Traffic Simulator for Checking Mix Behavior

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Some asphaltic concrete mixes designed by accepted stability procedures have shown signs of distress under heavy volumes and loadings of traffic. In an effort to ascertain the effect of traffic on specimens of known stability, a laboratory traffic simulator was designed and built.

The specimens tested are the same as those used in either the Marshall or Hveem stability tests. The specimen is placed in a collar equipped with heating coils and temperature sensors, which in turn is boxed in the frame of the instrument in such a manner as to permit the traffic simulator wheel to travel over the center of the upper surface of the specimen. The temperature of the specimens may be maintained at any desired point, during test, by either the heater coils on the specimen collar or dry ice packed in the box. Six specimens may be tested simultaneously.

Tests conducted with the traffic simulator indicated that some mixes which meet stability criteria show distress under the test, other mixes having lesser stabilities showed less displacement than similar mixes having higher stabilities, also other mixes which resist displacement for 2,000 to 3,000 passes of the traffic wheel will suddenly show distress with a few hundred additional passes.

The only purpose of the traffic simulator is to serve as a supplementary check on the behavior of mixes under a moving wheel load.

•RECENTLY some asphalt pavements designed under accepted stability test methods and criteria have shown a tendency to distress under heavy volumes of traffic. The distress occurs in the form of rutting or channelizing in the wheel track area and on occasion as slight rippling or washboarding in areas of traffic acceleration or deceleration. Because the mixes were designed by recognized standard methods, produced and laid under exacting controls, and on check tests possessed stabilities well above minimum criteria, it appears that stability in itself is not always adequate to assure the desired service performance under heavy traffic.

The Bituminous Research Laboratory undertook the development of a device by which the trafficability or resistance of an asphalt mix to displacement under traffic could be evaluated and used as a check on design by stability procedures.

The instrument had to meet the basic requirements: (a) that it be compact enough to be used in a laboratory in conjunction with stability test procedures; (b) that it simulate the effects of traffic moving in one direction as nearly as possible; (c) that climatic conditions such as temperature and weather could be imposed on the mix

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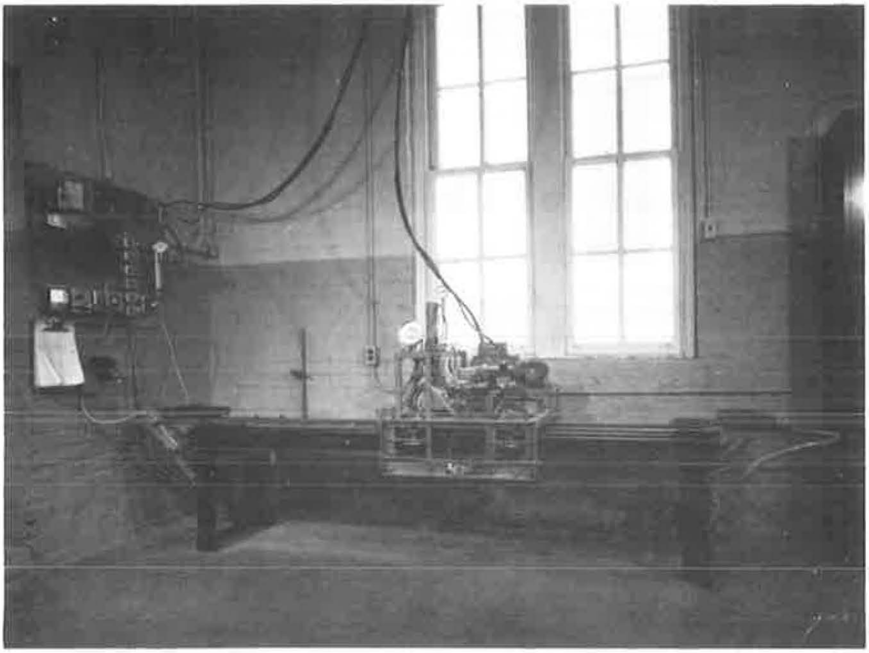

Figure 1. Traffic simulator.

under test; (d) that the extent and form of displacement under various volumes of traffic could be measured fairly accurately; (e) that the evaluation of trafficability could be related to the stability of the mix; and (f) that the trafficability of several mixes could be compared simultaneously.

Many ideas, concepts and theories of operation and controls, and tentative designs of the instrument were studied and investigated before development of the traffic simulator described herein. Because many adjustments and modifications were made as construction progressed, no detailed plans or drawings are available of the device.

Because the relation between the trafficability of a mix and its stability was of prime importance, it was decided that test specimens identical to those used in the Marshall and Hveem stability tests would be used in this test. Thereby the compaction variable would be eliminated and test results could be directly related to the method of stability test.

