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Laboratory tests used to evaluate the accuracy and repeatability of the Vibra-Tension included measuring the tension in a 1/2-inch diameter prestressing strand while varying 4 parameters: bridge length (unsupported length of strand), type of bridges (or strand support) used, position along the bridge length where measurements were taken, and the stress level. Measurements were made using two different types of transducers and under different weather conditions.

Results indicate that the Vibra-Tension can be expected to give accurate readings to within 2% of the true tension, and that the repeatability of the Vibra-Tension was good with a maximum of 1-6 percent variation, when proper operating procedures were used.

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HIGHWAY RESEARCH REPORT

AN EVALUATION OF THE VIBRA - TENSION MODEL ET-U

FINAL REPORT

June, 1973

STATE OF CALIFORNIA BUSINESS AND TRANSPORTATION AGENCY DEPARTMENT OF PUBLIC WORKS DIVISION OF HIGHWAYS	MATERIALS AND RESEARCH DEPARTMENT RESEARCH REPORT CA-HY-MR-6669-1-73-16

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Results indicate that the Vibra-Tension can be expected to give accurate readings to within 2% of the true tension, and that the repeatability of the Vibra-Tension was good, with a maximum of 1.6 percent variation, when proper operating procedures were used.

Tests showed that the operation of the Vibra-Tension required practice and care before measurements could be taken with confidence. With experience and employment of proper operating techniques, the Vibra-Tension can be an invaluable tension measuring device.

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DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

June 1973
Final Report
M&R No. 646669

Mr. George A. Hill
Assistant State Highway Engineer
Engineering Services
California Division of Highways

Dear Sir:

Submitted for your consideration is a research report titled:

AN EVALUATION OF THE VIBRA-TENSION, MODEL ET-U,

AN INSTRUMENT FOR MEASURING PRESTRESSING STRAND TENSION

Author and Project Engineer

John P. Dusel, Jr.

Principal Investigator

J. R. Stoker

Under the Supervision of

Eric F. Nordlin

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attachment

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The contents of the report reflect the views of the Materials and Research Department who is responsible for the data presented herein. The contents do not necessarily express the official views or policies of the State of California. This report does not constitute a standard, specification or regulation.

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I. INTRODUCTION

A. Background and Purpose of Research

The importance of being able to measure forces in prestressing strands has been evident since the concept of prestressed concrete was developed. To apply the proper initial prestressing force, it is necessary to know what losses in tensioned prestressing strands will occur, including those due to creep of the steel, friction across harping points, and anchorage seating. Determining the actual axial force present at any location in prestressing strand has been a continuous problem facing prestressing plant inspectors. The compressive load cells presently used measure only the tension in the prestressed strands at the end bulkheads, shown in Figure 1. The friction losses across harping points and the tension between harping points of harped strands cannot be measured directly with the load cell.

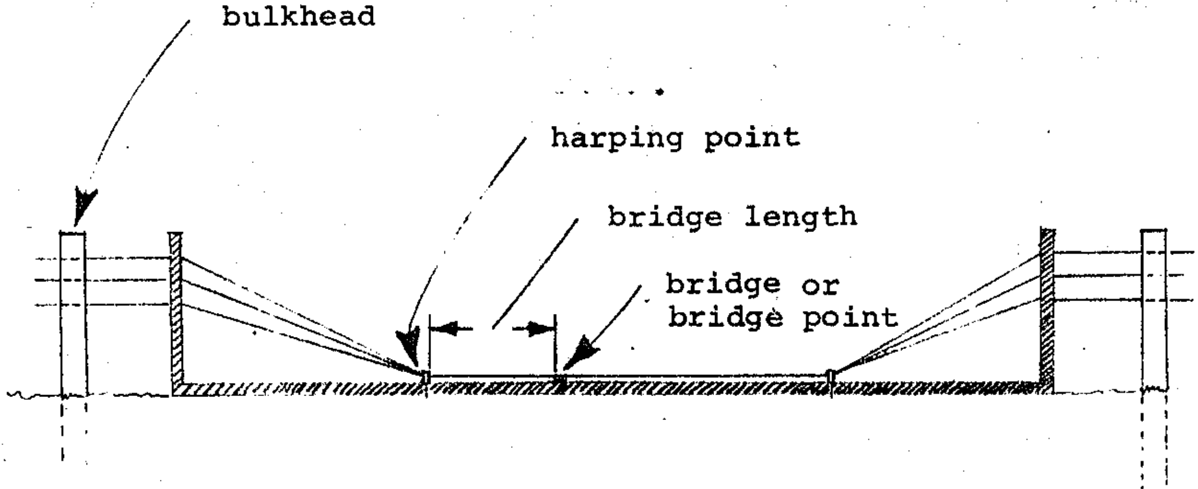


Figure 1

Defined Prestressing Terms

Considerable research and testing have been done to find a quick, accurate method of determining forces in tensioned cables and prestressing strands at any location along the strand. From initial attempts by the Materials and Research Department to develop a suitable instrument, the California Strand Stress Beam emerged in 1968[1]. The Stress Beam enabled the strand stress to be measured at any location along a tensioned member. The Stress Beam was useful as a research tool but subsequent testing uncovered several undesirable characteristics: (1) it is difficult for one man to take measurements, (2) a great amount of practice is necessary to be able to conduct tests with confidence that the results are accurate, (3) tension measurements take a considerable amount of time (approximately 15 minutes per strand), and (4) it is impossible to use the Stress Beam in an area where the strands are bundled.

Shortly after the Materials and Research Department had developed the California Strand Stress Beam, Vemco Industries of San Francisco introduced a new electronic instrument, the Vibra-Tension, which could rapidly measure tension at any location along a strand or cable. Early in 1969, a Vibra-Tension instrument was loaned to the Structural Materials Section for initial testing. After encouraging results were obtained during the first month loan period, an extended lease agreement was written for 4 months beginning May 27, 1969, and further evaluation of the Vibra-Tension unit was accomplished.

During the four month period, the Vibra-Tension instrument was field tested at prestressing plants in Sacramento, Visalia, and Los Angeles. The following pertinent conclusions were drawn from tests made at the various plants:

1. Tension readings on straight strands were always within 2% of compressive load cell readings when bridge points were solidly wedged and bridge lengths were between 15 to 35 feet. This has also been supported by the laboratory tests.

2. For harped strands, harping points were used as bridge points. At several locations one-quarter inch shims had to be used to separate the adjacent strands. Tension readings were very consistent and within 2 to 3% of the calculated tensions.

3. A set of 15 to 20 readings could be taken by the operator within 15 minutes, thereby minimizing any delay the contractor might have to incur.

4. Tension readings were taken directly, with no conversion chart necessary.

5. During the testing period, no recalibration of the instrument was necessary.

A lack of quantitative information on the effectiveness and accuracy of the Vibra-Tension under a variety of conditions established a need for further research. The purpose of this research project was to evaluate the Vibra-Tension, Model ET-U, determine its capabilities and limitations over a wide variety of measuring conditions, determine the accuracy and repeatability of measurements made, and develop a test method and an operating procedure for the instrument. According to the 1970 ASTM Index and Glossary[2], the terms accuracy and repeatability may be defined as follows:

Accuracy	Accuracy, Test Method - The degree of agreement between the true value of the property being tested (or an accepted standard value) and the average of many observations made according to the test method, preferably by many observers.
Repeatability	Repeatability - A quantitative measure of the variability of a single operator in a given laboratory employing generally the same apparatus. It is defined as the greatest difference between two single and independent results that can be expected by chance alone (based on the 95 percent confidence level).

B. Description of the Vibra-Tension

The Vibra-Tension, Model ET-U, is a unique, portable, electronic instrument that measures the fundamental frequency of vibration of a known length of wire rope, cable, or strand. Prior to testing, dials on the instrument are set according to the bridge length and type of strand used as shown in Table 1 of Appendix C.

The minimum bridge length which should be used when measuring 1/2 inch diameter prestressing strand is 12 feet. The maximum bridge length which can be measured by Vibra-Tension is 39.9 feet.

After proper instrument dial settings have been made, a vibration is induced in the strand with the operator's hand or a mallet, and the fundamental frequency of the impressed vibration is measured with one of two types of transducers, either the contact transducer, which is attached with a rubber strap to the strand, or the non-contact transducer, which is held steady at a suitable distance (1/4 inch to 2 inches) from the vibrating strand.

As the strand vibrates in its fundamental mode, the transducer converts the vibrations of the cable into current pulses; these electrical pulses are transformed into a direct tension reading with the assistance of a small analog computer within the instrument which computes the tension according to the "vibrating string" formula, $T = 4ML^2F^2$, where:

T = tension in pounds,

M = mass per unit length in $lbs\text{-}sec^2/ft^2$,

L = length in feet,

F = frequency in cycles per second

II. SUMMARY

A series of tension measurement tests were made on a 1/2" diameter prestressing strand to evaluate the accuracy and repeatability of the Vibra-Tension. The strand was tensioned on a 41 foot long W33 x 130 steel beam by a hydraulic prestressing jack, and tension was monitored with a calibrated load cell accurate to within 0.1%. The Vibra-Tension was evaluated over eleven different bridge lengths ranging from 8 feet to 39 feet at two different tension levels (25 kips and 30 kips). Two different bridges, a steel clamp and a wooden wedge, were used to achieve the various bridge lengths. The two different transducers, contact and non-contact, available for use with the Vibra-Tension were used to make each measurement.

Various sets of measurements were taken on different days under different weather conditions so that the repeatability could be determined. Changes in the weather had no apparent effect on test results. Measurements were made during both mild (15-20 mph) and calm wind conditions and between temperatures of 40°F and 75°F.

Measurements were found to agree with one another with a maximum variation of 1.6%. Factors which would contribute to the degree of repeatability are:

1. Battery charge.

2. Calibration of instrument.

3. Operator's precision.

Two sets of graphs shown in Figures 1A through 18A in Appendix A, one for each tension level and bridge length tested, were constructed comparing the distance of the transducer from the bridged end to measured tensions obtained from the Vibra-Tension and load cell. Each graph also compares results obtained from using wooden wedges and steel clamps as bridges.

From the above experiments and tests it was found that an accuracy within 2% of the true value of a prestressing strand tension can be expected if the operating procedure, as outlined in the proposed test method submitted with this report, is followed. Figures 19A through 26A in Appendix A show Accuracy versus Bridge Length graphs. Some of the factors which were found to greatly affect the accuracy of the Vibra-Tension are:

1. Bridge length of strand.

2. Location of the transducer along the bridge length.

3. Fixity of the bridge nodal points.

4. Type of transducer.

Other things which can be expected to affect the accuracy to a lesser degree include:

1. Type of bridge used.

2. Stress level.

3. Vibrations of forms and strands caused by personnel or machinery working in immediate vicinity.

4. Type or brand of strand.

III. CONCLUSIONS AND RECOMMENDATIONS

Tests conducted with the Vibra-Tension have shown that it is a useful instrument in determining tension in prestressing strands. It has many advantages when compared to present methods of measuring tension with load cells, jack pressures, and elongation. The Vibra-Tension is able to measure prestressing force at any location, including harped or continuous sections of one or more casting beds. Laboratory tests indicate that the Vibra-Tension can consistenly measure tension with a combined accuracy and repeatability error of less than 3.6% provided that operating instructions and test procedures are carefully followed. To obtain good results there are certain rules which are essential to follow:

1. Use a long bridge length, as near to the maximum Vibra-Tension length setting, 39.9 feet, as possible.

2. Locate the transducer and excite the strand at or as near the center of the bridged length as possible.

3. Use the non-contact transducer if accurate results are desired irrespective of where the transducer is placed over the bridge length. If measurements are to be made near the center of the bridge length and ease of operation is desired, use of the contact transducer is recommended. Both transducers produce equally accurate tension readings when used near the center of the bridge length.

4. Make sure the Vibra-Tension batteries are fully charged, and make sure the Vibra-Tension is properly calibrated before using.

5. Make sure the Vibra-Tension needle is stable before reading tension.

6. For bridge lengths less than 27 feet, wooden wedges must be used as bridge points to maintain accuracy within 2.0%.

Certain important observations were made after completing the tests:

1. Better accuracy was achieved at the higher stress level of 30 kips.

2. Both the contact or non-contact transducer produced good accuracy when positioned near the center of the bridge length. Use of the non-contact transducer resulted in constant tension readings, irrespective of its position along the bridge length, whereas the contact transducer gave consistently higher and inaccurate readings as it was moved away from the center of the bridge length.

3. The use of wooden wedges as bridges resulted in slightly more accurate readings than did the steel clamp. Any hard material such as wood or steel used as a bridge can be expected to produce accurate results.

4. Long bridge lengths, up to 39.9 feet maximum, usually resulted in higher accuracy.

5. Placement of the contact transducer and excitation of the strand at the center of the bridge length led to more accurate readings and faster stabilization of the Vibra-Tension meter needle.

6. Varying weather conditions had no apparent affect on results.

Learning and following correct operating procedures and practices are essential before accurate, repeatable readings can be made.

Adoption of the proposed test method and suggested changes to the Standard Specifications are recommended.

IV. DISCUSSION OF TESTS

A. Vibra-Tension Operation

The Vibra-Tension is a highly sophisticated electronic instrument developed for determining the force in prestressing tendons or other strand or cable systems that are subjected to a tensile load. The electronic circuitry and small analog computer within the instrument converts vibrations as sensed by the transducer to values of tension. Some of the major considerations when using the Vibra-Tension are covered below:

1. Transducers.

The fundamental frequency of vibration of a strand is converted to an electrical signal by either a contact or non-contact transducer. The transducers may be used interchangeably; however, it is recommended by the manufacturer that only the non-contact transducer be used for strand with a diameter equal to or smaller than 5/16 inches. The non-contact transducer has the advantage over the contact transducer of giving constant readings over the entire bridge length, but has the disadvantages of being hard to hold steady and to acquire stable readings, requiring judgment to determine the proper distance to hold the transducer from the strand, and having to determine the amount of excitation necessary to stabilize the meter. The contact transducer has the advantage of being much easier to operate. For prestressing strand normally encountered, either transducer will produce satisfactory readings. In order to obtain best accuracy, placement of the transducers should be restricted to the center one-quarter of the bridge length.

The contact transducer is a modified geophone which functions as a low frequency accelerometer. Use of this transducer is very simple. All that is required is to strap the transducer on the strand in a vertical position, either upright or upside down, with a rubber clip as shown in Figure 2. The readings may be affected if the contact transducer is attached horizontally. If the rubber clips are lost, any heavy duty rubber band may be used as long as its weight is equal to or less than that of the original rubber clip.

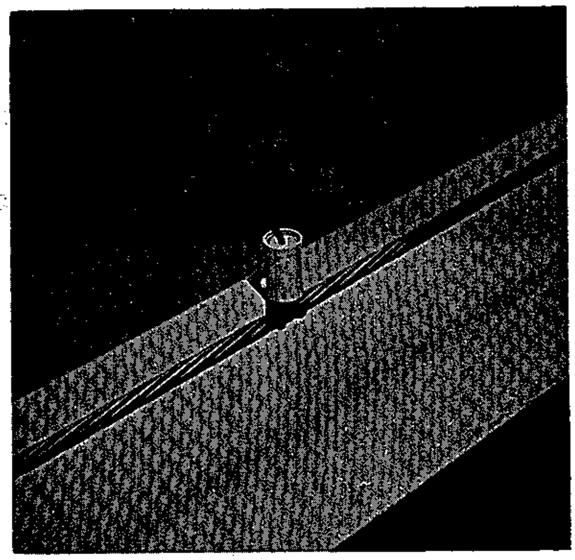


Figure 2

Position of Contact Transducer

The non-contact transducer is an electro-magnet which also functions as an accelerometer. This transducer should be held with the cylindrical axis parallel to the strand and with the edge of the transducer between 1/4 inch and 2 inches from the vibrating strand as shown in Figure 3. It must be held steady when taking readings. Movement of the transducer during readings will not allow the tension meter needle to stabilize.

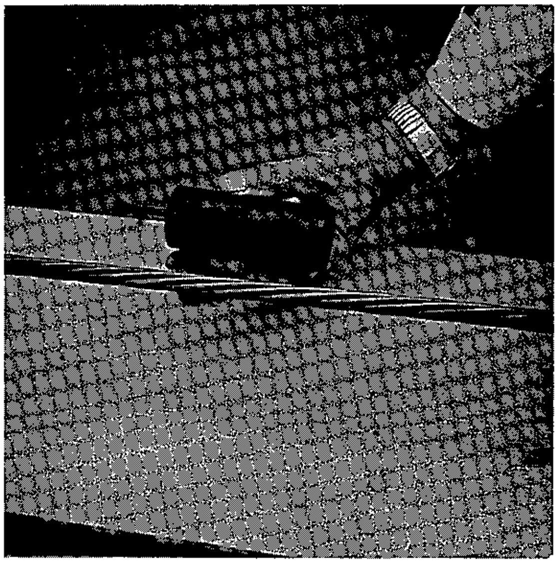


Figure 3

Position of Non-Contact Transducer

2. <u>Instrument Settings.</u>

The first step in determining strand tension is to make adjustments for the various parameters by setting the dials on the instrument panel. The major components of the instrument panel as indicated on Figure 4 are: an overlapping eight scale tension meter, calibration adjustment screw, scale selector switch, vernier dial, transducer input jack, ON/OFF buttons, charge indicator light, two battery charge test buttons, strand diameter dial, and a bridge length thumb wheel.

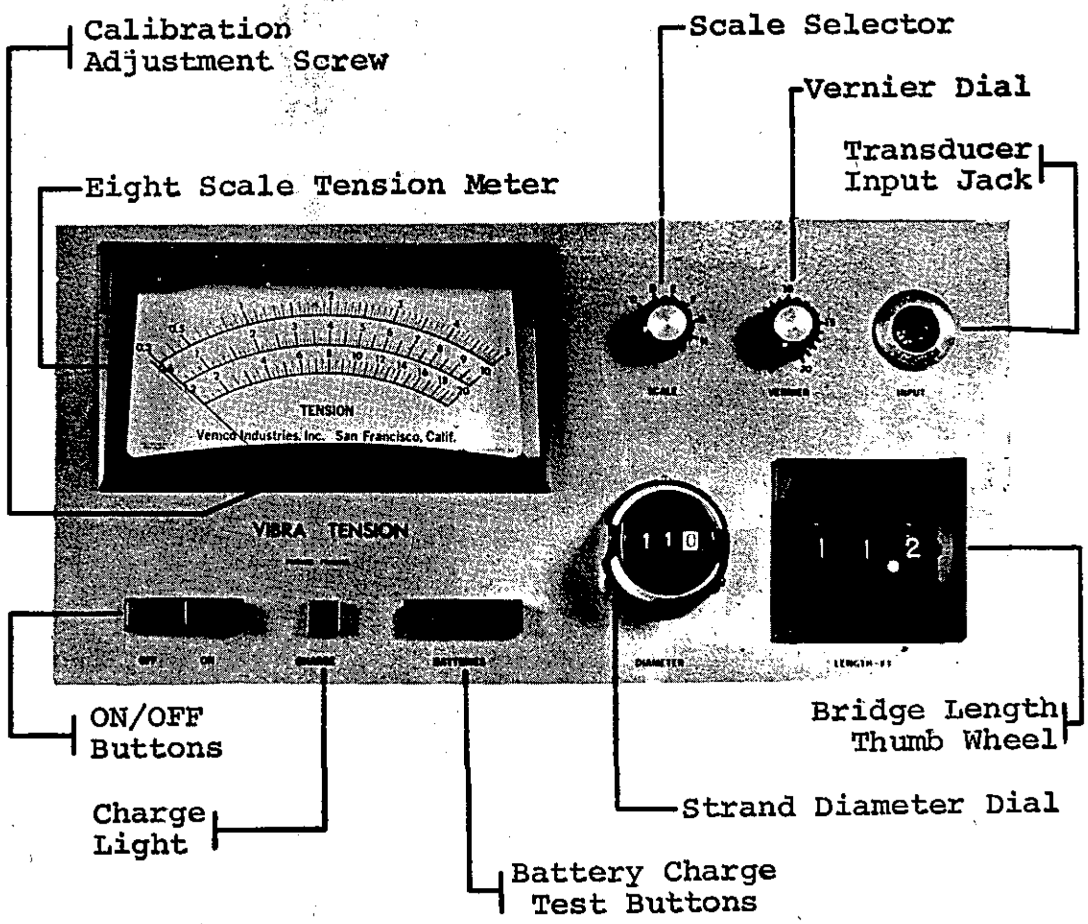


Figure 4

Vibra-Tension Instrument Panel

The direct reading tension meter has three scales, whose ranges can be changed by multiplying the scale numbers by the correct power of ten to include eight overlapping tension ranges. The top scale on the tension meter has three ranges: A, 300 to 5,000 pounds, D, 3,000 to 50,000 pounds, and G, 30,000 to 500,000 pounds. The middle scale also has three ranges: B, 600 to 10,000 pounds, E, 6,000 to 100,000 pounds, and H, 600,000 to 1,000,000 pounds. The bottom scale has two ranges: C, 1,200 to 20,000 pounds and F, 12,000 to 200,000 pounds.

