Use of Automatic Recording Apparatus in Design and Control of Bituminous Concrete

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An investigation was undertaken to develop instrumentation for the Marshall apparatus which would eliminate the human element and bias in obtaining stabilities and flow values. The study produced a field model automatic recording apparatus, as well as a research model which plots the load-deformation curve and, therefore, makes a permanent record of the test for later reference or analysis. The advantages of this equipment, as well as the potential use of the load-deformation curves, are discussed.

•UNTIL recently, art and experience have dictated the design and control of bituminous concrete. The suitability and acceptability of the mixtures, during construction, have been determined almost entirely on the basis of the individual judgment of the engineers. This empirical procedure has produced many satisfactory and durable surfaces. However, today the retirement of many experienced and capable engineers, the rapid expansion in road construction, the increase in traffic density and associated factors demand accelerated and more scientific methods for design and control of bituminous concrete.

To keep abreast of these developments and to cope with modern bituminous road construction, the Pennsylvania Department of Highways inaugurated studies to determine the best applicable methods for laboratory and field control of bituminous concrete. The overall objectives were to permit an evaluation of the various phases, using numerical values, and to determine the practicality of incorporating these design and control values in bituminous concrete specifications.

The scope of these studies covered development of apparatus and methods, and laboratory and field operations from sampling to evaluation of finished surfaces. This discussion, however, is limited to the development, use and potentiality of the automatic recording apparatus. The full potential of the equipment has yet to be learned. Its possible uses are discussed here and will be reported in future research work.

In the early 1950's the Pennsylvania Department of Highways began studies to determine the efficacy of the Marshall procedures and equipment. It became apparent that modifications, revisions, and supplemental and new equipment were needed to yield reproducible results. Disagreement in results was common as the results are dependent on the operator's skill in reading the Ames dial and removing the flow meter at the same time. It was reasoned that if such conditions exist in the central laboratory, greater differences could be expected in the field.

On the basis of these early studies, it was obvious that more research was needed before the objectives could be achieved. As the Department was reluctant to abandon the Marshall method and data obtained up to that time, development was concentrated on altering the apparatus for the purpose of eliminating the human element and bias from the testing methods. To accomplish this goal, the first step was directed toward the development of methods for obtaining reliable stability and flow values.

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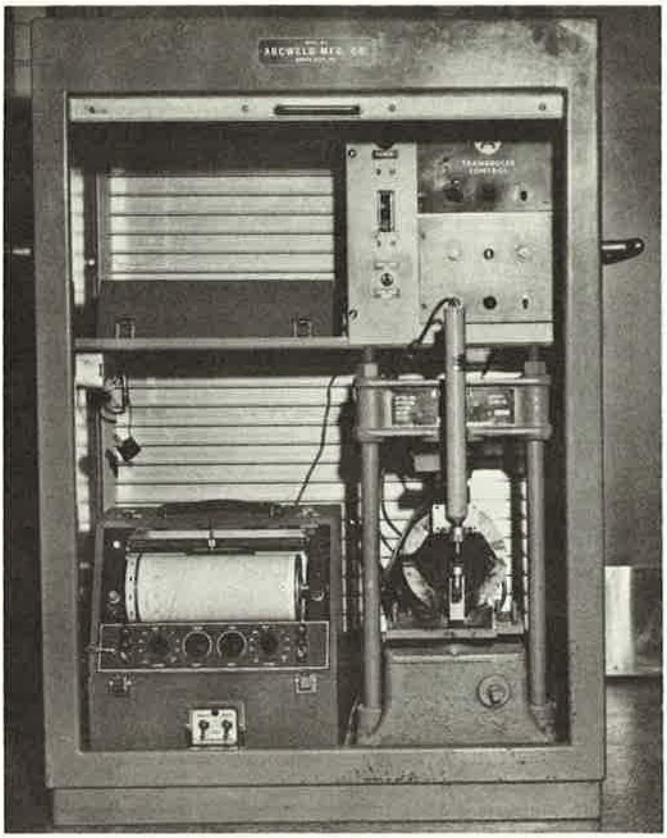

Figure 1. Instrumented Marshall apparatus.