The manner of imposing the moving wheel load on the test specimen was resolved in favor of an oscillating carriage which is driven during its forward motion by the wheel imposing the load on the test specimens and during the reverse motion by an auxiliary drive. During the reverse motion the loading wheel is retracted, thus simulating only one-way traffic over the test specimens.

The traffic simulator is shown in Figure 1. It consists of a main frame, supported on legs bolted to the floor, in which the test specimen retainer box is installed and on which the carriage travels; a carriage which contains the loading wheel and other drive and control appurtenances; and a main operating control panel. Electrical power and compressed air are conveyed from the control panel to the carriage by the cable and hose suspended overhead.

The main frame is about 11 ft long, 3 ft wide and stands about 2 ft above the floor. It is composed of steel angles and channels so arranged as to provide tracks for the forward and backward movements of the carriage and to support the test specimen retainer box. The frame is also equipped with a group of thrust springs at each end which absorb the thrust of the carriage at the end of each run and which on release give the carriage an initial push on the reverse run. An electrical counter is mounted at the front end to total the number of forward passes made by the carriage in the course

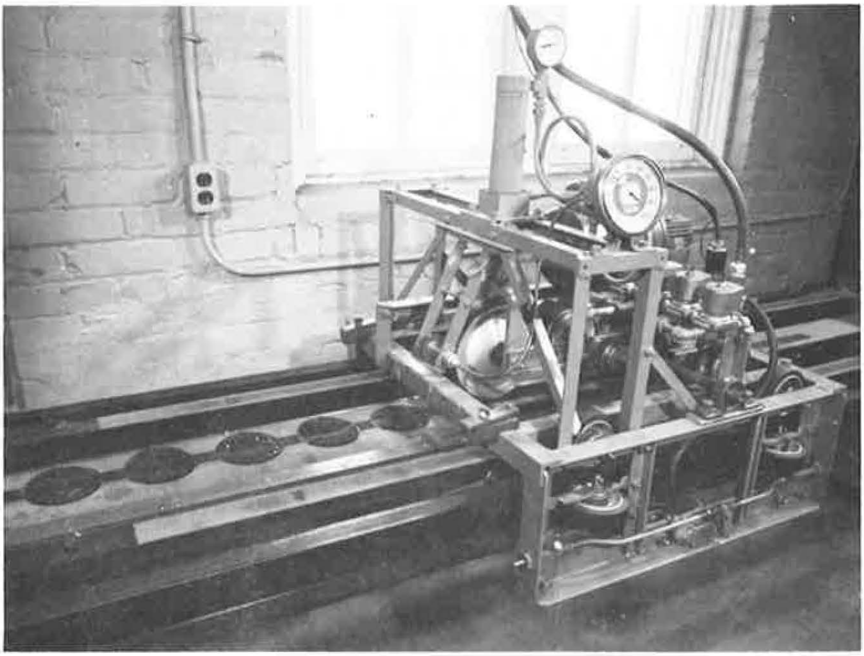

Figure 2. Traffic simulator, carriage and test specimen retainer box.

of a test. Adjustable spring load limit switch stops are provided at each end for the actuation of controls mounted on the carriage. The tracks on which the drive wheels of the carriage operate are surfaced with an abrasive for improved traction. At the forward end of the frame, space is provided for the installation of a removable test specimen retainer box in such a manner that the upper surface of the box is level with the loading wheel track and so that the loading wheel travels across the center of the surface of the test specimens (Fig. 2).

The carriage is designed to accommodate the loading wheel and the driving and control mechanisms necessary to operate it in an oscillating, to and fro, motion on the main frame. The carriage is equipped with two 4-in. diameter soft, solid rubber-tired, free-turning wheels on each upper side of the frame and four similar wheels on the underside of the frame to prevent the carriage from bucking during operation. Similar wheels are mounted, two on each side of the carriage, engaging the sides of the frame to prevent swaying (Figs. 2 and 3). A longitudinal rocker arm is mounted about centrally in the carriage. At its forward end is the loading wheel, 8 in. in diameter and 1½ in. wide and fitted with a 1⅛-in. wide soft, solid, rubber tire. At its rear, the rocker arm has two 5-in. diameter soft, solid, rubber-tired, reverse-drive wheels. The rocker arm is actuated by a 2-in. diameter vertical, double-acting, compressed-air ram which raises and lowers its front end to engage loading and reverse-drive wheels and also applies the desired pressure on the loading wheel. The loading wheel usually applies a load of about 80 psi to the test specimens, but this may be adjusted by varying the air pressure to the ram. The ram is operated and controlled by a limit switch mounted on the side of the carriage which actuates a number of electric solenoid air valves feeding air to the ram. The carriage is driven by a ½-hp motor mounted thereon and connected to the loading and reversing wheels through a reducing gear and belt and gear drives in such a manner that the wheels rotate in their respective directions continually. The travel speed of the carriage is about 4 mph, thus permitting about 1,400 passes of the loading wheel over the test specimens per hour. The travel speed may be somewhat varied by changes in drive gear or belt ratios. A tachometer attached to the loading wheel indicates travel speed. Holding clamps are provided at the front end of the carriage for the displacement measuring gage (Fig. 3). A small water tank

