THE AUTOBAHN

GERMANY'S EXPRESS HIGHWAY SYSTEM

Thesis for the Degree of B. S.

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Gerald E. Herr

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by

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Along the German Autobahn

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INTRODUCTION

This is the story of a great system of highways, their conception, financing, construction, use and present condition. This system of highways is known as the "German Autobahn."

Since soon after the development of the automobile and its more prevalent use by the common people, the German government had realized the need for a more adequate system of roads. No one in the government had any definite plans, however. Certainly no one even imagined the need for a vast system of expressways -- until Hitler came to power. His plans for Germany changed many plans and ideas in other minds.

Perhaps a brief description here of the type of road the Germans built will aid the reader in understanding the scope of the project and the care with which such a project was necessarily undertaken. The German Autobahn was fashioned somewhat after the Italian Autostrada. These two highways are very similar, but different from our common highways. These countries had different ideas than we have as to what is meant by an expressway. We understand that an expressway is a wider, straighter road on which we can travel faster and save time, but they went further. The only road we have which can compare to the Autobahn is the Pennsylvania Turnpike. The German expressways are highways that are especially designed to avoid passing through centers of dense population, to be absolutely free from grade crossings, to follow a straight line as nearly as possible and to exclude all unauthorized persons and vehicles. The term expressway presupposes an ideal paving surface, a well-designed location and all technical equipments for the needs of express motor traffic. To this end the designers used every bit of knowledge available and considerable imagination, together with high specifications and good materials to produce what is considered one of the greatest roads in the world.

CHAPTER I

THE AUTOBAHN IS CONCEIVED

The people of the world as a whole know very little about the plans Hitler had in his mind when he became Chancellor of Germany. One thing is certain; he did have very definite plans, and he wasted no time in putting them into action. It is believed that the time Hitler spent in prison provided him with plentiful opportunity to think of and develop his plans. One great part of these plans was the construction of a super-highway system that would link all sections of Germany. Whether or not his big plan then was to conquer the world is unknown.

Soon after Hitler was released from prison, he began campaigning for the office of Chancellor. He made many promises which attracted the attention and votes of the common people. Apparently they were not accustomed to politicians and their campaign speeches. They put him in office and anxiously awaited the fulfillment of his promises. Hitler's International Labor Day speech on May 1, 1933, hinted of a vast public works program and a plan to induct all German boys into manual labor. Highways especially would be developed, he said. At that timein Germany unemployed persons could be utilized for road work as "compulsory workers," as "emergency workers," or as "voluntary workers." The law stated they must (if provided with) work for their compensation. They did not work a 48 hour week, but only 2 1/2 to 3 days. The work that they did was work that would not ordinarily be done, it had to be productive in nature, temporary, and of public value. Hitler wanted to make use of this law and put all the unemployed to work on the new roads.

The unemployment situation was Germany's biggest problem, one-third of her capable workers being on the unemployed register. This was the ideal time for Hitler to introduce and promote his plan. He had two good points to argue: the project could serve the double purpose of relieving unemployment and of developing automobile traffic.

Previous to 1933, the highways in Germany were of such a nature as to not encourage the use of motor traffic to any great extent, being largely narrow allowances with paved or macadam surfaces, and not kept in too good a state of repair. Naturally, the design of any new system of roads had to take into consideration the conditions that then existed in Germany and still do exist in most European countries. These conditions were employed in the German conception of an express-way system. In Germany not only are roads narrow and crooked, but the custom of driving herds of livestock over the highways is a common one; there is a large amount of horse-drawn traffic; there are sections where the ox cart is in general use, and with the improvement of surfacing since 1930 came a great upturn in the use of bicycles. Operation of passenger automobiles on such roads obviously was highly unsatisfactory. Most towns even had

ordinances giving the bicycle the right-of-way over the automobile. A tourist traveling through a town on the main road was not even allowed to blow his horn at a bicyclist, no matter what the bicyclist did. A motorist who struck a pedestrian or a bicyclist was always at fault. A horn on an American automobile was a source of curiosity to the children and even some adults, for it seemed louder to them than the largest truck air horn would seem to us.

Even when new roads were built to by-pass the abrupt turns and the congestion of villages and towns, immediately the new road became a preferred site for industrial plants and residences, and in a short time it was almost as congested as the route through the heart of town.

What is now Germany formerly was a group of independent states that had no connecting system of roads. Establishment of the empire in 1871 did not change the situation greatly. Roadbuilding was left almost entirely to local authorities. They concentrated their efforts upon maintaining existing roads which for the most part followed the haphazard courses dictated by the needs of other centuries. Thus, prior to World War I little had been done in the 18 German states to fashion roads for automobile use. After the war rather extensive highway improvements were undertaken in the areas immediately tributary to cities. But this was neither sufficient nor efficient.

Hitler got to work immediately after making his Labor Day speech. He convinced the cabinet that an express system of highways was needed, and on June 23, 1933, the cabinet passed a law for the construction of a network of highways to cover all of Germany. Plans were drawn up for the new system which was to be built gradually to supplement the present highways by a system of main thorough-fares which would carry auto traffic over long distances, the old roads serving as tributaries. The general management of the construction was appointed to the Reich railroad system, and work was to be started immediately. However, it was September 23, 1933 when Hitler turned the first spadeful of dirt to get the project underway. At first the work was very slow; there was no coordination between the highway departments. Also, the idea of the railroad doing the work without supervision and inspection by highway and government officials did not satisfy Hitler nor his cabinet. They decided to fill two needs at once -- that of control of the expressways and centralization of all highway departments. On March 26, 1934, German highway administration, formerly divided between 26 state and county and 500 independent township highway departments, was centralized by enactment of law. Failure largely of these decentralized authorities to cooperate had prevented any real system capable of meeting modern traffic needs. The law provided a chief engineer for all German roads to whom the state and county highway departments were subordinated. The new law divided

all roads into four classes: (1) expressways, (2) federal highways, (3) state highways, and (4) secondary roads.

The construction and maintenance of the express-highways was delegated to a special company, called "Reichsautobahnen," which was legislated by its own law and financed by government bonds. These bonds were to be amortized by a toll paid for the privilege of using the highways, and justified by the savings to the motorist in oil, gasoline, tires and repairs. However, after some of the roads were opened, the idea of the toll was decided against and the road was free. The cost of the federal highways was financed by the Reich, and those of the secondary roads by the counties.

The administrative office, which paid for the roads, also owned them, which was not the case before the new law. For the through ways in cities and municipalities occasionally the federal, state or county government paid for as much as 18 feet of width of the street if the community had no great economic advantage from the thoroughfare.

CHAPTER II

REASONS FOR BUILDING THE AUTOBAHN

Before going any further into the financing and organization of the system, let us examine the reasons that were given for Germany's embarkment on such a large program. To be sure, a highway system was needed, but what of the Autobahn? Was a highway of that proportion justifiable? History bears out how justifiable it proved to be, but at the time of its conception Germany was weak and small, and no one thought her foolish enough to embark on a "conquer the world" campaign. So excuses and reasons had to be provided for a curious world. Facts and figures that could not be disputed were necessary.

The British were among the first to question the plan, in view of the fact that Germany's roads were much less extensively used than those in Britain or France. The German engineers were quick to reply that they were building for the future. They realized that the present traffic did not warrant the program, but they were certain the future traffic would require a perfected road system. They explained that the plan was instigated at that time in order to alleviate the unemployment, that like President Roosevelt, Chancellor Hitler was determined to lose no time in getting a *public works program under way. To be sure, the employment situation was serious here too. Reemployment, to both leaders, was a problem of first importance. More than 5 million Germans were out of work in 1933. An estimate of unemployment in the United States (with twice the population) at the same time exceeded 14 millions. It was expected that 500,000 to 600,000 people would be engaged directly and indirectly in the construction of the highways, and in the production and transportation of materials, doing away with much of Germany's unemployment problem.

While Germany was prompted to undertake this program largely as a means of providing employment, that was not the only reason actuating the policy. Roads suited for automobile use were recognized as essential to the stimulation of the automobile industry. It was found that that industry would produce more value per person than any other large industry, and what is more, it provided customers for another great domestic industry -- that of making motor fuel from coal. All this meant that the express roads made possible much indirect employment.

In 1937, with one third of the system in use, it was found that the results had exceeded expectations: The output of the automobile industry had doubled in less than two years and motor car registrations had increased from 661,800 in 1934 to 945,000 in 1936. In July, 1933, there were 497,000 private cars, 152,000 lorries and 819,000 motor bicycles. In July, 1937, there were 1,126,000 private cars, 322,000 lorries and 1,327,000 motor bicycles.

But the world's curiousity was still not appeased. Traffic was increasing rapidly, but outside of a very few big cities, which were crowded only at holiday times, in the opinion of the British especially, nothing like congestion was experienced. They felt that the old main roads, with a total length of 220,000 km., could meet any likely traffic requirements quite easily with only slight improvements. They argued that even the cheapest car was far out of the reach of the bulk of wage earners.

Therefore these reasons were soon found published in British and American magazines: (1) thickly settled communities are close together in Germany; (2) the streets of the old cities are narrow; (3) gasoline prices were high: and (4) the former subvention of the German railroad by the Reich.

1. The most important of these is that Germany is much more thickly settled than the United States, and the construction of bypasses, which would be the natural resort to accommodate express traffic, would create travel distances at least two or three times greater than the straight line between two points. Also, where the settlements are so close together as in Germany, the highway would consist almost entirely of a large number of bypasses. Traveling on such lines is naturally very costly and slow and destroys the general advantage of using highways.

2. On account of the age of German cities the streets are mostly very narrow; and since most of the

buildings (that are left now) are of great historical value, the streets could not be widened. I think now however, that a great many streets have been widened and the buildings moved or removed by bombs and shells, not of course at the consent of the German people. Perhaps another system of highways planned now would not have so much difficulty. But at the time the Autobahn was planned, the traffic had a very low speed limit; yet, in spite of the low speed, there was a relatively high number of accidents, which was another argument for large highways.

3. Gasoline was three or four times as expensive in Germany as in the United States, and so from the standpoint of economical operation there was a further need for highways on which one could maintain a steady and reasonable speed. The slow-downs and stops in the numerous congested cities made long travel by car very expensive. Experiments show that traveling on an expressway saves 20 to 35 per cent of the costs of operations.

4. The German railroad, which was indirectly operated by the Reich had always had the advantage in competition with automobile traffic because of an already existing and highly developed track system and because of the benefits arising from general subvention by the government. This subvention had its chief origin in the fact that the German railroad had to pay a large part of the war (World War I) debts. The success of this traffic

policy of the Reich was another cause for the stagnation of automobile traffic.

The government hoped to stimulate the public to an increased use of motor traffic by constructing this system of ideal highways, and to further help this cause the government ordered the abolition of all fees and other charges in connection with the purchase of new automobiles. (Such a law as that would indeed be welcomed in this country now, too.) The German government felt that by providing these roads and removing taxes from motor vehicles the number of motor users would be greatly increased; the Reichsbahn would be relieved of much unremunerative short-distance traffic and many non-paying lines could be closed. Germany was building roads 25 years in advance of traffic requirements. At the same time England was 25 years behind -- building the Silvertown Way 25 years after the need arose. It looks as though the British were jealous and trying to rationalize their lagging by questioning Germany's reasons. We, here in America, will also do well to take a lesson in planning for the future.

CHAPTER III

ORGANIZING AND FINANCING THE AUTOBAHN

The British, Canadians and Americans were not the only people who had their doubts about the new road system. Even some Germans, who did not view the new scheme through spectacles of party enthusiasm had a few doubts about the project. Germany already possessed the best roads in Europe (with the possible exception of Italy). Compared with American or even French or British standards of road traffic, they looked deserted. It seemed possible that the present system of roads could carry 10 times the existing traffic. Only when the future was viewed optimistically did it seem possible that sufficient traffic would develop to liquidate the cost of the scheme. Therefore this chapter is devoted to the different methods that were used to finance the Autobahn.

The "Autobahn" law created a new company for the construction and maintenance of the express highways; the German Federal Railroad Corporation, which was government controlled, was authorized to organize a subsidiary known as "Reichsautobahnen Gesellschaft" (Government Auto-Ways Company).

The railroad was chosen to supervise the construction because they already had a highly trained and efficient staff of specialists for railroad earthworks, bridges, approaches, etc. The experience of these men was used for the construction of the subgrade. Moreover, the close union between the railroad and the highway was supposed to abolish the old destructive competition of railroad and motor vehicles which was paid for by the public.

The head of the new company was the chief engineer of the German administration, who made the final decisions concerning the location of the highways and their design. Hitler appointed Dr. Todt to this position. Todt worked with the German railroad, which also had charge of the counties, townships and municipalities. Thus a link between the expressways and the other highway system was guaranteed, and the new organization had only to supervise the technical execution of the cooperative work of railroad and highway departments.

The new company divided the Reich into eleven districts, on the ground that each district was better able to adjust the construction of all local conditions than was a central bureau at the capital. These eleven districts were not made on the basis of the old political divisions, but purely onthe basis of unified traffic regions. These districts contained fifteen main construction offices and eighty regional district offices. The actual design and execution, subject to standard requirements, proceeded from the fifteen provincial offices with considerable direct discretion on details and design of bridges and other works to meet local conditions and needs.

Before the exact plans for the Autobahn were drawn up many studies were made. Dr. Todt had been chosen as general inspector of German roads with authority, to prepare and complete a national road scheme. To this end the road systems of other countries and the methods of adaptation to motor transport, which they had evolved were reviewed, and this included, among others, such special subjects as the Autostrada toll motor roads in Italy, rapid concrete road construction and expressways in the United States, and method of surface construction and road widening in Great Britain.

With reference to the first of these, Mussolini was Hitler's model in this as in many other projects. One of the first and most efficient of the great automobile super highways in the world (The Autostrada) was built in Italy soon after Mussolini came into power. The truck highway between Milan and Genoa had just been completed in 1932, so Hitler sent his Minister of Labor to Italy to study the Italian automobile road system.

The result of these studies was a motorway which combined and embodied innumerable features in design and construction never attempted in Canada or the United States. The foremost and most lasting impression created by inspection is the complete sense of safety and security and the total absence of monotony. Maximum safety of movement, maximum traffic flow and low cost of operation, highest attainable standards of visibility, and the straightest alignment possible are additional features attained.

Although the design of the roads was the most modern that could be conceived, it must be remembered that the program was instigated primarily to relieve unemployment. this aim greatly affected the technical methods employed in the construction of the roads. The use of machinery was discouraged; local stone, which meant local labor, was used, and much avoidable expense was incurred. The whole construction program was carried on with domestic materials. This meant that no precious foreign exchange was employed. The whole operation was carried on with marks. With a managed currency there was plenty of domestic money. There was no need for dollars, francs or pounds. No foreign loans were floated. The money was supplied by domestic borrowing. The German people readily bought the bonds of their government. Even if the cost rose as high as 2 million marks per kilometer ($800,000 per mile) as some prophesied, Germany felt she could justify the project for the reasons given in Chapter II.

But the people did not supply all of the money with bonds. The State Railways, which was in control of the new company, put up the first 50 million marks ($20,000,000) for initial construction. Subsequently the bulk of the finance was provided from the newly established on billion mark fund provided to carry out the "Hitler Employment Plan." Ultimately, the government controlled a German State Traffic Company, which included all rail and motor traffic. This was characteristic of the dictatorial policies which German governments had pursued for the past decade in working out the difficulties between rail and motor transport.

It was planned that not only would the railroads benefit from use of the roads, but many of its staff would become permanent members of the new system. Of the new company's permanent supervisory staff of nearly 5,000 men, one-fifth were railway officials furloughed to the Auto-Ways for the construction period. Some of those men would not return to the railroad.

Hitler's recovery program got underway; in June of 1933 more than 200,000 men had regained employment; the first contract was let on the first 3,000 mile unit of the road system, and industry and the retail trade was freed of their fear of country collapse through continued depression. By the middle of August of 1933 two million were back to work, most of them being employed in jobs created by the road construction program. Also in August, 1933, the State Railways announced that they were going to enter the motor truck transportation field with an initial purchase of 2,000 motor trucks. The railways allotted a minimum of 10 million marks for the purchase of truck equipment and establishment of trucking service, including motor parks, terminals and other facilities. This was a service long needed in Germany. Since the railroad had always had a monopoly on the transportation and freight business, there was no competition to create a fast delivery service. Not that a railway owned trucking business would provide competition, but it did show that the need was realized, and that an attempt to correct it was made.

The character and scale of the methods of construction attracted a good deal of attention in other countries where traffic problems were more acute than in Germany. A party of experts, politicians and interested persons, visited the Reich to inspect the roads and their construction in 1937. The most important question which they raised was the cost of the operations. What the complete scheme would cost was not stated, but the outlay to date was known. Up to 1937 the sum paid out on capital account was Rm. 1,739 millions. Of this amount Rm. 1,407 millions had been paid to the private contractors who had actually built the roads, divided thusly: some Rm. 580 millions were spent on earth and rock works; just over Rm. 400millions on the road bed, bridges and culverts; about Rm. 307millions on surface work; and Rm. 113 millions on the provisions of workers' camps, other social amenities and miscellaneous works. The balance of some Rm. 332 millions of Reich expenditure was used to pay for the carriage of materials to compensate land owners, and to meet interest and amortization charges.

