"THE AASHO HIGHWAY RESEARCH PROJECT"

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The AASHO road research project is a $22 million experiment aimed primarily at determining significant relationships between performance and traffic for highway pavements of known designs under controlled truck traffic with known loadings.

The project is sponsored by the American Association of State Highway Officials, and is being administered by the Highway Research Board of the National Academy of Sciences–National Research Council.

The cost is being borne by the States, District of Columbia, Hawaii, Puerto Rico, the Bureau of Public Roads, the Automobile Manufacturers Association, and the American Petroleum Institute with cooperation and assistance from the Department of Defense.

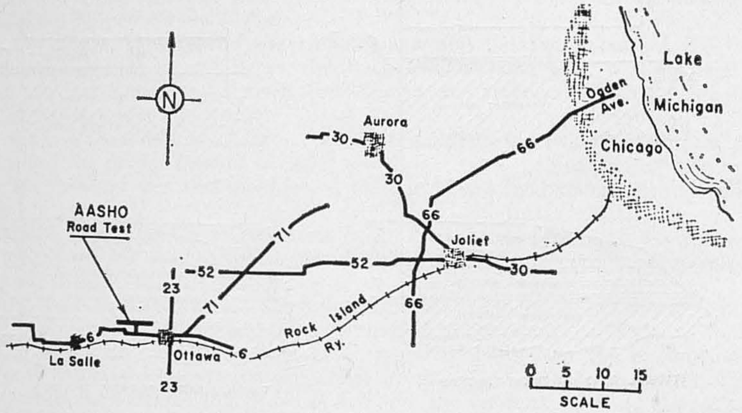
The test is being conducted on six carefully-constructed loops of pavement at Ottawa, Illinois, about 80 miles southwest of Chicago, in an area where climate and soils are typical of wide areas of the nation.

Nearly seven years of planning and preparation preceeded the beginning of the research phase of the AASHO Road Test in October, 1958; and the project represents the cooperative effort of many persons from various phases of highway engineering, research and science.

Basic planning for the project was under a Working Committee of the AASHO Committee on Highway Transport. When this committee had completed its task, the Highway Research Board was requested to undertake the project, and overall guidance was placed in the hands of a National Advisory Committee composed of representatives of several state highway departmetns, the Bureau of Public Roads, the Department of the Army, universities, related industry organizations, and highway user groups.

In addition, there are advisory panels which function in specific fields such as statistics, soils, instrumentation, public information, materials and construction, maintenance, vehicles, bridges, performance rating, and economic data.

The Highway Research Board established a field office at the project site in 1955, and now has a staff of about 140 persons employed there. Research operations are organized under three principle branches—rigid pavements, flexible pavements, and bridges. These branches are supported by staff-level service branches in the fields of data analysis, vehicle operations, pavement maintenance, instru-



1. Location map.

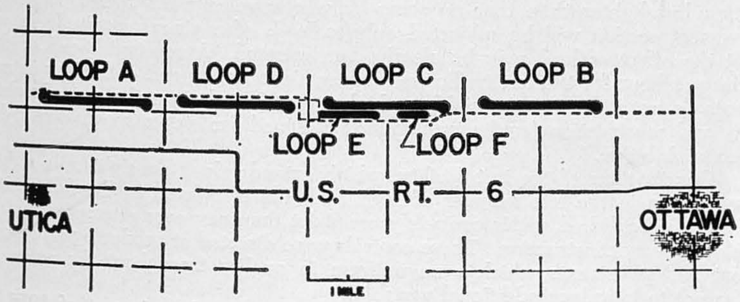
mentation, materials, and special assignments. The heads of these branches along with the Project Director, Chief Engineer for Research, Business Administrator, and Chief of Public Information comprise the project staff.

To provide personnel for operating the test vehicles, the United States Army Transportation Corps Road Test Support Activity was established by the Department of Defense. This is a special unit of about 300 officers and enlisted men who will be stationed at the project throughout the research phase of the test.

