DISCUSSION AND ANALYSIS OF THE MARYLAND ROAD TEST

Remarks by H. S. Fairbank, Deputy Commissioner,
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Mr. Sykes, gentlemen. I don't know how many of you are like our chairman--wholly unfamiliar with the Maryland Road Test, and don't know what it is, or what its purposes were. There has been a good bit of report of it in the press, in the technical magazines, and in the trade press, and a great deal of that report has been somewhat far afield from the facts. In fact, I expect that what I shall say to you today by way of comment on the test will be the first public expression about the test that will have been made by a person fully cognizant of all of the results that were obtained in the test. It was only last week, on Thursday and Friday, that the committee advisory to the Highway Research Board which was in control of the test met for the consideration of draft reports covering the entire experience in the test. So, until last week, all of the facts of the test were not available to anyone. Therefore, today I have the privilege of talking to you for the first time with a full knowledge of what went on in the test and what has been gleaned from it in the way of fact and conclusion.

I think it is quite appropriate that this opportunity to discuss the test in all of its fullness should occur at the time of a meeting of a division of the Council of State Governments, because the conception of the test, the origination of the test, resulted from a meeting instigated by the Council of State Governments. It was, I recall, Mr. Bane, who in 1949, persuaded Governor Lausche of Ohio to call a meeting of representatives of the governments of the States of East-North Central area and the Middle Atlantic and New England areas,--areas in which there had been at that time a very considerable development of the operation of motor trucks of rather heavy gross weight and axle loads. The purpose of the meeting was to consider what measures the states, severally and together, should take in the light of what was occurring in the operation of vehicles of the larger weights over the roads. A two-day meeting ensued at the end of which those states, or some of those that were represented at the meeting, decided to form themselves into a new organization of a permanent character which they called the Interregional Council on Highway Transportation. And that Council, as one of its first projects, decided to undertake the Maryland Road Test.

The purpose of the test was a limited purpose. The experience of the states prior to that time was based upon a general observation of the behavior of their roads and a knowledge of the maintenance costs of the roads. Their experience had indicated to practically all of the engineers of those states that a certain amount of damage was occurring on the roads which could be attributed to no other cause directly and immediately than the heavy loading of vehicles and, particularly, a heavy loading of the axles of vehicles. It had been observed, for example, that the pavements in the outer lanes of dual highways, where largely the traffic of heavy vehicles is concentrated, that those lanes became damaged to a greater extent and in a shorter time than the inner lanes, which are used to a greater extent for the passing of heavier vehicles by lighter vehicles. It had also been observed that, where on a two-lane road there was known to be a heavier movement in one direction--we'll say loaded vehicles outbound from manufacturing plants--a heavier traffic in one direction than the other, the damage caused or observed on the heavier side of the road was greater than on the lighter side of the road. It is natural to couple those facts together and to assume--as most engineers did--that the greater damage was the result of the heavier loading known or believed to exist from a general knowledge of the character of the traffic. But, it was impossible on the basis of what was then known, to assign any specific damage to any specific weight of vehicle. You see, the traffic consisted of a wide range of weights--of both light vehicles and heavy vehicles, and between the lightest and the heaviest there would usually be a rainbow gradation from one weight to the other. Now, when you see damage of the sort that is caused by heavy loads, you can feel fairly sure that a heavy load has been responsible, but what heavy load? What particular weight of vehicle, in what frequency of operation is the cause of what degree of damage? That could not be answered on the basis of the general knowledge that existed at the time of this meeting in Ohio, and it was for the purpose of obtaining a more specific body of fact which would attach certain evidence of damage to the operation of certain weights of vehicles, so that there could be a close relation established between the weight of the vehicle or its axles and the behavior of the road, that this road test was undertaken. The purpose was just that limited. The purpose of the Maryland Road Test, I want to emphasize, was not to determine whether or not we should build our future highways for this weight of vehicle or that weight of vehicle. The purpose of the Maryland Road Test was not to determine the economic necessity of loads greater or smaller than those now moved. The Maryland Test was not intended, and will not tell you what should be the maximum size or weight of vehicle, which if permitted to operate, would result in the lowest cost of transportation. The purpose of the Maryland Test was limited to the determination of the effects upon a typical road of certain specific axle loading.