The scale selector switch is provided only as a reminder to the operator to read the proper scale. It does not affect the operation of the machine or readings on the scale. The top scale using the D range would normally be used for 1/2 inch diameter prestressing strand.

The vernier switch is used to compensate for the added weight of the contact transducer on the vibrating strand. When the non-contact transducer is used, the vernier switch must be set on zero. Vernier switch settings for common strand diameters may be found in Table 1 of Appendix C.

The transducer input jack is used to attach the transducer to the Vibra-Tension instrument.

The ON/OFF buttons are used to turn the Vibra-Tension on or off. The OFF button should be depressed for storage and at all times when tension readings are not being made in order to reserve the batteries. The battery charge light indicates when the battery charger is operating. There are separate buttons to check the charge on the two batteries. The battery check reading to the left of the 5 on the top scale obtained when either button is depressed indicates that the batteries need charging. Charging is accomplished by depressing the OFF button and plugging the cord contained in the transducer storage compartment into a 110 volt source.

The cable diameter digital dial is used to input a number which corresponds to the diameter of the strand into the instrument. The diameter setting is obtained from Table 1 in Appendix C. Diameter setting is a function of the weight per foot of strand.

The bridge length is set on the length dial. It should be measured and set to the nearest 1/10 of a foot. The maximum bridge length which can be measured is 39.9 feet. Care should be taken to measure and set the proper bridge length in the instrument so that accurate tension values will be obtained. The bridge length should be measured between the face of the bridges from the first point where no movement or vibration occurs. A bridge length setting larger than the actual distance will give a low tension reading and a bridge length setting shorter than the actual distance will give a high tension reading.

3. Bridging.

Bridging is the establishment of two solid points or points of fixity on the strand which do not move or transmit vibrations. The length of strand between the bridge points (bridge length) must be free to vibrate without touching any other object. Many problems encountered in getting stable tension readings with the Vibra-Tension are a result of one of the following three oversights:

(a) Bridge Point Movement. For successful operation of the Vibra-Tension, it is necessary that both ends of the strand be rigidly fixed in position while only the strand between the bridge points vibrates. This is a common oversight and can cause erroneous readings. For prestressing strand, wood or steel wedges can be satisfactorily used to wedge against the bulkhead, forms, or harping point hold-downs to establish adequate bridging points. Excessive vibrations of the forms or bridge points caused by workmen or equipment will cause the tension meter needle to wander. The obvious remedy is to reduce excessive movement of workmen and equipment while making tension readings with the Vibra-Tension.

(b) Strand Vibrates Against Bridge Points. It usually is not necessary to exert a large force to establish a bridging point. The only requirement is that the bridging element be firmly pressed against the strand at the bridge point. If wedges are necessary, use them. Either steel or wooden wedges may be employed.

(c) Strand is Not Free to Vibrate. This can occur when the strand vibrates against rebar, adjacent strand, and other objects too close to the vibrating strand. The solution is to remove the obstruction or to increase the wedge size so that the vibrating strand is not touched. If this is not possible, choose a different portion of the strand to establish a bridge length.

4. Length Measurement.

Transducers used with the Vibra-Tension operate in a frequency range of 2.5 cycles per second to 65 cycles per second. For normally used 1/2 inch diameter, 270 ksi prestressing strand, such frequencies are obtained from vibrating lengths of 12 to 39.9 feet inclusively. Bridge lengths longer than 39.9 feet cannot be accommodated by the Vibra-Tension instrument. Use of lengths shorter than 12 feet will result in erroneous tension readings. Strand length should be measured to the nearest 1/10 of a foot and set on the bridge length dial. Usually bridge lengths between 27 feet and 39.9 feet produce more accurate readings.

5. Strand Vibration.

The fundamental vibration of the strand is obtained by striking the strand softly with the heel of the hand. One strike is normally sufficient for one reading. If after striking the strand the tension dial indicator is erratic or does not stabilize, stop the vibration of the strand and check the bridge points for fixity. If bridge points are solid, then try varying the severity of the excitation.

B. Testing Objectives

Tests conducted with the Vibra-Tension instrument were made to determine the importance of many factors on its operation. The testing objectives were:

1. To determine the accuracy and repeatability of the Vibra-Tension using both types of transducers at different stress levels and bridge lengths.

2. To find what effect different types of bridge points have on readings.

3. To determine which locations along the bridge lengths are the best to take readings.

4. To uncover any limitations of the Vibra-Tension.

5. To develop a test method and an operating procedure for the instrument.

C. Testing Procedure

Laboratory tests were conducted using 1/2 inch diameter prestressing strand manufactured by Suzuki Metal Industries and stressed at 25 and 30 kips. These loads were selected to represent the range of loads normally encountered in the 1/2 inch diameter strands. The strand was tensioned using a 41 foot long W33x130 steel beam as a prestressing bed. Suitable anchorage plates were bolted to each end. A prestressing anchorage wedge held one end of the strand while a stressing jack tensioned the strand at the opposite end. A load cell having less than .1% error, was placed at the jacking end and was used for monitoring tension and taking tension readings. The readings obtained from the load cell were then correlated with the Vibra-Tension measurements.

Settings for the Vibra-Tension instrument were obtained from the manufacturer of the Vibra-Tension and are shown in Table 1 of Appendix C. For the 1/2 inch diameter prestressing strand manufactured by Suzuki Metal Industries and used in this research project, a vernier setting of 6 was used with the contact transducer and a diameter setting was made at 214. To measure tension in strand manufactured by different companies, minor changes in dial settings as indicated in Table 1 are necessary due to slight variations in the strand unit weight.

At both stress levels eleven different bridge lengths, ranging from 8 feet to 39 feet were used. Both types of transducers were used to measure tension at various intervals along each bridge length.

In an attempt to bracket the fixity variable at the bridge point, a steel clamp shown in Figure 5 and a wooden wedge depicted in Figure 6 were used as bridges for each bridge length tested. Other objects suitable for use as bridges such as steel wedges and lengths of reinforcing bar can be expected to produce accurate tension readings, within the range of results produced by the steel clamp and wooden wedge.

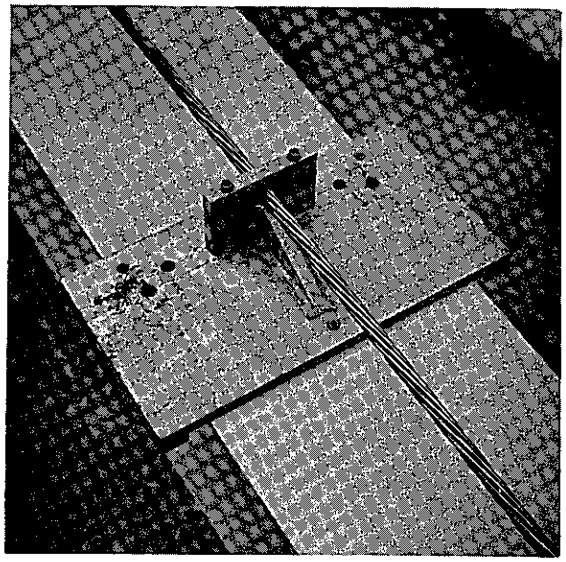


Figure 5

Steel Clamp Used as Bridge

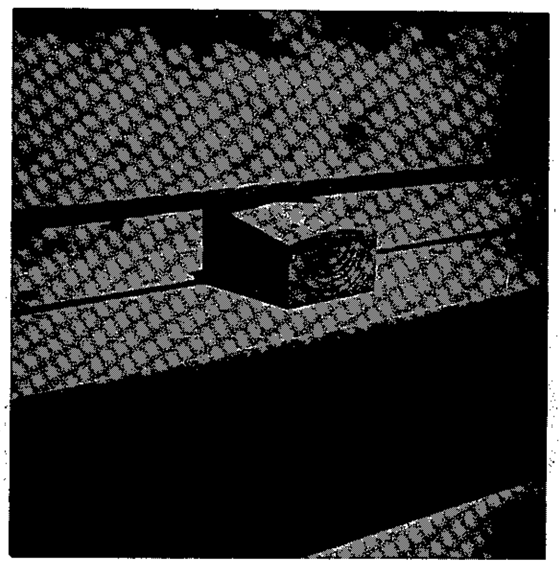


Figure 6

Wooden Wedge Used as Bridge

D. Testing Results

From tests conducted, the Vibra-Tension has been found to be a useful tool for inspectors to determine the actual tension at intermediate points in prestressing strands.

The Vibra-Tension can measure the prestressing force at any location along strands which may be harped or continuous through one or more casting beds. Tests indicate that the Vibra-Tension can consistently measure the tension in prestressing strand with a combined accuracy and repeatability error of less than 3.6% provided that the instrument is properly calibrated and correct operating procedures as specified in the proposed test method in Appendix C are followed.

A series of graphs shown in Figures 1A through 18A of Appendix A were made from research data and relate the strand tension, as monitored by the load cell and the contact and non-contact transducer, to the distance of the transducers from bridge points. Two general comments may be made about the accuracy of measurements. Accuracy seems to increase as the bridge length increases and greater accuracy seems to be achieved when transducers are placed near the center of the bridged span.

Figures 19A through 26A of Appendix A are graphs of accuracy versus bridge length. Tension in the prestressing strand and types of bridging devices are varied.

The effects which six parameters have on accuracy of tension readings are discussed as follows:

1. The Effect of Bridge Lengths on Accuracy. Bridge lengths seem to affect the accuracy differently, depending on the type of bridging devices used. Wooden wedges seem to give more accurate readings than steel clamps for all bridge lengths but the accuracy seems to be best with a bridge length near 20 feet. When steel clamps are used as bridging devices, accuracy increases as the bridge length increases.

2. The Effect of Types of Bridges on Accuracy. From the testing performed, the use of wooden wedges leads to a higher degree of accuracy than steel clamps used as bridging devices due to the attenuating or damping effect of wood. With long bridge lengths there is a very flat slope of accuracy versus bridge length plots for wooden wedges, whereas for steel clamps, the slope of the accuracy versus bridge length curve is noticeably steeper. Thus in the case where steel clamps might be used, a higher change in accuracy versus change in length can be expected than when wooden wedges are employed.

3. The Effect of Stress Levels on Accuracy. At the 25 kip stress level, wooden wedges give accuracy to within 2% of the actual stress in the prestressing strand if a bridge length greater than about 15 feet is used. Steel clamps can also be used but a bridge length longer than 27 feet is recommended if an accuracy to within 2% of the actual stress is required. With both wooden and steel wedges, as the stress increases, the slope of the curve of accuracy versus bridge length line decreases.

At the 30 kip stress level, wooden wedges give accuracy to within 2% for bridge lengths ranging from 12 to 39 feet. Steel clamps used as bridges give an accuracy to within about 2% for bridge lengths greater than about 17 feet.

Thus for shorter bridge lengths, as the stress level is increased from 25 kips to 30 kips, the slopes of the accuracy versus bridge length lines flatten and better accuracy can be expected.

4. The Effect of the Type of Transducer on Accuracy. When measuring tension with the non-contact transducer, the values of tension obtained are nearly constant and are independent of the position of the transducer along the bridge length.

Tension readings of measurements made with the contact transducer unlike those made with the non-contact transducer vary and the accuracy decreases as the measuring location of the transducer is moved from the center of the bridge length.

It was found that the contact transducer produces tension measurements of equally good or better accuracy than the non-contact transducer for short bridge lengths when placed near the middle of the bridge length, but much less accuracy in all cases when placed away from the center of a short bridge length.

Figures 1A through 26A in Appendix A depict these observations.

5. The Effect of the Location of the Transducers Along the Bridge Length on Accuracy.

a. Contact transducer:

The position along the bridge length where the tension measurement is taken with a contact transducer seems to make a considerable difference in the accuracy of the measurement. The center 1/4 of the bridge length seems to give the most accurate readings. The closer that readings are taken to the ends of the bridge length, the higher and less accurate they will be (see data).

b. Non-contact transducer:

The measuring position for the non-contact transducer, unlike the contact transducer, is not critical for accuracy. Values seem to remain constant and are independent of location along the bridge length.

6. <u>The Effect of the Location Where the Strand is Excited Along the Bridge Length.</u> The location along the bridge length where the strand is excited seems to make a difference in certain cases how quickly the meter needle stabilizes. From testing experience, one should try to excite the strand at or near the center of its bridge length, so that the primary mode of vibration is encouraged. If, for instance, the strand is excited at the 1/4 or 3/4 point, the second mode of vibration may tend to overshadow the first mode, and even though the needle may eventually stabilize, it will probably take longer. This can also apply to higher modes, but normally interference from vibrations above the 4th or 5th modes is small and does not seem to have much effect on reading the primary mode.

The repeatability of measurements made with the Vibra-Tension was determined to be good. Six sets of readings were taken at various bridge lengths and at two different stress levels on different days and weather conditions. Wind speeds varied between 0 and 20 mph and temperatures ranged from 40°F to 75°F.

These sets were compared with each other, and the differences between tension readings made in the center 1/4 of the bridge length were calculated. The average difference was found to be 1.15 percent, and the maximum was 1.6 percent.

Besides the above testing results, other important observations were made either during testing or as a result of the tests conducted. Many of these observations may be answered more easily in the form of questions. Some of the important observations are discussed as follows:

1. How hard should one excite the strand, and what instruments should be used for excitation?

Often it is necessary only to tap the strand very lightly with the palm of one's hand. A harder blow may be necessary to keep the needle stabilized for a longer period of time. The hardness of blow necessary to stabilize the meter can only be determined from experience. Either the hand or a rubber mallet is a good instrument for excitation. If a strand is excited too strongly near a bridge point, the needle may pin to the right.

2. What problems may be encountered in stabilizing the needle?

   a. If the batteries are weak, the needle may seem to almost stabilize, and then drop to zero. Low readings may also result if the batteries are weak.

   b. With the non-contact transducer, the needle may drift over the entire scale range at random if the transducer is not held perfectly still. The distance which the transducer is held from the strand is critical; sometimes a very small distance is necessary (1/4 inch) when the amplitude of vibration is very small as for a short bridge length.

   c. If the transducers are placed too close to the bridge point, the needle may pin, no matter how small the vibration induced in the strand, or the needle may stabilize only for a very short time.

   d. If a transducer is placed at a nodal point of a second or third harmonic and the strand is excited at the 1/4 or 1/6 points, there may be a problem in stabilizing the needle. It is desirable to place the transducer near the center portion of the bridge length, and also to excite the strand in this area.

   e. Loose wedges or vibrating forms will not permit the tension meter needle to stabilize. The most common fault which results in an unstable meter needle is a moving bridge point.

3. How short a bridge length can be measured using a 1/2 inch diameter prestressing strand?

   The minimum length of 1/2 inch diameter prestressing strand whose tension can be measured with good accuracy is 12 feet, as shown in Figures 15A and 16A in Appendix A. Wooden wedges seem to produce more accurate tension readings than do steel clamps at these short bridge lengths.

   Also the stress level of the prestressing strand seems to affect the minimum bridge length which can be measured. From experiments conducted at the 25 kip level using a steel clamp as a bridge and employing the contact transducer, the shortest length which can be measured fairly accurately is 8.5 feet. At 8.5 feet, with tension in a 1/2 inch diameter strand of 25.53 kips measured with a load cell, the tension value measured with the Vibra-Tension is 23.5 kips. Changing the bridge length from 8.5 feet to 8 feet, the tension measured by the Vibra-Tension drops from 23.5 kips to 6.5 kips. Changing the bridge length from 8.5 feet to 9 feet, the Vibra-Tension values jump from 23.5 kips to 26.7 kips.

At the 30 kip stress level using a steel clamp as a bridge the minimum bridge length which results in satisfactory tension readings is 10.0 feet. If the bridge length is changed from 10.0 feet to 9.0 feet, the tension readings made with the non-contact transducer drop from 30.9 kips to 7.5 kips, and those made with the contact transducer drop from 30.7 kips to 24 kips.

4. Why is the maximum allowable bridge length for all sizes and types of strand restricted to 39.9 feet?

The reason for limiting the bridge length to 39.9 feet is that with spans longer than 40 feet it is possible that the second or third frequency mode might be measured instead of the primary frequency. To avoid possible errors in frequency measurements, a suitable average maximum bridge length for a wide range of sizes of wire ropes, cables, and strands was determined by the Vibra-Tension manufacturer to be 39.9 feet.

V. REFERENCES

1. Nordlin, E. F., Ames, W. H. and Post, E. R., "Method to Determine the Axial Tensile Force in High Strength Prestressing Strand". State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 646322, April 1968.

2. 1970 Annual Book of ASTM Standards, Part 33, "Glossary of ASTM Definitions, Index of ASTM Standards".

3. Nordlin, E. F., Ames, W. H., "Investigation of Losses Associated with Pretensioned Girders", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 636383. July 1968.

4. Test Method No. Calif. 677-A, "Method of Determining the Tension in Prestressing Strand with the Vibra-Tension, Model ET-U".

VI. APPENDICES

APPENDIX A

Graphs of Measured Tension Versus Distance of Transducer from Bridged End.

