FINAL REPORT
ACCELERATED TESTING TRACK

Project No. HR7

Iowa Highway Research Board

Project No. 284S

Iowa Engineering Experiment Station

Iowa State College

Ames, Iowa

August 31, 1951

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Ladis H. Csanyi
Professor of Civil Engineering
Engineering Experiment Station
Iowa State College

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Mr. Mark Morris
Director of Highway Research
Iowa State Highway Commission
Ames, Iowa

Dear Mr. Morris:

Submitted herewith are fifty copies of the final report on Iowa Highway Research Board Project HR-7, An Investigation of the Feasibility of Designing, Constructing and Operating a Test Track for Testing Highway Pavements and Bases. This report has been prepared by Professor Ladis H. Csanyi who is in responsible charge of this project at the Iowa Engineering Experiment Station.

With the submission of this report, and the prior delivery on June 20, 1951, of the models of the test track, this project is completed. It should be remembered, however, that this project actually is only the first phase of a much larger program which includes the preliminary studies now completed and the larger task of designing, constructing and using the test track whose feasibility has been established. If this work is not undertaken, the time and effort expended to date on Project HR-7 will have been wasted. The Iowa Engineering Experiment Station is looking forward to a continuing program of cooperation with the Iowa Highway Research Board in the active prosecution of the future phases of the long-term research project.

Very truly yours,

George R. Town

GEORGE R. TOWN
Associate Director

GRT:rr

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ACCELERATED TESTING TRACK

INTRODUCTION

In May 1950 a proposal for a research project was submitted to the newly formed Iowa Highway Research Board for consideration and action. This project, designated RPS1 by the Board, encompassed the study, development, preparation of preliminary plans and specifications for the construction of a wheel track to be used in the accelerated testing of highway pavements. The device envisioned in the proposal was a circular track about seventy-five feet in diameter equipped with a suitable automobile-tired device to test pavements about five feet in width laid into the track under regular construction practices by small scale construction equipment.

The Board, upon review, revised and expanded the basic concepts of the project. The project as revised by the Board included a study of the feasibility of developing, constructing and operating an accelerated testing track in which pavements, bases and subgrades may be laid one full lane, or at least ten feet, in width by full size construction equipment in conformity with usual construction practices. The pavements so laid are to be subjected, during test, to conditions as nearly simulating actual traffic as possible.

This revised project, designated as Project HR7, entitled "Accelerated Testing Track", was approved and a contract was awarded to the Engineering experiment Station of Iowa State College for prosecution. One year after date of award of contract, which was September 1, 1950, was set as the completion date for the project.

The work on the project, designated by the Engineering Experiment Station as Project 284S, and entitled "Accelerated Testing Track", was assigned to Ladis H. Csanyi, Professor of Civil Engineering, for execution.

In accordance with the directive of the Iowa Highway Research Board, the scope of this study was limited to the determination of the feasibility of developing, constructing and operating an accelerated testing track for pavements which would yield results comparable or readily correlatable to actual service behavior of pavements. Therefore this report contains the general design and description of methods, means, conditions, apparatus and equipment needed to build and operate a track which would meet the desired qualifications. It does not contain detailed drawings, plans or specifications for the construction of such a testing track.

The directive also stipulated that the pavements, bases and subgrades to be tested shall be placed in the track by regular construction equipment and under usual construction methods. It further stipulated that these pavements, bases and subgrades be subjected to test conditions which are as nearly representative of actual traffic as possible.

The requirement that pavements, bases and subgrades be placed in the test track by regular construction equipment under usual construction practices posed no serious problem. But the requirement that these same pavements, bases and subgrades be subjected to test conditions as near those of actual traffic as possible and still yield accelerated results posed a rather serious problem. It is obvious that normal traffic conditions cannot yield accelerated results and that some suitable compromise must be made in which some of the severe effects of traffic are concentrated without the elimination of other aspects if accelerated results are to be obtained.

The compromise used for the basic design of this track possesses three main features:

1. Actual automotive vehicles will be used as the test medium. These vehicles shall be loaded to loadings equivalent to or exceeding loads encountered on the pavement in service, and they shall be operated at speeds known to place a severe stress on the pavement.

2. The track will be constructed so that direct comparison tests of several pavements and designs of pavement thickness or pavement mixtures

can be made simultaneously under normal conditions, either now present or anticipated in the future; or the tests may be made under accelerated test conditions.

3. The track will contain suitable instruments by which the behavior of the pavement may be observed and calibrated under normal conditions and correlated with its behavior under accelerated conditions. Accelerated conditions may be of such nature that the stresses imposed upon the test pavement will be greater than any encountered under normal conditions during its service life. These may include higher traffic volume, heavier loadings or both, as deemed desirable.

It is believed that this compromise will come closer than any other to fulfilling the requirements of the track and still yield results that can be suitably applied to the evaluation of designs of pavement and paving mixture and of the service characteristics of pavements.

Many other special features have been included in the proposed design of the track which permit test conditions to approach further the actual conditions encountered in service. Among these features are provisions for acceleration and deceleration of vehicles, temperature control of pavements, bases or subgrades, surface and subsurface moisture and drainage controls, and simultaneous comparative test of various thicknesses of surfacings and bases. The inclusion of these and other features permit the application during the test of a wide, flexible range of controlled conditions.

There are, however, many other factors and conditions encountered in service which cannot be included. Among these are most of the effects of time, such as weathering, long period consolidation of materials under traffic, slow chemical changes and leaching of materials in bases and subgrades subject to variations in subsurface moisture or drainage, and absorption or loss of moisture over the years by the effects of traffic. Nor can variations of traffic density and loadings that occur during the day be exactly reproduced.

Some of these may be beneficial to service life of the pavement while others may be detrimental or of no material consequence.

The track as proposed herein is not a device that will give all the answers. It is a tool, which when skillfully and wisely used, will quickly yield results that can be readily interpreted and applied to the evaluation of the service characteristics of a pavement, pavement design or paving mixture.

In addition to these used the track servés another purpose which may be more important. It is also a research tool by which pavement behavior under accurate control may be observed and studied. The results of these observations and studies can then be used to improve old pavements and develop new, cheaper and more durable ones.

CONCLUSIONS

During and upon the completion of this study and in the process of the development of the design and operation of the proposed track, the following conclusions were drawn:

1. The study and the consequent development of the proposed design indicate that a testing track which can meet the requirements, conditions and general purposes set for it in the directive of this project is wholly feasible.

2. The proposed track, when built, will yield more accurate, more directly comparable and more readily adaptable results for evaluating the service characteristics of pavements than any other similar track currently in existance.

3. Many adverse features of existing tracks have been either remedied or aliminated.

4. A wide range of test conditions may be imposed and accurately controlled either to simulate many important service conditions encountered on various types of pavements or to provide accelerated conditions during tests.

5. The tests can be conducted continuously, efficiently and economically.

6. Results can be observed and recorded for detailed analysis and filed for future reference.

7. The operation of test vehicles by automatic control can be simply, effectively and safely accomplished.

8. Proper utilization of the track coordinated with other laboratory tests can supplant the need for many costly time consuming test roads.

9. The total cost of constructing and equipping the track with all necessary and desirable accessories may be spread over several years in

appropriate stages without materially affecting its immediate practical utility.

10. The cost of the track (see breakdown on page 55) can be saved within a comparatively short time by reason of the track's ability to supplant many test road installations. The track's value will be enhanced as time goes on by its effectiveness as a research tool.

11. The track will provide an important research tool through which knowledge of the service behavior of pavements under various conditions will be gained and applied to formation of new concepts in improving existing pavements and devising new, cheaper and more durable roads.

12. The track will expedite the selection of suitable types of pavements, pavement and paving mixture designs, and the development of the use of local materials for these pruposes. These features are urgently required in meeting the pressing needs of the secondary and farm-to-market road program of Iowa.

RECOMMENDATIONS

The following recommendations, based upon current and future needs of the highway program of Iowa, and upon the design, construction and operation of the proposed track, are submitted:

1. That the construction of the proposed track be undertaken as soon as possible.

2. That the detailed design of the track, test vehicle control and other accessories and the preparation of detailed plans and specifications necessary for their construction or fabrication be awarded to competent organizations as soon as possible. It is desirable that this work be completed this winter to permit award of contracts for construction next spring if the track is to be placed in initial operation next summer or fall.

3. That provisions be made for close liaison between the organizations preparing detailed plans and specifications, or constructing, fabricating or providing parts for the track and the author of this report, so that all basic aspects may be included, developed or modified in keeping with the overall concept of the proposed design.

4. That a site for the track be selected as close as conveniently possible to the State Highway Department establishment in Ames. Such a site will permit ready access for supervision, observation and analysis of tests, laboratory control of materials and mixtures, and coordination of laboratory and track results.

5. That the track be provided initially with one truck as the test medium and at least four sets of outrigger guides and vehicle controls. Additional test vehicles may be secured and charged against specific projects undergoing test.

6. That all instruments required for detailed analysis of pavement behavior be provided as rapidly as possible.

7. That all construction equipment necessary for construction of pavements in the track be rented or borrowed. This will provide for the application of a wide range of construction techniques without increase in capital investment.

8. That the asphalt and concrete mixing plants be provided as early as possible to assure accurate control of paving mixtures and materials. During operation of tests these units may be utilized by the Maintenance forces of the Highway Department for preparation of materials used in their work.

9. That a competent staff be recruited for the operation and maintenance of the track and its accessories.

PURPOSE OF THE ACCELERATED TESTING TRACK

The primary purpose of a testing track is to provide a means, or a tool by which two basic objectives may be achieved. The first of these is the testing of pavements, bases and subgrades, either separately or in combination, in a normal or accelerated manner in order to evaluate their behavior in actual service quickly and surely. The second objective involves the use of the track as a research tool with which the many aspects of the behavior of a road and its several parts may be carefully studied.

Within the scope of the first objective, the track can perform many important functions. Roads of various standard designs may be simultaneously tested and directly compared in determining which is best suited to the specific traffic conditions imposed. Or the same road designs may be subjected to a series of traffic conditions in determining the range within which each performs most satisfactorily. By utilizing accelerated test conditions which impose conditions more severe than those encountered in service, and by correlating these with service conditions, rapid, dependable results may be obtained. As the records of such tests are accumulated, they may be evaluated and compiled into a ready reference to give engineers greater assurance in the selection of readways for their particular purposes.

In a similar manner, new materials, new roadway designs, new or improved paving mixtures, new construction methods and new or improved construction equipment may be readily tested, compared and evaluated as to their efficacy in producing better and cheaper roads. In performing the foregoing functions, the track will supplant the need for many test roads that require many years of service before they yield adequate or conclusive results, which apply only to conditions during the test and not to the conditions which the road may have to endure throughout its life. By its use, new and improved designs, new materials, equipment and methods can be readily tested and applied to greatly expedite highway construction and to give greater assurance of long and useful service.

Although the second objective deals primarily with research, many practical tests may also be included within its scope. In the research field, the costly instruments required to attain this objective provide a means of studying and determining the manner and intensity with which various types and designs of pavements, bases and subgrades transmit the dynamic loads imposed by traffic. A study of this nature would shed much needed light on our present methods of designing pavement thicknesses. It would supply the data needed to verify one or more of the many theories or to develop a new theory together with the formulas needed for the determination of the proper thickness of pavement of any type required for specific traffic conditions. It would further provide important data for determining the most economical and advantageous combination of type and depth of pavement, base and subgrade for the roadway carrying certain specific traffic. Other studies concerning the effects of subsurface drainage and moisture, excessive traffic loadings, temperature changes, characteristics of paving mix designs, determination of causes of pavement failure or distress may also be studied. In the realm of direct practical application, the instruments may be used to evaluate old and new soil stabilization methods, new surface and base mixes and designs, effects of new construction equipment and practices. Such studies would add greatly to our knowledge of pavement behavior and would materially assist in keeping highway paving designs and practices abreast of the ever increasing demand of traffic.

The track as designed would permit simultaneous operation of functions under both objectives and thereby allow the theoretical and the practical aspects to go forward together.

In addition to the major uses mentioned concerning the main purposes of the track, many secondary uses are also present. During regular tests tire wear, vehicle service, vehicle operating costs, tire traction, tire side slip and many other aspects of vehicle operation may be observed, recorded and studied.

PROCEDURE OF THE STUDY

The study was divided into four major parts. An extra part, not originally contemplated, was added as the work progressed.

The various parts are as follows:

Part I. Preliminary Studies.

Review and study of the design, construction, operation, limitations and results secured by similar devices either used in the past or currently in operation, together with all other pertinent adjunct phases.

Part II. Detailed Study and Design of Component Parts of the Track.

Study of all related factors and design of component parts such as size, shape, characteristics of the track, design, operation and control of test vehicles, types of tests to be included and conditions imposed during tests.

Part III. Coordination of Component Parts of Track.

Coordination and correlation of all component parts, factors, tests and conditions so that the operation of the track will be smooth, simple and efficient in performance and will yield the type of results desired.

Part IV. Estimate of Costs.

Estimate of cost of construction of the track together with all adjunct devices, vehicles and other necessary equipment.

Part V. Building of Operating Scale Models.

As the work progressed it was found that the construction of operating scale models of the track would assist in the development of some of the details of both the track and the test vehicles. The models would also serve in presenting many of the general features, some of the details, and the general operation of the track to interested lay groups.

Although the various parts of the study and development of the track are presented separately in this report, they were so intimately interrelated that they were actually processed simultaneously. Whenever any change was contemplated, no matter how small, its effect on all aspects of the development had to be considered, because it might have a material effect on many other factors and designs. Thus, continual coordination of all aspects and features of both design and operation had to be exercised throughout the development.

An attempt to discuss and describe all of the concepts, ideas, methods and means considered and the many various changes and modifications made in the process of development might be more confusing than helpful. Therefore, only the final development is described in this report. Wherever it is believed the reasons for any specific development are not obvious, they are discussed at length.

PART I

PRELIMINARY STUDIES

The general underlying concept involved in this project is not new. Many devices have been developed and built which yielded varying degrees of success in producing the desired results. One was in operation as long as thirty years ago in England. These devices varied from small single wheel tracks to full size roadways on which actual trucks were manually operated. A rather unusual track of this type is in Calcutta, India. On this track the pavements are not only tested for wheel loads but also for the effect of the hooves of the bullocks as they pull the vehicles along.

The primary difference between these existent tracks and the one contemplated in this project is in scope, magnitude and in the application of all modern developments and equipment in overcoming the short-comings of its predecessors. Therefore, in order that all prior information, knowledge and experience concerning these tracks might be accumulated, compiled, studied and applied as a basis and guide for the development of this track, a detailed review was made of all available literature pertaining to the design, construction, operation, performance, application and limitations of such devices.