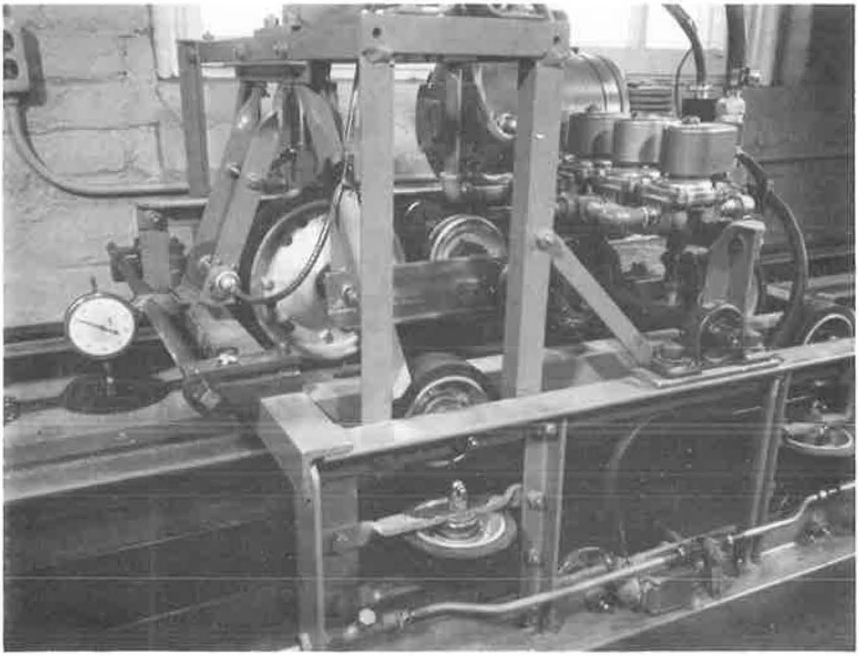

Figure 3. Traffic simulator carriage and displacement measuring gage.

operated by compressed air furnishes water to a fine water spray nozzle, simulating rain on the surface of the test specimens.

In starting, with power off, the carriage is manually pulled to the rear of the frame. The limit switch is then actuated so that when the power and compressed air are turned on, the ram lowers the rotating loading wheel, engaging its track to move the carriage forward. When the carriage reaches the front, several operations occur simultaneously. The thrust springs bring the carriage to a stop; the limit switch actuated by the stop raises the loading wheel and engages the reversing wheels, and the thrust springs release, starting the carriage in the reverse direction, thus reducing the strain on the reverse drive. When the carriage reaches the other end, a similar action takes place in which the loading wheel is engaged and the carriage moves forward again. By proper adjustment of the limit switch stops at the ends of the frame, a smooth forward and backward movement of the carriage may be secured.

The specimen retainer box is made of $3/8$-in. steel plates forming a box 36 in. long, 8 in. wide and $3\frac{1}{4}$ in. high. It is fitted with a $1/4$-in. thick steel cover in which $4\frac{1}{4}$-in. holes have been bored to hold and align the specimen holding rings in position centrally along the line of travel of the loading wheel on $5\frac{1}{2}$-in. centers. Six test specimens may be tested simultaneoulsy by this arrangement. In the bottom of the box under each holding ring position, three screws are provided for adjusting the surface of the test specimen level with the top of the retainer box.

The specimen holding ring is a steel tube $2\frac{3}{4}$-in. long machined to an outside diameter of $4\frac{1}{2}$ in. and an inside diameter of just slightly more than 4 in. so that a Marshall or Hveem stability test specimen 4 in. in diameter may be inserted tightly. The ring has a machined $1/8$-in. shoulder $1/4$ in. long around its top (Fig. 4). The shoulder fits into the hole in the cover of the box, thus aligning and locking the rings in position as the cover is bolted down. At the bottom of each ring is a $1/8$-in. thick circular steel plate. This plate serves as a solid base for the specimen and as a seat against which the screws in the bottom of the box act in adjusting the top of the specimen level with the top of the box. About 1 in. from the top of the ring a $1/8$-in. hole is provided through its side for insertion of a thermocouple to measure the temperature of the specimen during test. Each ring is also provided with a flexible heating tape, 1 in. wide and 24

