and placement criteria that would not exceed current railway practice. The selection and design of the track support and ballast systems were accomplished by others.

The project consists of an embankment with track support systems constructed adjacent to and offset 30 feet from the existing ATSF mainline. The test embankment is nearly two miles long on a slight grade, and transition sections at each end divert mainline traffic onto it and then back to the mainline. The embankment has nine test sections, and each section has a unique track support system. The support systems include concrete ties at three different spacings, a concrete tie section with a larger ballast thickness than used elsewhere, a concrete slab, a continuous concrete beam, a precast beam, stabilized ballast, and a control section typical of conventional ATSF construction. Each test section has identical embankment instrumentation. A road along the test embankment provides access for periodically reading the instruments and observing the test track.

The test embankment geometry is a standard ATSF design. The design studies established a minimum depth of six feet for the embankment, and this minimum depth was maintained throughout the length by overexcavating native soils and rock, as required. The embankment was constructed of highly plastic native clay which was placed to a uniform relative compaction of about 90 percent (ASTM D 1557). Six inches of lime stabilized clay was provided on the upper surface of the embankment to minimize the softening of the surface due to the effects of weathering. After completion of the embankment in the fall of 1971, approximately six inches of ballast was placed. In the spring of 1972, the remainder of the ballast was placed, and the track support structures were completed.

The instrumentation was installed in the fall of 1971. Between the fall of 1971 and April 1975, nine sets of static embankment data were obtained. Four sets of dynamic embankment data were obtained between the track opening in November 1974 and April 1975. Relatively large track displacements were experienced in the winter and spring of 1975, leading to closing of the test track in June 1975.

A study is now being undertaken by others to evaluate the performance of the embankment and track structures. The embankment and embankment instrument studies are being performed by the U.S. Army Engineer Waterways Experiment Station (WES). A Shannon & Wilson representative visited the site during the WES field investigations in May 1976. Observations were made in embankment test pits and of selected excavated instruments.

Scope

This report includes the compilation, analyses, interpretation, and presentation of selected embankment instrument data. The static data were obtained by representatives of Shannon & Wilson, and include horizontal and vertical deformations, moisture contents, and temperatures. Dynamic data were recorded and furnished to us by others. The dynamic data include horizontal and vertical deformations under traffic loads and embankment pressures under traffic loads. The static and dynamic response and performance of each test section are analyzed, and the results are summarized. Observations of embankment and instruments from the May 1976 site visit are also presented.

Presentation

Volumes I and II were prepared under this contract. This report is Volume I and contains discussions of project background and scope, available instrumentation data, data reduction procedures, performance of instrumentation, static and dynamic performance of the embankment, observations of embankment and selected instruments after track closure, and summary and recommendations. Volume II consists of Appendices A through E which contain a more detailed description of computer programming and analysis procedures, computer data listings, and computer plots.

Responsibility

The project was accomplished under the general direction of Mr. Rudy J. Dietrich, Senior Vice President. The project was accomplished under the direct supervision of Dr. J. Ronald Salley, Principal Engineer, who also participated in the analyses and preparation of the report. Mr. P. Erik Mikkelsen, Senior Engineer, was responsible for observing the recording of dynamic data by the Portland Cement Association (PCA), taking static data concurrently, and reducing and assisting in analyses of static and dynamic data and preparation of the report. Computer programming and data processing were accomplished by Mr. Holly Ellis. Mr. Stanley D. Wilson, Executive Vice President, reviewed the analyses and report.

EMBANKMENT INSTRUMENTATION AND AVAILABLE DATA

General

Each of the nine individual test sections has one main instrument array. The main arrays were supplemented by additional instruments spaced throughout the test section to verify that the performance of the embankment at the main array is typical of that particular test section. A schematic plan of the test embankment is shown in Fig. 1.

The main array has been positioned near the west (downgrade) end of each test section on the premise that measurements will be made principally under west-bound rail traffic. This provides an additional length of track for damping of non-uniform response, which may develop at the interface between different test track structures, before the main array is reached by west-bound traffic.

The embankment main array instrumentation includes vertical extensometers, portable horizontal extensometers which were inserted into horizontal tubing embedded in the embankment, pressure cells, and moisture-temperature cells. With the exception of the moisture-temperature cells, the instrumentation was designed specifically for this project. Wherever possible, existing equipment was adapted or stock components utilized. The location of the instrumentation within the embankment is illustrated in Fig. 2 and 3. Instrumentation design concepts and performance criteria are presented in Ref. 1, and detailed descriptions of the instrumentation are presented in Ref. 2.

Vertical Extensometers

Vertical embankment deformations between a common point at the surface of the subgrade and intermediate points within the embankment and at rock are measured with vertical extensometers.

Because of the common point at the surface of the subgrade, all permanent and dynamic deformations may be referenced to the extensometers anchored in rock.

The vertical extensometers were installed following embankment construction by drilling vertical holes through the embankment and into rock. Anchor assemblies were inserted into the hole and fixed in position either by grouting into rock or by hydraulically expanding prong anchors into the soil forming the sides of the drill hole. An LVDT transducer with linear displacement ranges of ± 1.0 inch was positioned immediately above each anchor point, and brass riser rods were extended and fixed to a common bracket in a terminal box seated at the embankment surface. Oil-filled PVC tubing surrounded each riser rod to minimize friction and was terminated at a slip coupling in the terminal box. Three anchors were generally placed within the embankment; however, if the rock was present within 12 inches of the base of the six-foot minimum thickness embankment, the lowest embankment anchor was eliminated. The hole was backfilled with polyurethane foam which was poured into the hole and allowed to expand into place. The purpose of the foam was to maintain an open hole in the soil with a material having a low elastic modulus that would not interfere with anchor deformations.

Three multi-position extensometer assemblies were placed in each main instrument array. One was placed under the center of the track, the second underlies the north rail, and the third was placed at the north side of the embankment, four feet from the rail. All three lie in the same embankment cross-section. Four single-position extensometers were also installed in each test section, all beneath the track centerline. Three were spaced at 100-foot (nominal) intervals east of the main array, and one was placed 100 feet west of the main array. The spacings were adjusted slightly so that each extensometer would lie directly beneath a tie for the tie-supported structures.

Horizontal Tubing and Portable Horizontal Extensometers

Horizontal tubing. At each main instrument array, horizontal, four-inch diameter corrugated, non-perforated, polyethelene tubing was placed at four levels in the embankment during construction as shown in Fig. 2. The tubing has specially machined three-inch diameter, Schedule 80, PVC couplings at 2.5- and 5.0-foot spacings which were anchored in the embankment. The couplings were attached to a three-foot length of PVC pipe which protruded one foot on the open side of the embankment. The tubing was installed in trenches across the embankment and back filled immediately around the tubing with sand, and the remainder of the trench was backfilled with compacted clay. Protective enclosures were placed around the ends of the tubes where they protruded from the embankment.

The PVC couplings provide the reference points for measuring horizontal static and dynamic embankment deformations. These couplings are coupled to the embankment by friction and are expected to conform to the free-field embankment deformation. The thin gauge corrugated tubing provides a flexible connection between couplings.

Coupling survey. Periodically after installation, the distances of the tube couplings from the ends of the PVC pipe at the end of the tubing were carefully measured with steel gaging rods having a reference hook on the end. The hooked end would be inserted past a coupling and then withdrawn until the hook engaged the shoulder of the far side of the coupling. A measurement would be estimated to the nearest 0.001 foot through use of a scale and a special end cap for the PVC pipe. The length to the end of the tube was also measured.

Portable horizontal extensometers. Three portable horizontal extensometers were provided for measuring the change in distance between two tube couplings under dynamic loading conditions. The gage length of the portable extensometers can be adjusted to 2.5 or 5.0 feet. Anchors at the ends of the extensometer expand and lock into the tube couplings. An LVDT at one end of the extensometer senses dynamic deformations caused by passing rail traffic. The available displacement range for this LVDT is ± 0.5 inch. A schematic of the device is shown in Fig. 3. Three of these instruments were available for positioning at a test section during the recording of dynamic data. The instruments are installed by positioning them in the tubing with the strain rods, extending the anchor points, and then removing the installation rods. The instruments are removed from the tubing by retracting the anchor points hydraulically and pulling on an attached cable.

Pressure Cells

Three pressure cells were installed in the upper portions of the embankment in each main array to measure stresses. Cell locations are shown in Fig. 2. The cells consist of two, six-inch diameter pressure diaphragms welded to 0.5-inch thick rings. The cells are oil-filled, and applied pressure is transmitted directly to a diaphragm in the attached LVDT pressure transducer. The diaphragm moves a magnetic core within the transducer whose output has been calibrated with pressure. A cavity on the back side of the pressure diaphragm is connected to a tubing which vents to the atmosphere in the eight-inch pipe terminal at the side of each main array.

Moisture-Temperature Cells

A moisture meter and soil cells were used for determining moisture content of the embankment. Thirteen soil cells were buried during the embankment construction at each of the nine main arrays. A soil cell consists of screen electrodes with fiberglass wrapping encased in a thin stainless steel case which is 1.0 by 1.3 inch. A small thermister for sensing temperature is also contained in the case. Location of the cells is shown in Fig. 2. Calibration studies were performed before installing the cells.

Data Acquisition Periods

Installation of embankment instruments was completed in October 1971, and an initial set of static data (vertical extensometers, tube coupling survey, and moisture-temperature cells) was taken at that time. Subsequent static data were collected in March and December 1972 and November 1973 during installation of track structures. A "running-in" period in November 1974 consisted of routing freight train traffic over the test track. Between freight trains, a "work train" was moved past each section at a very low speed (creep) and at a speed of 30 mph while dynamic data (vertical extensometers, portable horizontal extensometers, and pressure cells) were recorded. Static data readings were taken before the "running-in" period in late October and on November 8, 1974, after the dynamic data were recorded. The "running-in" period continued until November 14, 1974. The test track was then shut down while switches were removed and permanent track was installed at the transitions between test track and the mainline track.

The test track was opened to full mainline traffic on December 10, 1974. The first quarterly set of dynamic data was taken in December 1974 (nonconventional beam and slab track structures, Sections 4, 5, and 7) and January 1975 (conventional track structures, Sections 1, 2, 3, 6, 8, and 9). Static data were collected at the beginning, December 1974, and at the end, January 1975, of this quarterly set of readings. Additional sets of static and dynamic data were collected during the second quarterly readings in April 1975. The test track was closed in June 1975. The data acquisition periods are summarized in Table 1.

Actual car weights were used for the analysis of the dynamic embankment data. The "work train" used for the November 1974 loading consisted of a weighed locomotive, two loaded hopper cars, and caboose. Data from the December 1974 and January 1975 quarterly readings under mainline freight traffic were obtained with completely weighed trains. Rail seat loads were monitored by PCA during these periods, but the data from some sections were determined by PCA to be unusable because of calibration problems. These problems were overcome, and the April 1975 rail seat loads for all sections were available for analysis.

Sources of Data

Static data were collected by representatives of Shannon & Wilson, Inc. Recording of the dynamic data was accomplished by personnel and recording equipment of PCA. A Shannon & Wilson representative observed the collection of dynamic data on a part-time basis while collecting static data. PCA recorded dynamic embankment data along with track data and provided the data in analog form to Shannon & Wilson for analysis. The embankment and rail seat load data were in the form of oscillograph traces of instrument response for complete trains. PCA provided the appropriate constants for calculating response of the instrumentation in engineering units.

In some instances, dynamic data are missing because of hookup and recording problems. Time commitments and the availability of trains usually precluded a second attempt at recording dynamic data when recording problems were identified.

DATA REDUCTION PROCEDURES

General

The static instrumentation data were listed on data forms, key punched, and reduced to engineering units by computer data processing methods. Dynamic instrumentation data traces were manually reviewed to select instrument response for known train loads, and the data were listed on data forms, key punched, and reduced to engineering units, also by computer methods. The data reduction programs were written in FORTRAN IV language. A description of data reduction procedures is given in Volume II, Appendix A.

Static Data Reduction

Static data from vertical extensometers, from tube coupling surveys, and from moisture-temperature cells were reduced by separate programs. The programs all follow the same basic flow of operations shown in Fig. 4, i.e, input of special instructions, input of general data file, input of instrument data file (raw data), conversion of raw data to engineering units, and output of tabulated and/or plotted data. The general data file contains the calibration constants and position coordinates of each instrument. The instrument data file contains the raw data for each instrument on all acquisition dates from all test sections. The output for each set of static data consists of an initial data listing for each instrument type which is a list of input data and the calculated engineering units. A summary of engineering units is then tabulated for each instrument type. These tabulations are contained in Volume II, Appendices B through D, respectively, for vertical extensometer data, tube coupling surveys, and moisture-temperature cell data.

The vertical extensometer initial data listing presents the LVDT core deflection from the null position at which it was set during construction. The vertical extensometer data summary lists the changes in deflection from October 1971, when the first complete set of readings was taken at the end of embankment construction. The initial listings and the summaries are presented in Volume II, Appendix B along with plots of embankment deformation versus time. The plotted quantities correspond to the deformation between the surface and the first anchor and between adjacent anchor positions for multi-position extensometers.

The tube coupling initial data listings present the distances to each coupling and the spacing between couplings for each date. The tube coupling data summary presents the change in distance between adjacent couplings from October 1971 for each date, expressed both as a distance and a strain. Plots of strain between adjacent couplings are also presented with the listings in Volume II, Appendix C.

The moisture-temperature cell initial data listings contain temperature and moisture cell resistance readings for each cell and date. Moisture contents were not interpreted from the resistances because of the erratic nature of many of the results; this is discussed in detail in later sections. The initial data listings and summaries are contained in Volume II, Appendix D.

Dynamic Data Reduction

The program to reduce dynamic data follows the same general flow of operations as the static programs, see Fig. 4. Dynamic data for complete trains were recorded on oscillograph charts; typical traces for portions of trains are shown in Fig. 5 and 6. Occasionally, minor peaks on the traces suggested the presence of a wheel with a flat spot, but none are included in Fig. 5 and 6. Each instrument response for a known train loading was manually selected from the traces and input into the data reduction programs with the appropriate sensitivity, attenuation, and calibration factors. The response to the locomotive axle loads was primarily chosen for analysis because of the locomotives' near constant load of 65 kips per axle. This axle loading is significantly larger than that for typical cars which ranged from 5 to 35 kips. Deformations depend on the sum of the two or three axle loads on one end of each particular locomotive, which may be more or less than one-half the sum of the total locomotive load. Response to car axle loads was also analyzed on a selective basis and compared to the response from locomotives. The spacing and loading of the axles are shown in Fig. 7 for typical four- and six-axle locomotives and for a typical car.

Initial data listings for vertical extensometers and portable horizontal extensometers indicate deflection in inches due to the selected train loading. The listing also includes pressure cell response in psi. Weight of the locomotive axle and speed are also listed. The vertical extensometer data are further summarized in an abbreviated listing of axle load, car type, speed, and instrument response for each data acquisition period. These initial data listings and summaries are contained in Volume II, Appendix E.

PERFORMANCE OF INSTRUMENTATION

General

The embankment instrumentation was fabricated in 1970 and was installed in the embankment during the period of May through October 1971. Some instruments became inoperative after installation. They may be repairable, but no attempt has been made to repair them. Dynamic records were not obtained from a number of instruments which produced satisfactory response with static readout boxes. The reason for the failure to record these dynamic responses is not explained but may be attributable to the recording circuitry. A summary of dynamic instrument performance is presented in Table 2.

Vertical Extensometers

Static. Of the 126 total LVDT's comprising the vertical extensometers, only one ceased to function after the November 1973 data collection period. All others have performed satisfactorily. However, deformations of the embankment due to mainline traffic have caused many of the LVDT's to reach their limit of downward travel. This occured when the LVDT core moved downward about 1.4 inches from the null position at which it was set during installation. During the December 1974, January 1975, and April 1975 readings, respectively, 1, 6, and 31 LVDT's had apparently bottomed-out (taken as deflection from null equal to or exceeding 1.3 inches).

Dynamic. During the November 1974, December/January 1975, and April 1975 data collection periods, the number of LVDT's not producing valid data numbered 23, 25, and 59, respectively. In addition to the bottoming-out of the LVDT's, other sources of malfunction were possibly faulty recording circuitry and off scale on the recorder.

Horizontal Tubing and Portable Extensometers

Horizontal tubing. The horizontal tubing performed favorably, and no detectable tubing diameter changes occurred since construction. The tubes often produced water, and during the 1975 readings mud was generally found in the upper tubes. Field mice burrowed beneath the exposed PVC pipe at the ends of the tubes and caused some movements of the pipe. A thin layer of concrete was placed on the embankment side slope within the enclosure for the tube ends during the spring of 1975 to discourage the presence of field mice and to provide a more stable and desirable working surface.

Portable extensometers. The portable horizontal extensometers performed well in each set of dynamic measurements.

Pressure Cells

Of the 27 pressure cells installed, two did not give dynamic responses. The instrument numbers of the inoperative pressure cells are 2202 and 6201. Satisfactory response of the other cells was verified by observing a response to load, either with dynamic recorders or with a static recorder. Cells for which satisfactory dynamic traces were not obtained numbered 17 in the November 1974 recording session, six in December/January 1975, and six in April 1975. During the May 1976 site visit, Cell 2201 was also found to be inoperative, although it had performed satisfactorily in January 1975. Except for the three inoperative cells, the other problems are not explained, but may be due to faulty circuitry.

Moisture-Temperature Cells

Of the 117 moisture-temperature cells installed in the embankment, the temperature measuring capability of all but six was functioning satisfactorily in April 1975. The moisture cells, however, functioned less satisfactorily. Only about ten percent of the cells appeared to produce valid data in April 1975. The remaining cells produced variable readings that indicated moisture content increases that were unrealistically high.

STATIC PERFORMANCE

Vertical Deformations

General. Permanent vertical deformations of the embankment were determined from the nine sets of static vertical extensometer readings taken between the completion of embankment construction, October 1971, and April 1975. The extensometer data for the three multi-position extensometers in each main array have been summarized in plots of deformation versus depth. These plots are contained in Fig. 8 through 16, respectively, for Sections 1 through 9. Figure 8 shows plots of deformation versus depth for the shoulder, rail, and centerline multi-position extensometers for Section 1. The plotted deflections are relative to rock. The deflection versus depth curves were developed by taking the deformation of the anchor to rock (No. 4) as being the overall movement of the top of the embankment and subtracting movements measured by the intermediate anchors. For example, the movement at a depth of 1.3 feet relative to rock was determined by subtracting the deformation measured by the Anchor 1 extensometer between the embankment surface and a depth of 1.3 feet from the movement determined by Anchor 4 between the embankment surface and rock. The inclination of the curves reflects the direction and intensity of strain between anchor points. For curves inclined upward to the left, expansion of the embankment is indicated; for curves inclining upward to the right, settlement is indicated. A vertical portion of the curve would indicate no average strain over the vertical interval.

The permanent vertical deformations at the top of subgrade for each main array rail extensometer to rock are plotted versus time in Fig. 17. This plot shows some of the data presented in Fig. 8 through 16 in a different format. These data are discussed in following sections.

Deformations versus depth. The extensometer versus depth data are shown for four dates; the plots represent the changes in deformation from October 1971. The October 1974 readings preceded the "running-in" period and the November 1974 readings were near the middle of this period. The track opened to mainline traffic on December 10, 1974, and the December 1974, January 1975, and April 1975 readings were under mainline traffic.

The pattern of embankment swell for all sections was essentially the same. The pattern of embankment settlements varied somewhat between sections. The shoulder extensometers revealed a progressive and fairly uniformly distributed swelling of the embankment of about one inch to October 1974 and then showed little change through April 1975. The rail extensometers showed an average 0.5 inch swell to October 1974 and then a continued apparent settlement with time in essentially the upper 1.3 feet. This settlement ranged between 0.1 and 0.6 inch over the first half of the "running-in" period, October through November 8, 1974, 0.5 to 1.6 inches between October 1974 and January 1975, and 1.1 to 2.2 inches between October 1974 and April 1975. The rail settlements between January and April 1975 were probably larger than stated for Sections 1, 2, 3, 4, and 6, because the extensometers beneath the rail bottomed-out during this period.

The centerline extensometers showed slightly more than 0.5 inch swell to October 1974. The compression due to traffic was somewhat less than at the rail and mostly occurred in the upper 1.3 feet. The centerline compression was essentially nil for the beam structures, Sections 4 and 7.

The distribution of embankment heave with depth is shown on the deflection versus depth curves (Fig. 8 through 16) for the shoulder, rail, and centerline extensometers on October 1974, prior to embankment loading. The heave strain as indicated by the slope of the deflection curve is usually the smallest in the center of the embankment, largest at the top, and intermediate at the bottom. Larger heave strains at the top of the embankment appear to be due to low static stresses and the occasional presence of free water. The intermediate heave strains at the base of the embankment may be caused by the occasional presence of free water within the rock beneath the embankment.

Top of embankment displacements. Permanent displacements of the top of the embankment over the period of traffic are listed in Table 3; the data represent the changes in deformation from October 1974. This data is summarized graphically in Fig. 18 where top of embankment displacements at the rail extensometers over the period of traffic are plotted versus calculated top of embankment stresses. The top of embankment stresses were estimated using distribution of axle load to tie relationships determined from instrumented ties by PCA. A locomotive axle was then assumed to overlie a tie, and base of tie stresses were attenuated at 1.0(H) to 2.0(V) through the ballast. Stresses beneath nonconventional structures were estimated assuming 1.5 locomotive axles were supported by each ten-foot segment of structure.

An examination of the embankment displacements under traffic, which are presented in Table 3 and Fig. 18, led to approximate comparisons of the behavior of the test sections. Sections 1, 2, 3, 4, and 6 experienced essentially similar displacements beneath rail and centerline through April 1975. The rail extensometers in these sections bottomed out between January and April 1975, so the displacement beneath the rail may be more than the 1.7 to 2.3 inches indicated. The actual displacement may be about one inch more than that indicated, based upon the increase in the centerline settlement over this period. Sections 5 and 7 experienced about the same displacements which were the lowest observed. The rail settlements amounted to about 1.2

inches through April 1975. Sections 8 and 9 also experienced similar behavior with somewhat more settlement than Sections 5 and 7 but considerably less than Sections 1, 2, 3, 4, and 6. The rail settlements amounted to about 1.8 inches, and the centerline settlements were about 1.1 inches through April 1975. As indicated in Fig. 18, greater top of embankment stresses were associated with larger top of embankment displacements.

The patterns of embankment swell and deformation are further illustrated in Fig. 19 for selected main array cross-sections. The top of embankment configurations are shown relative to the as-built condition in October 1971, for the conditions of swelling through October 1974, and then progressive settlements over the period of traffic, October 1974 through April 1975. The cross-sections shown for the tie sections, No. 2 and 9, illustrate progressive deformation under load of the subgrade beneath the tie with deformations beneath the tie ends being substantially larger than at the tie center. The subgrade at Section 4, concrete beam, experienced deformation only below the beam and none below the centerline. The subgrade at Section 5, concrete slab, experienced nearly uniform deformations below the slab, although the deformations were slightly larger below the rail. The mechanism of vertical embankment deformation under load is considered to be a combination of displacement and removal of subgrade material by pumping rather than a reduction in volume of the material.

<u>Deformations versus stationing</u>. Vertical extensometer deflections versus stationing are summarized in Fig. 20 through 23 for all static reading dates. The plots show the deformation of the top of the embankment with respect to rock for all single and centerline multi-position extensometers to rock. Deflections of the rail multi-position extensometers are also shown. The data are variable but show an embankment swell to October 1974. Be-

tween October and November 8, 1974, the first half of the "running-in" period, essentially the only centerline deformations occurring were at the main arrays. Rail deflections are evident as previously discussed and amounted to about 0.5 inch at Sections 1, 2, 3, 4, and 6. At each of the December 1974 and January 1975 readings, rail deflections progressed another 0.3 to 0.7 inch in Sections 1, 2, 3, 4, and 6, but centerline deflections had increased only slightly. Centerline settlements between January and April 1975 increased in a range from about 0.5 to well over 1.0 inch, except for Sections 4 and 7 (concrete beams) which generally experienced heave. Sections 8 and 9 had the smallest increases of centerline displacement, about 0.5 inch, of the conventional test sections. According to the data, rail deflections in this period averaged about 0.75 inch, but the magnitude could be greater than shown because of bottoming-out of instruments as previously discussed. Relative displacements of the test sections under traffic were previously discussed and are summarized in Table 3.

Horizontal Deformations

Permanent horizontal embankment deformations between October 1971 and April 1975 were determined from the tube coupling measurements. The measured deformations revealed embankment spreading which increased with time. Extension strain for the center ten feet of the embankment versus time are plotted in Fig. 24 through 26 for each section. The extension strain increased with distance above base of embankment. The strain for the upper tube over the ten-foot interval averaged about 0.8 percent in this 42-month period. However, Section 5 had relatively low strain in the upper tube, 0.4 percent, while Sections 4 and 6 had relatively high strains, 1.2 and 1.5 percent, respectively. The remaining sections had intermediate values of strain in the upper tube ranging from 0.50 to 0.75 percent.

Embankment Strains

Embankment deformations determined from the vertical extensometers and the horizontal tube gaging may be expressed as embankment strain. The horizontal strains are listed in the summary table in Volume II, Appendix C, and vertical strains may be calculated from the summary of vertical deformations in Volume II, Appendix B using the anchor depths also listed in this appendix. Typical strains so determined are shown in Fig. 27 as average strain between measurement points on embankment cross-sections for Sections 7 and 9. The figure shows strain from October 1971 to November 1974 and from October 1971 to April 1975.

Strains plotted in the manner of Fig. 27 further illustrate previous findings. The horizontal strains (extensions) increase with time over the period of measurement, and with height above embankment base. The extensions are greatest on the unconfined north side of the embankment. Horizontal strains in the upper tube generally increased with loading and are greatest near the ends of the ties or the outboard sides of nonconventional structures.

Vertical heave in Section 7 appears least in the center of the embankment. The vertical heave in the bottom portion of Section 7 appears large compared to the horizontal extension and suggests that the larger vertical heave occurs below the lower tube near the embankment-rock interface. In Section 9, the settlement beneath the tie appears large compared to strains in the upper horizontal tube. This suggests that the maximum settlements are controlled by a mechanism in the upper few inches of the embankment.

Horizontal strains were further reviewed by comparing average strain in the upper horizontal tube with calculated top of embankment stresses. The intervals over which the strains were averaged are from 2.5 to 5.0 feet on each side of track centerline. These intervals are between couplings 4 and 5 and between couplings 7 and 8. These zones are at the outboard sides of track structures. The strain versus pressure data are presented in Fig. 18 for the period of traffic. As indicated in the figure, greater top of embankment stresses were associated with larger horizontal strain in the upper tube.

Moisture Content Changes and Temperature

Moisture contents, as determined from those cells appearing to produce valid data, are plotted versus time in Fig. 28. This data is only considered valid for indicating trends, and quantitative values of moisture content are not considered reliable. The data trends suggest no change for some cells and an increase of moisture content versus time for others. This was confirmed by limited exploration to depths of three feet in the embankment taken in Sections 4 and 9 in December 1974. Moisture contents on the soil samples below the lime-stabilized layer generally showed an increase from the as-constructed moisture content which ranged between 20 and 30 percent and averaged about 25 percent. For the first six inches below the lime-stabilized layer, the moisture content had increased to 32 to 38 percent. Below this, the moisture content ranged between 25 and 30 percent, showing little or no change.

Temperatures are plotted for two typical sections, 7 and 9, for two dates, November 1974 and April 1975, in Fig. 28. The total data appear to give reasonable annual cyclic changes with reasonable distributions within the embankment. At the time the data were collected, freezing within the embankment was not detected by the temperature cells, although the north side of the embankment was usually slightly colder than the southern side. Temperature changes near the base of the embankment lagged the near-surface temperature.

Measured Versus Observed Performance

Measurements of permanent vertical track displacements were made while the test track was under traffic by ENSCO, Inc., Ref. 3. During the "running-in" period, the Track Survey Device (TSD) indicated settlements on the order of 1.5 inches occurring at the main arrays. The largest measured apparent embankment settlement beneath a rail was 0.6 inch over the first half of this period, and the average for conventional structures was 0.4 inch. The difference between the measured track and apparent embankment settlements has not been explained. The differences appear to be due to differential ballast compaction and displacement. Reportedly by ENSCO, ballast in the vicinity of main arrays was disturbed during installation of track structure sensors and was not recompacted uniformly. This may account for the local nature of the settlements near the main arrays. The displacements were corrected after the "running-in" period by adding and retamping ballast at the main arrays and by shimming the track at nonconventional structure sections as required.

DYNAMIC PERFORMANCE

Data Selection

Dynamic data available from the November 1974 "running-in" period were developed by a "work train" consisting of a locomotive, two hopper cars loaded with ballast, and a caboose. Data were collected with this train traversing each test section at creep (two to three mph) and 30 mph. Data collected during December/January 1975, first quarterly readings, and April 1975, second quarterly readings, were with regular mainline freight trains traveling at 30 to 60 mph.

The approximate locomotive loads were known and average axle loads were obtained. The locomotives had either four or six axles, and the axle loads always averaged about 65 kips. Reliable rail seat load data were not available for all sections, except for the April 1975 session. The response of each dynamic instrument was, therefore, taken as the maximum response of the locomotive axle loadings, and this is used as the basis for comparing data for different dates. The effect of axle load magnitude is studied with data selected from weighed trains during the December/January 1975 data acquisition period. The effect of speed is analyzed with the creep and 30 mph loadings from the November 1974 "running-in" period.

As mentioned previously, locomotive axle loads were substantially larger than those for cars. This is illustrated in Fig. 30 which shows typical train distribution loads determined from the nine weighed trains during the December/January 1975 data acquisition period. The load distribution curves for all trains were plotted, and heavy and light train envelopes are presented as well as the load distribution for the average train. As illustrated, locomotives had 65-kip axle loads, and those for cars ranged from 5 to about 35 kips.

The following analyses and comparisons were made with incomplete dynamic data for reasons previously described. Because of the lack of data, more complete analyses were not possible.

Vertical Deformations

Deformation data. Peak dynamic deflections versus depth for locomotive axle loading for the centerline and rail vertical extensometers at the main arrays are shown in Fig. 31 through 39. All available data are plotted for the 30 mph run during the November 1974 "running-in" period and for the first two quarterly readings. These deflection versus depth plots are similar to those presented for the static data, and the plots are identified as to whether they resulted from a 65-kip axle load from a four- or six-axle locomotive. The deflection of a typical car with 16-kip axle load is also presented for the December/January 1975 data collection period. The car response is presented for comparative purposes and will be discussed in a following section.

The maximum vertical ground surface deformation generally occurred under the rail and ranged from 0.025 to 0.1 inch compression. The deformation at the centerline was generally 0.025 to 0.050 inch compression. The shoulder extensometers displayed only minor response, occasionally indicating small amounts of extension. The data show a general increase in deformation with time under the rail for Sections 4, 5, 6, and 7, and the deformations appear to be distributed through the embankment.

The absence of data for undetermined reasons at some sections precludes a definitive comparison of test sections. However, it is apparent that the dynamic deflections under the rail for Sections 4 and 6 during the December/January 1975 readings were particularly large at about 0.10 inch and deflections were low for Sections 2, 3, and 5 at about 0.025 inch. Much data is missing from the April 1975 readings because of bottoming-out of the sensors, but Sections 8 and 9 appeared to have relatively low rail deflections of 0.05 to 0.06 inch.

A summary of the dynamic centerline and rail subgrade deformations relative to rock at the main arrays is presented in Fig. 40. There is not enough data available to satisfactorily analyze the performance of all sections. However, the data generally reveal a pattern of increasing dynamic settlement with time for Sections 4, 5, 6, and 7.

Possible factors influencing deformations. The increase in vertical dynamic deformations with time in Sections 4, 5, 6, and 7 and the apparent fairly uniform distribution of deformation through the embankment give the impression that the embankment is softening throughout with time. In order for the embankment to soften sufficiently to explain the increased deformations versus depth, the embankment would have to increase in water content and expand in volume over the loading period. Field observations after track closure indicate that this did occur within the upper one foot of embankment, but below this it did not occur to the extent required to explain the increase in deformation with depth.

The recording of six-axle locomotives in the December/ January 1975 and April 1975 sessions apparently gave larger instrument response than the four-axle locomotive used in November 1974, because of the overlapping effects of adjacent axles. A comparison of responses for four- and six-axle locomotives in the instances where these loadings were recorded on the same section during the same day are presented in Table 4 and demonstrate the increased response (average of about 20 percent) due to the larger locomotive.

Although the 6-axle locomotive loading accounts for some of the increased deformation, it does not appear to account for all of the increase in Sections 4, 5, and 7. The increase in deformation with depth throughout the embankment suggests that the load imparted to the embankment increased with time. The reason for increased loading is unexplained, but it may be associated with a general deterioration of the track and ballast system. For Section 6, a tilting of the extensometer terminal box may have given the indication of apparent increases of deformation with depth. In our opinion, the basic deformation versus load characteristics of the embankment below a depth of one foot did not change significantly.

Instrument performance would be affected by interference at the common bracket when one anchor of a main array assembly has bottomed-out. Another factor which may contribute to increased dynamic deformation may be the presence of a "hard spot" in the subgrade beneath each extensometer terminal box which could result from the differential softening of the upper surface of the adjacent embankment. These effects will be discussed in a following section, Field Observations after Track Closure.

Horizontal Deformations

Position study. Table 5 summarizes the portable horizontal extensometer data collected for a study made during the first dynamic data acquisition period in November 1974. The data were developed by varying horizontal extensometer positions while receiving multiple passes of the "work train." The study was performed in order to select a limited number of instrument positions and gage lengths for acquisition of future data using the three available horizontal extensometers. It was established that the deformations were of a small magnitude, thus the larger (five-foot) gage length was chosen. Three alternate positions were tested, mostly for the three upper tubes, since strains in the bottom tube were very low. These positions are illustrated in Fig. 3 and Table 5, and their position code is described.

Based on the data, it was possible to calculate for some sections the distribution of horizontal strain due to locomotive axle loading from centerline to 2.5 feet, from 2.5 to 5.0 feet, and from 5.0 to 10.0 feet from centerline. These strains are plotted on embankment cross-sections in Fig. 41. It was established that, in general, the loading produced a net extension from centerline to 5.0 feet out. The zone from 5.0 to 10.0 feet was in compression. Positions across the centerline were chosen for future monitoring to minimize the canceling effects of combined extension and compression.

Sections 1, 2, 4, 5, 7, and 8 displayed the smallest maximum magnitudes of horizontal strain, generally less than 0.017 percent. The maximum horizontal strains at the other three sections were somewhat larger, ranging between 0.020 and 0.041 percent, see Table 5 and Fig. 41.

Deformation data. The portable horizontal extensometer data are summarized in Fig. 42. For each section, the dynamic deformations across the centerline in the three upper tubes have been shown for each date. In all cases, there were extensions on the order of 0.015 inch or less under locomotive axle loading. For the five-foot gage length adopted, the corresponding strain is about 0.02 percent or less. The data indicate that the horizontal dynamic strain decreases with depth for the conventional sections. The data are somewhat variable for nonconventional Sections 4 and 7. For nonconventional Section 5, the strains are smaller in the upper tubes. The relatively low strains in the upper tube for nonconventional track structures at Sections 4, 5, and 7 may be related to the confining effects of the structures which are only about nine inches above the upper tube.

The data show a general increase in deformation with time. Possible explanations for this were previously discussed for the vertical extensometers. Sections 4, 6, and 8 show relatively low amounts of change between December/January 1975 and April 1975. Remaining sections show a gradual increase in strain with time. Both four- and six-axle locomotives were recorded at Sections 1 and 5 during the April 1975 session, and the deformation was about 30 percent greater for the six-axle locomotive as shown in Fig. 42.

Deformations are shown for both creep and 30 mph loading of the work train in November 1974. Deformations under creep loading are generally the same as or slightly less than at 30 mph.

Dynamic Embankment Strains

Typical dynamic strains are shown in Fig. 43 for Sections 7 and 9 and further illustrate previous findings. The data were obtained during the November 1974 session. The horizontal strains show extension from centerline to five feet out and compression from five to ten feet. Vertical strains beneath centerline and rail are compressive and are high compared to horizontal strains in the upper portion of the Section 9 embankment.

Pressures

A summary of the pressure cell data is presented in Table 6. While most of the data appear reasonable, there are several erratic pressures which are shown in parenthesis. No dynamic records were obtained for four pressure cells. All pressure cells were tested independently of the dynamic recorders in the field, and two of these cells (2202 and 6201) were found to be inoperative. The ability to record the load cell response improved after the November 1975 data collection period.

The available data seem to suggest several trends. First, there is a general increase in pressure cell response with time at most sections. Possible explanations for this were previously discussed. Second, the pressure cells under the rail experience larger stresses than those at the centerline, except for Section 5 which is a slab. The recorded stresses under the rail on the conventional sections ranged from five to eight psi. The maximum stress recorded under the rail of the nonconventional structures ranged from two to ten psi. Measured subgrade pressure of the cells below the rail are plotted versus calculated top of embankment stress in Fig. 44. The data show a reasonable linear relationship, although the cells at Section 7 recorded higher stresses than expected for no apparent reason.