FIGURE 1A Bridge Length = 39.0 feet, Bridge Type = Steel Clamp

FIGURE 2A Bridge Length = 39.0 feet, Bridge Type = Wooden Wedge

FIGURE 3A Bridge Length = 36.0 feet, Bridge Type = Steel Clamp

FIGURE 4A Bridge Length = 36.0 feet, Bridge Type = Wooden Wedge

FIGURE 5A Bridge Length = 32.0 feet, Bridge Type = Steel Clamp

FIGURE 6A Bridge Length = 32.0 feet, Bridge Type = Wooden Wedge

FIGURE 7A Bridge Length = 28.0 feet, Bridge Type = Steel Clamp

FIGURE 8A Bridge Length = 28.0 feet, Bridge Type = Wooden Wedge

FIGURE 9A Bridge Length = 24.0 feet, Bridge Type = Steel Clamp

FIGURE 10A Bridge Length - 24.0 feet, Bridge Type = Wooden Wedge

FIGURE 11A Bridge Length - 20.0 feet, Bridge Type = Steel Clamp

FIGURE 12A Bridge Length = 20.0 feet, Bridge Type = Wooden Wedge

FIGURE 13A Bridge Length = 16.0 feet, Bridge Type = Steel Clamp

FIGURE 14A Bridge Length = 16.0 feet, Bridge Type = Wooden Wedge

FIGURE 15A Bridge Length = 12.0 feet, Bridge Type = Steel Clamp

FIGURE 16A Bridge Length = 12.0 feet, Bridge Type = Wooden Wedge

FIGURE 17A Bridge Length = 9.0 feet, Bridge Type = Steel Clamp

FIGURE 18A Bridge Length = 9.0 feet, Bridge Type = Wooden Wedge

Graphs of Measured Tension Versus Distance of Transducer from Bridged End.

FIGURE 19A Strand Tension = 25 kips, Bridge Type = Steel Clamp
Tension Measurements made at 3/8 point

FIGURE 20A Strand Tension = 25 kips, Bridge Type = Wooden Wedge
Tension Measurements made at 3/8 point

FIGURE 21A Strand Tension = 30 kips, Bridge Type = Steel Clamp
Tension Measurements made at 3/8 point

FIGURE 22A Strand Tension = 30 kips, Bridge Type = Wooden Wedge
Tension Measurements made at 3/8 point

FIGURE 23A Strand Tension = 25 kips, Bridge Type = Steel Clamp
Tension Measurements made at 1/2 point

FIGURE 24A Strand Tension = 25 kips, Bridge Type = Wooden Wedge
Tension Measurements made at 1/2 point

FIGURE 25A Strand Tension = 30 kips, Bridge Type = Steel Clamp
Tension Measurements made at 1/2 point

FIGURE 26A Strand Tension = 30 kips, Bridge Type = Wooden Wedge
Tension Measurements made at 1/2 point