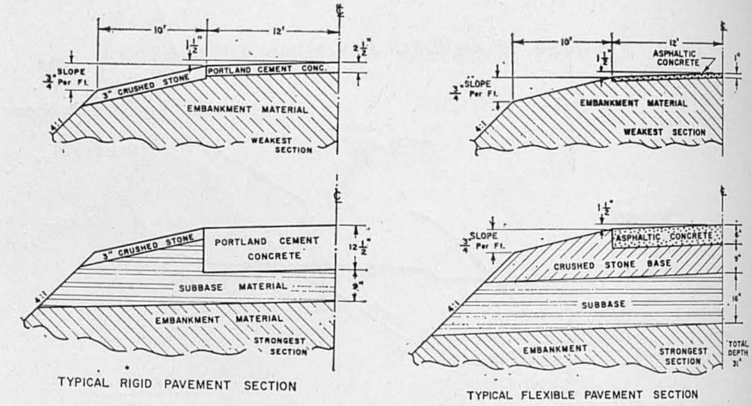
The AASHO Road Test is not only larger and more comprehensive than any previous large-scale highway research project, but is the first to be designed in accordance with modern scientific principles of experiment design.

Seven independent variables were selected for control at more than one level. The final selection was made after careful consideration from perhaps hundreds of possibilities by members of the National Advisory Committee. It was early agreed that orthogonal experiment designs would be used throughout. This decision meant in effect that every variable added practically doubled the size of the project. Thus, it was necessary to restrict severely the number of variables that will be studied. Those selected were considered by the Committee to be the most important for consideration in a test of this type. They are:

1. Pavement surfacing type. Half of the test pavements are surfaced with portland cement concrete and half with bituminous concrete.
2. Surfacing reinforcement. Half of the concrete pavements are reinforced and half are plain.



2. Layout of test loops.



TYPICAL RIGID PAVEMENT SECTION

TYPICAL FLEXIBLE PAVEMENT SECTION

3. Typical cross-sections of rigid and flexible test road construction.

3. Surfacing thickness. The asphalt concrete surfacing thickness varies in one-inch increments from one to six inches. Sections with surface treatment are also included.

Concrete slab thicknesses vary across the job in 1½ inch increments from 3½ to 12½ inches. Certain sections 2½ inches thick are included.

4. Base thickness. Under the flexible pavements crushed stone base varying in three-inch increments from zero to nine inches thick are included.

5. Subbase thickness. Under the concrete slabs, sand-gravel subbase with thicknesses from zero to nine inches in three-inch increments are included.

Under the flexible pavements subbases in four-inch increments range from zero to sixteen inches thick.

6. Axle spacing. On the main test loops half of the vehicles are single axle tractor semi-trailers, the other half are tandem axle tractor semi-trailers.

7. Axle load. Single axle loads on the project range from 2,000 lbs. to 30,000 lbs. Tandem axle loads from 24,000 lbs. to 48,000 lbs.

Special side studies permit consideration of base-type (crushed stone, crushed gravel, bituminous treated sand-gravel and cement treated sand-gravel) and the effect of paved shoulders. There are also included sixteen test bridges designed to permit study of behavior of structures under high stresses.

Controlled traffic with known axle loads and axle spacing is being operated at a rate of about fifty vehicle trips per hour for eighteen hours a day, six days a week. This traffic density is heavier than that found on most highways of the nation but lighter than that on some heavily traveled truck routes. Any given pavement section will be subjected only to loads of a given magnitude in order that the effect of load may be clearly demonstrated. A constant speed of thirty miles per hour for the test traffic was chosen since strains and deflections in pavements do not increase appreciably at higher speeds and since the cost of right-of-way and construction for the turnarounds designed for higher speeds would have been prohibitive.

Construction of the test facility, which extends along an eight mile right-of-way, began in the late summer of 1956 and was completed in the fall of 1958. It was accomplished under controls more strict than any ever attempted in large-scale highway construction. These controls were directed at producing an embankment and pavements which were uniform in quality throughout the entire job, so as not to introduce additional variables.

Construction of the earth embankments began in late August of 1956. By mid-November, when operations were suspended for the winter, more than a million and a quarter cubic yards of earth had been moved and the embankments were about 95 percent completed.

The upper three feet of the embankment material—about half of the total cubic yardage—was placed under rigidly-controlled conditions. The material, a fine-grained clay, was hauled from three borrow pits adjacent to the right-of-way, and placed in six-inch loose lifts.

Each lift was processed with rotary tillers which thoroughly mixed the soil and added the proper amount of water.

The lose soil was then compacted to four inches by pneumatic-tired rollers loaded to 15 tons.