Notice that compensation to land owners is mentioned as a minor item. It is interesting to compare the difference in cost of that operation there as compared to this country. It is true that the Autobahn was designed to miss all cities and therefore much èxpense was avoided, but still the expense was tremendously low. An expressway built here usually begins or terminates in the heart of a large city, or crosses the whole city. Such a highway is the John Lodge Expressway in Detroit. Land owners there hold out for the highest possible dollar and often get much more for their property than it is worth. Despite Germany's international importance industrially, she still remained predominantly an agricultural country. Thus not only were land values low, but also the population was more sparsely scattered than, say Great Britain. Two great difficulties which would have to be faced were new arterial roads to be constructed there were of small importance in Germany. Routes to be followed by the roads were chosen with a freedom impossible in a country where the land is much built up and where villages and towns are closely spaced, and the ground required was usually obtained at a cheap rate by normal purchase. When proprietors refused to sell, the land was expropriated. Up to the end of July 1936, out of a total of 1080 million marks spent on the Autobahn, only 58 million marks went to the purchase of land or right of way. This figure represents a much larger percentage than it is however, for by the middle of 1936 about 4,000 miles of route had been purchased and surveyed whereas only about 1,000 miles of road was completed and open to traffic.

The money was raised in various ways. Capital expenditure was, in general, provided by short-term operations;

with the help of a Reichsbank rediscount credit in 1934 and 1935; and by loans from other sources, including the Reich Unemployment Board. Railway Corporation credits were raised for motor-road construction, and were later funded. On November 11, 1936, the import and excise duties on gasoline and benzol were increased, and the price of motor fuel was raised accordingly. Further, the traffic tax was extended to include motor passenger and goods services conducted for gain. There was a small operating revenue, derived mainly from gasoline stations. No tolls were collected for the use of the roads; and it was believed that the higher gasoline prices were counterbalanced for the motorist by the saving of time, fuel, and wear and tear, which the new road afforded.

The very success of the scheme aided in the production of the necessary funds. As much as 35 per cent of the funds expended, it was estimated, would otherwise have been necessary for unemployment relief, while the general increase of prosperity provided, in the form of increased returns from taxes, 25 to 30 per cent more toward the cost. The rest of the cost was financed by loans as already stated.

In the construction of the roads, the relations between motor traffic and older forms had to be taken into account. In 1936 it was estimated that the railways were losing some Rm. 600 millions of traffic annually to the roads, but that to counterbalance this in part the motor industry was bringing new traffic to the railways to an annual value of some Rm. 150 millions. The gross revenue of the railways in 1936 was Rm. 3,985 millions, and the net loss was thus considerable; and in 1935, the Nazi Government, intent on the development of the motor industry, had refused to give a monopoly of commercial motor transport to the Reich Railway Corporation. In 1937, local road transport for gain, if conducted entirely within a radius of 50 miles, was unrestricted; but outside that radius all long distance carriers were compulsorily amalgamated in a Reichskraftwagen-Vertriebsverband.

Such in outline is the purpose, character and economics of these roads. They provided work for the unemployed, and cost over a million marks per kilometer to construct. While they were not needed for German traffic and may, in some cases, have diverted the use of good agricultural land, they are a source of pride to the German people. And they are a pattern and example for road engineers in other countries.

CHAPTER IV

SCOPE AND DESCRIPTION OF THE AUTOBAHN

The Autobahn was designed to be the best in the world and was built to form a net of arterial roads which covered all of Germany. This chapter is dedicated to the examination of that design, and the area and cities which the roads enveloped.

The roads were designed with eight specific requirements in mind: 1. Total exclusion of pedestrian, cycle and animal traffic; 2. Complete separation of opposing traffic streams; 3. The elimination of the "collision points" arising from one traffic stream crossing another; 4. The use of over or under bridges to secure such separation; 5. The control of traffic at road junctions by clear and systematic layout for each class of intersection; 6. Provision of a clear and simple system of road signals; 7. No right of access from adjoining frontage lands; 8. All advertisements, poles and disturbing factors on or near the road suppressed. These shall all be enlarged upon later in the chapter.

First, let us examine the scope of the system. The program involved the construction of six principal highways, two of which crossed the country from north to south, three from east to west and one in the northwest and southeast directions.

The German motor-road system, as originally planned, apparently contemplated the construction of approximately 5,000 miles of four-lane divided highway connecting all of the larger cities of the Reich. Of this total, only about 2,500 miles were completed due to interruption by the war. An examination of the map included herein will show many gaps in the system.

Broadly speaking, the scheme comprises a circular road around Berlin, from which the main Autobahn radiates. The radiating roads extend to East Prussia, to Gleiwitz through Breslau, to Munich and the Austrian frontier, to Karlsruhe through Frankfort, to Aix-la-Chapelle through Hanover, Essen and Cologne, and to the Danish frontier through Hamburg. These main radiating roads are linked up by a number of crossroads.

The location of the highways follows a somewhat tortuous course across the country, especially where the topography is at all rolling, This is due to their desire not to interfere, any more than necessary, with the natural features of the country.

A picture of the area served by the German express road program may be had by comparison with a similar area in the United States. A system of through highways serving the American cities would cover a territory of somewhat similar extent: Detroit, Toledo, Cincinnati, Richmond, Va., Washington,

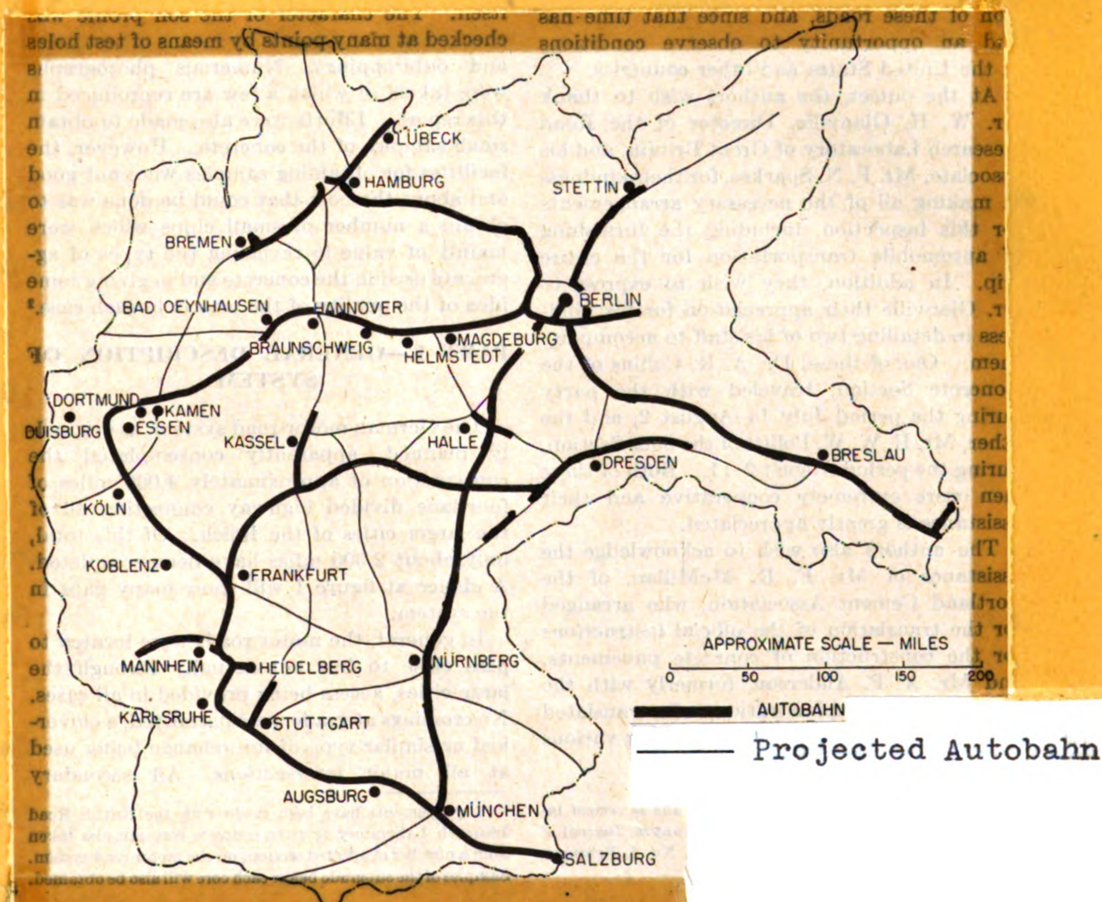


Figure 1

The German Autobahn System

Baltimore, Philadelphia, New York, Boston, Buffalo, and Pittsburg. In Germany the key points are Hamburg, Bremen, Hanover, Essen, Cologne, Frankfort, Karlsruhe, Stuttgart, Munich, Nuremburg, Dresden, Breslau, Beuthen, Berlin, Stettin and Koenigsberg. Population in the German area is nearly double that of the American area delineated above.

The plans first made called for the system to be built in three units. The first was to be about 3,000 miles of road and would require the transportation of 260,000,000 cu. yd. of earth, 54,000,000 bags of portland cement and 550,000 tons of steel for bridges, approaches, etc.

The Autobahn network was intended solely for the use of motor traffic; horse-drawn vehicles, cyclists and pedestrians were not permitted to use it. This restriction of the roads to the requirements of one class of vehicle considerably simplified the design as compared to arterial highways in this country.

The Autobahn was built to three different standards which may be roughly defined as suitable for flat or nearly flat lowlands without any considerable obstacles, for hilly regions, and for mountainous districts where the higher standard maintained elsewhere could not be justified on economic grounds.

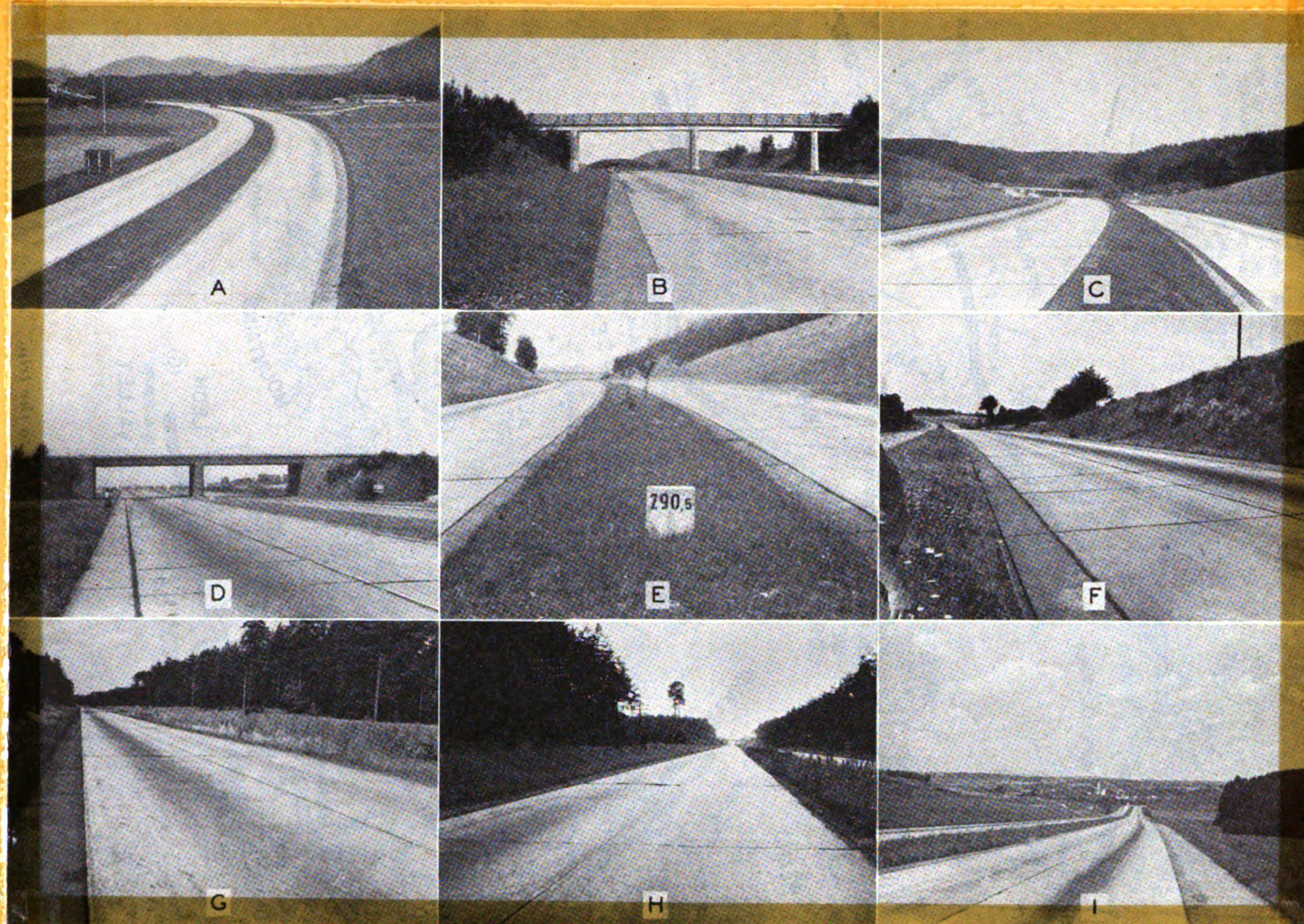
The constants of design based on those three types of country are as follows:

TYPE OF LAND	LOW LANDS	HILLY	MOUNTAINOUS
SPEED FACTOR:	110 MPH	95 MPH	80 MPH
MAXIMUM GRADIENT:	4 per cent	6 per cent	8 per cent
RADIUS HORIZONTAL CURVES:	6000-6500 ft.	2600-3300 ft.	2000 ft.
MINIMUM RADIUS VERTICAL CURVES,			
SUMMIT :	55,000 ft.	30,000 ft.	16,000 ft.
DEPRESSION :	16,500 ft.	10,000 ft.	10,000 ft.

Obviously the specifications for low lands could not be held in mountainous country for economic reasons. However, it was specified that the transition from a higher to a lower standard should be gradual, and that the change ought to be revealed to a driver by alteration of the character of the landscape. This condition by itself set a lower limit to the length of any section maintained at one standard, but the Inspector-General reserved the right to impose different lengths if he deemed it necessary. The standards were based principally upon theoretical considerations of the requirements of a vehicle moving at high speed, modified to some extent by practical knowledge. With foresight for the future, rather remarkable in a government, the roads were made suitable for speeds considerably in excess of those usual at that day.

In deriving these standards conservative assumptions were made as to the coefficient of friction between the tires and the road, and allowances included the fact, now pretty certainly established, that the coefficient falls as the speed increases. For the three classes of design, the coefficient was taken as 0.4, 0.45, and 0.5 respectively. By the use of the correct coefficient for the class of road under consideration and by making an allowance for the delay before a driver's reaction occurs, the distance necessary for a vehicle to stop from any speed can be calculated. From the stopping distance figure corresponding to the maximum speed for which the road is to be designed, a minimum figure for the radius of curvature over a convex summit can be deduced if a suitable assumption is made as to the height of the driver's eye above the road. Applying these principles, the Germans calculated their sight distances to be 900 ft., 700 ft., and 500 ft. respectively.

Were it possible to provide any degree of super-elevation on horizontal curves, there would be no theoretical minimum limit to the radius of curvature. But in practice, of course, allowance must be made for vehicles traveling at low speeds. It was therefore specified that in general the cross fall was not to exceed 8 per cent, but where the gradient was less than 1 per cent, it could increase to 10 per cent. These limits set the minimum radii of horizontal curves. As it is well established that some part of the centrifugal force occurring at a curve can be balanced

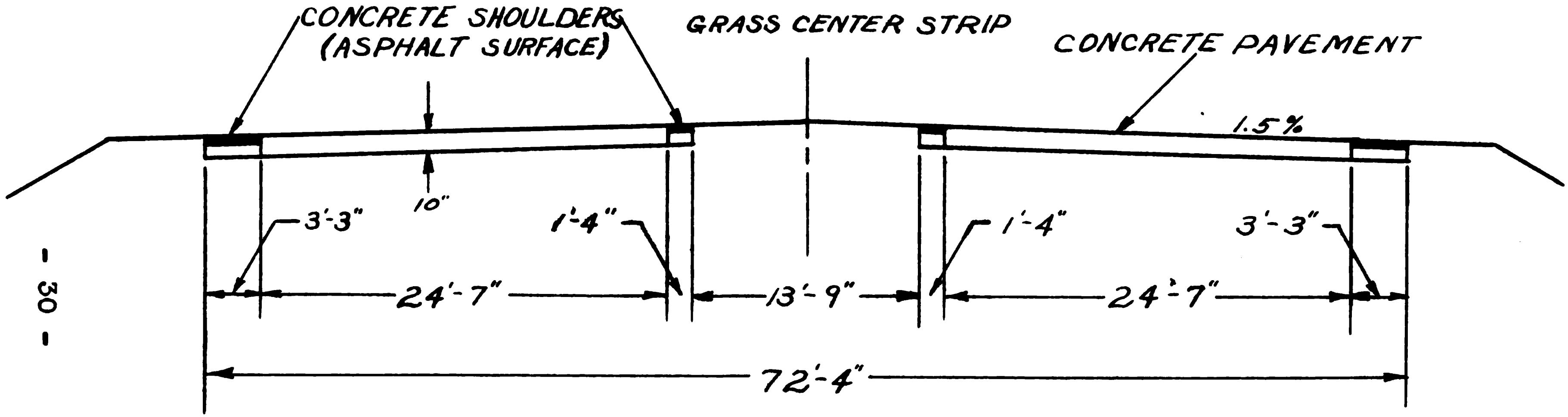


Typical Views of the Autobahn

(A-C) München-Salzburg; (D-F) Hannover-Ruhr; (G,H) Frankfurt-Stuttgart
(I) Stuttgart-München

by friction between the tires and the road, the assumption was made that the safe coefficient was 10 per cent, a figure which corresponds with the maximum cross fall allowable. The minimum cross fall was set at 2 per cent. The cross fall adopted at any particular curve depended upon the class of Autobahn of which it formed a part, since the speed to be provided for varied between the classes. Curves were of such large radius that it was not thought necessary to introduce them by transition, nor modify them by a widening of the pavement. In constructing superelevated curves the inner edge of the roadway was maintained at the general level of the line, and the outer edge raised. The full superelevation was maintained throughout the curve, and the transition was formed in the straight approaches on a gradient of 1 in 200. This design set a limit to the minimum distance between reverse curves, for the two ramps were not permitted to overlap. The length of sight line required for the designed speed was maintained on horizontal curves by the excavation of the sides of cuts and the setting back of bridge abutments wherever necessary.