FIGURE 1A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

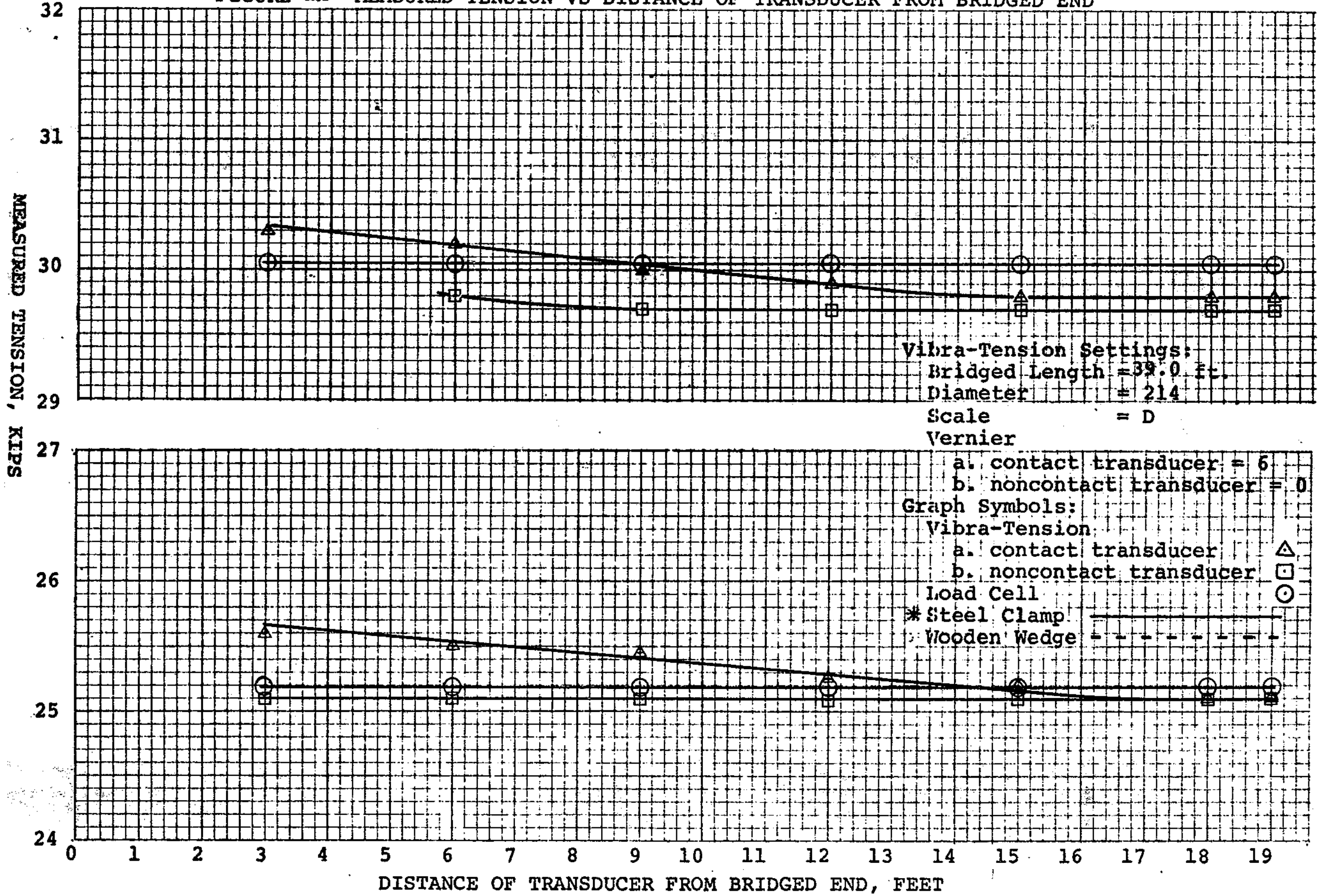


FIGURE 2A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

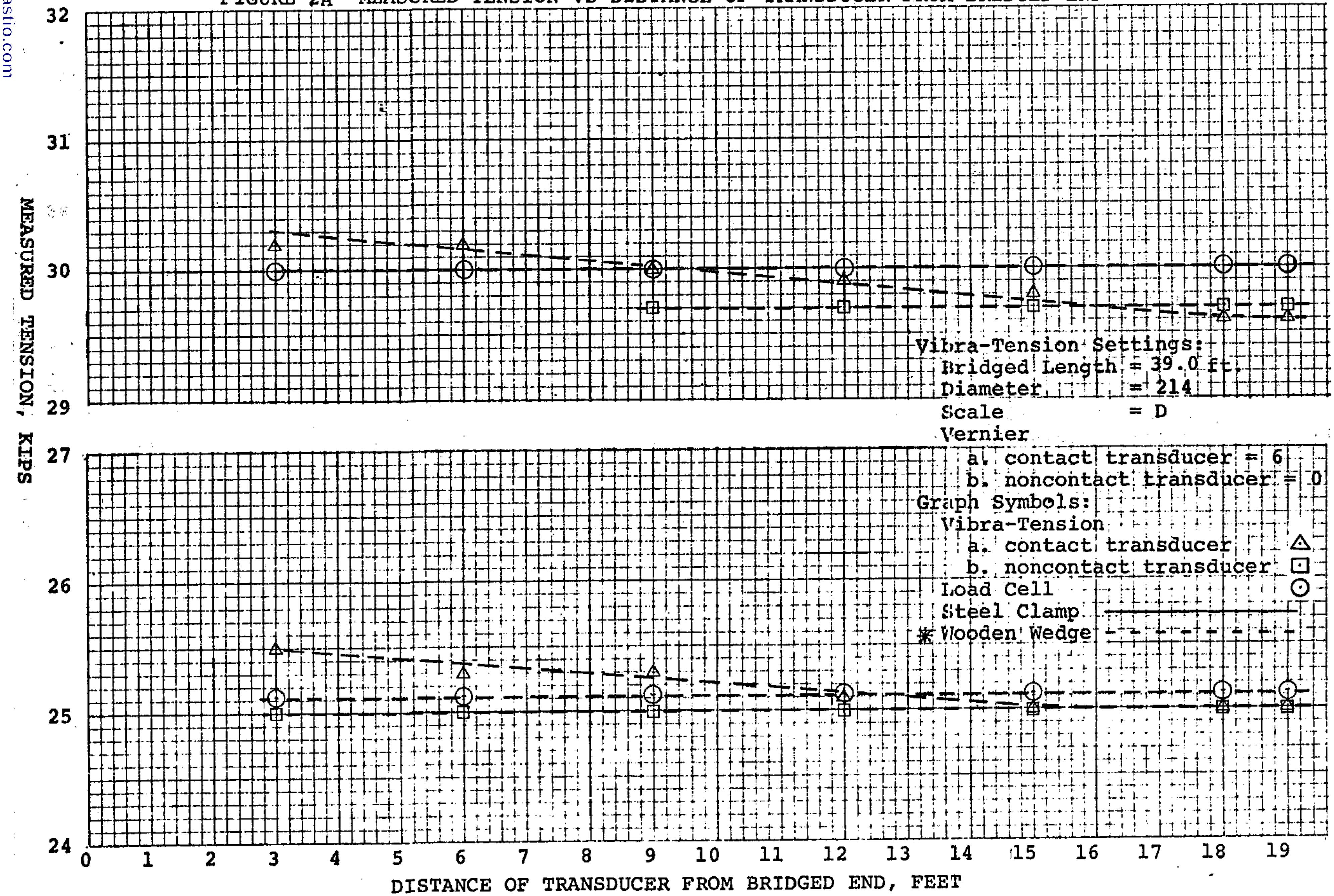


FIGURE 3A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

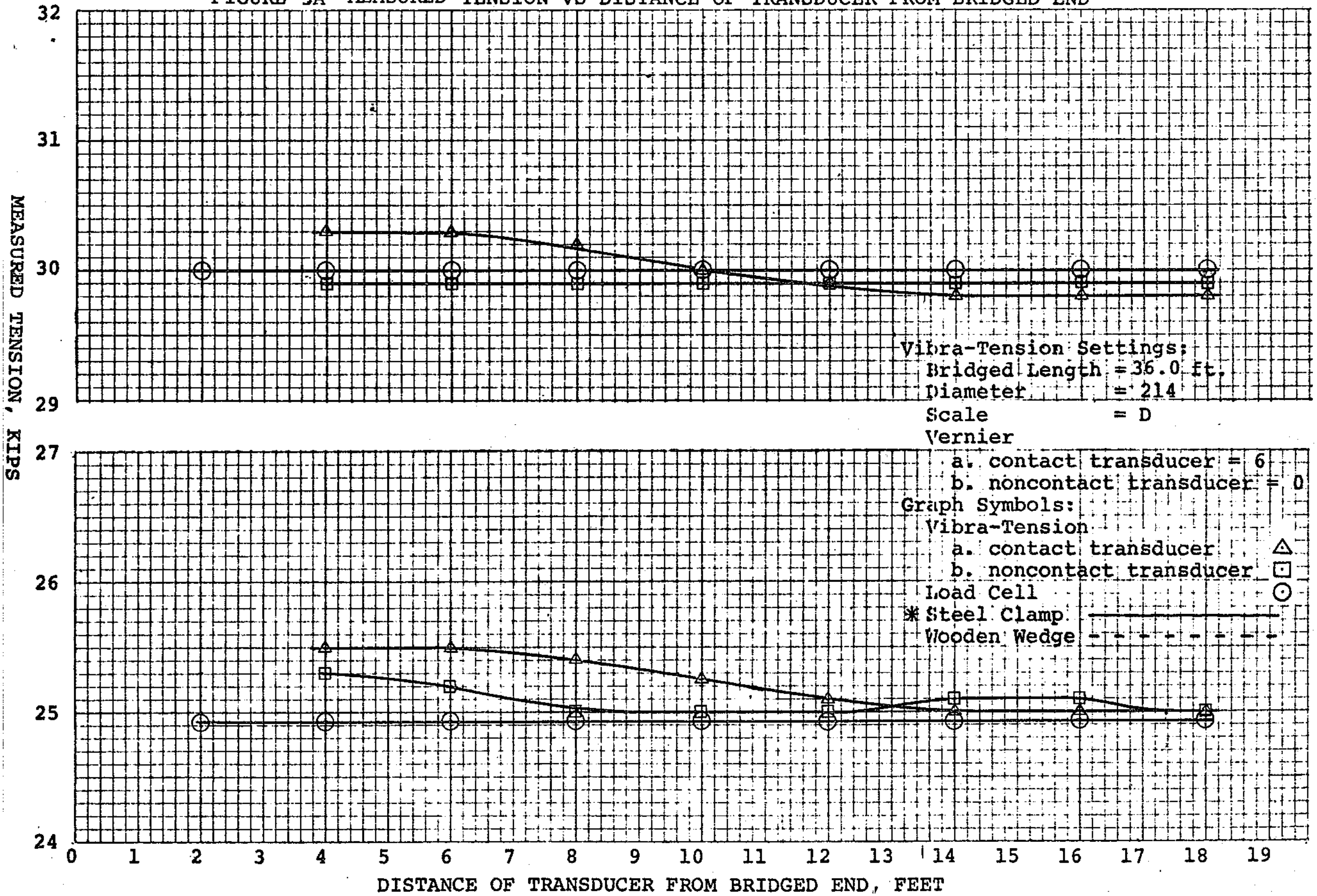


FIGURE 4A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

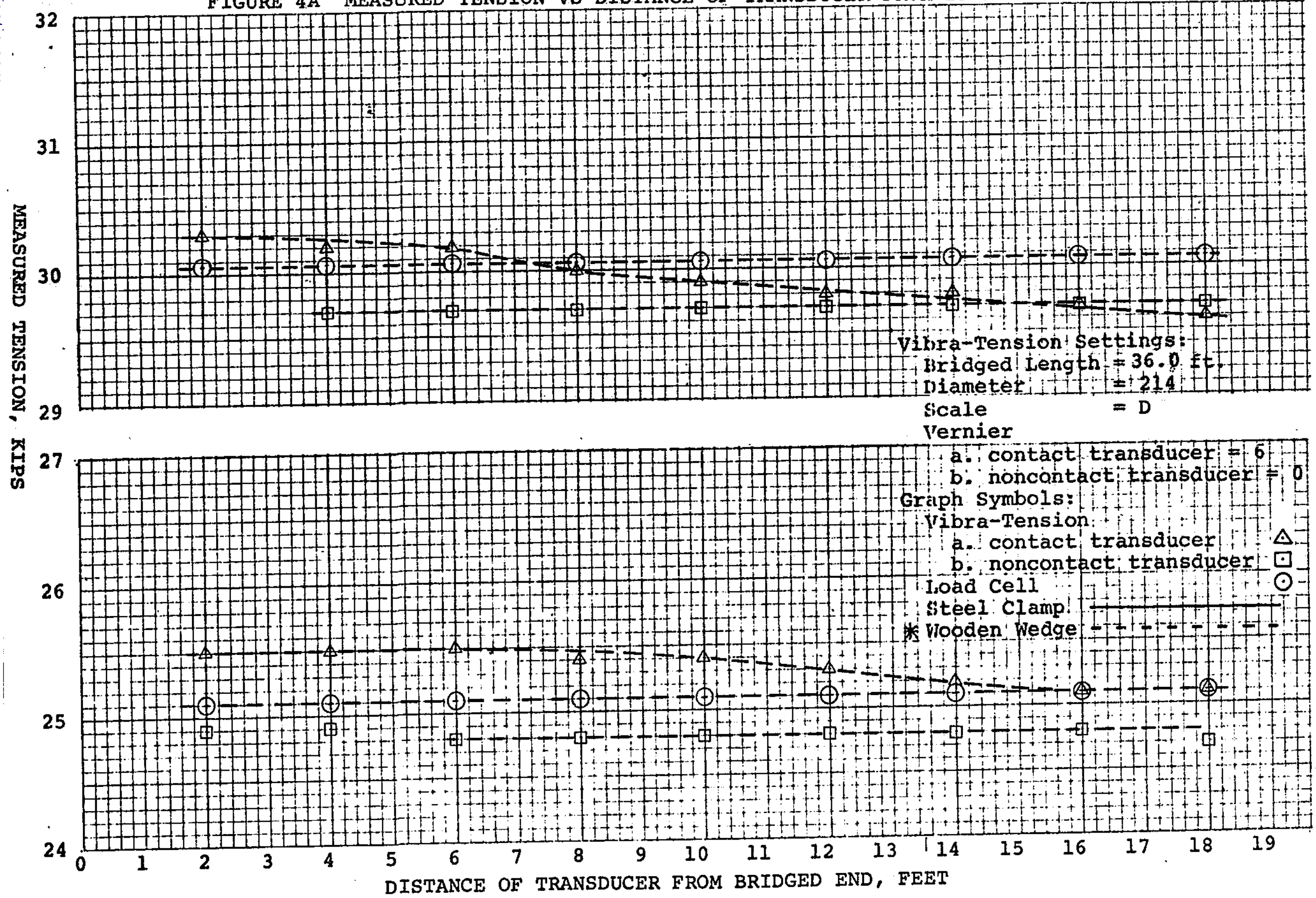


FIGURE 5A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

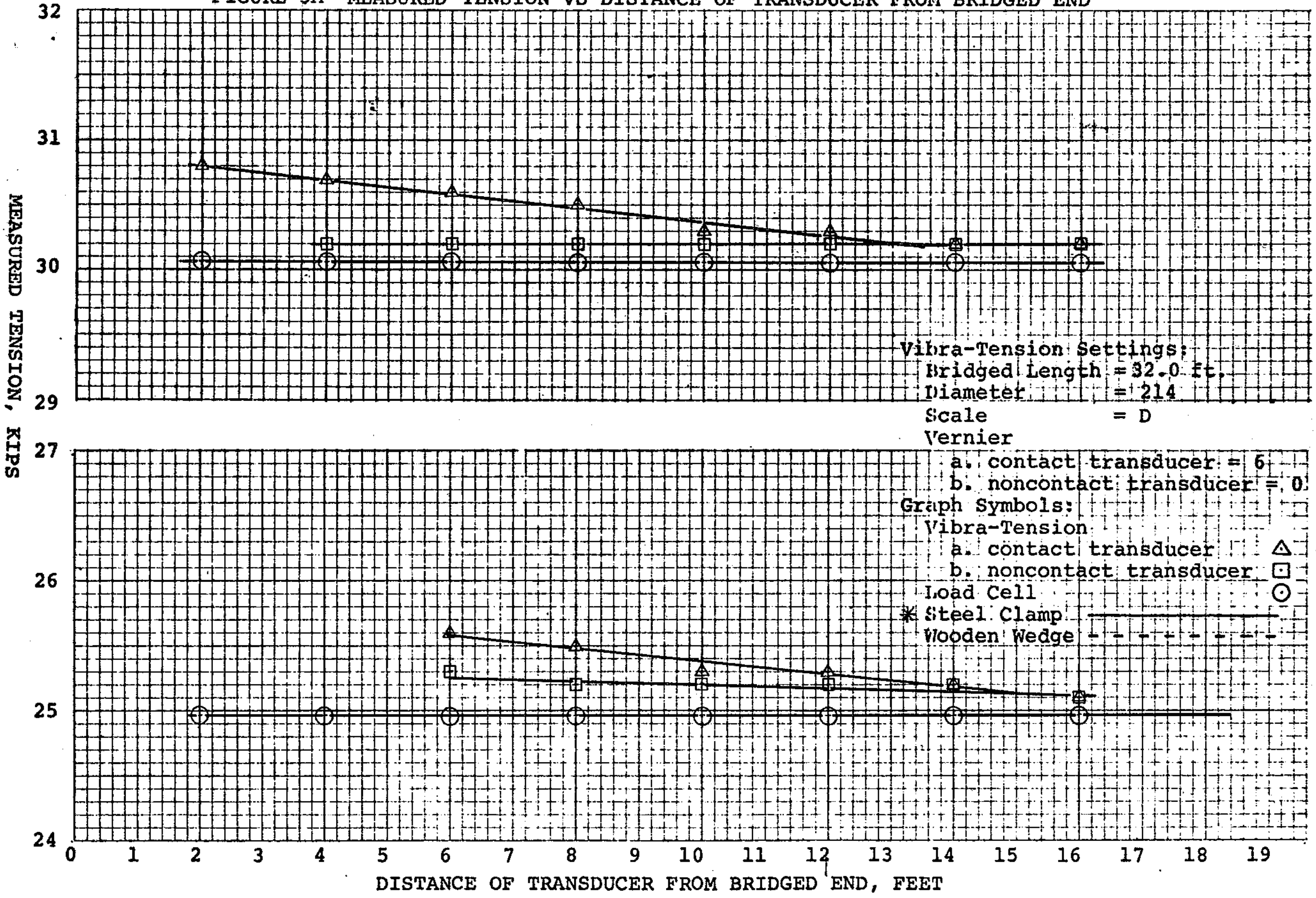


FIGURE 6A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

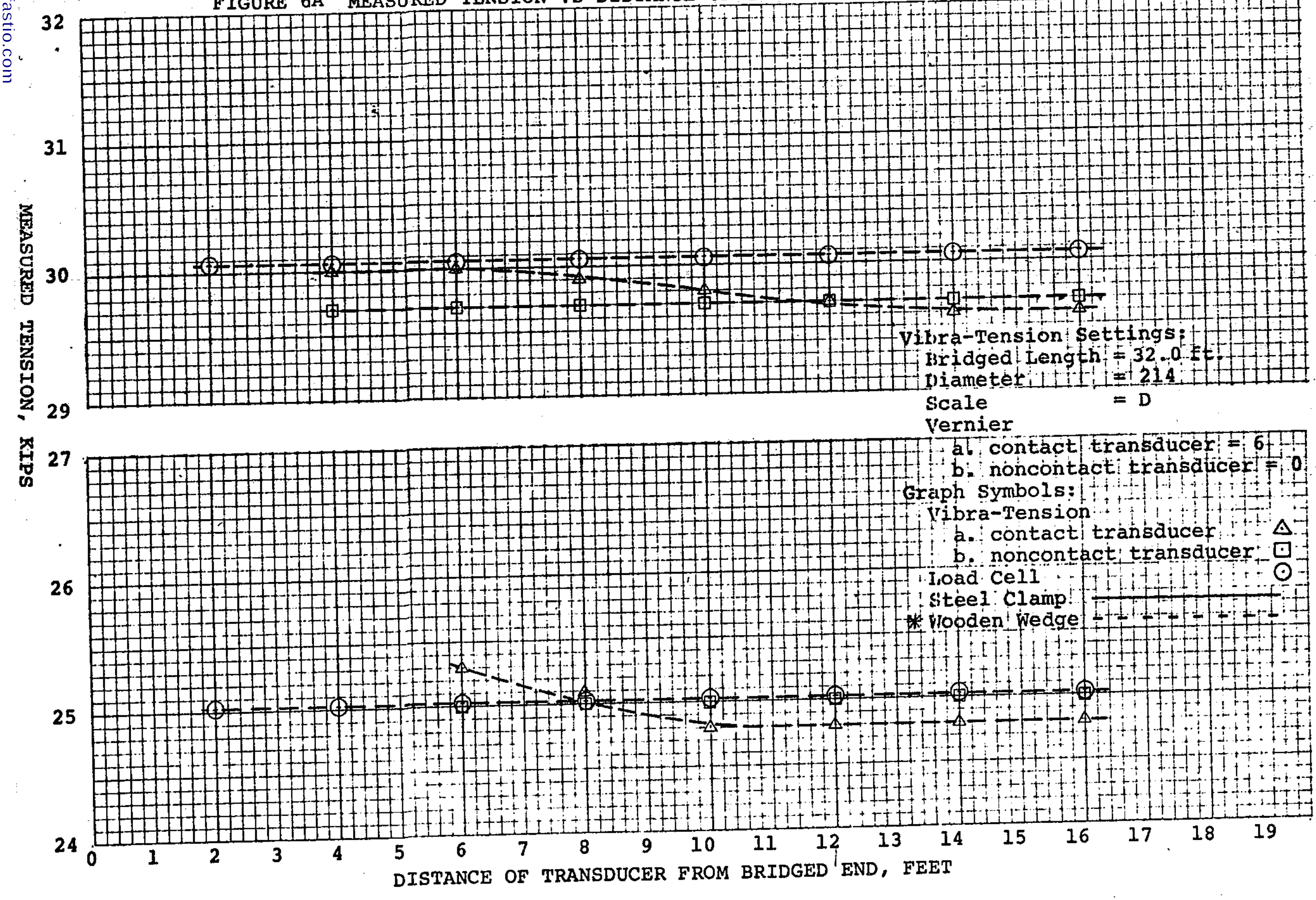