Specifications for the embankment called for holding density between 95 and 100 percent of standard AASHO maximum, and moisture content between plus or minus two percent of optimum.

In order to preserve this carefully-controlled compaction, all of the equipment working on the embankments was required to operate in controlled patterns, and no equipment was allowed to turn around or cross over the embankments except in designated transition areas which are not a part of the test sections.

During the earthmoving phase of the job, the contractors—S. J. Groves and Sons Company and Arcole Midwest Corporation—assembled a large concentration of heavy equipment in order to operate simultaneously in the four main test loops. At one period, it was estimated that some 225 pieces of equipment valued in excess of $5 million were on the job.

The embankments were completed and subgrading began in the 1957 construction season. Mechanical subgraders, riding on forms, brought the embankment to exact grade. The specifications permitted a tolerance of plus or minus one-eighth inch. This same operation was also carried out on succeeding layers of base and/or subbase, making it necessary to set forms twice on the rigid pavement tangents and three times on the flexible pavement tangents.

Another interesting feature of the specifications was the banning of all heavy hauling equipment from the center 27 feet of the embankments. This meant

4. **Concrete pavement operation.**

5. **Flexible pavement operation.**

that the subbase and base material was placed with equipment operating from the shoulder area of the roadway.

The subbase material is a sand-gravel mixture procured from a pit near the job site. The pit-run material was washed, screened and run through a batching plant in order to closely control the gradation. This material was placed on the subgrade by a conveyor belt system and a spreader pushed by a tractor.

The base material—a crushed limestone—was produced to specifications by a quarry near Romeoville, Illinois, and brought to a point near the job site by rail. This material was placed by running it through a modified paver which added water and employed a conveyor belt on its boom to carry the material to a self-propolled spreader.

The contract for paving the test loops was awarded in late August 1957 to the S. J. Groves and Sons Company, which subcontracted the asphaltic concrete paving to Rock Road Construction Company.

The remainder of that construction season was utilized to bring in equipment, set up plants, and construct pilot test sections. The pilot test sections, built between the main loops, allowed the engineers and contractors to experiment with various methods and equipment in placing paving to meet the specifications. For example, the rigid pavement pilot test section included placing of 2½-inch and 3½-inch reinforced concrete slabs. These usually thin sections do not represent normal practice, and special techniques were required.

Some Portland cement concrete pavement was placed on the loop turnarounds before operations were suspended for the winter.

At the beginning of the 1958 construction season, it was apparent that an all-out effort was needed if the target date for completion of construction was to be met. Some appreciation of the magnitude of this effort can be gained from the fact that the combined forces of the contractors and the project totalled nearly 700 persons at the height of operations.

Portland cement concrete paving was begun on the test tangents on May 19. Two identical paving outfits were placed in operation, and the work proceeded rapidly. The final section of rigid pavement was placed on July 10.

On the flexible pavement tangents, it was, of course, necessary to place an additional layer of material—the crushed stone base. Considerable preliminary work also was required on a pilot test section where various mix designs were tried, as well as various roller types, weights and rolling patterns for the different thicknesses of asphaltic concrete surfacing.

The first asphaltic concrete was placed on the test tangents on July 9, and the final piece of surface course was placed on September 24. Here, again, was an example of an unusual operation. Trucks carrying the asphaltic concrete from the plants were not allowed to operate on the center portion of the grade where they could dump directly into the paver. Instead, the trucks remained on the shoulder area, and the asphaltic concrete mix was transferred to the paver by a pneumatically-operated shovel.