In addition to the library study, many tracks in the United States were visited and inspected to secure first hand information. Their designs, operation, performance and results were discussed with their operators. Among those visited were the wheel tracks of the National Crushed Stone Association and the Bureau of Public Roads in Washington, D. C.; the Civil Aeronautic Authority in Indianapolis, Indiana; and the Kentucky Highway Department in Lexington, Kentucky. These wheel tracks are all comparatively small circular tracks from 12 to 30 feet in diameter. In all cases, the test pavements are laid by hand, and the test medium is an automobile tired wheel either drawn or driven over the test pavement. The test wheel in most cases travels at slow speeds from 4 to 12 miles per hour except on the Kentucky track where the driven wheel can attain 35 mph. The general criticisms levelled at these devices are that the pavements are laid by hand; that loads applied are very low and cannot be varied to approach actual loads encountered in practice; that none provide for acceleration, deceleration or braking effects; that the wheels always operate tangentially as the move around the circle; and that they require extensive correlation with traffic and service behavior before their results can be properly evaluated. In spite of these seeming handicaps, these devices have served as effective research tools and have yielded important results over the years of their operation.

The full size test track belonging to the Bureau of Public Roads and situated in Washington, D. C. was also visited and inspected. This track, having a test roadway about 12 feet wide, permits the use of regular construction methods and equipment in laying the test pavements. The test media used were regular trucks loaded to yield desired wheel loads. The difficulties encountered in this installation revolved about the human element involved in test operation. Drivers operating the test trucks suffered from driving fatigue and from the monotony of driving continuously around the track and therefore could not be depended upon to perform properly the various conditions of the test. Further, the operating costs were high due to the salaries of the drivers needed to drive the trucks. This track is no longer in operation due to the foregoing difficulties and because the officials of the Bureau of Public Roads feel, after many years of experience with their small wheel track, that it can serve all their purposes adequately.

Visits to the various test roads, including the Maryland Test Road under the direction of the Highway Research Board, yielded considerable first hand information concerning the initial designs, modifications made, performance, operation and application of such devices. In order to round out all of the information available concerning these devices, many outstanding authorities experienced in their use were visited to obtain their impressions as to the value of these tracks in producing accelerated results that can be used in evaluating the service behavior of pavements tested. Included among these were Dr. A. T. Goldbeck of the National Crushed Stone Association; Messrs. F. E. Kelley and W. Allen of the Bureau of Public Roads; Messrs. H. Boyd and W. Griffiths of the United States Army Engineers; Messrs. R. C. Herner and W. M. Aldous of the Civil Aeronautical Authority and Mr. Gregg of the Kentucky Highway Department. All of these men attested to the belief that such devices, when properly designed, carefully operated and controlled, and when results are intelligently analyzed, serve an excellent test media for rapid evaluation of service behavior of pavements and as research tools for the study and development of improved pavements.

Since this track is to include all modern developments and equipment applicable in its design and operation, voluminous correspondence was carried on with manufacturers of special equipment necessary for the control of vehicles, instrumentation, recording test data, and other auxiliary equipment required for the efficient and satisfactory operation of the track. Wherever application of such special equipment warranted, visits were made to the manufacturer for detailed discussions concerning its adaptation to this purpose.

PART II

DETAILED STUDY AND DESIGN OF COMPONENT PARTS

Before any design can be undertaken, it is essential that certain criteria concerning the function and operation of the track be established.

The Iowa Highway Research Board in its directive stipulated some of the criteria in a general manner. It set the requirements that the test road be one full lane or at least 10 feet in width; that it shall permit laying of the test road by full size construction equipment under regular construction practices; that actual traffic be simulated as nearly as possible; that accelerated results be obtainable; and that it serve as a research tool. Other criteria though not stated in so many words are nevertheless expected. These include that the track be efficient and economical in operation; that it be the most versatile and most modern of its kind; and that most of the short-comings of its predecessors be either remedied or eliminated.

The directive does not specifically indicate either the various types of tests that are to be conducted or the character of the research to be prosecuted. It expects, nevertheless, that the tests and research be of such character that results secured will be of the greatest benefit in expediting the construction and enhancing the character of Iowa's highways. It is obvious that the track cannot perform all of the tests that might be conceived. Its design, therefore, should be such that the track possess the widest range and flexibility in providing for as many tests as can be economically and practically incorporated within its scope.

A long list of desirable tests was compiled and each was investigated as to its bearing upon the complexity of design, construction and installation costs, operation of the track, and the accuracy of results obtainable. All these were used as criteria in determining the feasibility of the test for inclusion from either a practical or an economical standpoint.

The tests or conditions selected for inclusion are as follows:

1. Comparative test of pavements, bases and subgrades.
2. Individual test of pavements, bases and subgrades under various specific test conditions.
3. Determination of dynamic load transfer through various types and thicknesses of pavements, bases and subgrades under controlled conditions of speed and loading.
4. Determination of the causes for various types of failure encountered in various types of pavements.
5. Effect of subsurface moisture on bearing capacity of various subgrade materials.
6. Determination of the efficacy of various methods of controlling subsurface moisture or drainage.
7. Testing of new materials and new pavement bases.
8. Testing and comparing various methods of earth stabilization.
9. Testing the efficacy of new construction equipment and methods.
10. Side slip resistance of pavements under various speeds and loadings.
11. Effect of temperature on pavement behavior and subsurface moisture or drainage.
12. Load transfer between pavement edge and shoulder.

The tests contained in the foregoing list have been presented in broad general terms which include very many specific tests, giving the track a wide flexible range of application.

With these criteria as a basis, the various aspects of design were undertaken, developed and correlated. These are presented in detail under their respective headings.

Uniform, Permanent Base for Test Roads in Track

So many test roads yield results that are either almost impossible to analyze or the are so difficult to analyze that the conclusions drawn are highly controversial. In most cases the cause of this difficulty may be traced to the variance in their subgrade support. Thus, if the tests are to be under proper control, it is essential that the basic support of the roads tested on this track be as uniform as possible. This requirement holds for both vertical and lateral support.

To meet this requirement it was decided to build the track as a box shaped concrete trough, Figure 2, in which the test road may be placed and tested. Upon completion of a test the road can be removed and a new one placed in its stead. By use of this type of design, a uniform vertical and lateral support can be easily and permanently secured. Thus, successive tests can be readily compared.

For the general run of comparative tests a depth of two feet would serve adequately. (Figure 2.) This depth would accommodate the surface course, base, and a nominal depth of subgrade of the road under test. For special tests requiring greater depths, sections of the track provide for a depth of four feet (Figures 5 and 6), and a depth of ten feet (Figure 7).

This design not only provides for a uniform and consistent support for the test road in the track but also serves as the support for the guidance of the test vehicles during the test.

Grades of Test Roads in Track

After considerable deliberation it was decided that any effects of the small grades that could be introduced in the track would have negligible effects upon the test pavement. Further, by introducing sections for acceleration and deceleration in the track, effects similar to braking and applying power can be imposed upon the test road with greater stress.

Therefore it was decided that the track be built level over its length, except on curves and transitions where superelevation will be used on the surface of the road.

Width of Track

By directive, the width of the track is set at one full lane or a minimum of ten feet. This minimum width can also meet another criterion, namely, that of laying the pavements into the track by regular construction equipment under regular construction practices.

A ten foot width, however, is too narrow to include such tests as lateral support of the shoulder or the test of various types of shoulders. After considerable thought, it was decided that twelve feet would be the most effective and economical width, for a test pavement either 12 feet in width or 10 feet in width with a two foot shoulder.

A width greater than 12 feet might improve test conditions of shoulders, but it would also materially increase the cost of construction of the track and increase the difficulty in controlling the operation of the test vehicle. Furthermore, if many types of construction are to be properly utilized the next minimum width would be 16 feet in order to accommodate pavers that have a minimum width of 8 feet per lane.

Some questions may arise concerning the high degree of lateral support developed by the concrete sides of the track. At the inner side of the track representing the center line of the two lane road, this problem is academic because the support of the concrete side is no different than the adjacent lane, except, of course, when this lane has failed. Further, in this case the concrete side serves as the container for lateral pressure cells by which these pressures can be measured. At the outer edge, the question has considerable justification, particularly in tests of lateral ravelling of the pavement at the shoulder line. This condition, however, can be provided for quite easily by side sloping a section of the shoulder, a foot or foot and a half wide to any slope commensurate with the amount of lateral support desired. Thus the lateral support of this side of the track can be varied as desired.

Shape and Length of Track

The development of the shape and length of the track is dependent on many factors such as type, character and size of test vehicle, operating speed of the vehicle, continuity of operation of the vehicle, various conditions imposed during the tests, modern geometric design criteria, and accelerated character of the tests.

The general shape of the track is relatively easy to resolve. Since the operation of the vehicle is to be continuous and it makes successive passes over the test pavement in the track, the general shape of the track must be closed ring. Investigation of a circular track shows that it must have a diameter of several thousand feet if the requirement is to be met that tangential wheel action be reduced to a satisfactory minimum. Such a size would be impractical, thereby eliminating the circular form. It is apparent then that the track must be of some form of an oval, having straight sides wherein tangential wheel effect is entirely eliminated and curved ends where it is encountered for as short a period as possible. The characteristics of these curved ends are affected by several factors which must be considered before they can be worked out.

The type and character of the test vehicle has a material bearing on both the details of the shape and also the length of the track. The type and character of the test vehicle selected for this track is the standard passenger car, truck tractor or tractor and semi-trailer, depending upon the nature of the test. The reasons for this selection are given later in the discussion of the test vehicle.

Having made the selection of the test vehicle, the next decision was that of the operating speed of this vehicle during the various tests. Considerable study was devoted to this problem. The concensus of investigators is that slower speeds have greater detrimental effect on pavements, under equal conditions of loading, than higher speeds. This concept therefore eliminates the use of high speeds. Since the directive calls for the simulation of actual traffic, very slow speeds would not be suitable either. Also bearing in mind the accelerated character of the tests, very slow speeds would also be eliminated on this count. The studies made by other investigators also showed that moderate speeds of 25 to 35 mph would give good results. Since these speeds are within average traffic range, an average speed of 30 mph was selected for the operating speed of the test vehicles. In designing the various parts of the track, provision was made for operation of trucks up to 35 mph and passenger cars up to 45 mph. Lower speeds can be used if desired, higher speeds are dangerous.

The next decision necessary was the approximate length of the track. This decision is controlled largely by the accelerated character of the tests. It has been mentioned that this aspect can be attained either by using heavier loadings or making a greater number of passes (or both) than are encountered or anticipated on the road under test. Increased loading places no limits on length; increased passes representative of increased volume of traffic does. If the test track is long, fewer passes can be made by each test vehicle travelling at 30 mph than on a shorter track. Thus, a track as short as possible meeting all other conditions of test areas, geometric design, etc., would be desirable.

Since comparative testing of pavements is one of the most important features of the track, and since these should be made on its straight sections, the length of these becomes a decisive factor in developing the length of the track. It is deemed that a length of 100 feet for each test pavement would serve satisfactorily for tests and could adequately be laid by regular construction equipment without difficulty. Special instrumentation tests would need only 50 foot lengths. Since there are three of these, this phase would require a minimum of 150 feet on one side. Bearing in mind that a track as short as possible is desirable, it was decided that 300 foot straight sections on each side would provide for the simultaneous testing of four pavements, three on one side and one on the other, besides 200 feet allocated to special tests. This fits in with acceleration - deceleration tests conducted on the four transition curves between straight and curved sections. The same four pavements could be placed on these, two on each end of the track.

Having the straight sections, the development of the rest of the details was by trial. Various curves were investigated in seeking the sharpest that would meet the geometric design criteria of a maximum superelevation of 0.08 foot per foot of roadway width. It was found that a curve of 250 foot radius or 23 degree curvature would meet this at speeds of 30 mph. Such a curve and superelevation needs a transition of at least 200 feet per 1 foot of superelevation. Since the roadway is 12 feet wide, superelevation on curve is 0.96 feet; thus at least 200 feet of transition is needed. With these basic factors, various lengths of curve were adjusted with transitions. The combination that worked out best, giving the smoothest transitions and the shortest overall length, is shown in Figure 1. It includes two 300 foot straight sections, and two 250 foot radius curves, each 488 feet in length, connected by four transitions each 300 feet in length. The total length of this track is 2,776 feet or slightly over one-half mile.

Before adopting this design of the track, it must be checked against the accelerated test feature of the track. This, of course, was done in the process of development. The check is given here as a verification of its adequacy in meeting this requirement. Having a track one-half mile in length, with a vehicle traversing it at an average speed of 30 mph, and the vehicle operating continuously, it would make 1,440 passes over a given point in twenty-four hours.

Since this is on one lane, a two lane highway having a daily traffic volume of 2,880 vehicles per day would be simulated. When four test vehicles are operated simultaneously, the comparative traffic volume would be 11,520 vehicles per day. These traffic densities would serve satisfactorily for accelerated testing of most of the roads in Iowa. Bearing in mind that the effect of the test could be further accelerated by increased loadings to simulate only the truck portion of traffic, a single test vehicle could be made the equivalent of 14,400 truck passes per day if truck traffic is 10 per cent of total traffic. This density exceeds any encountered in Iowa, and when properly correlated could give accelerated results for any present conditions. By operating additional test vehicles almost any future condition could be met.

The design features of the track as to shape and length are deemed satisfactory and were therefore adopted.

The specialized details are as follows (see Figure 1): The major portion of the track in the general test area is 24 inches in depth, Figure 2, while adjustments on curves and transitions are shown on Figures 3 and 4. The special test sections include one section F-F, Figure 1 and Figure 5, 48 inches in depth and 100 feet in length, allocated to dynamic load transfer tests; and section D-D, Figure 1 and Figure 6, also 48 inches in depth but only 50 feet in length, allocated to dynamic load tests or pavement deflection measurements. Section C-C, Figure 7, is 10 feet in depth and 50 feet in length. This section of the track is provided with water troughs on each side from which water may enter and flow through the subgrade at any desired rate or under a controlled head. Suitable pumps circulate the water and control the flow and relative heads in the troughs. Conditions of practically no moisture or subsurface flow to hydraulic uplift under the pavement can be accurately controlled in this area. Incidently, this area is bulkheaded off from the rest of the test area.

The main walls of the track will be fitted with suitable piping to permit the application of steam or refrigerants for temperature control in the special test area and elsewhere as it may be deemed desirable. The main walls in the dynamic road test area and in the straight sections will be fitted with receptacles for the insertion of load test cells for load distribution measurements.

Since the track is oval in shape, it is necessary that some means be provided to guide the test vehicles around the curved sections and to control their position so that they travel over the same area of the track on each successive pass. To accomplish this, guide rails are erected on the walls of the track, as shown in Figure 2. Suitable outriggers on the test vehicles engage these guide rails as the vehicle travels around the track. Superimposed upon the guide rails are the controls for the automatic operation of the test vehicles.