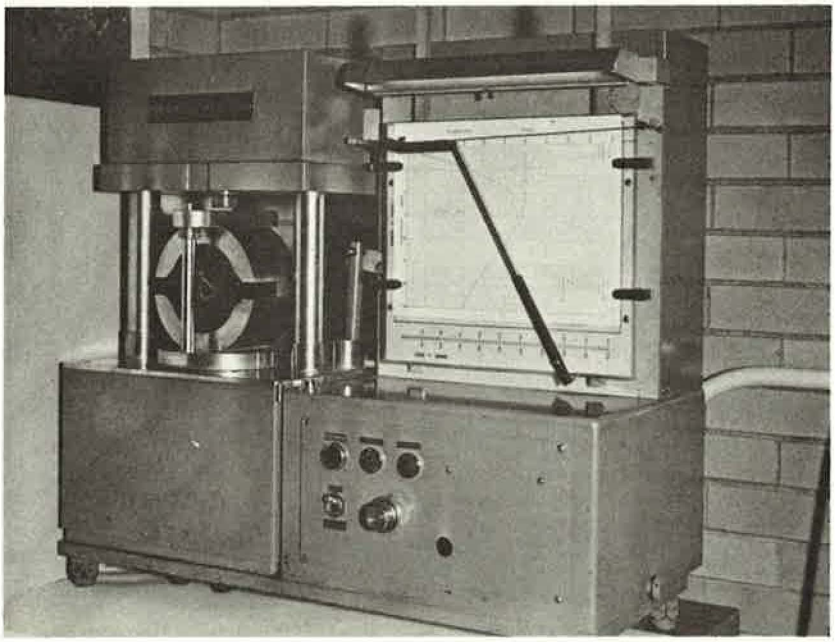

Figure 2. Instrumented Marshall apparatus, modified to withstand field handling.

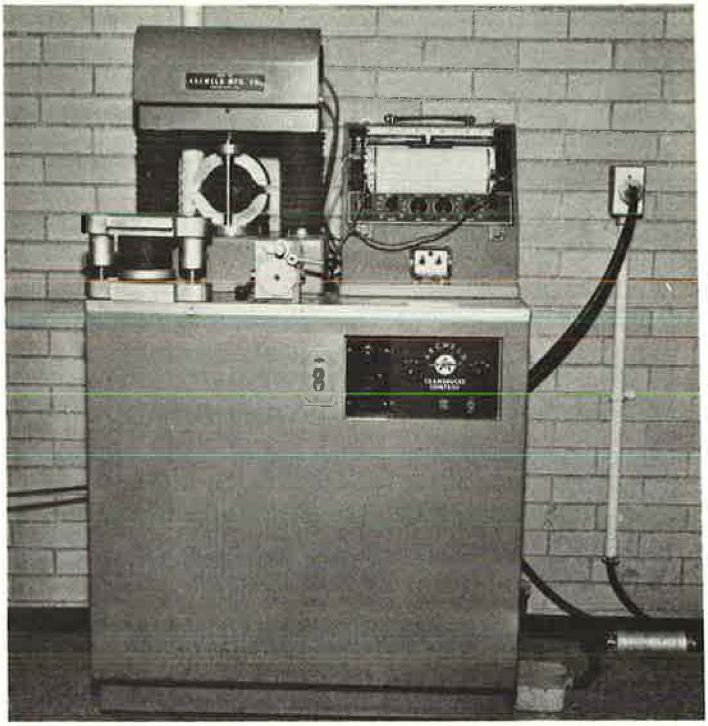

Figure 3. Hydraulic model.

