Final Report

Performance Test for Bitumen Coated Piles

by

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INTRODUCTION

In the Spring 1980 the Joint Highway Research Advisory Council approved a project in the Civil Engineering Department to develop a performance test for bitumen coated piles. The purpose of the present research is to develop field procedures for rapidly testing and checking the ability of a bitumen coating on the driven pile to reduce the downdrag force. Two previous projects investigated negative skin friction(1) and bitumen coatings(2).

BACKGROUND

Highway construction often requires that a fill be placed over compressible soil near pile groups. An example is the approach fill at bridge abutments. The fill causes the soil to settle. Friction between the pile and the soil resists the downward motion of the soil causing a force in the pile. These forces, called downdrag, can be large and develop with relative motion between soil and pile of a few millimeters.

Although several methods of reducing downdrag have been tried, coating the pile with bitumen appears to be the most successful.(3,4,5) As the downdrag forces build up on a bitumen coated pile, the bitumen layer begins shearing and thus regulates the maximum force that can be transmitted to the pile. The downdrag can often be reduced by 90 percent if a bitumen of the correct viscosity, stiffness modulus and thickness has been properly applied to the pile. There have been two reported cases where the reduction of downdrag load was lower than expected.(6,7) In one of these cases the problem involved difficulties in applying the coating and keeping it to the proper thickness prior to driving the pile.(6) Other difficulties can arise during construction such as having the coating scrape off as the pile is driven through granular layers. What is required is a test to check the performance of the bitumen coated pile after driving.

Most previous research addressed the ability of bitumen to reduce the downdrag. These investigations measured downdrag forces by instrumenting bitumen coated piles and observing the readings over a period of several months. That approach was certainly appropriate for testing the concept. It is not practical to use this method as a performance test because the excessive time required for testing does not allow for corrective action during construction.

To inspect and accept bitumen coated piles and pile installations with confidence in the same manner as other items of construction, a performance test is required that can be conducted over a period of several days. This test must be capable of checking the ability of the bitumen coating on a driven pile to reduce the downdrag. A short test duration is required so that design or construction changes, if needed, can be made while the construction is proceeding.

Experimental Approach

The purpose of the field test is to determine the effectiveness of the bitumen layer in reducing the downdrag on the pile after driving. The field test will be conducted similar to the standard pile load test except that an upward force will be applied to the pile and the rate of strain under each load measured. It is important that the loading apparatus in the field be capable of supplying the required range of forces and keeping each applied force reasonably constant for several hours. Pulling the pile completely out of the ground is not a part of this test.

The exact weight of the pile, pile coating and any other materials that must be lifted during the test is difficult to determine directly. The force required to overcome gravity will be referred to as the tare force. The tare force must be subtracted from the total force in computing the net force causing shearing of the bitumen layer. In the field test, the ability of the bitumen layer on a driven pile to reduce the force transmitted to the pile will be checked by putting an upward force on the pile, holding the force constant and measuring the rate at which the bitumen allows the pile to move. The upward force must be reasonably constant for a long enough time to establish and observe the rate of motion of the pile. The bitumen layer designed for the pile will probably be much thicker than that between the plates of the viscometer. The temperature at which the bitumen will be sheared in the field will also be different than it is in the standard laboratory test. The temperature of the bitumen on the pile will be approximately 50°F, i.e. a commonly assumed temperature of the soil. The proper bitumen must be selected from a series of laboratory tests that are run at different temperatures. From the tests at different temperatures an equation can be developed to predict the viscosity of the bitumen at the field temperature and rate of strain.(11)

LABORATORY TESTING

Sliding plate viscometer tests(8) were run according to the ASTM standard D 3570 on four asphalts: 1) AC40, 2) 85-100 penetration, 3) an experimental rubberized asphalt, 4) rubberized crack sealer AASHTO M173-60. The rubberized crack sealer was obtained from the Connecticut Department of Transportation as an alternate asphalt that might be helpful in bitumen coated piles. The rubberized asphalt was obtained from Prof. Jack E. Stephens of UConn and had been prepared as part of another experimental project in the C.E. Department. AC-40 and the 85 penetration asphalt were obtained from Mobil Oil Company as the type of asphalts indicated by recent publications as being suitable for field use.(6) In addition, penetration tests(9) and softening point tests(10), were run on AC 40.

Model tests were performed in the laboratory on the apparatus shown schematically in Figure 1. A model pile consisting of a one-quarter inch thick by four inch wide steel plate was coated with bitumen and placed between two metal angles. The thickness of the bitumen coating on the model pile was approximately one millimeter (0.040 in.). When this project began, it was hoped that a more sensitive and precise measuring system could be developed to track the upward motion of the pile. Some time was spent attempting to make measurements using the interference fringes from a laser beam reflected from a mirror attached to the model pile. These attempts were unsuccessful. The difficulties were later traced to the quality of the laser available at the time the tests were made. As a result the idea for using the laser was abandoned for the present project, and dial gages were used to track displacements. These should also be adequate for the field. In these model tests the moving components of the apparatus were carefully weighed in an attempt to determine the counterweight. No matter how carefully the tests were performed, the tare weight could not be predicted from our preliminary weighings. However, by using at least three different rates of strain on the model pile, the tare weight could be termined graphically.

TEST RESULTS

Results of the viscometer tests on AC-40 are shown in Fig. 2. In these figures the shear stress is reported in pascals (Pa) as computed from the standard test. This is the customary unit from the test. The values in tons/ft^2 can be approximated by dividing each stress in Pa by 1 x 10^5. To properly design bitumen coated piles requires stress-rate of strain results at three different temperatures and a range of strain rates to predict the shear stress under field conditions. In Fig. 2 the tests using the viscometer at temperatures of 10, 21 and 25 degrees centigrade are shown with solid lines.

The equation that describes the viscous behavior of bitumen is:(11)

$$t = m \left(\frac{\overset{\circ}{\gamma}}{10^{-5}} \right)^{n} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

$$m = m_o \, (10)^{-\delta_m T} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

$$n = n_o + \delta_n \, T \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

where: t = shear stress, $\overset{\circ}{\gamma}$ = the rate of strain; m and n are expressions that account for temperature and rate of strain; T = temperature in °C; δ_m and δ_n are coefficients.

The appropriate values for the flow parameter were obtained from least squares fits of the data at three different temperatures. For AC-40 they are: m_o = 0.252 T/ft^2, δ_m = 0.115, n_o = 0.623 and δ_n = 6.8 x 10^{-3}. If the value of the shear stress is desired in Pa, then the value m_o = 2.415 x 10^4 must be used; all other values are the same. The dotted line for T = 15° in Figure 2 was computed with this equation.

Results using AC40 in the model tests are shown in Fig. 3 and 4. Fig. 3 shows the results at five different levels of shear stress plotted against the resulting strain rate on natural scales. The unaccounted for tare stress is the intercept on the vertical axis. In this case it has a value of 100 Pa. Figure 4 shows the model test results plotted on log scales. The solid line was calculated from the results of the viscometer test. As can be seen from Fig. 4 when the tare stress is properly accounted for, the model pile indicates the same viscosity as determined with the viscometer.