Effects of Load and Speed

Figure 45 shows the vertical deformation of centerline extensometers to rock for three loading conditions with a four-axle locomotive during the November 1975 data acquisition period. These conditions are locomotive axle loads at creep and 30 mph and hopper car loads at 30 mph. The data show consistently that the locomotive produces 10 to 15 percent more vertical compression at creep (two to three mph) than at 30 mph. Data are not available to compare higher speeds with the data from creep and 30 mph.

The data indicate that the hopper cars produce greater vertical compression than the locomotive. They have lighter axle loads (61 kips) than the locomotive (65 kips), but influence of the more closely spaced wheels produced an average 30 percent greater instrument response than a locomotive axle load. However, no car axle loads greater than 35 kips were recorded for the mainline freight trains.

Deformations and pressures due to variable axle loads from freight trains at all sections are presented in Fig. 46 through

54. These data were obtained by selecting instrument response from a range of car weights. The cars were part of completely weighed freight trains in December 1974, Sections 4, 5, and 7, and January 1975, Sections 1, 2, 3, 6, 8, and 9 which traversed the test section at speeds ranging between 29 and 55 mph. The data from all sections indicate that the deformations and pressures increase up to a 20- to 30-kip axle loading for freight cars and show a decreased rate or no additional response above this for the 65-kip locomotive axle loading. This may be due to higher loads developing more beam action in the track structures. The relatively higher responses at the smaller axle loads may also result from the relatively close spacing of car axles compared to the 65-kip locomotive axles.

The dynamic responses of the nine test sections has been compared in a general way based on the rail and centerline vertical extensometers. The sections experiencing the least embankment response were Sections 5 and 7 with average rail and centerline dynamic deformations of less than 0.05 inch. Sections 4 and 6 experienced the greatest embankment response with 0.07 to 0.08 inch average rail and centerline deformation. Sections 8 and 9 had intermediate deformations, and Sections 1, 2, and 3 probably fall into the intermediate category, although some data are missing.

The typical train distribution of axle loads, Fig. 30, and the instrument response versus axle load figures just presented (Fig. 46 through 54) have been combined to present the instrument response expected for the light, typical, and heavy train distributions shown in Fig. 30. The rail extensometers to rock for Sections 7 and 9 have been studied in this manner, and the estimated responses are shown in Fig. 55 and 56, respectively.

FIELD OBSERVATIONS AFTER TRACK CLOSURE

Scope of Investigations

The investigations after track closure accomplished by WES were observed during the week of May 17 to 21, 1976, by a representative of Shannon & Wilson. The track had been closed to rail traffic in June 1975, and the conventional track structures had been removed by the time of the 1976 investigations. The WES investigations consisted of excavating ten test pits through ballast and to three feet below the top of subgrade. Ballast and embankment conditions were observed, materials were sampled, and in-situ California Bearing Ratio (CBR) tests were performed. Test pit locations were selected by WES after reviewing track maintenance records. WES also performed cone penetrometer probes and seismic soundings.

Stationing and indications of track performance at the locations of the ten test pits are shown in Table 7. At least one test pit was made in each test section, except for Section 6 where none was made. In three sections, Nos. 2, 7, and 9, test pits were made adjacent to the main instrument arrays. These pits were extended to uncover pressure cells and upper portions of the rail and centerline vertical extensometers.

Specific activities observed during the site visit included the excavating of test pits at the instrument arrays in Sections 2, 7, and 9. The other test pits had been completed at that time, and the open pits were observed, except for the pit in Section 1 which had been backfilled. Limited strength testing of the embankment material exposed at the sides of the pits was conducted by Shannon & Wilson. In addition to work performed by WES, representatives of Shannon & Wilson and PCA, using a backhoe and operator provided by ATSF, removed ballast from main instrument arrays in Sections 1, 3, 6, and 8 to inspect the condition of pressure cells installed by PCA and vertical extensometers installed by Shannon & Wilson. The following discussions were based upon these observations.

Instrumentation

Vertical extensometers. Rail and centerline main array vertical extensometers were inspected in Sections 1, 2, 3, 6, 7, 8, and 9. All terminal boxes were found to be well seated. Many of the extensometers had exceeded their limit of vertical movement, and brackets holding the strain rod ends were broken in 20 of the 46 instances observed. Of the seven main arrays inspected, only at Sections 8 and 9 were the rail extensometer brackets for the anchor to rock not broken. It is considered that a main array extensometer assembly has probably lost its usefulness once the deformations have become so large as to break any of the brackets holding the strain rod ends. However, when an extensometer is bottomed out but the bracket is not broken, the remaining extensometers in the assembly probably produce valid data. The condition of the extensometers observed is summarized in Table 2.

The terminal boxes and casings had been filled with transformer oil during construction. The oil was still present but contained varying amounts of water from condensation. For the rail terminal boxes at Sections 2, 6, and 7, a clay slurry was present in the terminal boxes. It is considered that excessive deformations of the terminal boxes, including tilting, may have damaged the O-ring casing seals in these instances, permitting the slurry to enter.

Excavations at the main instrument arrays of Sections 2, 7, and 9 uncovered anchor tips of the upper extensometer anchors. No indication of tip movement relative to embankment was seen. Also, the polyurethane foam used to backfill the LVDT casings had not deteriorated since placement. However, at Section 7, clay was observed to have squeezed into a construction joint in the foam about ten inches below the top of subgrade.

Calibrations of several LVDT's were checked by WES and were found to be essentially unchanged from the calibration at installation. Also, a check for anchor interference was conducted at Section 9 where Anchor No. 1 of the rail extensometer was deflected downward, and no response of the adjacent anchor was observed. This indicated that the anchors were not interacting with each other.

Pressure cells. Pressure cells in Sections 2, 7, and 9 were excavated and inspected. All had intimate contact with the soil. Two cells in Section 2 were found to be inoperative, as discussed earlier in the section, Performance of Instrumentation.

Embankment

Excavation of the test pits disclosed several features common to all sections investigated. The ballast in all sections was choked with red-brown, silty clay to varying distances above the subgrade. The clay apparently originated from the embankment and had worked its way into the ballast through pumping under traffic. The clay had penetrated the the ballast up to the base of all track structures, except for Section 8 where clay had risen to within about four inches of the tie base. Presumably, the penetration of the clay would have been more extensive if traffic and the presence of water had persisted. The extent of clay in the ballast above the base of the track structures and between the structures was not observed.

Another feature apparent during excavations for the test pits was the irregular top of subgrade surface. In tie sections, the subgrade was depressed beneath the ties with the depression becoming greater at the tie ends. The depressions were greatest in Section 1 with areas beneath tie ends being about four inches lower than areas between the ties and greater than five inches lower than the shoulders. The depressions were generally greatest in the sections delivering the maximum stresses to the top of the embankment (Sections 1, 2, and 3) and least in the sections with lower stresses at the top of the embankment (Sections 8 and

9). Section 6 is an exception having low top of embankment stresses and relatively high distortions. It will be discussed later. The depressions were somewhat greater beneath the north rail than beneath the south rail. The reason for this is not known. Estimated maximum top of subgrade stresses and measured distortions are summarized in Table 7.

As determined in the test pits, the lime-modified clay layer generally had an unconfined compressive strength greater than 4.5 tsf. Below this layer, the subgrade had softened to a strength of 1.5 to 2.0 tsf. The strength increased to 2.5 to 3.5 tsf at a depth of one foot and remained within this range to the maximum depth explored, three feet. The average unconfined compressive strength of the embankment as measured during construction was 2.9 tsf. The softening of the upper portion of the embankment is assumed to be caused by a swelling of the clay. The increase of water content within this zone may be due to a net addition of water to the embankment from the surface or by a redistribution of moisture within the embankment.

Section 6 had relatively large top of subgrade irregularities in spite of its relatively low top of subgrade stress level. This may have been affected by a layer of rubber-like substance at the ballast-embankment interface which was encountered during removal of ballast at the main array. Free water was present between the embankment and this material and overlying the material.

An impression obtained from the field observations is that the ballast was working downward into the lime-stabilized layer and that the soil was moved upwards into the ballast by a pumping action. Above the vertical extensometer terminal boxes at the top of subgrade, the ballast could not penetrate the 16-inch diameter top plates. Consequently, the extensometers became hard spots in the embankment, and they were forced down so that the base of ballast over subgrade and the terminal box moved down together. A schematic section illustrating this process is shown in Fig. 57.

SUMMARY OF PERFORMANCE

Instrumentation

Vertical extensometers. The LVDT-type multiple- and single-position vertical extensometers functioned exceptionally well during the 3.5-year period while in place up to the point where the deformation on some installations exceeded the limit of travel. Many rail and centerline extensometers had bottomed-out due to mainline traffic by April 1975. It would have been possible to reset most of the sensors, but this would have required excavations and removal of ties. No resetting of the sensors was attempted.

Horizontal tubing. The horizontal tubes functioned satisfactorily, both for making tube coupling surveys (permanent embankment strain) and for the portable horizontal extensometers (horizontal dynamic strain).

Moisture-temperature cells. The moisture-temperature cells did not produce reliable moisture data. The ten percent of the cells producing reasonable data in April 1975 showed either no change or a slight increase in embankment moisture with time. The cells appeared to function well as temperature sensors.

Portable horizontal extensometers. The three portable horizontal extensometer units functioned satisfactorily with respect to ease of operation, recording of dynamic deformation, and reliability, and the traces were well defined.

Pressure cells. All but three of the pressure cells functioned throughout the test program. Several cell recordings were not obtained, particularly during November 1974, apparently due to faulty recording hookups. Most of the pressure cells appeared to give reasonable stress values.

Embankment

General trends. The embankment instrumentation data indicate that before the test track was opened to traffic all test sections swelled gradually with time, both vertically and horizontally. The vertical distribution of swell was essentially linear and amounted to about one inch over the recording period of 42 months.

Under traffic, the upper portion of the subgrade deformed with time at the average rate of about 0.3 inch per month. The deformations appeared to be the result of displacement of the subgrade and loss of subgrade due to pumping. The progressive deformations were largest under the rail. Extensometers showed that these deformations took place within the upper 1.3 feet of the subgrade; however, observations suggest that only the upper few inches of subgrade were involved. The extensometer terminal boxes were forced into the subgrade by the ballast. Observations also disclosed a general softening of the subgrade within the six inches below the lime stabilized surface layer.

Relative behavior of sections. The increase in static deformations over the traffic period of November 1974 to April 1975 have been summarized in Table 8 as an approximate indication of the relative behavior of the sections. In addition, the dynamic vertical and horizontal deformations recorded in November 1974 and April 1975 have been shown. An actual comparison of performance is not possible because of the large number of sensors which had bottomed-out. However, the tabulated data give an indication of the magnitude of deformations that occurred.

Based on Table 8, the conventional track structure sections (1, 2, 3, 6, 8, and 9) experienced static embankment settlements beneath the rail which bottomed out the sensors to rock, except for Sections 8 and 9 which were somewhat less. Static extensions of the center ten feet of the embankment in the upper horizontal tube ranged from 0.2 to 0.4 percent, except for Section 3 with a low of 0.1 percent and Section 6 with a high of 0.6 percent. Dynamic deformations were generally somewhat less in Sections 8 and 9 than the other conventional sections. The improved performance of Sections 8 and 9 is associated with lower top of embankment stresses. Although the stabilized ballast, Section 6, also had relatively low embankment stresses similar to Section 9, the large deformations may have been influenced by a rubber membrane at the top of the subgrade. In Sections 1, 2, and 3 where tie spacings were 30, 27, and 24 inches, respectively, overall deformations were somewhat less for the closer tie spacings which produced lower calculated top of embankment stresses.

It was reported that the nonconventional structures, Sections 4, 5, and 7, deformed excessively and that subgrade pumping and spalling of the concrete occurred at all sections. The areas that were uncovered and inspected in the field showed less than the design thickness of ballast beneath the structures and standing water between beams (observed in December, 1974).

The nonconventional track structure sections experienced static embankment settlements beneath the rail greater than 1.0 inch, with Section 4 experiencing the largest at greater than 1.6 inches. Section 4 also experienced substantially larger extensions of the center ten feet in the upper horizontal tube. Dynamic embankment compression at the rail was relatively large at Section 4 (0.054 inch) and relatively low at Section 5 (0.026 inch). Because of its larger permanent dynamic displacements, it is concluded that Section 4 performed poorer than Sections 5 and 7. The only apparent difference between Sections 4 and 7, both concrete beam sections, is that Section 4 was cast-in-place and Section 7 was precast.

The track support structures and supporting subgrade generally experienced excessive deformations. It appears that the ballast character and thicknesses provided were not compatible with the support characteristics of the compacted subgrade comprised of locally available clay materials. The participation of the subgrade in the settlement mechanism appears to be limited to the upper few inches at the interface with the ballast. The conventional track structure sections which experienced the least permanent and dynamic deformations generally had lower top of subgrade stresses.

RECOMMENDATIONS

Instrumentation

The following recommendations relating to instrumentation are based on experience with this program and should be considered for future programs.

1. The physical parameters measured should be closely coordinated with the required input for analytical models.

2. Moisture cells should be deleted, unless the reliability of the measurements can be improved.

3. Centerline pressure cells and centerline single-position vertical extensometers for beam sections may be deleted.

4. A single anchor shoulder vertical extensometer may be used in lieu of multi-position extensometers. Consideration should be given to adding more extensometers beneath the rail and to instrumenting both rails at a given test section.

5. The recording range for vertical extensometer LVDT's in clay embankments should be increased.

6. Consideration should be given to eliminating the horizontal tubing unless dynamic strain measurements are made with portable accelerometers or velocity sensors which would be inserted into the tubing and locked in selected couplings. These sensors would measure both horizontal and vertical motions.

7. It is further recommended that the data be analyzed between recording sessions and that flexibility be

provided in recording sessions to troubleshoot inoperative instruments and hookups.

Embankment

For future railroad embankments, it is recommended that careful consideration be given to the compatibility of track structure, ballast type and thickness, and the subgrade. It appears that the performance of structures and subgrade over all test intervals could have been improved by the use of thicker ballast to reduce top of embankment stresses and by the use of a filter layer or filter membrane between the subgrade and the ballast to reduce pumping of the subgrade. The filter layer could consist of a six-inch thick, clean and well graded, sand and fine gravel.

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3. ENSCO, Inc. 1975. "Test Results Report in Support of Kansas Test Track Project." Report prepared for the U.S. Department of Transportation, Federal Railroad Administration.

TABLE 1

AVAILABLE DATA

Date Code	Date	Static Data: Tube Cplngs	Static Data: Vert. Ext.	Static Data: M-T Cells	Dynamic Data	Remarks
1	Oct. 1971	√	√	√		
2	Mar. 1972	√	√	√		
3	Dec. 1972	√	√	√		
4	Nov. 1973	√	√	√		
5	Oct. 1974		√			"Running-in" period, Oct. 31 thru Nov. 14, 1975 with work train
6	Nov. 1974	√	√	√	at 2-3 & 30 mph	
7	Dec. 1974	Sec. 4, 5, 7	√	√	Sec. 4,5,7	First quarterly readings with freight trains
8	Jan. 1975	Sec. 1, 2*,3,6, 8*,9*	√		Sec. 1,2,3,6,8,9	
9	Apr. 1975	√	√	√	√	Second quarterly readings with freight trains

Legend

√ Full set of data collected

* Data not available for lower tube (#1); tubing was inaccessible

TABLE 2

DYNAMIC INSTRUMENT PERFORMANCE

Test Section No.	Type Instrument ↓ / Position No. →	Acquisition Date: Nov. 1974				Dec./Jan. 1975				April 1975				Condition May 1976			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	¢	o	√	-	o	o	o	-	o	⊖	⊖	-	o	B	B	-	B
	R	o	√	-	√	⊖	⊖	-	√	⊖	⊖	-	⊖	B	B	-	B
	Sh	√	√		√	√	√		√	√	√		√				
	Si	√	√	√	√	√	√	√	√	⊖	√	⊖	⊖				
	P	o	o	o		√	√	o		√	√	√					
2	¢	√	√	-	o	√	√	-	√	⊖	⊖	-	[illegible]	F	B	-	OK
	R	⊖	√	-	o	⊖	⊖	-	o	⊖	⊖	-	⊖	B	B	-	B
	Sh	√	√		√	√	√		√	√	√		√				
	Si	√	√	√	√	√	√	√	o	⊖	√	o	√				
	P	o	x	o		√	x	o		o	x	√		D	D		
3	¢	o	√	-	⊖	√	√	-	√	⊖	⊖	-	o	OK	B	-	OK
	R	√	√	-	o	√	o	-	√	⊖	⊖	-	⊖	B	B	-	B
	Sh	√	√		√	√	√		√	√	√		o	OK	OK	-	OK
	Si	√	√	√	√	√	√	√	o	√	√	√	√				
	P	o	√	o		√	√	√		√	√	√					
4	¢	√	√	⊖	√	√	√	o	√	o	√	√	o				
	R	√	√	√	√	√	√	√	√	⊖	⊖	o	⊖				
	Sh	√	√	√	x	√	√	√	x	o	√	√	x				
	Si	√	√	o	√	√	√	o	√	√	√	√	√				
	P	√	√	o		√	√	√		√	√	√					
5	¢	√	√	-	⊖	o	√	-	√	√	?	-	√				
	R	√	√	-	√	√	√	-	√	⊖	√	-	√				
	Sh	√	√		√	√	√		√	o	√		√				
	Si	√	√	√	√	√	√	√	√	√	√	√	√				
	P	o	√	o		√	√	√		√	√	√					
6	¢	o	√	⊖	√	√	√	?	√	⊖	o	√	⊖	OK	OK	OK	OK
	R	√	√	√	√	o	√	√	√	o	o	o	⊖	B	OK	B	B
	Sh	√	√	√	√	√	√	√	√	√	√	√	o				
	Si	√	√	√	√	√	√	√	o	⊖	√	√	√				
	P	x	√	o		x	√	o		x	√	o					
7	¢	√	√	-	√	o	√	-	√	⊖	o	-	√	OK	OK	-	OK
	R	√	√	-	√	⊖	√	-	√	⊖	√	-	√	OK	OK	-	B
	Sh	√	√		√	√	√		√	√	√		√				
	Si	√	o	√	√	√	√	√	√	√	o	√	√				
	P	√	√	o		√	√	√		√	√	√					
8	¢	√	√	-	o	√	√	-	√	√	o	-	⊖	OK	OK	-	OK
	R	⊖	√	-	√	⊖	√	-	√	√	⊖	-	√	OK	OK	-	OK
	Sh	√	√		√	o	√		√	√	√		o				
	Si	√	√	√	√	√	√	√	√	√	√	√	√				
	P	o	√	o		√	√	o		√	√	o					
9	¢	o	√	o	⊖	√	√	⊖	√	√	o	√	o	OK	OK	OK	OK
	R	√	√	√	√	o	√	√	√	⊖	⊖	⊖	√	OK	B	OK	OK
	Sh	√	√	√	√	o	√	√	√	o	√	√	√				
	Si	√	√	o	√	√	√	√	√	√	√	√	√				
	P	o	√	√		√	√	√		√	√	o					

LEGEND:

Type Instrument

- ¢ = Vertical extensometer @ ¢ track
- R = Vertical extensometer @ N rail
- Sh = Vertical extensometer on shoulder
- Si = Vertical extensometer, single position
- P = Pressure cells

Performance

- √ = O.K.
- o = No performance or off scale
- ⊖ = Reverse trace
- x = Dead
- ? = Questionable response
- \- = No extensometer installed

Condition, May 1976

- B = Bracket broke
- F = Core stuck in bottom of coil
- OK = Does not appear broken. May have bottomed out.
- D = Dead cell

TABLE 3

EMBANKMENT SETTLEMENT (INCHES) AT MAIN ARRAYS

AFTER OCTOBER 1974

	Rail Extensometer to Rock, October 1974 to			¢ Extensometer to Rock, October 1974 to		
Test Section	11/74	1/75	4/75	11/74	1/75	4/75
1 Conc. Ties	0.6	1.3*	2.0**	0.4	0.6	2.0*
2 " "	0.6	1.6*	1.9**	0.2	0.5	1.6*
3 " "	0.5	1.5*	1.7**	0.2	0.5	1.8
4 CIPC Beam	0.4	1.6	2.0**	~0	~0	~0
5 CIPC Slab	0.1	0.5	1.1	0.1	0.4	0.9
6 Stab. Bal.	0.6	1.4	2.2**	0.2	0.4	1.6*
7 PCC Beam	0.1	0.6	1.2	~0	0.1	0.1
8 Conc. Ties	0.2	0.7	1.8*	0.2	0.4	1.2
9 AT&SF Conv.Const.	0.3	0.7	1.7*	0.1	0.2	1.0

Legend

*	One anchor of group possibly bottomed out (deflection > 1.3")
**	Rock anchor possibly bottomed out, and actual settlement may be greater than that shown
CIPC	Cast-in-place concrete
PCC	Precast concrete

TABLE 4

COMPARISON OF INSTRUMENT RESPONSE FROM 6 AND 4 - AXLE LOCOMOTIVES

Date	Instrum. No.	Average Response to First Locomotive Truck, mm. (Chart Movm. x Attn./Cal.Factor)		
		6 Axles	4 Axles	Ratio
4/25/75	1603.03	12.8 W	10.0(?)	1.28
	1602.03	9.6 W	7.5(?)	1.28
4/24/75	2602.03	3.7 W	1.5 E	2.4
	2603.03	11.8 W	8.5 E	1.38
	2604.03	8.0 W	9.0 E	0.88
	2502.00	28.0 W	25.0 E	1.12
	2504.00	27.0 W	23.0 E	1.17
	2203.00	23.0 W	23.0 E	1.00
4/22/75	8402.01	10.6 E	8.3 W	1.29
	8402.04	32.0 E	30.0 W	1.06
	8502.00	28.0 E	24.5 W	1.14
	8503.00	32.0 E	28.0 W	1.14
	8504.00	25.5 E	23.5 W	1.09
	8602.03	4.6 E	5.2 W	.88
	8603.03	12.0 E	8.5 W	1.41
	8604.03	15.0 E	10.5 W	1.43
Average				1.19

Generally only one set of data was obtained from each test section on each acquisition date regardless of number of locomotive axles, but always with a westbound train. At sections 1, 2 and 8, however, data were also collected eastbound, and comparative responses are shown above, where available.

Instrument No. Legend

X2XX.XX Pressure Cell
X4XX.XX Vertical Extensometer, main array
X5XX.XX Vertical Extensometer, single-position
X6XX.XX Portable Horizontal Extensometer

See Fig. 2 for position of instrument
Section No.

Key

E = Eastbound train
W = Westbound train
(?) = Train direction not known

TABLE 5

PORTABLE HORIZONTAL EXTENSOMETER

POSITION STUDY

NOVEMBER 1974

DEFORMATIONS DUE TO LOCOMOTIVE AXLE LOADS*

<table>
<tr><th rowspan="4">Section No.</th><th rowspan="4">Tube No.</th><th colspan="3" rowspan="2">Deflection Inches x 10^{-4}</th><th colspan="3">Dynamic Strain, Percent</th></tr>
<tr><th colspan="2">℄ Track to 5.0 ft.</th><th rowspan="3">5.0 to 10.0 ft.</th></tr>
<tr><th colspan="3">Instrument Position</th><th rowspan="2">℄ Track to 2.5 ft.</th><th rowspan="2">2.5 to 5.0 ft.</th></tr>
<tr><th>0.03</th><th>0.01</th><th>0.02</th></tr>
<tr><td>1</td><td>4</td><td>-89</td><td></td><td>103</td><td>-0.015</td><td></td><td>0.017</td></tr>
<tr><td></td><td>3</td><td>-66</td><td></td><td>41</td><td>-0.011</td><td></td><td>0.007</td></tr>
<tr><td></td><td>2</td><td>-10</td><td></td><td>0</td><td>-0.002</td><td></td><td>0.000</td></tr>
<tr><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>4</td><td>-73</td><td></td><td>94</td><td>-0.012</td><td></td><td>0.016</td></tr>
<tr><td></td><td>3</td><td>-47</td><td></td><td>28</td><td>-0.008</td><td></td><td>0.005</td></tr>
<tr><td></td><td>2</td><td>-16</td><td></td><td>0</td><td>-0.003</td><td></td><td>0.000</td></tr>
<tr><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>4</td><td>-117</td><td>-94</td><td>99</td><td>-0.020</td><td>-0.012</td><td>0.017</td></tr>
<tr><td></td><td>3</td><td>-89</td><td>-66</td><td>41</td><td>-0.015</td><td>-0.007</td><td>0.007</td></tr>
<tr><td></td><td>2</td><td>-14</td><td>-11</td><td>2</td><td>-0.002</td><td>-0.001</td><td>0.000</td></tr>
<tr><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>4</td><td>-70</td><td>-70</td><td>61</td><td>-.012</td><td>-0.012</td><td>0.010</td></tr>
<tr><td></td><td>3</td><td></td><td>-66</td><td>38</td><td colspan="2">-0.011</td><td>0.006</td></tr>
<tr><td></td><td>2</td><td></td><td>-42</td><td>15</td><td colspan="2">-0.007</td><td>0.002</td></tr>
<tr><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>4</td><td>-2</td><td>-27</td><td>23</td><td>-0.000</td><td>-0.009</td><td>0.004</td></tr>
<tr><td></td><td>3</td><td>-21</td><td>-48</td><td>28</td><td>-0.004</td><td>-0.012</td><td>0.005</td></tr>
<tr><td></td><td>2</td><td></td><td>-42</td><td>21</td><td colspan="2">-0.007</td><td>0.003</td></tr>
<tr><td></td><td>1</td><td>-2</td><td></td><td></td><td>-0.000</td><td></td><td></td></tr>
<tr><td>6</td><td>4</td><td>-84</td><td>-164</td><td>84</td><td>-0.014</td><td>-0.041</td><td>0.014</td></tr>
<tr><td></td><td>3</td><td>-71</td><td>-113</td><td>71</td><td>-0.12</td><td>-0.26</td><td>0.012</td></tr>
<tr><td></td><td>2</td><td></td><td>-19</td><td>4</td><td colspan="2">-0.003</td><td>0.001</td></tr>
<tr><td></td><td>1</td><td></td><td>-24</td><td></td><td colspan="2">-0.004</td><td></td></tr>
<tr><td>7</td><td>4</td><td></td><td>-52</td><td>28</td><td colspan="2">-0.009</td><td>0.005</td></tr>
<tr><td></td><td>3</td><td></td><td>-71</td><td>30</td><td colspan="2">-0.012</td><td>0.005</td></tr>
<tr><td></td><td>2</td><td></td><td>-48</td><td>15</td><td colspan="2">-0.008</td><td>0.003</td></tr>
<tr><td></td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>4</td><td>-15</td><td>-53</td><td>8</td><td>-0.003</td><td>-0.015</td><td>0.001</td></tr>
<tr><td></td><td>3</td><td>-24</td><td>-36</td><td>31</td><td>-0.004</td><td>-0.008</td><td>0.005</td></tr>
<tr><td></td><td>2</td><td></td><td>-30</td><td>10</td><td colspan="2">-.005</td><td>0.002</td></tr>
<tr><td></td><td>1</td><td></td><td>-30</td><td></td><td colspan="2">-0.005</td><td></td></tr>
<tr><td>9</td><td>4</td><td>-59</td><td>-122</td><td>122</td><td>-0.010</td><td>-0.031</td><td>0.020</td></tr>
<tr><td></td><td>3</td><td>-43</td><td>-25</td><td>30</td><td>-0.007</td><td>-0.001</td><td>0.005</td></tr>
<tr><td></td><td>2</td><td></td><td>-8</td><td>2</td><td colspan="2">-0.001</td><td>0.000</td></tr>
<tr><td></td><td>1</td><td></td><td>-6</td><td></td><td colspan="2">-0.001</td><td></td></tr>
</table>

*First axle of "work train" locomotive at 30 mph.

Legend

+ = Contraction
- = Extension

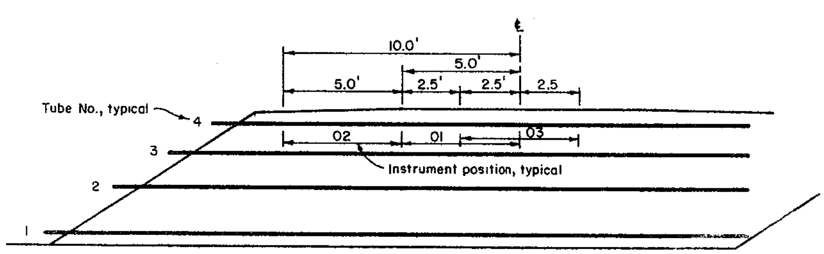


TABLE 6

SUMMARY OF PRESSURE CELL DATA UNDER LOCOMOTIVE LOADS

Test Section No.	Pressure Cell No.	Acquisition Period			
		11/74 Creep	11/74 30 mph	12/74 1/75	4/75
1	201	---	---	1.5	4.2
	202	---	---	5.2	6.2
	203	---	---	---	8.0
2	201	---	---	2.1	---
	202	x	x	x	x
	203	---	---	---	7.4
3	201	---	---	2.5	2.6
	202	0.6*	---	3.9	4.5
	203	---	---	5.3	(0.1)
4	201	2.3*	2.4*	(6.2)	1.9*
	202	2.6*	2.4*	2.3	(0.6)*
	203	---	---	4.2	(0.6)*
5	201	---	---	4.1	5.0*
	202	2.8*	3.9*	3.2	4.7*
	203	---	---	1.3	2.1*
6	201	x	x	x	x
	202	0.1*	(0.2)*	(0.4)	(1.0)*
	203	---	---	---	---
7	201	0.3*	0.4*	0.7	(0.0)
	202	0.6*	0.5*	0.8	0.5
	203	---	---	7.8	10.0
8	201	---	---	3.7	3.6*
	202	2.5*	2.5*	4.1	5.0*
	203	---	---	---	---
9	201	---	---	1.5*	3.7*
	202	2.2*	2.1*	2.7*	(1.7)*
	203	(0.8)*	(0.8)*	(2.2)*	---

LEGEND:

--- = No performance
x = Dead cell
1.5 = Pressure, psi (typical)
201 = Pressure cell @ ℄ low
202 = Pressure cell @ ℄ high
203 = Pressure cell @ rail high
( ) = Apparently erratic data
* = 4-axle locomotives (others are 6 axle)

TABLE 7

SUMMARY OF FIELD OBSERVATIONS

Section	Station of Pit	Reported Performance at Pit Location	Lime Layer Thickness (In.)	Approx. Unconfined Compressive Str., tsf 2"	6"	12"	18"	24"	Observed Max. Top S/G Deform. Below Shoulder (In.)	Approx. Max. Stress at Top of S/G tsf
1	8524+75	Heavy pumping	---	---	---	---	---	---	>5.0	1.4
2	8531+62	Heavy pumping								
	8535+16*	Heavy pumping	4.0	>4.5	1.5	2.5	---	---	4.3	1.2
3	8542+49	Heavy Pumping & spot raised								
	8540+20	Spot raised	4.0	>4.5	2.0	2.4	2.8	2.8	4.1	1.0
4	8547+80	Fairly good	~3.5	>4.5	2.8	3.2	---	---	2.4	1.0
5	8558+20	Heavy pumping	4.0	>4.5	1.7	2.6	2.1	2.4	2.4	0.6
6	---	Heavy pumping	---	---	---	---	---	---	>>2.0	0.75
7	8576+41*	Heavy pumping	4.5 (variable)	>4.5	1.4	3.0	3.5	3.6	3.5	1.0
8	8587+08	Good	3-4" @ ¢ 0" @ rail	>4.5	1.5	1.5	3.5	2.4	3.0	0.7
9	8595+33*	Trace pumping	3.5	>4.5	2.0	---	---	---	3.5	0.75

* At main instrument array.

Note: Strengths were approximately determined with a hand-held Torvane and a Pocket-Penetrometer.

TABLE 8

STATIC AND DYNAMIC DEFORMATIONS

BETWEEN NOVEMBER 1974 AND APRIL 1975

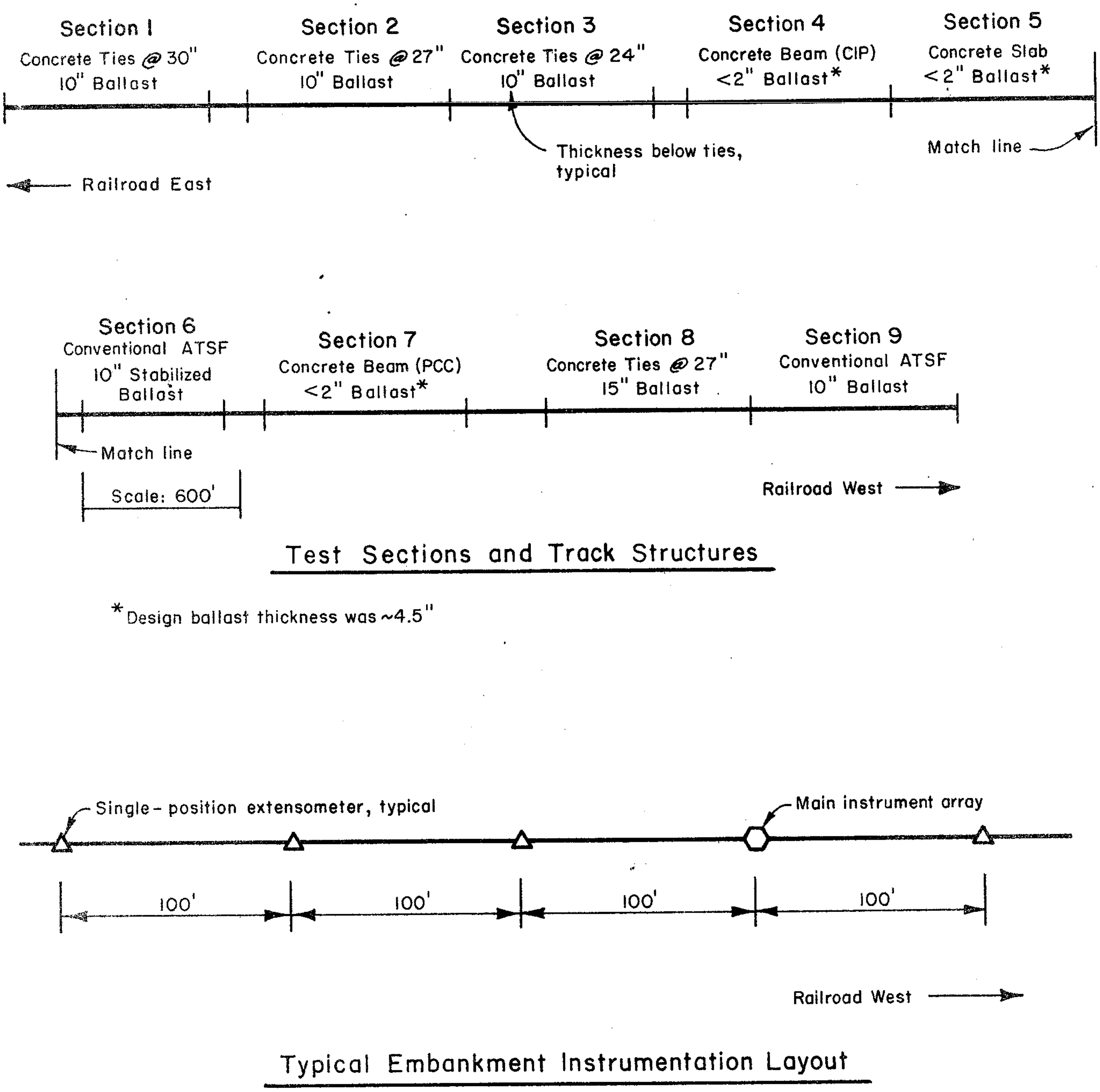
	Increase in Static Deformations Between Nov. 1974 and April 1975			Dynamic Deformations Nov. 1974/April 1975	
Section No. and Structure	Embankment Sett. @ Rail, inches	Embankment Sett. @ ℄, inches	Ext. of center 10' in upper horiz. tube,%	Embankment Comp. @ Rail, inches x 10^{-3}	Ext. of center 5' in Tube No.3, inches x 10^{-4}
1 Conc. Ties	1.4**	1.6*	0.20	75/(>60**)	66/(126)
2 " "	1.3**	1.4*	0.38	-	47/(109)
3 " "	1.2**	1.6	0.10	-	89/(142)
4 Conc. Beam	1.6**	0	0.46	54/>104**	38/(45)
5 Conc. Slab	1.0	0.8	0.10	26/(80)	21/(85)
6 Stab. Bal.	1.6**	1.4*	0.60	72/>99**	71/(95)
7 Conc. Beam	1.1	0.1	0.03	20/(109)	-/(44)
8 Conc. Ties	1.6*	1.0	0.36	52/58*	24/(80)
9 Conv. AT&SF	1.4*	0.9	0.25	64/50*	43/95

Legend:
- * One anchor of group possibly bottomed out (def'l.≥1.3")
- ** Rock anchor possibly bottomed out (def'l.≥1.3")
- ( ) 6-axle locomotive; others are 4-axle
- XX Dec./Jan. 1975 reading

Notes: Deformations may have exceeded the value shown for instruments possibly bottomed out.