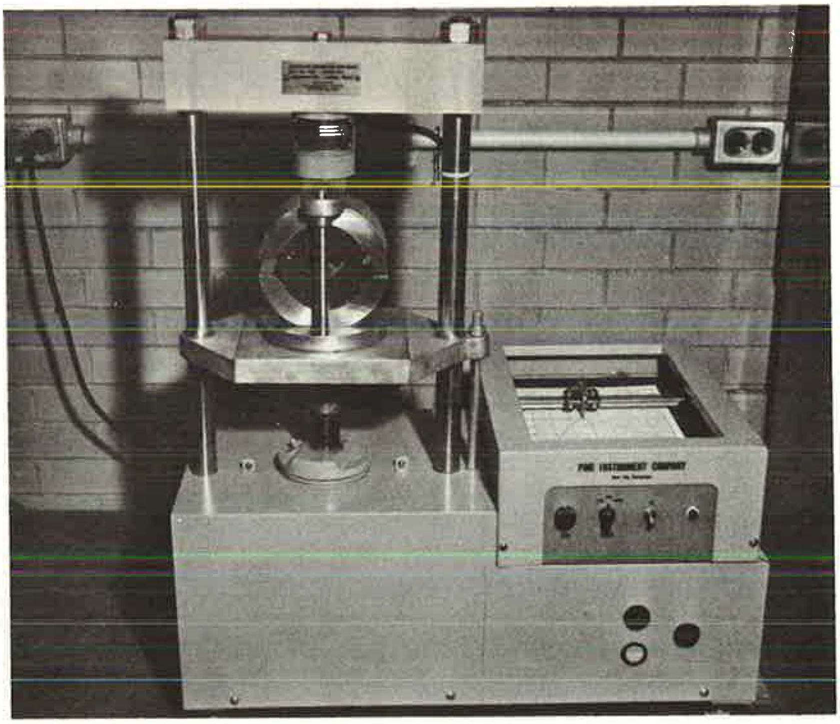

Figure 4. Field model automatic recording apparatus.

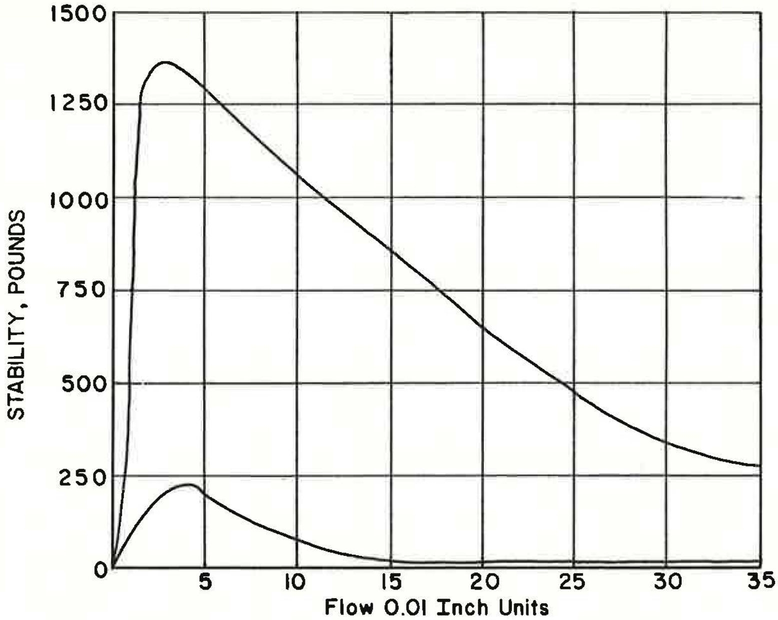

Figure 5. Sensitivity of recording apparatus.

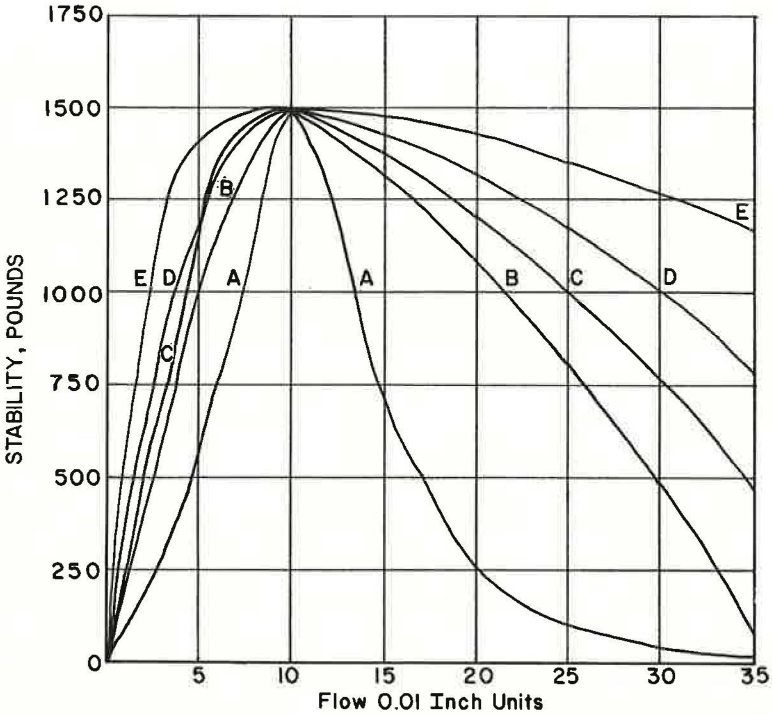

Figure 6. Identical flow and stability values—variable curve characteristics.