The axle loadings that were used in the test all were identical with limits of axle load which are provided in the laws of one or more states. There were four axle-loading conditions represented: first, a single axle load of 18,000 pounds--that is a load which is the limit permitted in the laws of, I believe, about 34 states; second, a single axle load of 22,400 pounds--that is a limit in I believe, about 11 states, clustered mainly along the Atlantic Seaboard; third, a tandem axle loading--and you know a tandem axle is two axles close together--a tandem axle load of 32,000 pounds, 16,000 pounds on each axle; and fourth, a tandem axle load of 44,800 pounds, 22,400 on each of those axles. Now, as I said, all of those loads that were used in the test were limits of loads carried in the laws of some of the states.

Now, for what reason did we want to know the relative effects of those loads? Obviously, there exists in all of our states a very considerable mileage of road that was built, not yesterday, or last year, but quite some time ago, and built over a considerable period. The development of traffic employing these heavy axle loads is, however, a matter of fairly recent occurrence. It wasn't until about 1940 that we began to see on the highways of the country generally any considerable number of axle loads in excess of 18,000 pounds. In fact, it was principally the effect of the second World War that set us on the path of increasing axle loading. Because of the necessity to accomplish as much transportation as possible with a limited number of vehicles, the states were urged to waive their axle load limits to permit the heavier loading of vehicles. And, as a result of that release from the restraints of laws and also as a result of the necessities of the time, there grew up a practice of heavier loading of vehicles and that practice has been continued into the post-war period, with evidence that because of the possibilities of reduced operating costs inherent in larger gross weight and larger pay loads, the trucking industry finds it profitable to load more heavily and is pressing to be permitted to load more heavily. Where the axle load limit is 18,000 pounds, the pressure is to get it a little higher. Where it is a little higher, the pressure is to get it still a little higher. And, up to the point where the industry finds it is no longer profitable to increase the load, I presume we can expect that self-interest on the part of the industry, as well as its desire to be of service to the public, will cause it to press for what it considers to be the permission necessary to enable it to perform a transportation service of maximum economy.

The question of what is maximum economy, at what point of loading that occurs, is a matter that has not been answered in any objective way, and it was not dealt with in the Maryland Road Test. It is a question that cannot be answered solely from the point of view of the operating costs of the vehicle because the reduction in the operating cost of the vehicle which comes with increased size is offset in some measure by the increased cost of the road which is necessary to support the heavier vehicle. So that the final determination of where the highest economy lies must rest upon a balancing of the tendency to reduce operating costs with increase of vehicle size and the tendency to increase road costs with the increase of vehicle size at some point. Possibly by future study and after a good many further tests, we might arrive at a determination of the optimum economy of axle loading, and at a decision as to what maximum loading is conducive to an optimum economy of highway transportation. That was not--I want to repeat again--the purpose of this test. The purpose of this test was solely that of determining the effect, as clearly as possible, upon what was regarded as a typical concrete road of certain axle loads--those that I have described--and the relative effects of those loads. And the reason for determining those relative effects was to provide some guidance to highway departments and legislatures, with which to meet and consider the demands for heavier loading from the point of view of the accountable effects of those demanded heavier weights upon the existing road system. I imagine we can build roads for any weight of vehicle. We can't, of course, build a road for an indefinite weight of vehicle. But the thing we are confronted with now is that we have many roads built; the roads are out there on the ground. They must perform a service over a reasonable period. So we want to know what will be the relative effects of lighter and heavier axle loads upon those existing roads. What will be the probability, or the possibility, of future life in those existing roads if we permit loading of one weight or another, and specifically, certain weights?

That was the purpose of the Maryland test, and only that. When the Interregional Council decided to carry on the test, it also decided to call upon the Highway Research Board--a branch of the National Research Council with a reputation for unbiased research--to conduct the research. The states that were represented--11 of them and the District of Columbia, and the Bureau of Public Roads--each contributed a certain amount of money; the manufacturers of motor vehicles promised and did contribute the vehicles that were used in the test.

These vehicles were assigned to that test only and operated under controlled conditions. The petroleum industry agreed to and did contribute the gasoline and the oil used and there were some other contributions, and all of them were pooled to carry on this test.

The test was directed by the Highway Research Board with the advice of a committee appointed by the Board which was representative of the of the participating states, the Bureau of Public Roads, and the cooperating industries. So, there was a joint industrial and state representation in this advisory group that at all stages was consulted in the planning and operation of the test.