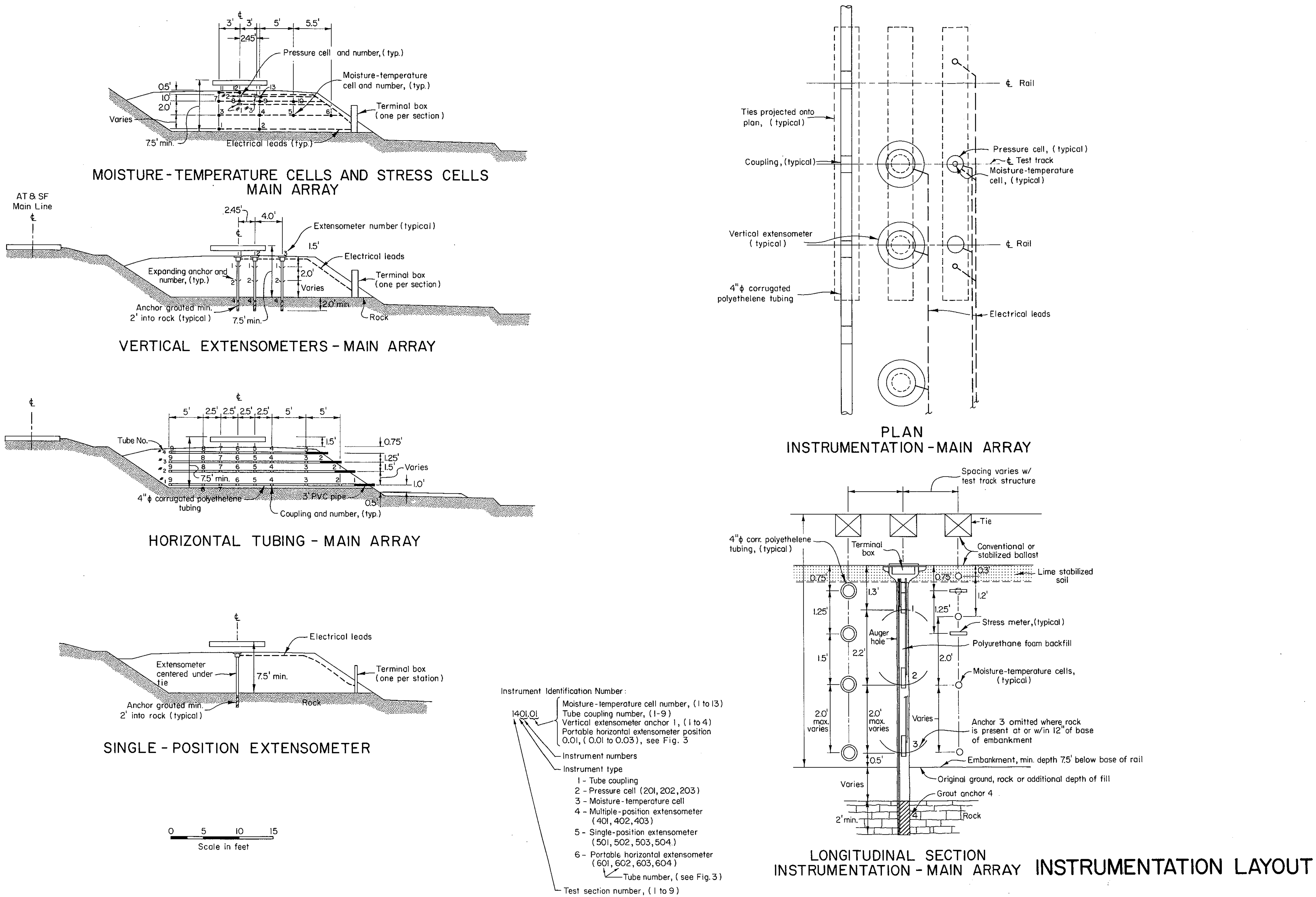
Abbreviations:

Comp. = Compression
Ext. = Extension
Sett. = Settlement



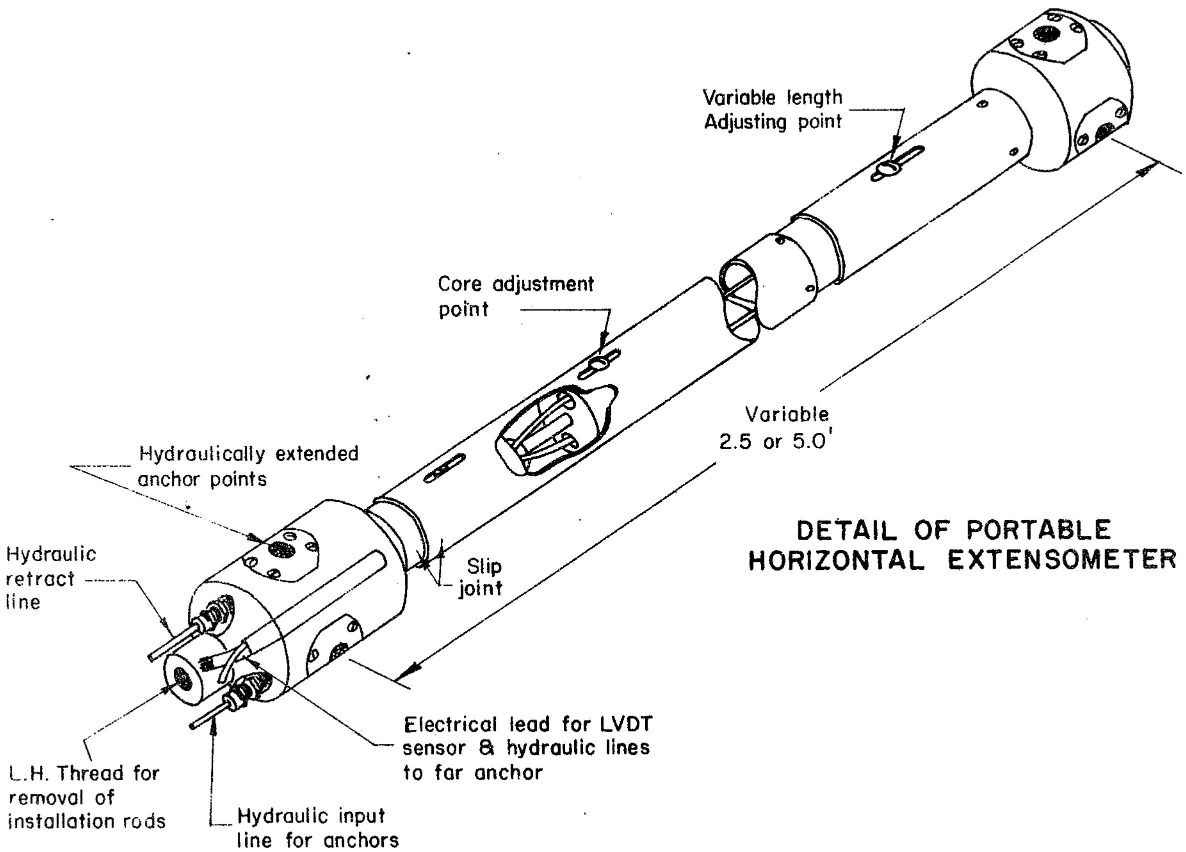
SCHEMATIC PLAN OF
TEST TRACK EMBANKMENT

FIG. 1



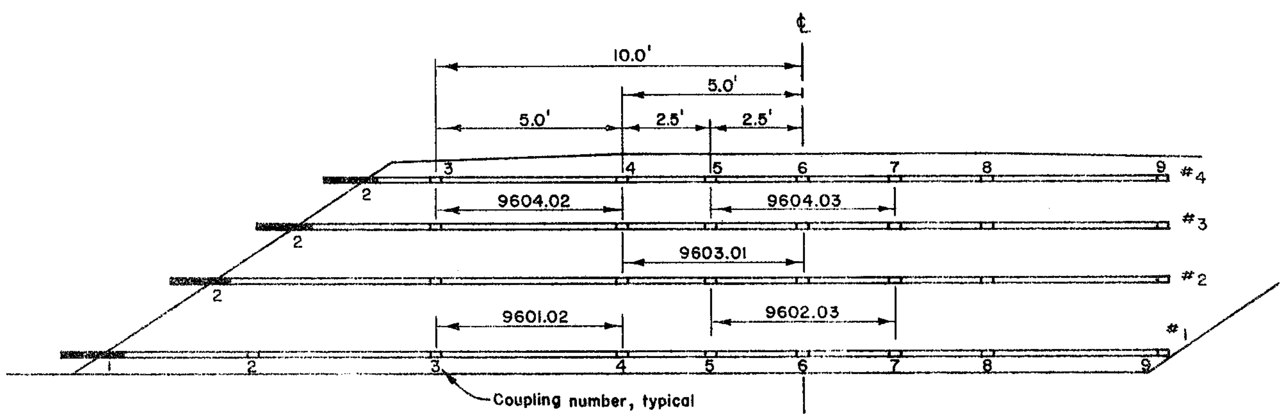
INSTRUMENTATION LAYOUT

FIG. 2



DETAIL OF PORTABLE HORIZONTAL EXTENSOMETER

TYPICAL CROSS-SECTION POSITIONING AND INSTRUMENT CODING OF PORTABLE HORIZONTAL EXTENSOMETERS



Notes:

1. Only 5-foot gage length was used.
2. The instrument coding is as follows:

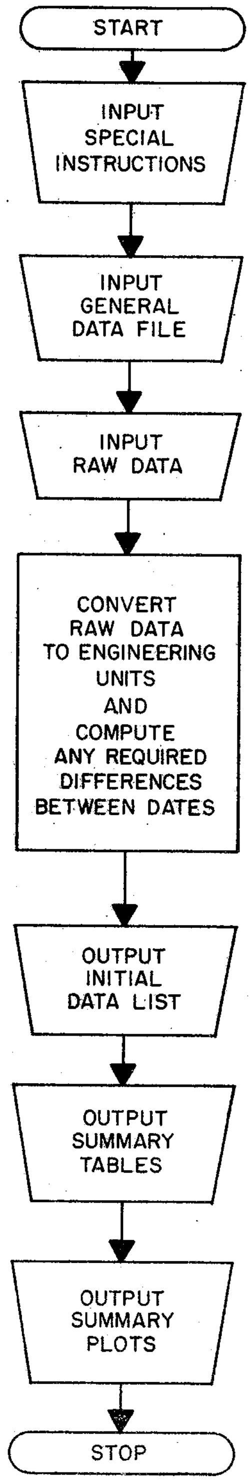
   9604.03
   - Extensometer position
   - Tube No.
   - Code for Portable Horizontal Extensometer
   - Section No.

3. Extensometer positions:

   .03 — Instrument across ℄ - Standard position
   .01 — Instrument ℄ to 5.0'
   .02 — Instrument 5.0' to 10.0'

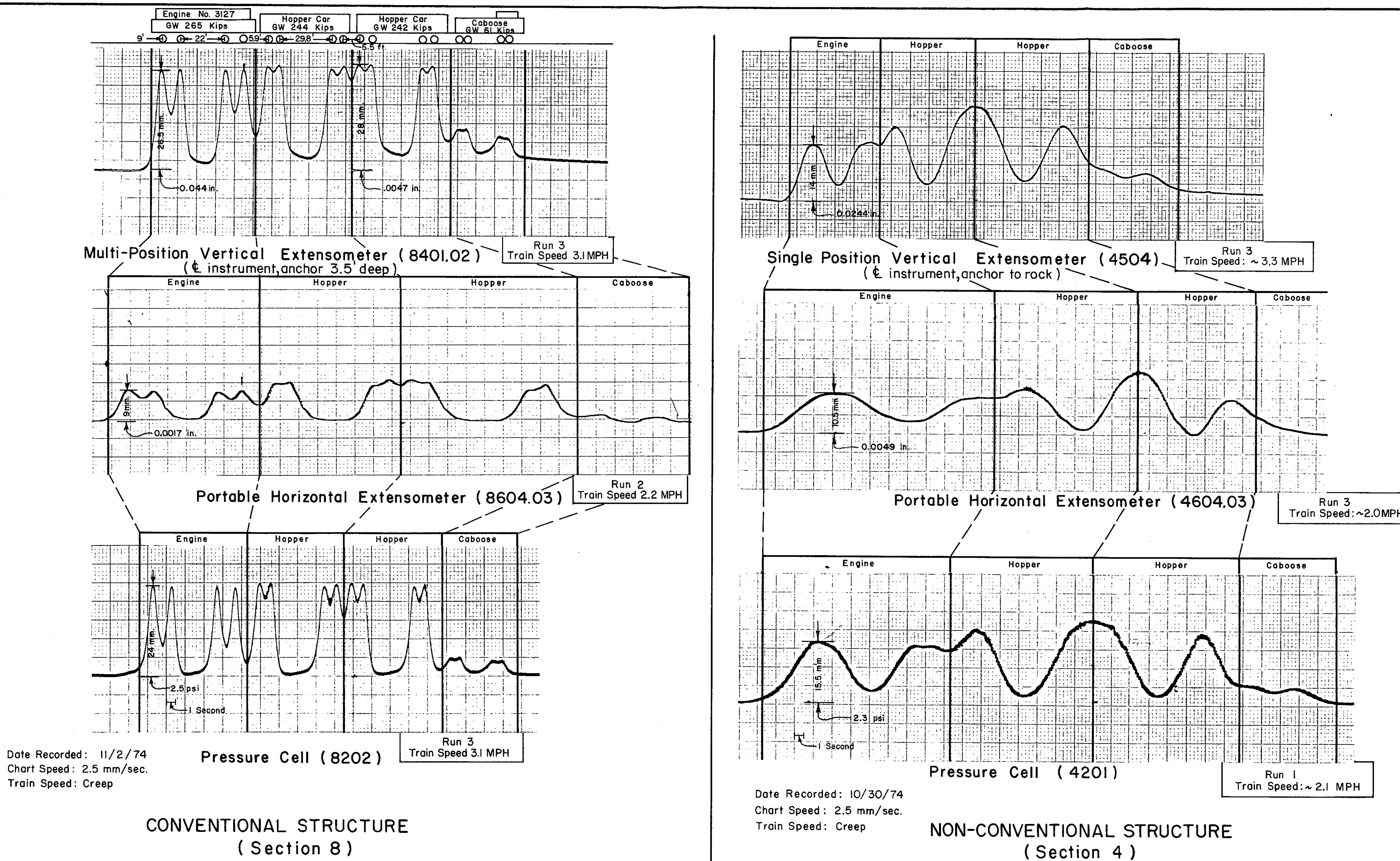
PORTABLE HORIZONTAL EXTENSOMETER

FIG. 3



GENERALIZED
DATA ANALYSES
FLOW CHART

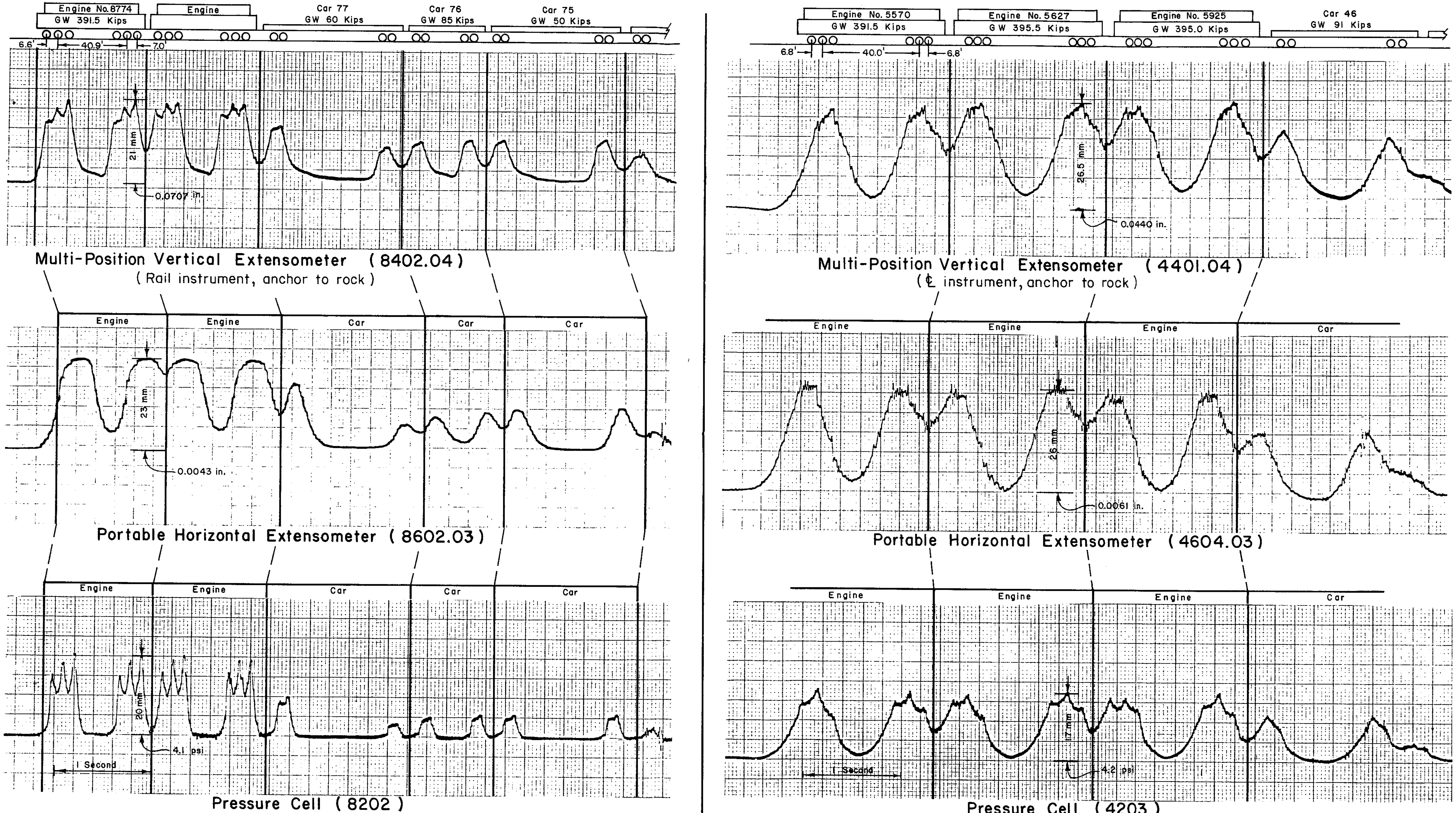
FIG. 4



Note: Typical stylus deflections are listed in mm and actual instrument response is shown in engineering units. Train speed was variable within each run.

TYPICAL DYNAMIC TRACES
WORK TRAIN LOADING

FIG. 5



Date Recorded: 1/9/75
Chart Speed: 25 mm/sec.
Train Speed: 40 MPH

CONVENTIONAL STRUCTURE
(Section 8)

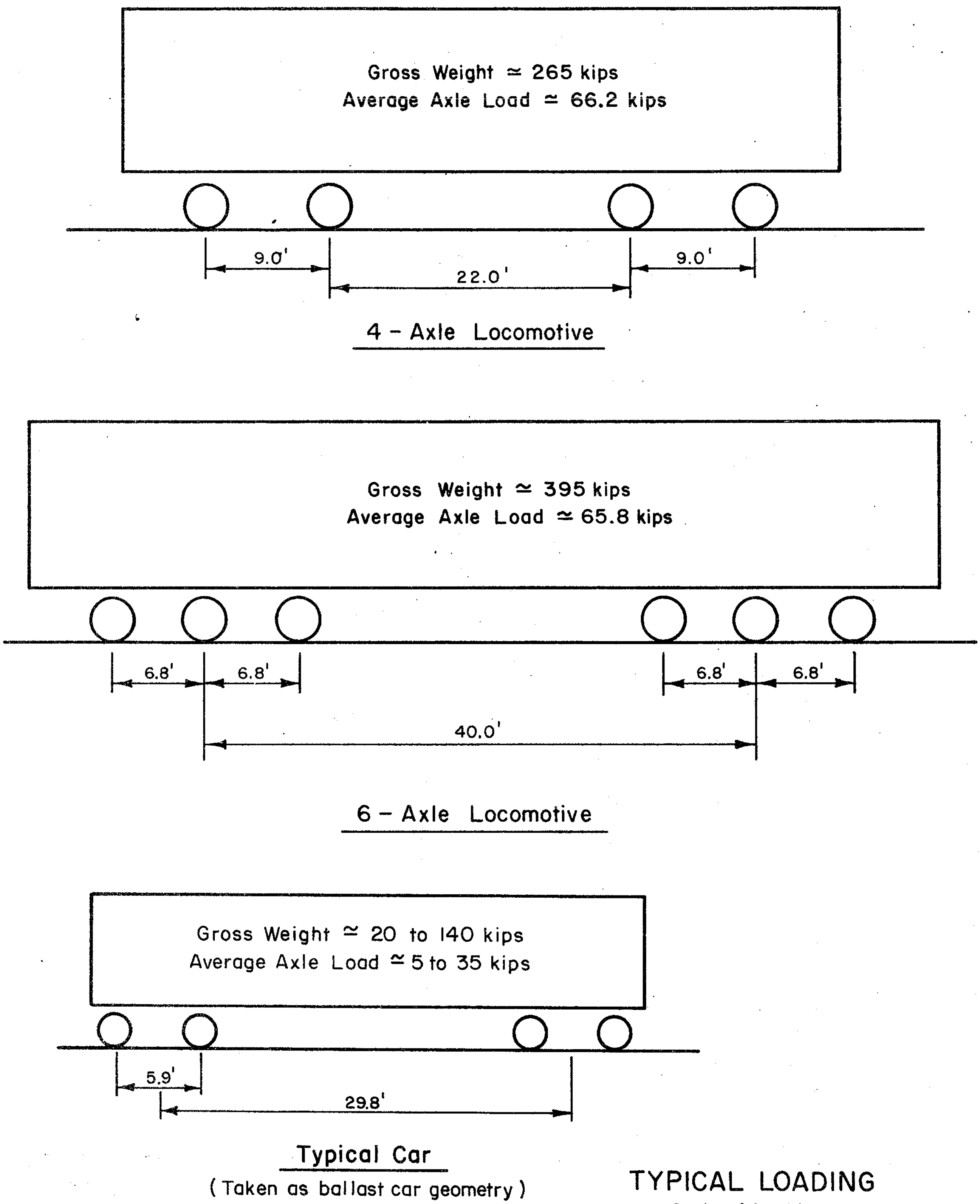
Date Recorded: 12/16/75
Chart Speed: 25 mm/sec.
Train Speed: 30 MPH

NON-CONVENTIONAL STRUCTURE
(Section 4)

Note: Typical stylus deflections are listed in mm and actual instrument response is shown in engineering units.

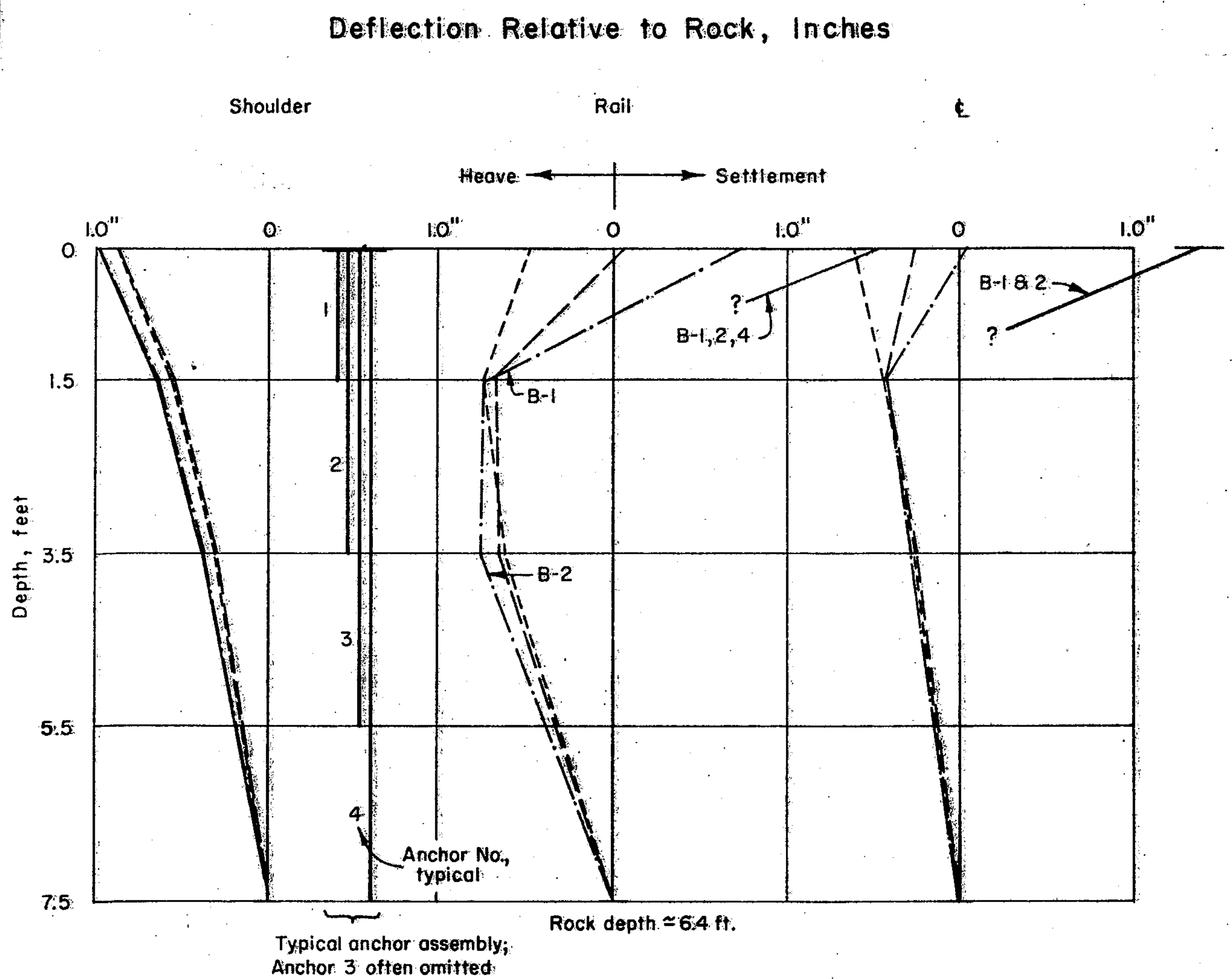
TYPICAL DYNAMIC TRACES
FREIGHT TRAIN LOADING

FIG. 6



TYPICAL LOADING SCHEMATICS

FIG. 7



Date	Symbol
Fall 1971 to 10/74	‒ ‒ ‒ ‒ ‒ ‒ ‒ ‒
Fall 1971 to 11/74	— — — — —
Fall 1971 to 1/75	—·—·—·—
Fall 1971 to 4/75	————————

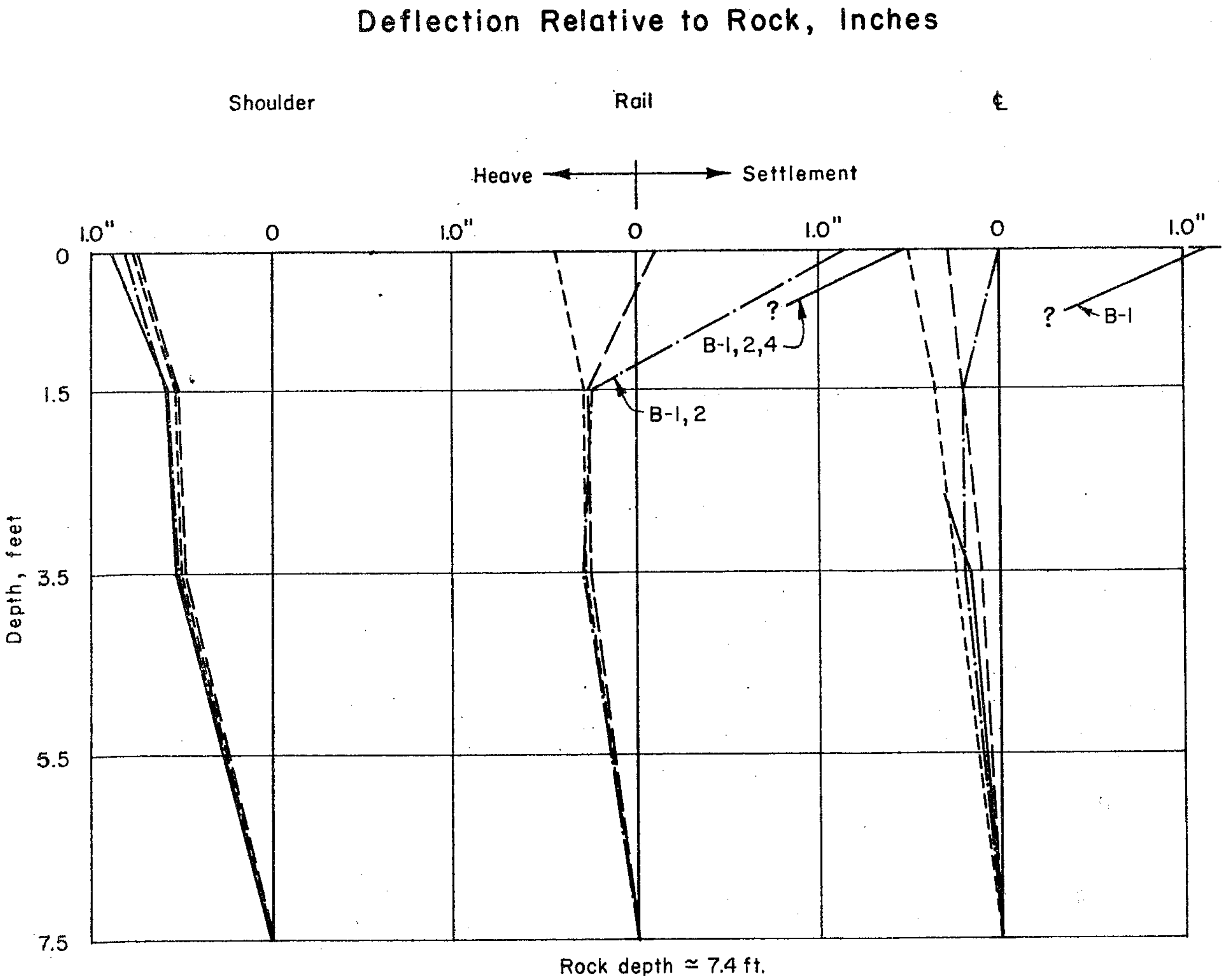
B-1 Indicates Anchor I possibly bottomed out (Defl. >1.3")

Deflections are changes since Oct., 1971.

Note: For presentation, rock assumed to be 7.5' below top of embankment.

VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. I

FIG. 8



Date	Symbol
Fall 1971 to 10/74	— — — — — — — (short dash)
Fall 1971 to 11/74	—— —— —— —— (long dash)
Fall 1971 to 1/75	—·—·—·— (dash-dot)
Fall 1971 to 4/75	———————— (solid)

B-1 Indicates Anchor 1 possibly bottomed out (Defl. >1.3")

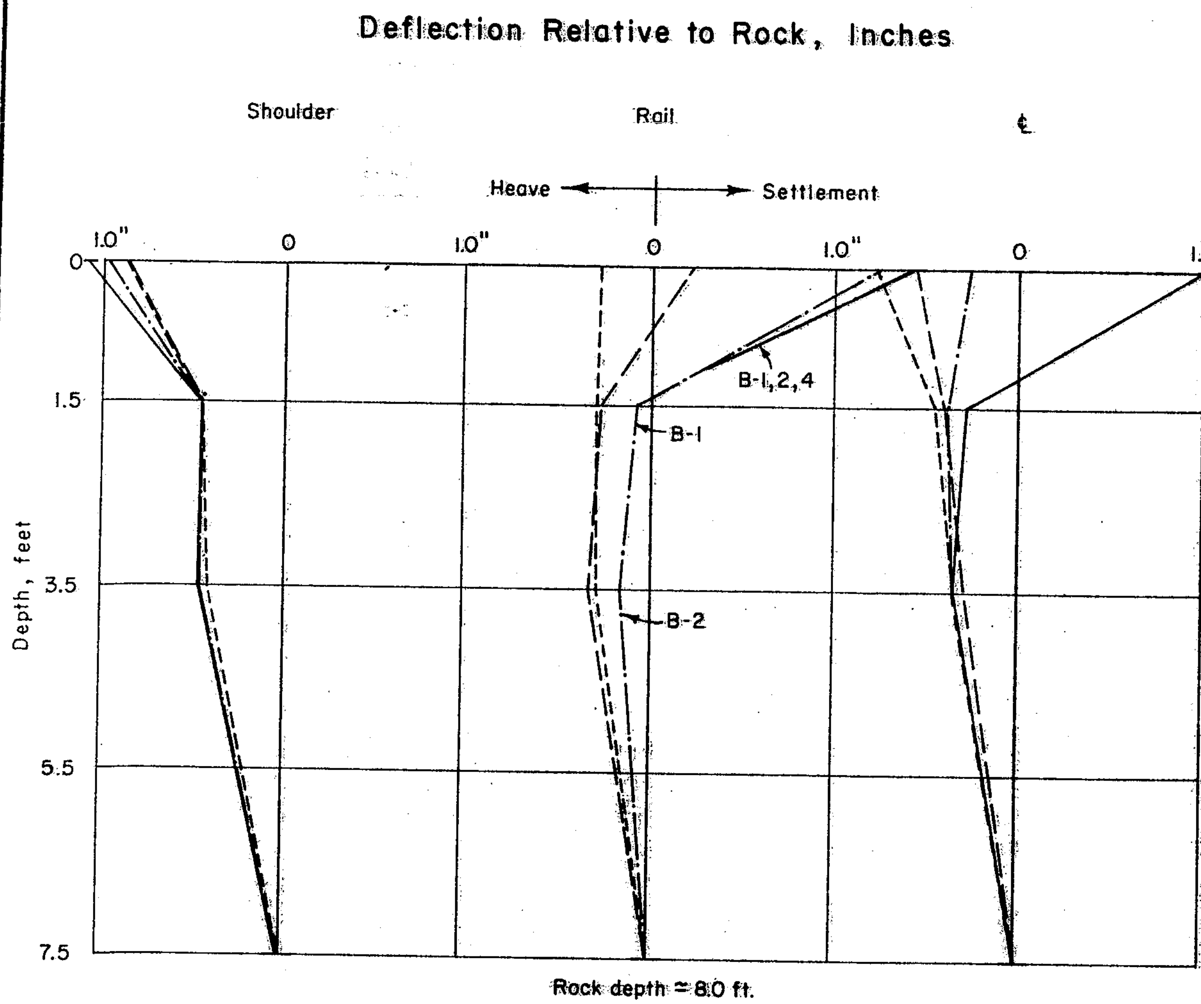
Deflections are changes since Oct., 1971.

Note: For presentation, rock assumed to be 7.5' below top of embankment.

VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 2

1

FIG. 9



Date	Symbol
Fall 1971 to 10/74	– – – – – – – –
Fall 1971 to 11/74	——— ——— ———
Fall 1971 to 1/75	—·—·—·—
Fall 1971 to 4/75	————————

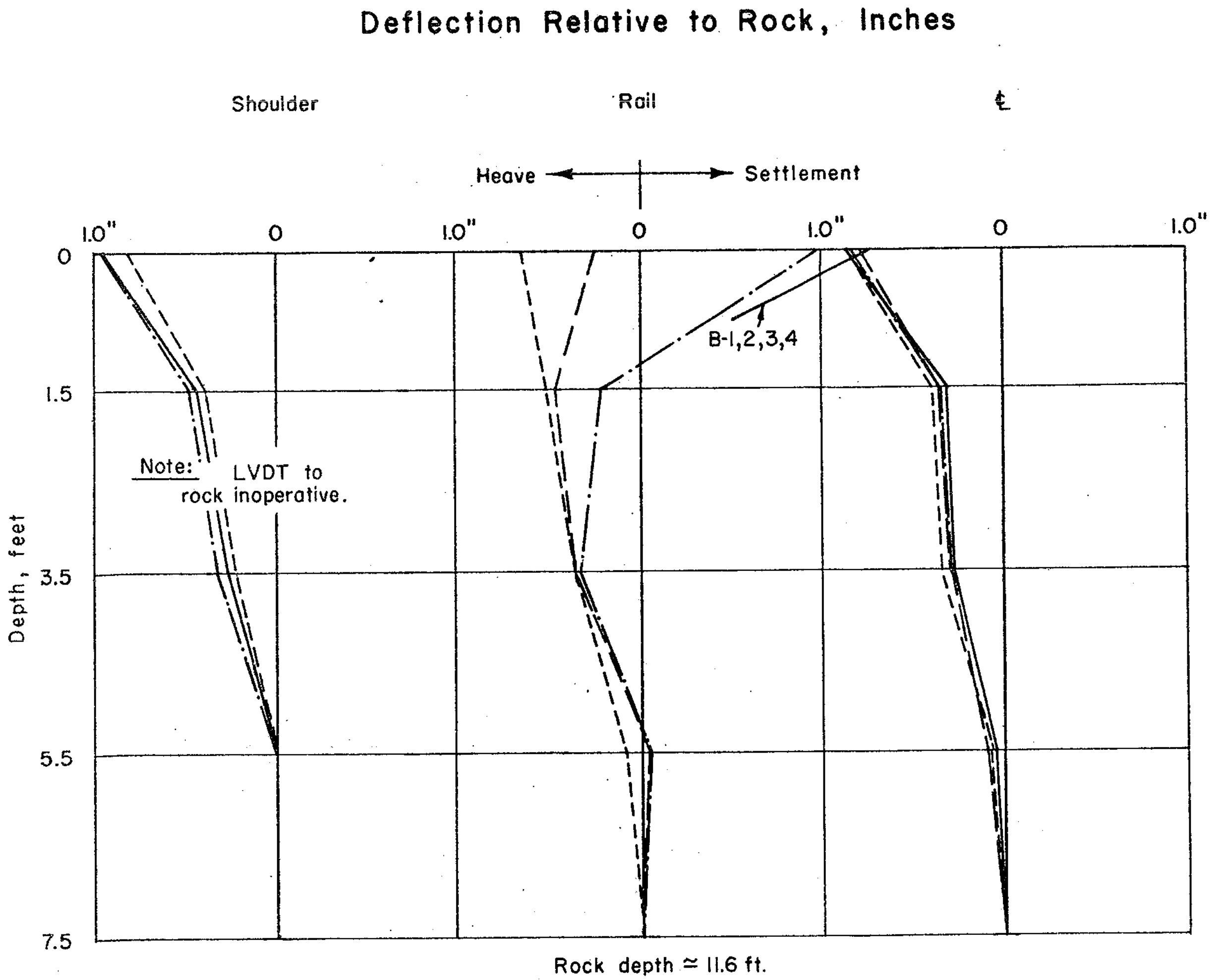
B-1 Indicates Anchor 1 possibly bottomed out (Defl. >1.3")

Deflections are changes since Oct., 1971.