FIGURE 7A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

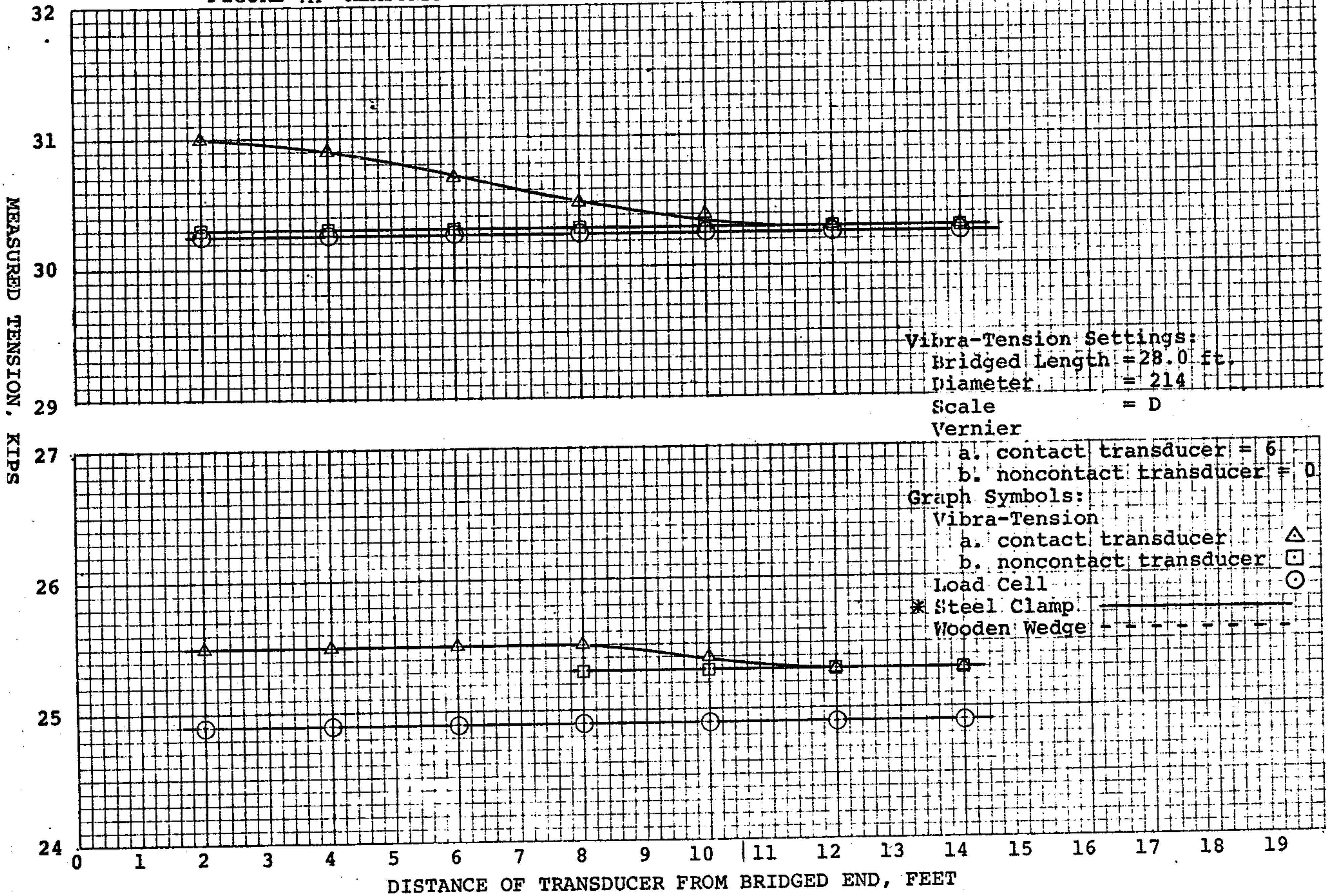


FIGURE 8A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

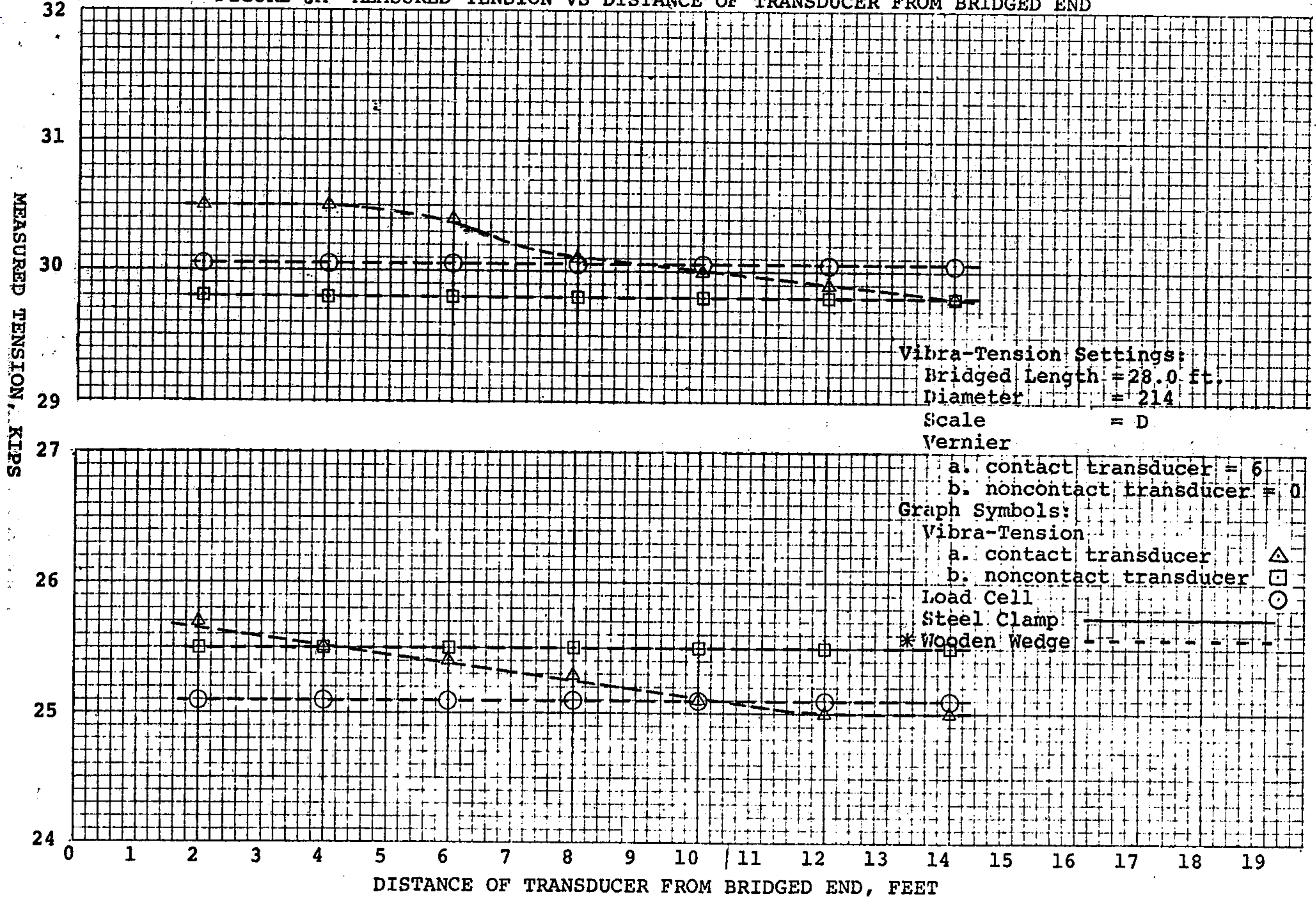


FIGURE 9A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

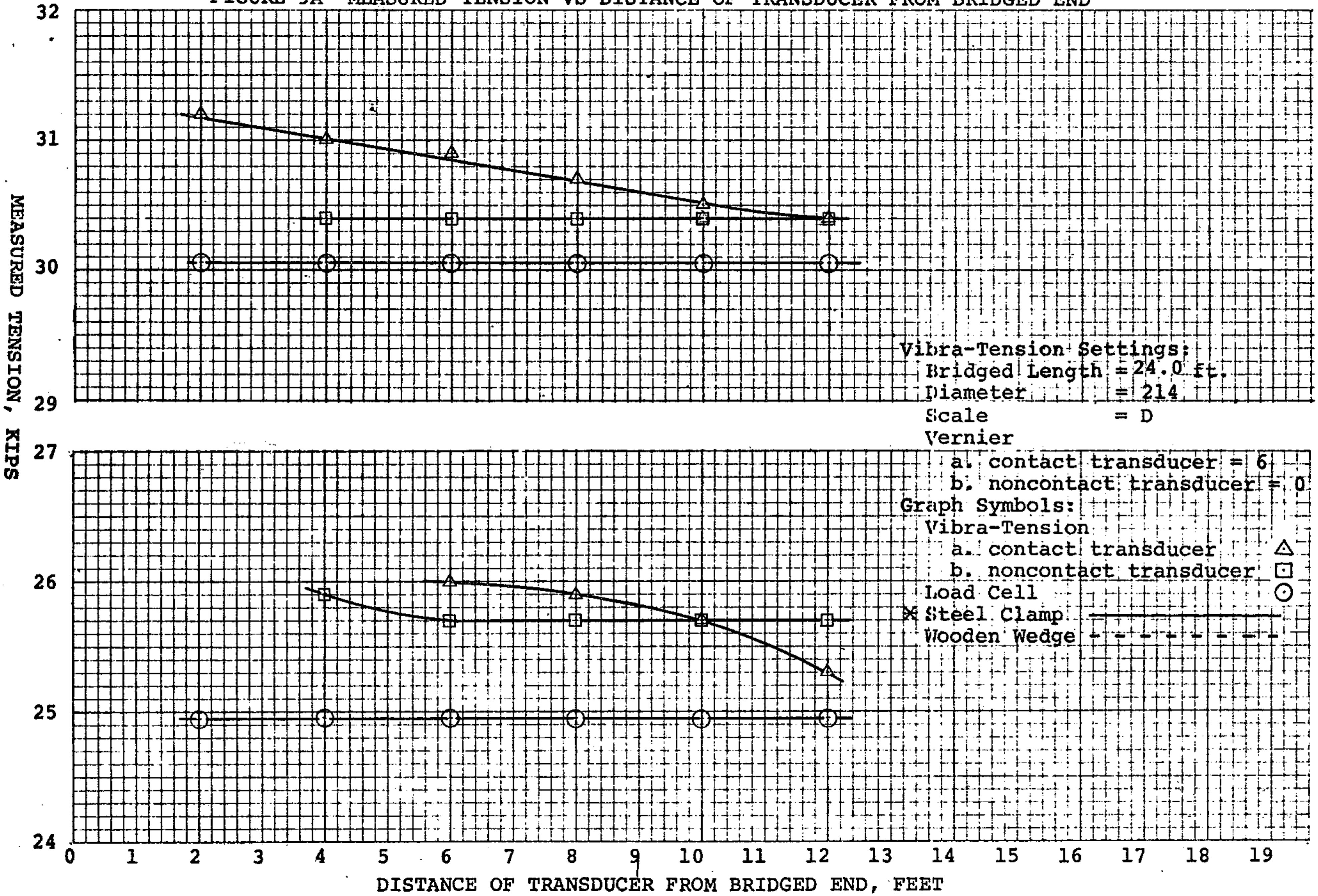


FIGURE 10A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

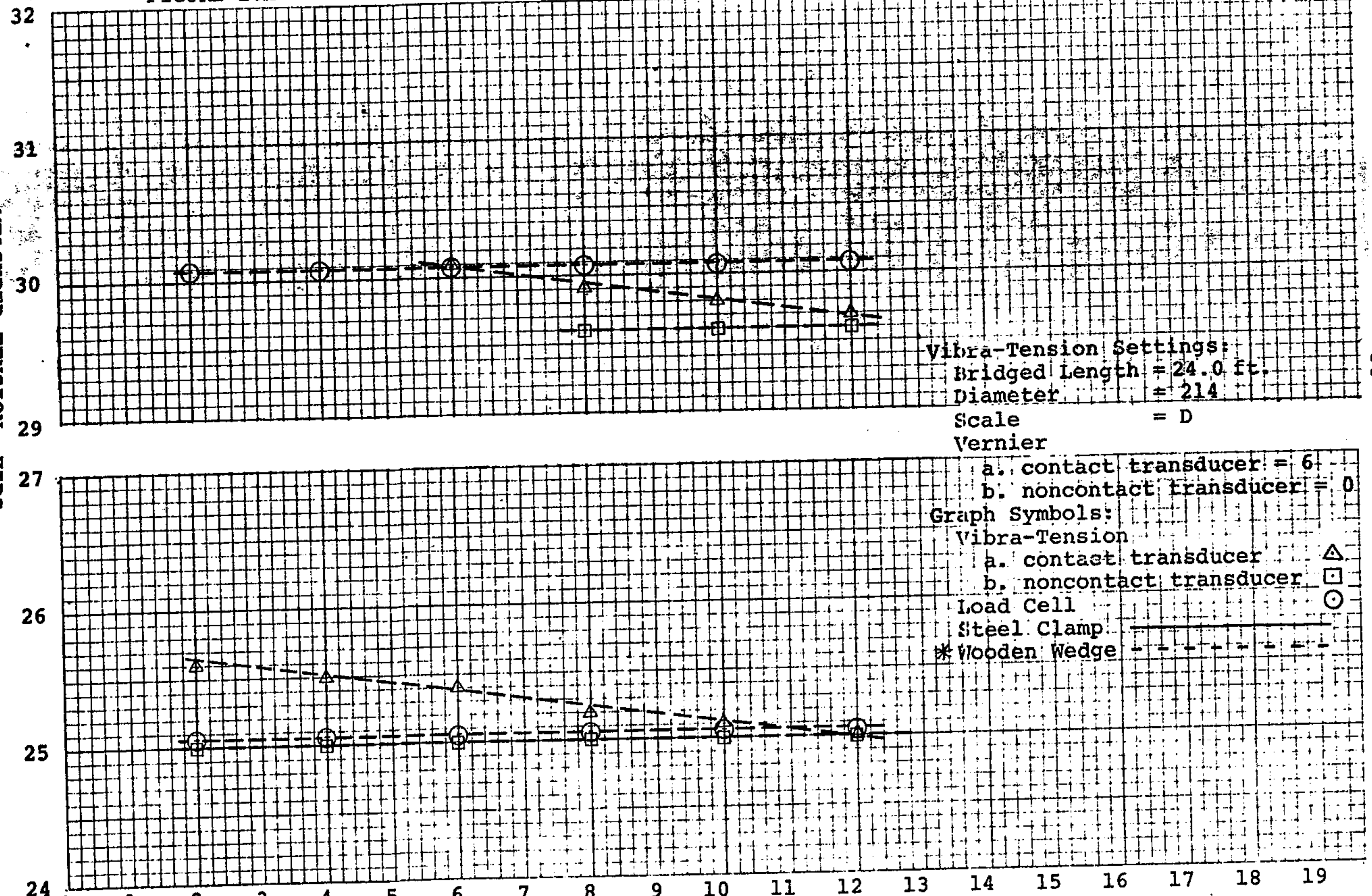


FIGURE 11A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

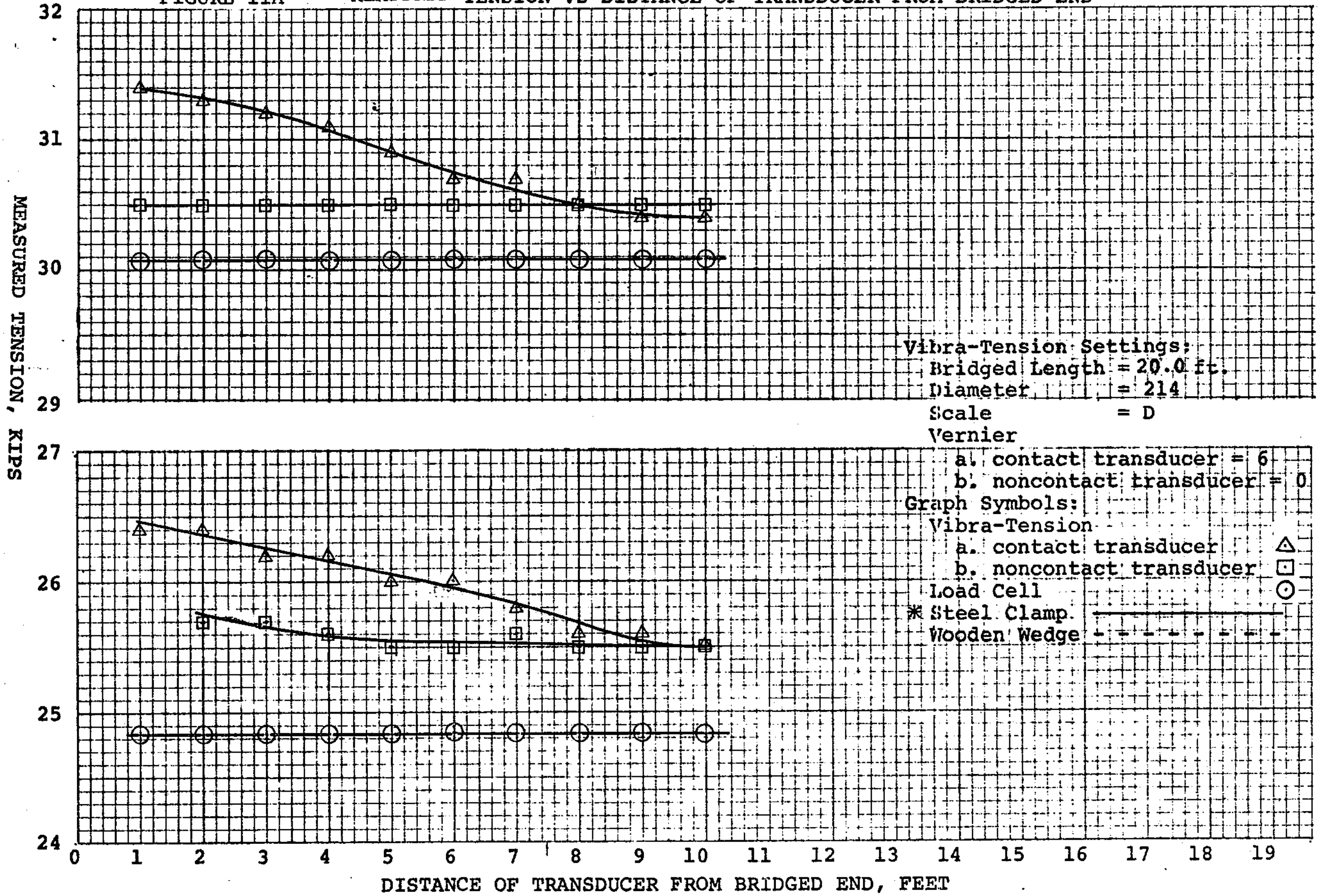


FIGURE 12A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