Examination of the accompanying drawing will supply all the details of the cross sections of a typical Autobahn. Standard design for any class of Autobahn called for a four-lane divided highway composed of two, one-way roadways each 7.5 meters wide, separated by a green strip 3.5 to 5.0 meters wide. All dimensions on the drawing have



TYPICAL CROSS SECTION OF FOUR LANE AUTOBAHN been converted to feet and inches for convenience of the American reader.

Each roadway has a uniform outward cross fall of 1.5 per cent,and is flanked on each side by shoulders laid flush with the road surface. These shoulders, which are usually 0.4 meters wide on the inside and 1.0 meters wide on the outside, are surfaced with bitumen to contrast strongly with the whiteness of the concrete of which the rest of the surface is usually constructed. On some of the last work done on the roads, the outside width was increased to 7 feet 4 inches, apparently with the idea of providing more adequately for emergency parking. The shoulder strips were usually about 10 inches in depth, the lower 7 inches usually being of concrete and the upper 3 inches of asphalt. In cases where dark-colored concrete or asphalt was used in the pavement proper, plain concrete was used in the top course of the paved shoulder strip.

The concrete base for the shoulder strip was constructed before the pavement slab and utilized as a base upon which to mount the rails carrying the heavy construction equipment used in the mixing, placing, and finishing operations. The asphalt top was placed to the elevation of the finished roadway after the completion of the pavement proper.

All pavement slabs were of uniform depth, 8 or 10 inches in thickness, although heavier sections were used

Figure 3
The Munich-Salzburg Road

Figure 4
On the Munich-Salzburg Autobahn

occasionally. So far as the design of the slab itself is concerned, practice appears to have been patterned largely after that followed in this country, except that the Germans did not use the thickened-edge section.

There is no curb and the ground beyond the shoulder strip is formed flush with the shoulder strip wherever possible. In cases of emergency therefore, there was available to a maneuvering vehicle, not only the extra width provided by the shoulder strip, but also the support of the ground beyond. Thus another safety factor was provided to insure a minimum accident occurrance on the Autobahn. This outer grass margin is about 6 feet in width and is continued as a gentle slope to merge with the normal ground level. No drainage ditches, as such, were formed. In general, the motor roads were located so as to take full advantage of scenic possibilities. Cut and fill slopes were rounded and were blended in with the natural terrain so as to give a very pleasing appearance. Careful attention was given to landscape so as to cause as little disfigurement as possible. These, together with adequate roadside planting, gave an appearance of age and permanence which is quite surprising when one realizes that the average age is only about 10 years. Notice this feature on the typical views shown. Their basic principle was that the natural beauty of the countryside must not only be maintained but actually be augmented by the works, so far as possible. Landscaping had to regard the following

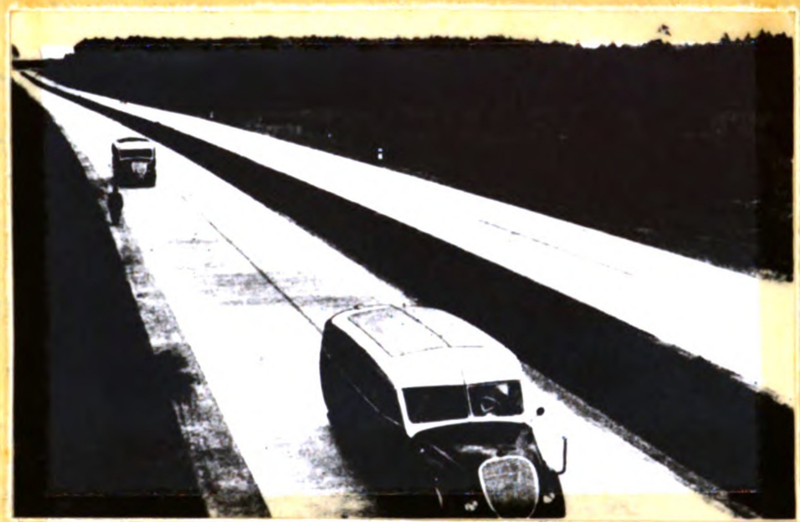


Figure 5
Typical Autobahn Construction

Figure 6
Branch to Access Road - Berlin-Stettin Route

considerations: All artificial earthworks should correspond to the topography; roadside conditions and new planting were based on the trees, herbs and grasses native to the district, and botanical conditions prevailed; fully grown trees and shrubs were preserved and used wherever possible and virgin soil and turf were set aside and re-used.

As stated before, the new roads by-pass all towns and villages and pass close to most large cities. All were routed in entirely new locations. There is not one level crossing from end to end of the Autobahn. All crossings are over and under, requiring thousands of bridges. Pedestrians also must use bridges to cross the highways. There was no speed limit on the roads until the American Army moved in, and then while the war was on, MP's patrolled the highways and even handed out tickets while German planes straffed them. Measures were taken to prevent ribbon development and speculation in the adjoining lands. Advertisement displays both upon the roads and adjoining lands were not permitted, and no telegraph poles or structures were permitted upon or in relation to the line of route. When the roads cut through farm lands, no provision was made for the farmer to enter on the highway at any point on his property. It is plain to see that all these features enabled the motorist to travel from one place to another with a minimum of expenditure on gasoline and maintenance, and at the same time providing him with a maximum factor of safety.

The next portion of this chapter will be spent in enlarging upon the different types of bridges, crossings, and junctions used in the construction of the Autobahn. The bridges of the Autobahn fall into categories: those carrying the Autobahn over natural obstacles, and bridges carrying minor roads over the Autobahn. The standard of loading to which the road bridges were designed varied with the class of road and the traffic anticipated. The maximum loading to which the bridges were designed consisted of a 24 ton maximum load carried on two axles, transmitting 8 and 16 tons respectively. Reinforced concrete foot bridges span the highways at many points where such safety measures are considered necessary. All grade crossings having been eliminated meant an average of two structures per mile of highway. Most of these structures, where the length of span would permit, were built of concrete in a variety of designs. Many structures, particularly piers and abutments of steel superstructures are faced with beautiful stone masonry, and all concrete surfaces are finished in a stucco effect, and in some cases blocked off to resemble masonry. All bridges carrying the new highway were built with a total width of 76 ft. giving a roadway width of over 60 ft. Where steel bridges were built almost all of the structures were electrically welded.

The largest bridge of all, the Elbe Bridge which is 1,170 meters long, is made of reinforced concrete; but the

Figure 7
Autobahn Showing Parking Space at Left

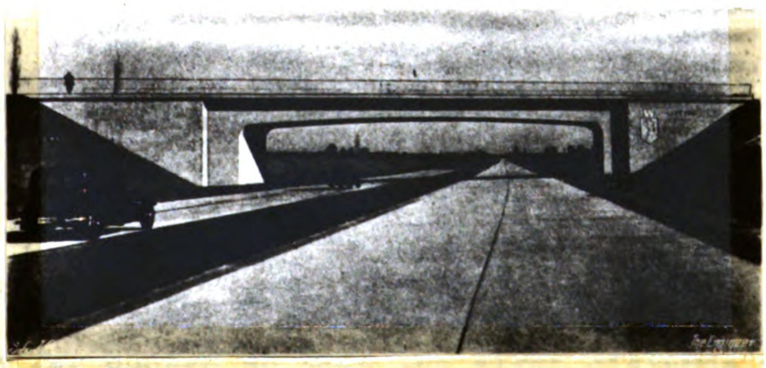


Figure 8
Portal Bridge Over Berlin Ring Road

Figure 9
Bridge Over Breslau-Kreibau Autobahn

Saale Bridge at Jena, which is 751 meters long, and the Elster Valley Bridge, which is 680 meters long, are both built of stone.

In addition to such large bridges as these, there are naturally very numerous smaller bridges of which the greater number carry minor loads over the Autobahn. The design of these structures was standardized to a large extent and can therefore be classed as road works. Typical designs are shown in the group of drawings presented.

All bridges which cross Autobahns are of sufficient span between abutments not only to require no narrowing of the Autobahn, but also to leave an additional clearance on each side of 2 meters to take drains and other service mains, etc. Where the Autobahn is crossed at a curve, the abutment is set back far enough so that the sight distance required for safety is not shortened, just as previously mentioned in another case. The standard clearance above the road surface is 4.5 meters (14 ft. 9 in.) and the deck of the bridge is usually constructed with vertical curvature on a radius which joins the two tangents formed by the gradients of the approaches. Too many bridges in this country have flat decks, causing a distinct bump when the vehicle boards and leaves the bridge.

In the most commonly used design there is a central support under the span rigidly connected to the superstructure,

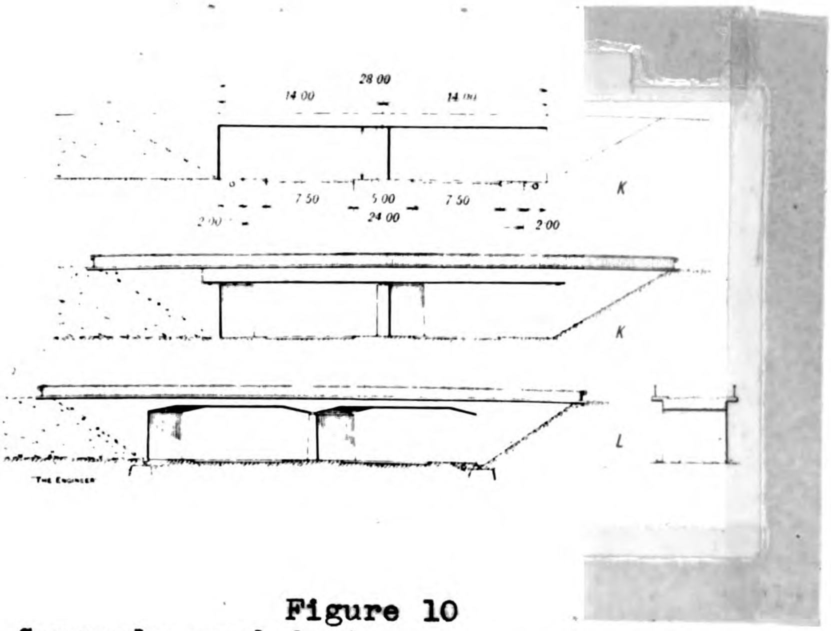


Figure 10
KK - Most Commonly used design.
L - Used when foundation material was particularly good.

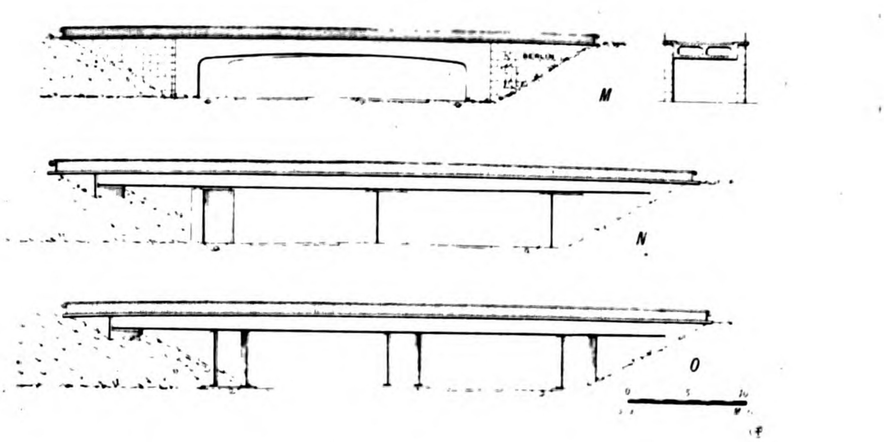


Figure 11
M - Portal Form - only type used over Berlin Ring.
N,O - Used where more open view was desired.

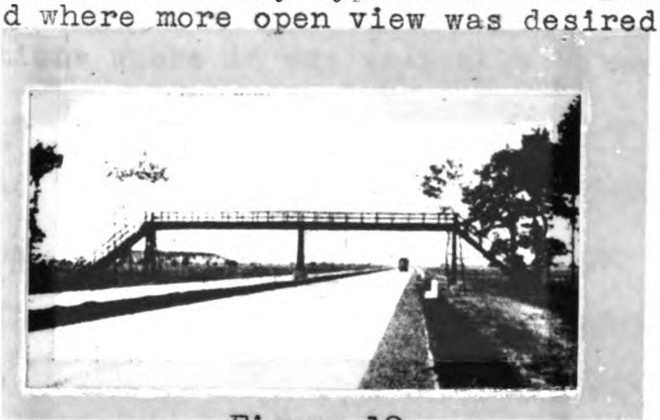


Figure 12
Typical pedestrian operpass.

which is carried on sliding bearings at the two abutments. Reinforced concrete is the material most usually employed, but a steel girder structure and composite steel and concrete designs were also standardized. The depth of the span was made as small as practicable in order to give an appearance of lightness, and the sliding bearings were frequently concealed in the abutments. When the foundation material was particularly good the design was sometimes modified. In the modified design there were no sliding joints and the bridge was carried by the line bearings beneath the abutments, which were counterweighted. By this means a particularly light appearance was achieved. In mining districts, where subsidence was a possibility and elsewhere when the stability of foundations was not trusted, the central support was dispensed with and the deck was carried by steel girders fixed at one end and sliding at the other. Bridges without central supports were also built at points deemed to have some special significance. The bridges over the Berlin ring road, for instance, all have the portal form. On curves or in other situations where it was desirable to give a more open view, the abutments were not made solid, and the bridge consequently had four openings. But this design offered the disadvantage that if the crossing is an oblique one there is difficulty in finding room for sliding bearings on the narrow supports and an arrangement with flexible concrete pillars as intermediate supports and fixed and sliding bearings at the abutments was sometimes adopted. For deep cuts arch forms were standardized.

Where the Autobahn passes over a secondary road the bridge was constructed in much the same manner as the more simple of the overbridges, but on account of the lesser width there was no central support.

A reference to the map shows that at numerous places there are junctions between the new roads. In addition, it is necessary to allow access to the Autobahn from the ordinary roads of the country. In order, however, not to interfere with the maintenance of high-speed traffic flow the number of access points was strictly limited only to the more important ordinary roads and the distance between access points is as much as 10 miles to 15 miles. All other roads are carried under or over an Autobahn without any connection with it.

In no other country, with the exception of the United States, has the problem of the design of road junctions to suit high road speeds been so carefully considered as it was in Germany. The road junctions were designed with three primary thoughts in mind: First, the highest degree of safety; second, a lay-out that will be quickly self-explanatory to the motorist; and third, the maintenance of a continuous flow without collision points or traffic intersections.

The types of junctions may be broadly divided into three types: access from ordinary roads, bifurcations of an

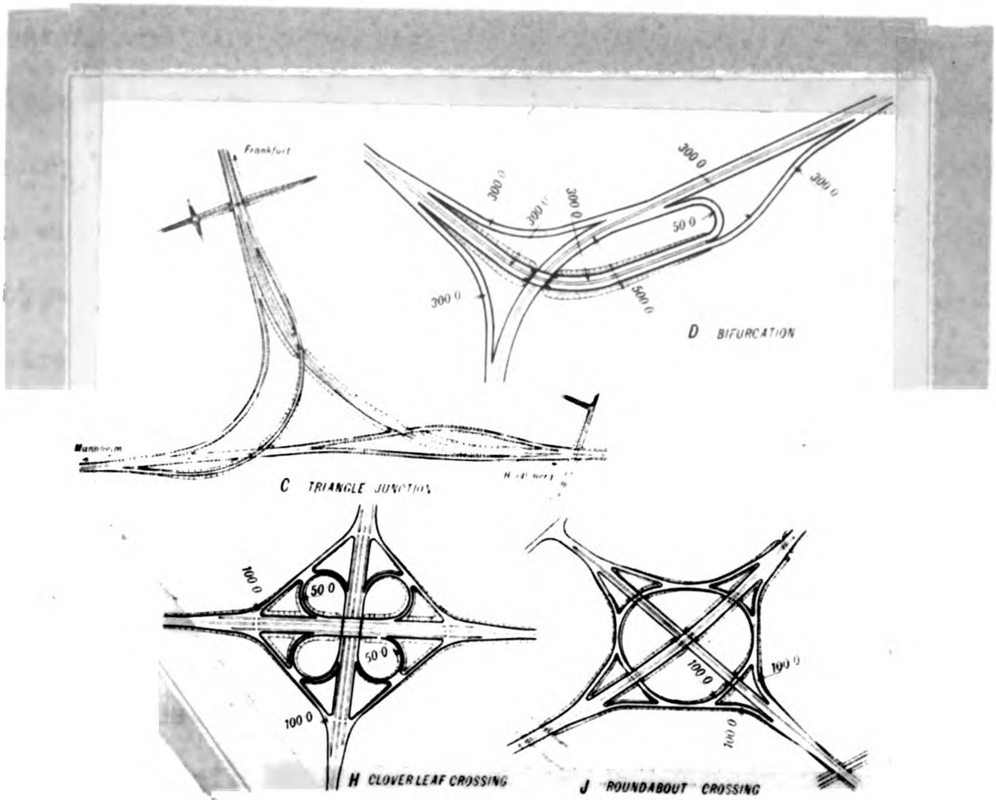


Figure 12A
The types of crossings and junctions used.