Note: For presentation, rock assumed to be 7.5' below top of embankment.

VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 3

FIG. 10



Date	Symbol
Fall 1971 to 10/74	– – – – – – – –
Fall 1971 to 11/74	—— —— —— ——
Fall 1971 to 1/75	—·—·—·—
Fall 1971 to 4/75	————————

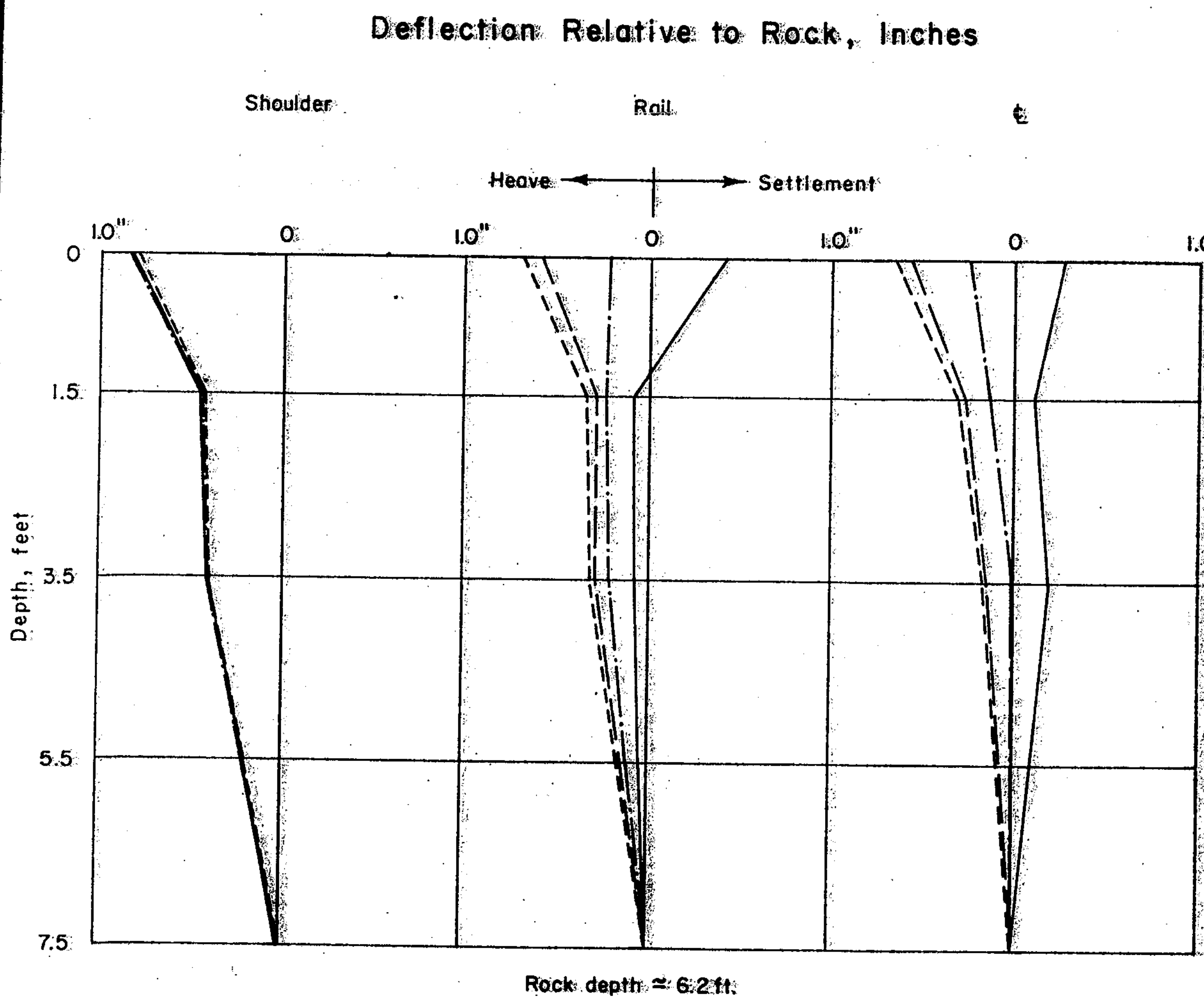
B-1 Indicates Anchor 1 possibly bottomed out (Defl. > 1.3")

Deflections are changes since Oct., 1971.

Note: For presentation, rock assumed to be 7.5' below top of embankment.

VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 4

FIG. 11



Date	Symbol
Fall 1971 to 10/74	— - — - — - —
Fall 1971 to 11/74	— — — — —
Fall 1971 to 1/75	— · — · — · —
Fall 1971 to 4/75	———————

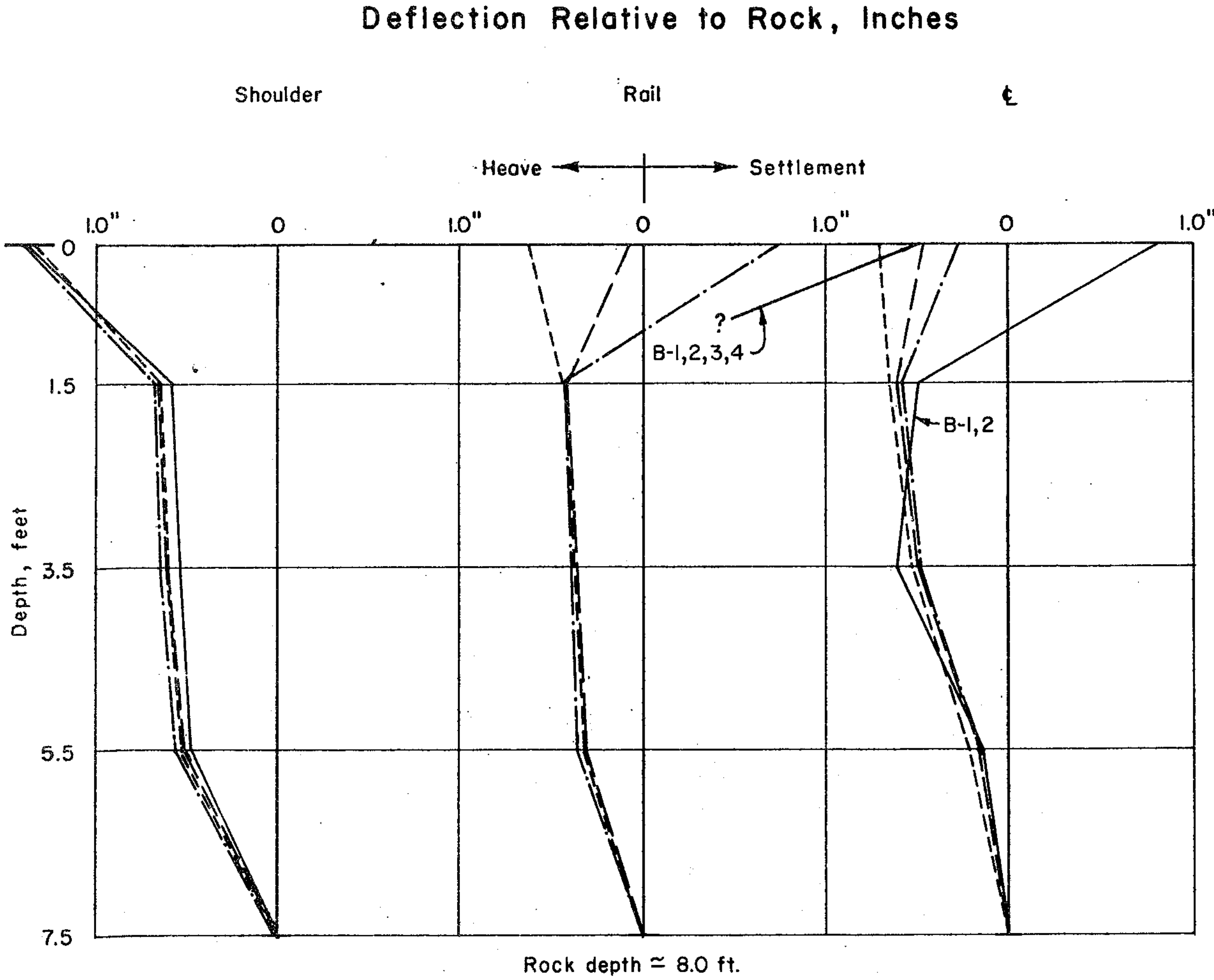
B-1 Indicates Anchor 1 possibly bottomed out (Defl. >1.3")

Deflections are changes since Oct., 1971.

Note: For presentation, rock assumed to be 7.5' below top of embankment.

VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 5

FIG. 12



Date	Symbol
Fall 1971 to 10/74	- - - - - - - -
Fall 1971 to 11/74	— — — —
Fall 1971 to 1/75	—·—·—·—
Fall 1971 to 4/75	————————

B-1 Indicates Anchor 1 possibly bottomed out (Defl. > 1.3")

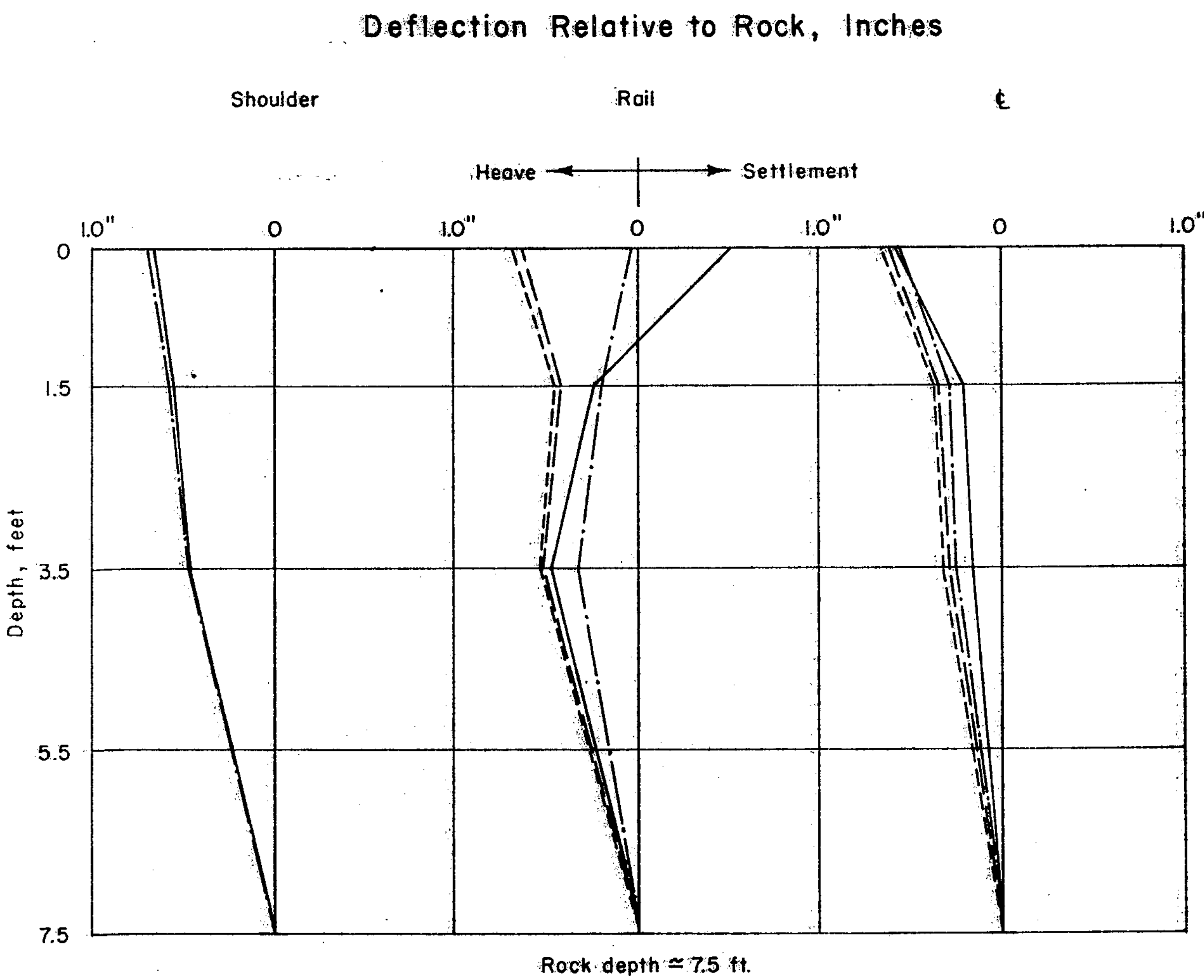
Deflections are changes since Oct., 1971.

Note: For presentation, rock assumed to be 7.5' below top of embankment.

VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 6

81

FIG. 13



Date	Symbol
Fall 1971 to 10/74	– – – – – – – –
Fall 1971 to 11/74	—— —— —— ——
Fall 1971 to 1/75	—·—·—·—
Fall 1971 to 4/75	————————

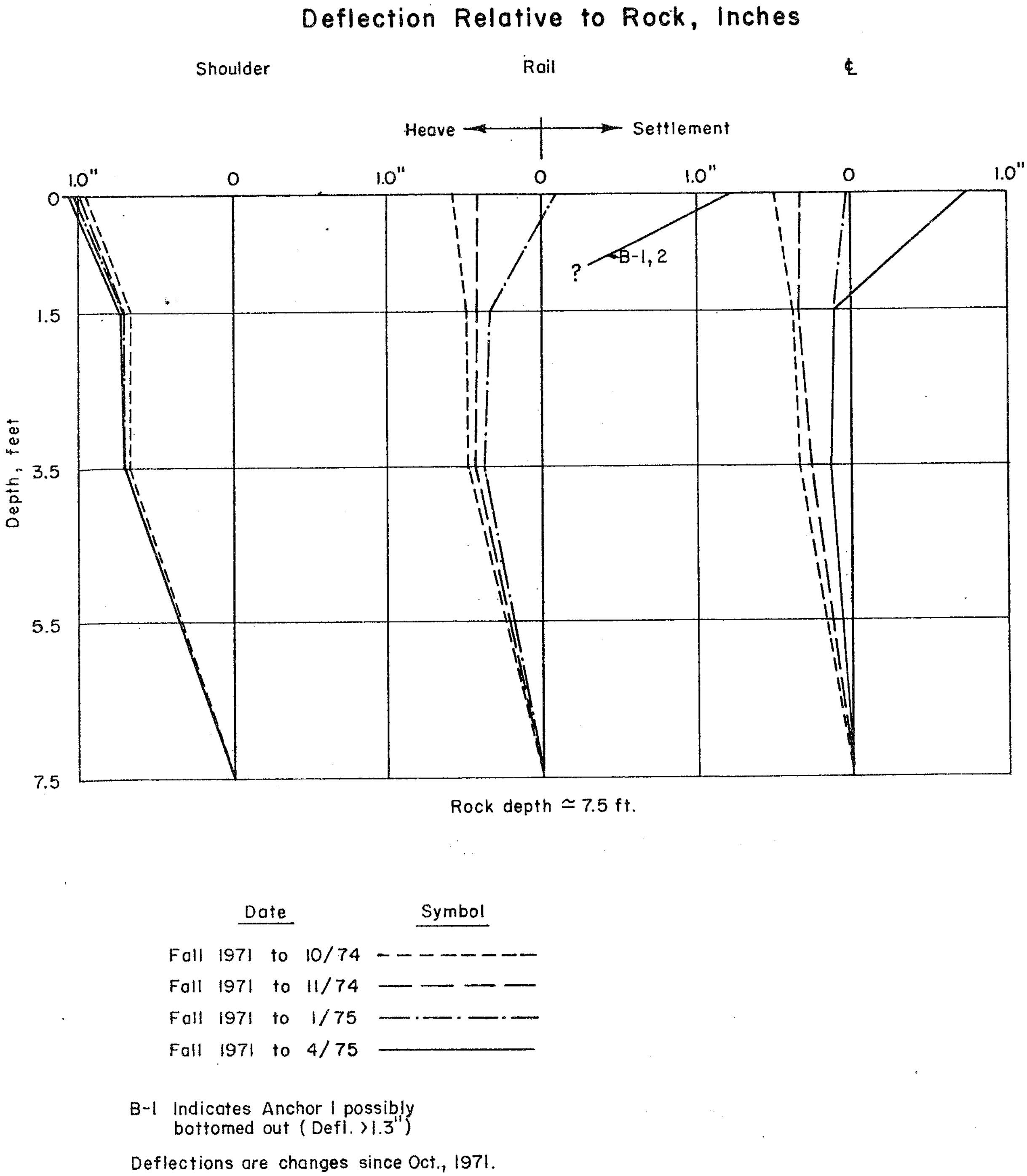
B-1 Indicates Anchor 1 possibly bottomed out (Defl. >1.3")

Deflections are changes since Oct., 1971.

Note: For presentation, rock assumed to be 7.5' below top of embankment.

VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 7

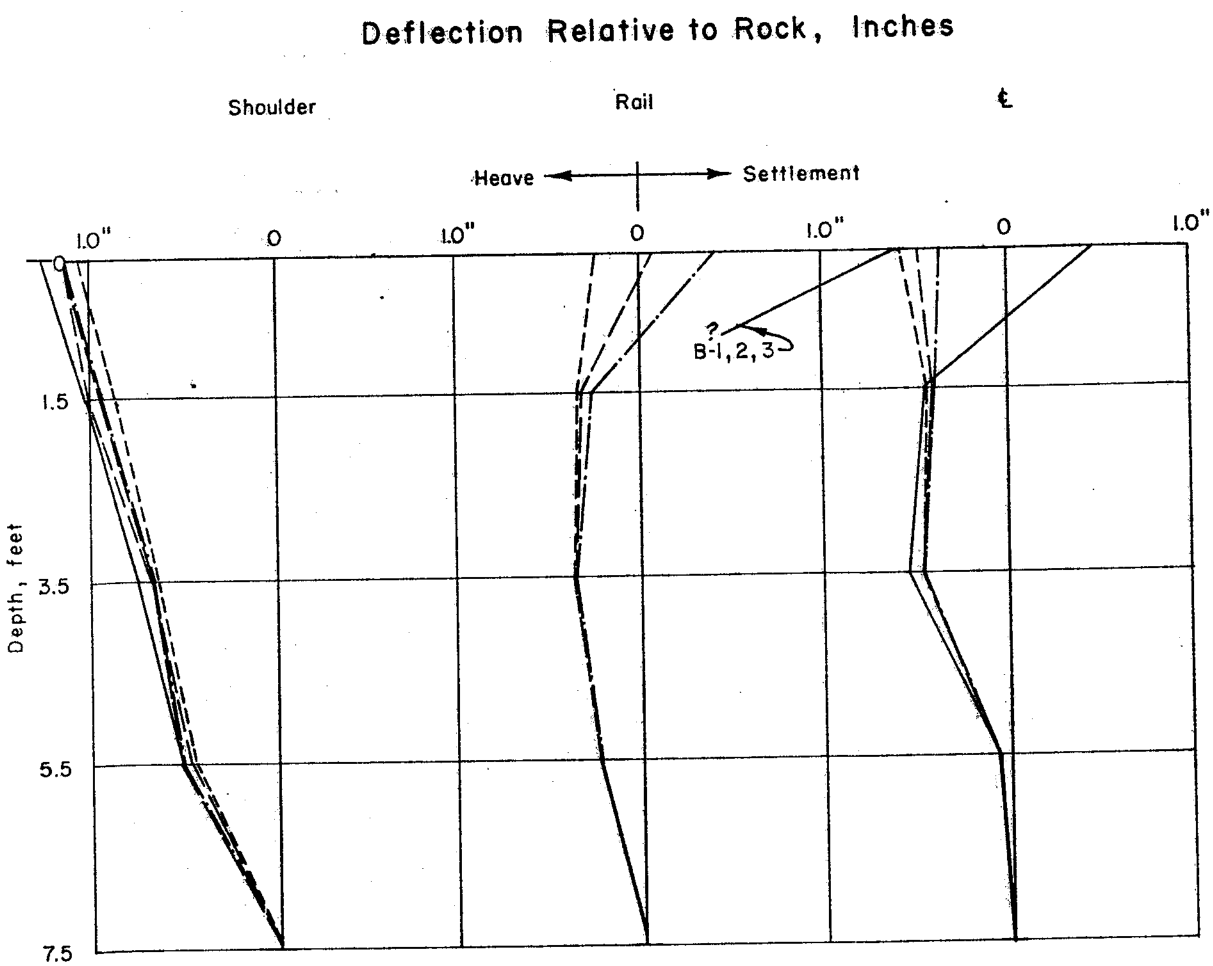
FIG. 14



Note: For presentation, rock assumed to be 7.5' below top of embankment.

VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 8

FIG. 15



Rock depth ≃ 19.5 ft.
The anchor is in a suspected clay-filled rock joint below a depth of about 7 feet

Date	Symbol
Fall 1971 to 10/74	– – – – – – – – (short dashes)
Fall 1971 to 11/74	—— —— —— (long dashes)
Fall 1971 to 1/75	—·—·—·— (dash-dot)
Fall 1971 to 4/75	———————— (solid)

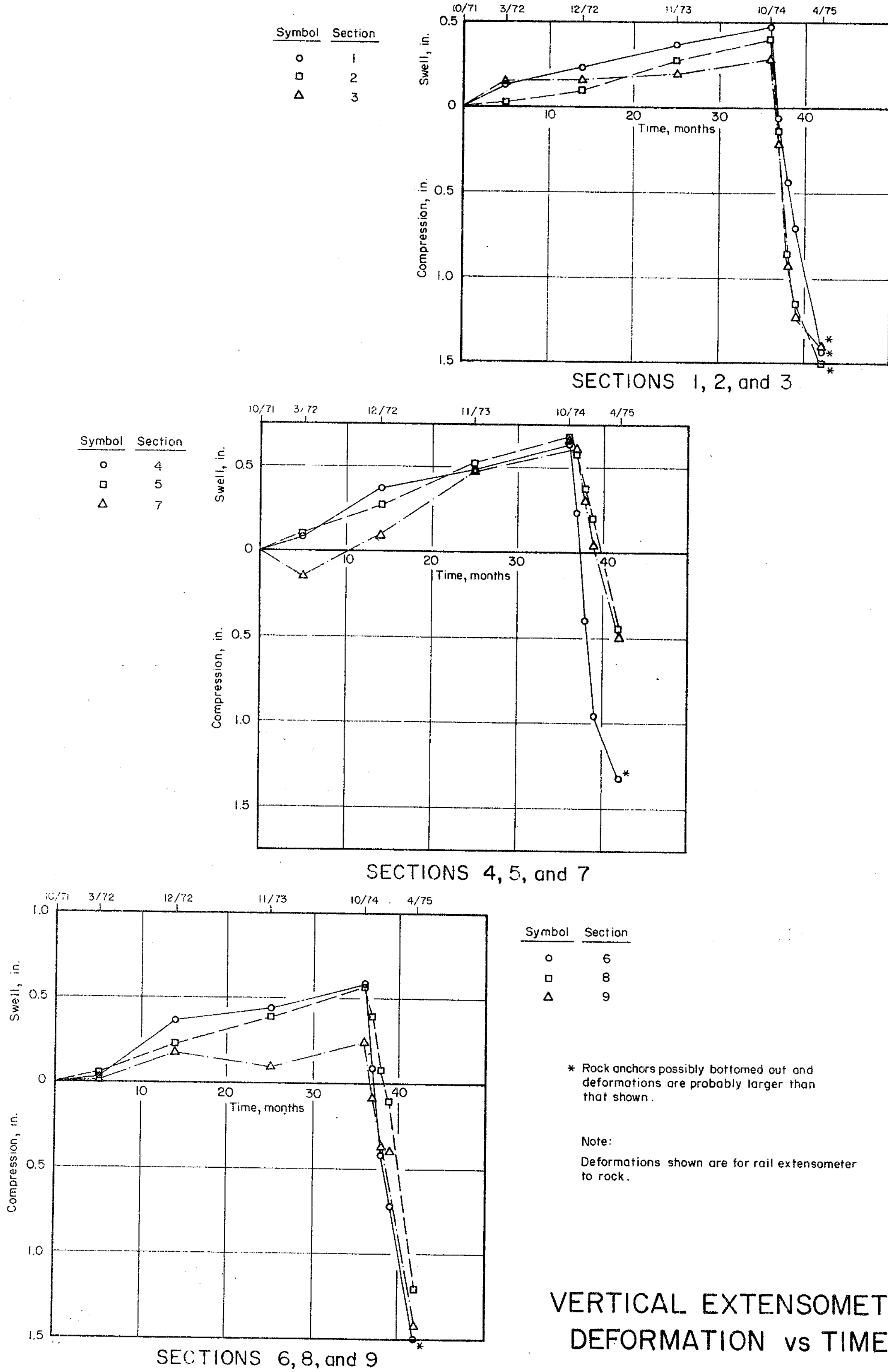
B-1 Indicates Anchor 1 possibly bottomed out (Defl. >1.3")

Deflections are changes since Oct., 1971

Note: For presentation, rock assumed to be 7.5' below top of embankment.

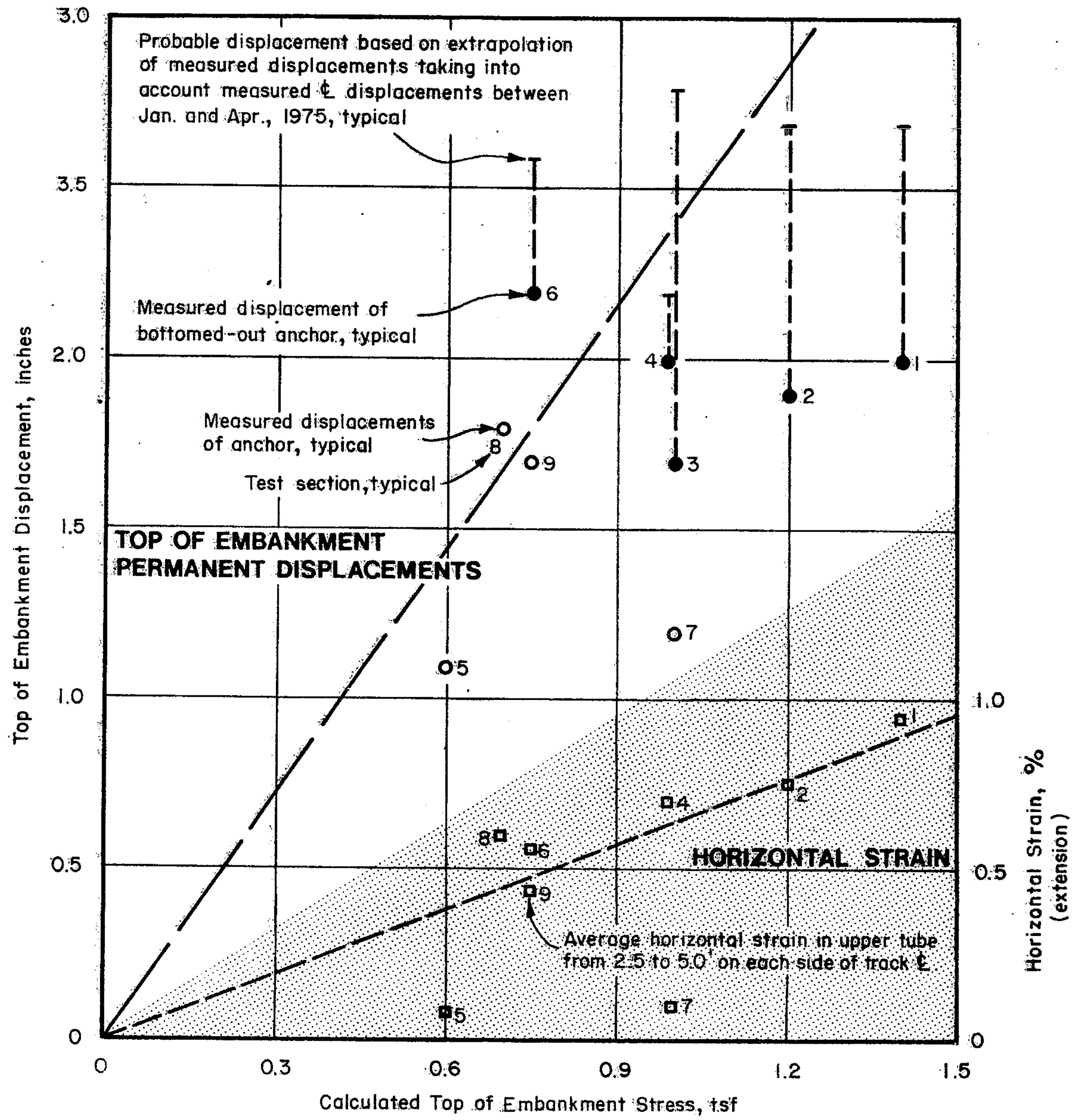
VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 9

FIG. 16



VERTICAL EXTENSOMETER DEFORMATION vs TIME

FIG. 17

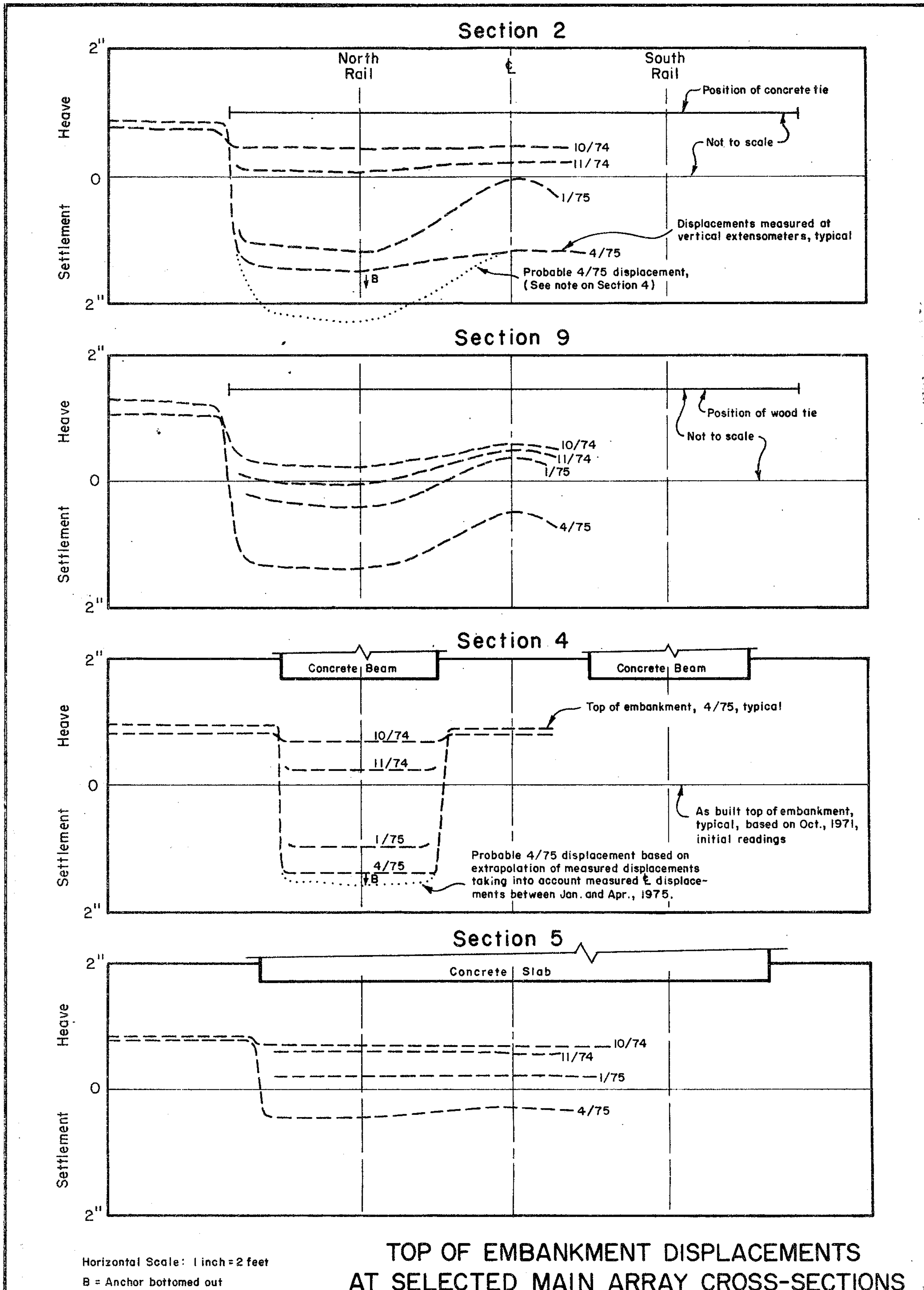


Notes:

1) Displacements shown are those measured over the period of traffic from Oct., 1974, thru Apr., 1975.
2) Data not available for Horizontal Strain of section 3.