In order to permit access of construction equipment, a parallel siding is provided on one side of the track (Figure 1). Where the siding joins the track, the outer guide rails are removable to permit entrance to or exit from the track. This siding is used also as a service area where test vehicles are serviced during operation of the test.

Test Vehicle

The test vehicle must have certain very definite characteristics if it is to meet the requirement that actual traffic be simulated as closely as possible during the tests. Among the more important attributes which the test vehicle must possess are the following: It must be capable of acceleration and deceleration in a manner similar to that of an automobile; it must be able to impose various desired loads upon the pavement; it must utilize regular automotive tires; its body must be capable of being fitted with single or tandem axles and single or dual wheels; and it must be subject to accurate control during test. In other words it must be as near to an actual car or truck as possible.

It has been indicated that the design and operation of the test vehicle and the design of the track are inseparably interdependent. The selection or design of the test vehicle, therefore, is dependent not only upon its own efficient, economical and practical adaptability but also upon the efficient, economical and practical correlative design of the track.

In the process of selection of the test vehicle, many special designs of carriages were developed and investigated as to their efficiency, degree of conformance to prescribed characteristics, initial cost, operating costs and track design. The designs included mono wheels, single drive axles, special chassis and both electrically and gas engine driven vehicles. Guides, including overhead, lateral and hold-down types were investigated. In all cases, the vehicles had to be either automatically or remotely controlled. Electric drive requires simpler controls of this character than gas engine drives, but the initial and operating costs are extremely high.

As the investigation progressed it became apparent that regular standard automobiles would make the best test vehicles provided they can be properly automatically controlled. There is no question concerning the ability of a standard motor car to reproduce actual traffic conditions. In fact, there is a tremendous psychological advantage in its adoption, particularly when test results are presented to lay groups and administrators who generally look with suspicion upon especially designed contraptions.

In investigating standard automobiles it was found that the tractor-semi-trailer combination would provide the best basic test vehicle. Besides furnishing actual traffic simulation, various wheel and axle combinations can be secured by simply changing the semi-trailer, and axle loads can be varied by proper loading of the trailer. A design of the track that would accommodate the tractor-semi-trailer combination would also be suitable for any type of standard passenger car, truck or tractor full-trailer combination. Thus almost every type of traffic could be reproduced on the track. Although at present the tractor-semi-trailer is thought to be the best, adequate testing and research in the future may disclose that the tractor full-trailer combination is superior. For example, the attachment of a series of trailers, having various loadings, wheel and axle combinations, could not only increase the scope of the tests but also increase the equivalent total traffic volume considerably. By this arrangement the operating cost could be reduced and the accelerated character of the test increased.

Since the final selection of the tractor-semi-trailer as the basic test vehicle depended upon the development of economical, suitable and practical controls of operation during test, this phase was investigated. It was found that simple, economical, practical controls could be developed, as explained and described later; therefore the standard automobile with the tractor-semi-trailer as the basic unit was selected as the test vehicle for this track.

Guiding the Test Vehicle

Since the track is oval in shape, and since the tractor-semi-trailer is the test vehicle, and since it is desired that the test vehicle retrace its path over the same portion of the pavement within a few inches laterally on each successive circuit, it is necessary that the vehicle be mechanically guided.

Manual operation and guidance of the test vehicle was rejected on the basis of the experience gained by the Bureau of Public Roads in the manual operation of regular trucks on their full size track, which is no longer used. They found that drivers could not be depended upon to maintain strict operation schedules, that there existed a wide range of driving characteristics among drivers which prevented uniform control of the test and that drivers suffered excessive fatigue from the monotony of driving around in circles. They also found that the use of drivers increased operating costs beyond reason, particularly where continuous tests for twenty-four hours per day were required. It appears from these findings that several drivers are needed for each test vehicle during each shift. Considering the salary of the drivers, and the character of the test secured, the use of manual operation is untenable in the proposed track. Therefore mechanical and automatic control of the vehicle is essential for the successful operation of the track.

The method developed for the guidance of the vehicles during the test is comparatively simple and fully practical. Each test vehicle is provided with suitable outriggers, and the track with appropriate guide rails. The outriggers engage the guides (Figures 8 and 9), and the vehicle moves around the track between the guide rails. Although the concept is simple, many prerequisites are necessary for its satisfactory operation.

A study of standard manufactured trucks disclosed that the distance between the frame of the body and the pavement varies with the loading and the type of tire used. In most cases this distance varies between 34 and 38 inches. Therefore the center of the guide rail should be 36 inches above the pavement, and its size should be sufficient to accommodate the outrigger roller mechanism, allow room for variations of loading and also for the sway of vehicles during operation. Based upon a suggested design for the outrigger roller mechanism (Figure 12), a twelve inch by three inch channel 20.7 pounds per foot would serve as a guide rail.

Since the lateral push of the vehicle is of low intensity even in negotiating the curves, the posts carrying the guide rails on both sides of the track can be placed at least ten feet on centers. Knee braces and ties should be provided for the posts (Figure 2) to relieve the concrete wall of the track of this strain. The final designs can be refined upon detail design of the track.

The outriggers used in this design are simply telescopic devices which act as extensions of the vehicle in guiding it between the guide rails of the track (Figures 8 and 9 and Plate 1). In general (Figure 10), they consist of a tube attached to the vehicle chassis in a suitable manner, a plunger which slides in the tube, a roller assembly attached to the head of the plunger to engage the guide rail, and a spring to maintain suitable pressure of the roller assembly against the guide rail.

The outriggers may be attached directly to the chassis of the vehicle and trailer (Figure 10), or they may be mounted on a bumper frame which can then be attached to the vehicle (Figure 11). The latter method is more desirable because it permits ready attachment or removal and transfer from one vehicle to another for succeeding tests or variation of test vehicles.

There are several critical factors that must be considered in the detailed design of the outriggers. In placing the vehicle laterally across the test pavement in any position desired, it is apparent that the length of the outriggers on opposite sides of the vehicle will vary materially in length. In placing the vehicle in an extreme position, namely, within 18 inches from the edge of the track so that its tires can run on the shoulder, it can be seen that the outrigger tube must be made comparatively short and the variations must be taken up in the length of the plunger. To meet this condition the plunger can be made up sectionally. The plunger can be made up either with a removable center section which can be replaced with a center section of desired length, or (more desirably) it can be made up with a left and right threaded center rod section that can be readily adjusted and locked to any desired length. In this way the length of the outriggers can be properly adjusted and set to guide the vehicle in any position laterally on the test pavement.

The plunger must be keyed to prevent its rotation during the operation of the vehicle. Both the plunger head end and the outer end of the tube should be fitted with an eye to engage a turnbuckle for taking up the spring pressure and locking the outrigger while the vehicle is being driven off the track for servicing.

A design for the outrigger roller assembly is suggested in Figure 12. This may be further refined in the detailed design. The main controlling features of this assembly are its attachment to the head of the plunger by a simple slip-on arrangement, its equipment with a ball or roller bearing swivel to permit its alignment in the channel of the guides while in motion, and its equipment with at least three low pressure tired wheels or rollers to prevent swerving of the vehicle should one or two of them blow our during operation.

This type of an outrigger can even be used to guide the vehicle around the curves if the steering wheels of the vehicle are locked in a straight forward position. Operating the vehicle in this manner would place a heavy strain on the guide rail supports at the curves and also upon the front wheels and steering mechanism of the vehicle. To alleviate this condition, a means of steering the vehicle around the curves was developed.

In the process of seeking and developing an efficient and practical means of steering the vehicle around the turns, many basic principles were investigated including the use of electric eyes, luminescent paints, energized guide wires with receiving antennae and other electronic controls. All of these proved much too complicated and delicate for practical rugged operation. The principle finally selected and applied is relatively simple and lends itself to direct integration with the operation of the outriggers as designed.

This principle utilizes the centrifugal force developed as the vehicle rounds the turn. As the vehicle enters the transition curves centrifugal force develops gradually pulling the vehicle outward until the force reaches its maximum as the vehicle passes around the curve. Then as it leaves the curve the force gradually diminishes along the other transition. The intensity of the centrifugal force developed is related to the speed of the vehicle and the radius of the curve. The effect of this force on the vehicle is opposed by the resistence of the tires to side slip, by the reaction of the spring in the outrigger and the steering of the vehicle. Since some side slip of the tires will occur, and since the outriggers will press against the guide rail with increasing intensity unless the car is steered around the curve, the plunger on the outer side of the curve will be pushed in while that on the inner side will slide out as the vehicle rounds the curve. By controlling the amount of this plunger movement by proper spring strength, this movement can be applied to operate a steering mechanism.

Such a steering mechanism can be devised in several ways. One way is suggested in Figure 11, which slightly modifies the regular design of the outriggers used on the front of the vehicle to incorporate a part of the steering mechanism. The modifications involve the separation of the inner ends of the outrigger tubes sufficiently to permit the installation of a part of the steering device. The plungers of both outriggers and fitted at their inner ends with piston rods that extend through guides in the base of the outrigger tube. The steering mechanism consists of two master hydraulic cylinders which are mounted between the outriggers. The pistons of the hydraulic cylinders are coupled and aligned with the piston rods of the plungers of the outriggers. The two master cylinders are connected by means of hydraulic pressure tubing to two operating hydraulic cylinders mounted on either side of the steering knuckle, and their actuated pistons are connected to the steering knuckle. A very sensitvie steering can be secured by proper design of the outrigger spring tension and the ratio between the diameter of master cylinder and operating cylinder.

The opemation of the system is positive and comparatively simple. As the vehicle enters the transition curve the plunger on the outer side is gradually pressed into the tube actuating the piston forward in the master cylinder, which in turn forces fluid into its operating cylinder and causes the operating piston to move the steering rod. As the outer plunger moves in, the inner side plunger moves out, permitting the fluid in the opposite operating cylinder to flow up into the master cylinder. In this action the hydraulic systems are always under positive pressures and in equilibrium and are ready to reverse their operation instantly. As the vehicle leaves the curve the intensity of steering is relieved by this opposite action of the system. As the vehicle enters the straight part of the track the system is balanced and very little steering is done.

Another method by which the same results can be achieved involves the connection of the piston rods of the plungers to a hydraulic valve which regulates the flow of the fluid under pressure into and out of the proper operating cylinders. This system is more complicated and costly than the former but it has the advantage that fluid pressure can be registered on a dial and is not subject to failure in event of a leak draining oil from the system.

In either case the main parts of the system should be mounted in such fashionthat they are easily accessible for inspection and servicing.

By the recommended method and device, the vehicle may be guided around the track with a delicacy of touch and uniformity of manner and travel practically impossible in manual driving.

Control of the Vehicle

The speed of the vehicle must be under control at all times, since certain tests involve the study of the effects of acceleration, deceleration and braking on the pavements; and since there is no driver in the vehicle, it must be either automatically or remotely controlled during it operation.

Both types of controls were thoroughly investigated. For remote control, numerous devices were studied including radio transmission, such as used in guided missiles and pilotless airplane flights, electric eye systems and sliding electrical contact systems. Although some of these could be applied in this case, they proved too delicate and much too costly for this type of application. For automatic operation numerous similar types of devices and others were studied including electric eye systems, sliding electrical contact systems and mechanical trips. Of this latter group the mechanical trip type of automatic control showed the greatest promise of positive action and economical installation and operation features. Thus this type was selected for development.

The basic controls required are for starting, accelerating, maintaining speed, decelerating and stopping the vehicle. Each control had to be worked out separately and correlated with a trip type of mechanism.

In starting the vehicle, the problem involved the changing of gears from low to high speed required in regular operation. In the case of passenger cars equipped with automatic drives, the problem was solved inherently. Here only two controls are needed, one on the accelerator and the other on the brake. It was hoped that a similar control could be found available on trucks. The search which was made disclosed that none was available because automatic drives are not practical for regular truck operation. An automatic drive could nevertheless be designed and installed in test vehicles built for this purpose, but the cost was so high that it was prohibitive. The study then turned to the development of an automatic gear shift. In the process of this study, truck manufacturers suggested a way this problem could be circumvented. They suggested the use of a tractor or truck of sufficient power to be started in high gear. Since this would normally be done but once a day, the wear on the clutch would not be excessive. This suggestion was adopted. In this case an auxiliary clutch handle mounted on the side of the vehicle, an accelerator and a brake control would meet our needs.

The vehicle will be started manually by actuating the auxiliary clutch from the ground beside the vehicle. Once the vehicle is started, it can be controlled by actuation of the accelerator and brake. This can be accomplished by electrical solenoids operating on a 24 volt vehicle battery circuit. The brake and clutch are interconnected so that heavy pressure on the brake will trip the clutch to disengaged position for stopping the vehicle.

Acceleration, maintenance of prescribed speed, deceleration, and stopping require special control devices. The variation or maintenance of predetermined speeds can be readily accomplished by attaching a Metron electric tachometer to either the wheel of the vehicle or preferably to a pilot wheel under the vehicle. This tachometer is connected to a calibrated Brown Instrument recording controller which actuates the accelerator and the brake. The recording controller can be set to operate the vehicle at two selected speeds and will maintain each of these speeds within a range of plus or minus 1/2 mph. The tachometer is connected to the recording needle which records speed in miles per hour. As the recording needle touches the upper limit of the operating speed the accelerator solenoid releases the accelerator; then when it touches the lower limit the accelerator is advanced. Should the needle overrun the upper limit materially, the accelerator is tripped and the brake applied.

Switching the controller from one speed to another is accomplished by a trip mechanism (Figure 12) mounted on the front outrigger and operated by trips placed at any desired point in the control rack situated on top of the outer guide rail. The trip mechanism is of the positive action type. Two trip arms are utilized, the one for high speed is actuated by stops placed on the upper part of the rack and the one for low speed is actuated by stops on the lower part of the rack. The two trip arms are geared together so that the actuation of one by a stop moves the other into an operable position. The bottom of the trip arms are fitted with contacts connected to the recording controller. These contacts set the proper speed limit of the controller in operation.

When the speed is switched from high to low, the system operates the brake until the low range is reached, then the brake is released and the speed is controlled by the accelerator. Switching from low to high speed is done by the accelerator only. Rates of acceleration or deceleration cannot be controlled because they are affected by the loading and the power of the vehicle. They must be observed and measured. Some adjustment can be made in the manner of energizing the control solenoids for faster or slower action. Once the rates of acceleration or deceleration have been adjusted they will remain the same as long as the engine and brakes are in proper condition.