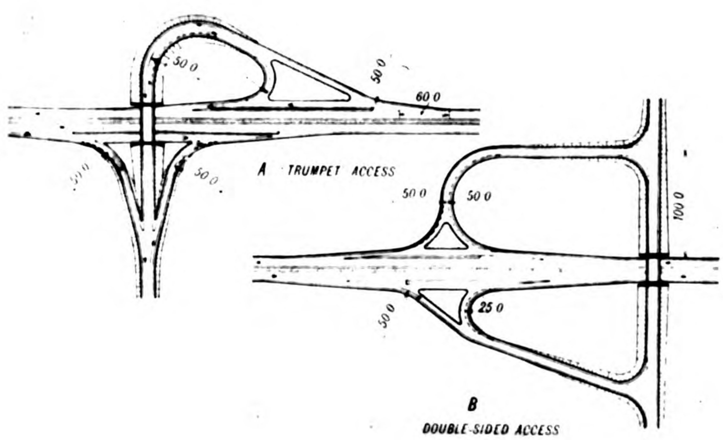


Figure 12B
Two types of accesses used..

Autobahn, and the crossing of two Autobahns. The first mentioned may be further subdivided into cases where the ordinary road continues over and beyond the Autobahn and cases where it joins the Autobahn and continues no further. All types of bridges and junctions mentioned herein are illustrated on the drawings included and should be referred to by the reader when ever the description is not clear.

The chief interest lies in the arrangement at the points where the feeder roads from each side join the Autobahn. It will be observed that the "mouth" of each feeder road is divided by a triangular island, and that there is a grass-grown strip, 2 meters wide, separating the Autobahn from the access road. Vehicles entering the Autobahn travel for 100 meters (328 feet) on a lane behind this strip parallel with the main roadway and are thereby enabled to gather speed before intermixing with the traffic upon it. In a similar way vehicles leaving the Autobahn must be given space in which to reduce speed; but in order to allow mistakes to be rectified and because a vehicle traveling fast needs more room, no grass strip intervenes on this side between the lane and the roadway. A connecting lane between those for entrance and exit allows a driver who has mistakenly turned out of the main roadway to regain it without reversal. Use was sometimes made of the triangular island by sitting a gasoline station on it. It should be noticed that vehicles leaving the Autobahn are not required to negotiate curves of less than 50 meters (164 ft.)

radius, but that entering vehicles, on one side, are given a curve of 25 meters (82 ft.) radius. Gradients generally are no greater than 4 per cent. The one-sided access design has been called the trumpet junction on account of a fancied resemblance to that instrument. When roads of lesser importance joined an Autobahn similar access structures were used, but the curves are more severe and the gradients steeper. Occasionally, where the distance between access points would otherwise have become unduly long, it was necessary to allow comparatively minor roads to join the Autobahn. In these cases the structure was much simplified, and the green strip and triangular island were omitted. Curvature and gradient are similar to those adopted for the less important accesses.

When an Autobahn bifurcates, the design adopted was usually a modified form of the trumpet structure, with less steep gradients and larger radii of curvature. This arrangement is particularly suitable when traffic to and from the "stem" of the "Y" predominates, and when there is little traffic between the two arms. But when the traffic is more or less equal in all directions, the sharp turn at 50 m. radius required to be taken by traffic in one direction across the arms is a disadvantage. Near Mannheim, therefore, where the three branches lead to Frankfurt, Heidelberg, and Mannheim respectively, the triangular structure was preferred. On account of a future branch from the Heidelberg road to

Figure 12C
The Mannheim-Frankfurt-Heidelberg Triangle

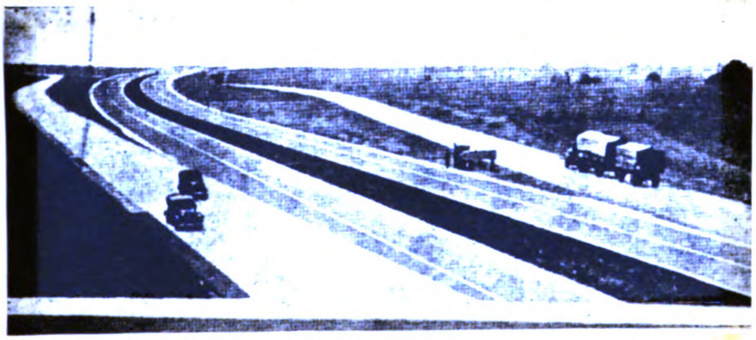


Figure 12D
An Autobahn grade separation

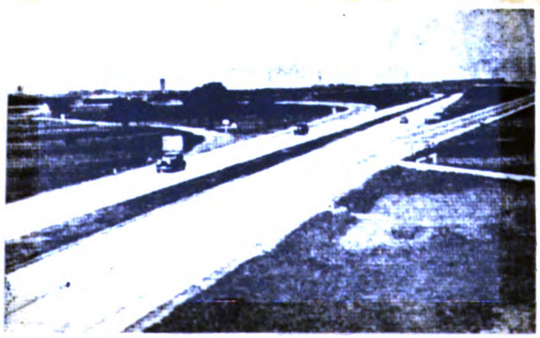


Figure 12E
An access system to the Autobahn

Karlsrube, that was contemplated, the lesser curvatures were given to the Frankfurt-Heidelberg and Mannheim-Heidelberg connections. The disadvantages of this solution to the problem of the bifurcation are the large area required and the three bridge crossings, all at somewhat acute angles. It is therefore expensive, and only used at this one point.

The four-leaf clover separation was generally reserved for the crossing of one Autobahn with another. This design was used at Schkenditz near Leipzig and at Hermsdorf in Thuringia. Through traffic is unhindered, but turning traffic is required to negotiate curves of 50 meters radius. Another solution to the crossing of two Autobahns is the Roundabout. This design was used at Leverkusen, at the crossing of the Cologne-Dusseldorf and Dortmund-Aachen highways. The roundabout scheme has the advantages over the four-leaf clover that all curves within the area have the same radius, 100 meters, and that drivers get a clearer idea of the arrangement when approaching it, especially if the ring road is elevated above the two crossing highways. It has, however, the disadvantage that interweaving of the traffic is necessary at four points on the ring road.

The system of road signals devised for the control and information of traffic on the Autobahn is simple, clear and positive. The danger sign, as such, is non-existant, because of the absence of danger features in the design. Only in certain forest districts is a form of danger sign located. These are to warn the driver of the possible movement of game across the road.

The signs that exist can be classified as follows: First, directional with distances; second, gasoline stations, with distances; third, parking; and forth, distance to the next junction.

The question of illumination of the expressways was one for debate. Two systems were put into effect at different places and an attempt made to determine which was best from all standpoints. The first was a direct lighting system -- that is, stationary lamps at various places along the road. Different types of lamps were used, but no one was employed on the whole road system. The second was illumination given by the vehicles themselves. As an aid for this type of illumination, reflectors were placed alongside the road, very similar to those used here in Michigan. Furthermore, bushes were planted in groups, and only species were used that would readily reflect the light from the autos. Thus at night the visibility was improved and during the day the landscape took on a more varied appearance. Moreover, the bushes made the road a separate unit that could be entered only at especially constructed entrances. From the standpoint of the psychology of the driver, the bushes were not of only one variety, but were so chosen and arranged as to break the monotony of a long trip. The hedges did not allow snow to pile up and block traffic, because they were not planted in a continuous line.

At various intervals on the grass strip in the middle of the highway, hedges were planted at right angles to the direction of the road. These hedges were slightly higher than the lights on the vehicles, so that the lights from automobiles moving toward each other did not blind the drivers. The arrangement of such hedges is especially important at curves, where the lights of the cars that are traveling in the inner lanes of the curve, shine directly into the windshield of the cars coming from the other direction. In addition to preventing the light from one side of the road distracting drivers on the other side, the hedges served the purpose of outlining the direction of the road by reflecting the light of the individual autos. The main disadvantage of these hedges is that where the road falls and rises perceptibly, the light shines over the hedges and thus defeats their purpose.

In regions where there is particularly heavy snowfall, as in East Prussia and the Bavarian Mountains, the highways are built on embankments to prevent the snow from accumulating on them. In the mountains the roads very often are one-way roads; that is, those ascending are in a different location from those descending. This was done from the point of view that conditions favorable for driving upward differ from those favorable for driving downward. Furthermore, from the standpoint of landscape beauty, such an arrangement is very often the best.

If the reader will permit the injection of a personal incident at this point, I would like to relate an experience my father had while he visited Germany in 1938. He used the Autobahns extensively during his stay, but it was some time before he became accustomed to the systems of access, for very few such structures had been built in this country before 1938. On one occasion an improper turn brought him on the wrong lane heading in the wrong direction. Expecting to find a cross-over a short distance up the road, he drove in search of one. All he found, however, was an occasional sign stating that the spaces between the hedges on the grass strips were not to be used as cross-overs. Also a police patrol station was encountered about every two miles. These police were not equipped with squad cars, but merely with telephones. The patrol stations were close enough together that a call reporting a violator to the next station was sufficient to stop that driver. If a waving policeman failed to stop him, road blocks were set up at later stations. After my father had driven over 10 miles without finding a cross-over, he decided to take a chance on crossing the grass strip. He made the crossing mid-way between two patrol stations, hoping he would not be seen. But the policemen were alert, and he was stopped at the first station. Since he was American, had an American car with a Michigan license, and convinced the policeman he could not read German, he was released with a warning. This gives you an idea of how far you can travel on a road of this type before you can turn.

There were many services on the roads offered to the Autobahn traveler. They included service stations, garages, refreshment stands, and tourist camps. These were all built and administered by the state and all were strictly modern and equipped with all modern conveniences.

To summarize the impressions of all those who have traveled on the Autobahn: The foremost and the most lasting impression is the sense of safety and security regardless of the high speeds at which traffic travels; the absence of monotony, linked up to the aesthetic quality of the results achieved; and the marked absence of any feature arising from the work which would cause disfigurement or destroy the beauty of the countryside. Apart from the speed and quality of the construction, the design made provision for a traffic growth well in advance of requirements, and the scale of the work and standards of design opened a new era in the conception and engineering of public highways.

CHAPTER V

CONSTRUCTION PROGRESS MADE AND MATERIALS USED

Naturally, the building of the Autobahn was known of throughout the world, and since the materials used were supposed to be the best obtainable, experts from all over the world came to investigate. So great was the interest in the highway building program that special arrangements were necessary for handling the engineers and other visitors who called at the office of the Inspector-General of Roads in Berlin. The office records showed that practically every country in the world had sent technical advisors to Germany to acquaint themselves with the development. There was outstanding interest in observing what could be accomplished when a far-flung highway program could go forward without any decentralization of control and under conditions where influence on the selection of route was disregarded if it hampered the attainment of broad objectives.

This chapter will tell of the progress those visitors found during their visits throughout the construction, and also of the materials that were used in that construction.

On September 7, 1934, Dr. Todt announced that work on the new highways had begun in fifty-one places and that 52,000 men were employed on construction work while another 100,000 found jobs producing the materials used. By October, 1934, some 1,500 kilometers (about 900 miles) were already in hand. The first section required over eight months to complete, for it was May 19, 1935, when it was opened in the presence of Hitler and numerous government officials. This first section ran fourteen miles from Frankfort to Darmstadt.

By the end of 1934 there were about 80,000 men directly employed on the works, and in 1937 men employed (including structures and material supply) were stated to be over 250,000. The work in all cases was executed by contractors, but in some cases, owing to the remote position of the work, about 20,000 men lived in workers' camps, and each camp was under the control of a leader. These camps will be described in the next chapter.

By September 1, 1936, a total of 750 miles of road had been completed and 650 were open to traffic. The Reichsautobahnen had fulfilled their primary aim of reducing employment, so that in 1937 when labor and materials were becoming scarce, the policy was changed. No longer were operations organized to use a maximum of manual labor. The labor employed per mile fell off considerably because of the increasing use of machinery. Although the total number of workers, including auxillary employment in the production of materials, rose as high as 250,000, as mentioned before, the number employed varied seasonally. From the time the roads were begun in September, 1933, to September, 1937, the number of hours worked was 82 millions. The maximum number were at work on the project in 1936 when 124,000 earned their pay checks by working directly on the roads. In 1934 there were 84,000 so employed and in 1935 over 115,000. The use of machinery made its mark on the figures in 1937 when the maximum number employed at any one time was 101,000.

Those 82 million hours of work did not show as many miles of completed road as one might expect. By September, 1937, 1533 kilometers (960 miles) of the new roads were open to traffic, and some 1650 kilometers (about 1000 miles) were under construction. In the work up to that date only 397,000 tones of iron and steel had been used, as compared with three million tons of cement, which was about 12% of the total national output. Vast quantities of stone, sand, pebbles and earth had been used, and the carriage of materials for the motor roads was officially mentioned as one reason for the rapid expansion of goods traffic on the railways which occurred in 1937. It was probably also one cause of the shortage of goods wagons in the coal and iron centers of West Germany. With less than three years of work done on the roads up to May, 1936, over 350 million dollars had been spent.

Progress continued at the approximate rate of 500 to 600 miles per year after the who program really got rolling. The first years did not yield that average for only 1200 miles were completed at the end of 1937. On September 28, 1936, Hitler dedicated the first 1000 kilometers (about 620 miles) of Autobahn with a speech in which he emphasized that Germany must make herself independent of "the good or ill will of sources lying outside Germany...." The automobile roads, Hitler said were being built for all eternity for the German people whom he pictured as riding in automobiles as readily as the people of the United States.

On April 7, 1938, Chancellor Hitler broke ground near the frontier town of Wals for the first Austro-German automobile road. This road connected the two large and famous cities of Vienna and Munich, and made the trip between only a matter of a few hours.

The world said Germany was crazy when they saw Germany's motor speedway business report for 1938. With 3065 kilometers (1900 miles) completed by the end of that year, the cost had been 1,000,000 marks per kilometer. Since the road was not half finished according to the original plan, many thought there was considerable cause for concern. But they had not seen anything yet. Germany was preparing for war and wanted as many of the roads completed as possible. Therefore the expenditure for 1939 was 152,000,000 marks more than it was in 1938. Construction costs proper in 1939 amounted to 921,300,000 marks, with contingent expenditures set at 199,500,000 marks, making a total of 1,120,800,000 marks.

Very little construction was done after the start of the war, but enough of the roads had been completed to provide an efficient arterial system 3,000 miles long which could accommodate the transportation of troops at the rate of 500 and artillery at the rate of 200 miles per day.

The material, especially the cement used in the construction of the Autobahn, was considered by most Americans to be inferior to materials used here, as judged by American standards. However, judging from the condition the pavement is in, it may yet be seen that their materials were not so inferior after all. Mr. M. A. Swayze, who made a trip to Germany in 1945 specifically to study the cement industry, reports as follows: "The great majority of the plants visited were making a product which was inferior in practically every way to the cements manufactured in the United States or in Great Britain. Their control of raw mix proportions was generally lax, and fine grinding of these materials which we believe essential for good quality was nowhere near that of American practice. The burning operation is much lighter than ours, even in plants with modern kilns, and free lime contents as high as 2.5 percent are not uncommon."

Mr. Swayze's appraisal was, of course, based on observations of conditions in 1945. To just what extent economic donditions, particularly an acute fuel shortage, may have tended to lower postwar manufacturing standards as compared with those in effect during the thirties, cannot be stated definitely. Furthermore, the cements used in the construction of the motor roads were supposed to meet special requirements for flexural strength, drying shrinkage, and fineness which were not imposed in the case of the ordinary product. Even so, it seems probable that even these specially selected cements were quite inferior, when judged by our standards, to modern American cements. For example, Swayze's survey indicated that, entirely aside from the matter of fuel economy, the methods for controlling uniformity of product, such as facilities for storing and handling clinker, proportioning materials including the gypsum, etc., were very crude as compared to modern American practice. This conclusion would, of course, apply as well to the prewar German cement as to the postwar product.

The Autobahn cements were undoubtedly somewhat coarser than our present-day American cements. The Germans required that between 5 and 25 percent be retained on a sieve having 178 openings per inch. Compare this with the modern American cement, which rarely will have more than 3 or 4 percent retained on the standard No. 200 sieve (200 openings per inch). Particle-size distribution in the typical autobahn cement was also probably quite different. According to Swayze, practically all finish grinding in German cement mills is by open circuit as compared with our modern closed-circuit operation used air separators. In open-circuit grinding, the final cement product contains the various sizes just as produced in one continuous passage through the grinding mills. In closed-circuit grinding, the various sizes are classified by means of air separators and the coarser particles are returned to the mills for further grinding.