A site for the road was selected in Southern Maryland near the town of La Plata on U. S. Route No. 301. There, there was found a section of concrete pavement one and one-tenth miles long, which by reason of the fact that there was a way around it by another road, could be cut off from use by normal traffic. It could be isolated--the traffic could be routed around it. That one and one-tenth mile of concrete road, then, was chosen as the test specimen and over it the following vehicles were operated: two with single axle loads of 18,000 pounds; two with single axle loads of 22,400 pounds; two with tandem loads of 32,000 pounds; and two with 44,800-pound tandems. The one and one-tenth miles was first divided into two approximate halves--actually, one part of it was longer than the other. The south end was one-half mile long exactly; the north end was six-tenths of a mile long. On the south end, one of the two lanes was made the specimen to be tested by 18,000-pound single axle load vehicles. The other, immediately adjacent to it, was the specimen to be tested by the 22,400-pound single axle load vehicles. At the other end of the road, the two lanes were subjected to the two tandem axle vehicles.

The pavement was built originally in 1941, so that when the test began in June 1950, it was then about nine years old. In those nine years it had been subjected, of course, to all the forces of nature that could be brought to bear on it in that period--to heat and cold, to frost, etc. At the time of the beginning of the test, the road was in very good condition. It was not a badly cracked road; in fact, it was a road that was very little cracked. There were some exceptions to that. In two places the road had been constructed on a fairly deep fill and, sometime in the prior history of the road, there had been a settlement of the fill and the slabs of the road had been mudjacked, or brought up to grade, and in the process of attempting to correct their alignment and offset the effects of the settlement that had occurred, the slabs were cracked by the upward pressure of the mud that was pumped under them. Those places had been cracked and, therefore, those parts of the road were excluded from the test. There had been some other cracking that had formed, but a very little amount--I'll tell you later just what that cracking amounted to. So the road at the beginning of the test was a road that had been in existence for nine years and was in a very good condition.

The road in its prior history, so far as we have been able to determine, had been subjected to a light traffic. A traffic count and a weighing operation made just before the beginning of the test showed that at that time there was no traffic in a day-long test with axle loads in excess of 18,000 pounds on the road. This was before the test. So, it had been subjected to a fairly light traffic. Therefore, when this heavier test traffic was put on the road, the road was perhaps feeling the effects of such heavier traffic in considerable frequency for the first time in its history. And, if in its previous history it had not cracked, and in its test history it should crack, that, it was felt, would be indication that the difference in the behavior of the road before and after was pretty clearly attributable to the change in the character of the loading applied to the road. Bear that in mind!

Now, in order that you may have some firsthand impression of what this road was and the way in which the test was conducted, I think I can give you that impression best--rather than by attempting to describe it in words--by using the movie which I brought with me, which will show you just what happened on the road up to the time of the ending of the traffic test.

At this point, I want to absolve the Highway Research Board and anybody else--including any of the other participants in the test--of responsibility for anything that I say or anything that's in this picture. What I say is my responsibility--what you see in the picture is the responsibility of the Bureau of Public Roads. We made the picture.

I would like to say that this picture is a production print--it is not finished or ready for release. The picture as you will see it here this afternoon represents only that phase of the test up to the end of the control-traffic operation. We intend to extend the picture, to introduce into it in the form of animated pictures and model demonstrations the results of the observations that were made of the character of the soil underlying the pavement, of the stresses and the strains and the deflections which resulted in the pavement slabs, as a result of the passage of these various loads, to interpret as clearly as possible the causes of the behavior of the road which you will see in the picture to follow.

Now we may have the picture: (At this point the moving picture on the Maryland Road Test was shown with comments, from time to time, by Mr. Fairbank.)

Well, that is what happened during the period of the controlled-traffic tests. That covered a period of six months--June to December 1950. Since that time, a year and a half nearly, the engineers that conducted the test have been analyzing the detailed observations of what occurred during the time of the test.

About 1400 samples of soil were taken from beneath the mile-long pavement. I don't suppose there is a piece of pavement in the country in which the underlying support condition is so well known as it is now on that pavement. Fourteen hundred samples of soil were taken and 6,000 tests were run on those samples of soil. There were 12,000 measurements of strain and deflection that had to be analyzed, and all that kept the engineers busy for this year and a half since the completion of the tests. But it was necessary that we go through with that analysis of what occurred in order that we would be in a position to determine with accuracy, to what extent the failures that occurred and were observed in the traffic tests were actually due--and in what manner they were due--to the application of the load. In the meantime, while there has been no knowledge on the part of anyone except those that were immediately concerned with the conduct of the tests of the actual facts that were developed except as they were evident in this cracking record which you have now seen, there has been a great deal of report of what went on in the test, what its purposes were, what the results were, that has appeared in the newspapers, in the technical and the trade magazines, and much of this report has been misrepresentative both of the purpose of the test and of the results obtained in the test. There has been a great deal that has been said with all the appearance of complete knowledge that has been based on no knowledge at all. There has been a great deal that has been said very positively, as fact, which has not been fact at all.