During the previous project, it was difficult procuring appropriate bitumen in the United States.(2) The tests were run on asphalt "blown down" by the Tilo Company of Stratford, CT. However, the AC40 used in these tests appears to be promising as a bitumen layer for coating piles. The properties of AC40 are compared to Shell's Recommendations in Table 1. As can be seen from Table 1, the properties of AC40 are close to Shell's specifications.(12) Shell developed these specifications to ensure that the bitumen coated piles could be stored for several days without having the bitumen soften and run off. The stiffness modulus criterion ensures that the bitumen coating will not crack off while driving the pile. The viscosity criteria are a guide. The force transmitted to the pile is a function of viscosity, temperature and thickness of the bitumen layer. The thickness is varied to regulate the force.

The results using the 85 penetration asphalt are shown in Figures 5, 6 and 7. Figure 5 shows the results of the sliding plate viscometer test at 22°C. The line shown in Figure 5 was found using a least squares fit of the data. Figure 6 shows the plot of the three rates of strain used in the model test. It also shows the intercepted value on shear stress axis of 50 Pa. Figure 7 shows the results from the model test using raw data and the corrected

TABLE 1

Property	AC40	Shell's Recommendations
Viscosity at 20°C	6.8×10^7 poise	$> 1.5 \times 10^7$ poise
Viscosity at 10°C	8.1×10^8 poise	$< 10^{10}$ poise
Stiffness Modulus at 5°C & 0.02 sec	~ 1000 kg/cm^2	< 1000 kg/cm^2
Penetration Index	-0.3	≤ 2.0
Penetration at 25°C	49	53-70
Softening Point (R+B) °C	54°C	55-65°C

data. The data were corrected by subtracting 50 Pa from each shear stress value. The solid line in Figure 7 is the line calculated using the laboratory viscometer data. The raw data are shown with the dots surrounded by a circle. As can be seen from Figure 7, the raw data indicate a shear stress that is higher than indicated by the viscometer. However once the raw data are corrected by subtracting the appropriate tare stress as indicated by the model test results, then the data from the model test fall very close to the line predicted from the viscometer results.

Results using the rubberized crack sealer are shown in Figure 8 and Figure 9. Figure 8 shows the viscometer test results using the rubberized crack sealer. There is a bit more scatter than with the conventional asphalts. The viscometer test results did not predict model behavior very well. The raw data from the model are shown in Figure 9. The model test results did not plot in a straight line. No correction could, therefore, be made. The model data, as can be seen in Figure 9 plotted below the line calculated from the laboratory viscometer tests indicating that less average stress was required in the model tests to achieve a given rate of strain. The phenomenon for this asphalt was traced to the fact that there are tiny particles of rubber in the asphalt. These particles apparently influence the test results from the viscometer more than the ones in the model. The thin asphalt layer in the viscometer apparently allows the rubber to exhibit more resistance to shear than in the thicker bitumen layer of the model.

FIELD TEST PROCEDURE

General

Considering the mechanism by which the bitumen layer dissipates the downdrag and the phenomena observed in the lab and model test it is possible to develop a field test procedure. The test will be performed by applying relatively constant upward force on the pile and measuring the upward motion of the pile until the observations allow the speed of the pile under that force to be determined. The largest force will be applied to the pile first. Tests at a minimum of two smaller forces will follow.

For each test the plot of displacement vs. time on natural scales yields a straight line whose slope is the speed of motion. A plot, on natural scales, of the force vs. speed of motion will yield a straight line that can be extrapolated to the vertical axis for determining the tare force. Data for this plot do not have to be reduced to stress and strain since the tare force can be used for subsequent calculations. Assuming the flow properties of the bitumen can be predicted from the laboratory tests, the variable affecting the field test is the thickness of the bitumen coating as driven which can be calculated thus:

$$\text{Thk. of Layer in inches} = \frac{\text{Rate of motion in inches/sec}}{10^{-5}}\left[\frac{1}{m}\cdot\frac{P}{A}\right]^{\frac{1}{n}} \quad . \; . \; . \; . \; . \qquad (4)$$

where: P = Upward force causing motion in tons = [Total Upward Force - Tare]

A = Total area of pile coated with bitumen =

[Length of Pile x Total Coated Perimeter] in ft^2

m, n as defined before in the equations of viscosity, in units to

yield $tons/ft^2$

The thickness backfigured from Eq. 4 for each applied force should be the same.

The pile for testing will have to be bitumen coated throughout its length. Full length coating will be no problem when the pile is driven to rock. It might cause problems if the pile is an end bearing pile in granular soil since the bitumen coated sides near the tip could reduce the capacity. As an alternative, a shorter test pile could be driven for testing then completely withdrawn when the test is complete. Testing a shorter pile also allows a check on the critical items in the process:

1. Proper application of the bitumen
2. Proper storing and handling
3. Proper driving
4. Proper viscosity and thickness

In addition extracting the pile after the test allows a more detailed inspection of the effects of driving on the bitumen layer. The test described here must not be confused with the conventional pullout test. It is not necessary to remove the pile from the soil to complete this test.

The test will probably require at least eight hours after the reaction frame has been set up. For planning purposes it is recommended that the set-up time plus two days should be allowed for taking the necessary measurements. The time required for taking the measurements depends on the force that can be applied. The load range for testing will have to be specified by the engineer. The applied force must be large enough to ensure that the pile moves at a measurable rate, but must not be so large that it pulls the pile out of the soil.

Dial gages are sufficiently precise to measure the pile displacement. The gages must be protected from the sun or the test could be run at night.

Among the reasons for testing the bitumen layer with the largest force first is the fact that this is the manner in which consolidating soil applies its load. The rate of settlement is greatest at short times after loading, then continually decreases with increasing time. This phenomenon should also be kept in mind when considering remedial actions. The performance of the bitumen layer may be better or worse than desired. If the layer appears too thin as a result of the field test, several courses of action are open to remedy the situation. The simplest is to allow the fill to consolidate the clay layer for an additional period before building the structure that will load the piles. The force that develops in the pile is proportional to the rate of strain. The rate of strain depends on the rate of settlement and the rate of settlement decreases with time. Therefore, the easiest solution is to wait until the rate of settlement is small enough.

Test Details

1. Loading Apparatus

The field test requires a reaction frame and one or two air operated hydraulic jacks as shown in Figure 10. Note that the arrangement is similar to the standard reaction frame except that the pile will be pulled up instead of pushed down. Note that the harness for pulling the pile requires substantial capacity. A possible configuration is illustrated in Fig. 11.

The reaction girder shall be supported on four anchor piles not less than 10 feet or 10 pile diameters, whichever is greater from the test pile. These distances should be measured from the face of the test pile to the face of the reaction pile. For load and load-transfer beams, select girders of sufficient strength and section and attach them to the upper ends of the anchor piles. This reaction frame shall be capable of resisting twice the maximum anticipated test load without exceeding 75 percent of the maximum travel of the jack. A harness capable of withstanding twice the maximum anticipated test load shall be securely attached to the top of the pile and connected to a sufficiently strong structural member above the jacks.

2. Load Application System

The load shall be applied by means of one or more air operated hydraulic jacks. The jacks must be able to maintain the load within 1,000 lbs. The combined capacity of the jack(s) must be twice the greatest force anticipated during the test. The jack(s) shall have spherical bearing plates so that they will bear firmly against the harness. The load shall be monitored with load cells.

3. Movement Measurement

The movement of the pile shall be measured with three dial gages having 2 inch travel and an accuracy of 0.001 in. The gages must be installed so that they are parallel to the longitudinal axis of the test pile and the applied load. The gages must be attached to a simply supported reference beam, which is to be completely independent of the test pile and loading apparatus.