It is probable also that the German cements were not as hard burned as our modern cements. Apparently the only requirement for soundness was a 2-hour boiling test. The autoclave test has never been used. According to the best technical thought in this country, an autoclave test is absolutely essential for the proper control of soundness. Many failures in the United States, particularly in the southeast, have been attributed to the absence of an autoclave requirement in specifications, and it will be interesting to note when discussing the present condition of the autobahnen that such a requirement has never been used by the Germans.

Cements for concrete road construction were selected from the commercially available products, on the basis of the following characteristics:

1. High flexural strength.
2. Moderately high compressive strength.
3. Low drying shrinkage.
4. Moderately coarse grind.

In addition, as mentioned above, all cements were required to pass a 2-hour boiling test for soundness. This was a field control test for uniformity during manufacture, the other tests being used primarily as prequalification tests to determine the acceptability of a particular source.

In addition to straight portland cement, the Germans recognized two types of portland-blast-furnace slag cement: Eisenportland, containing about 70 percent portland cement and 30 percent blast-furnace slag, and Hochofen cement, containing about 15 percent portland cement and 85 percent blast-furnace slag. Because of its slow hardening characteristics, the Hochofen cement was not used to any extent in road work. The Eisenportland, however, was used quite extensively, particularly in northern Germany. The manufacture of this type was, of course, limited to those plants sufficiently close to the blast furnaces to make the utilization of the slag economically justifiable. The availability of almost unlimited quantities of slag, together with the great saving in fuel, made the manufacture of Eisenportland very attractive; and it is understood that in the neighborhood of one-third of the entire mileage of motor roads contains this type of cement.

The instructions governing the selection, processing, and control of aggregates for concrete pavement construction were such as to insure excellent results from the standpoint both of the quality of the hardened concrete and the uniformity of the consistency of the mixture as it was placed. Aggregate quality was insured through the use of compressive strength and wear tests in the case of crushed rock and wear tests in the case of gravel. Hard rocks, such as granite, basalt, and quartzite, were preferred. Durability was judged apparently on the basis of experience, as the record does not indicate that laboratory tests for soundness were used. Blast-furnace slag was permitted but it was not used to any extent. The requirements for blast-furnace slag were stated to be about the same as for crushed rock. Considerable attention was paid to the matter of impurities, and freedom from flat and elongated particles was insured by requiring that the breadth of an individual particle should be not less than 65 percent of its length and that its thickness should be not less than 25 percent of its length.

In the matter of separated sizes, German practice differed markedly fromthat employed in this country in that it was apparently the universal practice to require that the sand or fine aggregate be furnished in at least two fractions, 0-0.12 inch and 0.12-0.28 inch. To insure better control of grading, the material below 0.12 inch was sometimes still further separated into two or three sizes. It is obvious that with so many separations, very close control of the total fine aggregate grading could be obtained.

For the larger sizes, the separations were usually 0.28-0.59 inch and 0.59-1.18 inches. These were the size separations for the top course. In two-course construction, a somewhat larger (1.58-1.97 inches) maximum size was used for the bottom course.

Most of the pavements on the autobahnen were constructed in two courses. This was necessary not only because of the difficulty of properly compacting a single course of very dry concrete 8 to 10 inches in depth, but also because this type of construction made it possible to use a somewhat inferior type of aggregate in the lower course -- a matter of considerable economic importance in some instances.

It was the general practice to design all paving mixes in the laboratory prior to construction, using the same cement and aggregates to be furnished later to the job. The basis of the design was the development of a mix that would have sufficient workability for placing and finishing with the equipment to be used on the work, and result in concrete conforming to the following requirements for strength at 28 days, using a cement content of not less than 1.35 barrels per cubic yard and not more than 1.57 barrels per cubic yard:

	Lbs. per sq. in.
Flexural Strength:	
Minimum	540
Average	640
Compressive Strength:	
Minimum	4,700
Average	5,700

It was further provided that the strengths at 7 days should not be less than 70 percent of the above values. It was the practice also to check the strength design by means of tests of compression and flexure specimens made during construction and by means of tests on cores made at the age of approximately 60 days.

The amount of mixing water was not specified directly but was indicated as the minimum required for the chosen method of placing. For the zero-slump concrete which seems to have been used normally, a water-cement ratio between 0.35 and 0.50, by weight, was specified. A somewhat higher water-cement ratio was permitted when the concrete contained crushed stone than when gravel was used.

These specifications on materials should show the reader that much care was taken to insure that the road would last, even if their requirements were not as high nor as rigid as those in this country.

CHAPTER VI

SPECIFICATIONS AND CONSTRUCTION METHODS

There were many differences between Germany's design and construction methods as compared to those here and in Canada. There were several reasons for the variations, the most important of which was the personal ideas and eccentricities of the German engineers. Other reasons were the necessity for changes due to climatic conditions, sub-soil conditions, etc. The German engineers decided exactly what they wanted and proceeded to lay plans for securing it. All machinery, etc., was designed to fit the construction of the kind of pavement they required. Routes were laid, land acquired, etc., and the roads built exactly along those lines, without any deviation or compromise. This chapter is dedicated to the construction methods used and the specifications that had to be followed in that construction.

When the work was begun a difficulty was encountered in that many of the men enrolled for the construction of the roads had, as a result of years of unemployment, forgotten their skill. Moreover, owing to that lack of political unity which has already been mentioned, every district and town had wages fixed by itself without any particular reference to those existing elsewhere. Very soon after the work was begun it was found essential to eliminate such wage differences, and a system of standard wages was formulated. The distress of the unemployed was so great in 1933, when the Autobahnen

Company was formed, that it was decided to begin work in as many different localities as possible in order to benefit a large number of workers. The result was, as seen from the map in Chapter IV, that many gaps in the system exist. These gaps were much larger and more plentiful during the construction. In 1937 with about 800 miles of road completed, the longest route open was from Hanover to the uncompleted Berlin ring, a distance of about 150 miles.

Contrary to the general belief at that time, and even now, highway construction in Germany was not carried on by forced labor, but all was let on contract. To accomodate the workers, many of whom were living at some distance from their homes, camps were built. The buildings were of timber and were designed to be portable. They were usually arranged around a square and a camp generally consisted of twelve dormitories for eighteen men each, a social or living room, a kitchen and bathrooms. The administration of each camp was left largely in the hands of the men themselves. The outfitting of the camps was under the control of the Inspector-General. Mr. Walter L. Sanders, district engineer at Ottawa for the Ontario Department of Highways, visited the construction camps in 1937. He said that conditions were an eye-opener to him and the specifications demanded were extremely high. The men living in camps had accomodations as good as in a hotel. There were even bedspreads on the cots, he said. The men were well paid and married men working on road jobs received extra pay as separation allowance.

Previous failures in road construction have often been due to an insufficient study of subsoil and foundation conditions. Attention has always been given primarily to surfacing, regardless of the ever-increasing weight of motor cars and trucks. The subsoil under the road surface is, however, as important as the foundation under any other engineering work and the German engineers recognized this fact. A thorough investigation of soil and sub-grade conditions formed a major part of the routine of German motor road construction. It was emphasized that such investigation should take place at a sufficiently early stage to influence, if necessary, the choice of alignment. Whenever possible, bad subsoils were bypassed. Where such areas could not be avoided, detailed investigation was carried out to determine the magnitude of the settlement of soft undersoils due to loading, the time required for such settlements to occur, and the most economical height, and slope of embankments. When it was necessary to place high embankments over yielding subsoils, the completion of the earthwork was planned so as to permit the major portion of the settlement to take place before the concrete slab was placed. The course of the settlement was accelerated through lateral displacement of the subsoil by overloading or by blasting.

On each section, the first field work consisted of testing, digging and drilling, and studying excavation and soil from the neighborhood. The field laboratory test of subsoil of the highway controlled all processes from the beginning of construction. In addition to direct testing, the indirect dynamic testing was also used. This process consists of a vibrating machine sending out waves to the soil to be tested, while a seismograph indicates the oscillations at various distances from the center of vibration. From the speed with which the waves pass through the soil, conclusions can be drawn as to the nature of the subsoil.

The soils of Germany vary from cohesionless sands to plastic silty clays and clays. Most of the silty clays were of such nature as to require careful moisture control for adequate compaction. Such soils would be subject to frost heave under adverse drainage conditions, and pumping at joints would occur on them if free water entered expansion joints or cracks and if a sufficient number of heavy loads passed over the pavement. The practice of placing a layer of granular material under the pavement was, no doubt, a contributing factor in the prevention of pumping in such cases.

A modern soil technique was employed in the first stage by means of a soil survey along the line of tentative route. The soil samples were taken and forwarded to the central laboratory and analysed for the determination of the special steps which might be necessary to ensure maximum consolidation and maximum stability. Only after the work had passed the standards imposed, was actual construction of the roadway authorized.

Soils were classified as follows: (a) top soil, (b) non-cohesive soil, (c) cohesive soil, (d) stone (e) waterlogged soil (peat, ooze, etc.). The different types of soil were removed separately and drainage facilities were required. The material used in the construction of embankments was placed in successive layers, the soil being tipped from above and then distributed to the correct level. A portable apparatus for measuring the height of each layer as it was constructed was devised. Consolidation was effected by mechanical means. The weight of the tamping machines used depended upon the gauge of the rails used for the transport of material. Light models were used on the shoulders, which were consolidated first, from the edges toward the center of the embankment. If any spreading occurred at the foot the extruded material was used in finishing at the toe of the embankment. Irregularities in the upper surface of the embankment were eliminated by light rolling. The soil constituting the foundation of low embankments was required to be homogeneous; intrusive deposits were removed and replaced by appropriate material. No settlement was supposed to take place on such a foundation provided the embankment was well consolidated. On weak foundations the amount of settlement to be expected was calculated and taken into account.

Layers of peat up to 13 ft. were removed and replaced by sand. If the water content of the peat was not too high, drainage channels were cut in the subsoil and filled with subsoil material. It was found that if the height of the embankment was considerable and thorough consolidation was effected by machinery very little settlement took place after construction was finished. Where excessive peat was encountered it was removed by blasting and replaced with stable material.

Special attention was paid to the uses of fertile top soil for encouraging material growth on slopes, and existing vegetation was carefully protected. Where the formation consisted of stone, care was taken to make it smooth and all projecting material was removed. Cracks were filled with non-capillary soil. Where too much rock had been blasted the formation was leveled by applications of lean concrete. Embankments of hard rock were constructed in successive courses. Soft rock was consolidated with heavy tamping machinery. Where other types of soil were placed on a foundation of stone an intermediate filter course was provided.

Special care was exercised in the selection of the soil used in back-filling engineering structures and consolidation was effected with tamping units weighing up to 1,100 pounds. Hand tamping was not permitted. A suitable drainage system was required here also. Drainage channels were laid under the road bed itself and any ditches necessary for drainage during construction were subsequently filled. Stone-filled drains were provided with a filter course in order to prevent entry of embankment material.

The following recommendations that were made concerning the foundations, earthworks, and drainage of the road, were taken directly from PUBLIC WORKS for December, 1936:

"(1) The choice of surfacing must depend largely on the nature of the subgrade; surfacings of the "flexible" type should be constructed on stable subgrades only. Concrete surfacings have given satisfactory service on unstable subgrades, but adequately dowelled joints must be provided.

"(2) Concrete foundations are recommended on subgrades which are liable to frost damage. Foundations of stone pitching require special protective measures; surface repairs effect no permanent improvement when such foundations have become displaced either in the later stages of construction, under traffic, or by frost.

"(3) In soils where the proportion of particles of less than 0.02 mm. diameter does not exceed 3 per cent, frost damage does not take place. If the particle size is very uniform, the safe proportion of such particles may be as high as 10 per cent.

"(4) Measures of protection against frost include the provision of a layer of porous material (gravel, sand, brushwood), or of a bituminous insulating layer.

"(5) All types of soil, with the exception of soils containing a high proportion of organic matter (e.g., peat), can be successfully used in the construction of embankments. The consolidation of plastic soils, however, must not be undertaken in wet weather, as tamping then increases the plasticity of the material by incorporating a further quantity of water.

"(6) Tamping or vibration is preferable to inundation methods, though these may be successfully combined with either of the former.

"(7) In cases where a considerable proportion of plastic material must be used, greater stability is obtained by placing and thoroughly consolidating alternate layers of plastic and porous soil. The stabilization of such a core is exceedingly gradual, and there is constant liability to spread or subside.

"(8) The mixture of clay or loam with sand or gravel is not successful in practice, as a comparatively small amount of clay dangerously increases the plasticity of the mixture.

"(9) Careful and uniform consolidation is of first importance. The depth of soil to be placed and consolidated at a time should in no case exceed 40 in.; the usual maximum is 30 in. In the case of backfills in the construction of abutments the soil should be placed and consolidated with light machinery in layers not exceeding 8 in. thick, in order to avoid damage to the adjacent structures. The provision of a dry masonry course behind wing walls of abutments is actually injurious, as the soil of the fill becomes forced into the interstices of the stone and thus permits subsidence.

"(10) The generally accepted limiting slope for embankments (1:1$\frac{1}{2}$) and excavations (1:2) is too steep for plastic soils.

"(11) Drainage courses constructed on the face of embanked or excavated slopes assist surface drainage only; they are without influence on the shear resistance of the interior, and hence cannot prevent spreading.

"(12) Side ditches are usually superfluous except where they are required for the drainage of adjacent land; in most cases they suffice for the removal of surface water only, and this can be more economically effected by means of channels or percolation courses. The latter, which must be of sufficient depth, afford the best means of eliminating ground water or the interior drainage of embanked or excavated slopes.

"(13) The culverts, etc., should be laid in a course of porous material which widens considerably towards the upper surface; this procedure eliminates the irregular incidence of frost action above the culvert, and hence minimizes possible injury to the surfacing during frost.

"(14) Blasting is the most economical method of removing peat strata of considerable depth."

Notice that in the design of the earthwork, danger from frost damage was given special attention. Soils which contained more than 3 percent of particles smaller than 0.02 millimeter were classified as subject to damage by frost either by heaving or by softening. It was recognized that water must be able to reach the frost zone by capillarity before frost damage could occur, and if the ground-water surface was at a greater distance below the frost zone than the capillary rise in the soil, no frost damage would result provided there was no entrance of water from the shoulders or side slopes. Efforts were made to avoid frost damage by the following means:

1. Placing the concrete slab a sufficient height above ground water to avoid saturation by capillarity, or lowering the ground-water table by drainage.

2. Replacement of soils susceptible to frost damage with soils not susceptible to such damage.

3. Use of layers of coarse granular material or of impervious strata such as bituminous concrete slabs, to prevent capillary rise of ground water.

The following statement, from a publication entitled "Guiding Principles for Roadway Slabs" issued for the use of engineers engaged in the design and construction of the Autobahn, illustrates the importance placed on investigation of possible frost damage: "The prevention of frost damage must in every single case be exhaustively investigated according to terrain and change in soil, and may not be handled in a routine manner."

In areas where ground water was found to flow toward the road, it was intercepted by longitudinal drains. Drains were also used to lower the ground-water elevation under the roadway when such a procedure was considered effective and economical.

In a great majority of the mileage, the concrete slab was placed on embankment. In flat terrain the grade line was raised 3 feet or more above the natural ground level, and in cuts the roadway was excavated below grade and back-filled with selected material. This procedure provided good drainage and in the open plains simplified snow removal.

Cohesionless sand was used in fills wherever it was available. Sand was hauled long distances to avoid the disturbance of farm lands that would result from taking borrow with a shorter haul. When sand was not available for the entire embankment, it was used in the top 8 to 32 inches. A thickness of 8 inches was most common. The sand was placed the full width of the grade in fill sections.

Where sand for the entire fill was not available, relatively thin layers of granular material were placed at several elevations and to the full width of the embankment.

Embankment slopes were made steep (usually 1½:1 or steeper) to reduce to a minimum any encroachment on farm land, and embankment slopes were protected against the entrance of moisture by sodding immediately after completion. In some instances a full-width layer of granular material was placed in the bottom of embankments composed of cohesive soil, to aid in the drainage.

Cohesionless sands were compacted with a rammer called a "jumping frog." The device was actuated by explosions of gasoline in a cylinder and the explosions were controlled by a manually operated spark. The weights of the "frogs" for embankments varied from ½ to 1 ton and for the area under the paved shoulder a machine weighing 800 pounds was used.

Cohesive soils (silty clays and clays) were compacted with smooth-face and sheepsfoot rollers. The thickness of each layer of soil before rolling was approximately 18 inches. A field laboratory was maintained on each project where cohesive soil was used, and the moisture and density of the soil were carefully controlled. Very little effort was made to compact sand or cohesive soil back of bridge abutments and, as a result, there are many settlements in the approaches to bridges. That such settlements were anticipated is evidenced by the fact that stone setts were placed adjacent to many bridges so that fill settlement could be corrected conveniently. The setts were arranged in a fanlike pattern similar to that employed in the case of Durax block in this country.