Thus, if it is desired that the vehicle operate at 30 mph on straight sections, decelerate to 20 mph on transition approaching curve, maintain 20 mph around the curve and accelerate to 30 mph on the transition leaving the curve, the controller is set at 20 mph for low speed and 30 mph for high speed. A low speed trip is placed in the bottom of the control rack at the end of the straight section and a high speed trip is set in the top of the rack at the end of the curve. As the vehicle passes the low speed trip, the low speed trip arm is actuated. This swings the high speed trip arm into operable position and puts the controller in low speed operation. The controller immediately releases the accelerator and applies the brake until the low speed range is reached; then it releases the brake and puts the accelerator into operation. As the vehicle passes the high speed trip at the end of the curve, the high speed arm is actuated putting the low speed arm in operating position and switching the controller into high speed range. The controller advances the accelerator until the proper speed is reached then proceeds to maintain this speed. In this manner the vehicle may be automatically controlled to repeat any predetermined sequence of operation on each circuit of the vehicle around the track.

The pilot wheel, tachometer, power supply, recording control and actuating solenoids should be designed in such manner that they may be installed or removed easily from the test vehicle and that they may be used in all types of vehicles. One set of controls then will last a long time.

Since as many as four test vehicles may be required to operate simultaneously on the track under certain test conditions, another serious problem arose. This problem involved the elimination of the possibility of crashes between vehicles.

Here, too, a wide variety of devices were investigated including electric eyes and radar. None of these were found suitable because they could not see around a curve. After a considerable search a ready-made device was found available on the market. This is the regular signal system used in the Chicago elevated system and in the New York City subways. By a slight modification of its trip arm to include a clear trip in addition to the regular caution and stop trip (Figure 13), this device can be readily integrated into the regular control mechanism.

As in the control mechanism, a group of trip arms are attached to the outer end of the outrigger plunger. In this case, however, the inner guide rail is used for the trips and one of the rear outriggers for the trip arms. Three trip arms are used, two are connected as in the controller for green and caution and a third for stop. The regular trip arm is used except that a short stub trip is welded at right angles to the regular arm (Figure 13). The trip mechanism is mounted on the top of the guide rail in a position to engage the three trip arms in the various signal conditions. The operation of the trip mechanism is controlled by the passage of the vehicle which breaks a light beam to actuate an electric eye.

The various positions for the signal conditions are shown on Figure 13. The green and caution trip arm contacts are connected directly into the high and low speed settings of the recording controller. The stop trip arm is connected to a relay which disconnects the recording controller and forcefully applies the brakes which automatically trips the clutch and brings the vehicle to a quick stop.

Signal trips are placed around the track and are interconnected in such fashion that the passage of the vehicle places that trip in stop position. As the vehicle passes the next signal, that trip goes into stop position and the first remains in stop position; when it passes the next signal, the first trip goes to caution, the second remains at stop while the third goes to stop. Then on passing the next signal, the first trip goes to green, the second to caution, the third to stop and the last to stop. In this way each vehicle has a safety margin of at least the distance between two signals to prevent a rear end collision.

If it is decided that four vehicles must be used simultaneously, then 12 signals must be provided, each about 230 feet apart. If provision is to be made for the use of a lesser number of vehicles as the maximum, each vehicle requires 3 signals for safety.

Thus with a 12 signal installation, in the event of a breakdown, the following truck receives the caution signal at least 460 feet from the stalled vehicle. Upon receipt of the caution signal it slows down to slow speed. Then at least 230 feet behind the stalled vehicle it gets the stop signal, the brakes go on and the vehicle stops at least 100 feet behind the stalled vehicle. Each succeeding vehicle goes through the same sequence until the four have come to rest.

The vehicles can be stopped in a like manner manually by covering one of the electric eye controls.

All of the devices used in the control of the vehicles as suggested here are of standard manufacture, simple in construction and operation, have been tested and are believed foolproof. They require little or no modification other than special adjustments to meet these applications. By their use, standard vehicles can be adapted to the purposes of this track.

Instrumentation of Tests

In the selection and design of a pavement for a roadway, certain basic considerations must be properly coordinated in securing a pavement that will possess the greatest efficiency and economy during its life. These factors include the pavement's ability to carry satisfactorily and safely the traffic it must endure during its life, the character of the ground upon which the pavement is to be laid, the initial construction cost and the maintenance and repair costs during its existence. Considering the wide diversity of traffic conditions a pavement must meet during its lifetime, the many subgrade conditions it must meet in its length, the many types of pavements available and the many varied methods of design propounded, it can be easily believed that the proper integration of all these factors and conditions into an economical and durable pavement with any degree of assurance of success is probably the most difficult problem that confronts a highway engineer.

Considerable research is being conducted in classifying the various types of soils and in developing means of making them better suited to highway purposes so that the engineer may have a better, more uniform foundation upon which to lay his pavements, for a road is no better than its foundation. Considerable work is also being done in classifying the characteristics and patterns of both traffic and its movements, so that the engineer may better evaluate and estimate the traffic conditions his road will meet during its lifetime. A multitude of various types of pavements have been and are being developed to meet almost any combination of traffic conditions as to speed, volume and weight. In fact, it may be said that there is a type of pavement available for almost any specific traffic condition or combination of conditions. Similarly, there are many types of bases through which the loadings of traffic may be distributed over the subgrade. There are also many methods of design available for determining the thickness of a pavement required to meet any condition of subgrade, type of base, pavement and traffic loading. In fact, there are so many of these methods which yield widely divergent results for the same conditions that they frequently are more confusing than helpful.

Thus, even though a highway engineer has many diversified aids at his disposal to assist him in making his selection and designs, somehow these fail to give him the assurance that any particular selection or design will meet the test of time. Even though considerable work has been done in correlating tests and designs with service behavior, conditions vary so widely in specific cases that many of the results secured can act only as guides. Furthermore, none of the design theories has been conclusively proved and all are therefore in constant controversy. So the highway engineer, after making his selection and design, turns to test roads to gain assurance that his road will meet the test of time.

Until conclusive proofs have been obtained to substantiate the methods of design, no assurance of success can be attained. The confirmation of the methods of design during the past has been severly limited due to lack of suitable equipment necessary to conduct studies which supply the necessary proof. New devices and methods have been developed during the past several years for studying critically the behavior of pavements, bases and subgrades under dynamic loading. One of these devices, involving the use of SR4 strain gages in the measurement of dynamic load transfer and distribution in pavements, bases and subgrades has been developed by Army Engineers and the engineers of the American Railway Engineers Association. Other recent developments are load and deflection gages for the measurement of road and base deflections under load, and the adaptation of radioactive isotopes to the measurement of moisture content of soils in situ as developed by the engineers of the Civil Aeronautics Authority. Many of the tests made with the use of these new devices have disclosed many unusual and unsuspected phenomena occurring in our roads which throw many of our basic concepts of design in doubt. Much more work is necessary before our concepts can be substantiated and really dependable formulas and design criteria evolved.

It is to this end and to the development of better methods of evaluation of pavements that the research phase of the track is primarily directed. Any clarification of present methods or the development of new methods of design and the better understanding of the behavior of the various types of pavement under dynamic loading would make this track worth while, because such information would give the engineer a greater assurance of success in his selection and design of roadway pavements. The track, therefore, has been designed to accommodate the use of load pressure cells and road deflection and moisture content measuring equipment.

Considerable study was devoted to the dynamic load pressure cell techniques. Existing equipment was examined at the A.R.E.A. laboratories in Chicago and at the Hathaway Instrument Company in Denver, Colorado. Reports of work done with the use of this type of equipment by the A.R.E.A., Army Engineers, the Kansas State Highway Department and others were carefully studied to select the type of equipment best suited to this track. It was found that the load pressure cells are still in the process of development and that this track could assist materially in their development and applications. However, the instruments used in conjunction with the cells are well developed. These instruments include recording oscillographs, together with suitable amplifiers and other accessories. It is believed that three 24 channel recording oscillographs together with the necessary accessories to handle 72 pressure cells would adequately meet the initial needs. Later, if found desirable, additional units can be provided.

The load distribution and deflection mat equipment developed by C.A.A. has not been included in the initial set-up of the track. However, provision has been made for its inclusion at a later date in conjunction with special studies.

Neither has the radioactive isotope moisture content measuring equipment been included at this time. The present units utilize extremely hot cobalt isotopes, making their routine use too dangerous. Their inclusion has been postponed pending further development in the use of less dangerous isotopes; however, provision has been made for their immediate use under a special project or later, when their use is safer, under general projects.

Flow meters, pumps and controls have been included for the control of subsurface moisture content or drainage in the special test area. Still other instruments such as straight edges and other pavement irregularity measuring devices can be purchased or built in the shops of the the Highway Department

Traffic counters, counting the passes of the test vehicles, have also been provided for.

In order that instruments may be housed and stored properly and safely, a suitable building near the special test area of the track should be provided. This building should contain a room in which the load pressure cell equipment can be permanently mounted together with all the necessary controls. This room should face the special test section and should be provided with a large window for observation. The building should also contain a room where the various records can be analyzed and all necessary calculations made and where the records may be filed. Rooms for storage of other equipment and spare parts for minor repair, for overhaul and cleaning of equipment, for lockers of employees on duty and for an office should also be included. A small observation booth should be built on the roof of the building from which the entire operation of the track may be observed.

A weather shed was also investigated in the course of this study. In this shed, covering about 150 feet of the track, any type of weather could be manufactured and imposed upon the section of the pavement contained under its roof. This shed would contain a sprinkler to simulate rain of various intensities, a snow or hail making machine, infrared and ultraviolet lamps to develop almost any intensity of sunshine, heating and cooling fans and refrigerator coils to create icing and freezing of the pavements. The provision and use of this shed will furnish a means of testing the weathering of pavements. It will also permit conducting tests under a wide range of weather conditions regardless of prevailing natural weather. Thus summertime conditions can be tested during the winter. All of the equipment required for this shed can be secured from regular manufacturers who have provided similar equipment to the Army Air Corps for their weather tests of aircraft. The shed, however, is not included at this time because of the expense involved. If it is deemed desirable, it can be provided at a later date.

By inclusion of the instruments recommended, the track can perform as an efficient and effective research tool over a wide range of problems, as well as serving as an effective means for conducting tests of a strictly practical nature. Other provisions incorporated in the basic design of the track permit the inclusion of additional instruments to further increase its scope.

Auxiliary Equipment

Certain auxiliary equipment should be provided or made available in order to make the track a self contained unit and to assure accurate and proper control in the manufacture of paving mixtures. The auxiliary equipment needed are the following:

1. The necessary pavement construction equipment should be made available through rental or loan. In this manner a wide variety of equipment can be secured economically for both the actual construction of the pavements and also for testing their efficacy in performing their functions. Purchase of such equipment would, of necessity, materially curtail the use of diverse methods of construction; also, considering the short time such equipment would be used in comparison with the time required for testing of pavements, the expense would be unwarranted. The test pavements may also be laid under contract, in which case no equipment on hand would be needed.

2. Equipment required to remove pavements upon completion of the tests fall into the same category as construction equipment. Its purchase is not recommended for similar reasons.

3. A small asphalt plant having a one half ton mixer should be provided. All bituminous mixes can be made in this plant under strict controls. Plant mixing of aggregates for bases, stabilization and other pruposes may also be accomplished under strict control. This is essential if some of the variables are to be eliminated in certain tests. Further, the plant can furnish materials when commercial plants may be either too busy or shut down during slack periods. The plant, of course, is subject to operation only while mixing pavements for the track. At other times it may be used by the maintenance forces in the manufacture of materials to be used in their work. It can also be used for training inspectors in asphalt plant operation. Thus it need not be standing idle while tests are being conducted on the track.

4. A small concrete plant should be provided for the same reasons given for the asphalt plant.

5. A small portable steam generator of 125 horsepower capacity with

steam return facilities should be provided for temperature control of pavements.

6. A small portable gasoline or diesel engine driven refrigerator unit should also be provided for the same reasons given for the steam generator unit.

7. A small test vehicle repair shed should be provided for minor repair of test vehicles and installation of controls and outriggers on the vehicles. If the track is built close to the main truck repair shop of the Highway Department, this work can be done there in addition to major repair and overhaul of the test vehicles.

PART III

COORDINATION OF COMPONENT PARTS OF TRACK

It is apparent from the foregoing that the many features of the design and operation of the track, test vehicles and instrumentation are closely interrelated and that it was essential that they be carefully correlated and coordinated in the development of the track. The best way to test whether or not such correlation and coordination has been achieved is to consider the tsack in its process of actual operation.

Operation of the Track

Having decided the various types of roads to be tested and the characteristics of the tests to which the roads are to be subjected, the laying of the test pavement can be begun.

The first operation involves the placing of the desired subgrade within the regular test area of the track. The guide rails at the exit and entrance to the siding are removed and short ramps are installed temporarily to give access of trucks and construction equipment to the track pavement area. The materials of the subgrade may be brought in by trucks and dumped into the track. Stabilizers, graders, rollers, and other construction equipment can then enter the track and prepare the base in the desired manner and finish it to the desired grade. Upon completion of the subgrade, the desired base can be similarly placed and finished. In the event that the base beneath the pavement and the shoulder area should differ, temporary steel bulkheads may be placed until one or the other has been laid. Then the bulkheads are removed and the other material is placed. Both can be compacted together. Upon completion of the base, the surface can be laid. In this case, if finishing machines are used, they will spread the surface to proper width and the shoulder can be placed last. In case of road mix construction, the bulkheads can be used again temporarily to separate the pavement and shoulder during construction. Where no shoulder is required and the pavement occupies the full width of the track, the work is materially simplified. In cases where no shoulder support is desired, the shoulder should be laid and then removed to the desired slope or depth.

The special test area pavement should be laid in conjunction with the regular test area. In this case, however, provision should be made for the introduction of the necessary test cells in their proper locations in the various parts of the pavement.

During construction of the test pavement, the test vehicles should be fitted with the necessary controls and outriggers. The outriggers should be set to the position the vehicle is to travel on the pavement laterally. The outriggers should then be locked ready for driving onto the track. Special gas tanks of a capacity to run the test vehicle for a 23 hour period should be mounted and filled.

Upon completion of the construction of the test pavement and preparation of the test vehicle for operation, the test vehicle is manually driven onto the track. The outriggers are then released to engage the guide rails, and the guide rails at the siding replaced to close the circuit of the track.

Having established the test sequence and the operating speeds of the test vehicles, the operating controls on the vehicle and the control trips on the control rack are set accordingly. Before starting the test, each test vehicle to be used in the test is run around the track with a driver in attendance to check its operation. The vehicles after check are lined up immediately behind one of the signal controls with the engines running.

The test is then ready to begin. The first vehicle is started by engaging the clutch with the auxiliary clutch lever mounted on the side of the vehicle. As this vehicle moves forward and passes the control signal, its trip moves into stop position. In the meanwhile the operator walks to the next vehicle. There he watches the signal trip and as sonn as this moves to the caution position, he starts the next vehicle. This procedure is followed until all test vehicles involved in the test have been started. The succeeding vehicles are started on the caution signal in order to allow them to accelerate in time to reach their position just behind the green signal. In this way the spacing between vehicles can be kept to a minimum. Of course if only one or two vehicles are used, they may be started after the caution signal is up, depending upon the spacing desired.