Embed the reference beam's supports at least 10 feet into the ground, at a horizontal distance of not less than 10 feet or 10 pile diameters, whichever is greater, from the closest face of the test pile and from any reaction piles or supports for the weighted box or platform. Maintain a clear distance of no less than 6 inches nor more than 12 inches from the test pile to the reference beam or any projection for supporting a dial. The beam and projections should be at approximately the same elevation as the attachments to the pile on which the dial gages will bear. Attach the dial gage supports to the reference beams so as to allow the stem of each gage to rest on an attachment to the pile sides, which are to be at 120° spacing and equal radial distances. These attachments are to be steel angles, approximately 3- by 4-inches with the 4-inch dimension projecting from the pile. The surfaces on which the gage stems bear should be smooth-finished; glass or sheet acrylic, attached by plaster of paris or other suitable material, are acceptable.

Reference points for elevation should be established on the reference beam supports on the reaction frame. The elevations of these points should be checked to a precision of 0.001 feet before and after each test.

4. Testing

A complete test sequence requires measurements under a minimum of three different loads.

A test shall consist of the measurement of pile displacement at a minimum of five different times under a reasonably constant load. The reading shall continue until the displacement vs. time plot yields a straight line.

CONCLUSIONS

1. The adequacy of a bitumen layer to reduce downdrag can be measured in a test that requires no more than a few days to run.
2. The test can be run with the same type equipment presently used to load test piles.

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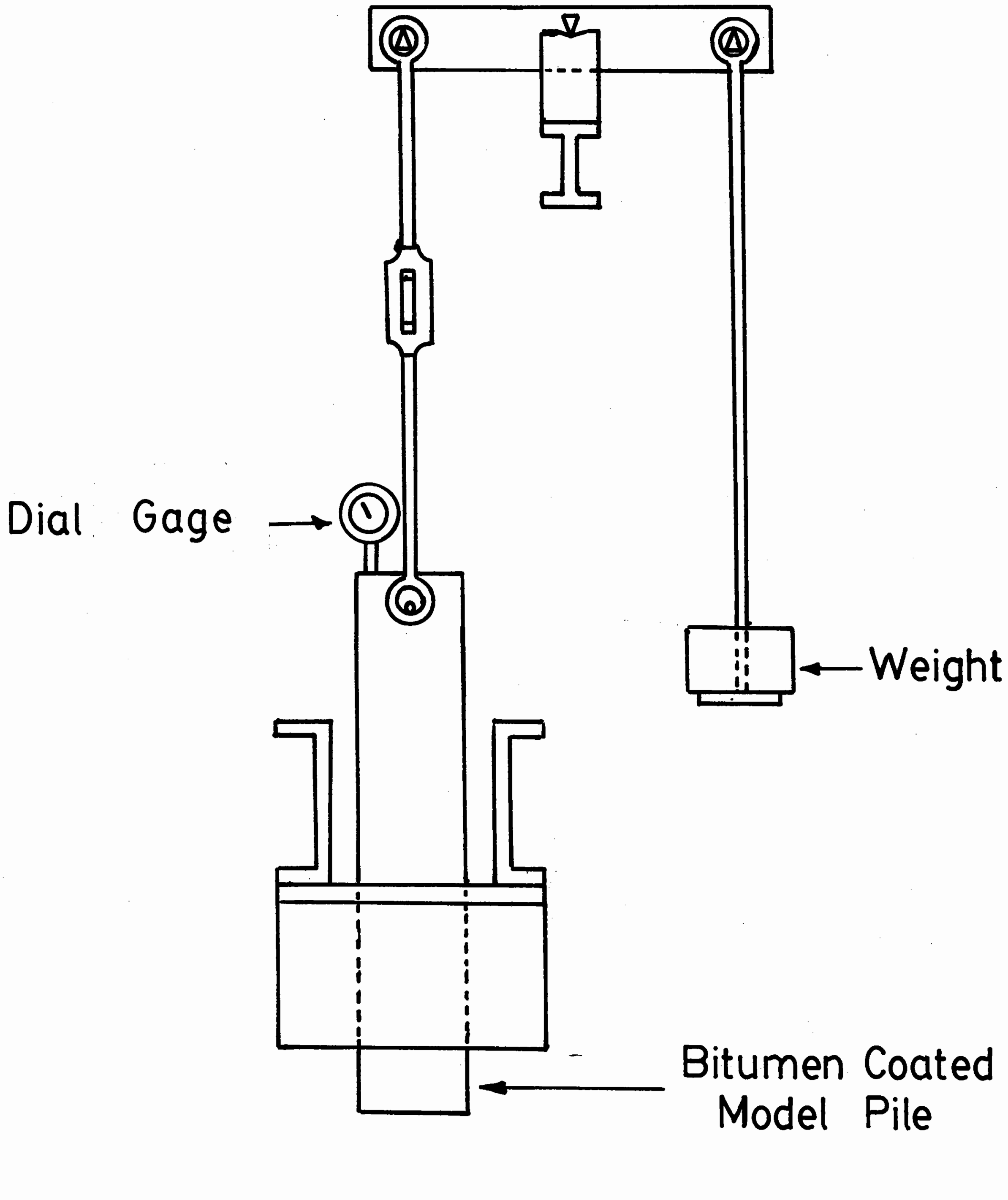