In order that you may understand the character of some of those reports, I want to refer to a few of them. And then I want to compare the statements made with the actual facts. It has been widely heralded recently that a consulting engineer, employed by a trailer manufacturing company--a man of high reputation--has made a study of the road and of the test and that he pronounced the test a failure. That has been circulated all over the United States. It comes to us in press clippings every week from this state, that state, and all over. The fact that this consulting engineer--as I say, a man of high reputation--the fact that he did not say the test was a failure, and on being informed that he was being represented as having said so, completely disclaimed responsibility for the statement--the fact that he did not say the test was a failure but, on the contrary, said that the test was a most useful test, a most informative test, and one from which there was a great deal to be gained in the determination of the effects of loads, that fact will not catch up with the repeated statement that this consulting engineer said that the test was a failure.

The subgrade underlying the road originally was believed to be a corrected or stabilized subgrade. Before we had gone very far, after the first soil tests had been made, we found that the subgrade had not been stabilized throughout; in fact, there had been a rather incomplete effort to stabilize it. And, as I'll tell you later, the character of the subgrade was at one end very good and through the rest of the length of the road, not good at all. I'll go into that a little later.

But the statement has been made and repeated frequently, that the pavement was laid on muck. Muck! Muck means something like marsh--marsh is something very soft. You, ladies and gentlemen, saw the picture of the trenches that were cut along the full length of the road immediately after the test was concluded. Did that look like muck? That soil stood up there hard and firm when it was dug vertically by the trenching machine. But the statement is made and repeated all over the country that this road was built on muck; and so the test was not fair.

The cross section of the pavement was a rather unusual one. Each lane had thickened edges on both sides of the lane--9 inches at the outside edge, 9 inches at the longitudinal joint and, by parabolic transition between those two thickened edges, 7 inches in the center. Now, there is a great deal of thickened edge pavement but not much that is thickened in both lanes. Generally, the outside edges of the two-lane pavement are constructed about 9 inches thick and the thickness at the center joint is made seven inches or some reduced thickness. So, this 9-7-9 double parabolic cross section was a rather unusual one. Whatever the effect of the 9-7-9 double parabolic design was--in my judgment it was perhaps to make the pavement somewhat stronger--it did not result, as has been asserted, in an entrapment of water on the subgrade. The statement that it did has been made by people who didn't know whether there was any such entrapment of water or not. It has been made to discredit the test. The fact is that the soil moisture tests and the examination of the subgrade where slabs were removed for that purpose, show that there was no such water entrapment.

It has also been asserted that the distribution of the traffic transversely across the road was abnormal; that there was a greater amount of loading applied near the outside edges of the pavement than is normally the case in a road in actual use. You saw in the motion picture an animated representation of the transverse distribution of the traffic on the test lanes compared with a normal transverse distribution on an ordinary highway. It turns out, regardless of what the original intent in distributing the traffic was, that in the actual application of loads, the transverse distribution of those loads near the outer edges of the pavement was very similar to the transverse distribution as it occurs on a normal road.

Now I think I've said previously that before this test was made the road had probably been subjected to very little traffic of axle weight exceeding 18,000 pounds. In the tests, the loads were applied with very considerable frequency. The two single axle loads were applied with an average frequency of about 1,300 a day. The two tandem axle loads were applied with an average frequency of around 900 applications a day. That's many more applications of these heavier loads than had occurred on the road prior to the test. In fact is is almost infinitely more, because previously the road had been subjected to almost no loads of these magnitudes. The fact is that this was an accelerated test--it was designed as an accelerated test. We had to get the relative effects of these loads in a reasonable length of time. We couldn't spread the traffic test out over ten years. We wanted to compare the effects of these loads in a short period, so we had to multiply the number of applications of the load. That fact has been utilized for purposes of discrediting the test. It is said that this road was subjected to a traffic which isn't ever experienced on any road. That isn't true either. There are heavy traffic roads in many of our states which carry as much and more traffic of the heavier axle loading as the test road. For example, just yesterday I looked over some of the weighings that have been made on roads in some of the Northern States. On a road in New Jersey, I found 2,500 applications of loads over 18,000 pounds a day. That's twice what we had on the test road. In Massachusetts, I found roads on which there are 1,000 applications a day--practically up to what we had on the test road. In the Southern States--North Carolina, for example--I didn't find so many applications of loads above 18,000 pounds. Whether or not that means that your trucking industry does not feel the necessity of operating at more than 18,000 pounds or whether your enforcement of the law in North Carolina is unusually perfect--I don't know. But the fact is that the weighings of traffic as they were made on the roads of North Carolina, do not disclose any large number of applications in excess of 18,000 pounds.