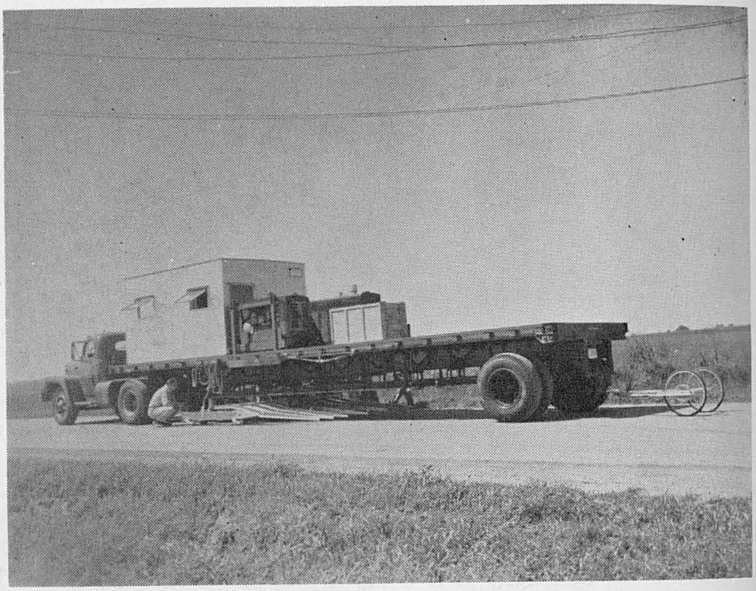
The final construction work consisted of bringing shoulders up to grade, joint sealing, seeding, and surface treatment of frontage roads. This work was complete when test traffic was officially inaugurated on October 15.

Obviously, large-scale highway construction, carried out under rigid specifications, required a huge program of sampling, testing and inspection. Qualified engineers supervised a corps of technicians in this phase of the job. Many thousands of samples were taken, both at the source of the materials and on the job. During some phases of the work, production line methods were needed to handle the continuous flow of samples.

One piece of equipment that was highly important in the materials testing program was a continuous drying oven, designed by staff members and built locally. This oven required only 23 minutes to dry a sample of material as opposed to the several hours required in a conventional oven.

Another interesting piece of test equipment was a device which employs nuclear energy to determine the density of materials. The operation of this equipment is based on the fact that the attenuation of gamma radiation increases with increase in density. Experimentation with this equipment has been under way at the project for about two years, and the device was used to determine in-place density of the base course material.

6. Four of 16 test bridge slabs.



7. Transverse profilometer. This instrument measures depth of ruts in the traffic wheel paths.

During the final construction season of the spring and summer of 1958, the project purchased and made ready the fleet of 70 vehicles which are now being operated over the test pavements. The vehicles wer purchased on a competitive bid basis, so arranged that no one manufacturer could monopolize the test vehicle fleet.

As a result there are 10 different makes of trucks and tractors and seven different makes of semi-trailers being used on the job. These include Ford, Chevrolet, GMC, Dodge, International Harvester, Reo, White, Mack, Diamond T, and Autocar trucks and tractors; and Andrews, Kingham, Lufkin, Highway, Hobbs, Dorsey, and Alabama semi-trailers.

The vehicles were loaded with concrete blocks tied down with steel bands. The first attempts at loading employed hollow-core building blocks in order to hold down the over-all density of the loads and make them somewhat comparable to average on-the-highway loads. It was discovered, however, that these loads resulted in a center of gravity too high for safe operation on the 200-foot-radius turnarounds on the main loops. As a result, many of the building blocks have been replaced with solid concrete blocks.

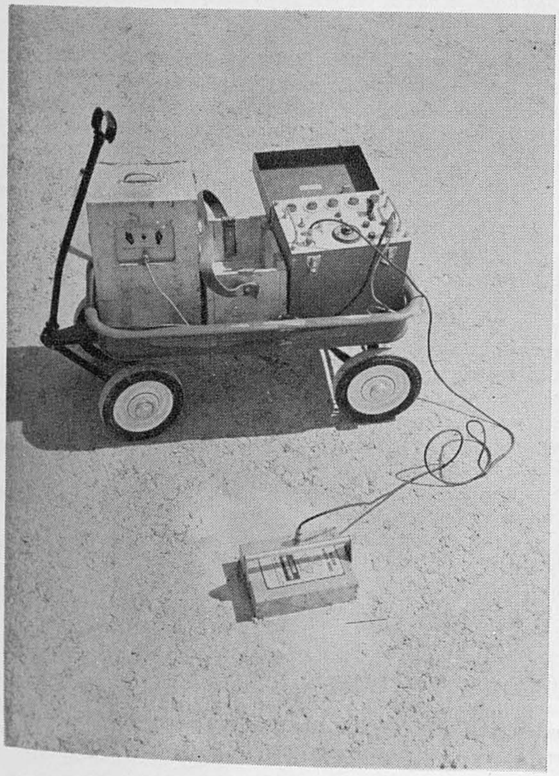
The vehicles are being operated in 10 traffic lanes in five of the six test loops. The smallest loop, with 2000-foot tangents, is being used to provide information on the behavior of the pavements with no traffic whatsoever, and for special tests under static loading. Another small loop, with 4400-foot tangents, is subjected to the lightest axle loads—2000 single on one lane and 6000 single on the other lane.