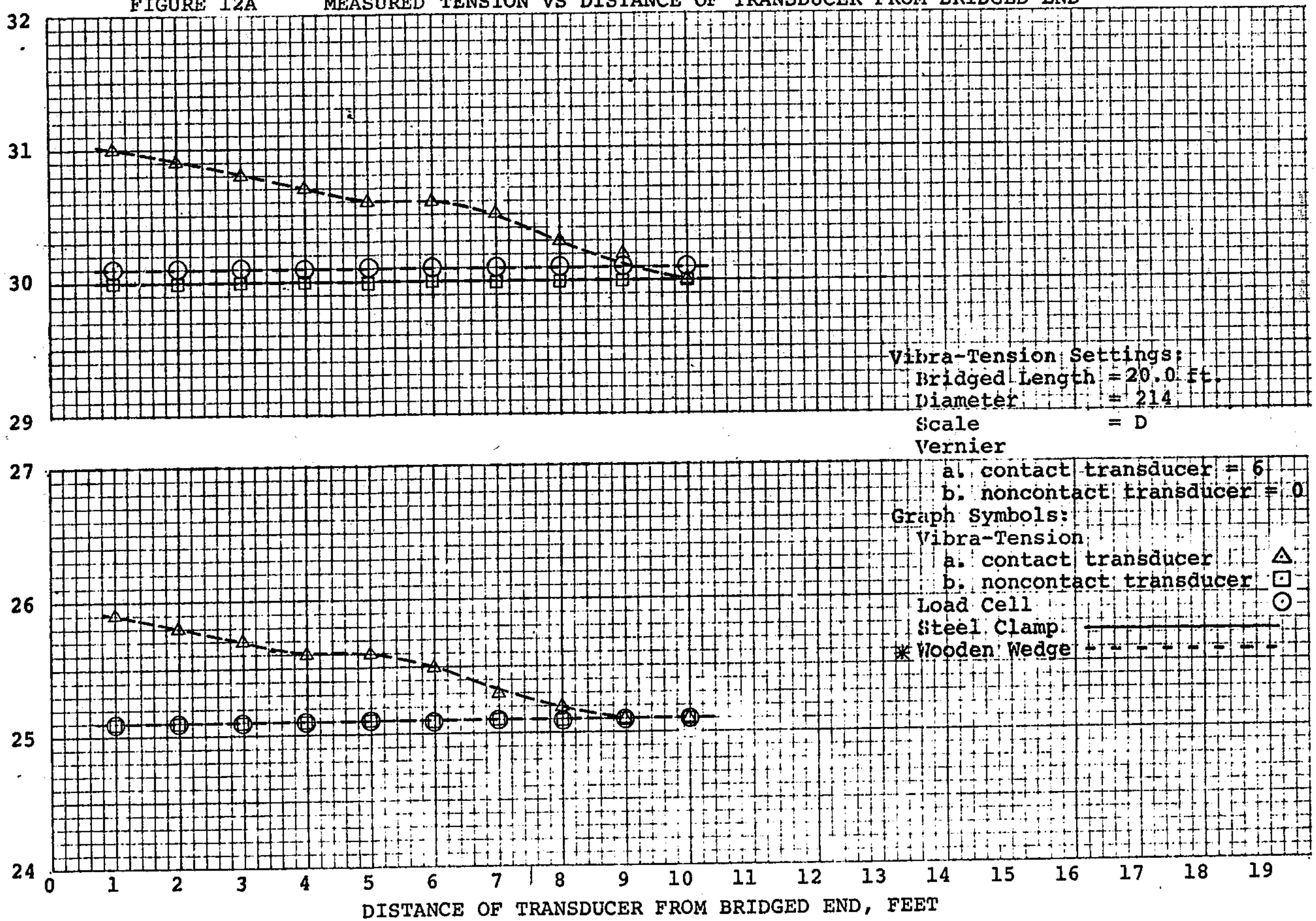


FIGURE 13A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

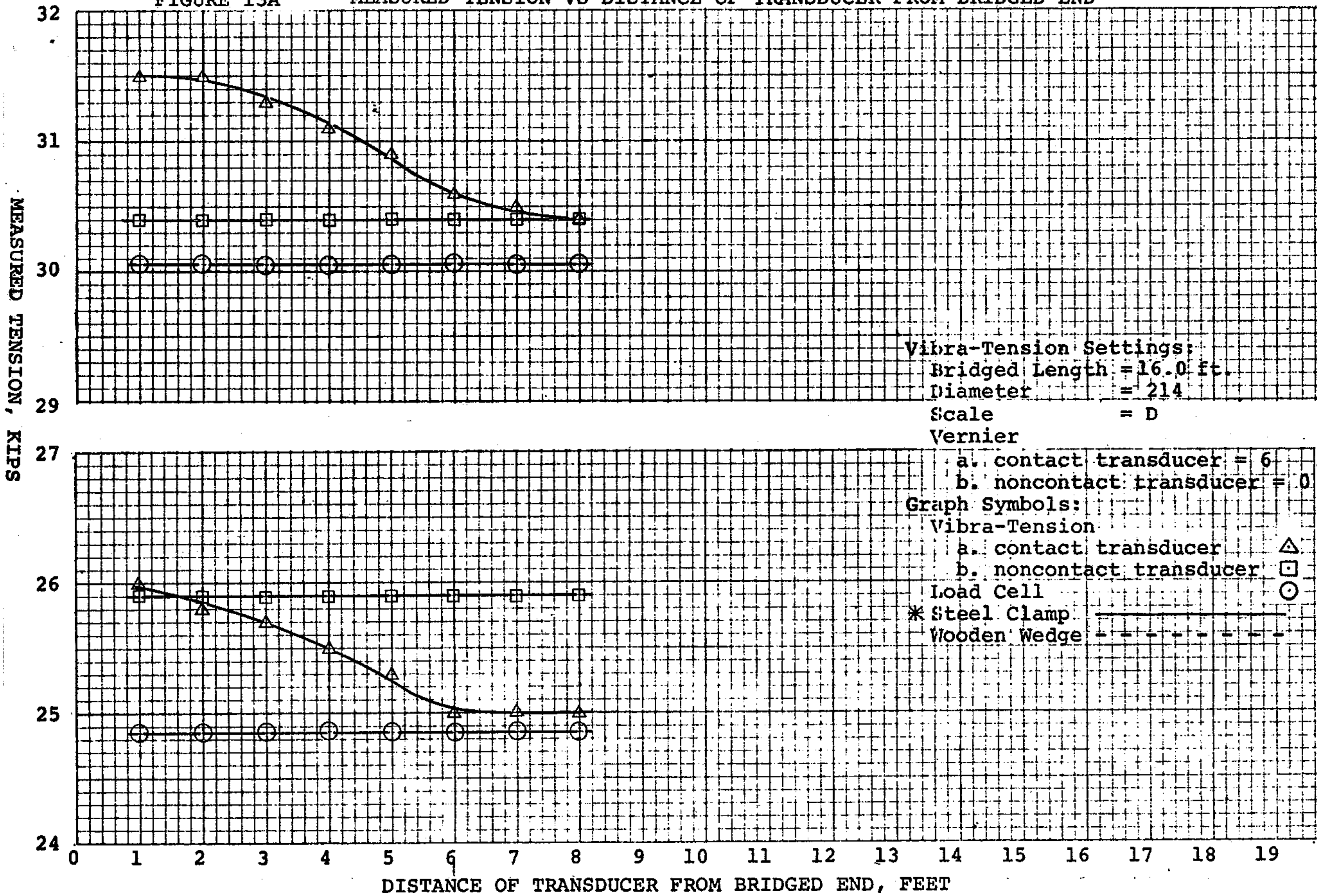


FIGURE 14A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

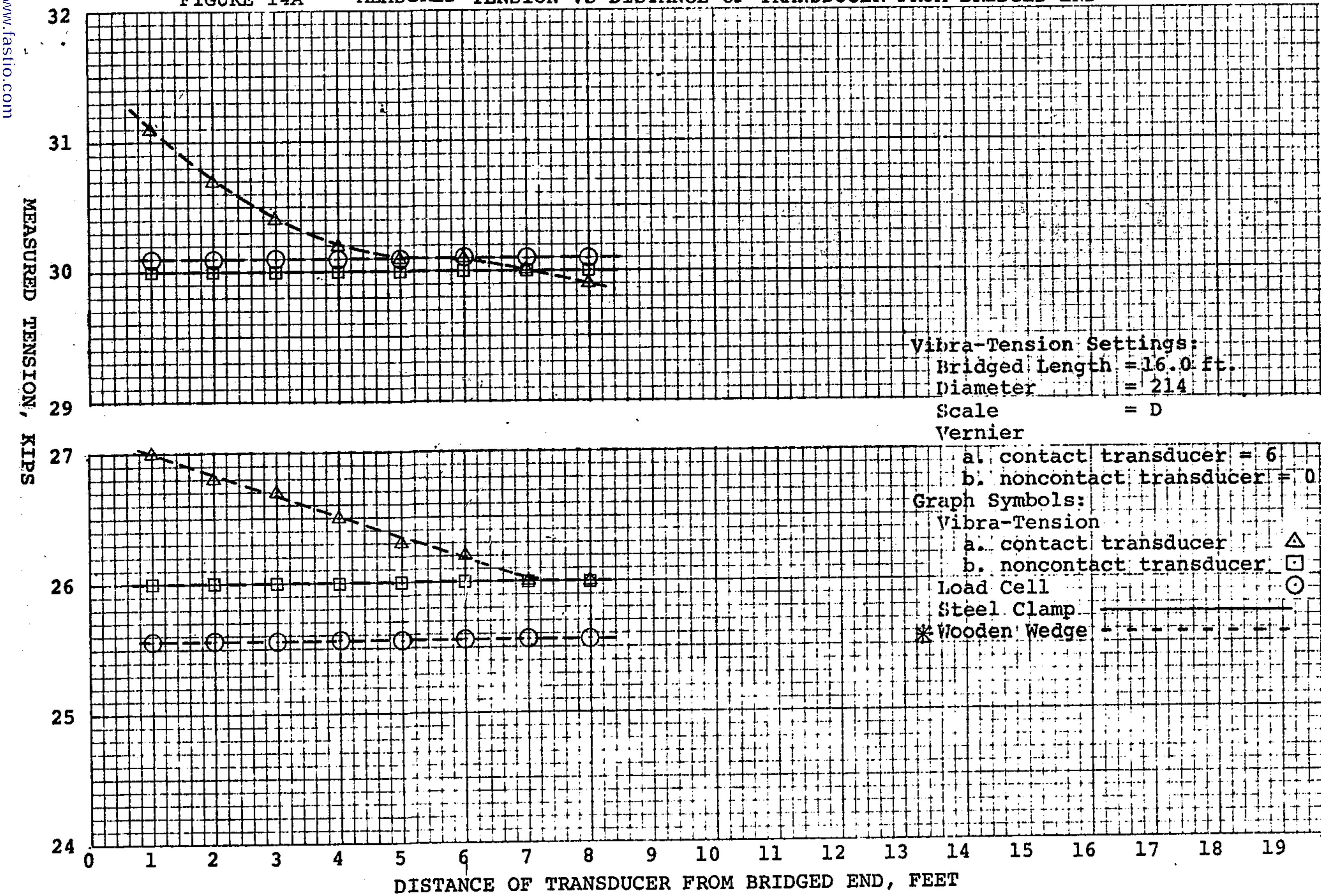


FIGURE 15A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

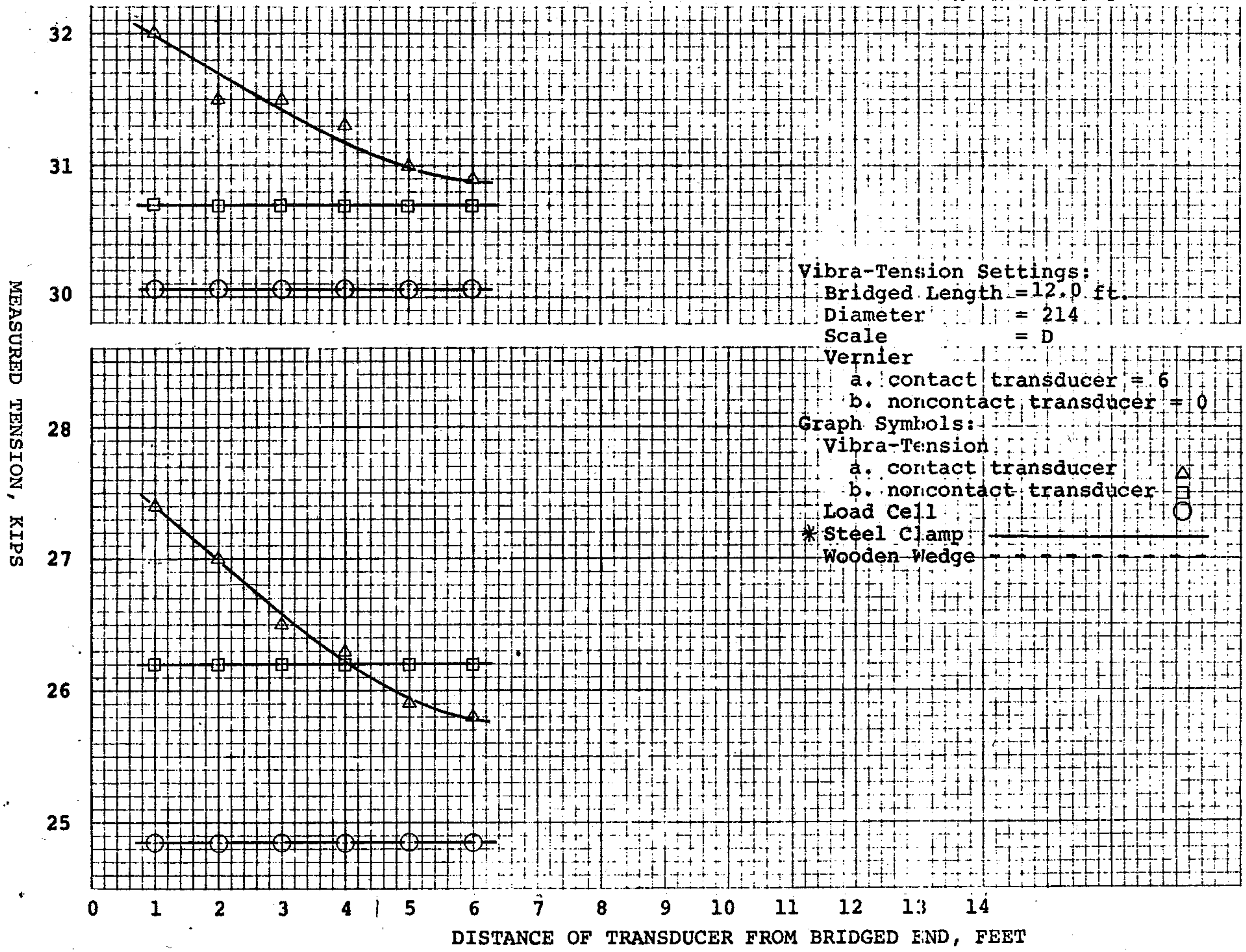


FIGURE 16A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

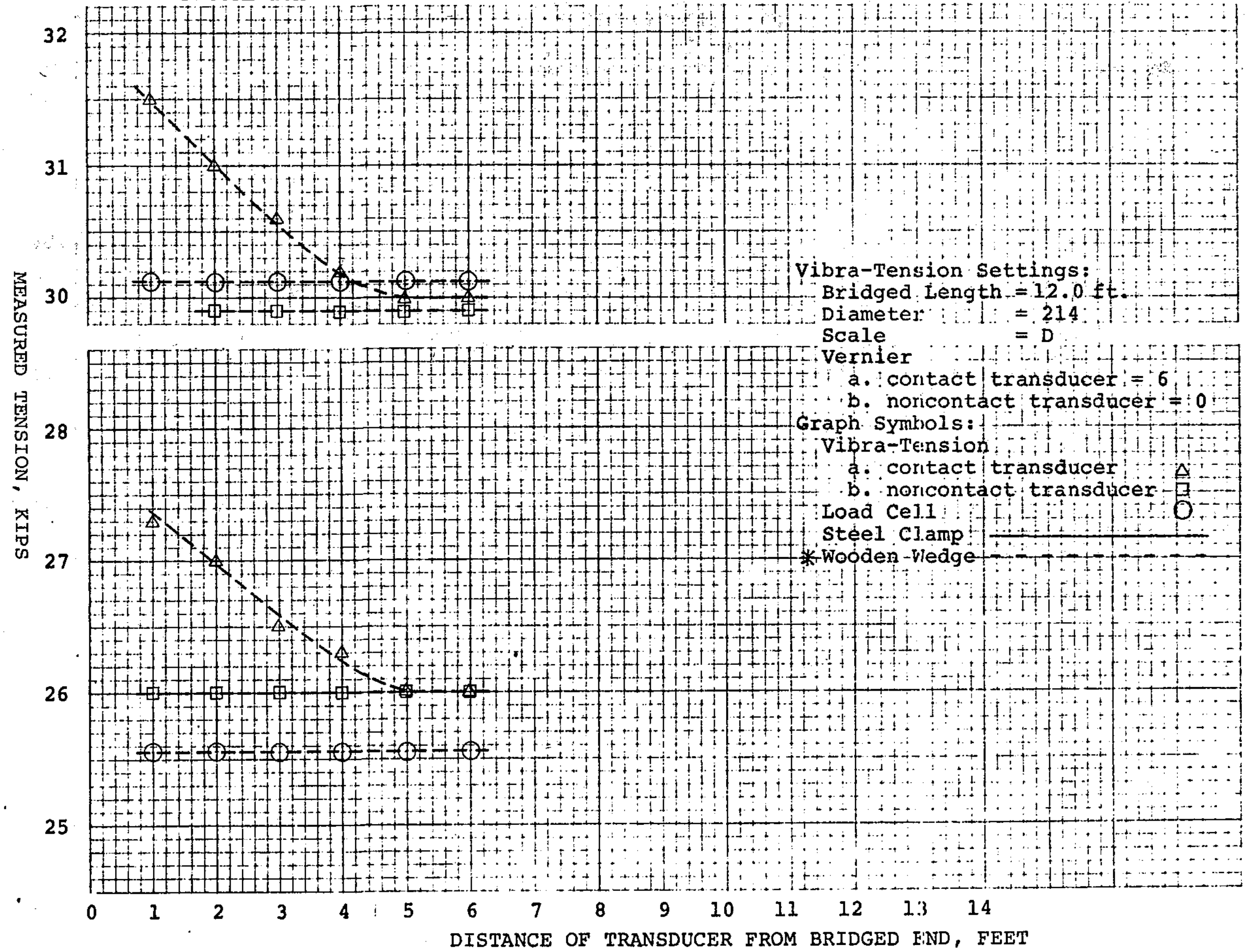


FIGURE 17A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

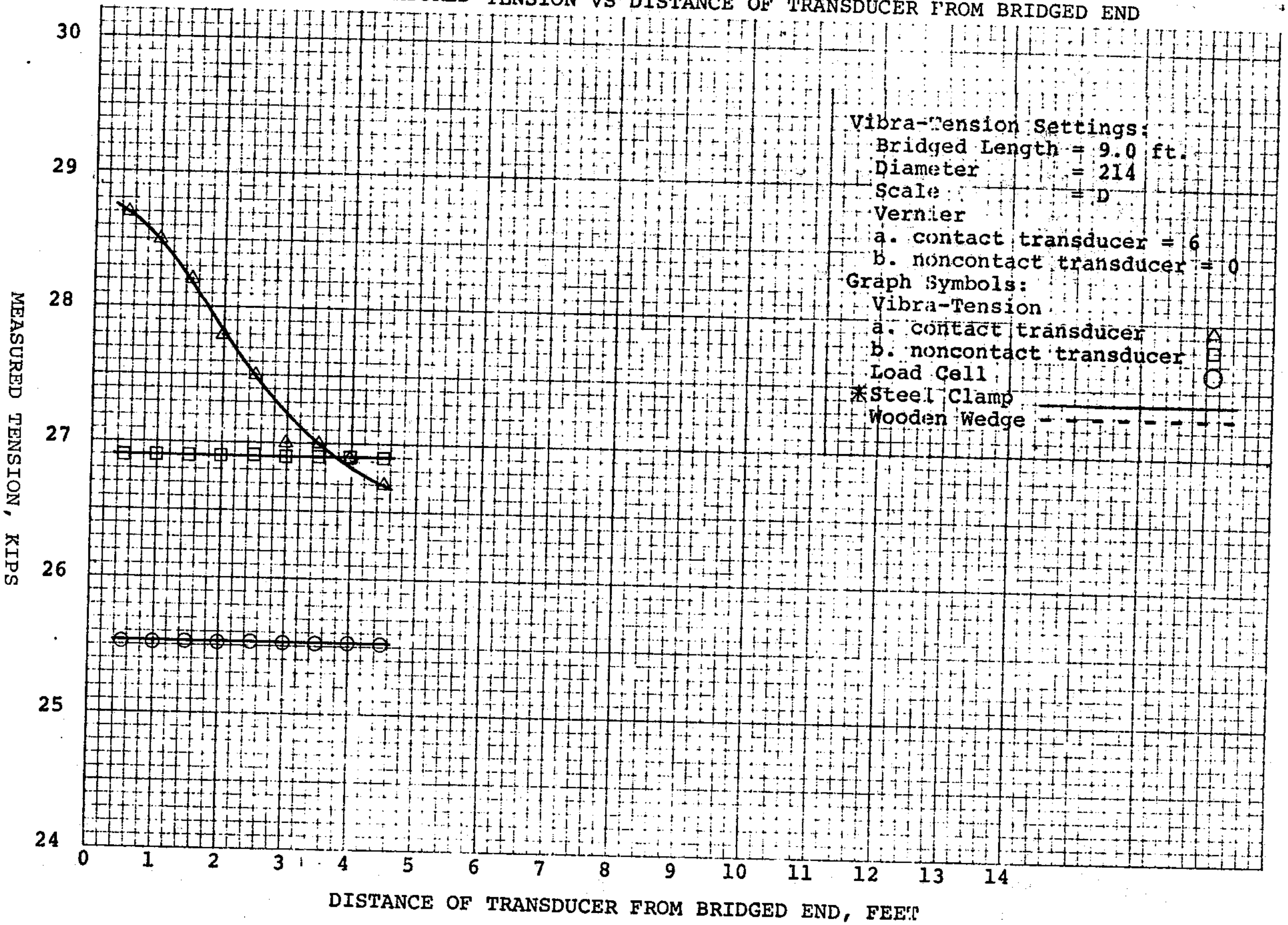


FIGURE 18A MEASURED TENSION VS DISTANCE OF TRANSDUCER FROM BRIDGED END