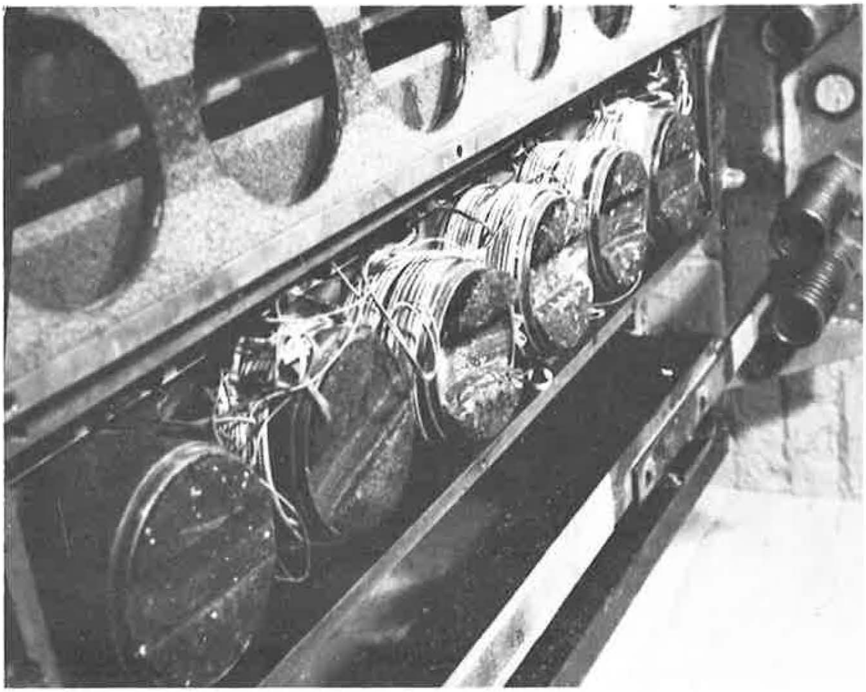

Figure 4. Assembly of specimen retainer box.

in. long, operating at 110 and about 200 w, which is wound around the outside of the ring for heating the specimens (Fig. 4). Plug-in electrical connections for both the heaters and thermocouples are provided inside the box. Specimen temperatures up to 200 F may be secured by this heating system. If cooling of specimens is desired, the inside of the box around the holding rings may be packed with dry ice.

The traffic simulator is operated from a main control panel mounted on the wall beside the instrument (Fig. 5). The electrical power controls, mounted across the top of the panel, consist of a main power switch, thermal overload relay, toggle switch for automatic controls on the carriage, drive motor start-stop switch, and a plug-in outlet for connection of overhead power cable to the carriage. Compressed air at 150 psi is piped to an air pressure regulator valve and gage, mounted on the right side of the panel, from which compressed air at the desired pressure is conveyed to the carriage by the overhead flexible pressure air hose. Specimen heating is controlled by a 15-amp, 0- to 240-v variac with telltale voltmeter and individual toggle switches connecting to the heater tapes on the respective holding rings. These controls are mounted in the center of the panel. The thermocouples inserted in each of the specimens are connected to a dial pyrometer through a selector switch. Thus, the temperature of any one of the specimens may be read at any instant. These instruments are mounted at the lower left-hand section of the panel and are connected to the specimen retainer box by plug-in multiple wire cables.

The temperature of the specimens is controlled manually in the following manner. The variac is set at 115 v and the individual switches are turned on. The temperature of each of the specimens is read periodically noting the rate of rise of temperature. As the temperature approaches the test temperature, the voltage on the variac is reduced so that the desired temperature is maintained. Temperature may also be maintained independently on individual specimens by operation of their respective control switches. In this manner specimens may be tested at different temperatures.