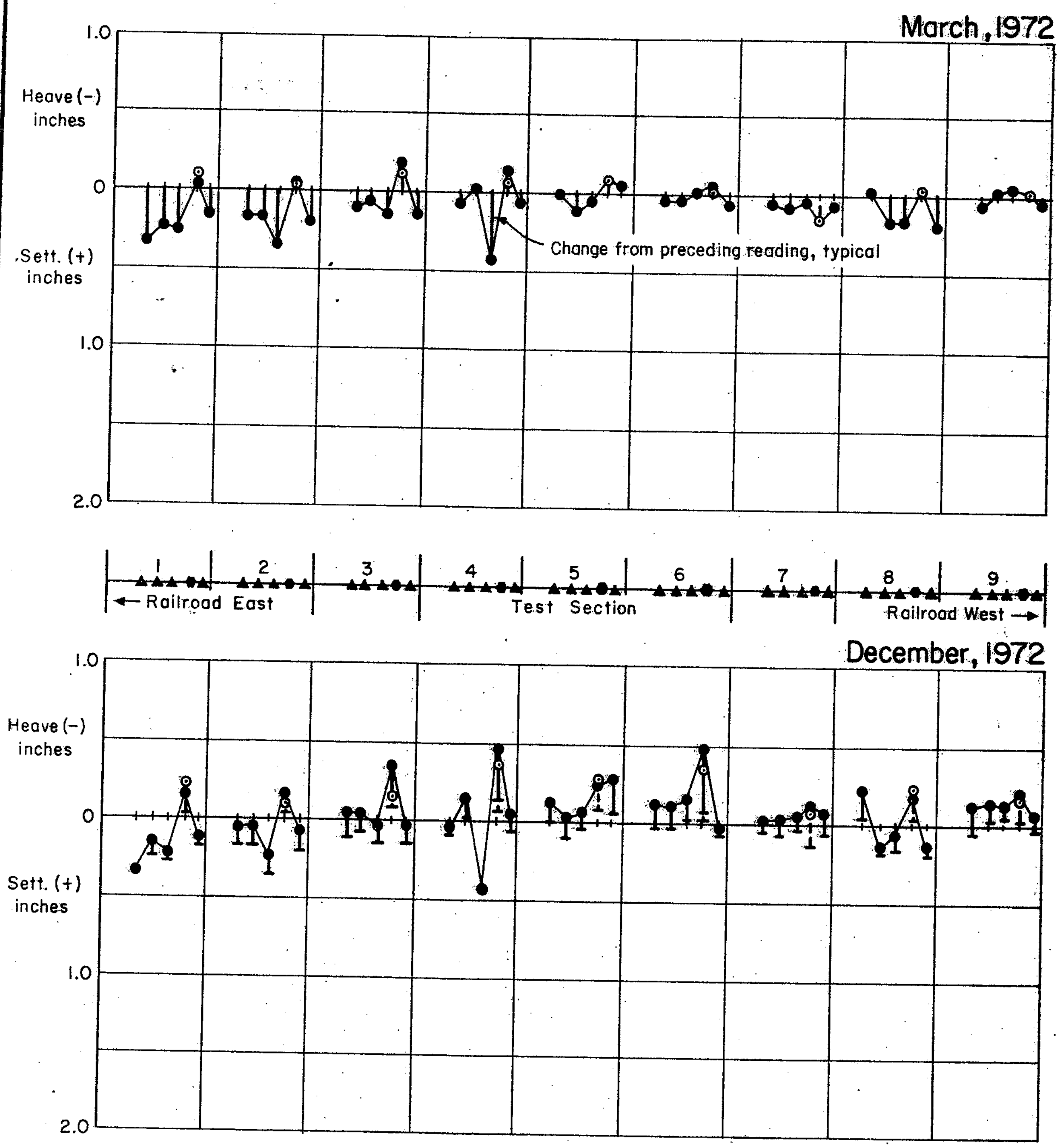
TOP OF EMBANKMENT
PERMANENT DISPLACEMENT AT RAIL
AND HORIZONTAL STRAIN vs STRESS

FIG. 18



TOP OF EMBANKMENT DISPLACEMENTS
AT SELECTED MAIN ARRAY CROSS-SECTIONS

FIG. 19



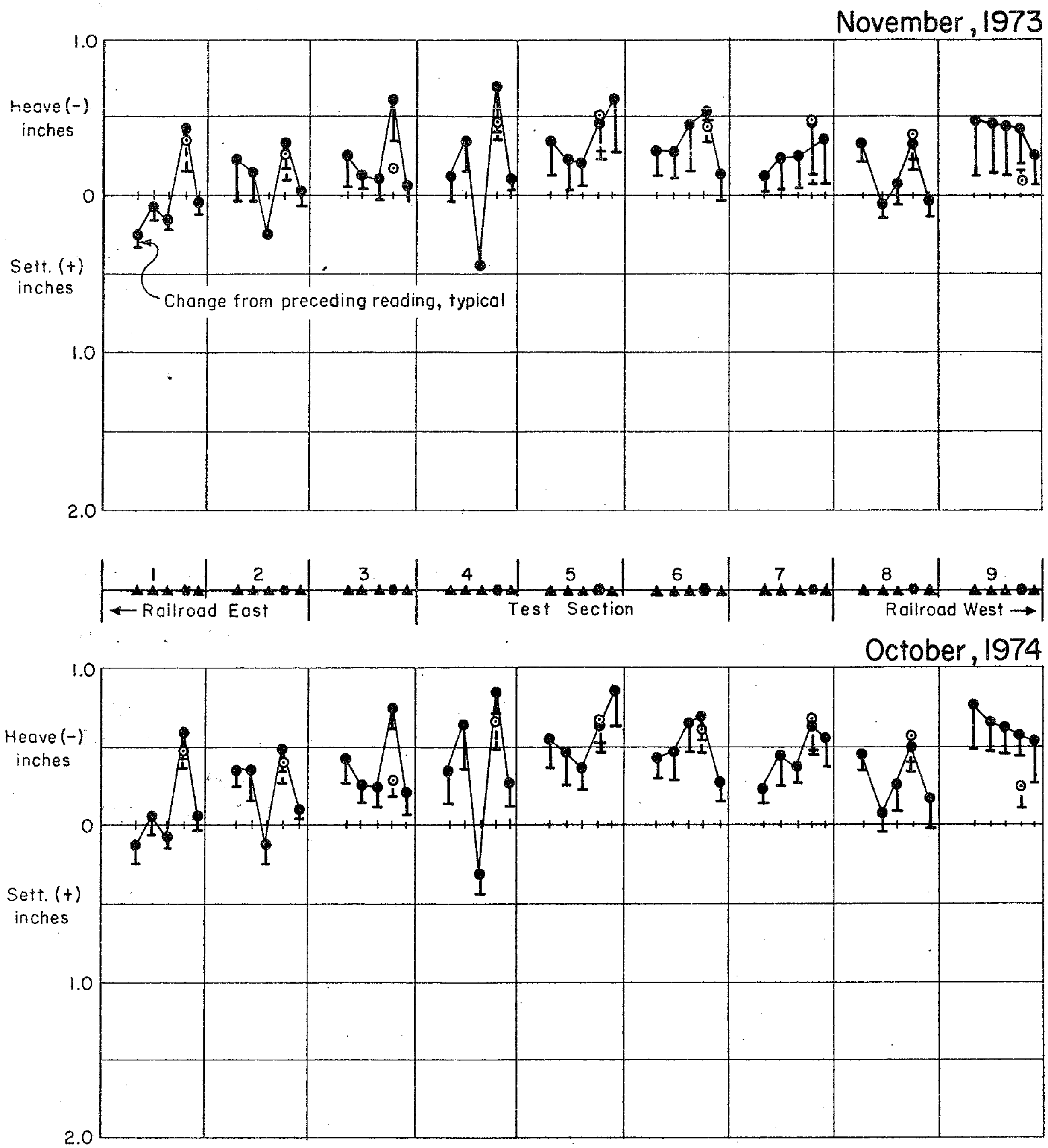
Note: Deflections shown are between top of embankment and rock since Oct, 1971.

Legend:

- ● Centerline extensometer to rock
- ⊙ Rail extensometer to rock
- ⬢ Main instrumentation array
- ▲ Single-position extensometer

VERTICAL EXTENSOMETER DEFLECTION vs STATIONING

FIG. 20



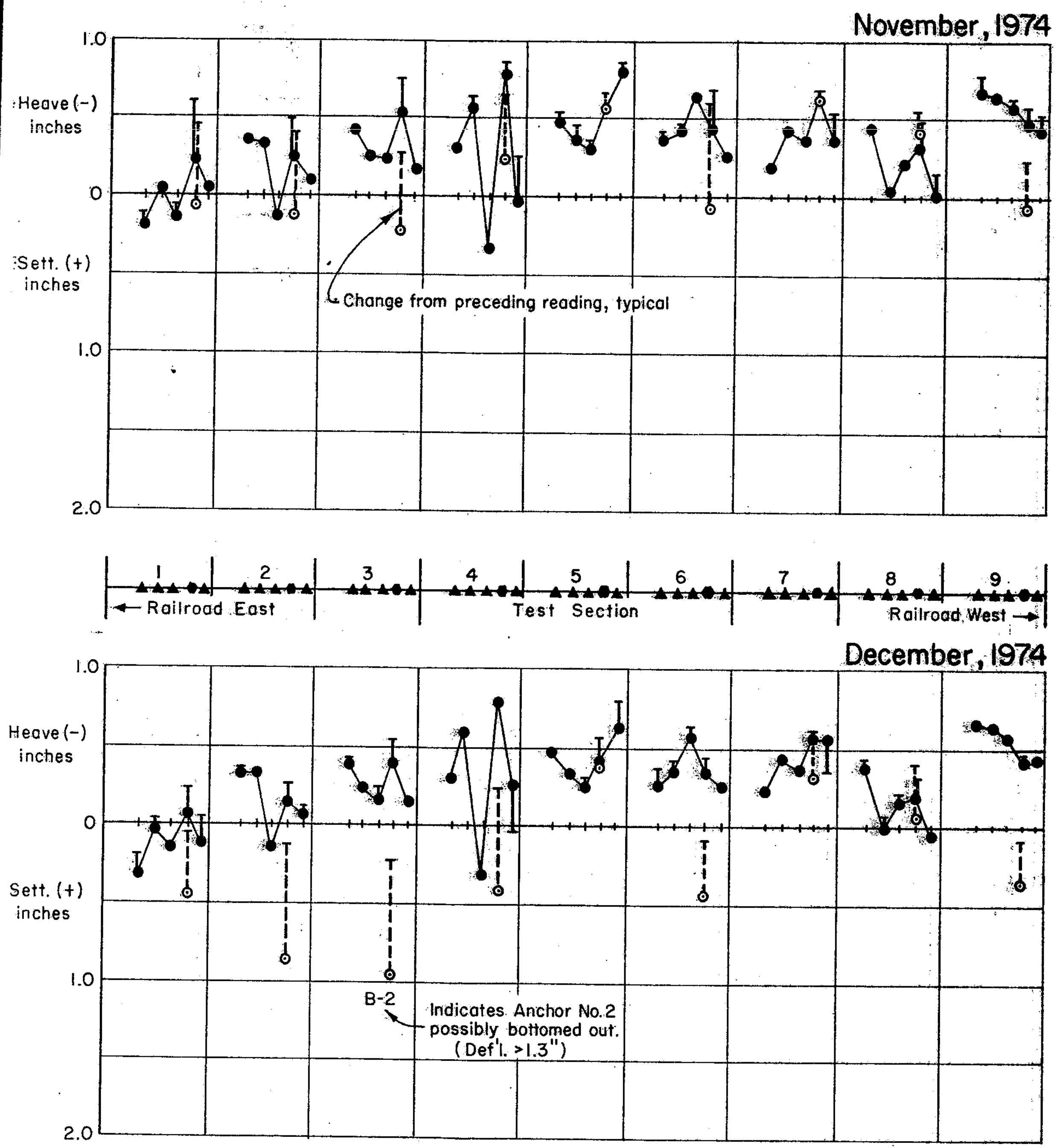
Note: Deflections shown are between top of embankment and rock since Oct, 1971.

Legend:

- Centerline extensometer to rock
- Rail extensometer to rock
- Main instrumentation array
- Single-position extensometer

VERTICAL EXTENSOMETER DEFLECTION vs STATIONING

FIG. 21



Note: Deflections shown are between top of embankment and rock since Oct, 1971.

Legend:

● Centerline extensometer to rock

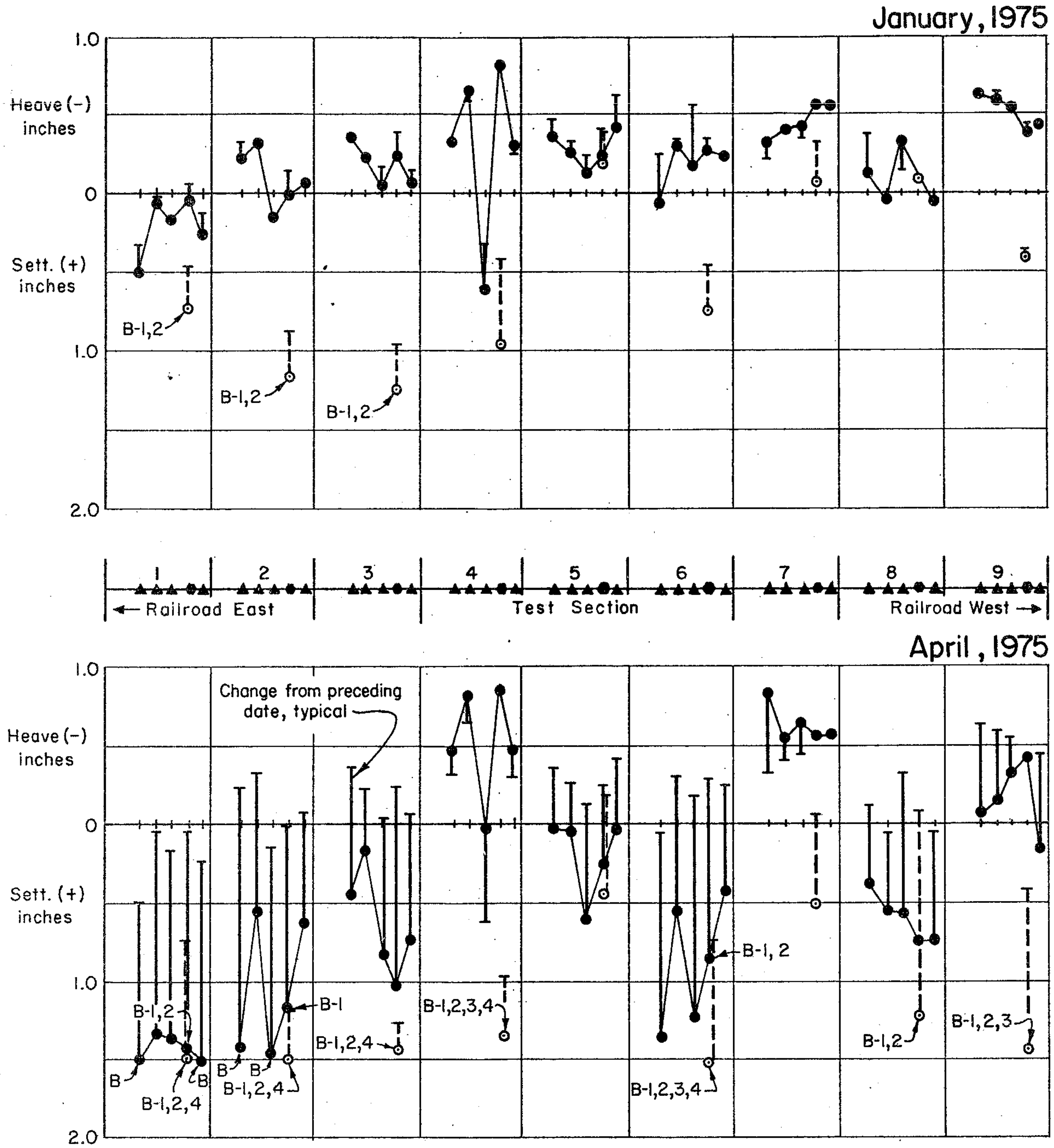
⊙ Rail extensometer to rock

● Main instrumentation array

▲ Single-position extensometer

VERTICAL EXTENSOMETER DEFLECTION vs STATIONING

FIG. 22



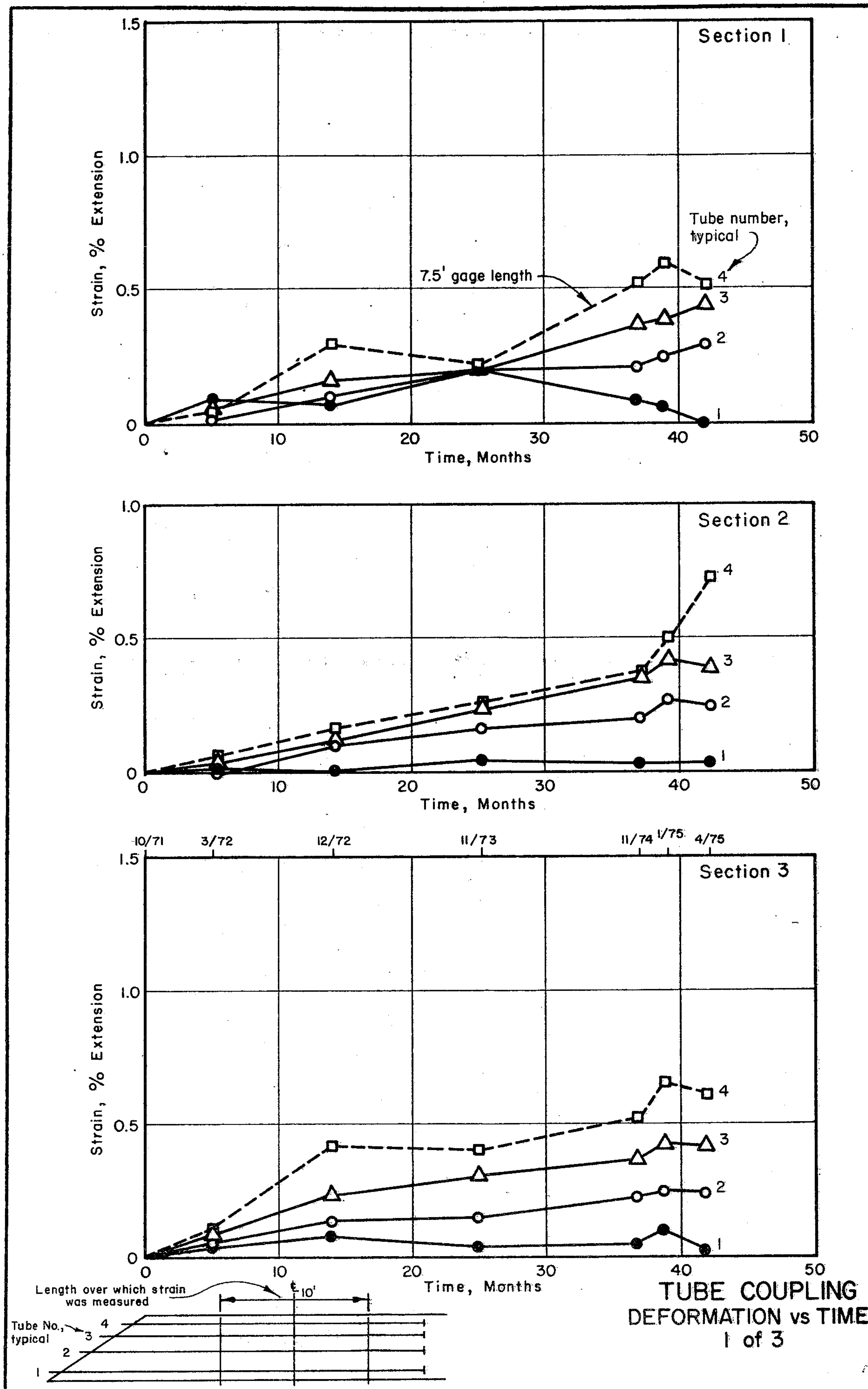
Note: Deflections shown are between top of embankment and rock since Oct, 1971.

Legend:

- ● Centerline extensometer to rock
- ⊙ Rail extensometer to rock
- ● Main instrumentation array
- ▲ Single-position extensometer

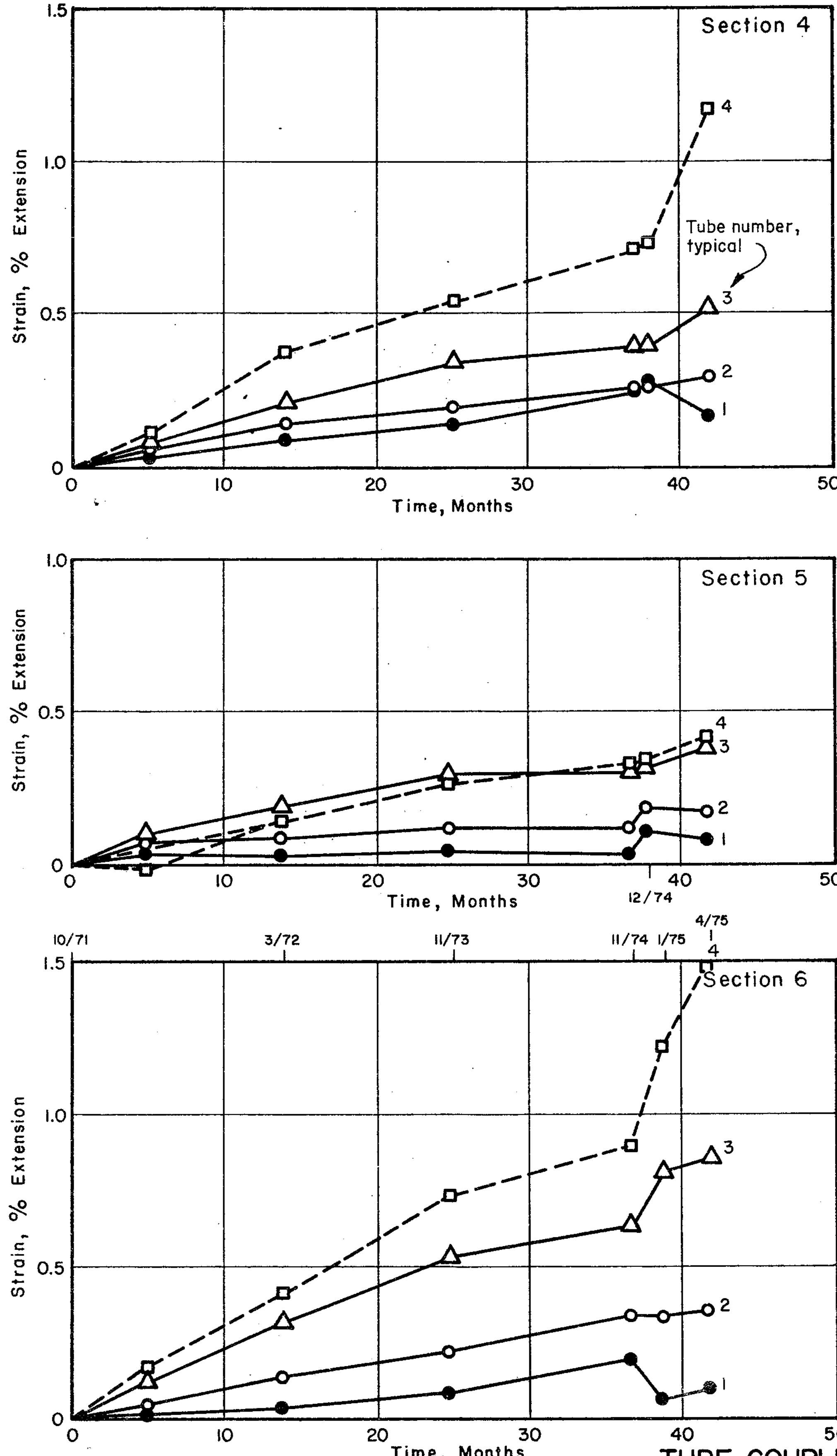
VERTICAL EXTENSOMETER DEFLECTION vs STATIONING

FIG. 23



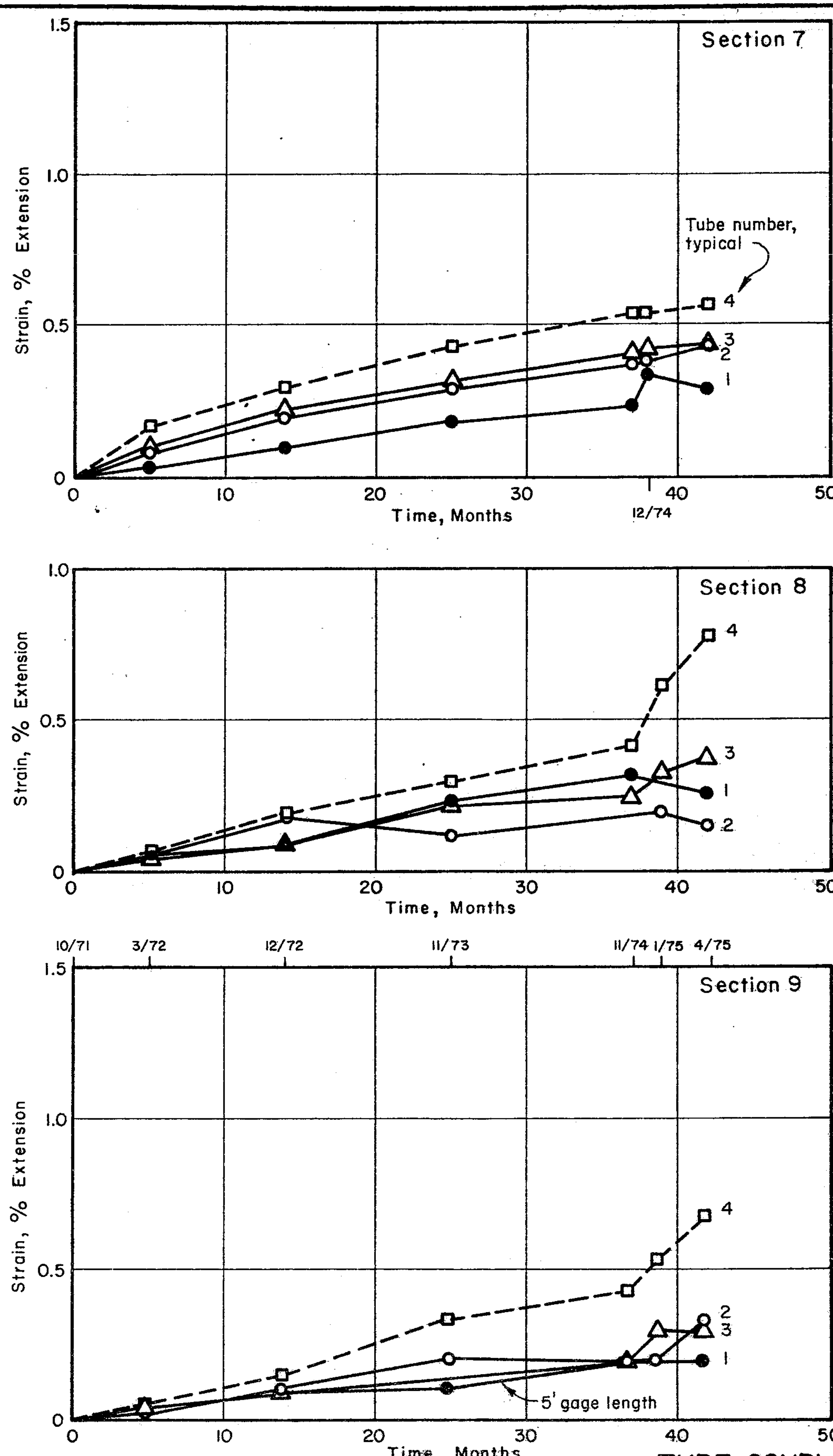
TUBE COUPLING
DEFORMATION vs TIME
1 of 3

FIG. 24



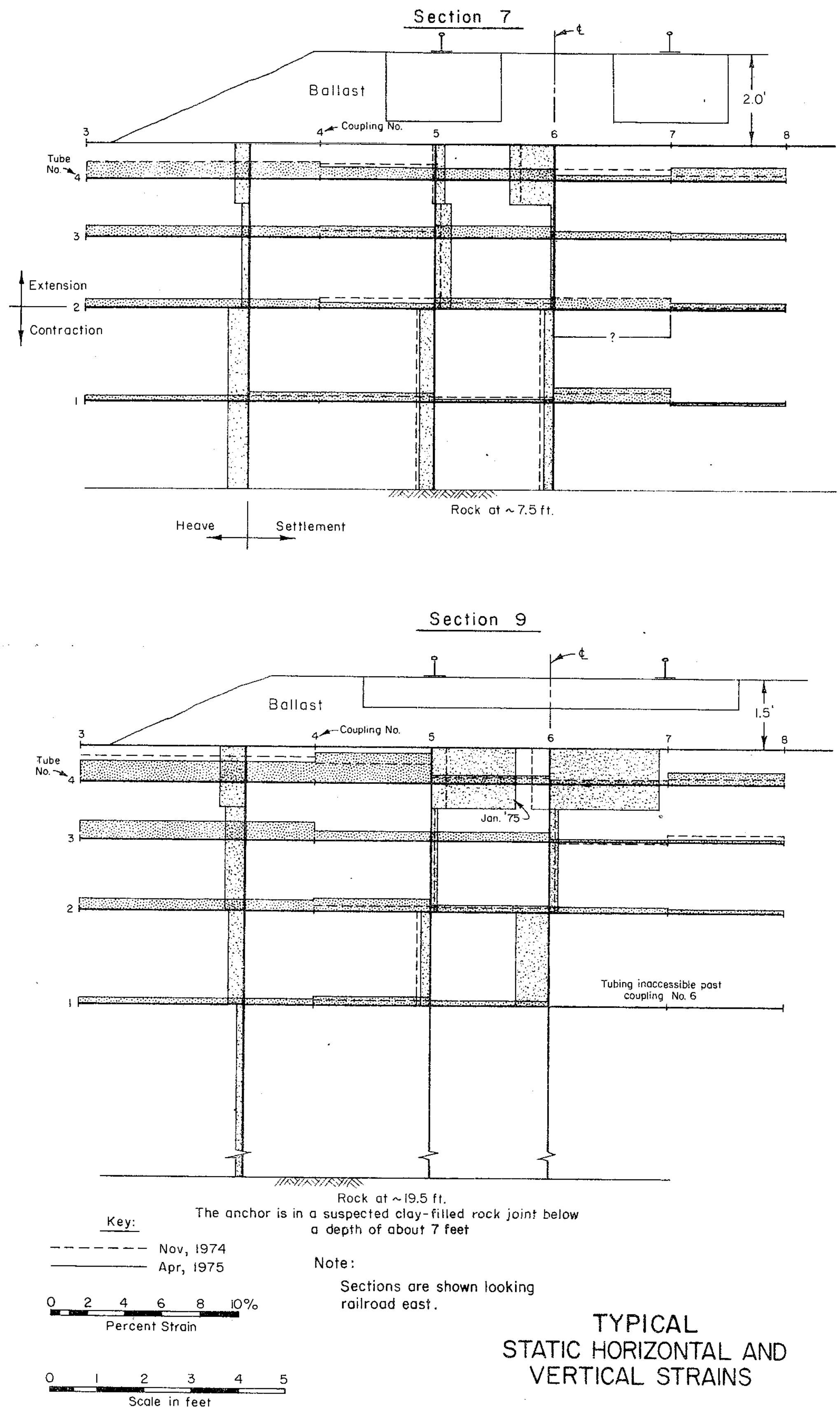
TUBE COUPLING
DEFORMATION vs TIME
2 of 3

FIG. 25



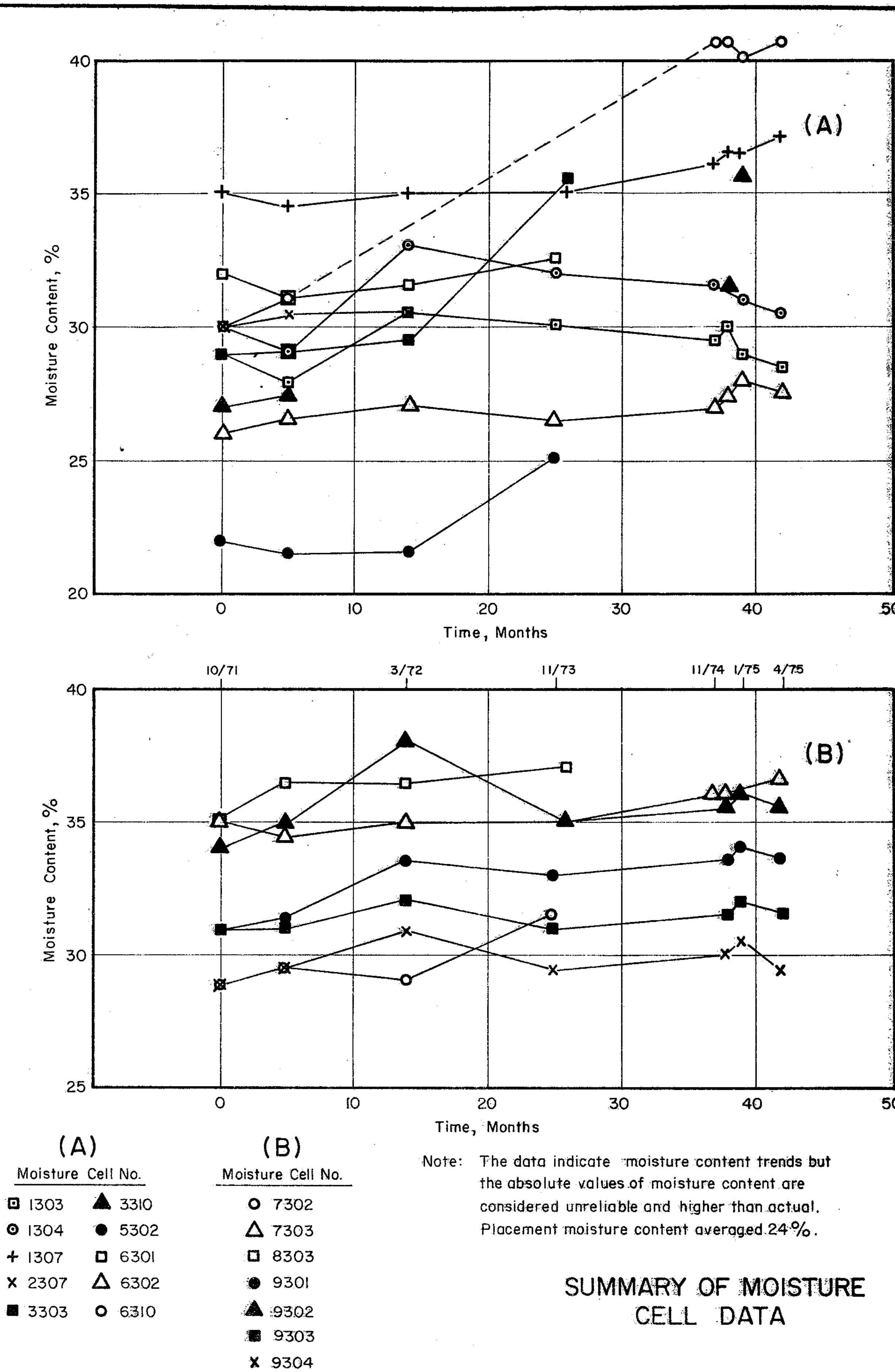
TUBE COUPLING
DEFORMATION vs TIME
3 of 3

FIG. 26



TYPICAL
STATIC HORIZONTAL AND
VERTICAL STRAINS

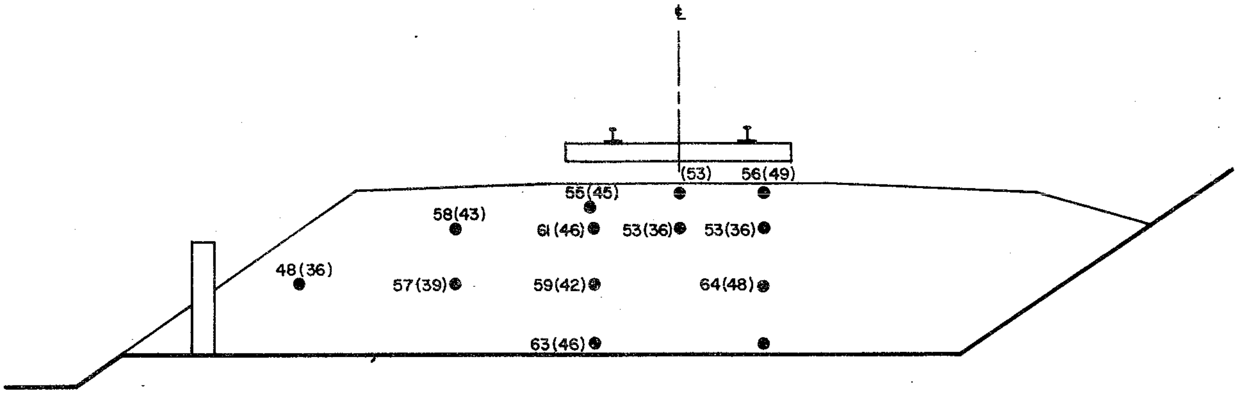
FIG. 27



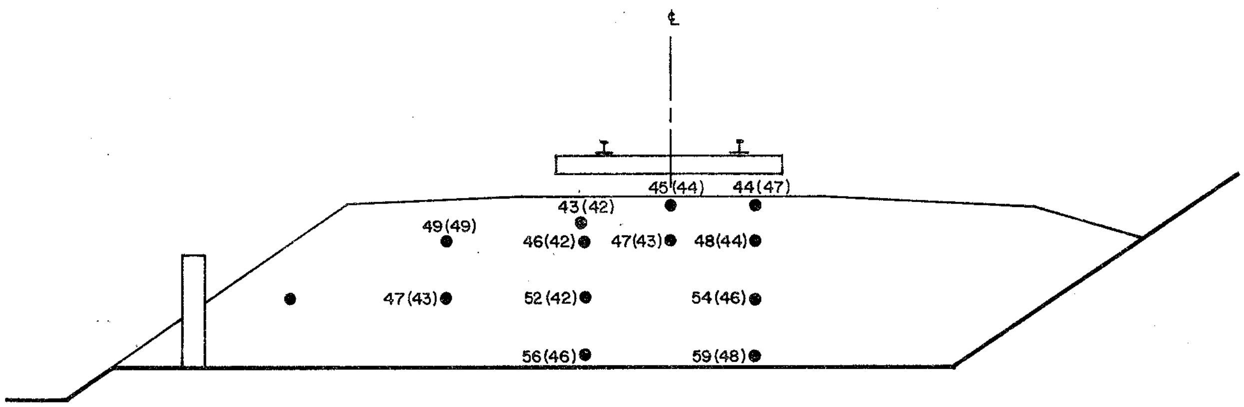
Note: The data indicate moisture content trends but the absolute values of moisture content are considered unreliable and higher than actual. Placement moisture content averaged 24%.