The other four loops, generally called the "main" test loops, have 68000-foot tangents. The axle loads in these loops are 12,000 single and 24,000 tandem, 18,000 single and 32,000 tandem, 22,400 single and 40,000 tandem, and 30,000 single and 48,000 tandem. The latter two loads are heavier than any allowed on the highways today.

The tangents of the test loops are subdivided into structural sections 24 feet wide and made up of various thicknesses of surface, base and subbase. Flexible pavement sections are 100 feet long; reinforced concrete sections are 240 feet; and plain concrete sections are 120 feet. All sections are separated by short transittion areas.

Within any given tangent the experiment design calls for a complete factorial in which all levels of each selected variable appear in combination with all levels of every other variable. For example, in the flexible tangents of one test loop, there are three thicknesses of asphaltic concrete (3, 4 and 5 inches), three thicknesses of crushed stone base (0, 3 and 6 inches), and three thicknesses of sand-gravel subbase (0, 4 and 8 inches). All possible combinations of these thicknesses are included to make a 3x3x3 factorial with a total of 27 different structural sections. Some of these sections are replicated, or repeated, in the tangent; and some special study sections are included to make a total of 42 structural sections. Since traffic on the inner lane carries one axle load, and traffic on the outer lane carries another axle load, each 12-foot lane is considered to be a separate test section. Thus, there are 84 test sections in this tangent. On the entire project, the number of test sections is 836, and all are located at random within their respective tangents.

The Army personnel operating the test vehicles are quartered in a $450,000 housing-administration area provided by the project. Drivers work in two shifts per day on a schedule which is shifted every two weeks so that traffic coverage during day and night hours is about equal. Operations are halted on Sundays, and each driver is also off duty one other day per week. On a normal shift, a driver is on duty about 10 hours. However, a 10-minute break each hour and half-hour meal periods make actual driving time about seven and a half hours per



8. Field unit for nuclear measurements of construction densities.

9. Traffic in operation on one of the test loops after a snow storm.

shift. It has, of course, been realized that the drivers provide an excellent opportunity for studies of fatigue and the effects of monotonous driving conditions. Plans for such studies are being made by the appropriate agencies.

The effects of the controlled test traffic on the pavements is being measured and recorded by means of a complex system of electronic and mechanical instruments and data handling equipment. Many of the instruments are entirely new, developed specifically for this project, and represent in themselves an important step forward in highway research. The majority of the devices are electrical in nature; and, therefore, are highly sensitive, and can be placed in otherwise inaccessible spots, can detect phenomena which take place too fast for visual observation, and can be used with automatic recording equipment.

Electric transducers installed on or in the pavements include strain gages, thermocouples, frost depth indicators, curvature strips, and conventional linear differential transformers to measure deflection.

Measurements from these transducers are recorded on electronic equipment installed in movable vans which can plug into terminal boxes along the roadway and record transient behavior of the pavement as the test traffic is running.

This recording equipment is designed to digitize the output of the electrical transducers and to punch the data into paper tape.

The tape is then brought into the project's data processing complete IBM set-up is installed at the project for handling the data.

Analysis of the data will be done to a great extent on a Bendix G15-D digital computer which is also installed at the project. However, some of the more cumbersome and time-consuming analyses will be done on larger computers at nearby universities.

Perhaps the most interesting of the instruments in use on the project are those designed to measure surface deformation.

These include an automatic model of the "Benkelman Beam," an instrument designed to measure and record surface deflections in flexible pavement near the rear wheels of a loaded trailer. This device operates automatically at regular intervals as the vehicle moves along the roadway at about three miles per hour. Its seven probe arms measure eleven deflections, and the data is automatically recorded on equipment carried on the trailer.

There is also a transverse profilometer, consisting of a truss supporting nine pneumatically-operated probes. This device is carried along the roadway by a van and placed down at any desired spot. It can be used to provide a nine-point profile; or by employing the probes in groups of three, to read directly the rut depth in flexible pavements. The recording equipment installed in the van can be used to automatically average the readings from the two outer probes and subtract this average from the reading of the center probe, thus giving a direct depth-of-rut result.