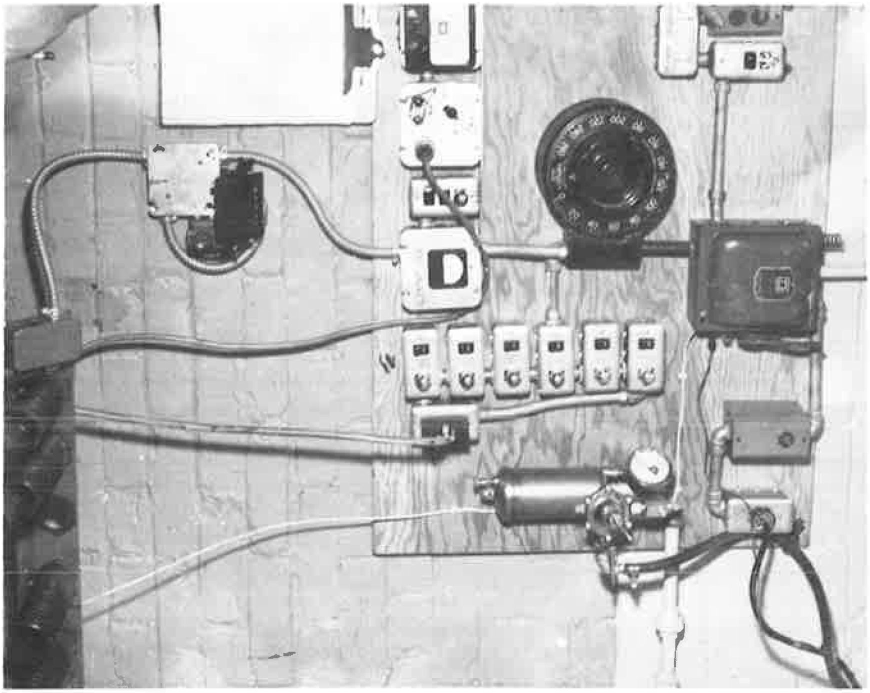

Figure 5. Control panel.

TRAFFIC SIMULATOR TEST PROCEDURE

Because the traffic simulator test was devised primarily as a check on behavior of mixes under a moving load, it is desirable that at least two specimens of mixes compacted by standard procedure for test by Marshall or Hveem stability be made available.

The compacted test specimen is inserted into a holding ring over the base plate with its top surface flush with or slightly below the top of the ring. If the specimen fits loosely in the ring, metal shims are inserted around its side to tighten it. A small hole is bored into the specimen through the thermocouple hole in the ring and the thermocouple is inserted. The holding ring is placed into the retainer box over the adjusting screws. When all holding rings containing specimens, or dummies if sufficient number of specimens are not available, are in position in the box, the box cover is put in place with the tops of the rings inserted in the holes therein. The cover is then bolted down onto the box, thus bringing the rings into proper alignment. Each specimen is then adjusted to bring its top surface level with the top of the box by the adjustment screws.

As soon as the specimens are in position, the heaters are turned on and the specimens are brought to the desired test temperature. Tests have been conducted at room temperature, and at 100, 140 and 160 F; however, 100 F has been arbitrarily selected as the test temperature for most so far conducted. About 20 to 30 min are needed to raise and adjust controls to maintain specimen temperature at this level. When specimens have attained the test temperature, the surfaces of the specimens are again checked for level with the top of the box and readjusted if necessary.

The Ames dial displacement gage, reading to 0.001 of an inch, is attached to the carriage. The carriage is then moved over a bench mark on the forward end of the frame and the displacement gage is set at zero. The gage is then moved on its support to the center line of loading wheel travel and locked into position. Gage readings are taken on the surface at back, center, and front of each specimen. The points where measurements were taken are marked on the specimen and beside the specimen on the box cover to assure that subsequent measurements are taken at the same points.

At the beginning of the test, the counter is set for 300 passes and the compressed air pressure is set for desired loading on the loading wheel. Forty pounds pressure has been used in most tests conducted because it provides an equivalent of 80-psi tire loadings on the specimens. The main power switch is then turned on, the automatic controls on the carriage are actuated and the drive start button is pushed; the carriage moves forward and backward automatically. Specimen temperatures are checked periodically with the pyrometer. After 300 passes have been completed, the counter automatically stops the carriage.

The displacement gage is again attached to the carriage, the bench mark is checked and readings are taken at the same points on the specimens as before. The initial 300 passes set the specimens in their holders. If desired, the readings at this time may be taken as the data for further displacement in preference to the original readings. If the specimens tend to rotate in the holders, they should be wedged into position by side shims. After the readings have been taken, the gage is removed, the counter is set for a total of 1,000 passes and the test is continued. Displacement readings are taken and recorded after each successive 1,000 passes. The test may be continued for any number of passes desired or may be discontinued when specimens show excessive displacement or distress. Usually the tests have been conducted for 5,000 passes.

On completion of the test, total displacement at each of the three points is calculated for 1,000, 2,000, 3,000, 4,000, and 5,000 passes. Thus, mixes may be evaluated or compared on the basis of the displacement occurring after a certain number of passes or of the number of passes required to create a predetermined amount of displacement. Generally, comparisons have been made on the basis of total displacement occurring at the center of the specimen at 5,000 passes. Mixes that show a displacement of more than ⅛ in. at or before 5,000 passes are arbitrarily deemed suspect to distress under traffic. Displacements occurring at the front or rear of the specimens in the form of excessive depression or heave are indicative of a tendency of the mix to shove. Such results must be evaluated independently.

On removal from the rings after completion of the test, the specimens may be subjected to further observation and test. The specimens may be sawed in sections by a diamond saw and the effects of traffic upon orientation of particles, degradation of particles, absorption of asphalt by particles, densification of mix and other features may be observed and tested.