Fig 1 Schematic of Model Pile Test

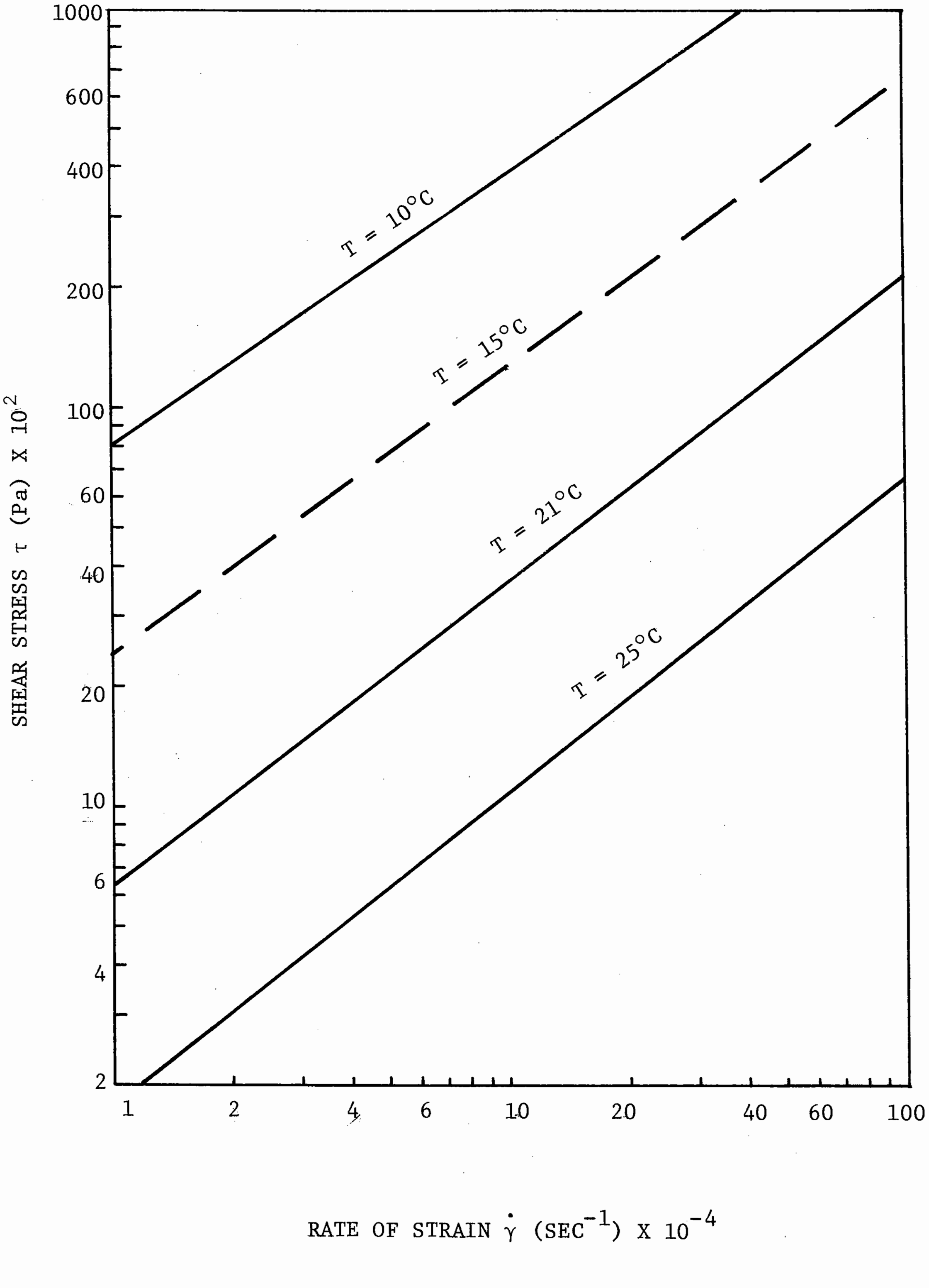

FIG. 2 VISCOMETER TESTS AC40 ASPHALT

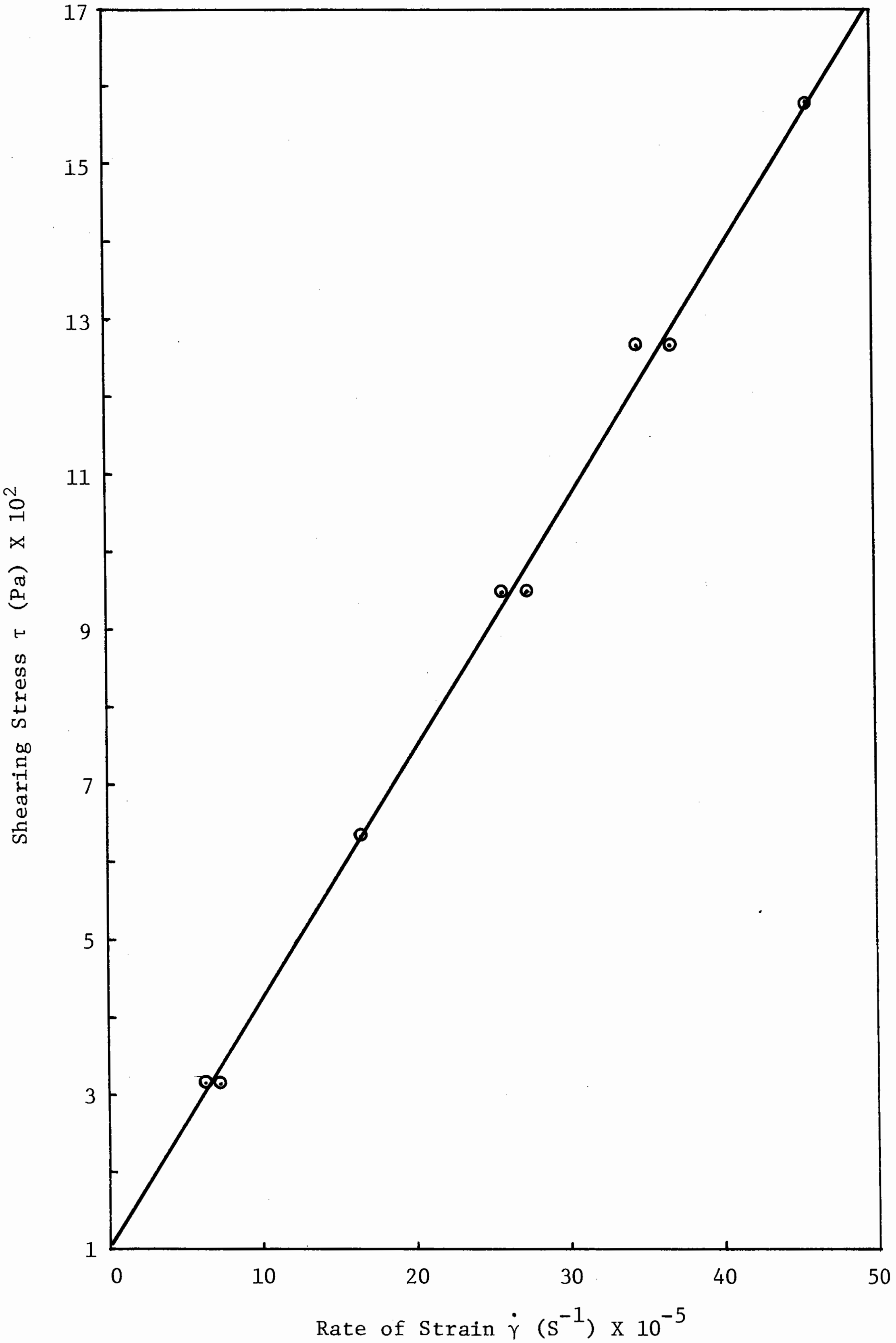

Figure 3 Plot to Determine Tare Weight - Model Test with AC40