The fact that the south end of the road on which the single axle loads were applied was shorter than the north end of the road on which the tandem axle loads were applied has also been seized upon to discredit the test. They say, of course there was more cracking under the 44,800-pound load than under the 18,000 pounds--the 44,800-pound lane was longer than the 18,000-pound lane. Well, the answer to that is that the amount of cracking on each of the lanes--caused by each of the test loads--has been expressed in terms of the amount per 40-foot slab. And the comparison, instead of becoming better, from the standpoint of the heavier load, becomes worse. As you saw in the picture, the 44,800-

pound axle load, tandem axle load, compared with the 22,400-pound, gave a ratio of 1 to 6. When we compare the effects of those loads, slab by slab, in cracking per forty-foot slab and on the same kind of pumping subgrade, we find a ratio of 1 to 7.

The difference in the number of applications is a valid criticism of the test. On the south end the single axle loads were applied more frequently than on the north end where the tandem axles were applied. If we had had as many applications of the tandem axle loads as we had of the single axle loads, the relative effect as demonstrated of those tandem axle loads would have been even greater than those that are pictured in the film. For, as you know, the tandem axle loads in spite of their smaller number of applications caused much more cracking than the single axle loads. If we had as many applications of the tandem axles as of the single, then the comparison would have been worse from the standpoint of the tandem axles.

Another criticism that has been made is the road before the test was already cracked to a certain extent. It was. There were some cracks--I've told you about some that were caused by the effort to raise a few of the slabs on the fills that had settled. These, as I said, were excluded from consideration in the test, but there were some other cracks that had formed before the test was begun. In lane one--that's the lane that was subjected to the 18,000-pound axle loads and which was a half mile long--there were 31 feet of cracks. Since the lane is 12 feet wide, there was enough cracking in the half-mile length of lane one to be equivalent to two and one-half cracks across the lane. That's how much that lane was cracked before the test. Similarly, lane two, which was the 22,400-pound axle load lane, had 71 feet of cracks. That's the equivalent of a crack clear across the lane in about six slabs in the half mile. Lane three had 30 feet of cracking, and lane four had 62 feet; about the equivalent of 5 cracks across the 12-foot slabs. That was the amount of cracking that existed before the test.

The cracking which resulted from the application of the test loads was given briefly in the picture. I'll repeat it for you. In the entire operation from June to December, 196 feet of cracks were measured in lane one--that's the 18,000-pound lane. In lane two, the 22,400-pound lane, 1,269 feet--a 1 to 6 ratio. In lane three, up to December 23, the 32,000-pound tandem axle lane, 1,050 feet. As you saw in the picture, the traffic had to be stopped on lane four on October 13. It was found necessary to halt the traffic in order to preserve one or two slabs of the road for purposes of stress measurement. If the test traffic had been continued there would have been no uncracked slabs to work with in a few days. So we had to stop the traffic on October 13, and at that date lane four had 3,700 feet of cracks and lane three 300 feet. That's a 1 to 12 ratio.