Another method that can be used in starting the vehicles involves placing them around the track in their respective positions and starting them simultaneously.

Once the vehicles have been started, only one man is required on duty to observe the operation of the vehicles from the observation booth and attend the operation of the test instruments. His only real function is to watch the operation of the test and be on hand in case anything unforeseen occurs.

The test is continued in operation for 23 hours, after which the vehicles are stopped by simply covering one of the signal control electric eyes. This will stop the first truck passing this signal; the rest will stop automatically. It is desirable to stop the test vehicles ahead of the exit to the siding. After the vehicles have stopped, the exit section of guide rail is removed, the outriggers on the vehicles are taken up, and the vehicles are manually driven onto the siding. Here they are serviced (oil changed, greased, gased), controller records are removed, and the vehicles are generally checked. While the test vehicles are being serviced, the pavement in the track can be inspected and any measurements can be made that are desired concerning pavement behavior or reaction. One hour is provided for this purpose.

As soon as the test vehicles are ready, they are again driven out on the track and prepared for the resumption of the test. When the hour is up, they are started out again on another day's run. This procedure is repeated daily until the test is terminated or until the pavement shows signs of distress or failure.

During a day's operation, a test vehicle, operating at an average speed of 30 mph for 23 hours per day will make 1,380 circuits of the track for a total of 690 miles a day. After 30 days of operation, the vehicle will have made 20,700 miles. Thus, if a test requires 90 days, the vehicle will have travelled 62,100 miles and be ready for an overhaul.

Upon completion of a test, the old test pavement and base may be removed by regular construction methods and a new set of pavements laid ready for the next test.

The recording controller chart shows the exact operation of the vehicle on each circuit. By use of electric eyes, ticks can be impressed on the record and each circuit identified. These records, when coordinated with pavement behavior records, yield a permanent record of each test. These, supplemented by other measurements and photographs, can be filed for future reference and comparison.

PART IV
COSTS

The estimated cost of construction of the track and the provision for all appurtenances, accessories and auxiliary equipment deemed necessary for its successful operation was based on the preliminary designs recommended and general costs prevalent in Ames, Iowa, at the time this study was made. Since the designs submitted in this report are of a preliminary nature, it is expected that the refinements made in the actual designs will in some instances effect a material saving in cost. As cases in point: The thickness of the concrete floor of the track was designed roughly to meet comparatively poor subsoil conditions. If upon selection of the site of the track good subsoil conditions are found, the suggested thickness of 12 inches can be reduced to 8 inches with a consequent saving of about $7,000 in concrete alone. Concerning the steel suggested, it may be found that the channel tie rods suggested may be either replaced with lighter angles, rods or piping, or eliminated entirely if adequate side support can be developed at the walls of the track. These examples serve to illustrate that the costs as estimated in this report are liberal and are subject to reduction rather than increase.

For the purposes of clarity and composition, the estimated costs are broken down into eight separate parts. It is believed that such a breakdown will also assist in the development of a system of stage construction, if deemed desirable, in which the total cost of the entire installation may be spread over several years in accordance with character and priority of the tests desired. The eight sections of the breakdown are as follows: 1. Engineering and design. 2. Land acquisition. 3. Construction of the track with its accessories. 4. Test vehicles. 5. Instruments and instrument building. 6. Auxiliary equipment. 7. Trial operation. 8. Recapitulation and total cost.

1. Engineering and Design Costs

Engineering and design costs include the development of detailed designs and the preparation of plans and specifications for the construction of the track and for fabrication and installation of all appurtenances, accessories, instruments, instrument building and auxiliary equipment. It is estimated that this work will cost about $10,000.

2. Land Acquisition

According to the recommended designs, about sixteen acres of land will be required for the track and its auxiliary equipment. Estimating about $500 per acre, the purchase of the land needed would cost about $8,000.

Preparation of the land for the construction of the track will no doubt require a certain amount of clearing and grading, depending upon its topography and prior use. A sum of $3,000 has been allocated to cover this contingency.

3. Construction of the Track and Its Appurtenances

Since the concrete portion of the track is of relatively simple design which requires simple reusable forms, it is believed that concrete can be placed at $20 per cubic yard. At such a price the concrete of the track would cost $42,000.

The steel required for the guide rails, posts, ties and knee braces was priced at 16 cents per pound. In conformance with the suggested design, the steel would cost about $23,000.

Construction of the siding is estimated to cost about $1,000.

It is suggested that signal equipment for the safe operation of four test vehicles simultaneously should be provided at the outset even though only a small number of tests may require this extreme condition. The difference in cost between supplying all at once and only, say, for two vehicles is comparatively small, since the difference is only in additional signals. The wiring must be run around the track in either case. Furthermore, the average unit price of equipment would be lower if a larger number of units were purchased at the same time. Since 12 signals are required for the simultaneous operation of four vehicles and each signal is estimated to cost $600, the cost of these would be $7,200. Electrical conduit and wiring incidental to these signals is estimated at $2,800. The total cost of signals is therefore about $10,000.

The furnishing and installation of the piping necessary for instrumentation and temperature control of pavements in the test area is estimated at $2,000.

4. Test Vehicles and Their Accessories

It is proposed that one test vehicle composed of a tractor and semi-trailer unit be provided initially. By the provision of this vehicle at the outset, the operation of the track and vehicle can be worked out at once and all necessary adjustments made to assure smooth, continuous operation during the tests. The cost of this vehicle may be charged against the first test or against many tests if it is held as a spare. Since the test vehicles are of regular automotive manufacture, they may be pruchased as required in conjunction with the tests. The cost of a test vehicle is estimated at $12,000.

It is also proposed that four complete sets of outriggers and vehicle controls be provided with the track. It is, however, suggested that one set be purchased immediately in conjunction with the test vehicle. After their operation has been tested, adjusted and modified, if necessary, the other three sets as modified can be purchased. With four sets on hand, any condition of test can be met and in most cases spares would be on hand to keep the test in continuous operation in the event of breakdown.

Since both the outriggers and vehicle controls will fit all vehicles and since they can be used over and over again in successive tests with only minor maintenance and replacement, their cost can be amortized over a long period by charging a fee for their use on the separate tests.

It is estimated that the cost of the outriggers will be about $2,500 per set or $10,000 for the four sets.

It is estimated that the vehicle controls will cost about $5,000 a set or $20,000 for four sets.

5. Instrumentation and Instrument Building

Only the provision of the dynamic load pressure cell equipment is proposed at this time. The purchase of other test equipment such as the C.A.A. pavement deflection and moisture recorder and other devices that may be developed would be deferred until such time as they are specifically required by test procedures.

It is believed that instrumentation for the application of 72 pressure cells would adequately serve most conditions of tests contemplated. This equipment would include three twenty-four channel oscillograph recorders, 72 amplifiers and other necessary instruments and wiring plus 72 pressure cells. This equipment would be a permanent part of the track and its costs may be charged off against the various tests. It is estimated that this equipment will cost about $50,000.

Since these instruments are of a permanent nature and are costly, it is essential that they be properly housed. A suitable combination building for housing this equipment and other equipment that may be made available later, and providing for various other functions, has been suggested. Such a combination building would cost about $25,000.

The subsurface moisture test section of the special test area requires suitable piping and circulating pump for suitable moisture control. The furnishing and installation of this equipment is estimated to cost about $1,000.

6. Auxiliary Equipment

The auxiliary equipment proposed at this time includes a portable steam boiler, a portable refrigerator unit, and a small bituminous mixing plant. The concrete mixing plant suggested can be deferred to a later date.

The portable steam boiler should be of about 125 horse power and be fully automatic and have a pressure of at least 90 pounds. Such a boiler costs about $5,000.

The refrigerator unit should also be of a portable type and of sufficient size to cool a 25 foot section of the pavement to at least 30 degrees F. Such a unit will cost about $5,000.

The small asphalt plant should contain a 1/2 ton mixer and be equipped to manufacture all types of bituminous paving mixtures, soil cement, soil bituminous and soil aggregate plant mixed stabilization mixtures. It should also possess all necessary appurtenances. Such a plant will cost about $40,000.

7. Trial Operation of Track

All newly designed equipment of an automatic nature requires some time to adjust and test out its operation. The track is no exception. In this case some time is also required to instruct the personnel in its operation if efficient, successful operation is to be attained. It is estimated that about 30 days should be devoted to this purpose. The cost involved will be about $3,000.

8. Recapitulation and Total Costs

1.	Engineering and Design		$10,000
2.	Land Acquisition		
	Cost of land	$8,000	
	Preparation of land	3,000	11,000
3.	Construction of Track		
	Concrete	$42,000	
	Steel	23,000	
	Siding	1,000	
	Signals	10,000	
	Piping	2,000	78,000

4. Test Vehicle and Accessories

Test Vehicle	$12,000	
4 sets Outriggers at $2,500	10,000	
4 sets Controls at $5,000	20,000	$42,000

5. Instrumentation and Instrument Building

Instruments	50,000	
Building	25,000	75,000

6. Auxiliary Equipment

Boiler	5,000	
Refrigerator	5,000	
Asphalt Plant	40,000	50,000

7. Trial Operation — 3,000

Total Estimated Cost $269,000

Stage Construction Cost Breakdown

In the event it is deemed desirable to spread the cost of the entire project over a few years through stage construction, the following stages are suggested:

Stage 1.

1.	Engineering Costs	$ 10,000
2.	Land Acquisition	11,000
3.	Construction of Track	78,000
4.	Test Vehicle and Accessories	42,000
7.	Trial Operation	3,000
		$144,000

Stage 2.

5. Instrumentation and Instrument Building $ 75,000

Stage 3.

6. Auxiliary Equipment $ 50,000

By such staging, comparative and endurance tests of pavements could be conducted immediately, followed later by research and material control functions. Under this method it must be remembered that much valuable time and opportunities would be lost in checking internal behavior of pavements, necessitating repetition of tests to secure this information for improving the design of the pavements tested before instrumentation and material controls were provided.

PART V

OPERATING SCALE MODELS

As the work on the project progressed it was noted that the construction of operating scale models would materially assist the development and study of certain features of the track. It was also found that such models would greatly simplify the explanation and clarify the protrayal of the general layout, basic concepts and operating of the track in the presentation of these features to interested officials and the public. It was therefore decided to include the building of such models as an additional part of the project.

The development of the design of the model disclosed that a single model could not serve all of the desired purposes. A model constructed on a scale suitable for the study and portrayal of details would be much too large and cumbersome for convenience in depicting the overall layout and operation of the track. Therefore, two models were built, each of a convenient size and to a scale best suited to its particular purpose. One model, Plate II, designated "Model of Road Track" shows the general layout, operation and essential appurtenances of the track as a whole. The other model, Plate IV, called "Model of Special Test Section" shows the details of the semi-trailer tractor test vehicle, its outriggers, the guide rail and other various aspects of the special test section of the track.

Model of Road Track

The scale and consequently the size of this model was controlled by several important qualifications. These included convenience of size of the model, cost and the availability of the smallest scale model of test vehicle that could be properly mechanized.

Since the scale of the model test vehicle establishes the scale of the track and consequently the size of the model, a search was made for small scale models of test vehicles. Eight such models of various scales were secured and examined for their ready adaptation to mechanization and their effect upon the size of the model. The smallest of these model test vehicles suitable for proper mechanization has a scale of 1 inch equals 6 feet. Translation of this scale to the layout of the track, Figure 1, makes a model 20 feet in length and 8 feet in width. This is much too large for convenience. Upon further study it was found that the size of the model could be reduced to 12 feet by 8 feet by omission of the transition curve sections of the track. Since the transitions are not essential to the main purpose of the model, they were omitted and the model constructed on a scale of 1 inch equals 6 feet.

For the sake of convenience in handling and storing, the model was built in three sections each 8 feet by 4 feet. Dowels and clips were provided for easy assembling and spacers and tie bars were provided in racking and locking the sections together for protection in handling, in moving and in storage.

The model of the test vehicle, a semi-trailer tractor unit, secured in the "5 and 10 Cent Store" for nineteen cents, necessitated some changes for adaptation to suitable mechanization. These changes involved provision of small scale size rubber tired wheels to develop the traction needed for operation and new axles and axle bearings to give them longer life in service. Plastic outriggers were also installed to guide the vehicles around the track.

The model test vehicles were mechanized by the installation of small $1\frac{1}{2}$ to 6 volt, 1/2000 horsepower direct current electric motors. Endurance test of these motors under track operating conditions disclosed that they possessed a service life of but three hours due to failure of the commutator brush spring contacts. The motors were dismantled and fitted with new brush spring contacts that will materially extend their usefulness. Due to the high operating speed of these motors, it was necessary to build and install tiny reducing gear trains having a ratio of 8 to 1 between the motor and the drive axle in order to attain the proper relative operating speeds of the vehicles. Due to the size of the motor and space required for the gear reducer, the drive was placed on the rear axle of the semi-trailer. Electric power is supplied to the motor by a power control pack through the guide rails and sliding contacts attached to the vehicle. The power control pack converts 110 volt alternating current to 1 to 7 volts direct current by means of a seven volt transformer, a selenium rectifier, and a variable resistance. By varying the track voltage between 3 and 6 volts, relative speeds of the vehicle equivalent to 20 to 45 miles per hour can be secured. The model test vehicles may be operated in either a clockwise or counter-clockwise direction around the track by operating a current reversing switch on the power pack.

The model as built, Plate II, possesses an oval track having the equivalent of two 300 foot straight sections and two curves of 250 foot radius. The transitions are omitted for the reason previously discussed. The track is fitted with representative guide rails. The model is also provided with scale model gas tanks and oil bin in the service area, Plate III, an instrument building and an administration building, a small vehicle repair and fitting shop, Plate II, weathering shed, scale models of some construction equipment including a motor grader, roller and motor dump wagon and four model test vehicles. In the final recommended designs, the instrument and administration buildings have been combined into a single building. The pedestrian crossover will be required in the single building as shown on the model. The pavement area of the model has been painted various colors to indicate the presence of various types of pavement under test.