Perhaps the most difficult of the instrumentation problems was the development of a longitudinal profilometer. This device measures and records, on oscillograph tape, the slope of the pavements in the wheel paths of the test vehicles. It operates as the trailer is towed along the roadway at about seven or eight miles per hour. Development of this instrument included, among other things, a unique horizontal reference system.

The longitudinal profilometer is one of the most important devices on the project, and will be used frequently. It is estimated that during the two-year test period, it will produce an actual 42 miles of oscillograph tape. Turning this analog record into digital form entails reading the tape at intervals of about seven per inch. Therefore, an automatic chart reader is used for this task. The digitized information is punched into paper tape which can be run directly into the computer for analysis.

It is obvious that with equipment such as has just been described that a large amount of data will be generated. It has been estimated that the test will produce some hundreds of millions of pieces of data. If it were not for automatic recording equipment and electronic computers, it would be impossible to conduct an experiment of this magnitude.

10. Test truck on flexible pavement tangent.

11. Tape to card punch. Data are recorded on perforated paper tape in the field and transferred to punched cards in the processing center.

It is difficult to say at this point in the research just what form the final findings will take or exactly how they will be used by highway administrators and engineers. However, some idea of the nature of what is being sought can be gained from the official objectives of the test. These objectives have determined much of what has and what will be done at the test site. They are:

1. To determine the significant relationships between the number of repetitions of specified axleloads of different magnitude and arrangement and the performance of different thicknesses of uniformly designed and constructed asphaltic concrete, plain Portland cement concrete, and reinforced Portland cement concrete surfaces on different thicknesses of bases and subbases when on a basement soil of known characteristics.

2. To determine the significant effects of specified vehicle axleloads and gross vehicle loads when applied at known frequency on bridges of known design and characteristics. The bridges will include steel I-beam design, conventional reinforced concrete design, and prestressed concrete design.

3. To make special studies dealing with such subjects as paved shoulders, base types, pavement fatigue, tire size and pressures, and heavy military vehicles, and to correlate the findings of these special studies with the results of the basic research.

4. To provide a record of the type and extent of effort and materials required to keep each of the test sections or portions thereof in a satisfactory condition until discontinued for test purposes.

5. To develop instrumentation, test procedures, data, charts, graphs, and formulas, which will reflect the capabilities of the various test sections; and which will be helpful in future highway design, in the evaluation of the load-carrying capabilities of existing highways and in determining the most promising areas for further highway research.

The first objective, of course, embodies the basic purpose of the project. Stated simply, it asks for significant relationships between performance and traffic for pavements of certain designs under controlled truck traffic with certain loadings.

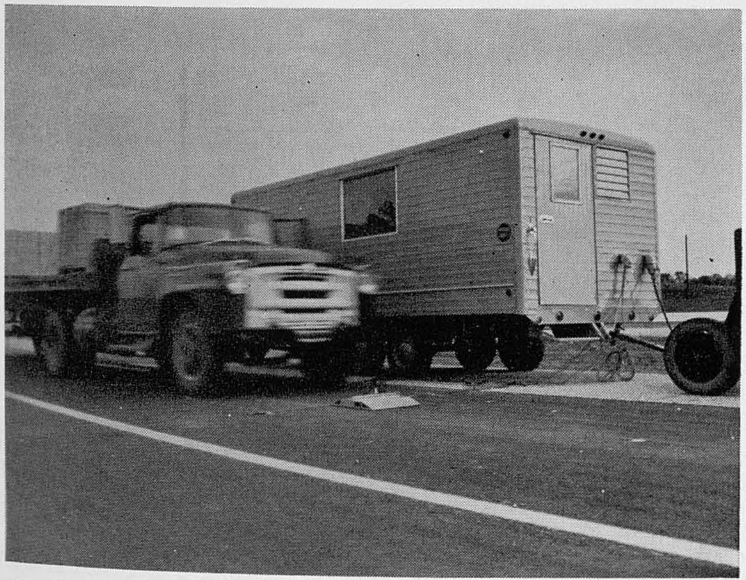
There are two key words in this objective: significant and performance. The word significant, in this case, does not relate to some one's judgment of what is and what is not meaningful. It is used here in its mathematical sense. That is, if a relationship is said to be signicant, there is a stated probability that it is truly so within the environment of the experiment. A significant relationship may be defined as one in which the effects on one variable are known to be caused by the other variables with a specific degree of certainty.