One of the points that has been made--perhaps most effectively--in criticism of the test, has been that the road was not maintained. They say that the test simply demonstrates what everyone knows will happen when a road subjected to a great deal of heavy traffic is not maintained. The fact is that the maintenance of that mile of road in six months cost about $2,750. That's at the rate of $5,000 a year, a very substantial sum. What they actually mean is that the road was not undersealed. As the picture pointed out, the cracking of the pavement was closely associated with the phenomenon of pumping. Pumping causes the removal of subgrade soil. Id did that on this pavement. And those who find fault with the manner in which the test was conducted say that that pumping should not have been permitted to continue. The fact that it was permitted to continue was the result of a deliberate decision. Remember that one of the measures of the relative effects of these axle loads--a readily visible measure --was to be the relative amount of cracking caused in each of the lanes by the different vehicles. If, after the pumping had proceeded a while, it had been possible perfectly to fill the void created by pumping a little bituminous material under the slab, and to do so without cracking it (which, as you have seen, had previously occurred on this very road), it might have been possible to prevent the road from cracking, but then there would have been no measure of the relative effects of these various loads. So the fact that the pumping was allowed to continue and that subsealing was not practiced was in line with the deliberate purpose of the test, and affected equally and relatively the lanes subjected to all four test loadings. We didn't underseal any of the lanes, and the fact that there was more pumping on the heavier than on the lighter side is evidence of the greater pumping effect of the heavier loading. The heavier loading caused a faster removal of the subgrade soil. All of the loads were heavy enough to cause cracking of the slabs after they had been undermined, but the heavier loads, by causing a more rapid undermining as well as by the greater concrete stresses they induced, caused the cracks to form earlier and with greater frequency. The result was a greater amount of cracking in the same time under the heavier loading than under the lighter loading, thereby affording a relative measure of the effects of the different loads. That was the purpose and plan of the test; and the fact that subsealing was not used as a maintenance measure is not a valid criticism of the test, but was simply inherent in the method of the test that was used.

Now, I think I can summarize the many tests and observations that were made subsequent to the completion of the traffic test in a very few words.

First, as to the character of the subgrade; there were five general classes of soil, classified as A1, A2, A4, A6, and A6-7. An A1 soil is a granular material of very firm and stable character, not affected by water. It does not have much fine material in it and is, therefore, not susceptible to pumping. An A2 soil is also a granular material, not quite as good as the A1, but still a very good subgrade material. A4 soil generally makes only a fair subgrade material, and in the A6 and A7-6 classes you find the silts and clays, and the silty clays, most of them pumpable materials, which are definitely poor materials for the subgrade of a road.

Now here are the facts that were found about the subgrade of the test road. There was no A1 or A2 soil--that is, good soil--under the lanes that were subjected to the tandem axles, none at all. Under the lanes that were subjected to the single axles--both of them, the lighter one and the heavier one--there was some soil of that character. Referring to lane one, which was the 18,000-pound lane, 27 per cent of the length of the lane was underlain by a gravelly soil, classified as A1. Of the adjacent 22,400-pound lane, 25 per cent of the length--almost the same percentage as in the 18,000-pound lane--was on this same good soil. Of the A2, which is the other good soil, there was only 2 per cent under lane one (18,000 pounds) and 6 per cent under lane two (22,400 pounds). Taking the two good soils together, there was 31 per cent of the length of the 22,400-pound lane and only 29 per cent of the 18,000-pound land that was on good soil. So the advantage lay with the side of heavier loading. Of the A4 soil, there was very little anywhere on the road. This class of soil, normally a fair subgrade material, occurred on this road mainly at the point of transition from cut to fill. At those points it generally contained some root material. Critics of the test have not failed to note this condition, but the fact is that the A4 soil constituted a very small part of the length of the subgrade. Under the two single axle lanes, it constituted 4 per cent of the length of the lanes. Under the two tandem axle lanes, it constituted 14 per cent. The greater part of the road in all four lanes consisted of soils of the A6 category. These were silty clays; they were bad soils, pumpable soils. In the 18,000-pound lane 56 per cent of the subgrade was composed of this bad soil; of the 22,400-pound lane it composed 54 per cent--again a slight advantage in favor of the heavier side. In the tandem axle lanes, 68 per cent of the length of the 32,000-pound lane, and 65 per cent of the 44,000-pound lane was underlain by this bad soil--once more a slight advantage for the heavier side. The rest of the subgrade was made up of soil of the A7-6 class, a soil quite similar to the A6 soil, but of this there was only a little under any of the lanes.