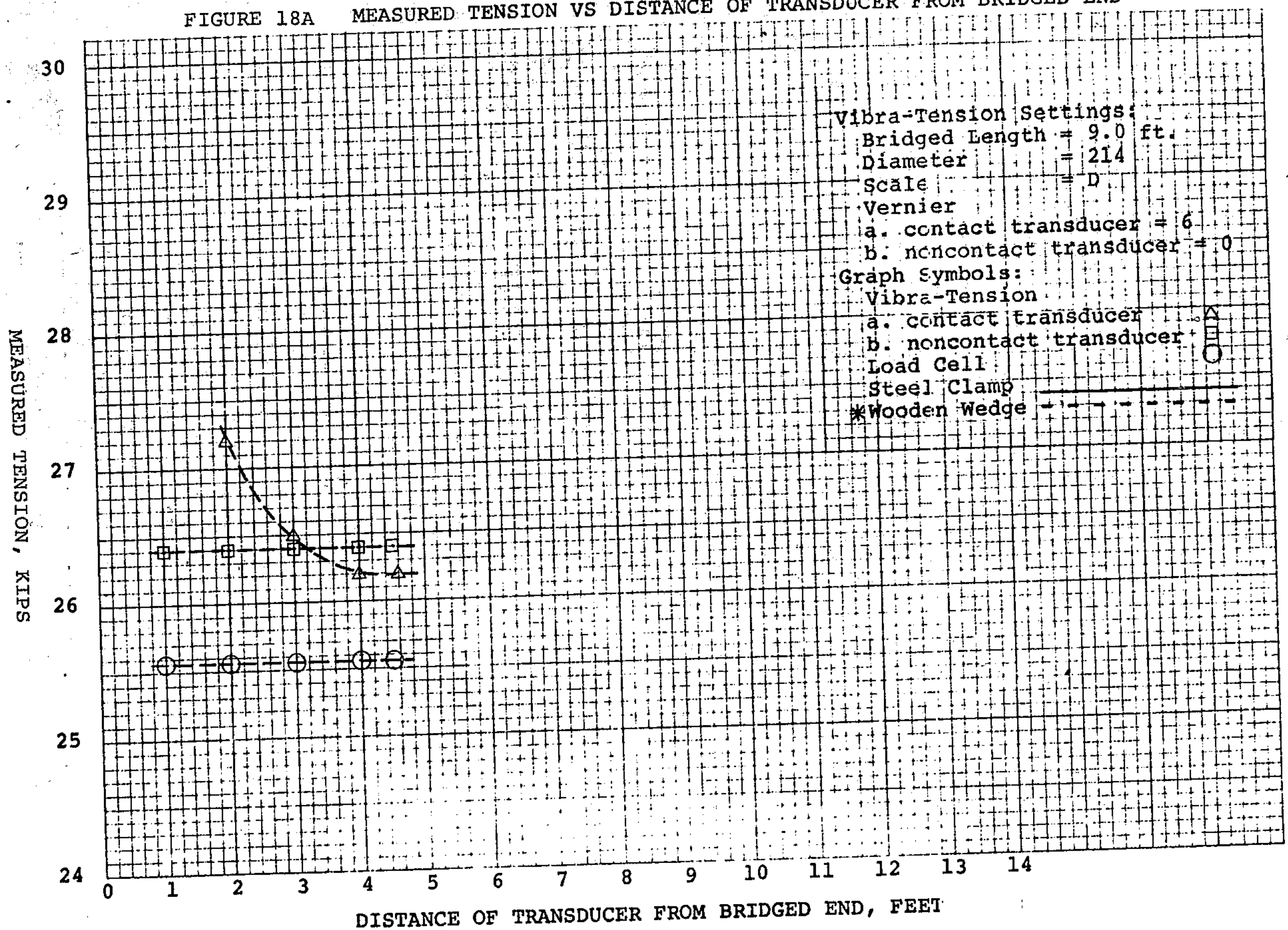


FIGURE 19A ACCURACY VS BRIDGE LENGTH

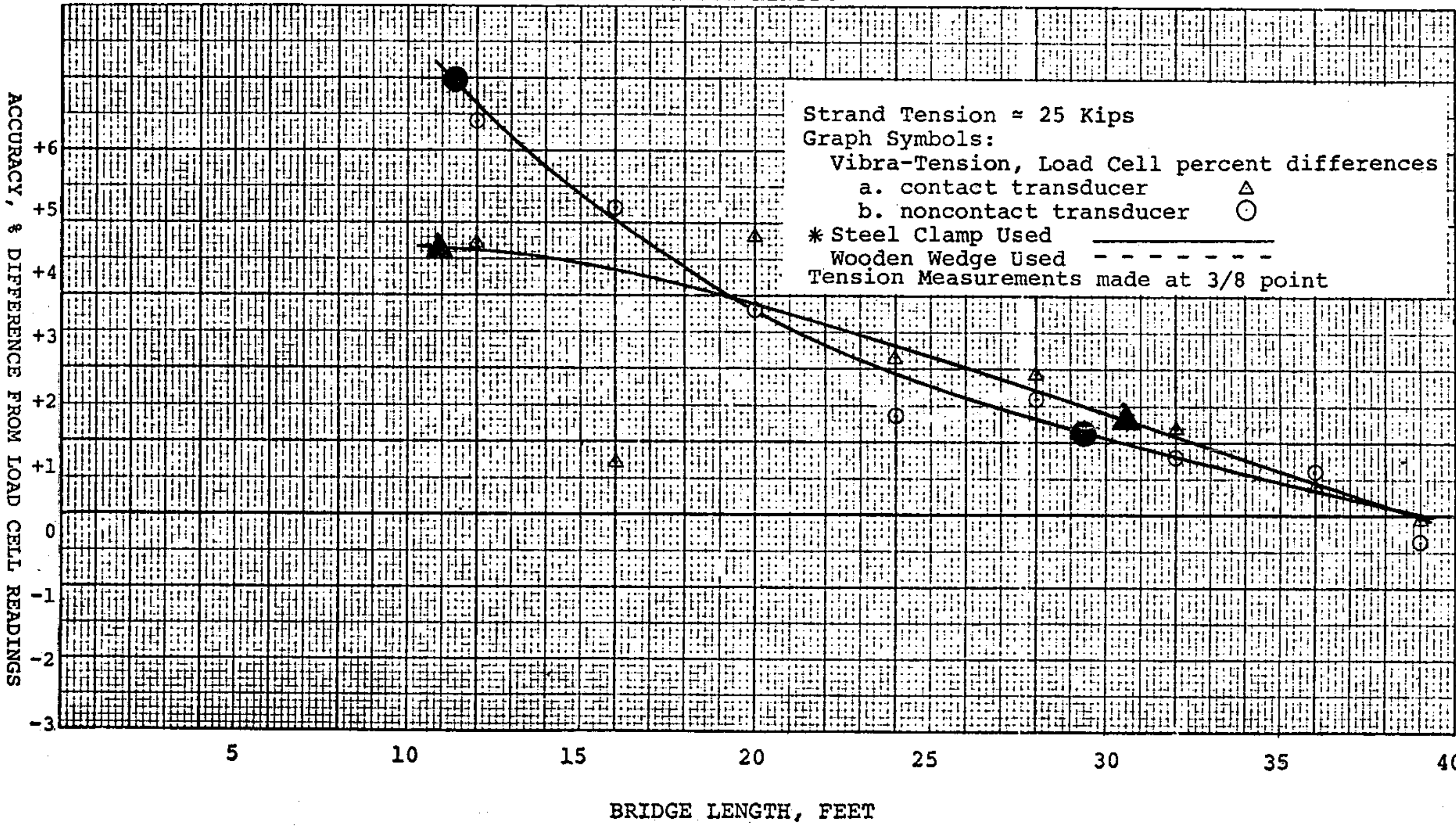


FIGURE 20A ACCURACY VS BRIDGE LENGTH

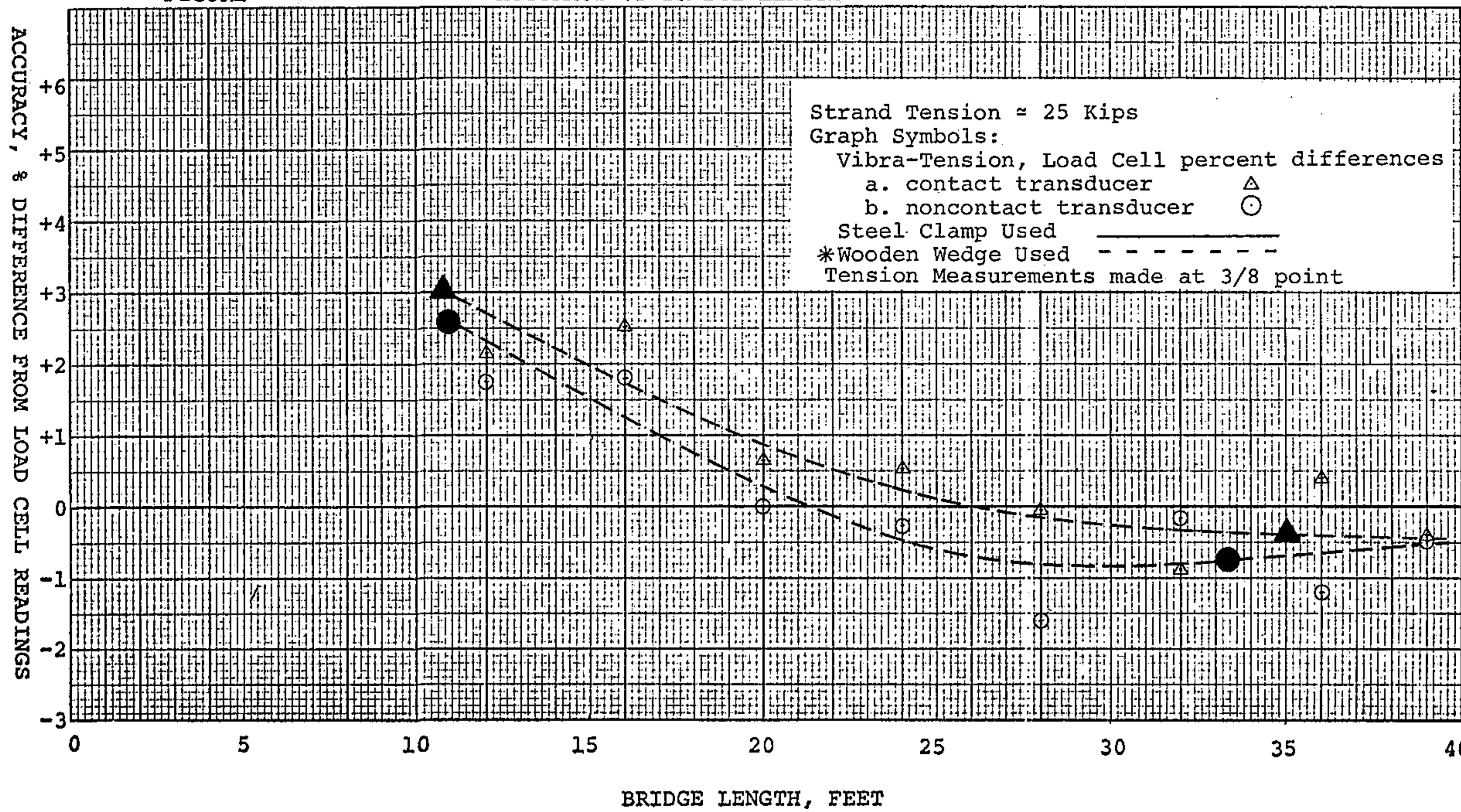


FIGURE 21A

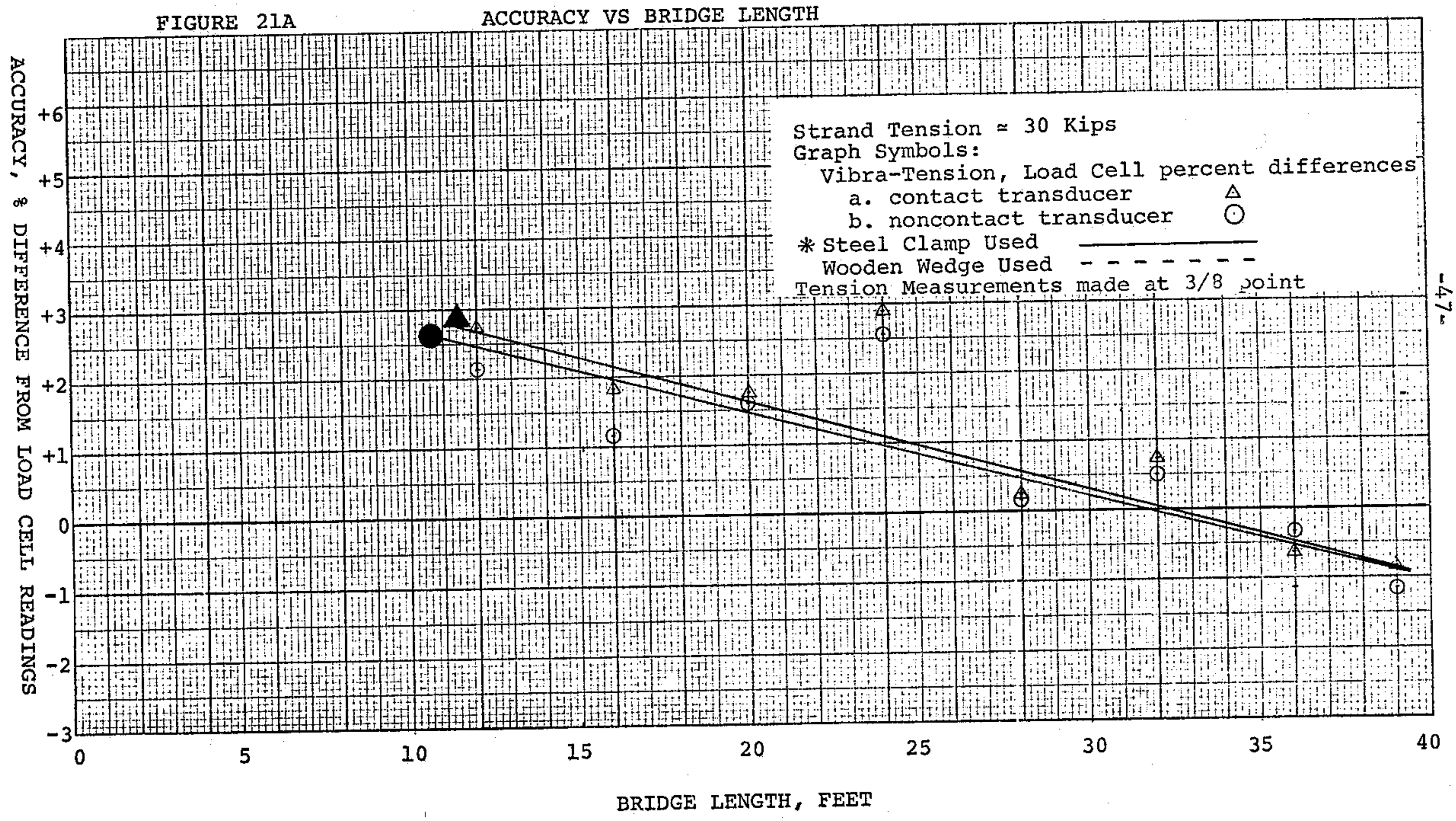

ACCURACY VS BRIDGE LENGTH
Strand Tension ≈ 30 Kips
Graph Symbols:
Vibra-Tension, Load Cell percent differences
a. contact transducer △
b. noncontact transducer ⊙
* Steel Clamp Used
Wooden Wedge Used
Tension Measurements made at 3/8 point
ACCURACY, % DIFFERENCE FROM LOAD CELL READINGS
+6
+5
+4
+3
+2
+1
0
-1
-2
-3
0
5
10
15
20
25
30
35
40
BRIDGE LENGTH, FEET