Over 95 per cent of the roads were constructed of Portland Cement. Possibly one of the main reasons why the

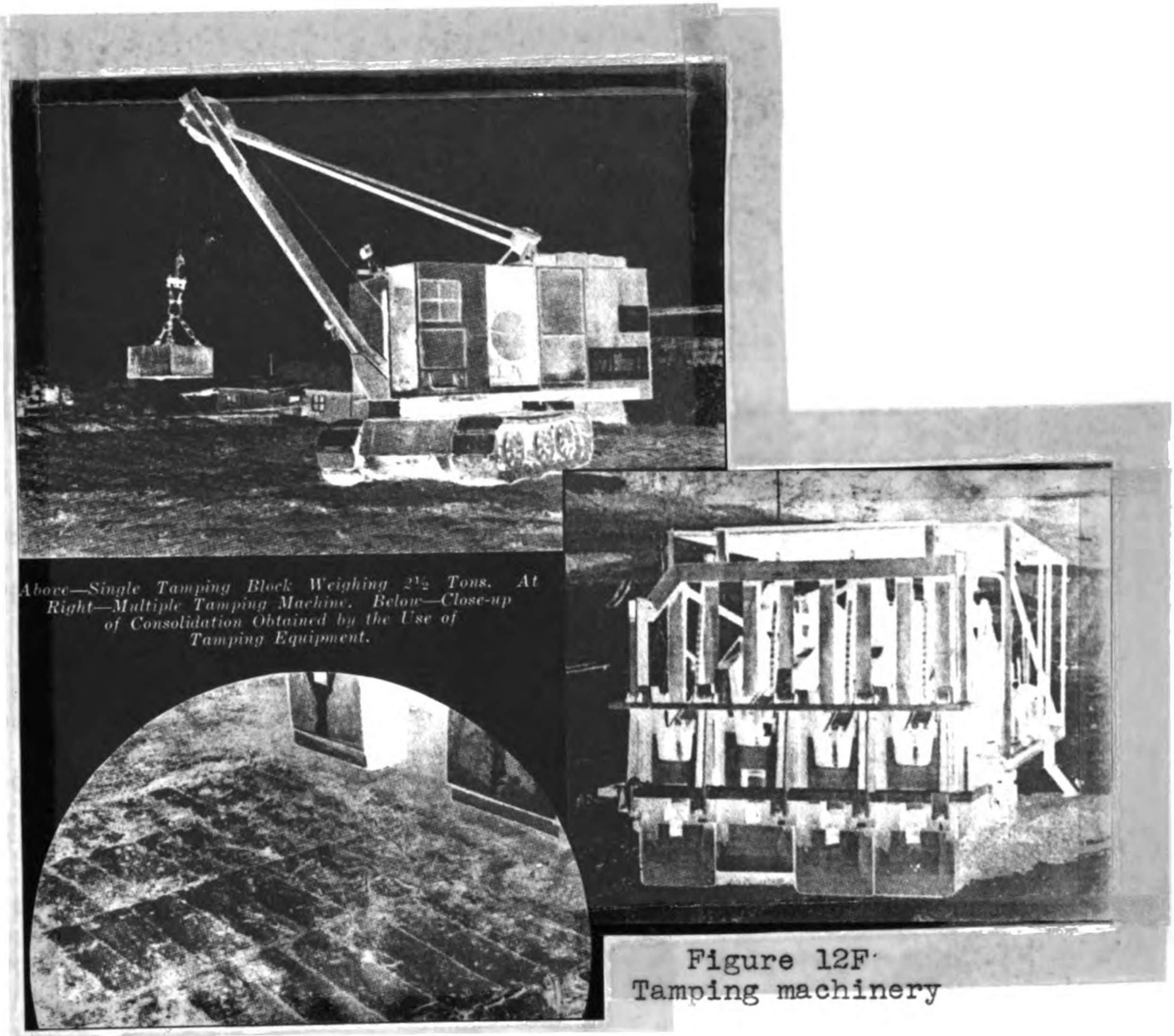


Figure 12F
Tamping machinery

Figure 12G
"Jumping Frog" used to compact cohesionless sand.

Germans decided on Portland Cement concrete for their new roads was an economic one. Cement plants are scattered all over the country, and therefore its production was entirely a domestic matter. However, the specifications for the cement were high as shown in Chapter V and only about one-third of the manufacturers could meet the requirements. Since ample supplies of material were available, the specifications were maintained. Coarse and fine aggregates were carefully selected. For fines, two grades of sand were usually specified. There were three, four or five gradings of coarse aggregate. With bins and weighing equipment for each of the seven sizes, a batch ready for the mixer was made up of a specified amount of each of these seven aggregates. The cost of this careful grading was considerable, and there was doubt in many minds as to whether such refinement was justified by the somewhat better results. It is true that consistently high-strength was obtained -- around 5,800 lb. per sq. in. compressive strength, but this was due largely to the great reduction in the water content. In work done here with accurate water control and using a plastic mix of about one inch slump, strengths of about 5,000 lbs. at 28 days are easily obtainable, and the quality of this concrete has been good.

We have covered the soil research that was done prior to the laying of the road, and also all other earthwork specifications that existed. Now let us follow the laying of the road from the excavation to the final curing. Excavated material was deposited in layers of 1 ft. 6 in. to 3 ft. 6 in., and consolidation of filled ground was carried out either by a $2\frac{1}{2}$ ton drop hammer or by a consolidating machine in which four hammers operated side-by-side. The formation of the subgrade was made with a spreader, or leveling beam, and compacted by a tamping beam which followed. The beams covered the full width of the roadway. The tamping force used was approximately 3 tons per square foot. The specifications called for the earthwork to be formed within an accuracy of 2 inches. The sand cushion base was then placed, usually to a depth of about 6 inches, and the final leveling of this foundation was required to be accurate within one-half inch.

When the construction began, extreme practices were used. The complete pavement then consisted of 3 to 4 inches of gravel spread on a subgrade, 5 inches of porous lean concrete, a 6 inch course of average grade concrete, followed by a 3 inch course of excellent grade concrete, with a wire mesh between the last two courses. Later, this procedure was modified, and the pavement consisted of a 6 inch sand cushion on the subgrade, a 6 inch course of average concrete and again the 3 inch course of excellent concrete, with the wire mesh between the two courses of concrete. The steel mesh reinforcement used weighed 4 pounds per square yard. The reason for the two courses was said to be that the vibrating machines in use could not properly vibrate 8 or 9 inches of concrete in one operation. The manufacturers of those machines claimed that they would do the job, and proved it to the inspectors, whereupon the procedure was modified again and the whole slab was laid in one course. In 1938 when steel began to become scarce, the use of the reinforcing mesh was discontinued, and to compensate the slab was thickened from one to two inches, making a total thickness of 9 to 10 inches. In all cases the slab was of uniform thickness with no widening at the edges.

Immediately following the application of the sand cushion, they constructed parallel to the center line on each side of the proposed concrete pavement, submerged flat topped courses, that on the outside are 39 inches wide and on the inside 16 inches. These courses were left 2 inches below the surface of the finished pavement and afterwards surfaced with a bituminous mixture to the level of the concrete. Several types of forms were used, but one of the most common was the form with a rail set into the form braces. All equipment traveled on these rails, so that it was possible to have the subgrade made almost perfect and kept in that condition until the concrete was poured. These rails were usually 70 pound steel rails and the sleepers they were set on were about 8 inches thick.

Just previous to placing the concrete, waterproofed paper was laid on the sand cushion. This not only prevented water being absorbed from the concrete, but also assists in giving the slab freer movement for expansion and contraction due to reduced friction. The use of this heavy paper was extremely important especially with the no-slump mix that was used.

German highway engineers apparently were not content with the machinery which we are accustomed to here. Perhaps in this respect, more than any other, lies the major difference. Equipment on a concrete pavement was several times as large as we would see here. Individual machines weighed as much as 20 tons. Actual construction was carried out by means of a construction train containing all the necessary machinery. This equipment, spanning the entire 25-foot-wide pavement slab, was carried on the steel rails which, in turn, were mounted on the concrete shoulder strips as previously mentioned. Some of the machines moved under their own power. The construction train contained 36 constructional units, including wooden huts for construction engineers, tampers for consolidating the sand cushions, machines for spreading the underlay paper, concrete mixers for base coat, concrete spreaders for the first mixer, concrete tamper for the first mixer, concrete mixer for the top coat, concrete tamper and spreader for the second mixer, concrete finisher, and tent covers for the finished slabs. During the operation of laying the pavement slab itself, the concrete was finished to a special steel form installed inside and braced against the steel rails. Hand finishing

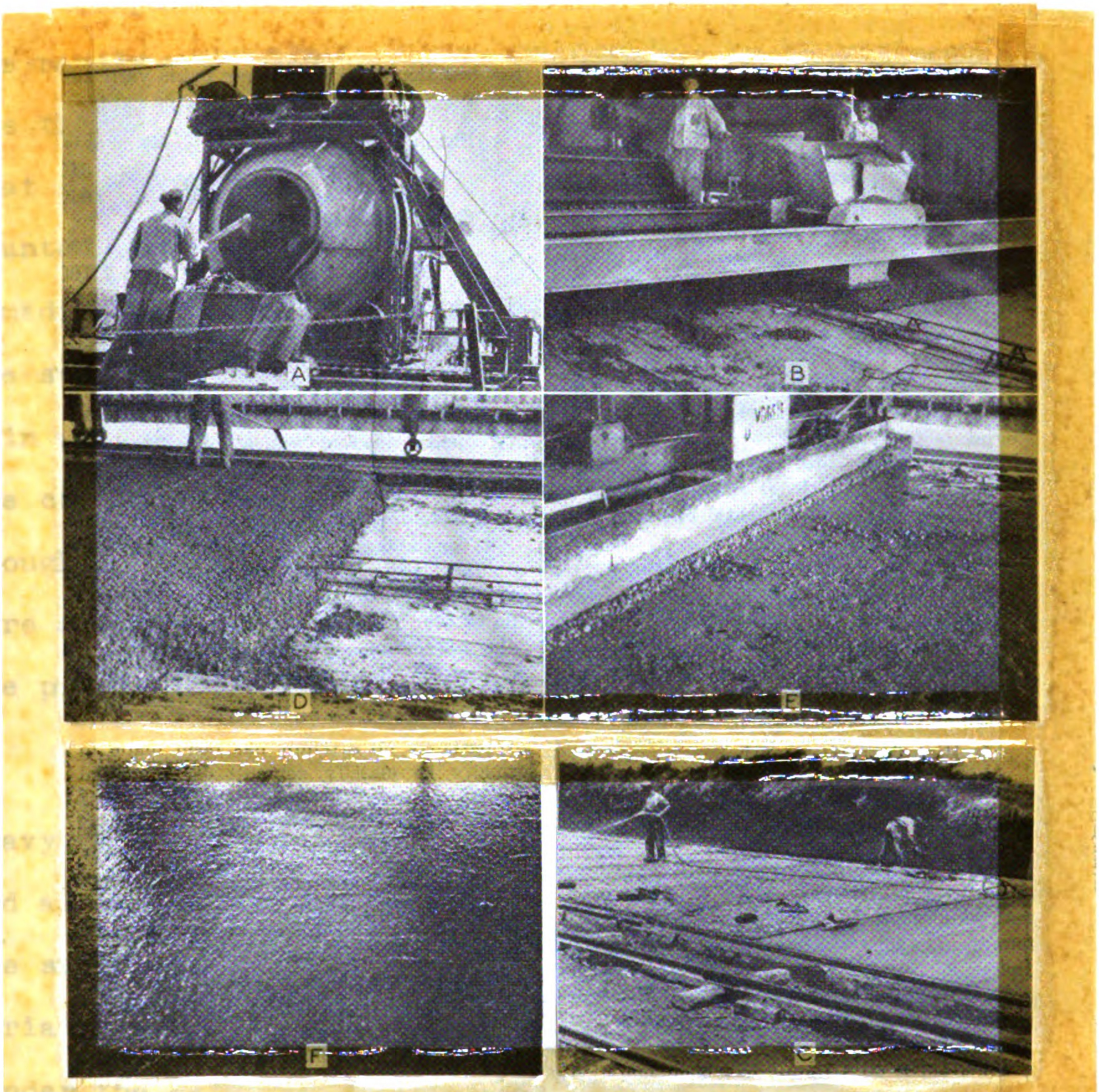


Figure 13
Construction on the Autobahn South of Stuttgart

A. Mixer discharging a batch of concrete into the spreading hopper. B. Hopper moves forward under the sunshade and discharges. D. After spreading - note the very dry concrete. E. Vogele finisher starting its second pass. F. The final finish secured after several passes. C. Watering curing mats over final finish - note light rail which was used to carry sunshades.

was rarely used. Following the six construction machines was the superintendent's office, also on wheels, and behind that a series of large screens constructed on steel frames mounted on wheels. If caught by rain, these screens were immediately placed over the freshly laid pavement to protect the surface. This eliminated the danger of scaling in a rain without any protection. These screens also protected the concrete surface as part of the curing, being of heavy enough material to keep out the heat of the sun. There were also screens over the top of the finishing machines for the protection of the operators.

An extremely dry mix was used, but with the very heavy equipment, there was a minimum of finishing required, and as a result there was very little trouble from scaling. The surface was required not to show more than a 3/16 inch variation; the contractor was required to grind the surface (under the watchful eye of a hard-boiled inspector) to comply with this regulation. Concrete cylinders were taken from the completed pavement at varying ages on every half-mile of road for testing purposes. Besides these and tests on all constituents of the concrete, tests were made on samples from the mixers.

Batching was effected by weight, usually at a railway siding which might be several miles from the construction site. The aggregates were delivered by rail to sites from which skips were charged with the correct mix.

The cement was then added and the skips transported to the mixers on the construction site. The water ratio varied from 0.4 to 0.5 depending on the aggregate, usually with 7% more water in the top course than the lower. An example of a bottom-course concrete used on the Mannheim-Karlsruhe road is quoted as follows:

Water - Cement ratio	-	46%
Cement, per cubic meter	-	325 Kg.
Cement, per batch	-	300 Kg.
Proportions of mix	-	300:1800 kg.
Water per batch	-	138 liters

The normal cement content of the concrete was 528 lbs. per cubic yard. That portion of pavement which was laid in one course, near the end of the construction period, was of this uniform quality throughout. The surface finish of the road was checked by an irregularity detecting machine, which gives an autographic diagram.

The mixer was sometimes mounted separately and sometimes on the same frame as the spreader. Spreaders were of the vertical-discharge hopper type. After receiving a load of concrete they were discharged by moving the hopper slowly from one side to the other as the entire machine moved forward. The extremely dry mixture is entirely unsuited for use with an ordinary power-driven screed, which exerts comparatively little compactive effort but merely smooths the surface after the concrete has been distributed by the spreader. German engineers have developed several types of compaction equipment. In fact, considerable research appears to have been conducted on the problem, the results of which are available in a detailed report by R. Schade issued in 1940.

There were two general types of finishers used on the motor roads, the Vogele and the Dingler. The Vogele was a three-element machine, the first and third elements being reciprocating screeds of the usual type. Mounted between the screeds was a heavy plate which could be operated either as a vibrator or a tamper. Vibrating frequencies were originally quite low (150-250 per minute) but were later increased to as high as 3,600 per minute. It was sometimes operated alternately as a tamper and as a vibrator in successive passes, and frequently several passes were required to obtain the desired finish. The Dingler machine was a very much heavier piece of equipment. It consisted of a series of tamping hammers, with 4- by 10-inch faces, weighing 55 to 120 pounds each and mounted in a row just behind the front screed. The height of fall was about 6 inches and they were operated at about 70 blows per minute. These tamping hammers were apparently only used for compacting the lower course. The final finishing was by means of a combined screed and tamper operating at about 600 strokes per minute and several passes were usually required to produce the required finish.

Another unique feature was the practice of conducting

Figure 14
Construction on the Autobahn North
of Kassel using the Dingler machine.

A. Concrete mixer spanning subgrade with industrial railway on the right. B. Tamping machine in action compacting the lower course - note dry mixture. D. The appearance of the concrete in the surface course before and after compaction by the tamping screed. E. The finished surface being given a light brooming. C. The low sunshades used during the preliminary curing. F. Woven-reed curing mats shown in place. These were left in place for 3 weeks and were kept continuously wet during that period.

the placing, finishing, and preliminary curing operations under sunshades. These were mounted on light wooden frames spanning the entire pavement and carried on light steel rails mounted outside and parallel to the concrete shoulder strips. In this way the concrete was protected from sun and wind from the time it was placed until it had hardened sufficiently to receive the final curing mats. The frames used for protecting the concrete during placing were sufficiently high to permit the equipment to pass under them and to accomodate the men working on the final finish. The frames used for the preliminary curing were low and were completely enclosed.

The shelters only covered the fresh concrete until it had set, usually one day, and then curing mats were placed over it. The curing was done in different ways. In some cases very heavy cocoanut matting was followed by damp earth or sand and allowed to stand for three or four weeks. In other cases, after the shelters passed forward, the surface behind them was covered with plaited straw mats, or sand, and kept wet for three weeks. Sometimes the concrete was watered every day for about a week after this protection had been removed.

Construction, in general, was full width in one operation, with a longitudinal center joint of the weakened plane type. But lane-at-a-time construction was occasionally used, the longitudinal joint between the slabs in this case being of the butt type. Light steel tie bars were used across the longitudinal joint to prevent separation of the pavement slabs due to settlement or other causes.