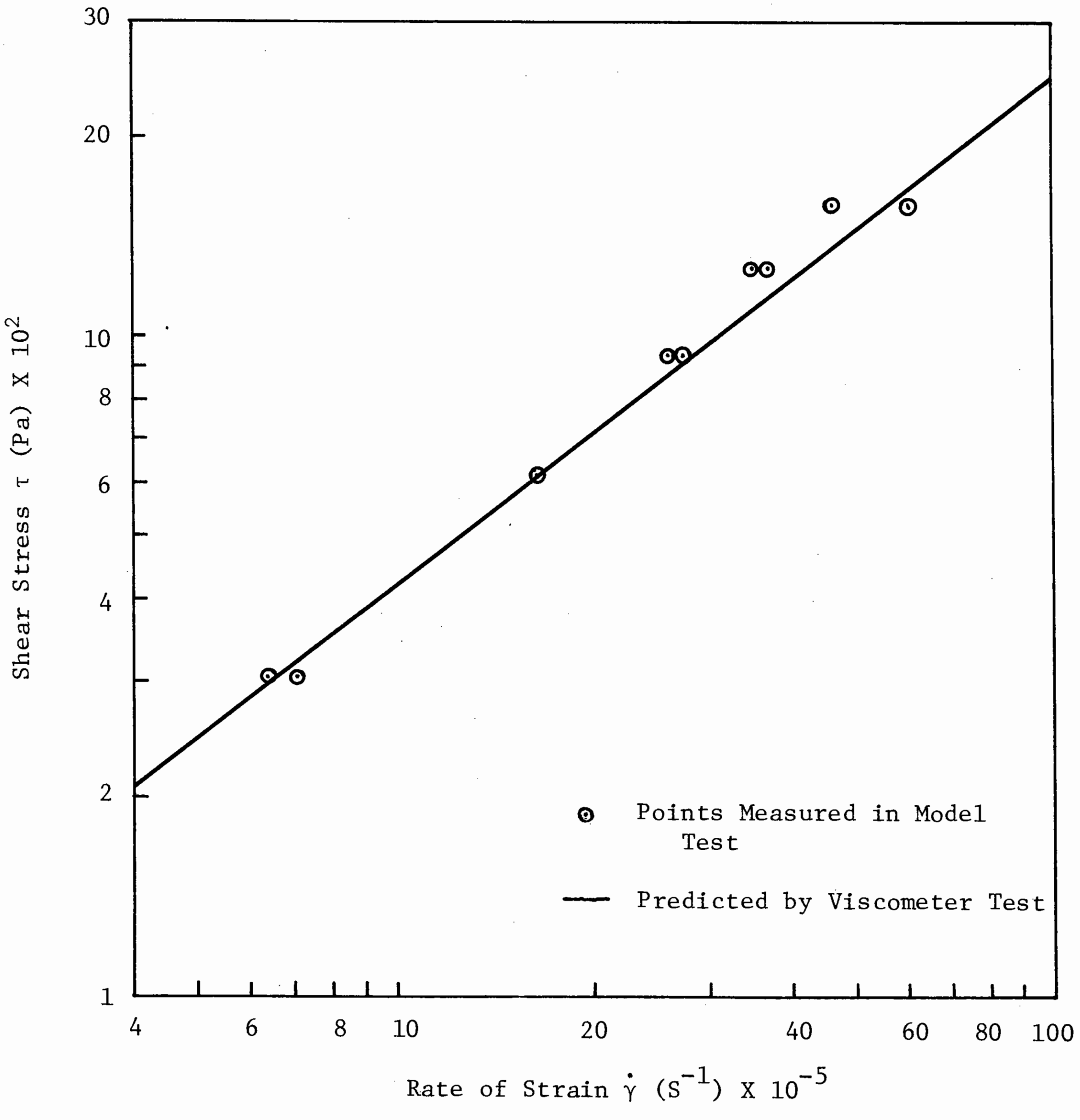

Figure 4 Model Test Results AC40

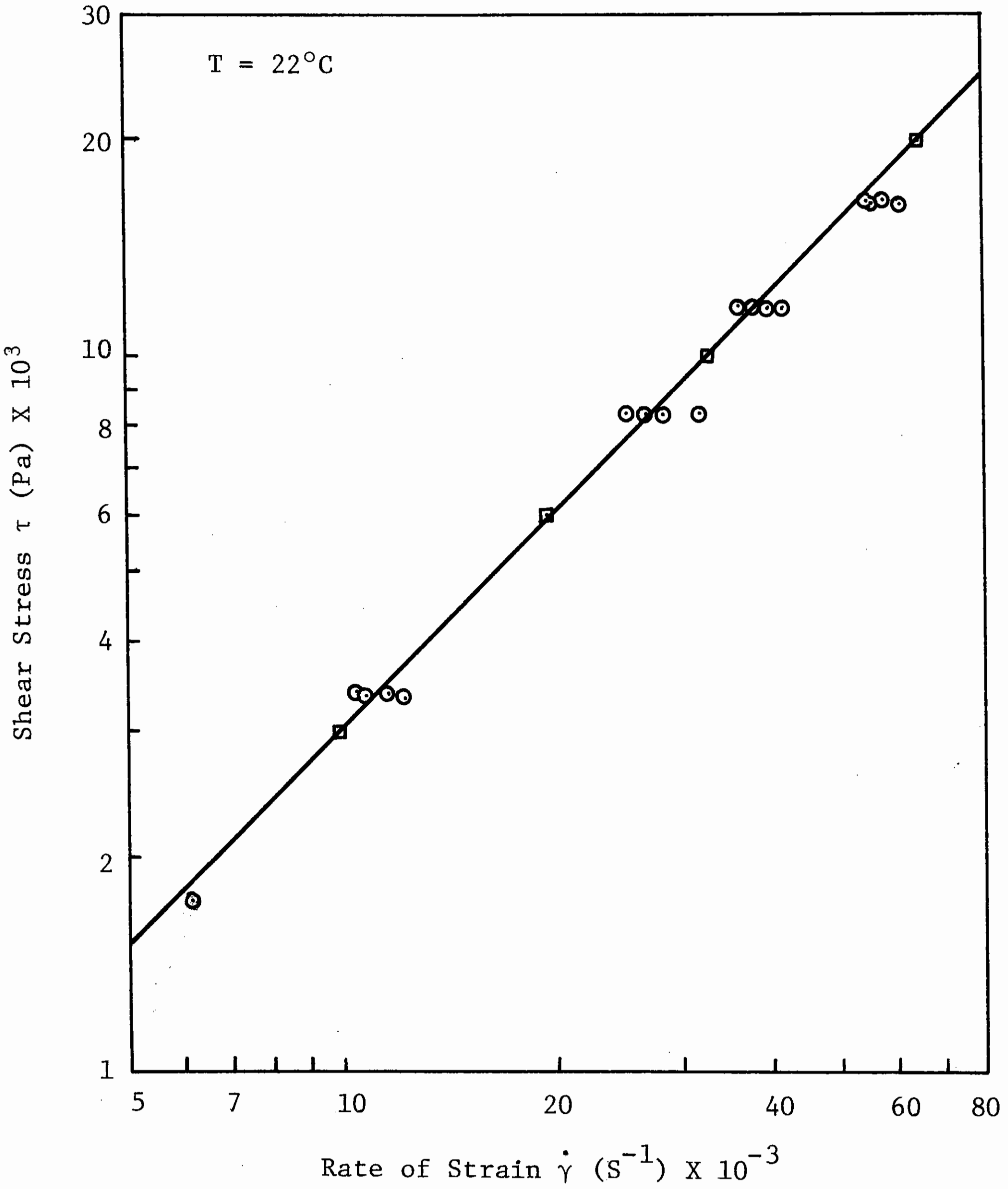

Figure 5   Typical Vicometer Results (85 PEN)