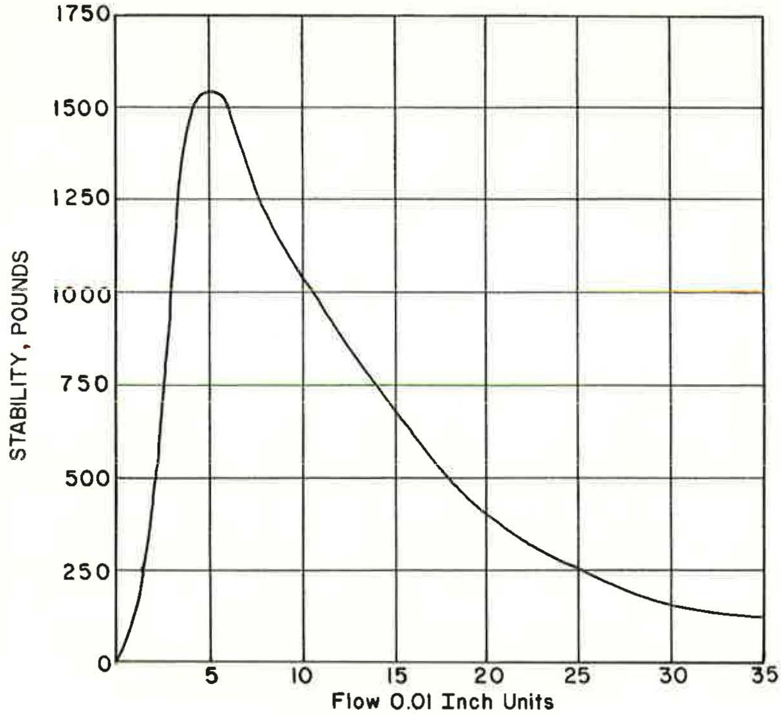

Figure 7. Bituminous mixtures with brittle characteristics.

Figure 8. Bituminous mixtures with plastic (flow) characteristics.

DEVELOPMENT AND CONSTRUCTION OF AUTOMATIC RECORDING APPARATUS

The Department, in cooperation with the Satec Sales Engineering Company, developed and constructed an instrumented Marshall apparatus (Fig. 1). The proving ring was replaced by a 10, 000-lb load cell, four-column axial loaded weighing unit employing strain gages for the reading components which has an accuracy of 2 percent. A direct

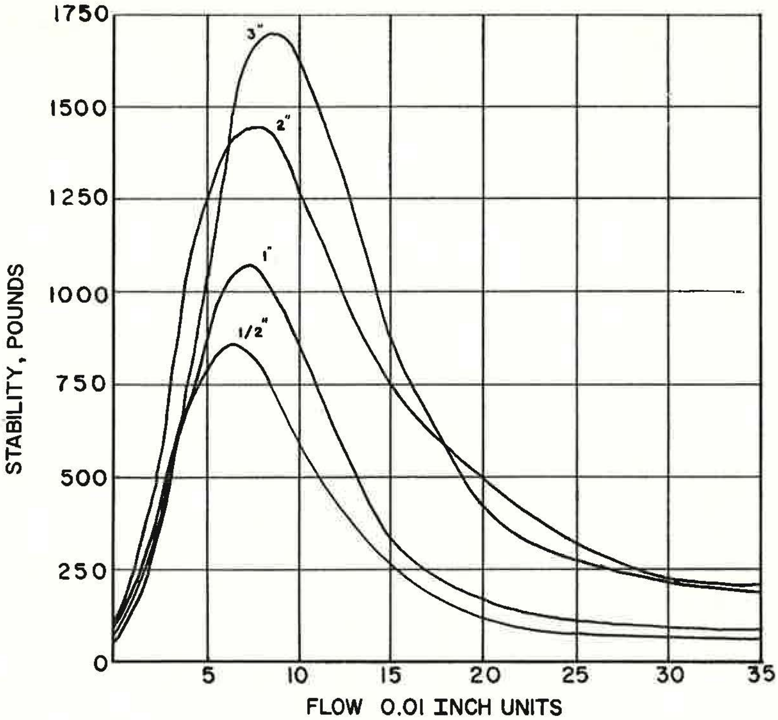

Figure 9. Effect of variable rate of loading—inch per minute.

current power supply is used to supply power to the load-cell gages. The combination of the load cell and dc supply produces a dc millivolt output, which increases when force is applied linearly. This output is fed into the y-axis of an x-y recorder's 10-in. length.

The flow gage was replaced with a linear variable transformer. The transformer and zero adjusting screw are mounted on the standard compression fixture. Alternating current is supplied to the transformer's primary winding. The ac output of this transformer (secondary) is fed into a demodulator which converts the ac signal to a dc millivolt signal. This dc signal is, in turn, fed to the x-axis of the x-y recorder's 7-in. width.