Model of Special Test Section

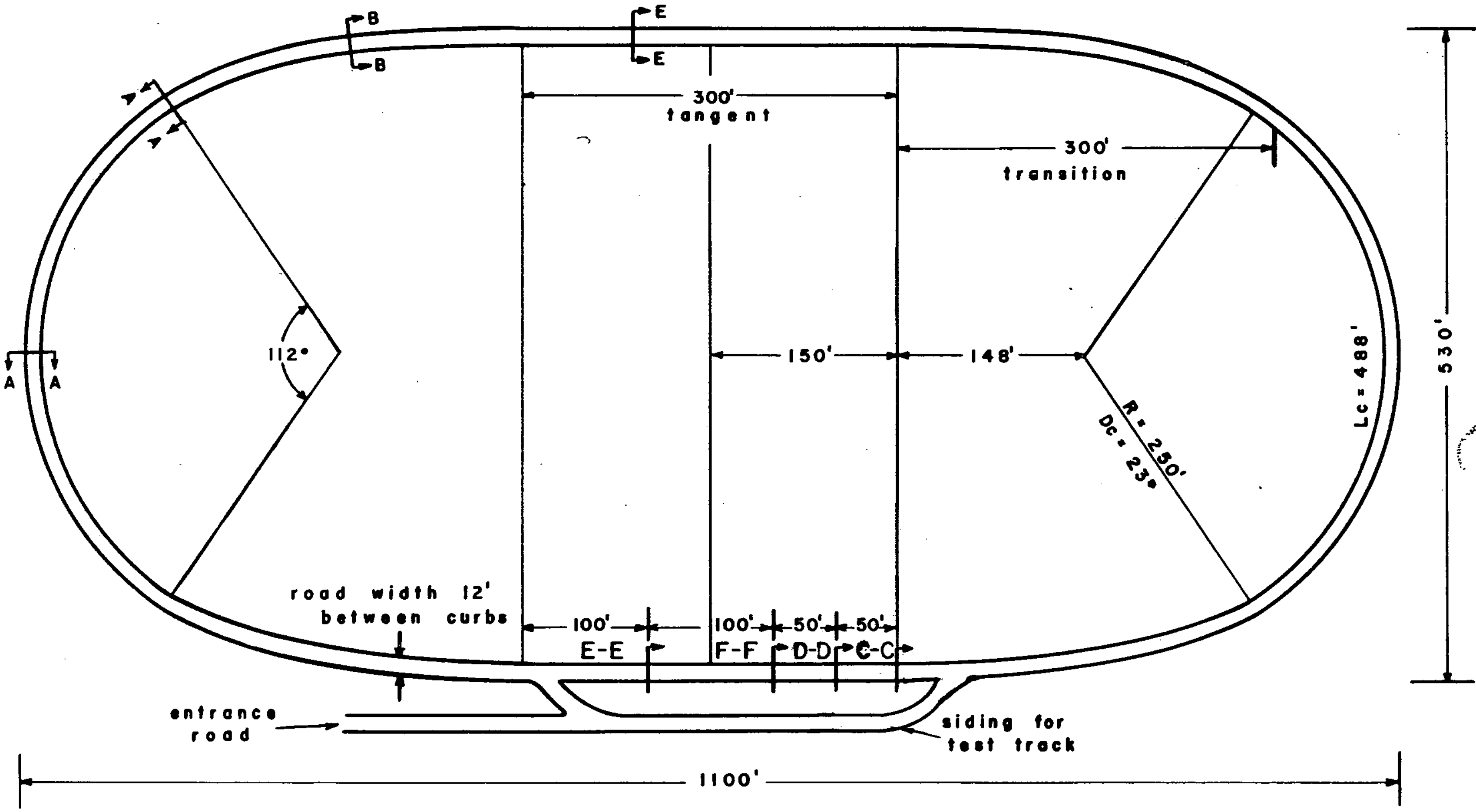
The scale of this model was based upon the best scale model of the test vehicle, semi-trailer tractor unit, that could be secured. The model of the test vehicle used in this model was presented to the project by the Des Moines District Office of the International Harvester Company. This is an accurate scale model of their semi-trailer tractor unit having a scale of 1 inch equals two feet. This scale was used in developing the model, guide rails, etc. The model, Plate IV, shows the respective characteristics of the several test sections such as the General Test Pavement, Plate V; Load Distribution Test Section, Plate VI; Subsurface Moisture Test Section, Plate VII. It also shows some details of the guide rails.

The model test vehicle used in conjunction with this model, Plates I, V and VI, shows some aspects of the construction of the outriggers and their placement on the vehicle. The model of the semi-trailer as supplied was that of a long van type enclosed semi-trailer. This model was cut down and shortened to conform more nearly with the type of semi-trailer recommended for use in actual operation. The model test vehicle was mechanized by use of two small electric motors such as those used on the test vehicle of the Model Road Track, Plate III. One of the motors was mounted to drive a front wheel of the tractor and the other to drive a wheel of the semi-trailer. This was done to permit both forward and backward operation of the vehicle on the model. Power is provided for the motors by four six-inch dry cells, inside the model, connected in series parallel to give 3 volts direct current. A separate power pack converting 110 volts alternating house current to 1 to 4 volt direct current is supplied with the model.

The model is also provided with electrical contacts embedded in the pavement of the model which actuate panel lights on the control panel, Plate V, to simulate the action of load pressure cells as the model vehicle moves over the pavement.

The control of the movement of the model test vehicle over the pavement of this model is accomplished by a control panel mounted on the left side of the model, Plates IV and V. This control panel, Plate V, consists of a plug receptacle at the left end to receive the power from the power pack. To the right of this is a selector switch for use of either batteries or power pack as the source of power. Next is the knob of a variable resistance for control of the speed of the model test vehicle. Continuing to the right is the directional switch for controlling forward or backward motion of the model test vehicle. Lastly, on the right are the four panel lights that represent the operation of pressure cells embedded in the pavement of the model.

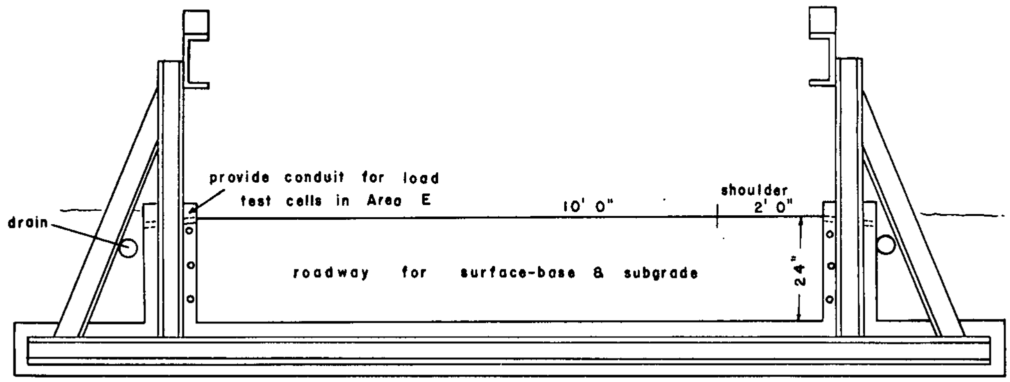
The Special Test Section Model and all test vehicles were built, or remodelled, adjusted and mechanized by the author who was in charge of the project. The Road Track model was built by students from the Industrial Education Department of Iowa State College hired for this purpose.



Scale: 1" = 100'

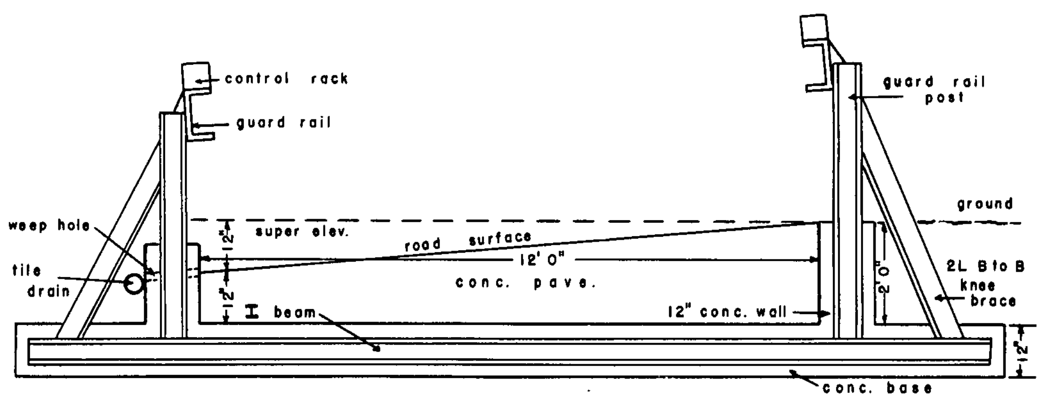
– Plan of Track –

Fig. 1



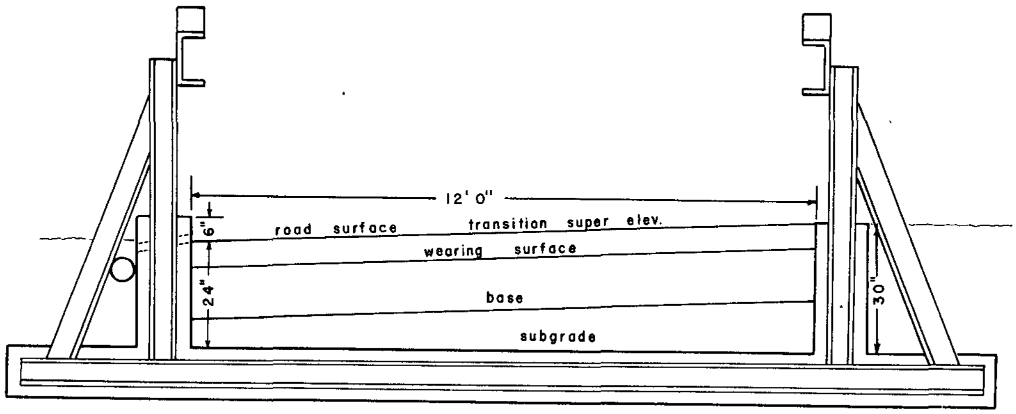
Scale: $\frac{1}{2}$" = 1'-0" Section E-E

Fig. 2



Scale: $\frac{1}{2}$" = 1'-0" Section A-A

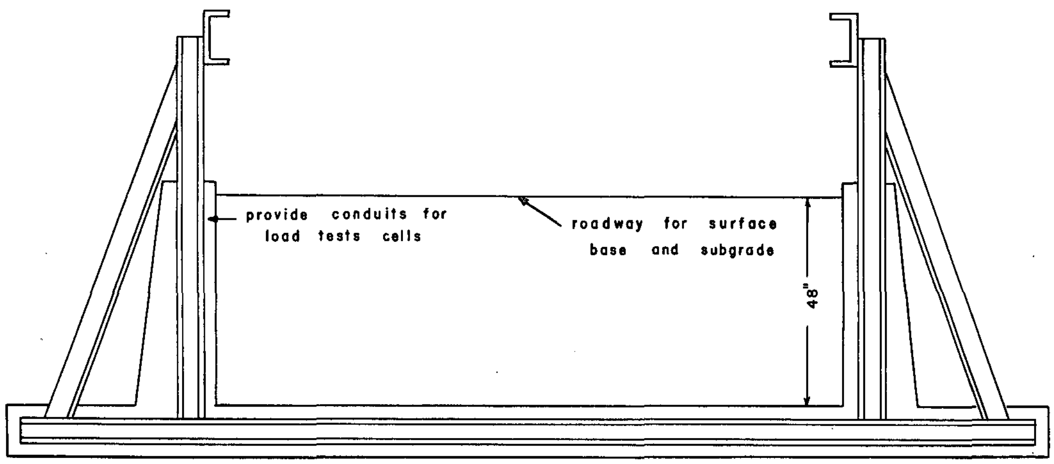
Fig. 3



Scale: $\frac{1}{2}$" = 1'-0"

Section B - B

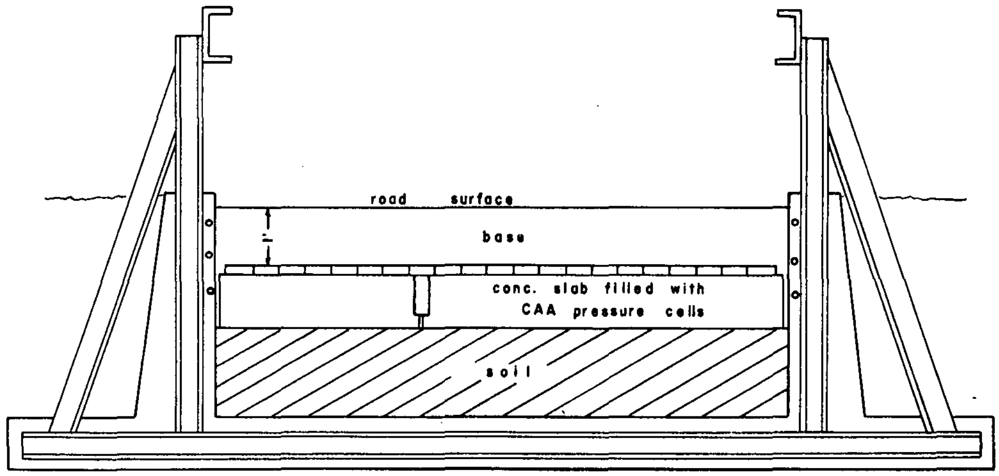
Fig. 4



Scale: $\frac{1}{2}$" = 1'-0"

Section F - F

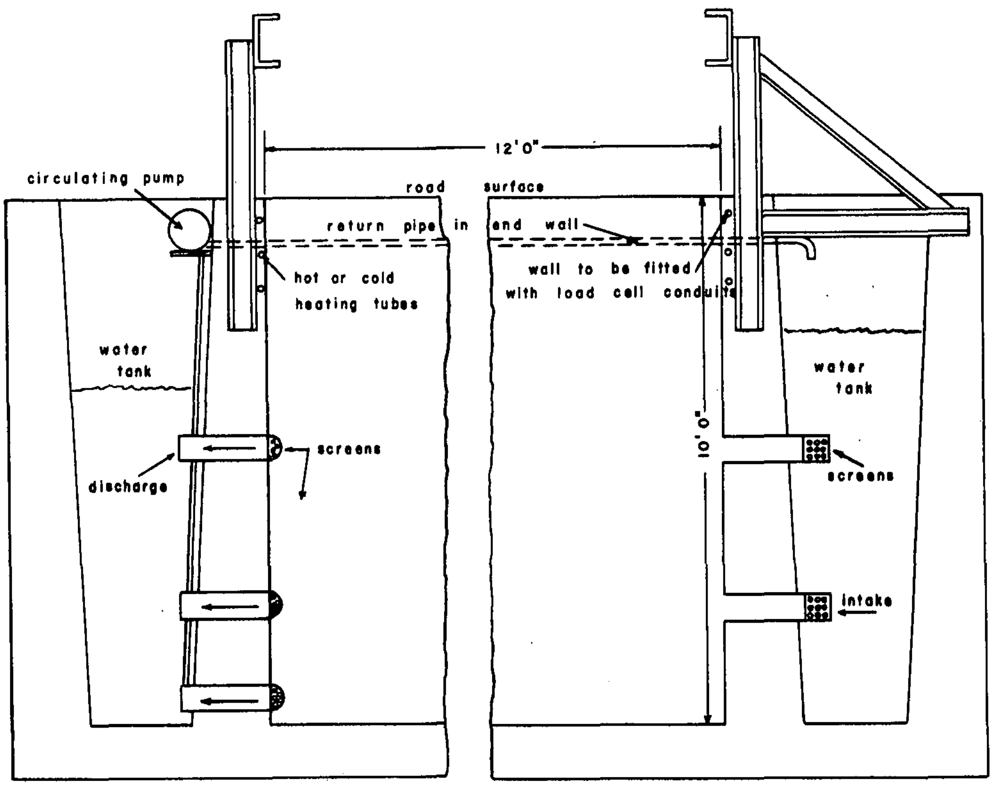
Fig. 5



Scale: $\frac{1}{2}$" = 1'-0"