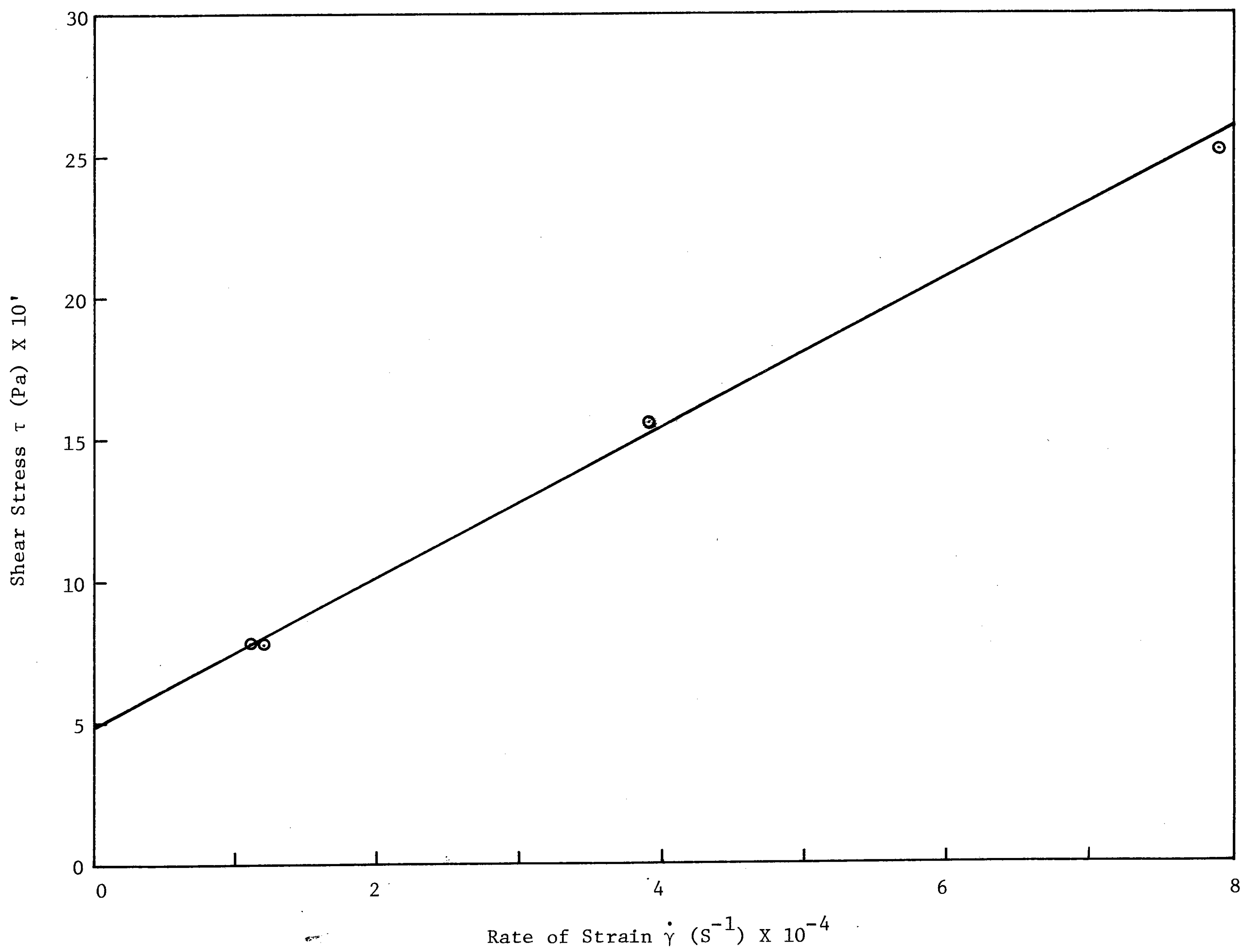

Figure 6. Plot to Determine Tare Weight - Model Test with 85 PEN

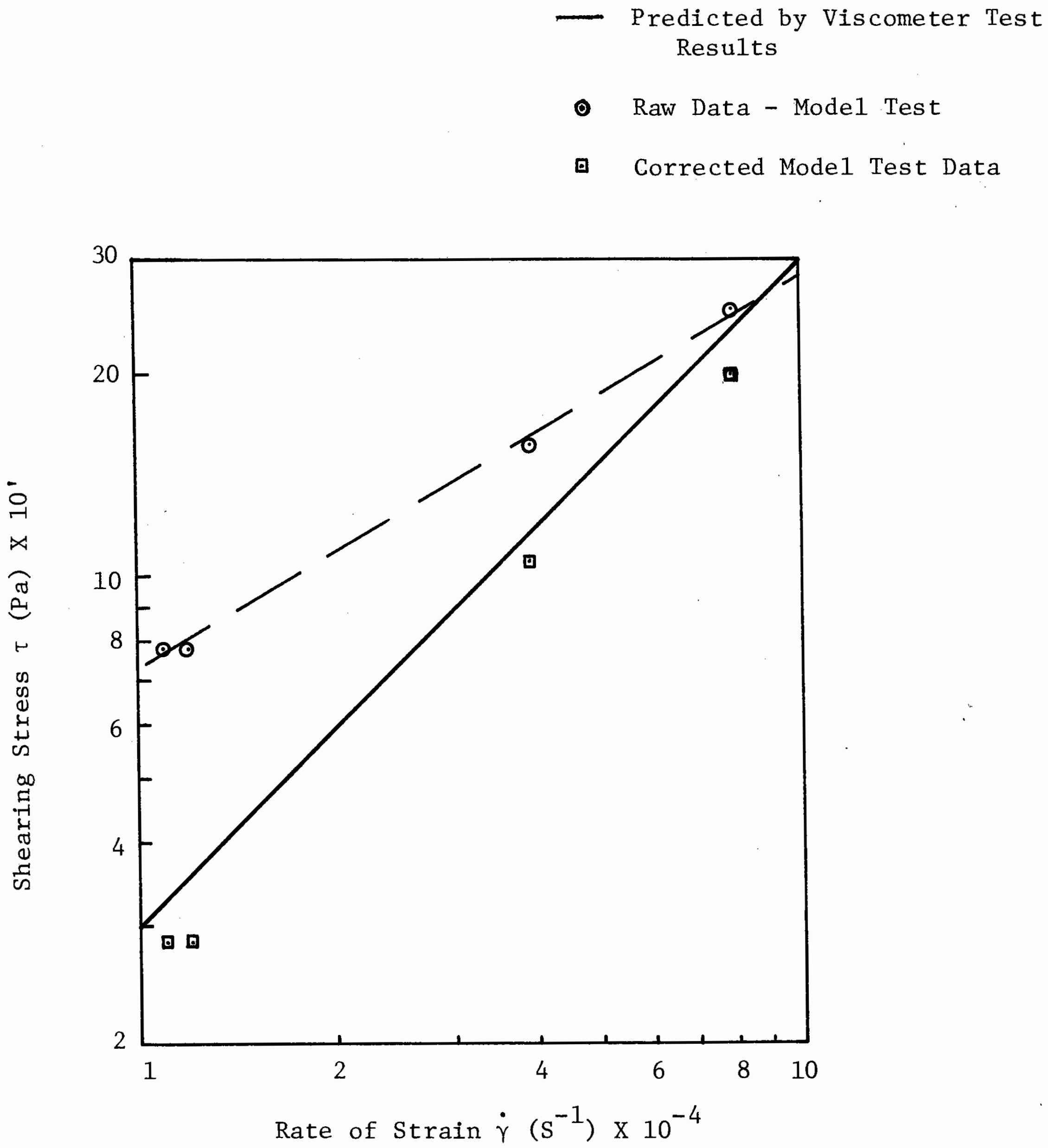

Figure 7 Model Test - 85 Pen. Asphalt