This first model (Fig. 1) performed beyond expectations. It not only eliminated the human element and bias in obtaining maximum stability and flow values, but also automatically produced a graphic recording of the load and deformation values during testing. (See Figs. 5 through 13 for typical curves plotted by this equipment during testing of bituminous surface courses.)

Continued laboratory experiments have demonstrated conclusively that results obtained with the modified apparatus were in agreement with those obtained with the conventional apparatus. Generally, because of variations in individual results, only two specimens for the modified apparatus are required to obtain the same average value, whereas six are needed for the original apparatus. Although the advantages of the modified apparatus were confirmed and established, the first apparatus was too delicate for field operations.

Field Model

On the premise that field control was mandatory before design and control measures could be adopted, and in view of the delicacy of the modified apparatus, efforts were concentrated on the development of a rugged field model. A sturdy field model which could withstand field handling and abuse was developed (Fig. 2).

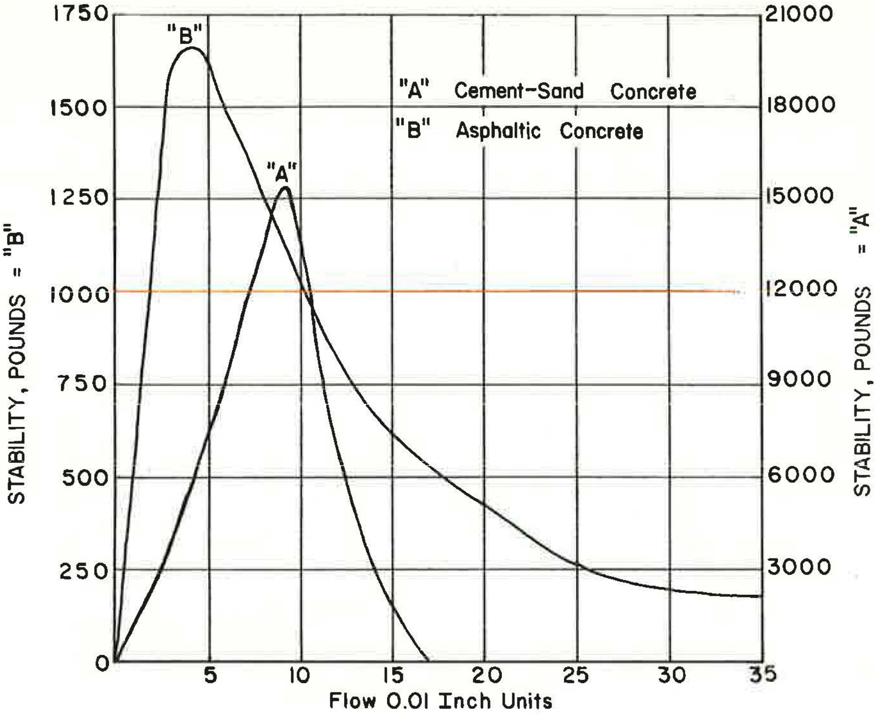

Figure 10. Flow behavior of selected specimens.

This vastly improved model incorporates two load ranges, 2, 500 and 5, 000 lb, and a 0 to 0. 35-in. flow range with a 2-in. /min loading rate. It can be operated automatically or manually. An auto on-off manual switch on the panel permits the operator to select the desired operation. In general, it consists of a drive mechanism, drive chain, ramscrew, assembly, drive motor, drive belt, gear reducer, and mechanical x-y recorder. The mechanical x-y recorder consists of a load cam assembly, platen, and recording pen.

The flow measurement system consists of a cam and necessary mechanical linkage to drive the recording chart upwards a distance 20 times the distance the loading platform moves upward. On a 7-in. chart, 0. 35 of an inch flow is graphed by a 7-in. upward movement of the chart. The unit has a built-in fulcrum, linkage and pendulum-type scale system which indicates the total load on the specimen by moving the recording pen horizontally from left to right. Because both measurements are mechanical, the apparatus is relatively trouble free and easily calibrated. The apparatus has an accuracy of ± 2 percent for load or deformation. The control panel on the front of the tester obeys the commands of the operator. For the 2, 500-lb range, the weight on the pendulum arm is moved to the top position, and to the bottom for the 5, 000-lb range.