FIGURE 22A ACCURACY VS BRIDGE LENGTH

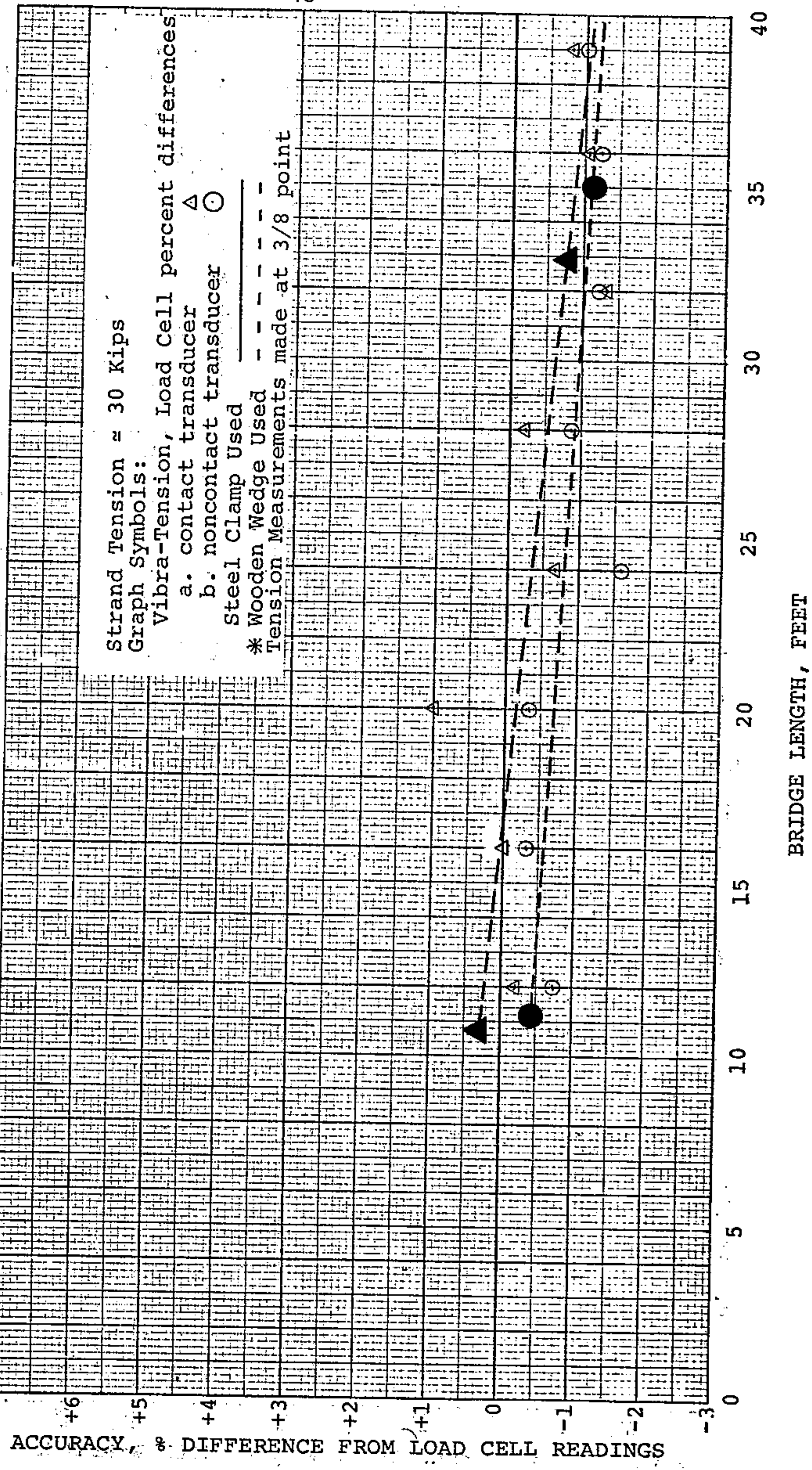


FIGURE 23A ACCURACY VS BRIDGE LENGTH

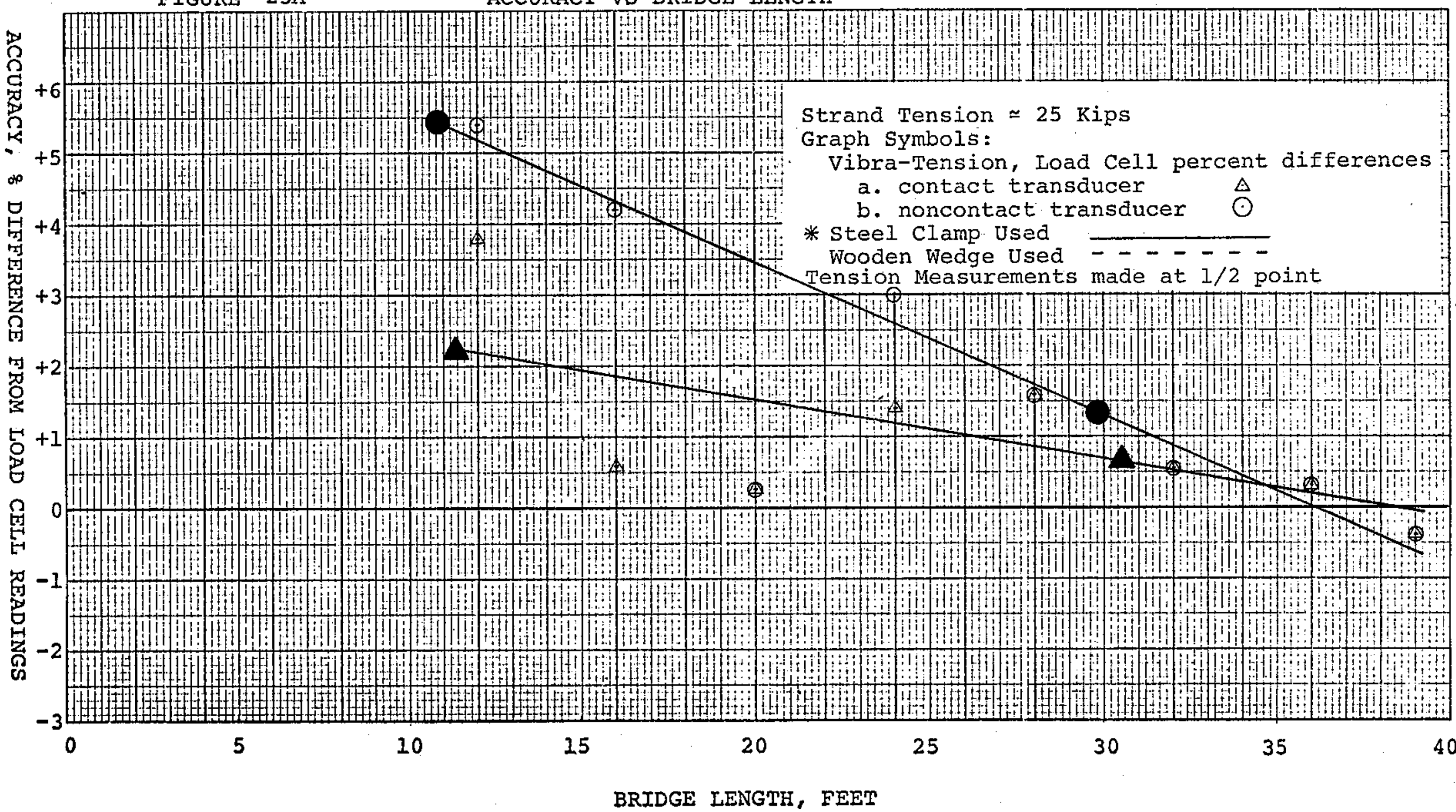


FIGURE 24A ACCURACY VS BRIDGE LENGTH

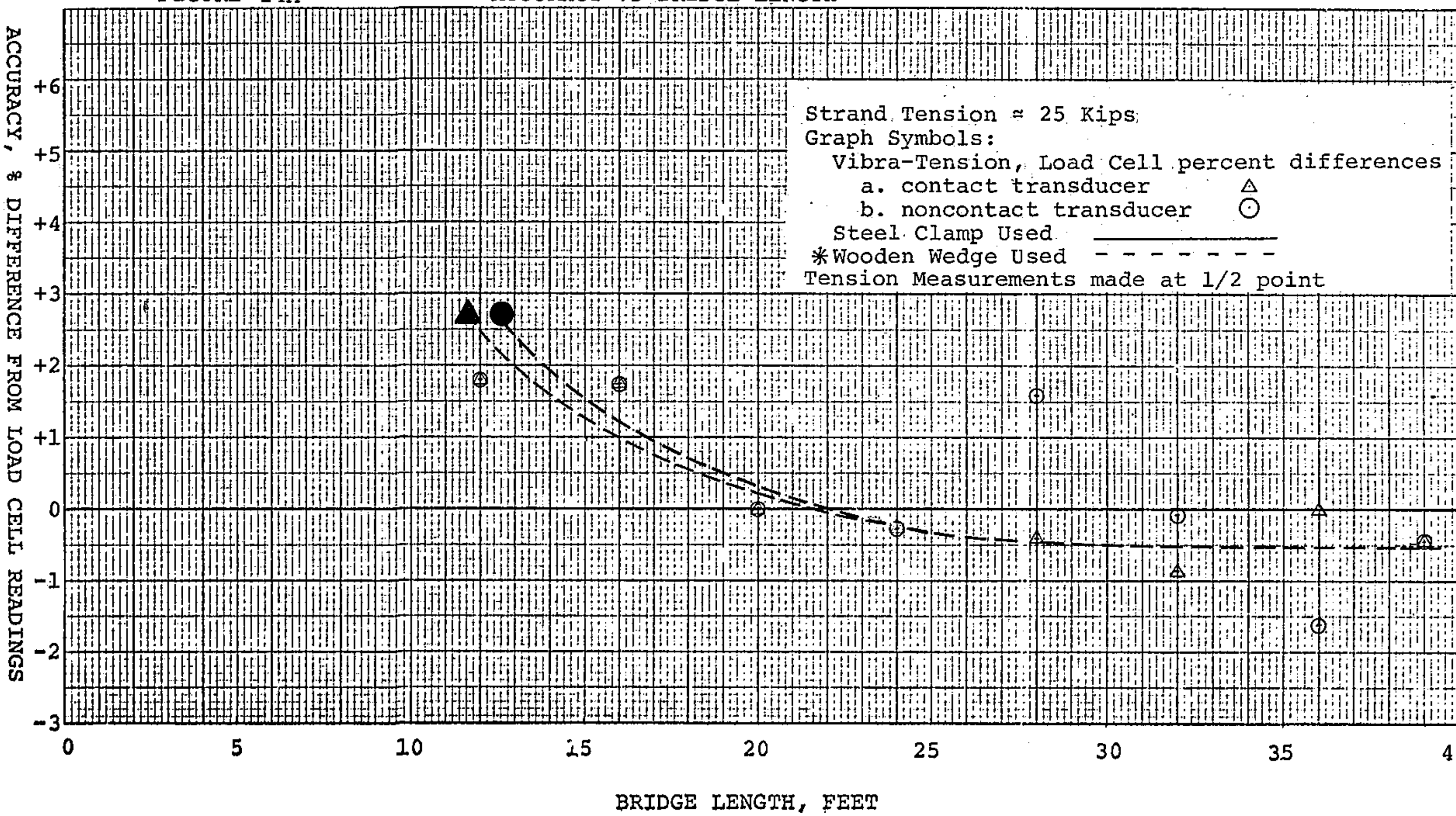


FIGURE 25A ACCURACY VS BRIDGE LENGTH

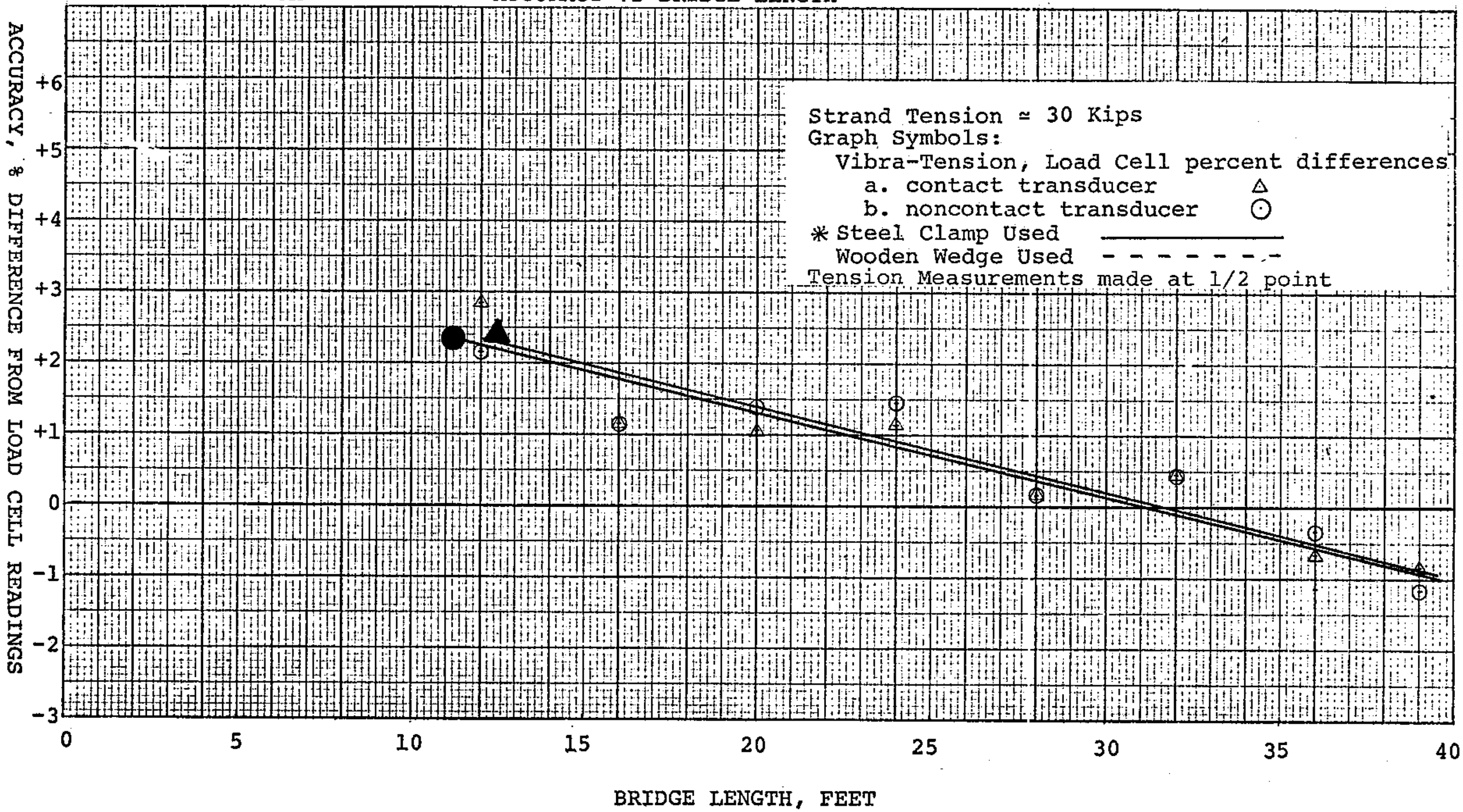
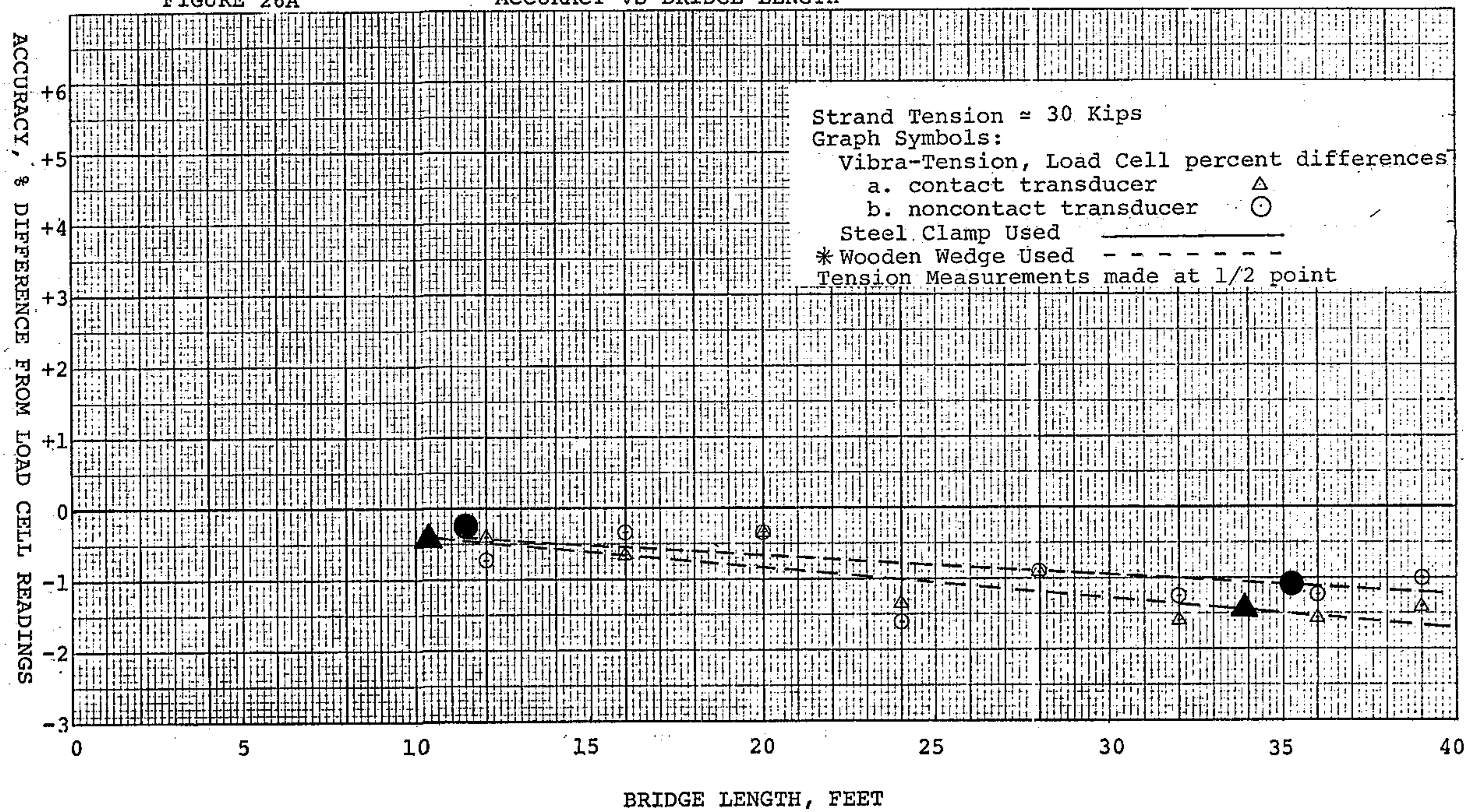


FIGURE 26A

ACCURACY VS BRIDGE LENGTH



APPENDIX B

PROPOSED REVISIONS TO THE STANDARD SPECIFICATIONS

SECTION 50 PRESTRESSING CONCRETE

50-1.08 (Below paragraph to be inserted between paragraphs 8 and 9 of existing specifications).

Vibra-Tension equipment may be used by State forces to check conformance of prestress forces to contract requirements. Such testing shall be performed in accordance with Test Method No. Calif. 677-A. If this testing determines the prestress forces to be less than those specified, the Contractor shall take steps necessary to achieve the specified prestress forces.

APPENDIX C

PROPOSED TEST METHOD NO. CALIF. 677-A

MATERIALS AND RESEARCH DEPARTMENT

State of California
Department of Transportation
Division of Highways

Test Method No. Calif. 677-A
October 1, 1973
(10 pages)

METHOD OF DETERMINING THE TENSION IN PRESTRESSING STRAND WITH THE VIBRA-TENSION, MODEL ET-U

Scope

The use of the Vibra-Tension, Model ET-U for determining the tension in prestressed, pretensioned straight or harped strands of prestressed concrete members is described in this test method. Tension is measured as a function of the fundamental frequency of a vibrating strand.

Procedure

A. Apparatus.

1. Vibra-Tension, Model ET-U. This is an electronic instrument which converts the fundamental frequency of vibration of a stressed prestressing strand to tension. The Vibra-Tension uses a transducer to monitor the vibration of a prestressing strand. Two types of transducers, a contact and a non-contact, are available for use.

B. Test Procedure.

1. Check the batteries prior to using the Vibra-Tension. Turn the Vibra-Tension off and press the battery test buttons, one at a time. A charged battery is indicated by the tension meter pointing past the right edge of the tension scale. If the meter reads on or to the left of the 5 on the top scale, then the batteries need recharging. Recharging is accomplished in the following manner:

   a. Press the Off button.

   b. Plug the charger cord into any 110 volt 60 cycle AC outlet. The red light indicates that the batteries are being charged.

   c. Continue charging until both battery tests indicate to the right of the 5 on the top scale. Normal charging time is 6 hours.

Charging the instrument overnight is advised when it is to be used the next day. Electrical protective circuits in the Vibra-Tension prevent overcharging. With a full charge the instrument has power for 4 to 6 hours of continuous use. If the batteries do not respond to charging, the instrument should be returned for servicing to the Structural Materials Section of the Materials and Research Department in Sacramento.

2. Calibration. Check calibration of the Vibra-Tension whenever it has been transported by common carrier, over rough terrain, or otherwise roughly handled, and also after recharging. The calibration check procedure is an exact point of reference and can be performed whenever necessary. The procedure is as follows:

   a. Check batteries; if properly charged proceed. If not, charge batteries before proceeding.

   b. Set strand Diameter setting to 305.

   c. Set bridge Length dial to 5.0 feet.

   d. Set Vernier to 0.

   e. Set Scale selector to C.

   f. Connect non-contact transducer to Input jack.

   g. Connect charge cord to any 60 cycle 115 volt AC outlet.

   h. Turn Vibra-Tension on and allow 2 minutes for warm-up.

   i. Place non-contact transducer in instrument storage compartment so that it picks up a 60 cycle signal from the battery charger.

   j. Read tension on scale C of the Tension meter. It should read 4,750. If reading is off, adjust to correct reading by means of adjustment screw on Tension meter frame. See Figure No. 1.

   k. Turn Vibra-Tension off.

1. To insure that the contact transducer is working properly, both the contact and the non-contact transducers may be used to measure the same tensioned strand. Accuracy within 2% of the true strand tension may be obtained by using either steel or wooden wedges as bridges if the bridge length is greater than 27 feet. But wooded wedges must be used for bridge lengths shorter than 27 feet to obtain an accuracy within 2%.

3. Bridging. Bridging is fixing two points, one at each end of a length of strand under investigation so that any movement or vibration of these points is prevented. The length of strand (bridge length) between the bridge points must be free to vibrate. Bridge points may be located at harping points, bulkheads or at any other convenient place and can be established by the use of steel or wooden wedges firmly placed. If a harping hold down device which provides for strand separation is used, steel or wooden wedges may be employed to further spread individual strands apart. To facilitate bundled strand separation at the harping point, a small section of reinforcing bar can be placed near the harping point between layers of strands prior to stressing and may be left in the girder. Wooden wedges should always be removed prior to placing concrete. Usable bridge lengths for 1/2 inch diameter 270 ksi prestressing strand are 12 to 39.9 feet inclusively. To insure that accuracy within 2% of the true strand tension is maintained, wooden wedges may be used for the entire usable bridge length range. However steel wedges or clamps must be restricted for use for bridge lengths longer than 27 feet to maintain a 2% accuracy. Normally, the use of a long bridge length, between 27 to 39.9 feet, results in the best accuracy.

4. Tension Measurement. The measurement procedure is as follows:

   a. Determine manufacturer, grade and size of strand. Determine strand diameter setting and scale setting from Table 1 or, if unable to determine proper setting, contact the Structural Materials Section of the Materials and Research Department in Sacramento for advice. Set the strand Diameter dial and Scale selector to the proper settings. The Scale selector is not connected to the electrical circuitry of the Vibra-Tension, and should be used by the operator only as a reminder of which scale he should read. A picture of the Vibra-Tension is shown in Figure 1.

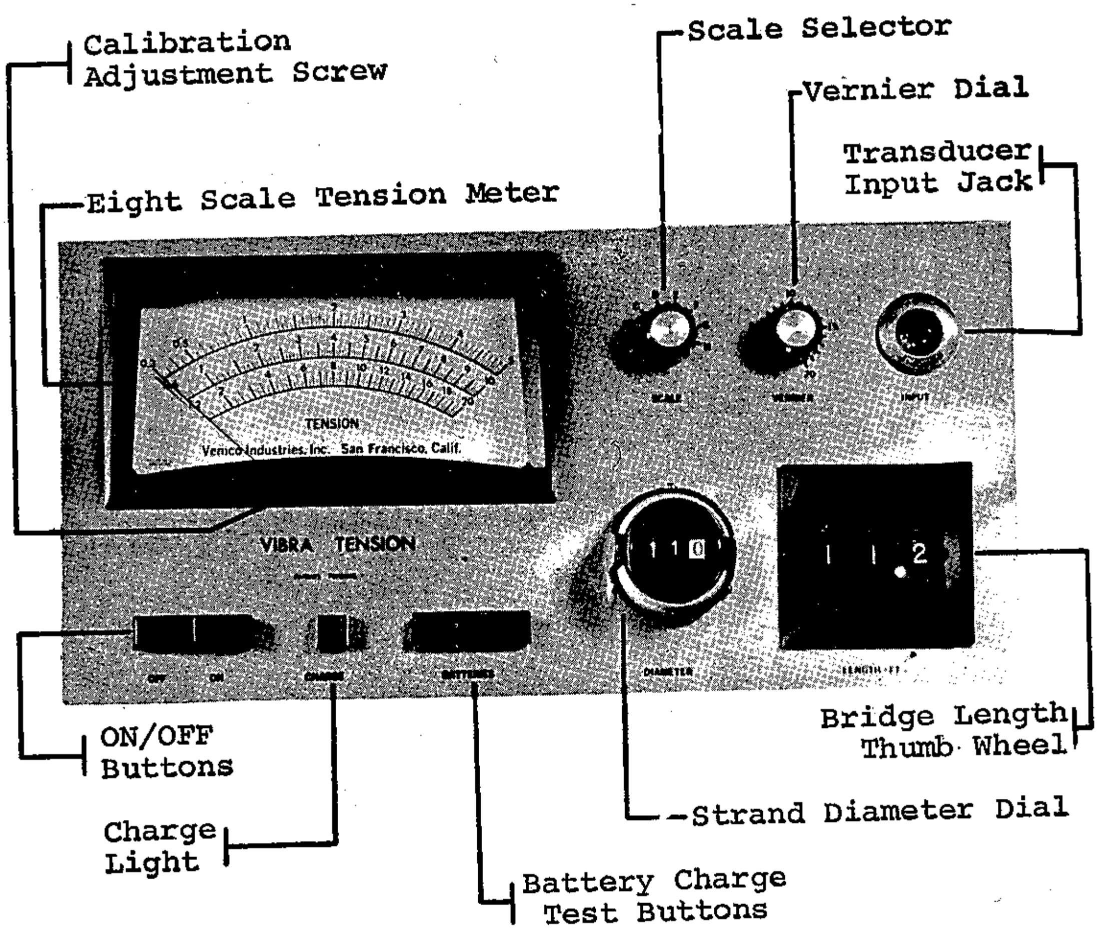


Figure 1

Front Panel of Vibra-Tension, Model ET-U

b. Set Vernier dial to zero if using the non-contact transducer. If using the contact transducer, determine the Vernier setting from Table 1 and adjust the Vernier knob.

c. After the strand has been tensioned, measure the bridge length to the nearest 1/10 of a foot and set this length on the bridge Length dial. This measurement should be made between initial contacts points of the bridge points and the strand.

d. Turn instrument on and allow two minutes for warm-up.

e. Plug either transducer into the Input jack.

f. Locate transducer in the center 1/4 span, preferably at the center of the bridge length. If using the non-contact transducer, make sure the Vernier dial is set on "0", then position the transducer parallel to and approximately 1/4 inch to 2 inches away from the strand as shown in Figure 2. The non-contact transducer should be held steady during readings.

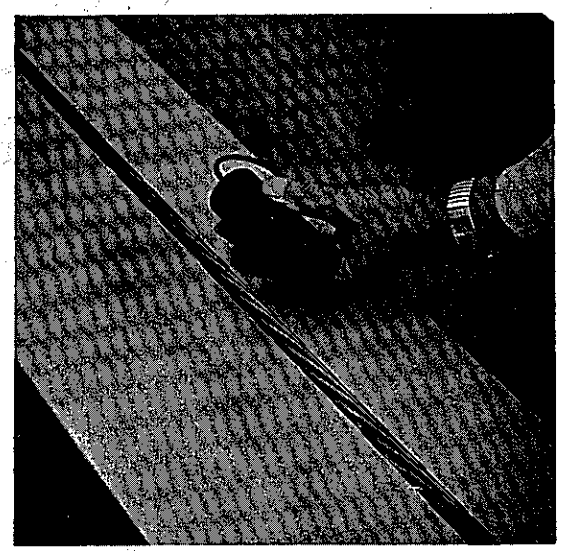


Figure 2

Position of Non-Contact Transducer

The contact transducer should be fastened to the strand in an upright position as shown in Figure 3, and should be placed as close to the center of the bridge length as possible.

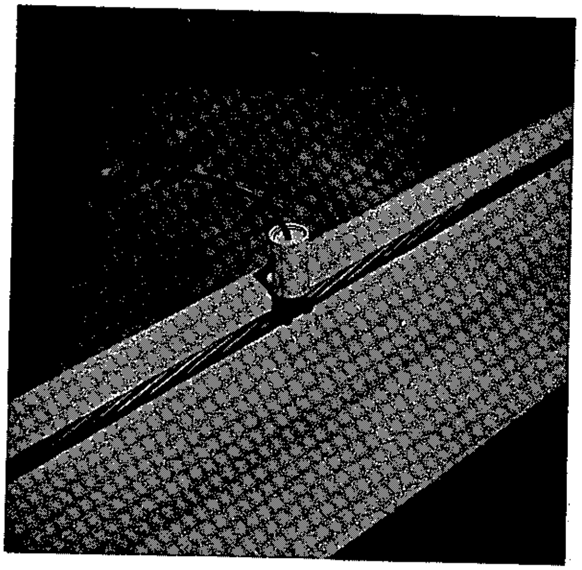


Figure 3

Position of Contact Transducer

g. Vibrate the strand by lightly tapping with the heel of the hand near the center of the bridge length.

h. The Vibra-Tension tension meter has three scales which are used as 8 overlapping scales. The top scale is used as A, D, and G scales. The center scale is used as B, E, and H scales. The bottom scale is used as C and F scales. The scales and corresponding ranges are shown below:

A	300 - 5,000 lbs.	E	6,000 - 100,000 lbs.
B	600 - 10,000 lbs.	F	12,000 - 200,000 lbs.
C	1,200 - 20,000 lbs.	G	30,000 - 500,000 lbs.
D	3,000 - 50,000 lbs.	H	60,000 - 1,000,000 lbs.

Read the strand tension from the appropriate scale after the needle has stabilized. To obtain an average value, three readings should be recorded.

i. Turn instrument off when measurements are not being made to protect batteries.

5. Troubleshooting.

If the Vibra-Tension does not function properly:

a. Check batteries. Erratic readings may be caused by weak batteries.

b. Check all settings.

c. Check bridging points. Loose bridging points will emit a low pitched buzzing sound or allow strand to vibrate on both sides of the bridging point.

d. Check transducers. If an unstable reading occurs with the contact transducer, try setting the Vernier to zero and using the non-contact transducer. The non-contact transducer is less sensitive to external vibration and shock.

e. Check for vibration of forms. If the vibration induced into the strand damps out very quickly, move one or both of the bridge points to a firmer point on the form.

C. PRECAUTIONS

The Vibra-Tension is a delicate electronic instrument and should receive the same care as any other precision instrument. Special attention should be given to the following:

1. Handle with care to prevent dropping or other rough handling.

2. Protect against dust and moisture.

3. Store the transducers and charging cable in the storage compartment when not in use.

4. Always turn instrument off when not in use.

Careful attention must be given to the bridging points as they are the most frequent source of error in making a tension measurement. If after several attempts to obtain a stable reading you fail to do so, you should check bridging points for vibration or check to make sure nothing is touching the vibrating strand between bridging points. Vibrations of the casting bed or strands caused by workmen working in the area can affect the accuracy of the tension readings.

REPORTING OF RESULTS

Keep neat, orderly notes of all measurements and results. Record the following values: Strand manufacturer, strand tension, diameter setting, scale, vernier setting, bridge length, and transducer used. Report total length of strand, strand location in tendon, and location of bridge length (e.g., on straight strand or on center portion of harped strand).

TABLE 1

VIBRA-TENSION SETTINGS FOR DIFFERENT MANUFACTURERS COMMONLY USED PRESTRESSING STRANDS

Manufacturer	Strand Diameter** (Inches)	Unit Weight (Lbs./Ft.)	Scale	Vernier Setting*	Diameter Setting
C.F. & I. Steel	7/16 H	.400	D	8	186
	1/2 H	.532	D	6	216
U.S.Steel	7/16 H	.395	D	8	185
	1/2 H	.525	D	6 1/2	214
Bethlehem Steel	7/16 H	.395	D	8	185
	1/2 H	.538	D	6	216
Armco Steel	7/16 H	.390	D	8	184
	1/2 H	.520	D	6 1/2	210
Suzuki Steel	7/16 H	.402	D	8	187
	1/2 H	.531	D	6	214
Shinko Steel	7/16 H	.394	D	8 1/2	185
	1/2 H	.524	D	6 1/2	214
Tokyo Rope Steel	7/16 H	.398	D	8 1/2	185
	1/2 H	.520	D	6 1/2	211
Sumitomo Steel	7/16 H	.396	D	8 1/2	185
	1/2 H	.529	D	6	214

** H = High Strength 270 ksi strand
* Set at zero for non-contact transducer

REFERENCES

1. Report dated June 1973, "An Evaluation of the Vibra-Tension, Model ET-U, an Instrument for Measuring Prestressing Strand Tension".

2. Manufacturers Literature, "Vibra-Tension Model ET-U.

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