In order to make statements about the significance of relationships, an experiment must be designed in accordance with certain principles of mathematical statistics. This has been done at the AASHO Road Test; and the test is—in terms of time, space and cost—probably the largest statistically-designed experiment ever undertaken.

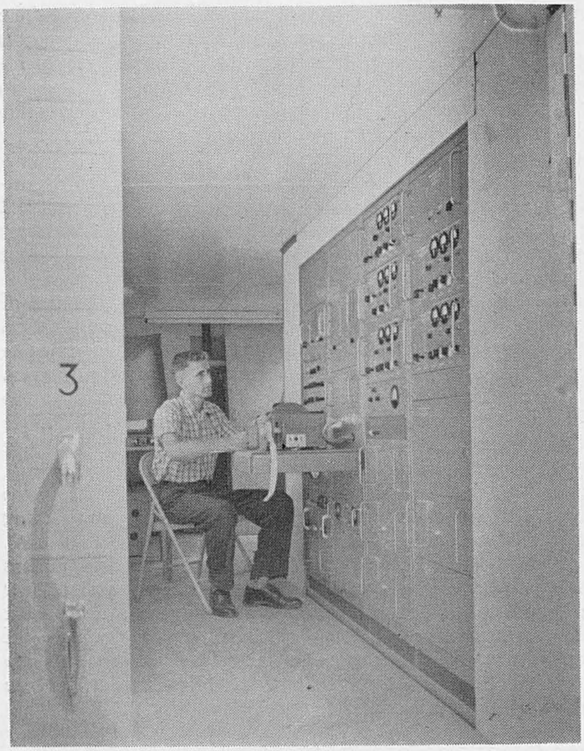
One very important feature of the design of the experiment is the use of the complete factorial in which each design factor level occurs in combination with all other design factor levels. Such a design makes it possible to estimate the effects of design factors and their interactions independently of one another. In other words, if two test sections of different thickness are subjected to the same traffic and one behaves better than the other, it will be possible to deduce whether the difference in behavior is attributable to the difference in thickness or not. In previous road tests no such deduction has been possible.

Two other important features in the design of the test facility were randomization in the layout of the experimental units, and replication, or repeating of experimental units, at least on a limited basis.

Randomization, in effect, "shakes loose" the effects of the design factors from the effects of error variables so that unbiased estimates are obtained for design factor effects. In simple terms, randomization is nothing more than what is accomplished by shuffling a deck of cards. Any card has an equal chance of being anywhere in the deck. At the road test, any test section had an equal chance of being anywhere on its respective loop tangent, and the loops themselves are located along the right-of-way in random order.



12. Test vehicle passing instrument van. Such vans contain instruments to measure deflections and strains under traffic.



13. Instrument van interior view.

Replication, or providing more than one experimental unit with the same design factor levels, amounts to performing the same experiment twice. This provides the means for measuring experimental error so that the reliability of the results can be appraised. Thus, there are, in the test facility, a certain number of identical test sections being tested under identical axle loads.

The second key word of the first objective of the test is performance. The objective asks for significant relationships between the performance of pavements with different structural characteristics and the number of applications of a specific axle load.

Performance is necessarily a relative thing; and whether a pavement, or any other product, performs well or performs badly can never be anything except a matter of human judgment.

There is, however, a method of utilizing the collective judgment of a group of persons to validate indices derived from objective measurements. This method will be followed at the road test by using a Performance Rating Panel composed of 13 men with backgrounds in highway engineering.

The process of deriving a "performance index" for any test section begins with the panel making individual "present serviceability" ratings of selected test sections. In evaluating a test section, the rater considers only the present ability of the section of pavement to serve high-speed, high-volume mixed traffic such as might be found on an interstate highway. He may rate the pavement as "good" even though he strongly suspects it may fail in the near future.