SUMMARY OF MOISTURE CELL DATA

FIG. 28



Section 7



Section 9

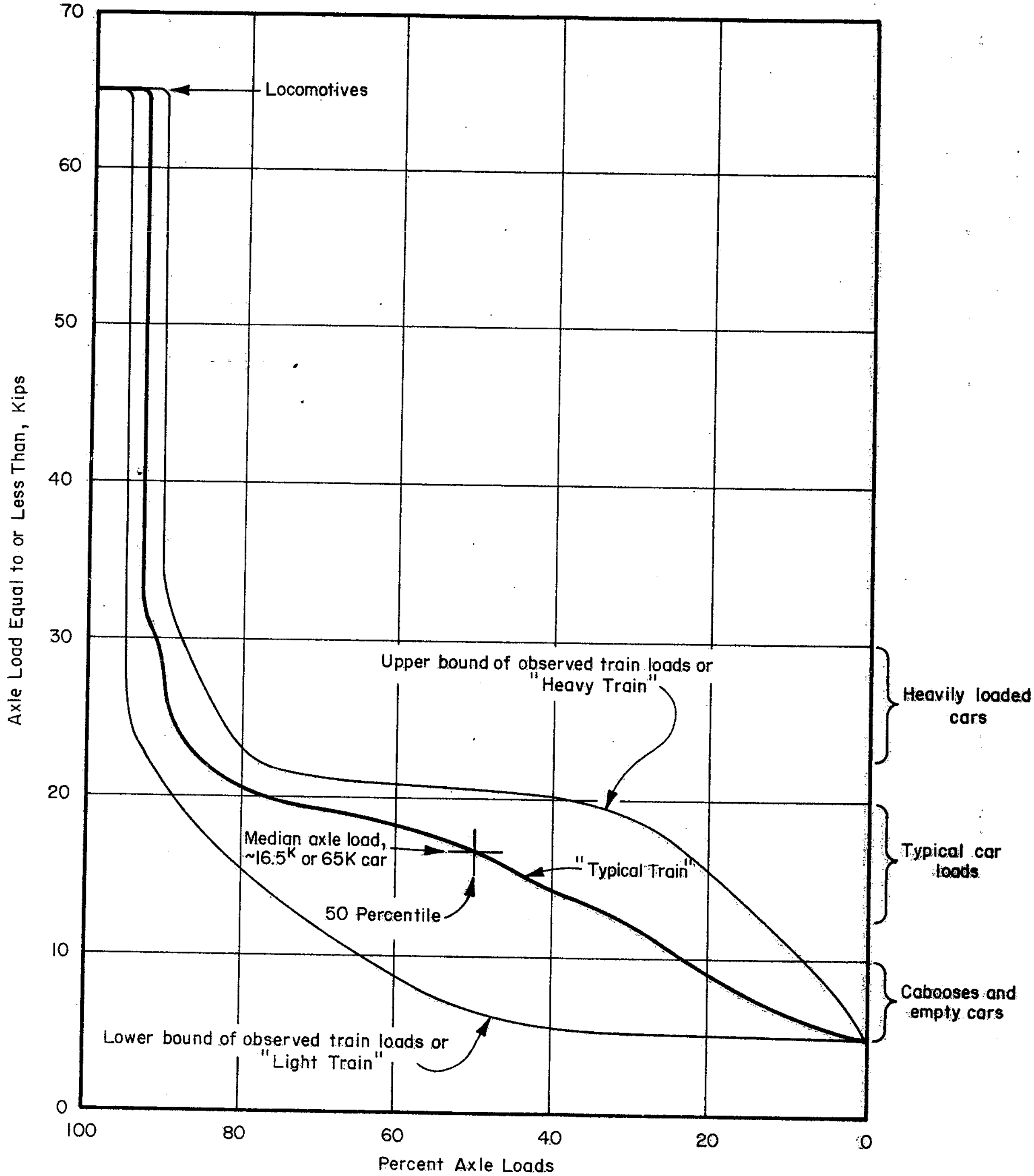
Legend:

56 Nov, 1974

(49) Apr, 1975

TYPICAL TEMPERATURE DATA

FIG. 29

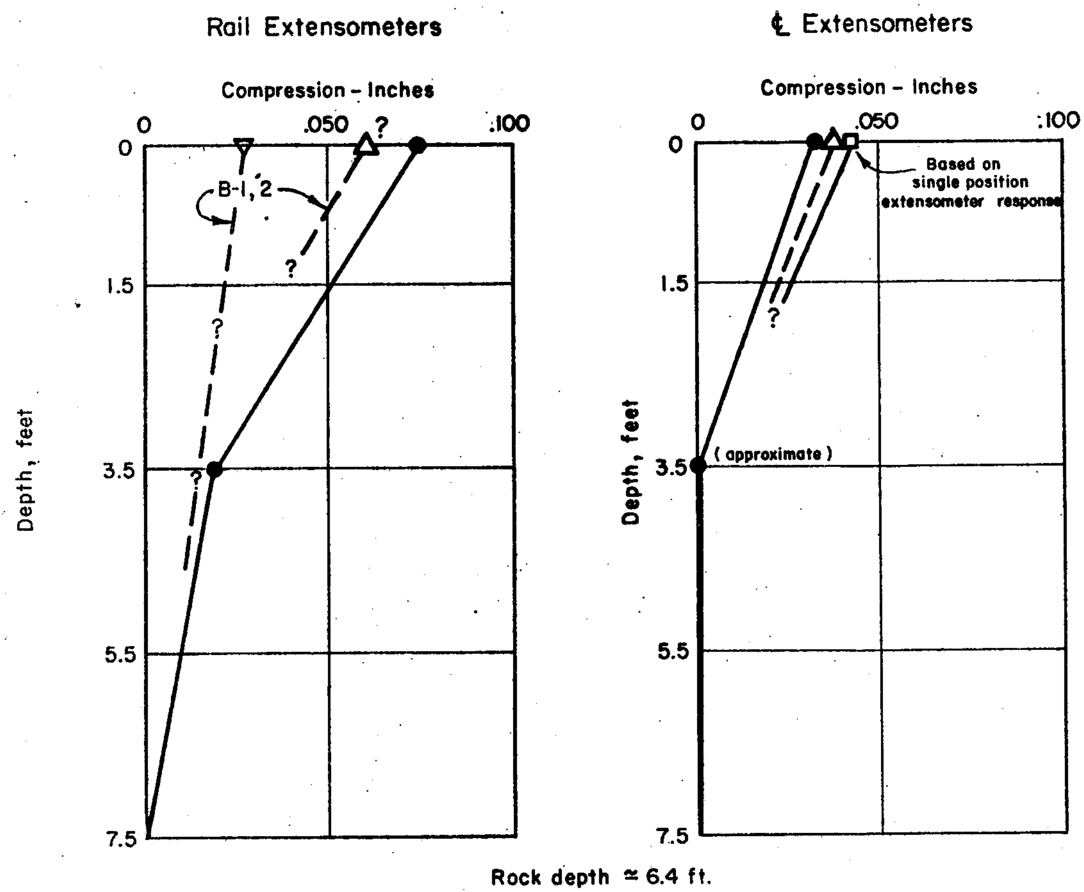


Note:

"Typical train" is an average of 9 weighed trains observed during the Dec., 1974, — Jan., 1975, data collection period.

TYPICAL TRAIN
DISTRIBUTION OF AXLE LOADS

FIG. 30



Legend:

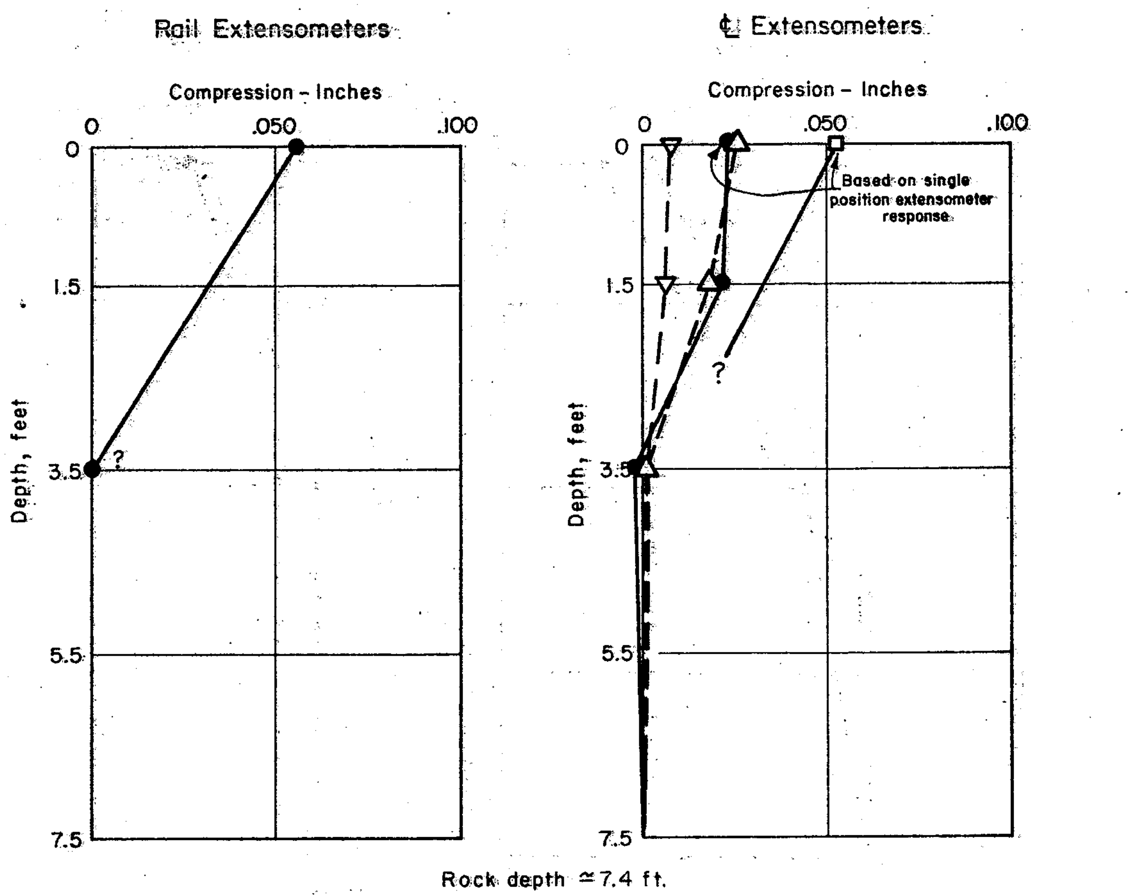
- ○ Nov., 1974 30 mph (1st of 4 axles)
- △ Dec. – Jan., 1975 (Max. response of 6 axles except as noted)
- ▽ Typical car load, ~16K/axle, Dec.–Jan., 1975
- □ April, 1975
- ● ▲ ■ 4 axle locomotive, ~ 65K/axle
- ○ △ □ 6 axle locomotive, ~ 65K/axle

Note:

For presentation, rock assumed to be 7.5' below top of embankment.

DYNAMIC VERTICAL EXTENSOMETER DEFLECTION vs DEPTH TEST SECTION NO. 1

FIG. 31



Legend:

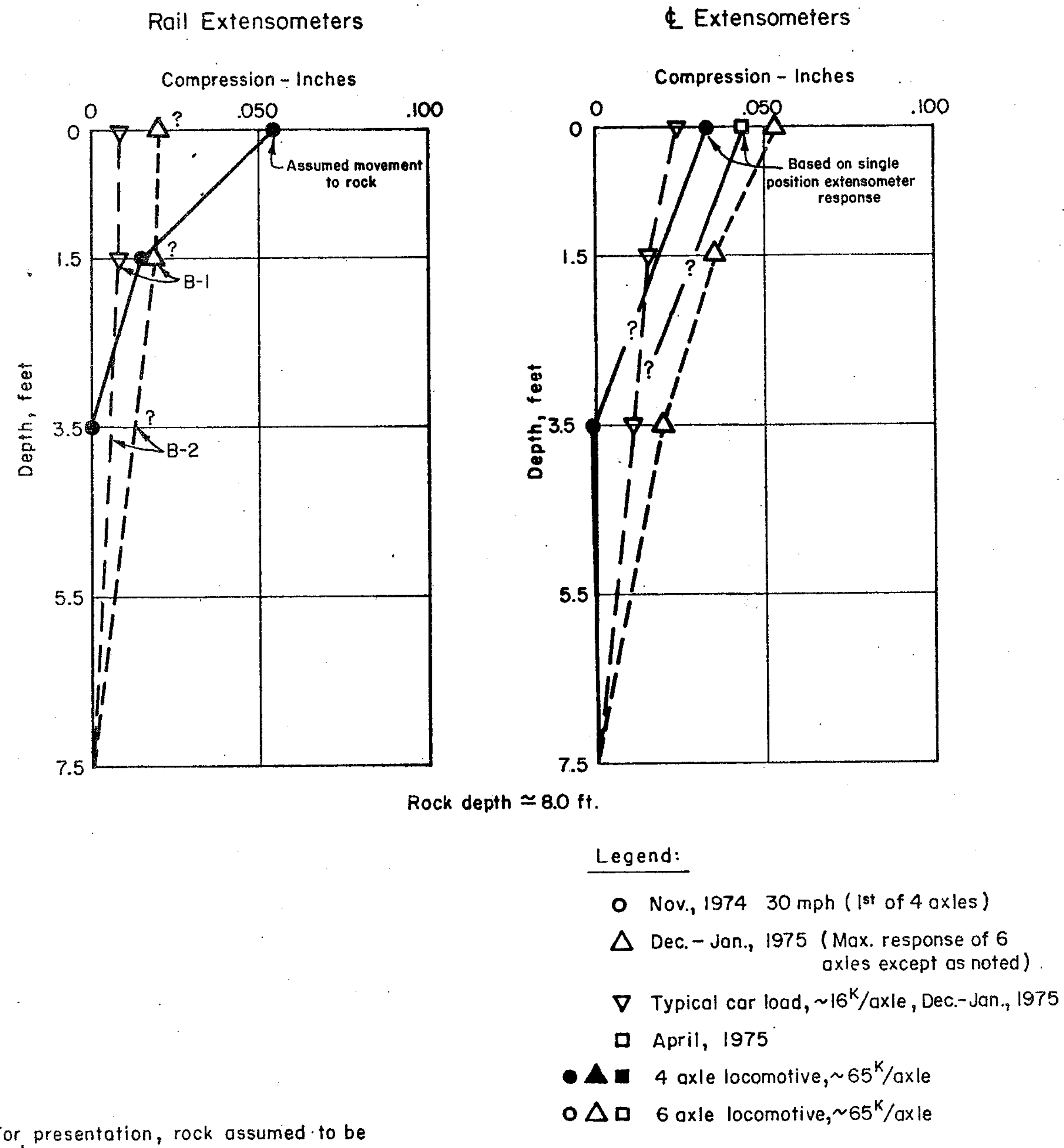
- ○ Nov., 1974 30 mph (1st of 4 axles)
- △ Dec. - Jan., 1975 (Max. response of 6 axles except as noted)
- ▽ Typical car load, ~16K/axle, Dec.-Jan., 1975
- □ April, 1975
- ● ▲ ■ 4 axle locomotive, ~65K/axle
- ○ △ □ 6 axle locomotive, ~65K/axle

Note:

For presentation, rock assumed to be 7.5' below top of embankment.

DYNAMIC
VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 2

FIG. 32

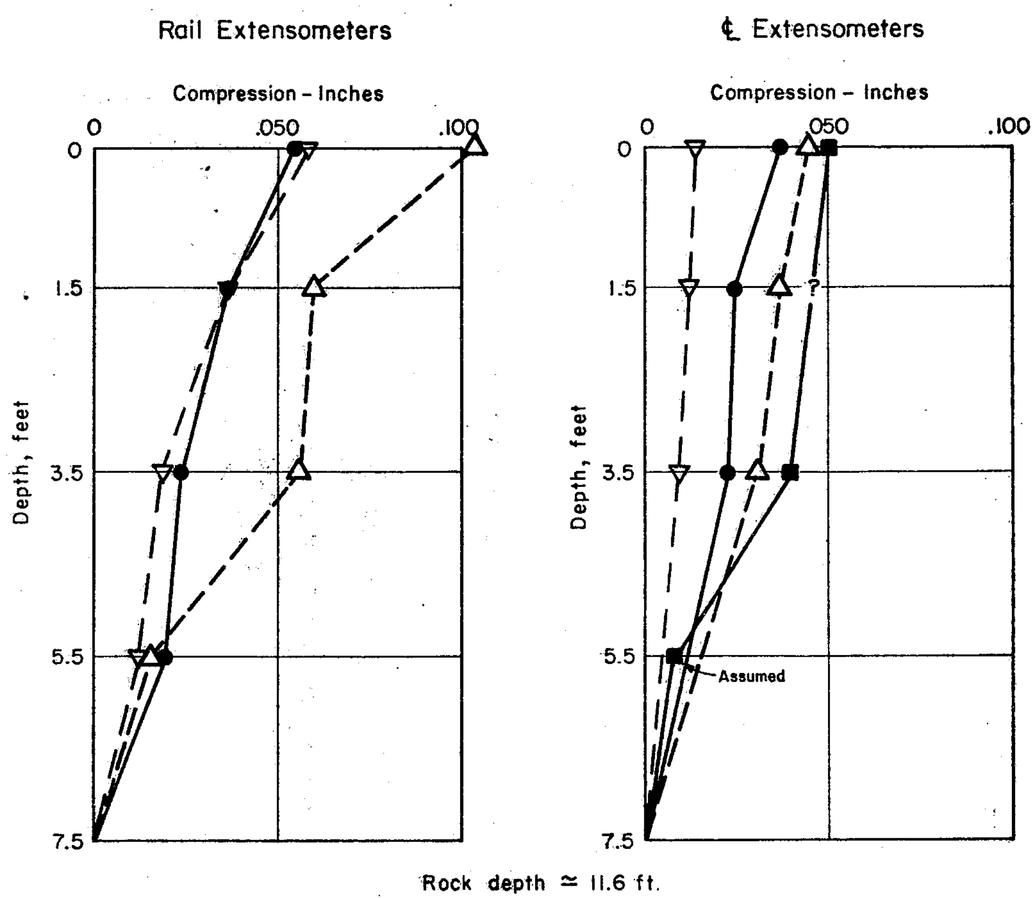


Note:

For presentation, rock assumed to be 7.5' below top of embankment.

DYNAMIC
VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 3

FIG. 33



Legend:

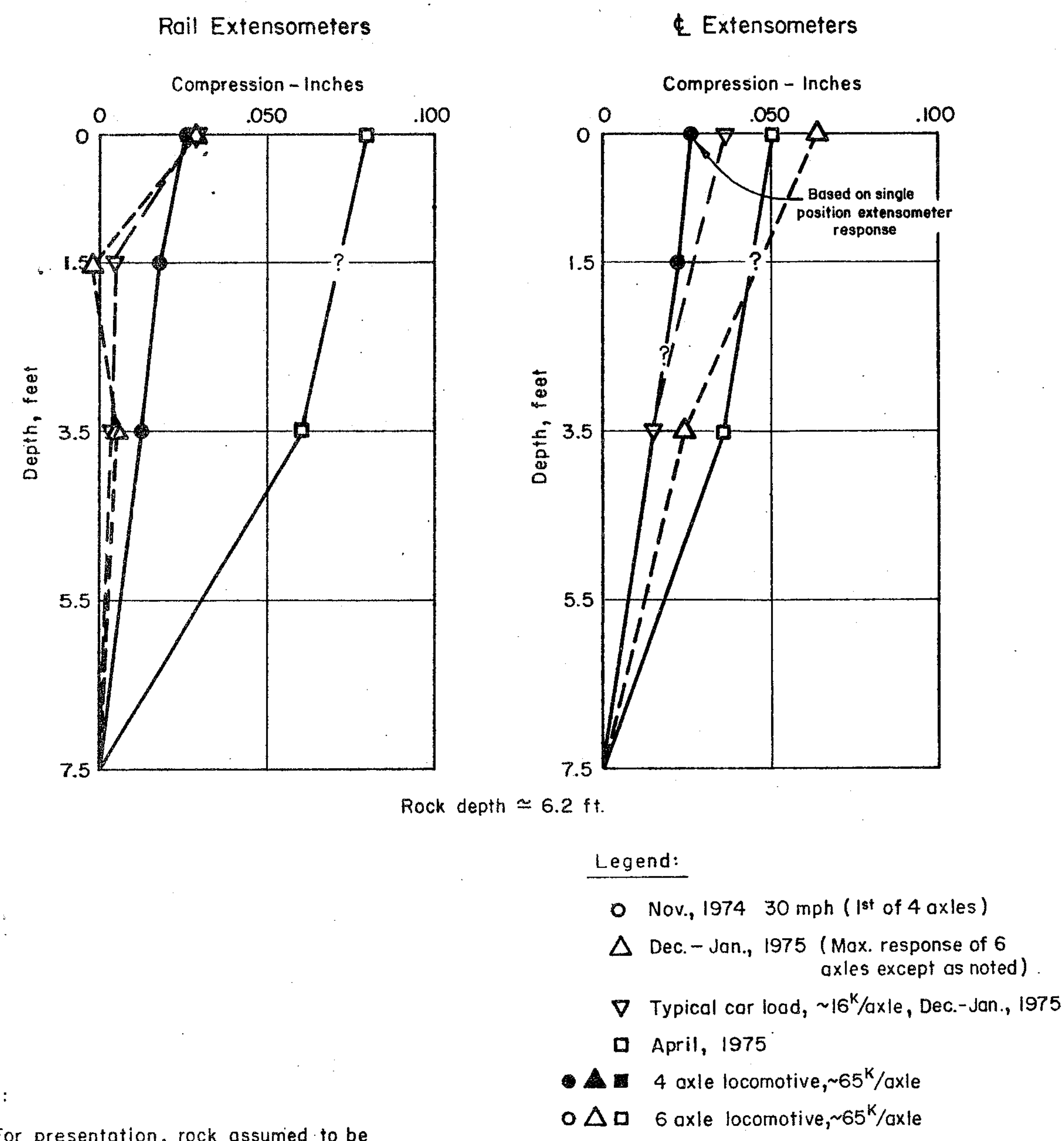
- O Nov., 1974 30 mph (1st of 4 axles)
- △ Dec. - Jan., 1975 (Max. response of 6 axles except as noted)
- ▽ Typical car load, ~16^K/axle, Dec.-Jan., 1975
- □ April, 1975
- ● ▲ ■ 4 axle locomotive, ~65^K/axle
- o △ □ 6 axle locomotive, ~65^K/axle

Note:

For presentation, rock assumed to be 7.5' below top of embankment.

DYNAMIC
VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 4

FIG. 34

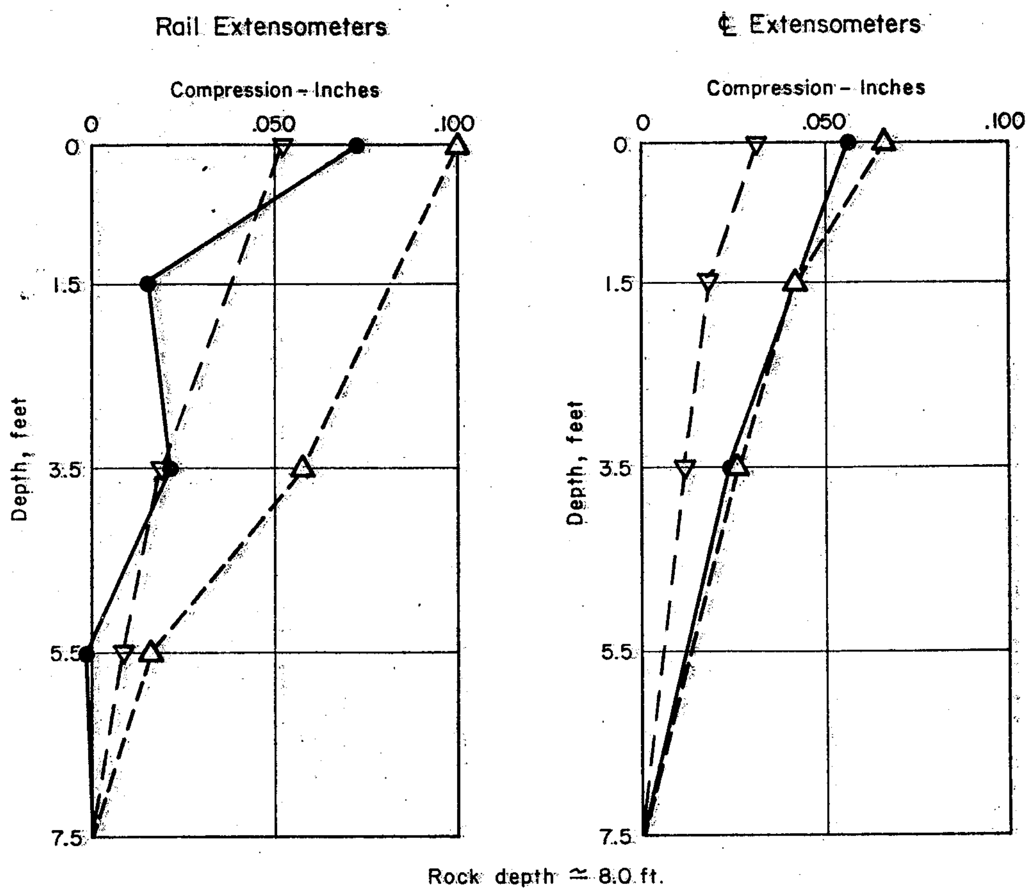


Note:

For presentation, rock assumed to be 7.5' below top of embankment.

DYNAMIC
VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 5

FIG. 35



Legend:

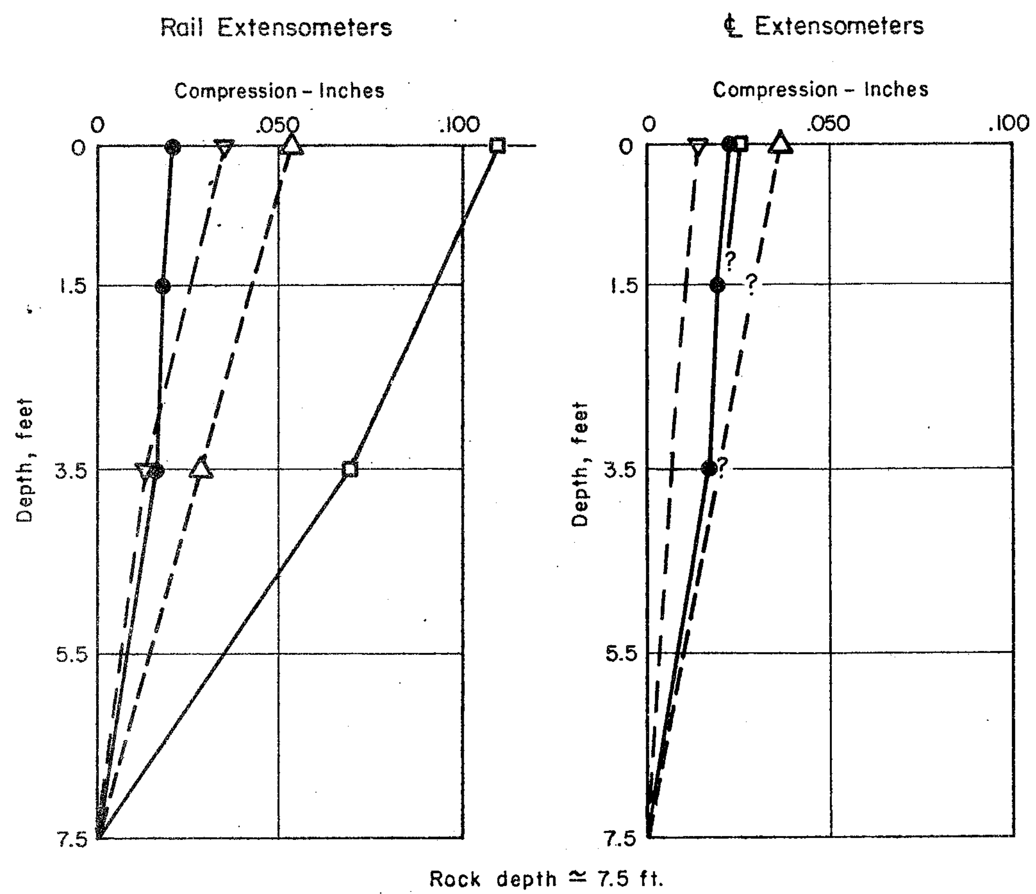
- ○ Nov., 1974 30 mph (1st of 4 axles)
- △ Dec. – Jan., 1975 (Max. response of 6 axles except as noted).
- ▽ Typical car load, ~16K/axle, Dec.-Jan., 1975
- □ April, 1975
- ●▲■ 4 axle locomotive, ~65K/axle
- ○△□ 6 axle locomotive, ~65K/axle

Note:

For presentation, rock assumed to be 7.5' below top of embankment.

DYNAMIC
VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 6

FIG. 36



Legend:

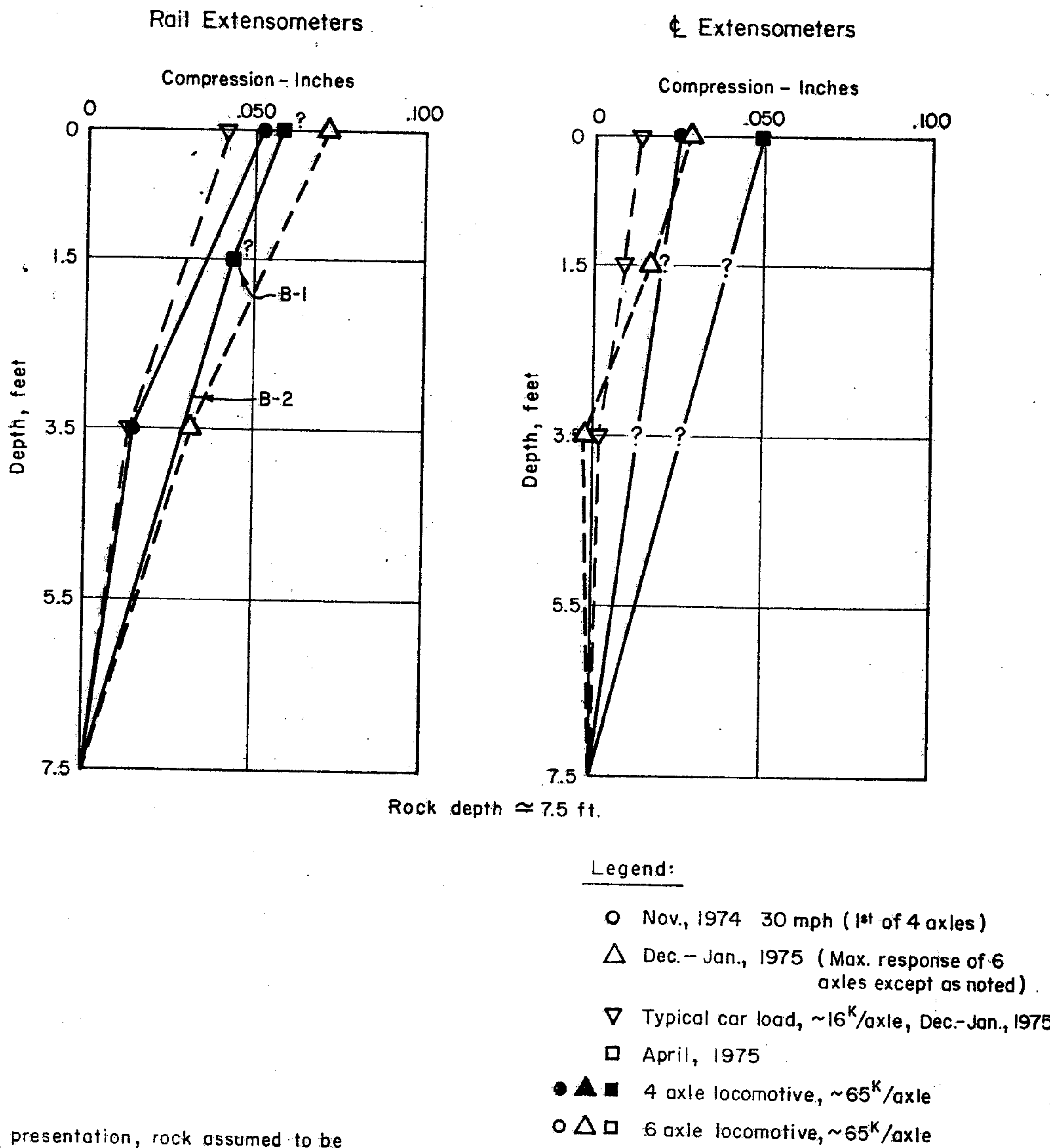
- o Nov., 1974 30 mph (1st of 4 axles)
- △ Dec.–Jan., 1975 (Max. response of 6 axles except as noted)
- ▽ Typical car load, ~16K/axle, Dec.-Jan., 1975
- □ April, 1975
- ● ▲ ■ 4 axle locomotive, ~65K/axle
- o △ □ 6 axle locomotive, ~65K/axle

Note:

For presentation, rock assumed to be 7.5' below top of embankment.

DYNAMIC
VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 7

FIG. 37

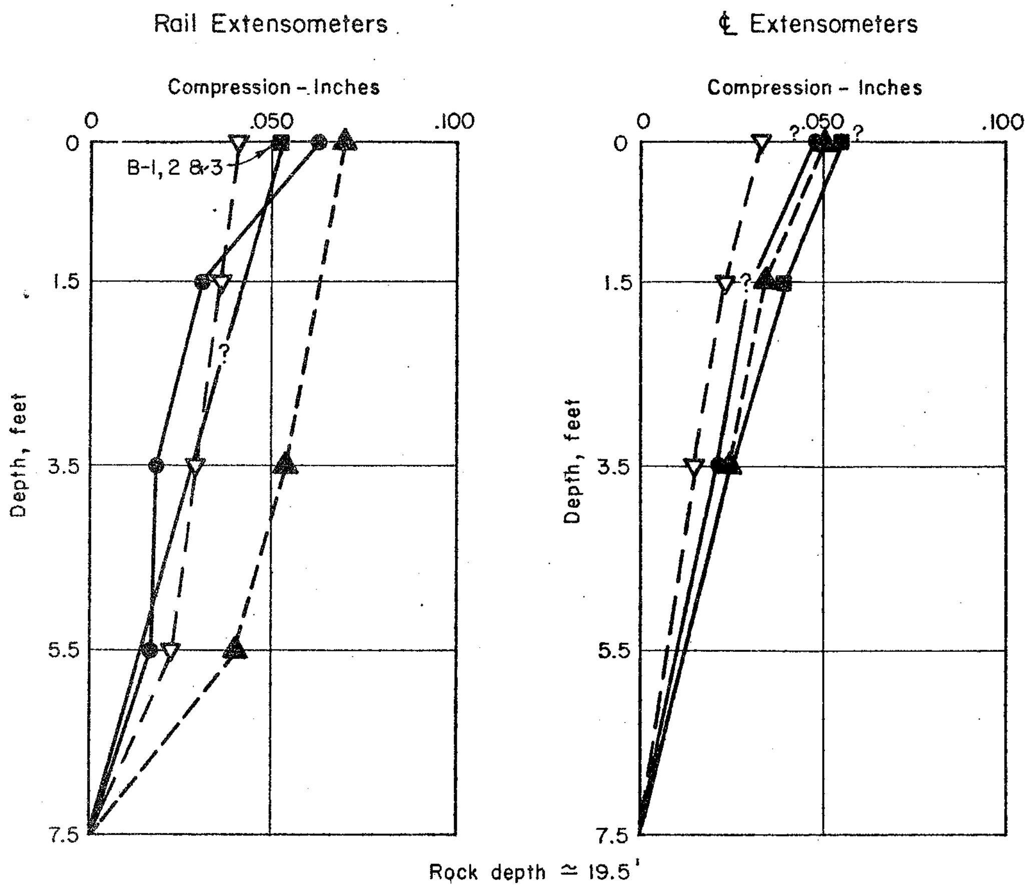


Note:

For presentation, rock assumed to be 7.5' below top of embankment.

DYNAMIC
VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 8

FIG. 38



Legend:

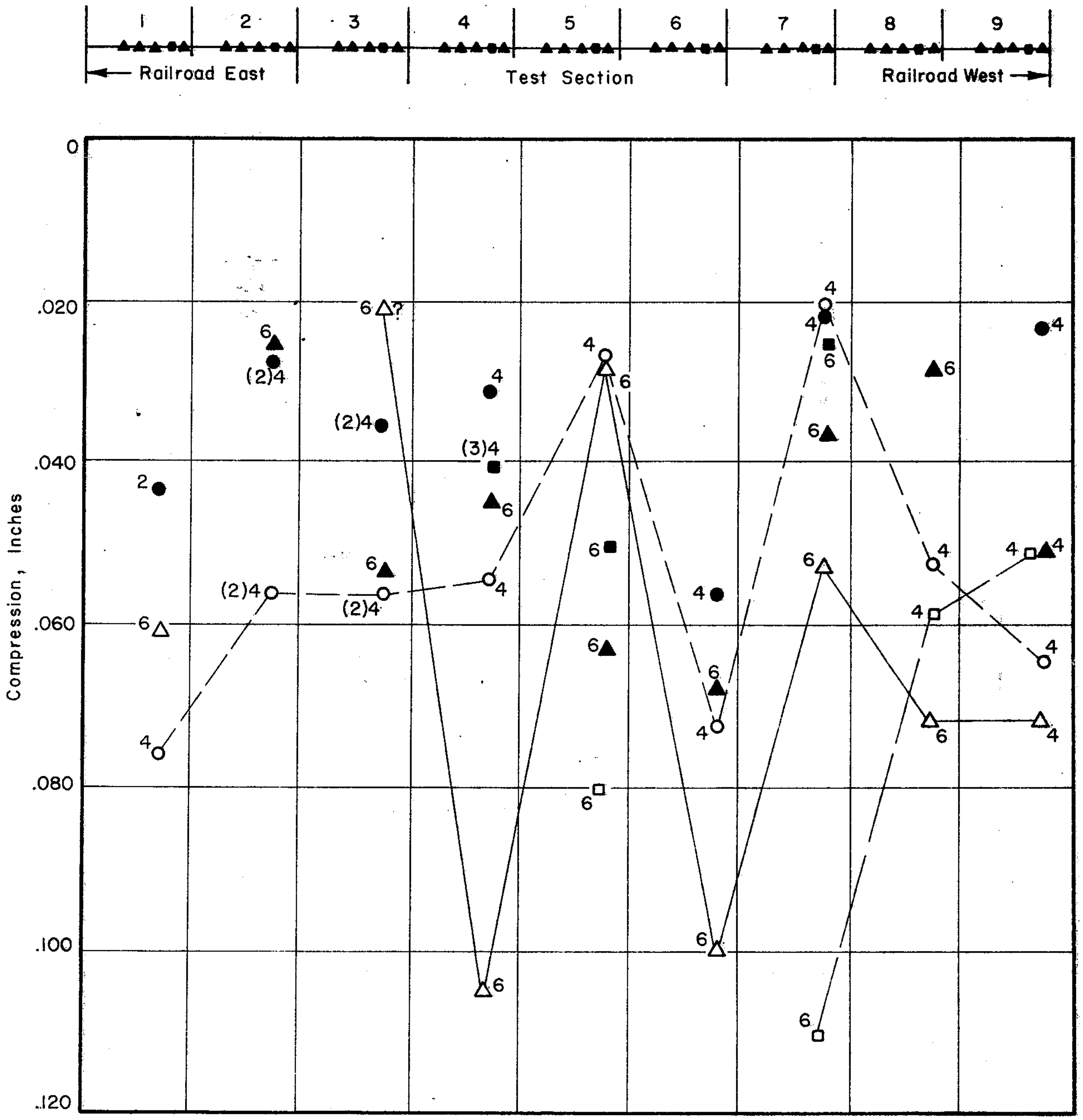
- ○ Nov., 1974 30 mph (1st of 4 axles)
- △ Dec. – Jan., 1975 (Max. response of 6 axles except as noted)
- ▽ Typical car load, ~16K/axle, Dec.-Jan., 1975
- □ April, 1975
- ● ▲ ■ 4 axle locomotive, ~65K/axle
- ○ △ □ 6 axle locomotive, ~65K/axle

Note:

For presentation, rock assumed to be 7.5' below top of embankment.