Because of the difference in the length of the single and tandem axle sections, and because of the differences in their subgrade support, it has not been possible until recently, with the completion of the detailed soil studies, fairly to compare the effects of the tandem and single axles. It was always possible with reasonable accuracy to compare the effects of one tandem axle with the other, and one single axle with the other--those comparisons are made in the picture--because the lanes compared were immediately adjacent to each other and of the same length, and because transversely there was very little difference in the character of the soil under the road. But, longitudinally, there was a great difference in the soil, and until we had the precise determination of the character of the soil and could take account of the length of the pavement on the various soils, we could not with fairness and assurance compare the effects of the tandem axles and the single axles. With the information now available, we can reduce the cracking recorded to a common measure of so much per forty-foot slab on soils of exactly the same character. In the report that will soon appear that comparison will be made, mainly on the basis of the A6 soils, which were the bad soils. And the record as it comes out is something like this: Up to October 13, when traffic was suspended on the heavy tandem axle lane, the test having begun in late June--there had been no cracking at all on the portion of lane one, the 18,000-pound lane, that was laid on the bad A6 soil. On the adjacent number two lane, where the 22,400-pound axle trucks were operated, up to October 13 there had been an average of 13 feet of cracking per forty-foot slab. On lane three, the lighter tandem axle lane--32,000 pounds--there had been an average of 4 feet of cracking per forty-foot slab. All of this, bear in mind, was on the same kind of soil, and all on the basis of the same length measurement. And, now, let's look at the 44,800-pound tandem lane. The average cracking there was 50 feet per forty-foot slab, up to October 13 when operation of the trucks was stopped.

Now, continuing, by December 23 the number one lane (18,000-pound lane) had developed a few cracks. As a matter of fact, the first crack in that lane--on the portion of it supported by this A6 soil--occurred on October 15, just two days after traffic was stopped on the 44,800-pound lane; and up to December 23, the 18,000-pound lane had cracked an average of 4 feet per forty-foot slab. This indicates that by the end of the test the 18,000-pound lane had cracked very little; the 22,400-pound lane had cracked seven times as much; and the 32,000-

pound lane--compared on the basis of the same soil and the same length--had cracked about half as much as the 22,400-pound lane and about four times as much as the 18,000-pound lane.

Now, let me refer briefly to some of the principal results that have come out of the detailed examination of the stresses and deflections that occurred in the road. A question as to which there has been some doubt is that of the relative effect upon a road of a single axle load and a tandem axle load. Earlier tests, made some years ago, generally under static loading, had resulted in an accepted conclusion that if two loads are separated by as much as about four feet, the effect of the combination of the two loads comprising the tandem would be no greater than the effect of one of the loads acting separately. In recent years there has been some misgiving about that, and we have come to accept as a working principle the idea that about 32,000 pounds on tandem axles is about equivalent to 18,000 pounds on a single axle, and that equivalency has gotten into the laws of a good many states. The results of these tests indicate that that is not quite true. The results of the strain, stress and deflection measurements made in the Maryland test indicate that the 32,000-pound tandem axle load caused damage to occur a little more rapidly than the 18,000-pound single axle. This is true notwithstanding the fact that the 32,000-pound and 18,000-pound loads caused almost exactly the same stresses in the pavement. The reason is that the 32,000-pound tandem caused a greater deflection of the pavement than the 18,000-pound single, and, the deflection being the stroke of the pump, the pumping occurred at a faster rate under the 32,000-pound than under the 18,000-pound load. Although the two loads, under any given condition of support produced the same stress, the support was removed by the 32,000-pound tandem load at a faster rate than by the 18,000-pound single axle load, and so a cracking or rupturing stress was reached earlier under the 32,000-pound load than under the 18,000-pound load. That is a very significant conclusion. The indication is that equivalence would occur at some tandem axle loading a little less than 32,000 pounds, but the test does not indicate what that equivalent loading would be. The difference in effect of the 32,000- and 18,000-pound loads was not particularly serious, and from the standpoint of practical application, the test does not suggest that there should be any departure from the present acceptance of the 32,000-pound tandem axle load and the 18,000-pound single axle load as equivalents. But it does indicate that proposals to increase the 32,000-pound limit would take us in the wrong direction; that is, they would result in a wider disparity of effect between the tandem axle loading and the single axle loading.

Another result that comes out of the stress measurements which may be of interest to you is that--contrary to what may be supposed by some, but entirely surprising to those of us who have had the experience in our youth of skating over thin ice--the effect of higher speed is not to increase stress in a pavement but to decrease it. When the trucks were operated at forty miles an hour over this road the measured stress generated in the concrete was less than when they were operated at five miles an hour. The faster speed caused more than 20 per cent less stress in the pavement than the slower speed. Now, the reason for that is probably that a concrete pavement has weight and inertia. It has to have a little time to yield under a load. If a load passes over it so fast that the pavement doesn't have time to bend under the load, the stress that is produced is less than that caused by a load that remains on it longer and bends it more. So, the effect of speed--in the absence of impact--is to reduce the stress caused by a load.