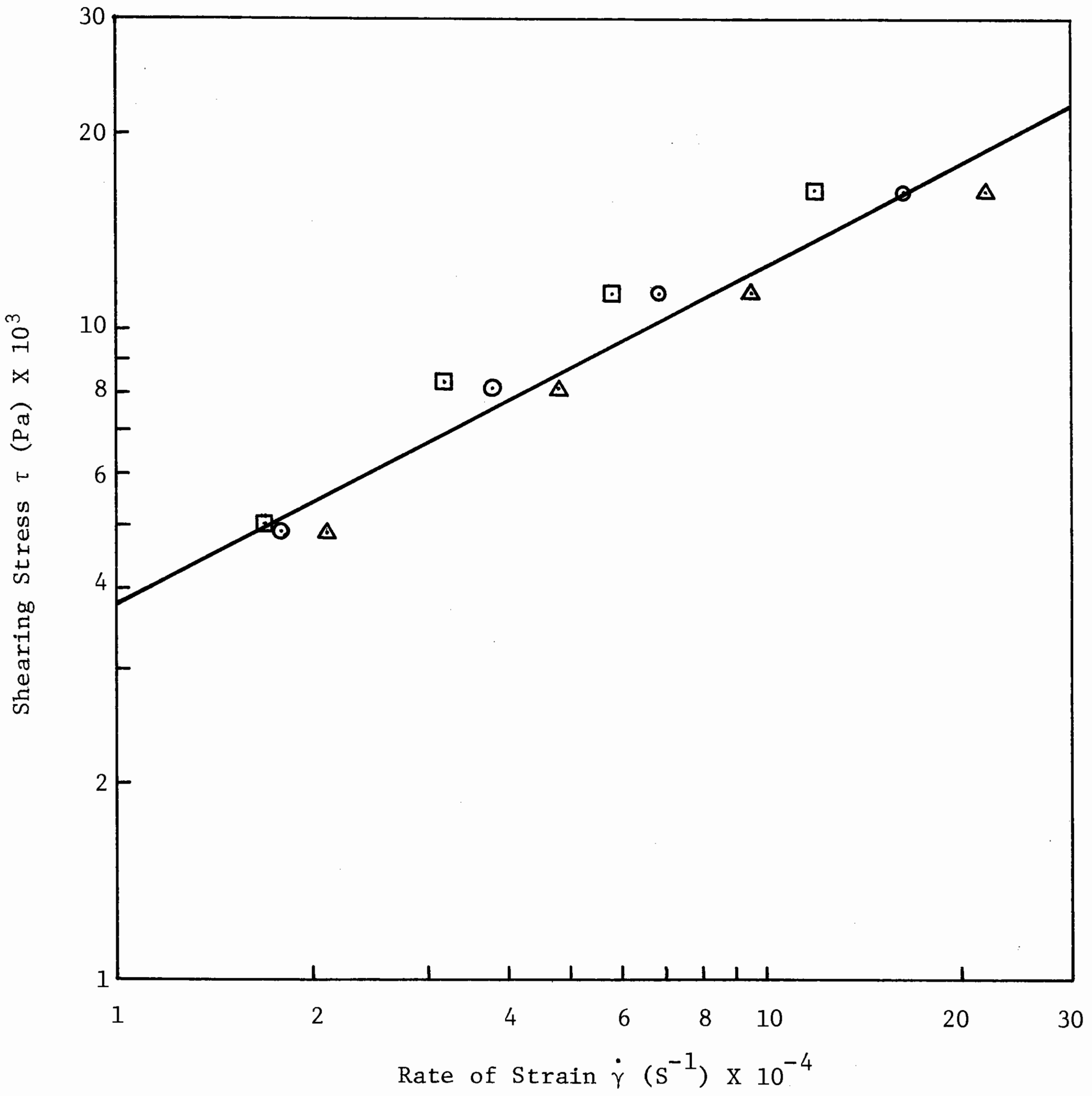

Figure 8 Viscometer Test "Crack Sealer"

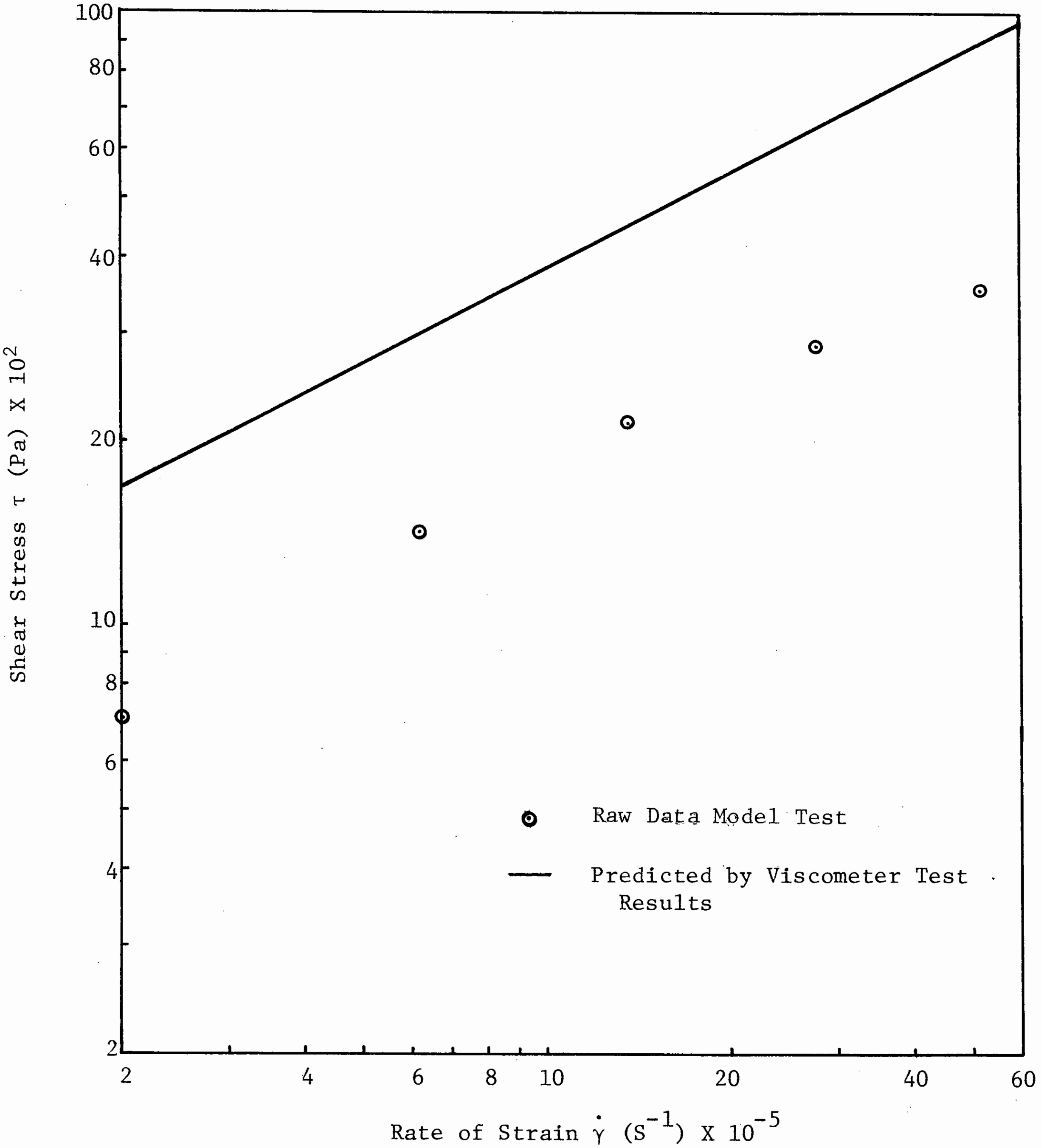

Figure 9 Model Test "Crack Sealer"