Section D-D

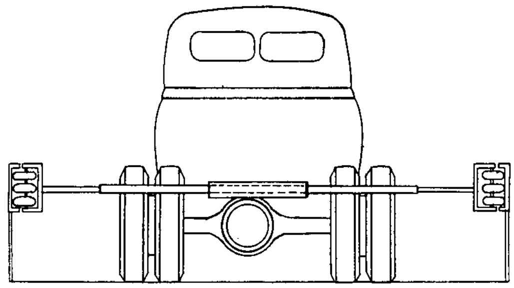
Fig. 6



Scale: $\frac{1}{2}$"= 1'- 0"

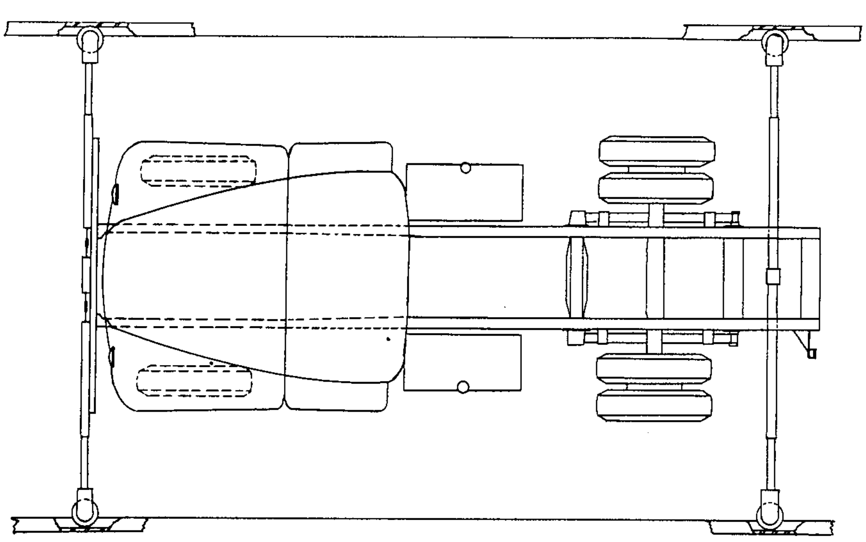
Section C-C

Fig. 7



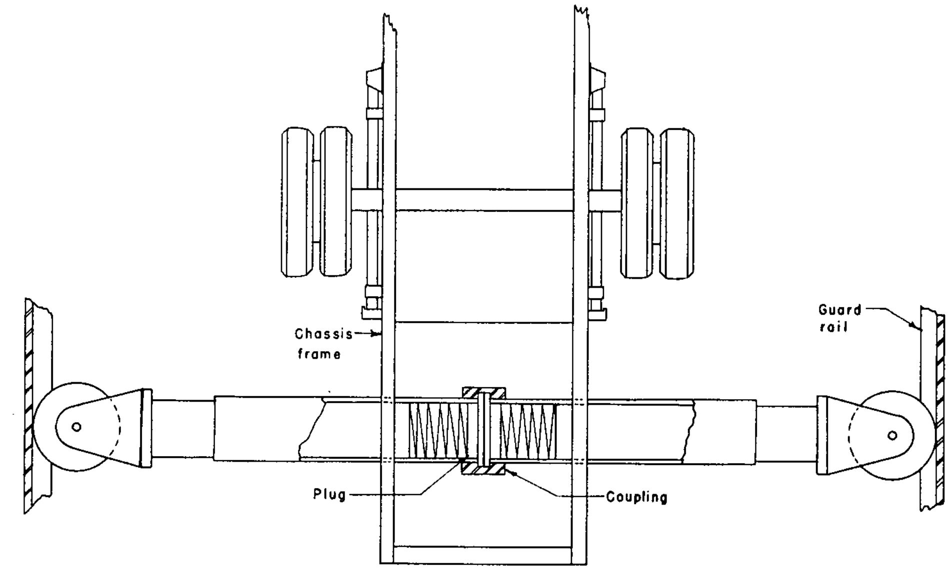
OUTRIGGER MOUNTING ON VEHICLE

Fig. 8



OUTRIGGER MOUNTING ON VEHICLE

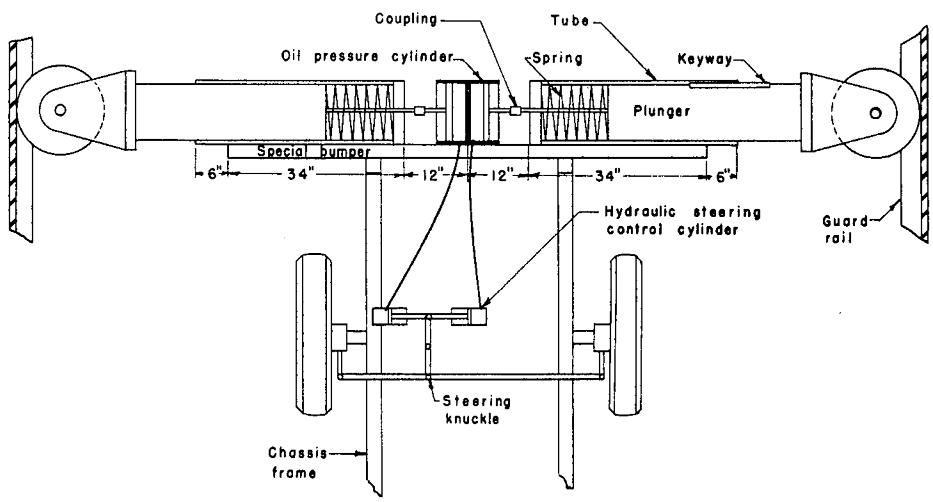
Fig. 9



OUTRIGGER DETAIL

REAR END AND TRAILER

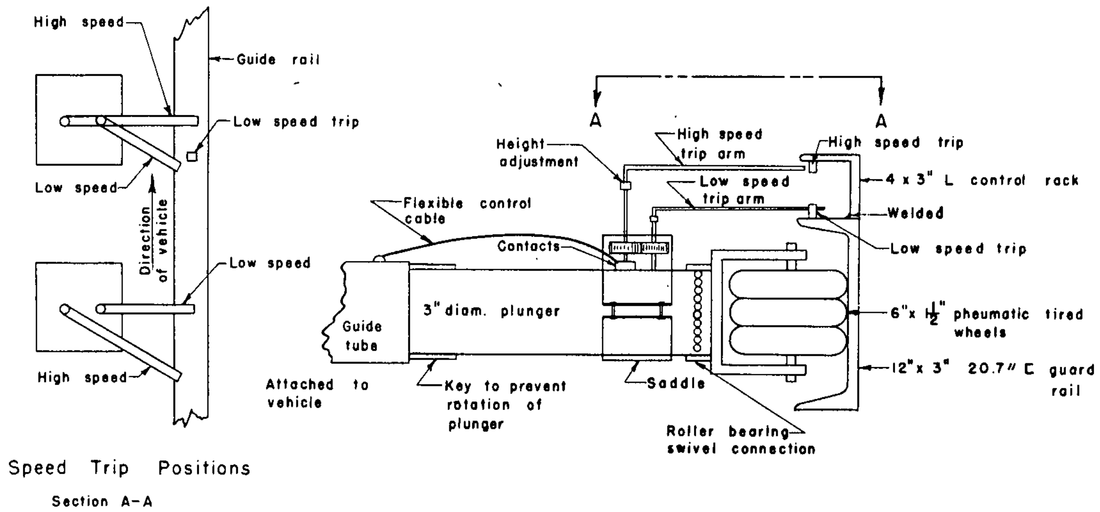
Fig. 10



OUTRIGGER DETAIL

STEERING CONTROL — FRONT END

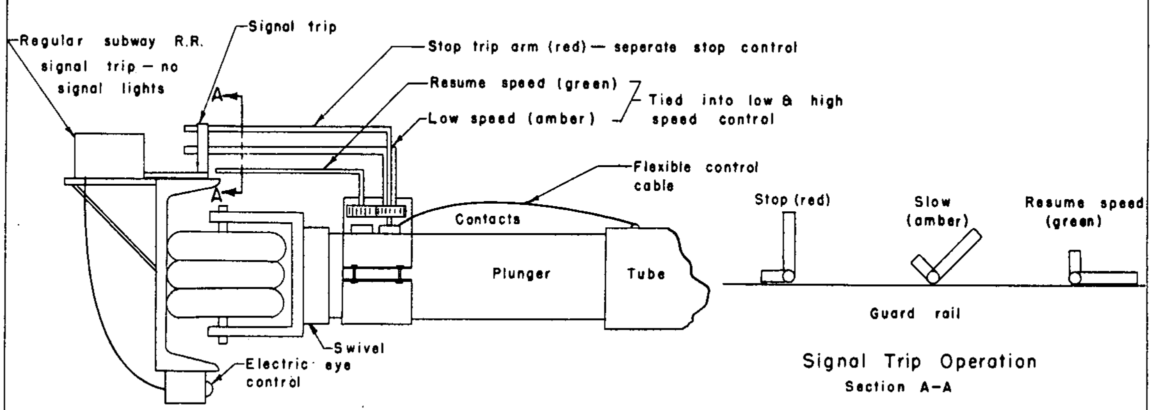
Fig. 11



SPEED CONTROL AND OUTRIGGER GUIDE DETAIL

OUTER RAIL— FRONT END

Fig. 12



SIGNAL CONTROL