Research Model

For laboratory research experiments, a hydraulic model was also developed and constructed (Fig. 3). This apparatus has a capacity of 30, 000 lb which can be modified to test loads up to 50, 000 lb. The hydraulically driven platen has a rate which can be varied between ½ and 3 in. /min within a tolerance of ± 5 percent. Load ranges can be set for 0-2, 500, 0. -5, 000, 0-10, 000 and 0-30, 000 lb for the full scale range as required and are measured by a temperature-compensated strain gage load cell, providing an accuracy of ± 1 percent. Ranges for the flow values can be varied to suit the desired graphic recording in ranges of 0-0. 20, 0-0. 35, (normal) or 0-0. 50 in. The flow is measured by a linear variable transducer and control providing accuracy to ± 1 percent. The data are recorded on a standard manufactured drum type recorder.

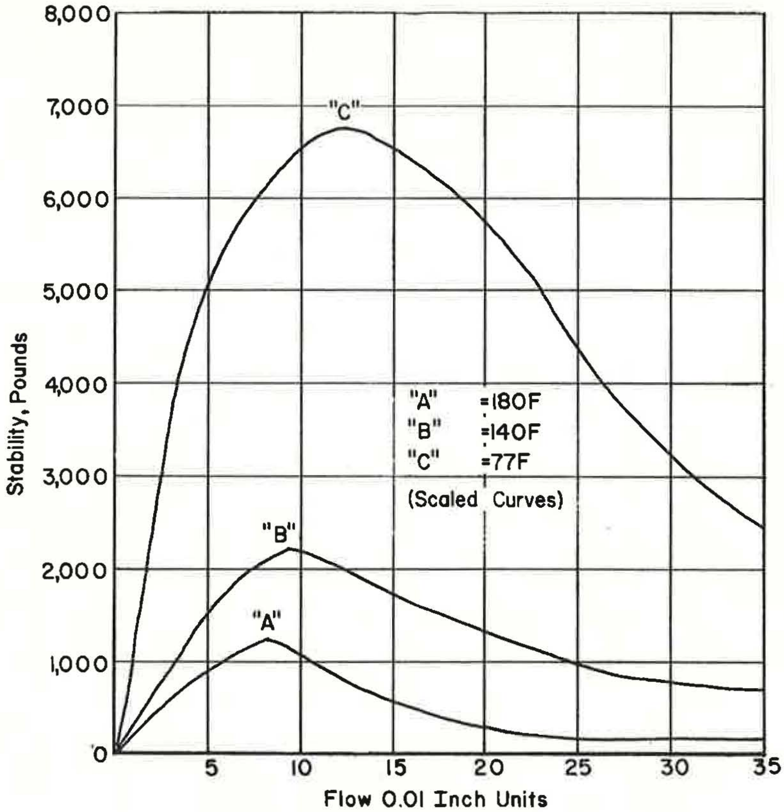

Figure 11. Flow vs decreasing testing temperatures.

Subsequent Field Models

In 1964, the Rainhart Company designed and constructed an apparatus which meets the Department's requirements (Fig. 4). It consists of a flat-bed x-y rectilinear recorder, electric strain-type load cell, 0-2, 500, 0-5, 000 and 0-10, 000 lb for the full scale range, with exchangeable and replaceable solid-state amplifier circuits and limit switches to protect the press and recorder from overloading in any range. Recording starts automatically when the breaking head has been properly seated on the specimen. This apparatus has a capacity to accommodate specimens up to 6 in. in diameter, and has an accuracy of ±2 percent for load or deformation.

In 1965, a field model was also designed to accommodate specimens up to 6 in. in diameter, and the load capacity was increased to 10, 000 lb. The original models can also be converted to the new capacities.

GRAPHIC RECORDING OF LOAD-DEFORMATION CURVES

A group of load-deformation curves plotted by the device illustrate the versatility and magnitude of testing possible with the automatic recording apparatus.

Figure 5 shows the sensitivity which can be recorded. Graphing of stabilities below 250 lb or within the normal ranges is possible. It is also possible to obtain low flows. In this case, without the use of the automatic recording apparatus, it would have been necessary for the operator to read both the stability and flow values within one second.

The family of curves in Figure 6 depicts the large number of variously shaped curves that can be obtained with the identical stability and flow values. It can be safely assumed, despite the same numerical stability and flow values, that mixtures represented by the individual curves will perform differently and in accordance with the characteristics of the curves.