The transverse joints are all expansion joints 1/2 inch wide at the bottom and 3/4 inch wide at the top. The spacing of transverse joints varied widely, however. The first laid were installed at an irregular spacing of 30-40-50 feet and no dummy joints were used. This irregular spacing was to overcome the rhythmic effect of the uniform joint spacing. These joints had dowels across them. In most cases the length of the slabs was determined in relation to road curvature and subsoil conditions, as will be shown later in some handbook specifications. Later construction showed uniform spacing of joints. For nonreinforced sections the joint spacing was generally 26 feet, whereas for reinforced sections spacings varied from a minimum of 39 feet to a maximum of 98 feet. An average expansion joint spacing from 40 to 60 feet. Weakened-plane contraction joints were frequently installed, particularly in the case of the longer expansion-joint spacings. The joints were formed with a wooden batten about 5 in. deep placed and left at the bottom of the slot. Above this a Wieland jointing strip, 2½" deep, was laid and the concrete was then laid continuously without regard to the joints, so that there is a thickness of about ½" of concrete at the top of the joint about the Wieland strip. This latter is a hollow steel form, 2 1/2 inches deep and 3/4 inch wide.

It is made in lengths of about 12 feet and before being placed in position is painted on the sides with bitumen. It fits over the wooden batten and lies above it, as already explained. Immediately after the finishing machine had left the surface of the concrete, a shelter on wheels, running on rails, with a platform a few inches clear of the concrete was run into position. Men working in this shelter removed the concrete on top of the Wieland strip and finished off the arrises by hand. The Wieland strip was left in the concrete for three or four weeks, steam then being blown into it through a hole at one end and passing out through a hole at the other end. This procedure melted the bitumen and the strip was then withdrawn. The space, 3 inches deep between the concrete slabs, above the wooden batten was then filled with bitumen and asbestos. The wooden batten remained in place.

In a handbook issued in 1937, describing methods of concrete highway construction on the German motor roads, it is stated, "Joints shall be spaced 33 to 50 feet apart. The lengths of successive slabs need not be varied. In mild equable climates, on stretches, in flat country or in excavations (if foundation conditions permit), and in cold weather construction, wide spacing is permissable, a narrower spacing being requisite if the annual temperature range is considerable. On high embankments, lower embankments of recent construction, on subgrades which are unstable or where the geological character varies considerably, in hot-weather construction or on curves of less than 330 feet radius, the spacing may be further reduced to a minimum of 20 feet where conditions are especially unfavorable, such as approaches to large engineering structures. On bridge abutments the joints should be of the expansion type and should not be dowelled. The former practice of varying the length of road slabs has been abandoned because (a) the danger of resonance effects is negligible; (b) increased stability can now be ensured by use of dowelled joints. All joints are to be formed at right angles to the road axis, the possible utility of oblique joints becoming negligible at high speeds. Joints are to be continued across the full width of the pavement, since it was found that staggered joints may cause the formation of cracks.

As regards dowelling of joints, dowels shall be provided in all cases where frost heaving or subsidence is likely to occur. The dowels must permit longitudinal movement of the slabs and transmit stresses across the joints without injury to the concrete. They must therefore be placed accurately in relation to the gradient and direction of the pavement, and midway through the thickness of the slab. Round dowel bars in expansion joints shall be at least 0.84 inch in diameter and 29 inches long; average spacing is 12 inches, a closer spacing being adapted near the corners.

Dowels shall be connected by steel flats with blunted edges or supported by concrete blocks. The round end of each bar is left exposed, the tapered end being painted with a thin insulating coating of bitumen and protected by a cap which permits 0.8 inch expansion of the bar, packed with cork, shavings, etc. The holes in the joint inlays fit the dowelled bars very accurately.

Transverse dummy joints are dowelled in the same way as expansion joints but the bars are 0.7 inch in diameter and are not capped. On curves of less than 2,000 feet radius and on stretches where subgrade conditions are known to be unsatisfactory, anchor bars 5 feet long and 0.56 to 0.84 inch in diameter must be provided across longitudinal or transverse expansion joints, in the middle third of the slabs, in order to permit longitudinal movement at both ends. The prescribed spacing in 30 inches. Similar bars should be provided across the full width of expansion joints on stretches where irregular subsidence or frost heaving are likely to occur; also in longitudinal dummy joints along the full length of slabs at intervals of 5 feet.

Emphasis is placed on the necessity of providing proper support for dowel bars and for completing the whole joint assembly before it is placed in position."

Germany's highway program was much different and on a very much larger scale than anything that country had ever attempted before. The construction of new national motor highways along very modern lines and the improvement of about 25,000 miles of existing roads, meant many new equipment requirements. Because of economic conditions very little machinery could be imported, which meant that they had to develop new equipment and that this be done in a rather short time. While in some ways their equipment development had followed along lines very similar to that with us here, there are many cases where, because of certain different influences, it has been very much different. One of the things which seemed to have had the greatest effect in general design and method of operation was hauling equipment. Back of this, possibly the lack of petroleum for motor fuel and rubber for pneumatic tiresmade it necessary for them to use the industrial railway all the way through construction from the start of excavation to the completion of the slab, instead of motor operated pneumatic tired, or crawler equipment which is general practice here. Also, Germany did not have an automotive industry with its mass production, making available a wide range of alloys and special features of design as we have. These have had a very definite influence on our construction equipment. This, coupled with the general tendency of the German engineer to build large heavy machinery for the same type of work was brought out by several different companies at the same time. This naturally made many detailed differences, which, along with not too great a tendency for standardization, made two machines which were exactly alike somewhat of an exception. As has been indicated, most of the hauling all the way through the construction of a highway was done by the industrial railway. In some cases, on grade construction, the cars were loaded by hand, and if the grade was not too steep, moved by hand, but generally they were either loaded by power shovels or long conveyors fed by hand and moved by small locomotives, either steam or diesel. Fundamentally the power shovel used for excavation in grade construction was similar to that used here. Steam was the most common, but with a tendency toward diesel in the newer models, which were mounted on crawlers, very similar to those common with us. There were many detailed differences and a general one of interest is the dipper door attached by two large arms, one on either side and near the top. To dump the load the door was swung on an arc across the bottom of the dipper, sliding from under the load. This saves height but takes considerable pull through a long distance to dump the complete load. Another method was to use a system of gears and a brake drum attached directly to the back side of the dipper. A spring loaded brake holds the door in closed position and to dump the load this brake is released, instead of using the latch as was common practice here. They used some large shovels, but most of those on highway work were about one-half cubic yard in size.

While very heavy machinery was used in building the express roads, work was proceeding also on the old highways of various types. That system comprised 212,000 km. There was a strong demand for all sorts of mechanical equipment. As it was more practical to overpass the narrower local roads, the express roads run mostly through cuts. Heavy excavating machinery was employed. Narrow-gage track paralleled the work. Industrial locomotives and dump cars were used.

All of this greatly stimulated the highway machinery industry. The industry had pretentious exhibits at the 1937 spring fair in Leipzig. Diesel engines were used almost entirely in a wide range of sizes. Pneumatic tires were employed on a surprisingly large proportion of the equipment. Tire treads of artificial rubber were used. While synthetic rubber costs more than the natural product, its resistance to abrasion makes its use practical on tires to be put to particular hard use.

The exhibits showed a strong tendency toward welding in the manufacture of machinery. Provision for minimizing oiling was made by enclosing gears and by use of anti-friction bearings. Portable crushing and screening plants were made in a multitude of sizes. Demonstrations of rock drills and pavement breakers constituted one of the features of the fair. Many improvements in this type of equipment were claimed, greatly reducing the need for blasting. Improvement was claimed on the vibratory motors. Vibrators permit the use of coarser aggregate.

Tractor track said to have a much longer life than that previously used was on exhibit. Improvements in transmission permitted greater speed on some of the motorized equipment. Dirtmoving machinery, small and large, was much in evidence, as were compressors and pumps in wide variety. As Germany was particularly proud of its chemical products, considerable space was devoted to wood preservations and a variety of tars. Much was claimed for chemicals that accelerated the setting of concrete.

These scattered additional facts are of interest: The rate of progress on the Autobahn varied slightly but the average was about 240 yards of 24 foot 6 inch roadway in an eight-hour day, and about 440 yards for a double shift. The record was 580 yards per day. The surface finish obtained on the work is of the fine grain or sandpaper characteristic. A coarse aggregate or broom effect was carefully avoided. Such grinding as was necessary to bring the level of the pavement within the required accuracy was done in a number of places on the Berlin-Brunswick road, but grinding was almost unknown on later work. Owing to the severity of the winter climate the work was carried out for the most part only in the summer and autumn months.

About 5 per cent of the roads had bituminous surfaces. These surfaces were retained for those cases where resilience of construction was required, either because of doubtful properties in the subsoil or where slight crust movements were anticipated. The foundation was of hand-picked Telford stone with a macadam subcrust. The total thickness of these two was about 11 inches. The bituminous-concrete surface was usually laid in two courses, a base coat of 2 1/2 inches and a surface course of 3/4 inch, giving a total consolidated thickness of about 3 1/4 inches.

In concluding this chapter it might be of interest to give a brief summary of a typical section of highway built in Germany in the vicinity of Berlin, as part of the so-called "Berliner-Ring."

The figures quoted cover the construction of approximately 22 miles of highway constituting only a small part of the entire "Ring" which circles the city at an average distance of about 20 to 25 miles from its center.

The excavation, or grading work was started in the fall of 1934, and finished in the summer of 1936. At two places it was necessary to dynamite swamps and replace them with fresh material. At another point it required the raising of a railway 12 feet in order to pass under it. With the grading finished in the summer of 1936, the section was paved and open to traffic on June 5th, 1937.

In the construction of this highway the following organization was required:

Five large grading contractors; two contractors applying the sand cushion, six steel companies erecting bridges; twelve paving and concrete structure contractors, and about forty medium and smaller firms.

The average number of men employed during grading was 1,500 and an additional 800 for the levelling.

For the bridge construction there were about 2,000 men working daily in 3 shifts for several months. It was noticeable that very rapid progress was made in all bridge work. Altogether there were about 1.3 million working days utilized.

Equipment used included the following: 35 miles of railway tracks; 1,100 dump cars; 50 locomotives; 15 large shovels and 20 large concrete mixers.

More than 3,000,000 cu. yd. of excavation was necessary, and 625,000 sq. yd. of concrete pavement.

In this pavement there was 36,000 metric tons of cement; 180,000 metric tons of gravel and 100,000 tons of sand.

In the approaches and junctions with the main highway there was 95,680 sq. yd. of granite paving blocks used and 60,000 sq. yd. of gravel and sand.

In the elimination of grade crossings it was necessary to erect 38 structures as follows: 13 overhead bridges of which 2 were steel; 2 steel structures over railways; 11 subways; 4 tunnels; 5 archway crossings; 1 large bridge crossing another main highway and a double valley.

This structure required 45,000 cu. yd. concrete; 1,432 tons structural steel; 3,750 tons steel for other uses; and 915 cu. yd. masonry work and 80,000 bricks.

The biggest bridge on the section is the one crossing the Hudersdoff Valley. In the first viaduct, 2,968 ft. long, is an embankment 2,400 ft. in length with an average height of 30 ft., and another viaduct 787 ft. long.

In the construction of the bridges whose piers were concrete encased with stone masonry, it was necessary in the case of 5 piers to put them down 50 ft. below the surface by means of compressed air caissons. All steel construction was by electric welding. Additional materials used in the other structures were: 7,500 tons of structural steel; 65,400 cu. yd. of concrete; 520,000 bricks and 410 cu. yd. of natural stone.

CHAPTER VII

CONDITION OF THE AUTOBAHN TODAY

We have covered the entire history of the Autobahn up to the war, but what of its use during the war and its condition now? This chapter is devoted to that subject.

Prior to the war the Autobahn was used to good advantage by buses and trucks, as well as automobiles. During the war all forms of transport were completely taken over by the Reich. Motor fuel was conserved for the armed forces and little use was made of the Autobahn except by the troops and supporting industries. As motor fuel became scarce, motor cars were transformed to wood burners.

Comparatively speaking therefore, the roads were carrying very little traffic, either prior to the war or during it. In 1939, rough counts on the road between Berlin and Brunswick and on the road between Heidelberg and Mannheim showed, in each case about 150 vehicles per hour, or roughly nine vehicles per yard width per hour. The traffic on the Autobahn observed during the summer of 1947 was very light both as to the number of vehicles and the axle loads. Harold Allen and F. H. Jackson of the Public Roads Administration made the survey just mentioned and noted that in traveling during a Sunday afternoon from Helmstedt to the outer Berlin circle, a distance of 70 miles, no vehicles were seen in a period of 45 minutes. Six light trucks were counted in the

70 miles. In many places in this area and other sections of the Autobahn, the pavement had not been discolored by the oil streak parallel to the center line which usually results from the passage of a large number of heavy motor vehicles. The appearance of the pavement indicated that the greatest volume of traffic on the system was from Frankfurt to Kassel, south of Frankfurt toward Heidelberg, and from Frankfurt to Hannover via the Ruhr Valley. Due to the very light traffic on the system, now and in the past, it is difficult to make any comparison of the pavements with those in the United States laid under similar climatic conditions and on similar soils. It is likely that the volume of traffic on most of the primary roads in the United States is considerably greater than was observed at any location on the Autobahn.

Since the present condition of the Autobahn is largely dependent on the climate that exists in Germany, it is in order to examine that climate here. Western Germany has a milder climate than would be expected from its latitude because it is exposed to mild westerly winds. There is little difference between the north and south sections since in the latter the higher elevations counterbalance the southern location. The mean annual temperature of Hamburg is 48°F., of Leipzig, 47°F., and of Munchen, 45°F. The average annual rainfall varies from 16 inches in the plains to 47 inches on the southeast uplands. July is normally the rainiest month and January or February, the driest. The snowfall occurs during the months of January, February, and March, and in that period snowfall occurs about 30 days in the northern lowlands and 30 to 50 days in the southeastern highlands.

It would be difficult to select an area in the United States having an extensive mileage of concrete pavement in which the soil and climatic conditions are exactly the same as those found in Germany. The area including southern Michigan, Ohio, Indiana, Kentucky, western Pennsylvania, and West Virginia has similar geologic formations, soil conditions, and a fairly comparable climate. The temperature and rainfall data for six cities in the selected area of the United States and for four cities in Germany, as supplied by the United States Weather Bureau, are shown in the following table:

COMPARISON OF CLIMATOLOGICAL DATA FOR
GERMANY AND MIDWESTERN UNITED STATES

City	Temperature					Annual average rainfall
	Average		Variation*			
	Jan.	July	Max.	Min.	Range	
Germany:	°F.	°F.	°F.	°F.	°F.	Inches
Berlin	30	64	99	-15	114	23
Hamburg	32	63	92	- 6	98	29
Frankfurt	32	66	100	- 7	107	24
Munchen	28	64	97	-14	111	36
Average	30.5	64.2	97	-10.5	107.5	28
United States:						
Indianapolis, Ind.	28	75	107	-22	129	38
Columbus, Ohio	31	75	106	-20	126	34
Pittsburgh, Pa.	32	74	103	-20	123	35
Charleston, W. Va.	38	77	108	-17	125	46
Frankfort, Ky.	36	78	111	-17	128	43
Lansing, Mich.	23	71	102	-26	128	31
Average	31.3	75	106.2	-20.3	126.5	37.8

* Over a period of 35 to 75 years.

A comparison of these data shows that the average temperatures for January are approximately the same in both areas, that the average July temperatures in the United States cities are approximately 10 degrees higher, and that the range from maximum to minimum is greater in the United States. The rainfall in Indianapolis, Columbus, or Pittsburgh is comparable to that of Munchen, but for the rest of Germany it is lower than that of the middlewestern area of the United States. Data as to the penetration of frost in Germany were not available from the weather records.

The use of the paved shoulder strips, described in detail previously, has been effective in keeping the traffic on the pavement. As a result, there has been no rutting or destruction of the sodded area of the shoulders. The sod is very thick and tough and even though there has been very little mowing or other care given to the shoulders or embankment slopes, they are in good condition and look reasonably neat. The asphaltic surfaces of the shoulder strips are generally in good condition. Occasional local failures may be noted. Typical views of the shoulder strips can be seen on the pictures in Chapter IV.

Reports made as a result of inspections of the road, in 1939, within 70 miles of Berlin, made the following remarks: The concrete constructed in 1934 and 1935 had not cracked as much as that constructed before 1934. This was attributed to the fact that machine finishing was introduced in 1934. It was noted that unreinforced concrete laid on a cambered road without a longitudinal joint had cracked at the center of the roadway where the width was 15 ft. or more, and that unreinforced slabs more than 30 ft. long had some transverse cracking. Several of the roads which had a considerable number of cracks carried very little traffic.

All of the structural defects that usually develop in concrete pavements in the United States are to be found but, aside from frequent transverse cracking, defects such as joint spalling and faulting, settlement, etc., are not serious except in the Frankfurt area.

Transverse cracking is common and is not confined to any particular part of the system. There seems to be no relation between transverse cracking and terrain or soil conditions. In most instances the cracks are closed and are not discernible at speeds normally traveled by automobiles. In some cases the cracks are open and the expansion joints have closed. This condition was noted on a section just north of Gottingen, near Kassel. Transverse cracking seems to be most pronounced on the route from Hannover to Frankfurt through the Ruhr Valley, from Frankfurt to Kassel, and from Frankfurt toward Heidelberg. The cracking shown in the figure 15 is typical.