SLOW-STOP INNER RAIL-REAR END

Fig. 13

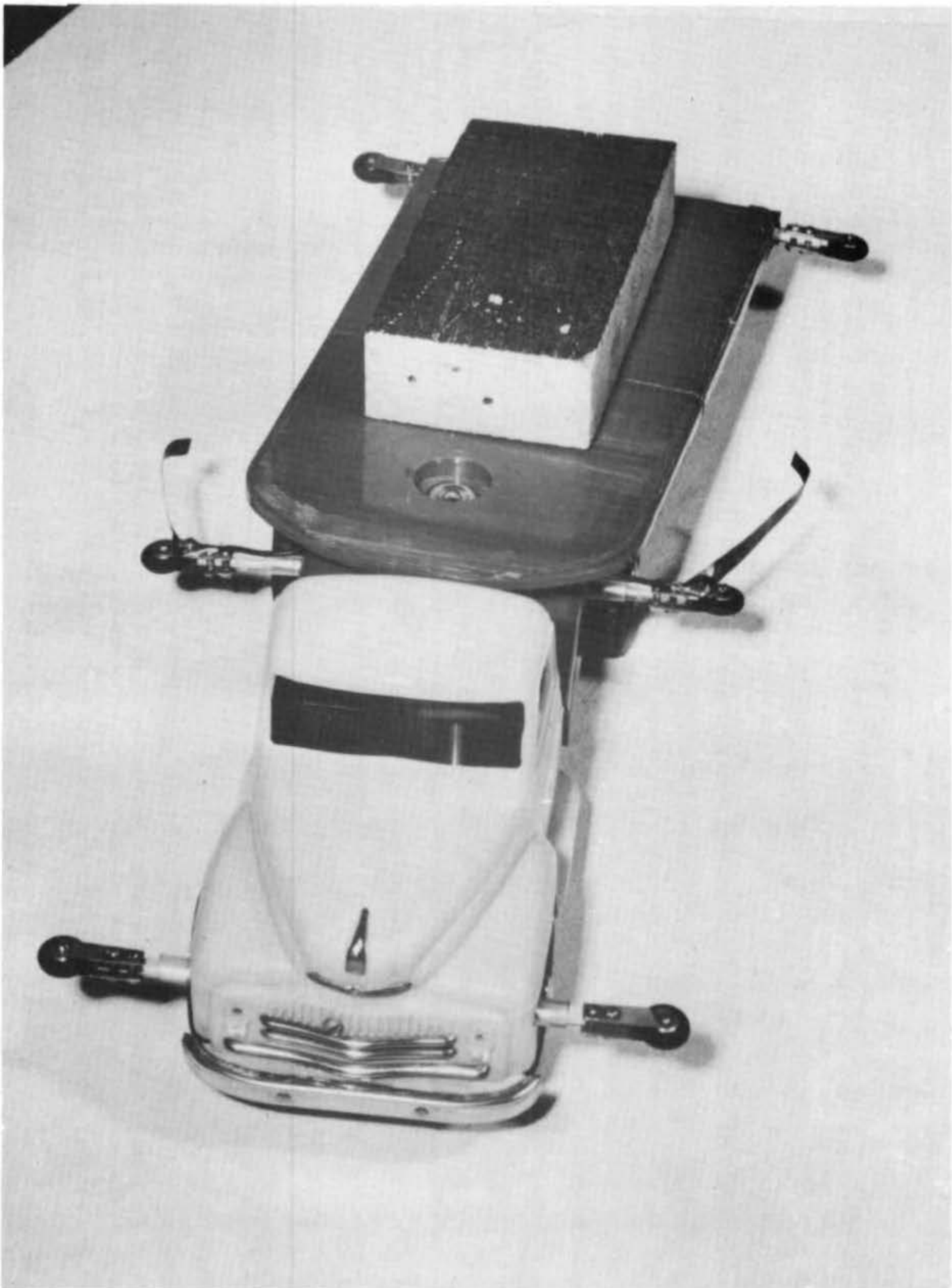


Plate I. Model of Test Vehicle

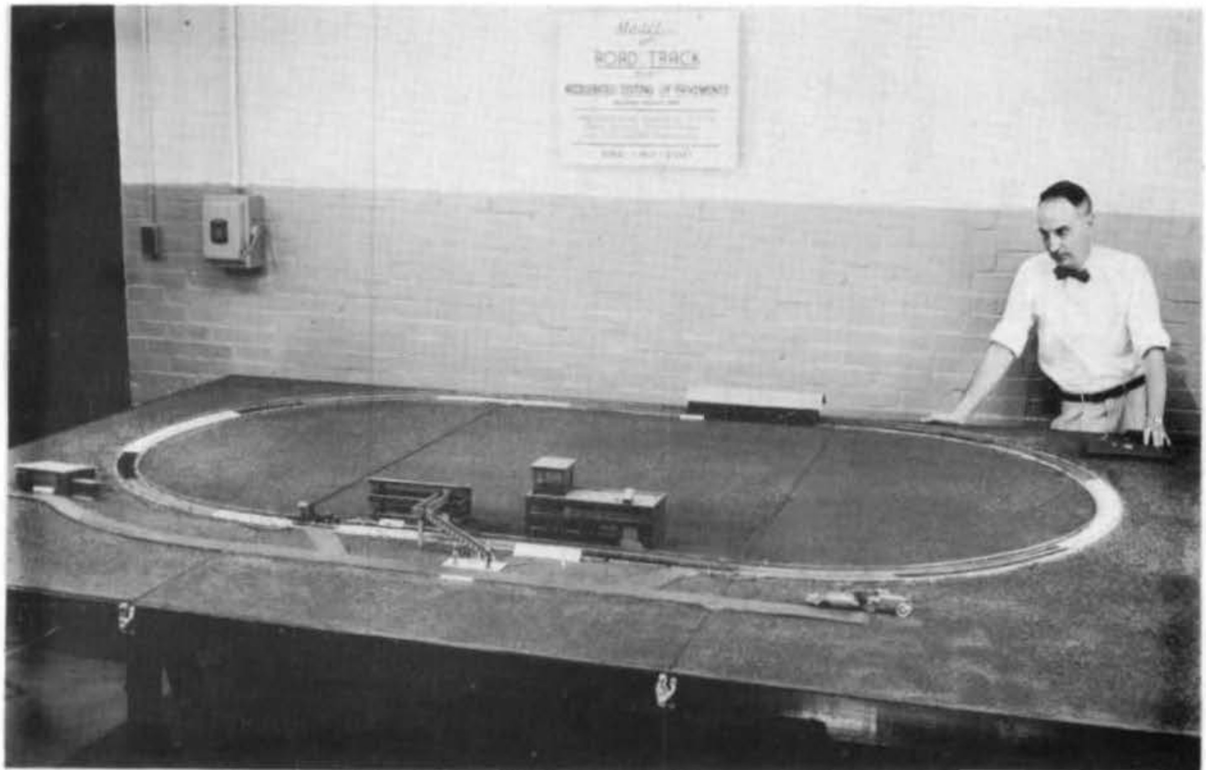


Plate II. Model of Road Track

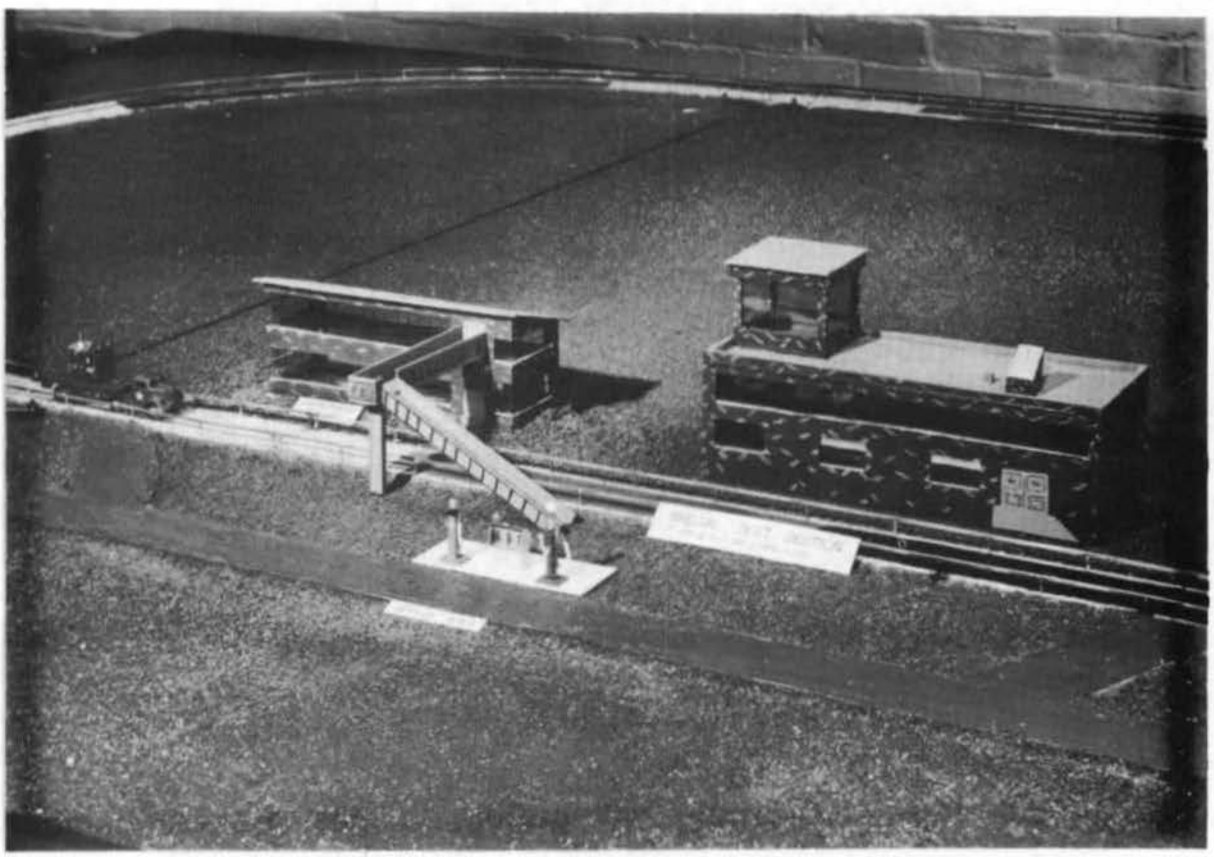


Plate III. Special Test Section of Model of Road Section

Plate IV. Model of Special Test Section

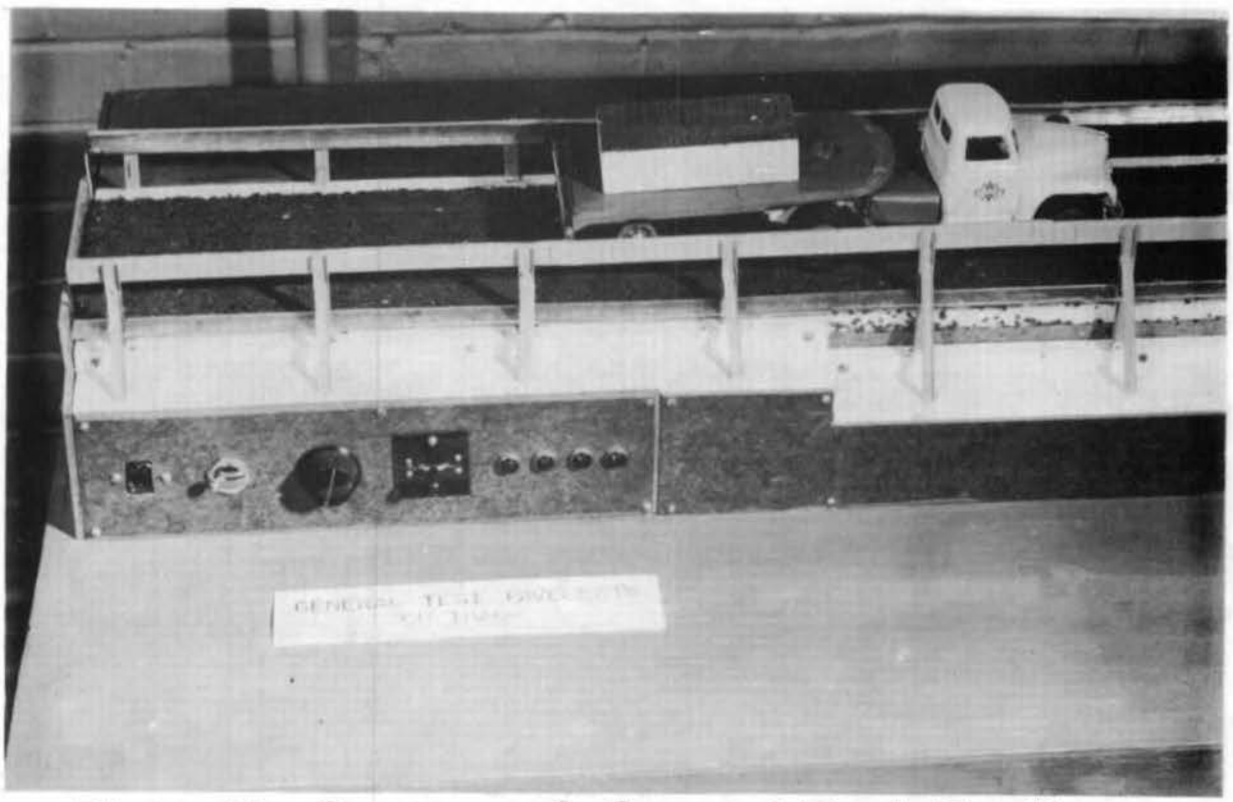


Plate V. Portion of Special Test Section and Controls

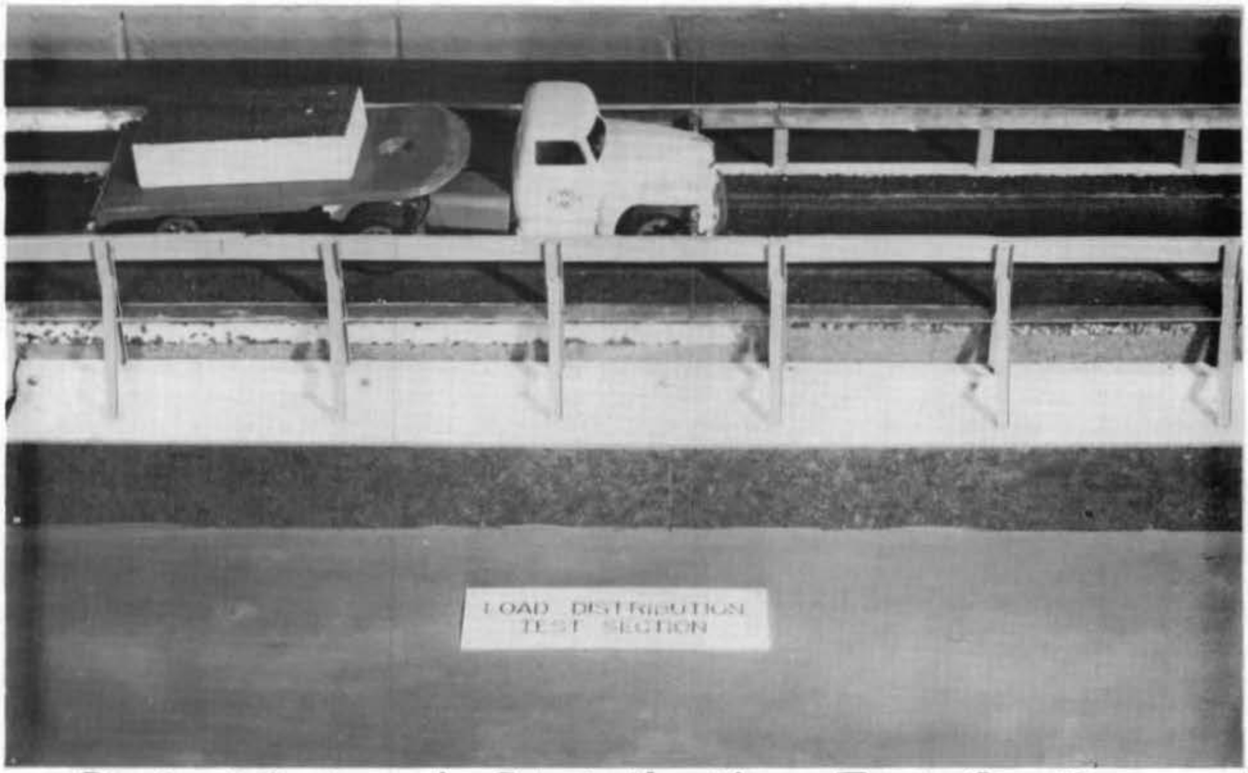


Plate VI. Load Distribution Test Section

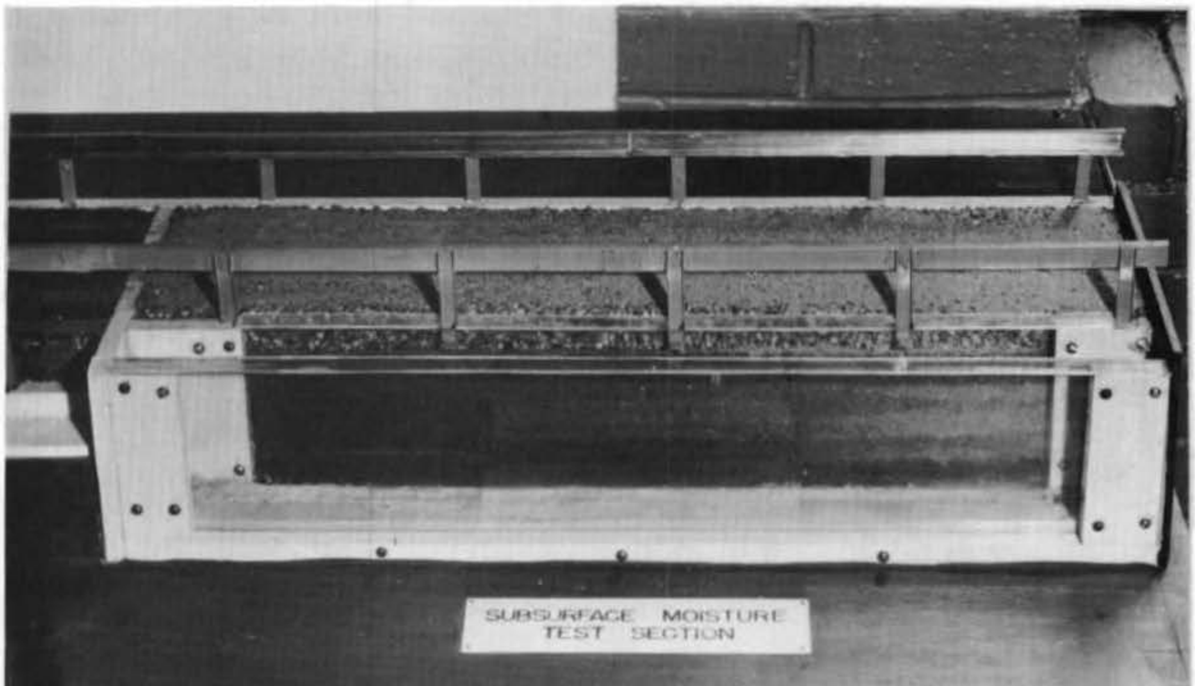


Plate VII. Subsurface Moisture Test Section