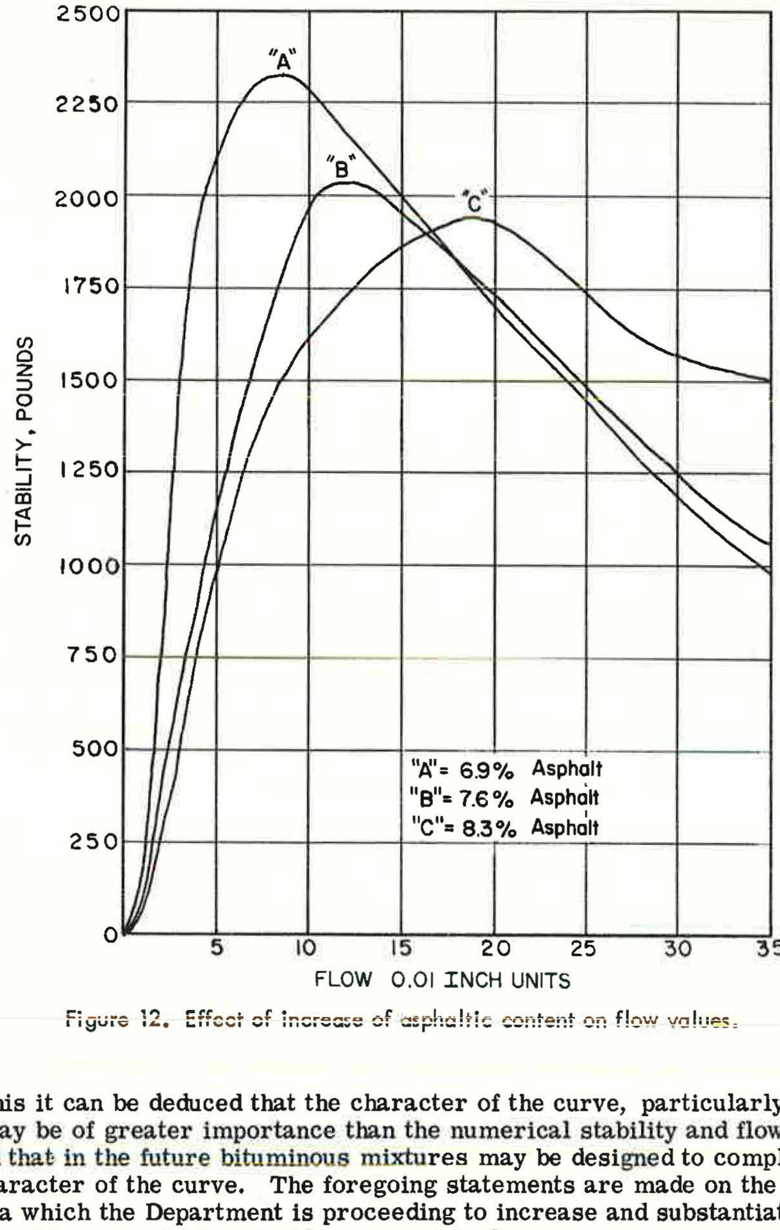

Figure 12. Effect of increase of asphaltic content on flow values.

From this it can be deduced that the character of the curve, particularly the fall-off portion, may be of greater importance than the numerical stability and flow values. It is believed that in the future bituminous mixtures may be designed to comply with the desired character of the curve. The foregoing statements are made on the basis of limited data which the Department is proceeding to increase and substantiate in future research, making use of this valuable research tool.

It is believed that bituminous mixtures which exhibit brittle tendencies develop curves as plotted in Figure 7, and mixtures which tend to rut and shove develop curves as shown in Figure 8.

Figure 9 shows that flow increases only slightly, whereas the stability increases considerably, both in proportion with increasing loading rates for the same bituminous-concrete mixture.

Reliability and significance of the flow values are questioned on the basis of the curve in Figure 10. Curve A represents portland cement-sand mixture containing one part portland cement and three parts Ottawa sand, and curve B a bituminous mixture containing a graded aggregate and 6.0 percent asphalt cement. Cement concrete has a flow value of nine and asphaltic-concrete a flow value of five. However, asphaltic-concrete flow changes at elevated temperatures, whereas the cement concrete does