DYNAMIC
VERTICAL EXTENSOMETER
DEFLECTION vs DEPTH
TEST SECTION NO. 9

FIG. 39



Note: Deflections are for locomotive axle loading, 30 mph and over.

Legend:

Extensometers		
℄	Rail	Date
●	○	Nov, 1974
▲	△	Dec./Jan, 1975
■	□	Apr, 1975

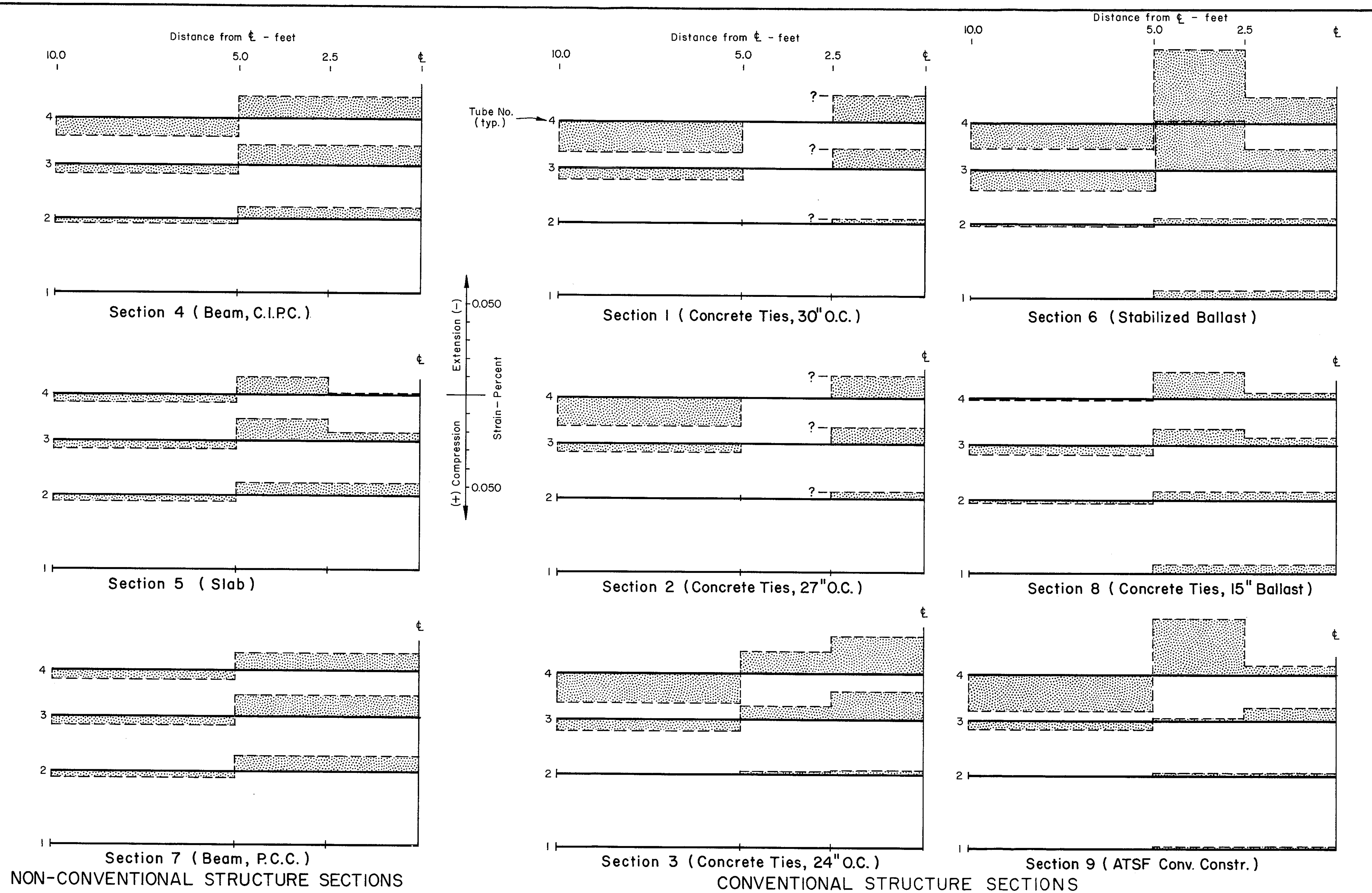
4 - 4 axles

6 - 6 axles

(2),(3)-Data presented from anchor positions 2 and 3 where data to rock is not available.

DYNAMIC DATA
VERTICAL RAIL EXTENSOMETERS
TO ROCK
DEFLECTION vs STATIONING

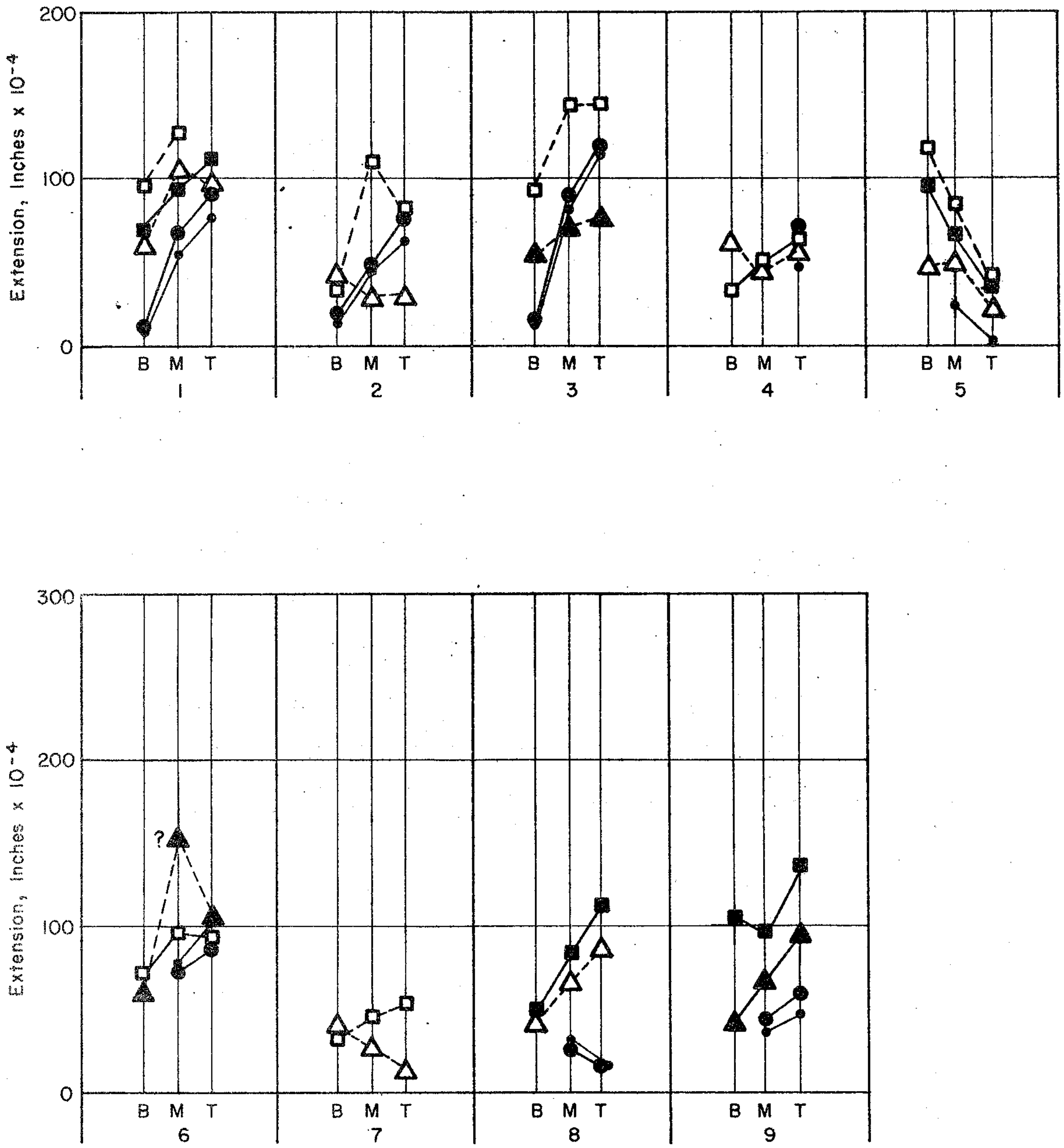
FIG. 40



DYNAMIC HORIZONTAL STRAIN
POSITION STUDY

Note: Based on results presented in Table 5.
Average strain presented are for first axle of "work train" locomotive at 30 mph in November, 1974.

FIG. 41



Legend:

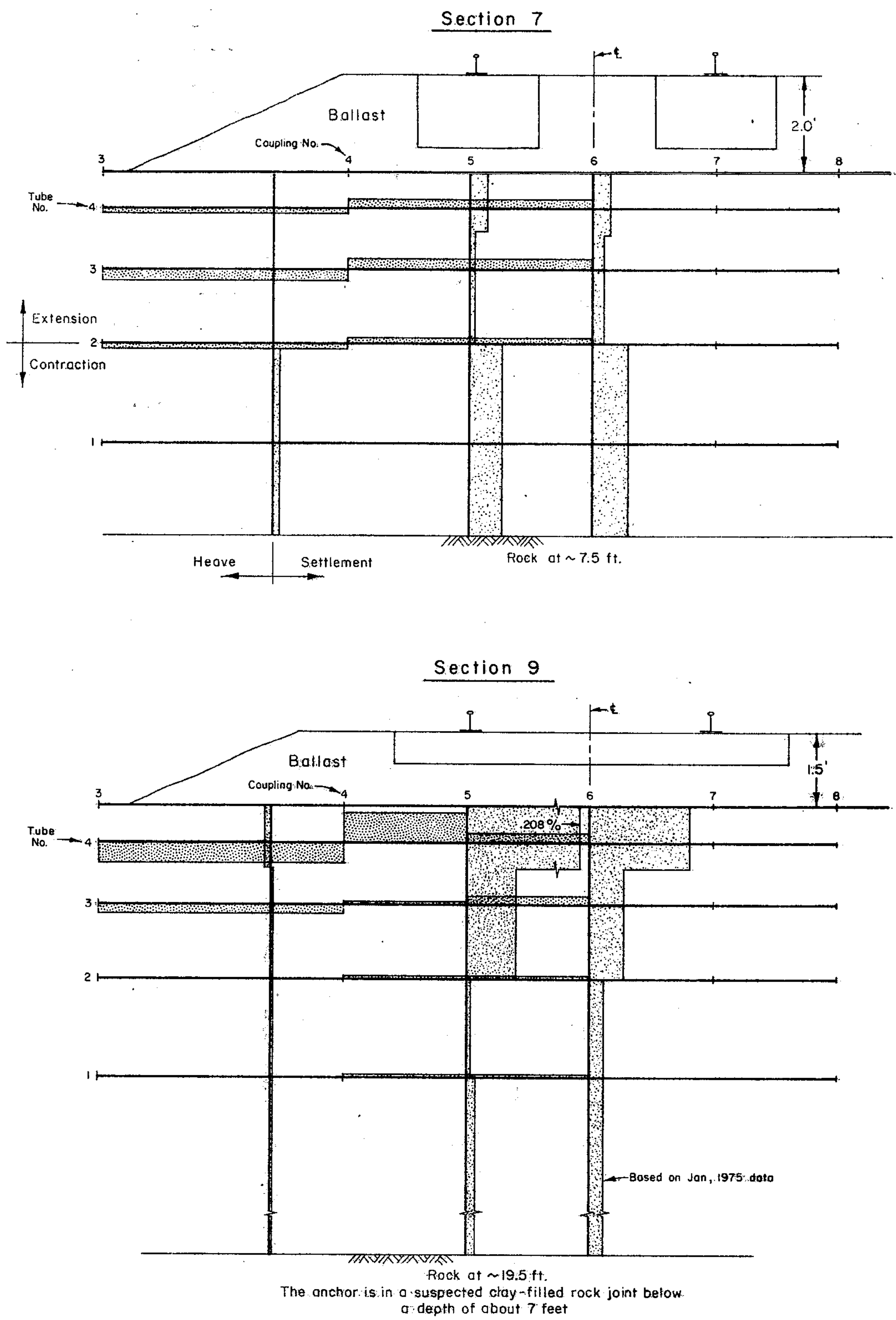
B = Bottom position, Tube 2
M = Middle position, Tube 3
T = Top position, Tube 4
Locomotive:
o Nov., 1974, creep
O Nov., 1974, 30 mph
△ Dec., '74 – Jan., 1975
□ April, 1975

Notes: Deformations measured with 5' gage length spanning ¢ in upper 3 tubes; see Fig. 3, position .03.

Solid points represent 4-axle locomotives.
Open points represent 6-axle locomotives.

PORTABLE HORIZONTAL
EXTENSOMETER DYNAMIC DATA

FIG. 42



Note: Sections are shown looking railroad east.

Acquisition date : Nov, 1974

Load type : First axle, locomotive (4 axles)

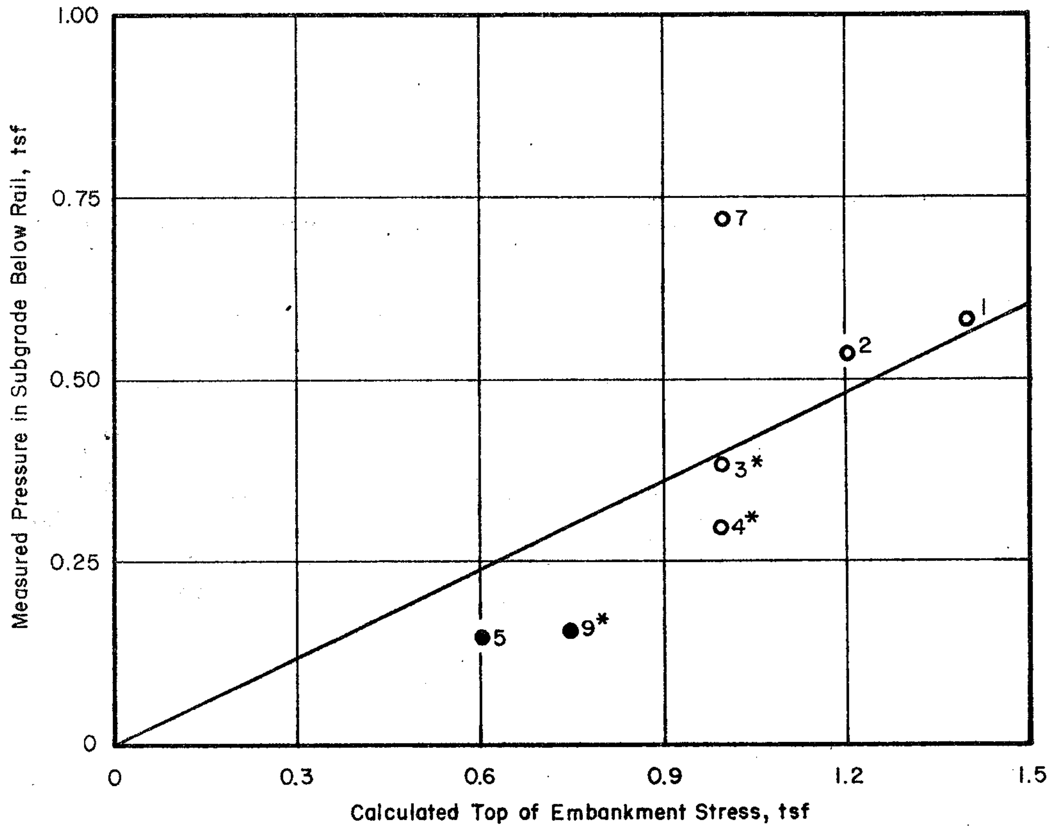
Speed : 30 MPH

0 0.1 0.2 %
Percent Strain

0 1 2 3 4 5
Scale in feet

**TYPICAL
DYNAMIC HORIZONTAL AND
VERTICAL STRAINS**

FIG. 43



LEGEND

● Pressure from 4-axle locomotives

○ Pressure from 6-axle locomotives

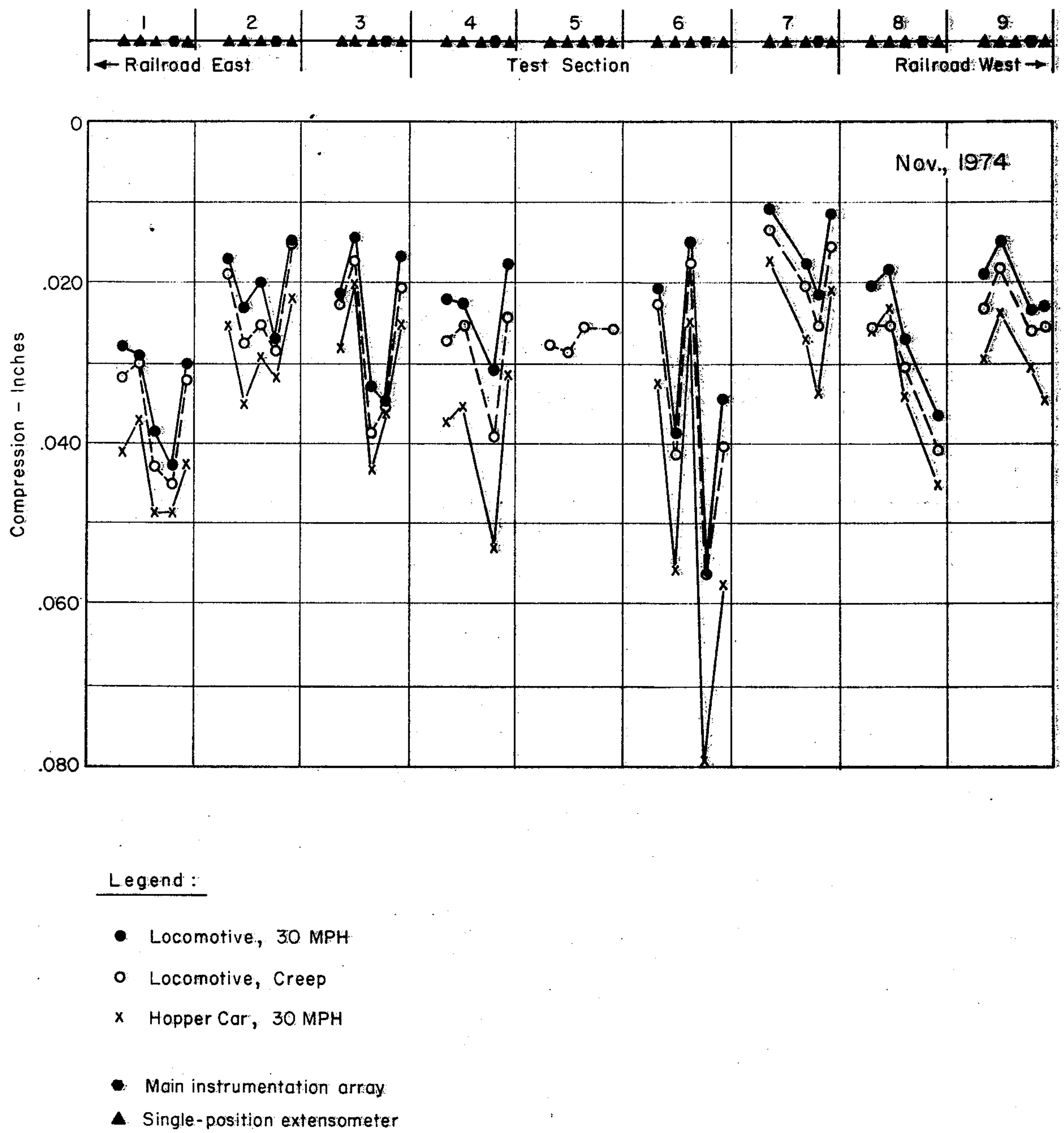
Notes:

1) Data shown are for pressure cell No. 3, below the rail, 0.75' below top of embankment.

2) Data shown are from April, 1975, except those marked
   * which are from Dec., 1974 — Jan., 1975.

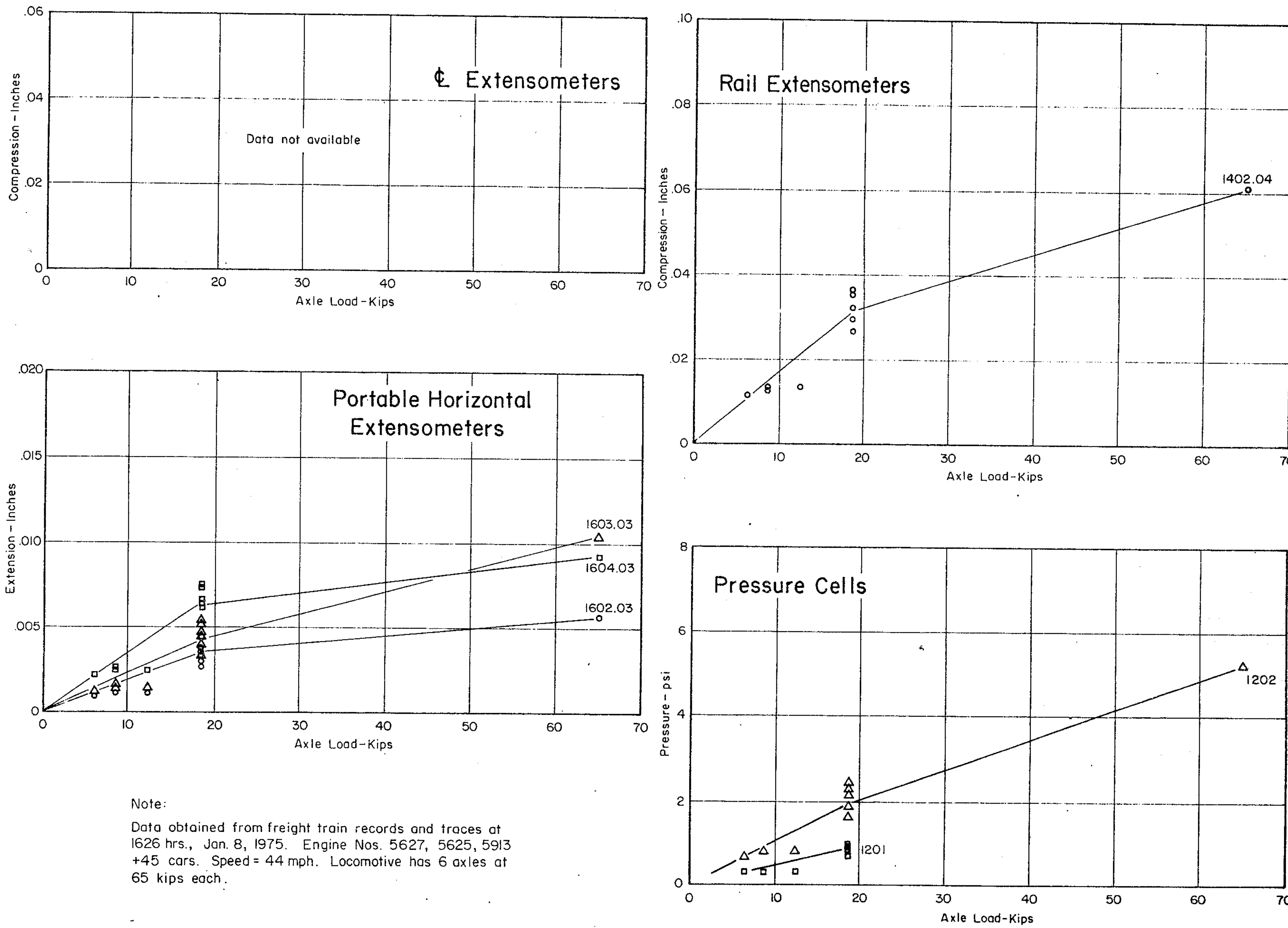
MEASURED EMBANKMENT
PRESSURE vs CALCULATED STRESS

FIG. 44



℄ VERTICAL EXTENSOMETERS
TO ROCK
MAXIMUM DYNAMIC
DEFLECTION FROM WORK TRAIN

FIG. 45

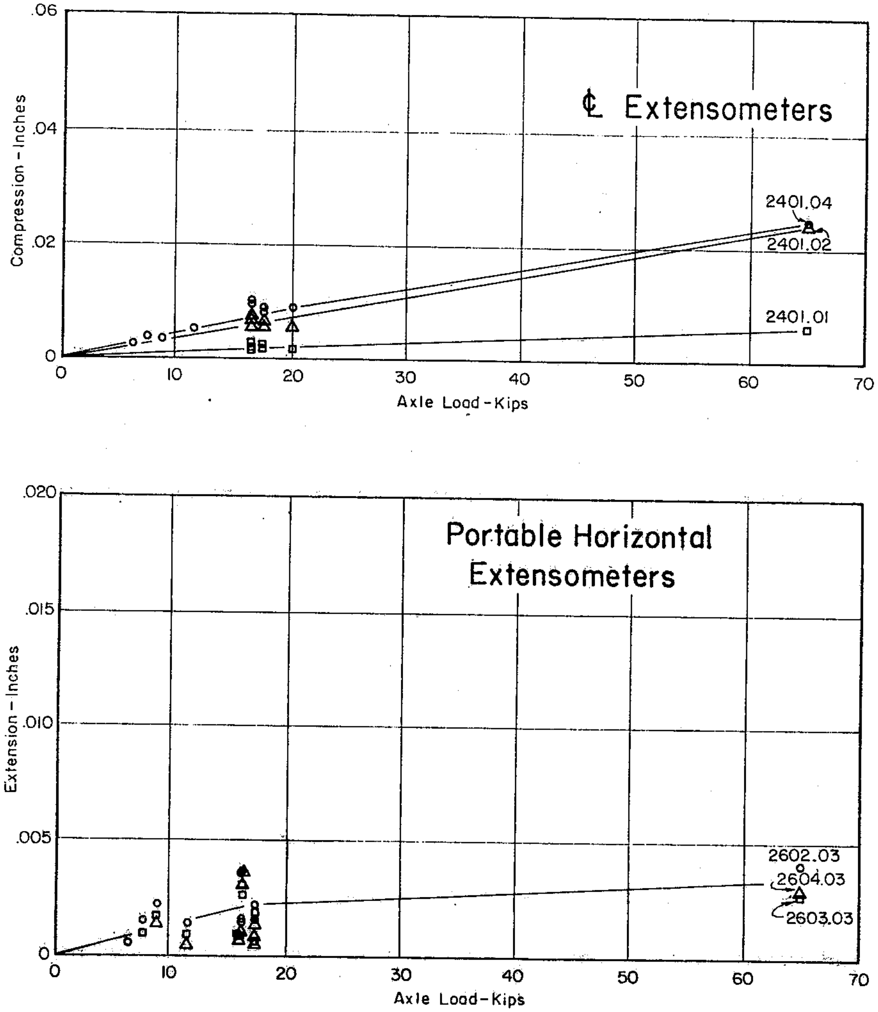


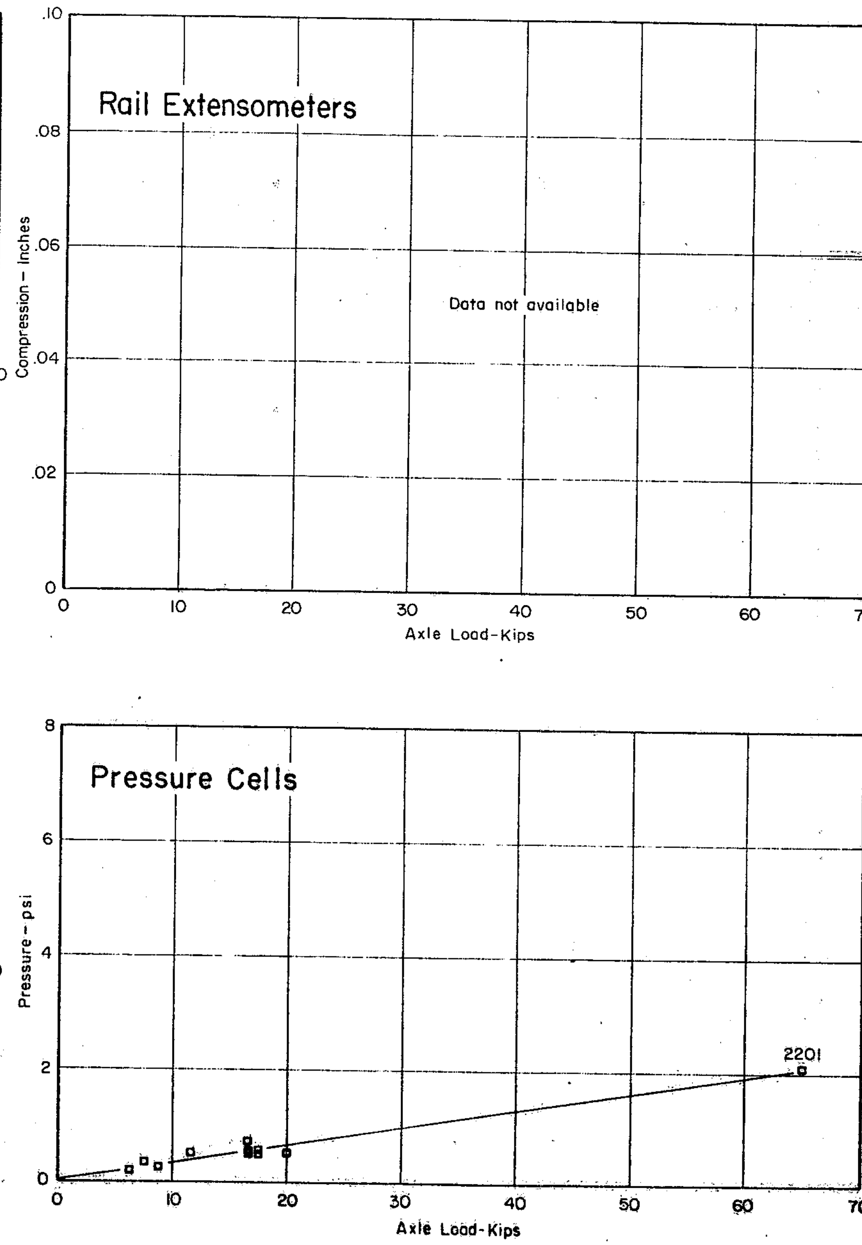
Note:

Data obtained from freight train records and traces at 1626 hrs., Jan. 8, 1975. Engine Nos. 5627, 5625, 5913 +45 cars. Speed = 44 mph. Locomotive has 6 axles at 65 kips each.

DYNAMIC DATA
AXLE LOAD vs DEFLECTION AND PRESSURE
SECTION I

FIG. 46





Note:

Data obtained from freight train records and traces at 1403 hrs., Jan. 13, 1975. Engine Nos. 5615, 5586, 5563, +45 cars. Speed = 52 mph. Locomotive has 6 axles at 65 kips each.

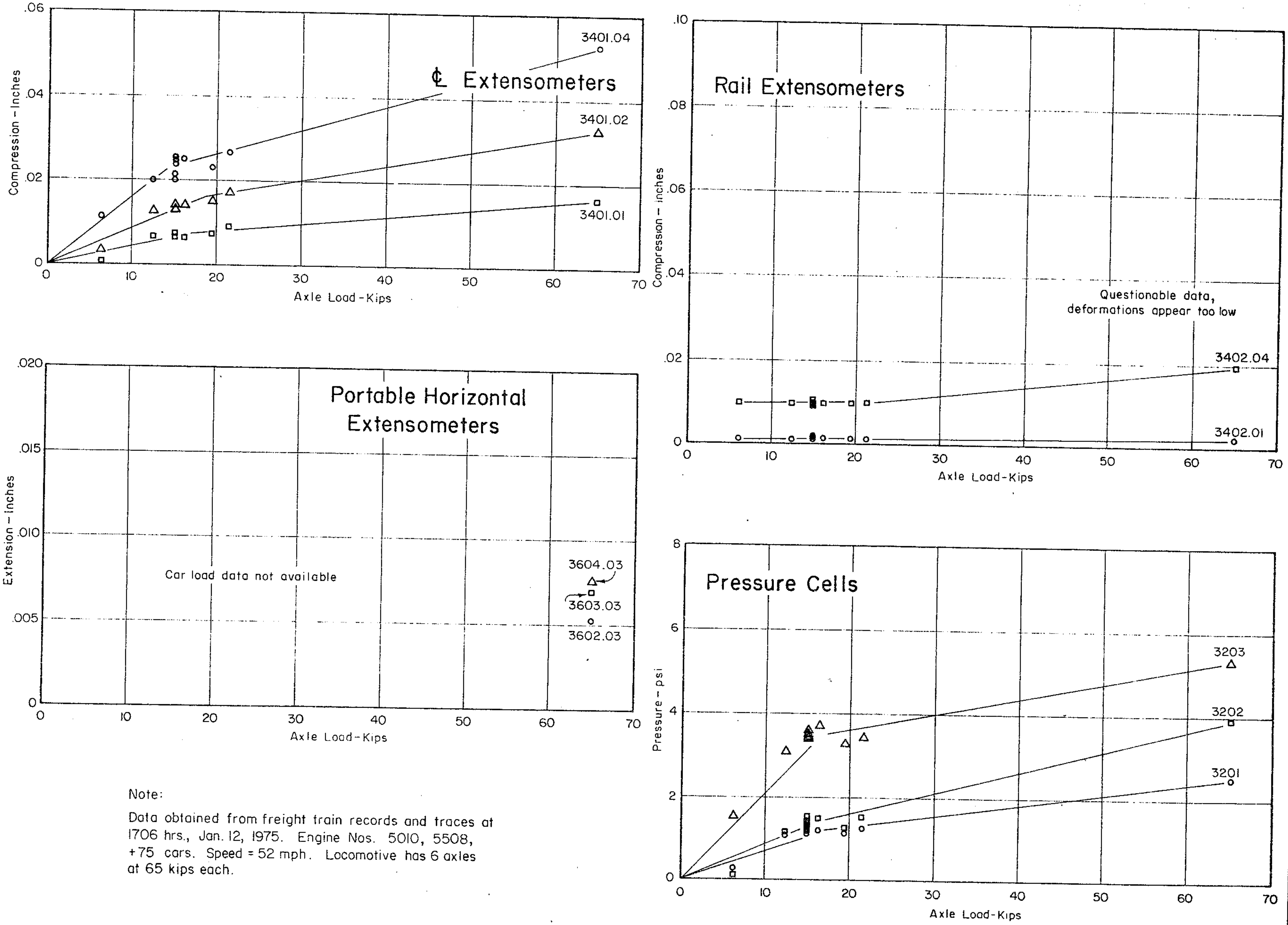
DYNAMIC DATA

AXLE LOAD vs DEFLECTION AND PRESSURE

SECTION 2

FIG. 47

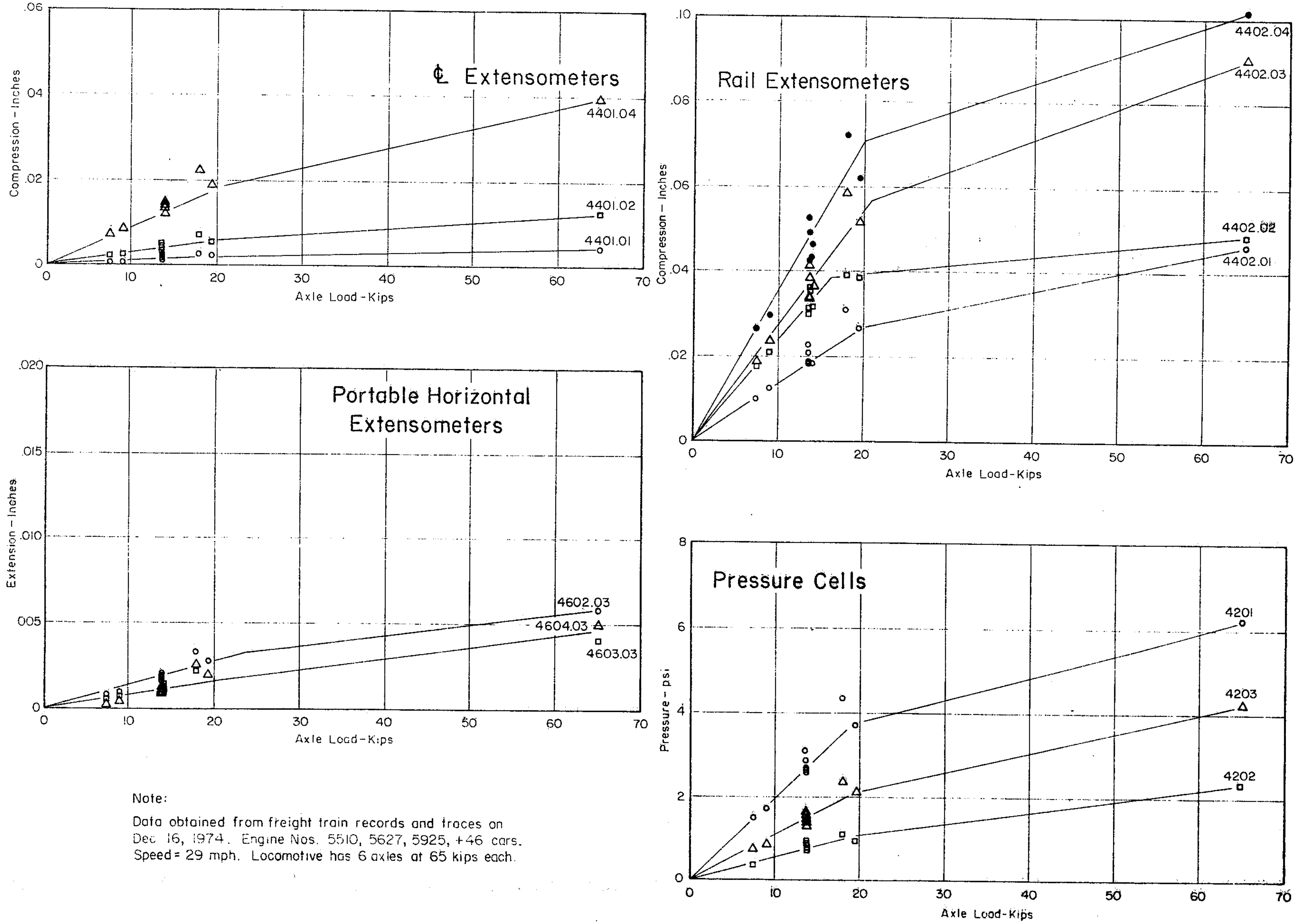
DYNAMIC DATA
AXLE LOAD vs DEFLECTION AND PRESSURE
SECTION 3



Note:

Data obtained from freight train records and traces at 1706 hrs., Jan. 12, 1975. Engine Nos. 5010, 5508, +75 cars. Speed = 52 mph. Locomotive has 6 axles at 65 kips each.