TEST RESULTS

Mixes of different compositions behave in various ways in the traffic simulator test. Most mixes having a fairly good resistance to displacement under a moving load displace in the test in a shape similar to a catenary wherein the greatest displacement occurs in the center of the specimen and but little at the ends (Fig. 6). In such cases the material appears to be pushed to the sides of the wheelpath. Other mixes of lesser resistance tend to displace sharply at the rear of the specimen with displaced material pushed ahead into a heaved section at the forward end. Some mixes resist displacement for 30,000 to 50,000 passes, whereas others displace excessively within 1,000 to 2,000 passes. Others resist displacement for 3,000 to 4,000 passes and then fail suddenly after a few hundred additional passes. Still others displace somewhat in the first 1,000 to 2,000 passes and then resist further displacement up to and beyond 5,000 passes. Temperature appears to have a material effect on behavior. Some mixes resisting displacement at 100 F up to 5,000 passes show excessive displacement within a few thousand passes when the temperature is raised to 140 F. This is particularly true of mixes with higher asphalt contents. Generally, the amount of displacement at 140 F is greater than at 100 F for the same mixes.

Test specimens cut into sections on conclusion of the test exhibit some interesting results. A definite orientation of coarser aggregate particles can be noted in mixes having higher asphalt contents and larger quantities of fine aggregates. Degradation of particles in dryer mixes can also be observed. Excessive absorption of asphalt by

TABLE 1

TRAFFIC SIMULATOR TEST RESULTS

Filler (%)	A. C. (%)	Displacement[a] (0.001 in.) No. of Passes 1,000	3,000	5,000	Marshall Stab. 50 Blows	Displacement[b] (0.001 in.) No. of Passes 1,000	3,000	5,000	Hveem Stab. Dry	Iowa Stab. Wet
(a) Ocheydan Aggregate										
Lime:										
0.0	4.1	47	60	70	470	57	67	NR	34	27
	4.6	55	90	110	927	62	75	NR	53	19
	5.1	120	192	400	450	130	137	140	32	26
2.5	4.1	85	85	100	1,725	90	91	NR	38	39
	5.1	102	157	185	1,925	130	160	178	35	35
	6.1	109	140	162	1,470	74	74	81	47	27
5.0	5.0	90	118	118	937	55	92	115	40	28
	6.0	104	128	139	970	10	30	51	52	28
	6.9	79	160	189	1,875	60	90	112	40	26
7.0	4.9	72	90	100	2,045	25	40	40	44	32
	5.8	78	95	131	1,120	4	12	21	46	36
	6.7	122	240	NR	1,500	120	145	155	35	47
10.0	5.2	70	90	106	2,373	70	80	123	47	24
	6.2	127	187	230	1,308	175	268	NR	46	45
	7.0	485	NR	NR	1,875	477	NR	NR	40	26
Loess:										
2.5	4.0	125	210	NR	488	120	140	NR	40	43
	5.0	95	110	110	815	46	70	87	40	41
	6.0	122	153	160	803	50	60	60	46	36
5.0	5.0	68	88	110	1,600	40	60	69	42	36
	6.0	122	149	181	1,440	10	29	40	41	26
	7.0	443	NR	NR	1,335	50	NR	79	36	42
7.0	5.0	95	100	211	1,030	NR	NR	NR	47	34
	6.0	75	75	204	1,315	6	10	10	62	25
	7.0	135	158	165	1,263	28	28	28	36	42
10.0	6.0	70	72	90	1,780	95	100	100	52	23
	7.0	175	240	NR	1,170	NR	NR	NR	50	36
	8.0	317	NR	NR	1,480	41	70	75	44	43
(b) Garner Aggregate										
Lime:										
0.0	4.2	NR	NR	NR	190	98	115	NR	44	28
	4.7	70	120	140	430	139	160	175	32	35
	5.1	135	185	192	310	111	140	151	43	32
2.5	4.2	80	130	145	1,045	115	140	NR	44	35
	5.2	60	90	110	1,410	87	110	115	46	36
	6.1	130	180	207	1,215	25	68	100	51	27
5.0	5.0	360	NR	NR	710	30	129	130	53	23
	6.0	148	248	NR	1,230	97	110	110	54	30
	7.0	571	NR	NR	1,060	507	NR	NR	51	49
7.0	5.0	50	59	72	1,730	58	65	88	42	28
	6.0	70	80	204	1,375	77	90	110	48	30
	7.0	125	310	NR	965	180	283	NR	37	55
10.0	5.0	48	68	70	1,790	95	120	127	50	26
	6.0	85	100	120	1,255	160	160	185	53	28
	6.8	104	130	145	1,630	155	250	NR	52	23
Loess:										
2.5	4.0	NR	NR	NR	1,245	70	80	NR	52	27
	5.0	80	80	95	1,275	50	85	100	54	27
	6.0	50	70	75	1,240	30	37	37	48	25
5.0	5.0	80	85	103	1,340	85	105	105	42	43
	6.0	123	142	181	1,170	0	15	25	39	45
	7.0	135	271	NR	1,080	95	130	149	50	49
7.0	5.0	31	40	40	1,505	57	63	63	46	30
	6.0	102	125	139	1,080	80	80	80	47	30
	7.0	139	170	190	1,550	119	150	185	32	65
10.0	5.0	70	75	78	1,690	70	72	72	68	60
	6.0	50	55	65	1,460	40	40	40	41	68
	7.0	90	90	90	2,025	35	40	40	38	49
	8.0	157	165	185	1,585	25	40	56	28	63
(c) Columbus Junction Aggregate										
Lime:										
0.0	4.0	25	63	110	820	5	15	25	NR	42
	4.5	9	9	40	660	20	33	40	43	41
	5.0	25	40	40	730	35	40	40	35	47
2.5	4.0	5	11	28	750	16	25	25	41	44
	4.8	8	10	18	870	3	20	20	40	47
	6.0	8	8	20	810	5	10	35	41	47
5.0	4.9	0	23	30	1,028	25	25	30	39	47
	6.1	33	37	50	960	25	25	25	43	52
	7.0	23	40	52	890	15	35	40	35	52
7.5	5.1	18	25	35	1,410	20	40	48	40	44
	6.0	22	70	87	1,230	9	30	40	41	51
	6.9	15	23	45	1,240	20	40	57	37	53
10.0	6.0	17	45	55	1,510	15	15	45	41	46
	7.1	23	50	63	1,310	35	41	53	29	67
	8.2	10	40	53	657	65	105	110	NR	NR
Loess:										
2.5	4.0	10	35	39	1,060	11	15	15	33	41
	5.0	3	15	17	1,050	25	30	30	38	43
	6.0	3	10	10	1,090	11	15	25	40	47
7.0	5.0	0	8	10	1,380	3	3	7	39	47
	6.0	9	12	15	1,550	10	10	18	47	43
	7.0	10	20	25	1,500	14	14	18	34	53
10.0	5.0	NR	NR	NR	1,710	5	9	9	44	36
	6.0	10	10	10	1,500	10	10	10	43	67
	7.0	6	10	21	1,050	3	5	10	39	73