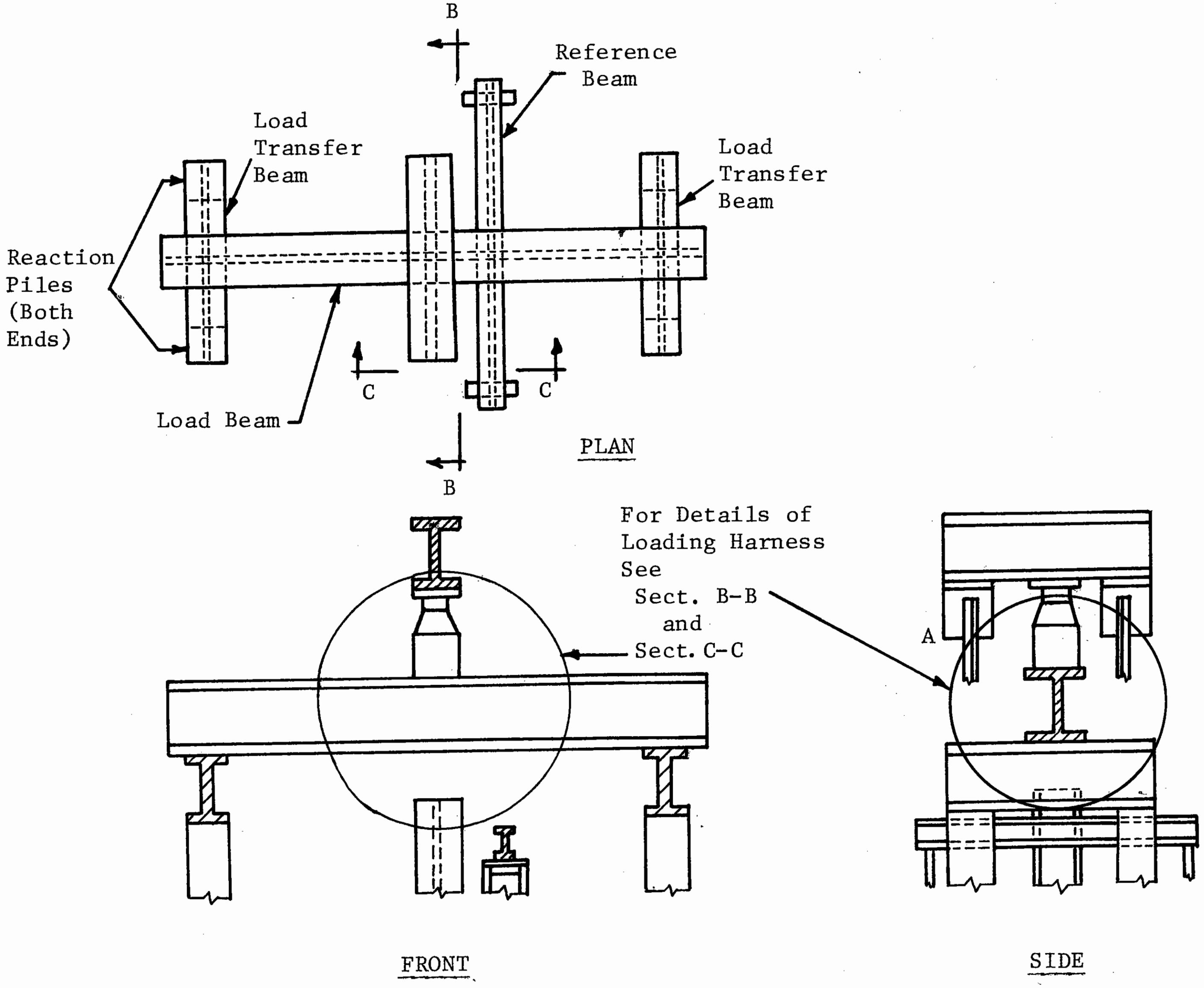

Figure 10 Layout of Reaction Frame

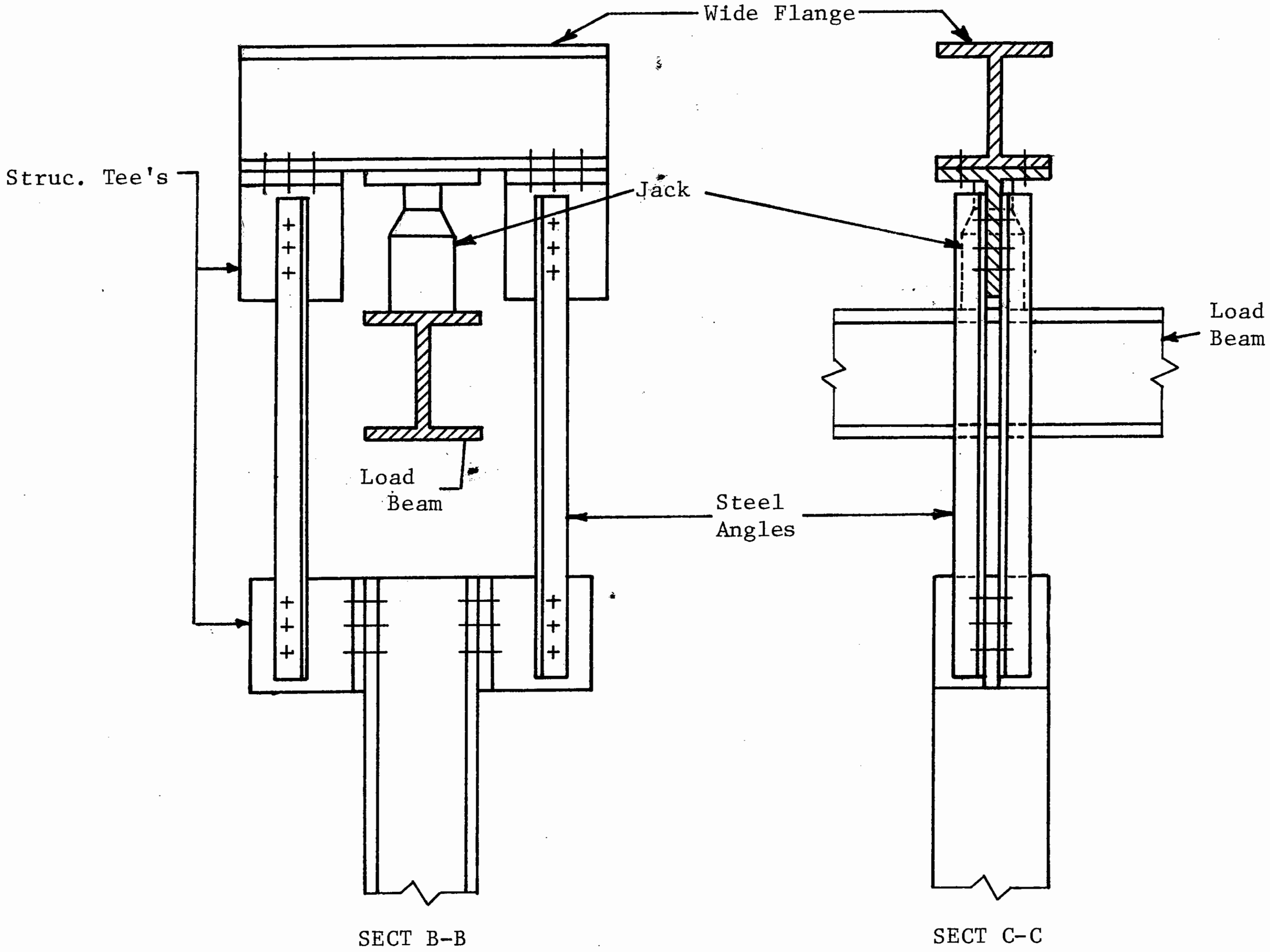

Figure 11 A Proposed Configuration of Loading Harness