But, what happens when there is impact? In this test, in which the traffic was operated in both directions on each lane, the phenomenon of faulting at the joints, which is characteristic of roads normally traveled, did not develop. When traffic moves over a road in one direction only in each lane, there is a tendency for the edges of the slabs at the far side of the joints to be depressed to a greater extent than the edges at the near side. Under this condition the wheels of vehicles drop from the higher slab to the lower slab, and there is, of course, a certain amount of impact. As I have said, that condition did not develop in this test because the traffic ran in both directions, so what was the far side of the joints in one direction was the near side in the other, so the faulting effect was neutralized. However, at the end of the tests a faulted condition was simulated by laying a three-quarter inch plank the full length of one slab and then driving the vehicle over that plank and letting it drop off at the joint onto the next slab. When, under this condition, the stress was measured in the slab onto which the vehicle dropped, it was found to be less than when the vehicle moved directly from one slab to the other without drop. Now that may surprise you, but here's the way we can rationalize it. When the wheels of the vehicle leave the higher slab, they may be for an instant up in the air, or, if they are not actually in the air, at least their full weight is not on the ground. The wheels below the springs tend to drop faster than the body of the truck above the springs, so the springs tend to open up. When the wheels first come into contact with the lower slab the springs are in this extended position and the full effect of the sprung load is not felt by the road. By the time the spring is compressed again and the full weight of the vehicle comes down on the road, the vehicle has moved onto the slab a certain distance, and in this latter position it causes less stress than it would have caused had its full load been applied right at the transverse joint. So, there you have a possible explanation of the reason why under this condition a wheel dropping onto a slab with unquestionable impact, caused less stress than the same wheel rolling smoothly onto the slab.

One more result of the stress measurements which you will possibly find of interest was the fact that when the vehicles were operated with their wheels two feet from the edge of the pavement the stress that was produced in the pavement was just about half as great as when they were operated with their outer wheels only six inches from the edge. It appears that if we could keep the vehicles away from the edges of our pavements they would cause much less stress and much less pavement damage. It is the vehicles that travel near the edge of the pavement that cause the greater damage, and, unfortunately, of course, these are very often the larger trucks. They are practically forced into that position when the road is narrow, and few of our roads are so wide as to permit the trucks to get very far inward. They ordinarily operate near the edge. If they could be kept in a little and if our roads could be so designed as to encourage that, we would doubtless find that they would have a less damaging effect on the road. That might be done, as has been suggested, by building the concrete road a little wider and covering the outside edge of it with the shoulder, which would prevent the loads from getting out on the extreme edge of the concrete slabs. If that were done, it would be done as a means of reducing the effect of heavy axles and, of course, the additional cost of widening the road would therefore be attributable to those heavier axles, and it should be borne by them.

In closing, I wish to emphasize that the serious cracking which developed during the traffic tests occurred only on sections of the road in which the pavement was laid on fine grained soil, and occurred there in close association with the development of pumping. The only really good soil that was present anywhere under the test pavement occurred only at the end of the road on which the 18,000 and 22,400-pound single axle trucks were operated. At the conclusion of the traffic tests all of the test vehicles--the tandem as well as the single axle vehicles--were operated over selected slabs laid on this good gravelly soil for purposes of stress measurement. In addition, there were included among the vehicles used for this purpose some which had single axle loads as great as 30,000 pounds and tandem axle loads up to 60,000 pounds. In the slabs laid on this good gravelly soil none of these vehicles--not even those with the 30,000 and 60,000-pound axles--caused stresses of a sufficient magnitude to crack the pavement. And, of course, we know that the pavement in these sections actually was not cracked by the heaviest loads that were applied to it in the traffic test. It appears, therefore, that if we had under all of our roads subgrades as good as this gravelly soil provided, there would be no cause to fear the operation of most of the heavier vehicles now using our roads. The fact is, however, that we do not have soils of that character under many of our roads. On the contrary, there is widespread occurrence of soils of the A6 classification on which the serious cracking occurred in this test.

While this condition continues to exist, and that is likely to be for a very considerable period, because it will be literally impossible to strengthen the support of all of our pavements in a short time, the Maryland test indicates very clearly that we should proceed with great caution in permitting the operation of vehicles having single axle loads in excess of 18,000 pounds and tandem axle loads in excess of 32,000 pounds.