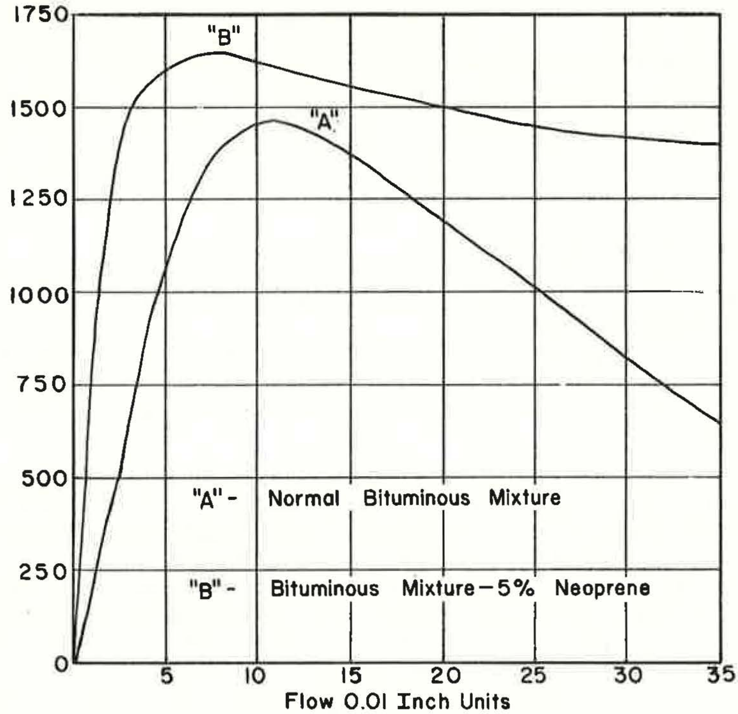

Figure 13. Alteration of curve characteristics.

TABLE 1

TYPICAL LABORATORY AND FIELD DATA

Item	Mix No. 1		Mix No. 2		Mix No. 3		Mix. No. 4	
	Stability	Flow	Stability	Flow	Stability	Flow	Stability	Flow
(a) Wearing Course								
Design	2, 200	12	1, 812	12	1, 700	9	2, 000	12
Lab. avg.	2, 110	12	1, 854	14	1, 415	11	1, 717	14
Field avg.	2, 086	10	1, 876	13	1, 446	9	1, 778	14
(b) Binder Course								
Design	1, 600	14	2, 000	16	1, 500	13	2, 964	15
Lab. avg.	1, 691	13	1, 839	16	1, 606	12	2, 126	9
Field avg.	1, 587	13	1, 910	17	1, 523	13	2, 141	9

not. Inasmuch as flow values of asphaltic-concrete in many cases increase with decreasing temperatures (Fig. 11), it can also be assumed that flow values are misleading with regard to the plastic state of bituminous concrete. However, some significance can be attributed to the flow values in Figure 12. At 140 F the flow values increase as the asphaltic content is increased.

The character of a curve can be altered as demonstrated by the two curves plotted in Figure 13. Curve A represents a normal bituminous mixture and curve B is the same mixture containing the same amount of asphalt cement with 5 percent neoprene based on the asphalt content.

CONCLUSIONS

It is easy to test bituminous concrete specimens with these models. A chart is inserted, the stability mold with the sample is positioned, a button is pressed, and the stability and flow values are recorded automatically. More accurate and undisputable results can be obtained in using the recording apparatus. In fact, the operation becomes virtually automatic in conducting this test. The advantages of the automatic recording instrument are

1. Only one operator is required.
2. Human element and bias are eliminated, thus affording more accurate and dependable results which can eliminate disagreements caused by differences in results obtained by different technicians.
3. Graphic recordings are produced which can be kept as permanent record.
4. Graphic recordings can be evaluated to determine additional properties and characteristics of bituminous concrete, thus opening a new field in research of bituminous concrete.

For the foregoing reasons, the Pennsylvania Department of Highways has for the past four years required bituminous concrete producers, working under Pennsylvania design and control procedures, to furnish as a part of their testing equipment to control mixtures, an approved field model automatic recording apparatus.

It is doubtful whether the design and control procedures could have been effected without the use of the recording apparatus. The design graphic recordings were a valuable aid in making adjustments during production. The recordings and data served as indicators as to what was actually occurring during the production.

Excellent results were obtained in the field. Table 1 (WC Mixes 1 and 2 and BC Mixes 1, 2 and 3) indicates the small variations in stability and flow between design, laboratory, and field tests when aggregates of the same gradation were used both in the design as well as in the field. Mixes WC 3 and 4 and BC 4 show the differences obtained when aggregate gradation used in the development of the design was different from that used on the project. However, field and laboratory results are in close agreement in all cases. Our experience is that these would be much greater using conventional equipment. The Department is highly pleased with the design and control procedure of which this apparatus is a vital part. The success of the adoption of the Department's design and control method is in large part due to the excellent performance of this testing equipment, and it is felt that this new equipment will result in important improvements to present design methods.