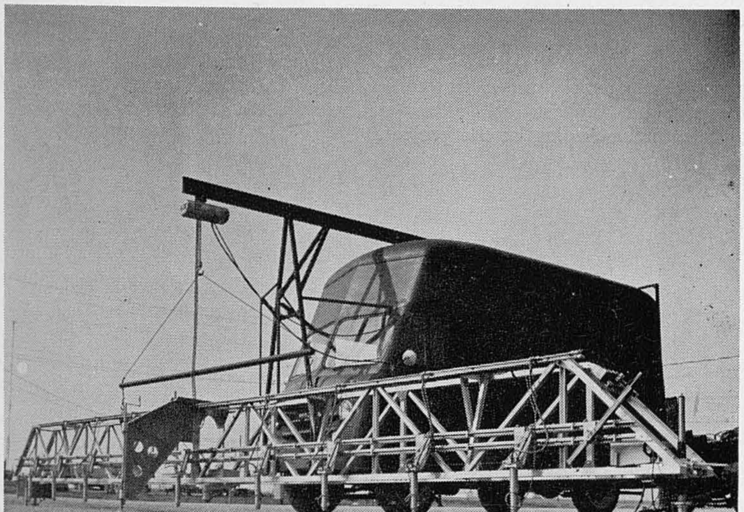
The mean present serviceability rating of the panel is then used to validate an index made up of a weighted sum of terms involving measurable elements of pavement behavior such as roughness, cracking, faulting, etc. When an appropriate summation of these elements is obtained, the present serviceability rating of any test section can then be determined without an actual rating by the panel. There will be, however, periodic ratings by the panel to check the validity of the indices.

Once a number of present serviceability ratings are obtained, they can be plotted against number of load applications or against time. This plot will represent the performance of a test section. The panel is then called upon to make a performance rating after examining the plot of present serviceability against time. A performance index is then derived in the same manner as the present serviceability index.

Although many variables will be analyzed, the performance index is the main dependent variable in the test and will be plotted as ordinate against the independent variables in studies of the relationships called for by the first objective. Once this index is established, the analysis becomes a matter of determining appropriate mathematical models for relationships between the index and the controlled variables of the experiment. Analysis of the data with respect to these models will determine the extent to which the controlled factors affected the performance index.

There is one further step—the development of a future condition index which can be used to predict the condition of a highway at some future date if it is to be subjected to known loading and environment. Some of the elements in this index may be the same as those in the present serviceability index, but it will also probably include such measurements as strains and deflections. The index will, of course, be validated by comparing predicted conditions with actual conditions on the future date.

Bridge research at the AASHO Road Test is being carried out as 16 separate case studies on spans built at four locations in the two main traffic loops carrying the heaviest axle loads. Eight spans were constructed with steel I-beams, four with conventional reinforced concrete beams, and four with prestressed concrete



14. Automatic Benkelman Beam measures deflection of pavement surface under load.

beams. All are simple 50-foot spans with three beams and a reinforced concrete deck.

The bridge studies have two principal objectives: (1) To determine the behavior of short-span highway bridges under repeated applications of overstress; (2) To determine the dynamic effects of moving vehicles on short-span highway bridges.

The 16 spans were all designed at higher-than-usual stress levels with some of the steel beam bridges being designed at stress levels which approximate the yield point of the steel.

The design of the three types of bridges were based on different criteria each aimed at answers to problems peculiar to the type involved. Because of the differences in the design criteria, there is no basis for comparison between the steel, prestressed and reinforced concrete test structures.

Four spans showed early distress and permanent distortion of such magnitudes as to cause their removal from the test. Nonetheless, considerable valuable data on their behavior was obtained.

The foregoing has been an attempt to present in brief what has been done at the AASHO Road Test and what it is hoped to learn from it. An earnest attempt is being made to obtain information most needed by highway administrators and engineers. Of course, the findings will also be useful to many others. The Bureau of Public Roads, for example, intends to use data from the test in studies it is making of highway cost allocation, and on the maximum desirable dimensions and weights of vehicles to be operated on the federal aid highway, including the interstate system.

The test traffic is now under way, and the collection and analysis of the vast amount of data has begun. The policy at the present time is that all data from the research phase of the test will be restricted until completion of the testing program. It is hoped, however, that the use of modern data handling techniques and analysis by electronic computers will enable the research staff to keep analysis close behind the actual collection of data. In view of this, it should be possible to produce reports containing the overall findings of the test some time in 1961.

In the meantime, preliminary reports will be published by the Highway Research Board. These reports will cover the basic concepts and planning for the project, the construction of the test facility, the plans for the collection and analysis of data, and so forth. They will provide the background necessary for a complete understanding of the project.