FIG. 48

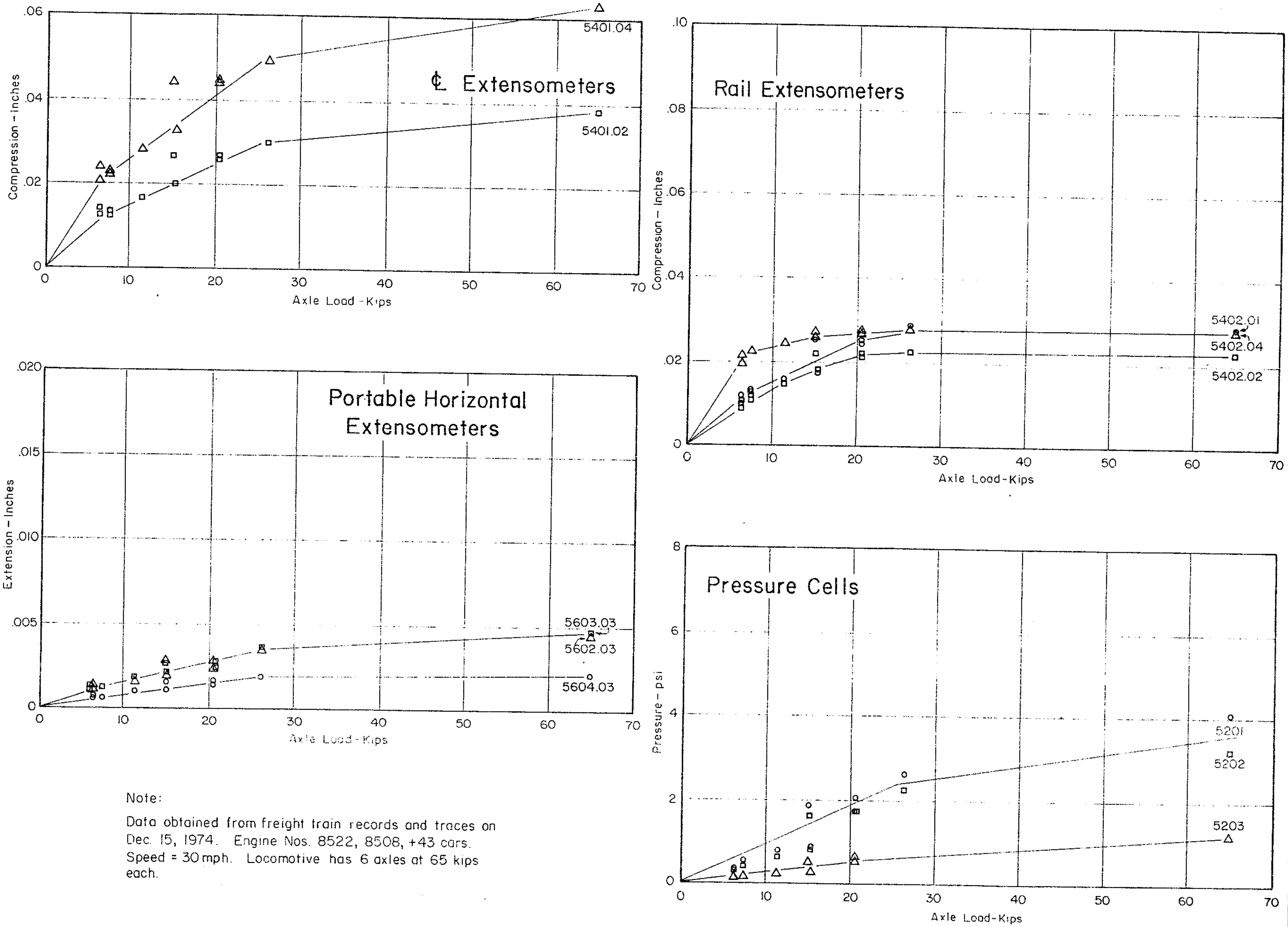


Note:

Data obtained from freight train records and traces on Dec 16, 1974. Engine Nos. 5510, 5627, 5925, +46 cars. Speed= 29 mph. Locomotive has 6 axles at 65 kips each.

DYNAMIC DATA
AXLE LOAD vs DEFLECTION AND PRESSURE
SECTION 4

FIG. 49



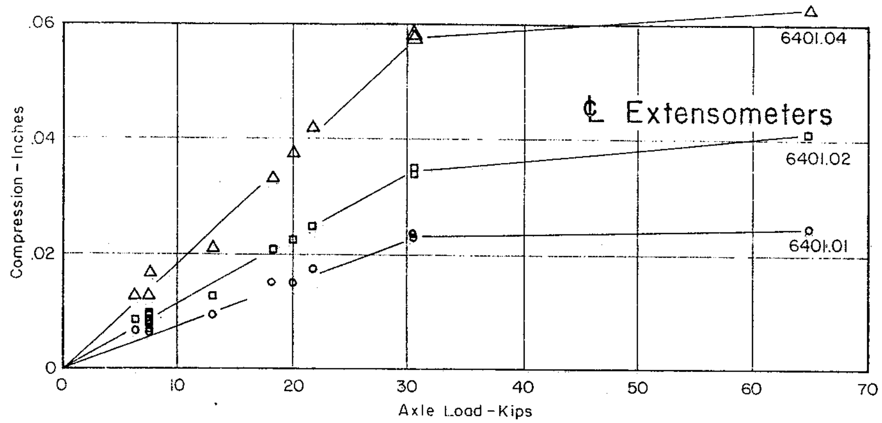
Note:

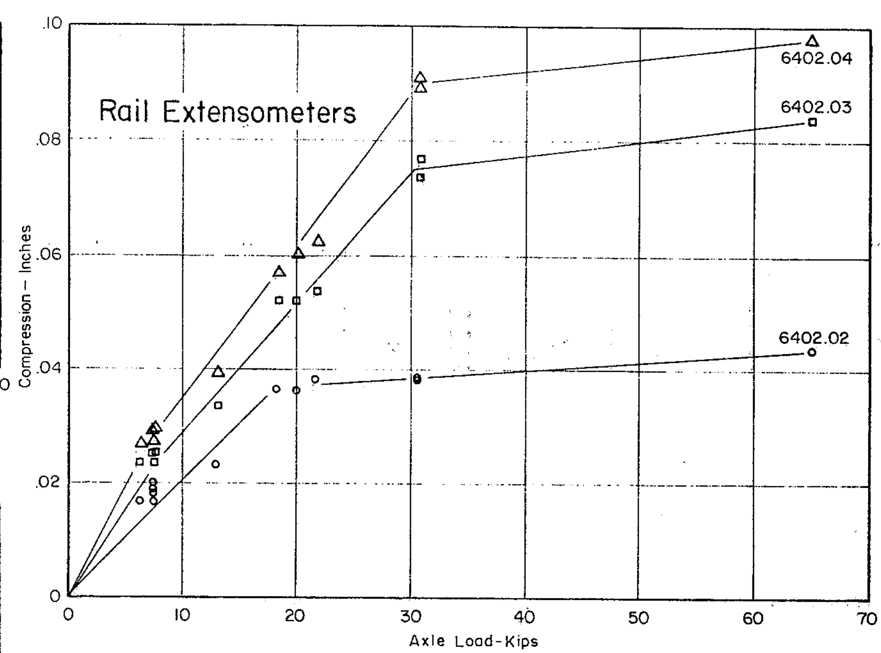
Data obtained from freight train records and traces on Dec. 15, 1974. Engine Nos. 8522, 8508, +43 cars. Speed = 30 mph. Locomotive has 6 axles at 65 kips each.

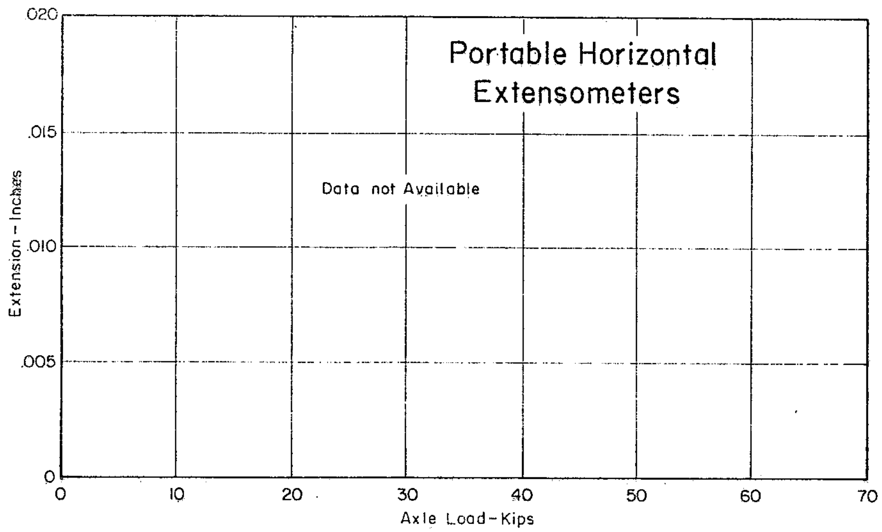
DYNAMIC DATA
AXLE LOAD vs DEFLECTION AND PRESSURE
SECTION 5

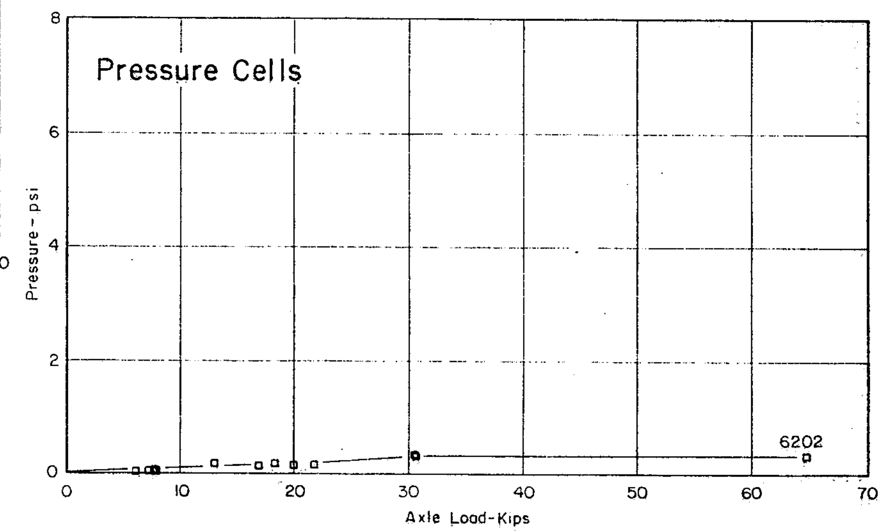
FIG. 50

DYNAMIC DATA
AXLE LOAD vs DEFLECTION AND PRESSURE
SECTION 6





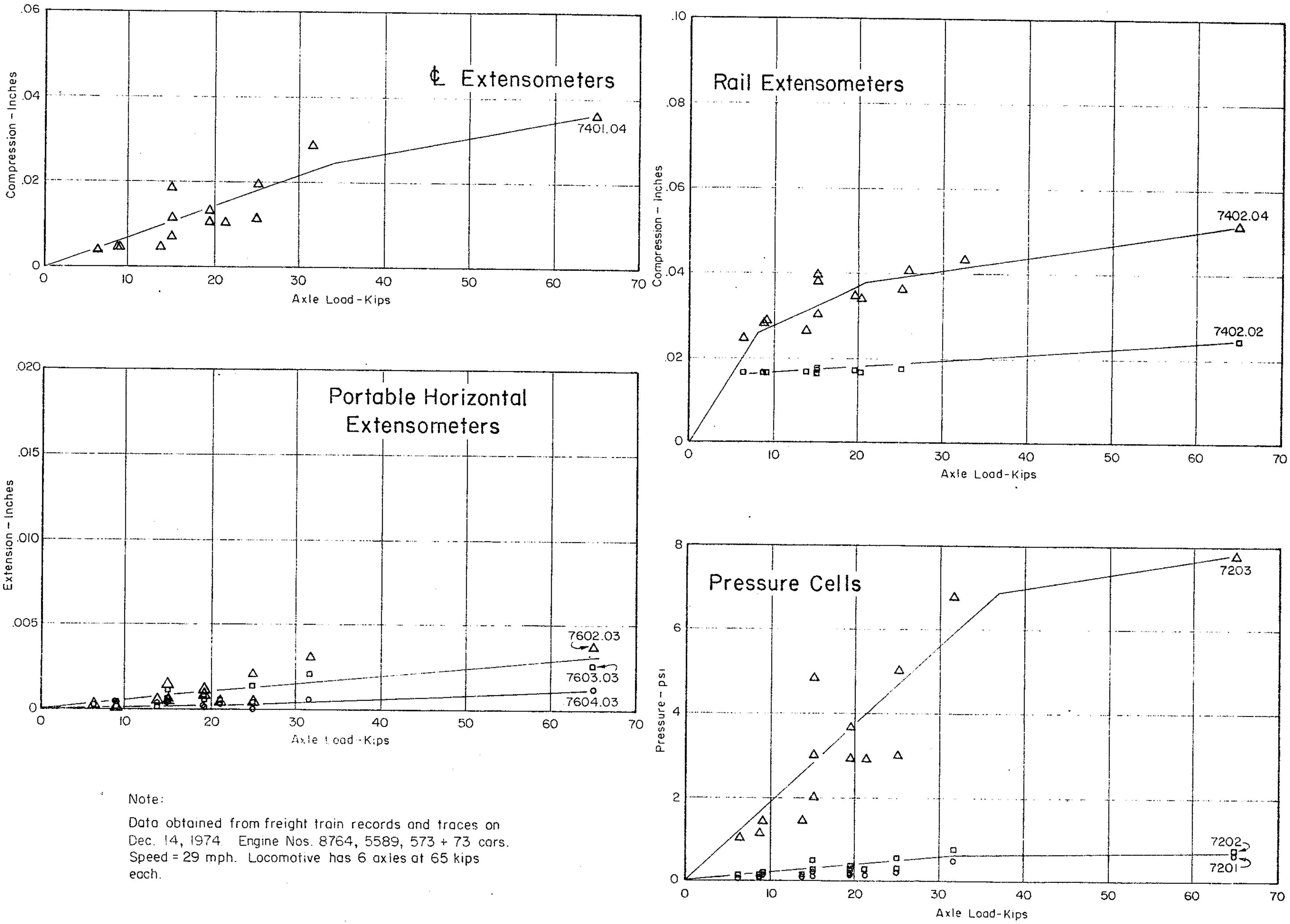




Note:

Data obtained from freight train records and traces at 1748 hrs., Jan. 11, 1975. Engine Nos. 8760, 8746, +43 cars. Speed = 55 mph. Locomotive has 6 axles at 65 kips each.

FIG. 51

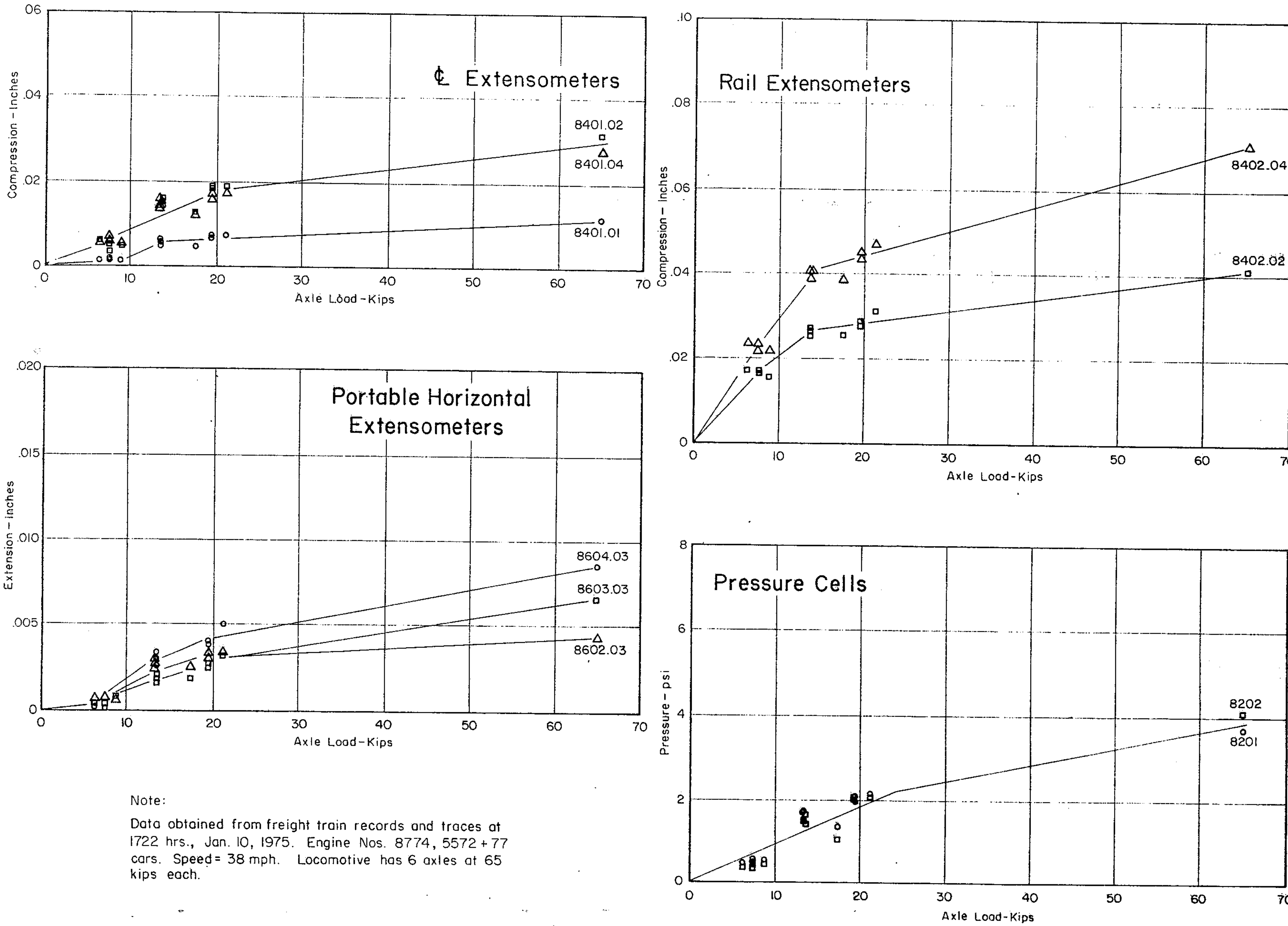


Note:

Data obtained from freight train records and traces on Dec. 14, 1974. Engine Nos. 8764, 5589, 573 + 73 cars. Speed = 29 mph. Locomotive has 6 axles at 65 kips each.

DYNAMIC DATA
AXLE LOAD vs DEFLECTION AND PRESSURE
SECTION 7

FIG. 52



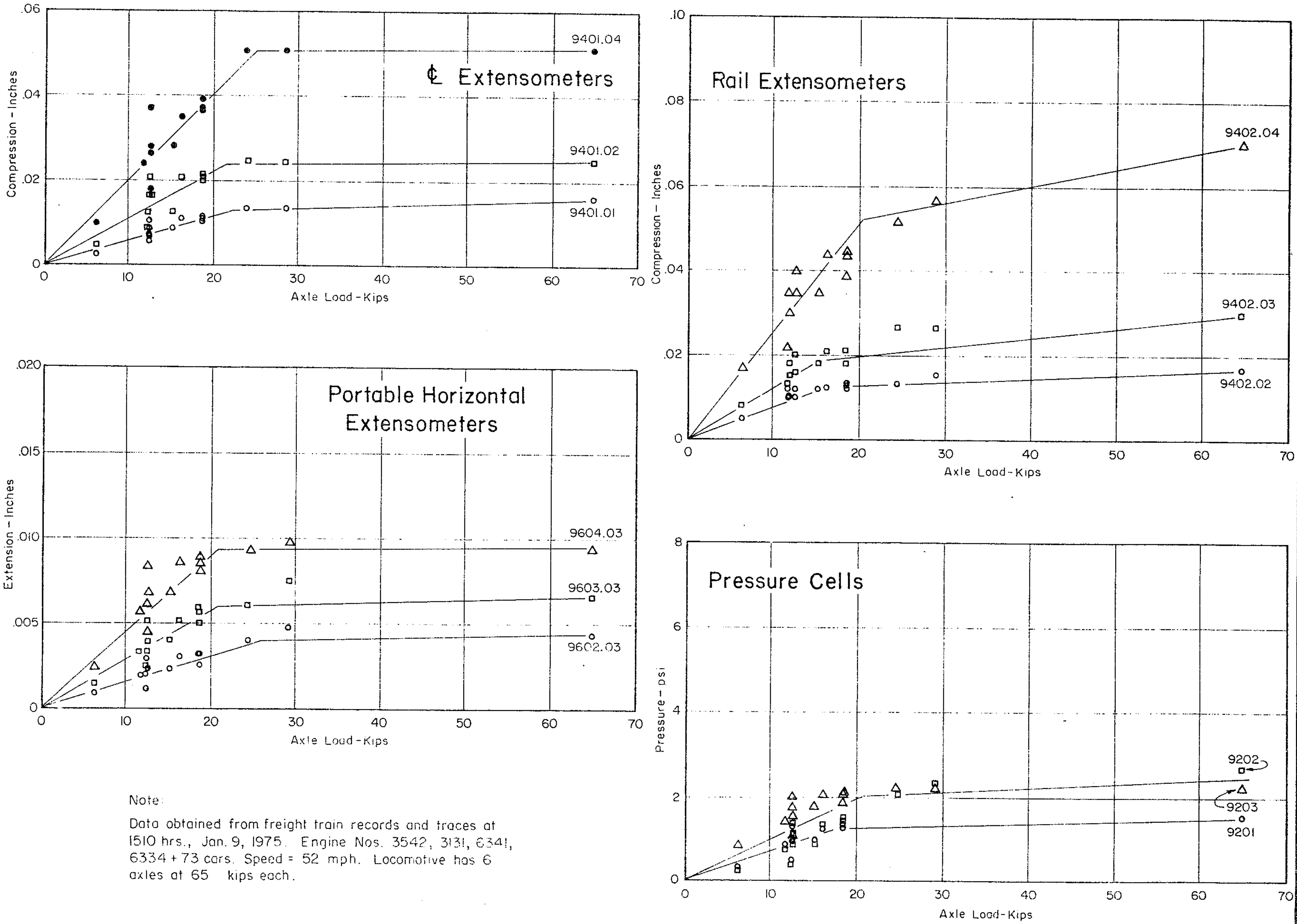
Note:

Data obtained from freight train records and traces at 1722 hrs., Jan. 10, 1975. Engine Nos. 8774, 5572 + 77 cars. Speed = 38 mph. Locomotive has 6 axles at 65 kips each.

DYNAMIC DATA
AXLE LOAD vs DEFLECTION AND PRESSURE
SECTION 8

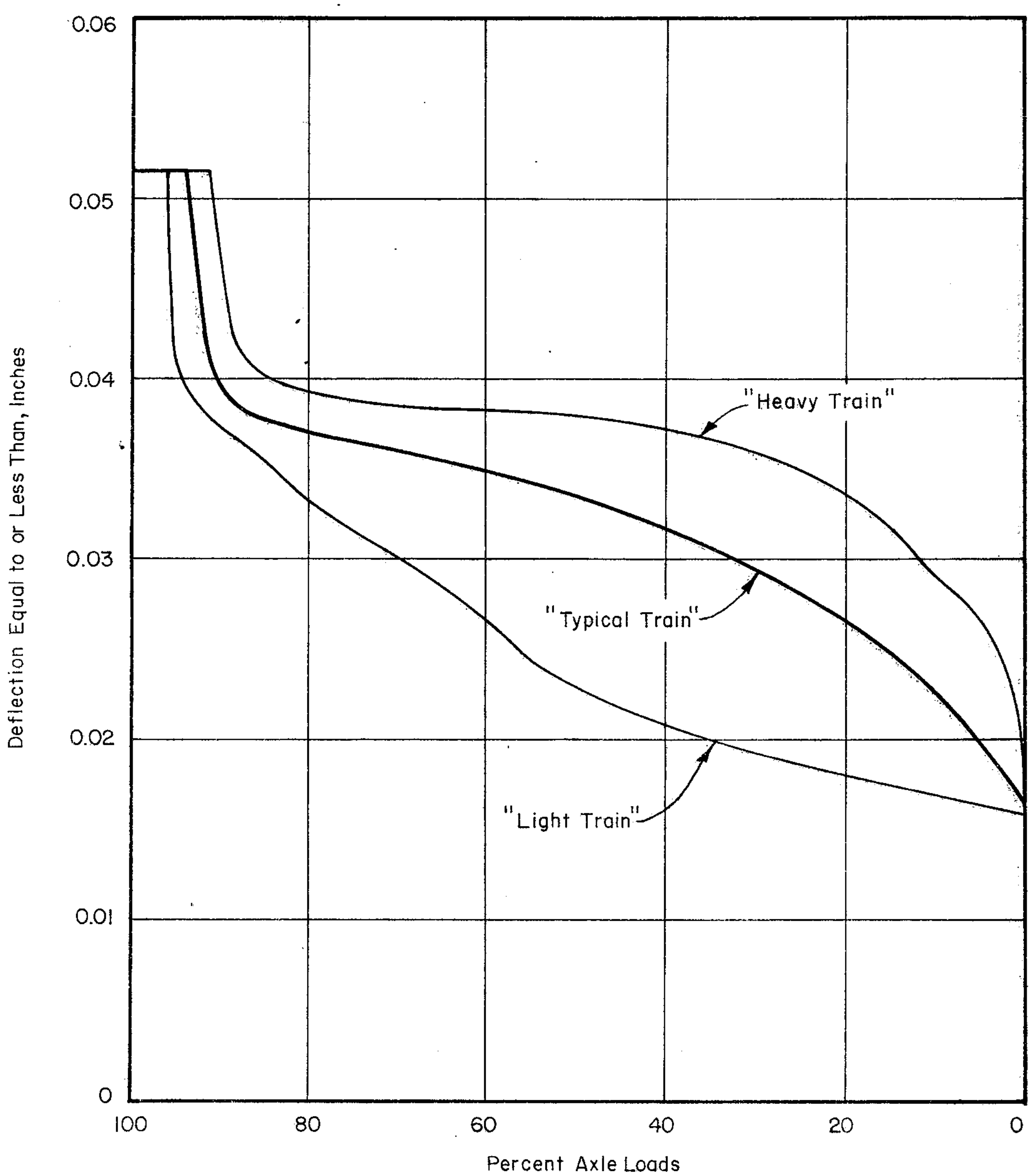
FIG. 53

DYNAMIC DATA
AXLE LOAD vs DEFLECTION AND PRESSURE
SECTION 9



Note:
Data obtained from freight train records and traces at 1510 hrs., Jan. 9, 1975. Engine Nos. 3542, 3131, 6341, 6334 + 73 cars. Speed = 52 mph. Locomotive has 6 axles at 65 kips each.

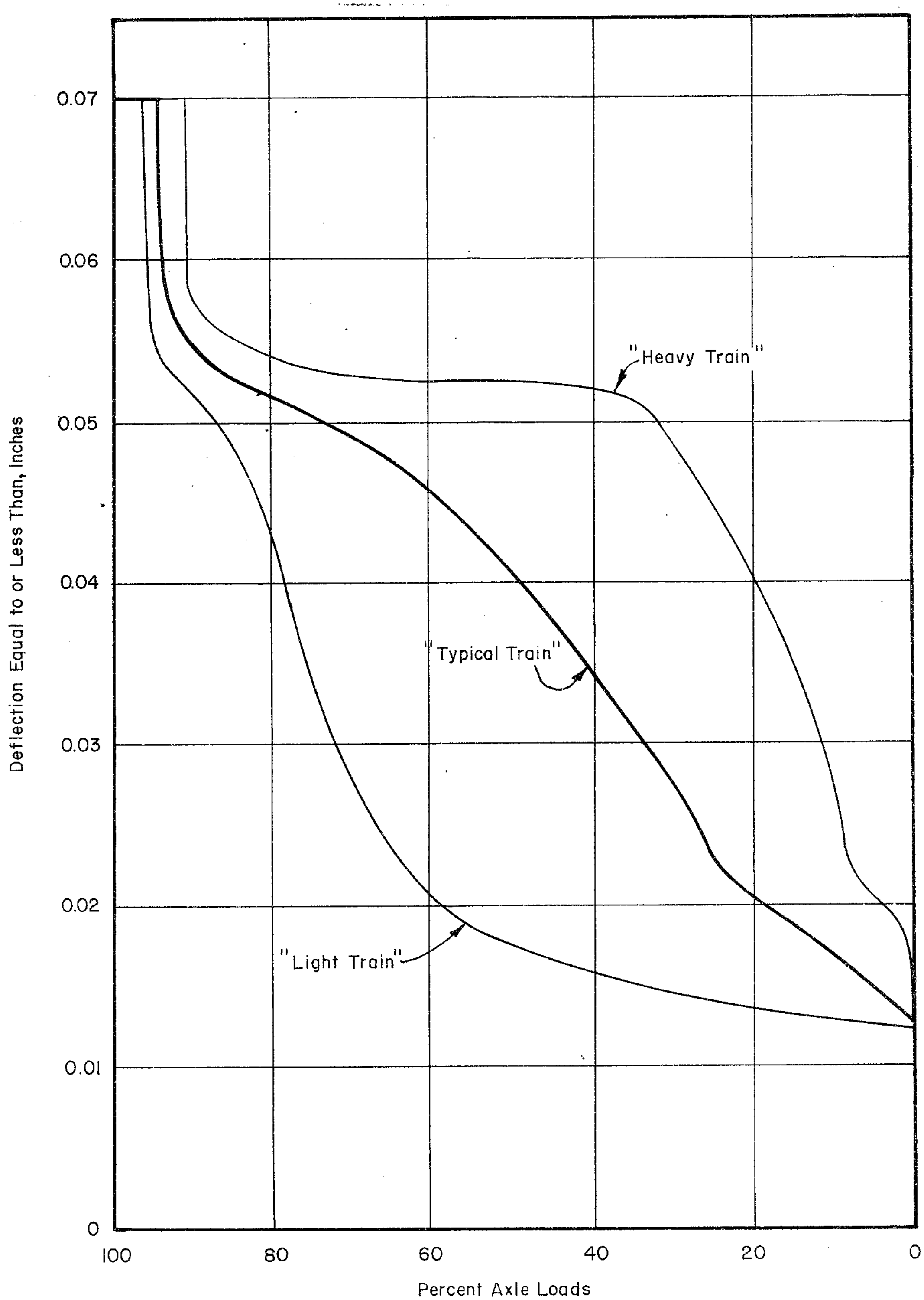
FIG. 54



Data shown for Instrument No. 7402.04.

DISTRIBUTION OF DEFLECTION
RAIL EXTENSOMETER TO ROCK
SECTION 7

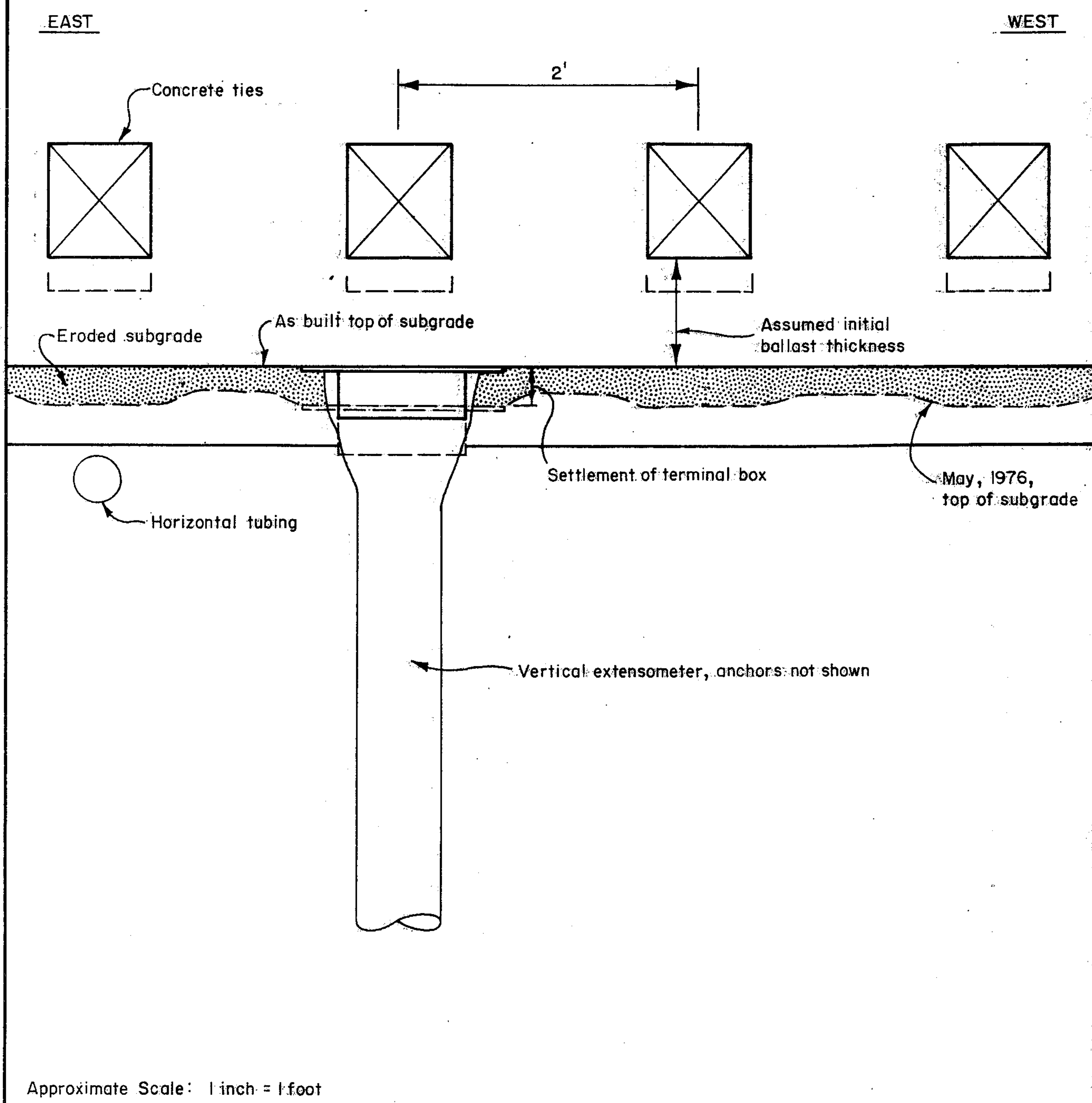
FIG. 55



Data shown for Instrument No. 9402.04.

DISTRIBUTION OF DEFLECTION
RAIL EXTENSOMETER TO ROCK
SECTION 9

FIG. 56



SCHEMATIC PROFILE ALONG NORTH RAIL
TEST SECTION NO. 3

GPO 914-162

FIG. 57