[a]Samples dynamically compacted. [b]Samples statically compacted.

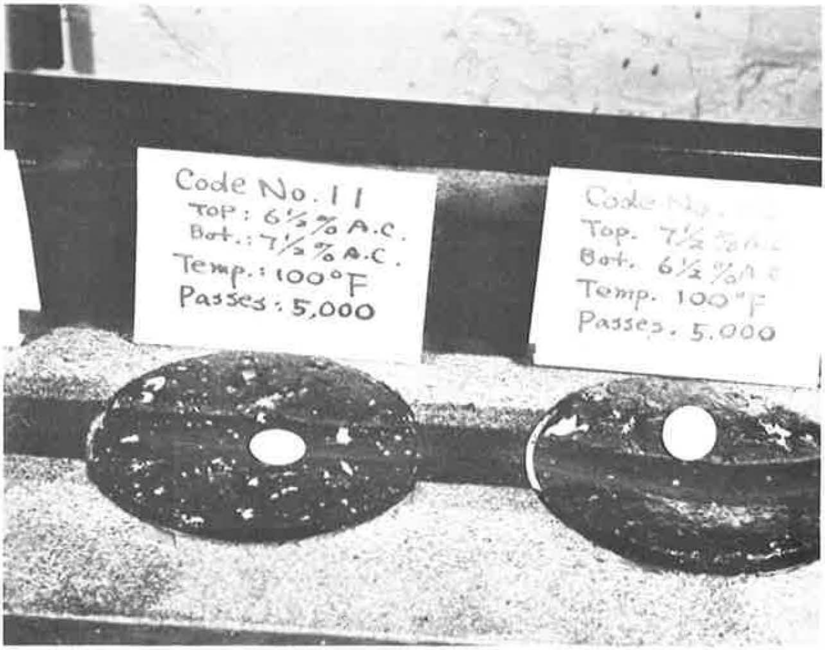

Figure 6. Displacement of mix after test.

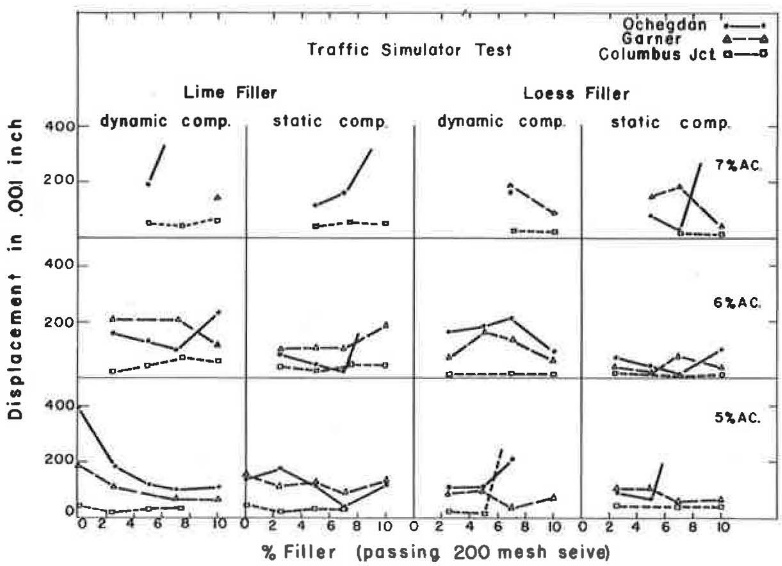

Figure 7. Displacement of samples at 5,000 passes.

aggregate particles is clearly apparent in mixes containing absorptive or relatively porous aggregates. Densification of the mix under the wheelpath is also quite noticeable. By proper sectioning of the test specimen, variations in density and asphalt content in several sections may be determined by test.

The results of an investigation conducted at the Bituminous Research Laboratory are presented here as an example of the type and character of results obtained in the traffic simulator test. The mixes in that investigation contained three different types of aggregates and two different types of fillers. Details of physical properties of materials, and mix proportions, are given by Csanyi et al. (1). The three aggregates used were a partially crushed gravel, designated as Ocheydan; a hard crushed limestone, called Garner; and a softer crushed limestone, referred to as Columbus Junction. The fillers used were a limestone filler and a pulverized loess filler. Mixes of each of the fillers containing a range of asphalt contents were tested for trafficability, Marshall, Hveem and Iowa stabilities. The results of these tests are given in Table 1, and the trafficability results at 5,000 passes are plotted in Figure 7. The notation NR, indicating no definite results, means that a displacement in excess of ½ in. was secured at that point in the traffic simulator test.

DISCUSSION OF RESULTS

The trafficability results at 5,000 passes (Fig. 7) indicate that the behavior of mixes containing various combinations and proportions of materials can be evaluated and compared as to their resistance to displacement under a moving load by the traffic simulator. The evaluation or comparison may also be based on the type of aggregate, type and quantity of filler or asphalt, methods of compaction, and specimen densities. The test also discloses the rate of distress with relation to number of passes and temperature.

The results also show that no direct relationship exists between trafficability of a mix and its stability, regardless of the method used to determine stability. Mixes with relatively high stabilities, particularly those with the higher asphalt contents, tend to fail, whereas mixes with lower stabilities stand up quite well under the traffic simulator test.

The traffic simulator test has been compared with field service behavior in only two instances. In both of these cases the mixes being laid possessed more than adequate stabilities and met all other criteria for a high-type pavement. On test in the traffic simulator these same mixes indicated a tendency to distress under a moving load. Within a year in service both pavements began to show some distress in the form of rutting and channeling in the wheel track areas. This experience confirmed that mixes designed in accordance with accepted criteria are not always adequate to meet the stresses of heavy traffic and indicated that some form of additional check, such as the traffic simulator, capable of denoting a tendency to distress, is needed if the desired service behavior is to be assured. Several other service comparisons are now in progress.

No attempt has yet been made to establish definite criteria for this test by which the suitability of a mix for various volumes or types of traffic may be assessed. However, based on experiences with mixes known to perform satisfactorily and on the behavior of the mix during test, certain specific test conditions have been adopted. These include a specimen temperature of 100 F during test, an applied wheel load of 80 psi, and an arbitrary maximum displacement of ⅛ in. after 5,000 passes as an indication of the ability of the mix to resist the effects of heavy traffic volumes. There is no assurance that these conditions are correct or that test results obtained under them are directly related to service behavior. Only further correlation between traffic simulator results and service records can establish their reliability or indicate the adjustments needed to develop dependable criteria for the instrument.

However the test results indicate that, under the conditions adopted, the traffic simulator may be used as a supplementary check of the behavior of a mix under a moving load. It may also be employed as a research tool to investigate the effects of simulated traffic on the internal structure and behavior of a mix.

REFERENCE

1. Csanyi, L. H., Cox, R. E., and Teagle, C. R., "Effect of Fillers on Concrete Mixes." Highway Res. Record 51 (1964).