Spalling at transverse and longitudinal joints was found principally in the area around Frankfurt. At the

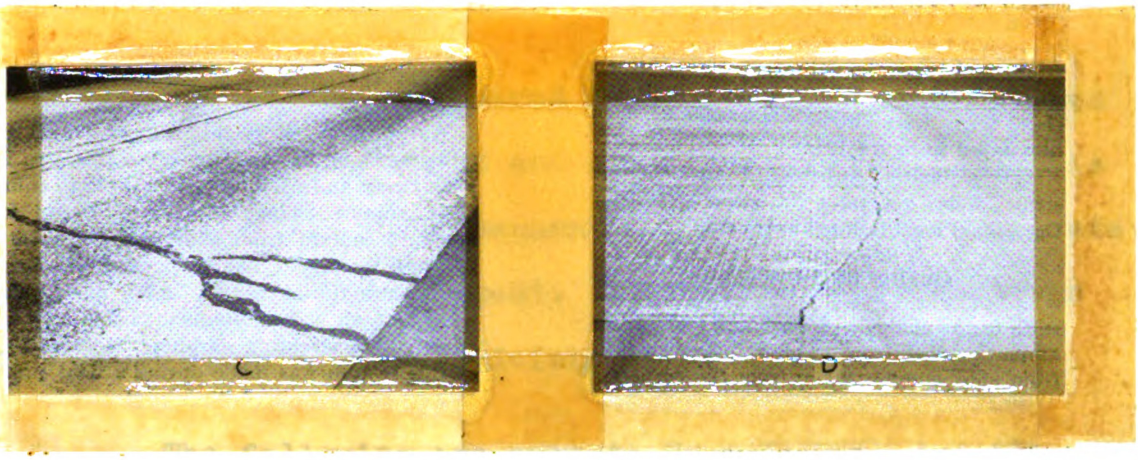


Figure 15
Transverse cracking is common throughout the system.

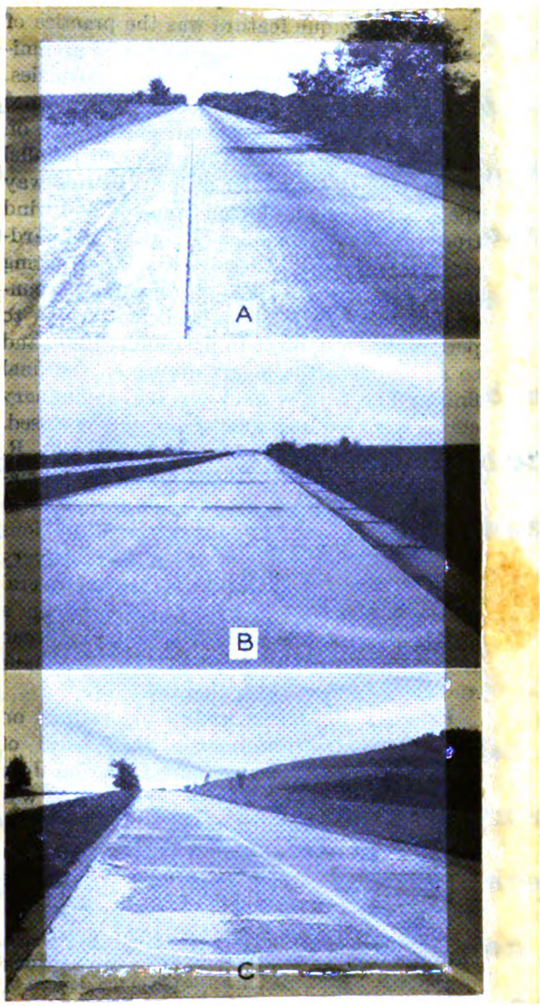


Figure 17

A. Faulting in the outside lane in Ruhr-Frankfurt area. The photograph was taken with the camera facing in the direction of the traffic and it should be noticed that the expansion joints in the left lane, which had not faulted, are visible while those in the right lane have had faulted sufficiently to be obscured. B. Warping resulted in high joints on the Ruhr-Frankfurt road. C. Surface scale was seen only on the Munchen Salzburg route.

transverse joints this appeared to be due in most instances to the infiltration of sand and other incompressible debris into the joint and the subsequent overstress of the concrete upon expansion of the pavement. Figure 16 illustrates the spalling at joints in the vicinity of Frankfurt.

The following are exerpts from Jackson and Allen's report: Faulting at joints and at transverse cracks, in most instances less than 1/4 inch, was observed in areas where there was evidence of a considerable amount of traffic. At a location approximately 50 miles west of Kamen faulting of joints in the outside lanes of the pavement was found to be 1/2 to 3/4 inch. In the Munchen-Salzburg section there were a few small corner breaks. With few exceptions, these were the only corner breaks found.

Some faulting and some spalling were observed at the longitudinal center joints. In many instances the longitudinal center joint was crooked.

The riding surface of the pavement over a considerable portion of the mileage inspected was poor as compared with standards in the United States. For example, in the section from Berlin to Braunschweig the pavement was rough and there were many small areas where there was evidence that bush hammering had been resorted to in an effort to produce a better riding surface. On the other hand, there were many long stretches of smooth-riding pavement. Here

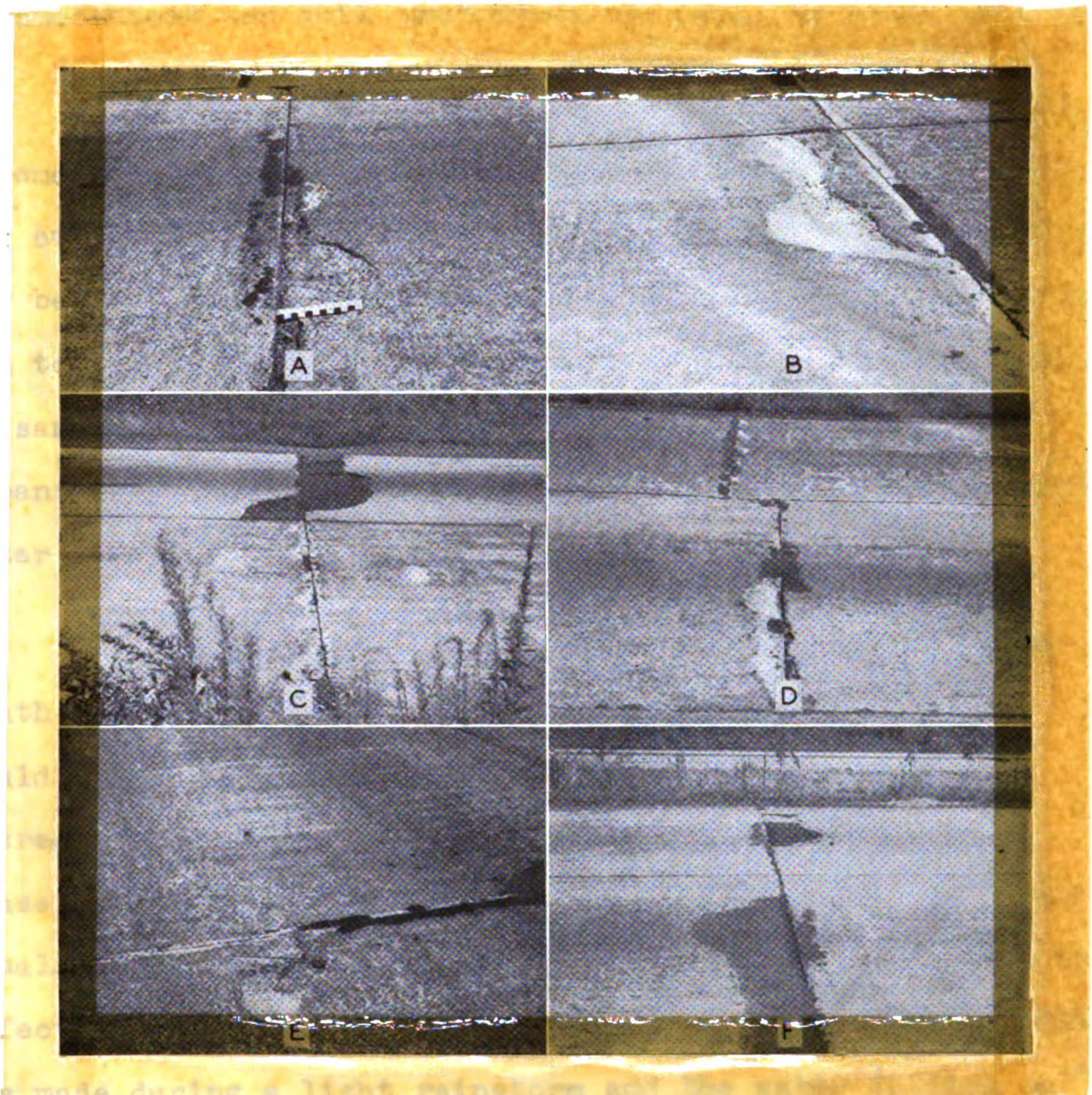


Figure 16

Spalling at joints occurred principally in the vicinity of Frankfurt.

again, there appeared to be no relation between the degree of smoothness and soil conditions, terrain, or other factors.

Evidence of mud pumping at joints in the concrete pavement is not found on the Autobahn. The absence of pumping over the areas where fine-grain soil subgrades predominate may be attributed to the passage of relatively few heavy loads and to the use of a layer of granular material such as sand or sand-gravel under the pavement. The sealing of the expansion joints and cracks to prevent the entrance of surface water was inadequate.

Warping was observed in a short section 31 miles south of Koln. The soil in this area is a silty clay and would be susceptible to sufficient volume change with an increase in moisture content from a dry compact state to cause warping. The layer of cohesionless granular material usually used under the pavement on the Autobahn would not be effective in preventing warping. Observation of this section was made during a light rainstorm and the water falling on the pavement was running away from the joints, indicating that they were high. This condition is illustrated in figure 17B.

So far as could be determined from an examination of the surface of the pavements and from chip samples taken from the corners or edges of the slabs, the quality of the concrete, with few exceptions, appeared to be excellent. The concrete had a good ring under the hammer and the difficulty encountered in breaking off the chip samples revealed, in general, a high degree of strength and toughness. As a further check on quality, a number of the chip samples were examined under the microscope in an effort to determine something of the character of the matrix, the presence and nature of voids, etc. Thin-section examinations were also made of many of the igneous aggregate types found in the samples. The examination of the chip samples revealed the concrete generally to be of excellent quality. There was no evidence of excess water. On the contrary, with the exception of a sample of bridge concrete, such voids as were noted were quite large and evidently of air origin, indicating that mixtures of very dry consistency had been used. This is borne out by the construction record. The bond between matrix and aggregate particles was in practically all cases sufficiently strong to fracture the aggregate particles themselves, again revealing good strength and probably a high degree of durability.

In the microscopic examination a magnification of 20 diameters was used, with a change to 50 diameters when some special detail seemed to indicate the desirability of the increased power. In none of the specimens was there any evidence of water gain beneath the lower surfaces of the aggregate particles.

A characteristic feature of the pavement surface is the general absence of the rather heavy mortar top which we frequently leave on our roads and which so often scales off, leaving the surface rough and unsightly. An examination of the surface indicated, in most instances, the use of a mix that contained just enough paste to fill the voids in the aggregate and leave a small excess for finishing. Surfaces were dense and compact, with the coarse aggregate either just below the top or actually exposed in some degree. Typical illustrations of variations in the surface texture are shown in figure 18. Figure 18A is a view of a surface on which the screed marks are still showing. The corrugations are quite shallow and are about 1 inch apart. This particular photograph was taken just east of the Bad Oeynhausen interchange on the road to Hannover. Other sections showed the same condition, particularly on the inner lanes which, of course, carry less traffic. Note in the lower right illustration that coarse aggregate up to 1 inch in size, which is close to maximum size used in the top course, is exposed. Many of the exposed aggregate surfaces are smooth, with a terrazzolike texture, probably the result of slight surface wear. In many places this type of surface was noted in the center of the traffic lanes (particularly the outside lane) with the original thin mortar surface showing at the extreme edges. In other sections where the coarse aggregate was exposed, particles of the hard igneous rock protruded slightly above the mortar, producing a slightly rough surface. This condition may have resulted from the scaling off of the light

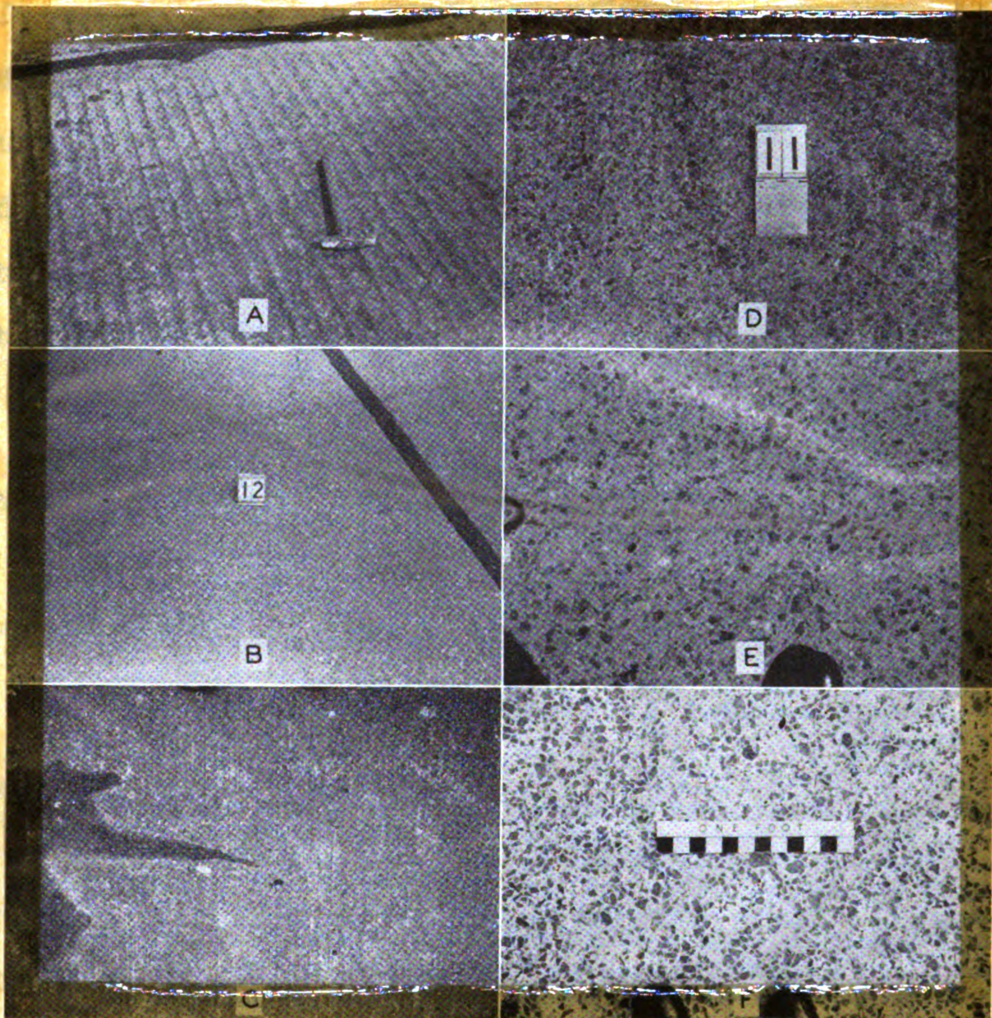


Figure 18

A. In some places screed marks still appear as shallow corrugations. B. A fine-grained sand finish. C. Black colored concrete. D-F. Typical appearance of varying degrees of coarse aggregate exposure.

surface mortar or it may have been the result of wear -- it is difficult to determine the exact cause. However, it should be emphasized that the slightly rough surface is not objectionable from the standpoint of riding quality. Neither should the exposure of the aggregate have any detrimental effect on the ultimate durability of the concrete, since the quality of both aggregate and concrete was excellent.

There was evidence of surface grinding in several places. This was undertaken, evidently, to correct irregularities resulting from the difficulty of finishing the very dry concrete generally used.

With the exception of one section in southern Germany, the entire 1,000 miles of pavement covered by this inspection were found to be practically free from scale, either of the surface or of the progressive type. Only on certain stretches of the Munchen-Salzburg section in Bavaria was surface scaling noted in any appreciable amount. Figure 17C is a general view of the pavement showing about the worst condition observed. This picture was taken about 20 miles west of the Austrian border at Salzburg. Figures 19A and C are details showing the type of scaling that has developed on this section. It is apparently of the surface type only; that is, the concrete below the scaled areas appeared to be sound. Figures 19A and C indicate a rather heavy layer of surface mortar at this point and this fact, coupled with the possibility that the winters in this region, due to its high elevation, may be somewhat more severe than elsewhere in western Germany, may account for the scaling. However, in this connection it should be noted that, according to weather records as shown previously, the average January temperature at Munchen was only slightly lower and the annual rainfall only slightly higher than for the more northern cities.

It has been stated that the scaling which developed on the Munchen-Salzburg section at a relatively early period was due to the use of inferior aggregate. A chip sample taken at the approximate location shown in figure 19A did not, however, reveal the presence of an appreciable amount of inferior material, although the petrographer did indicate that the coarse aggregate in this sample was an "altered granite." Just how much the generally poor subgrade conditions in this area, or other factors, may have contributed to the scaling is not known.

Only isolated scaled areas, all of the surface type, were noted elsewhere on the system. Figure 19D is a detail of a local scaled area on the Frankfurt-Stuttgart section, a few miles shuth of Frankfurt. From the standpoint of general condition this is one of the poorest sections on the Autobahn. As previously noted, considerable spalling at joints has also developed on this section. Figure 19B is a detail showing a thin surface scale on the Hannover-Ruhr section, about 30 miles east of the Bad Oeynhausen interchange.

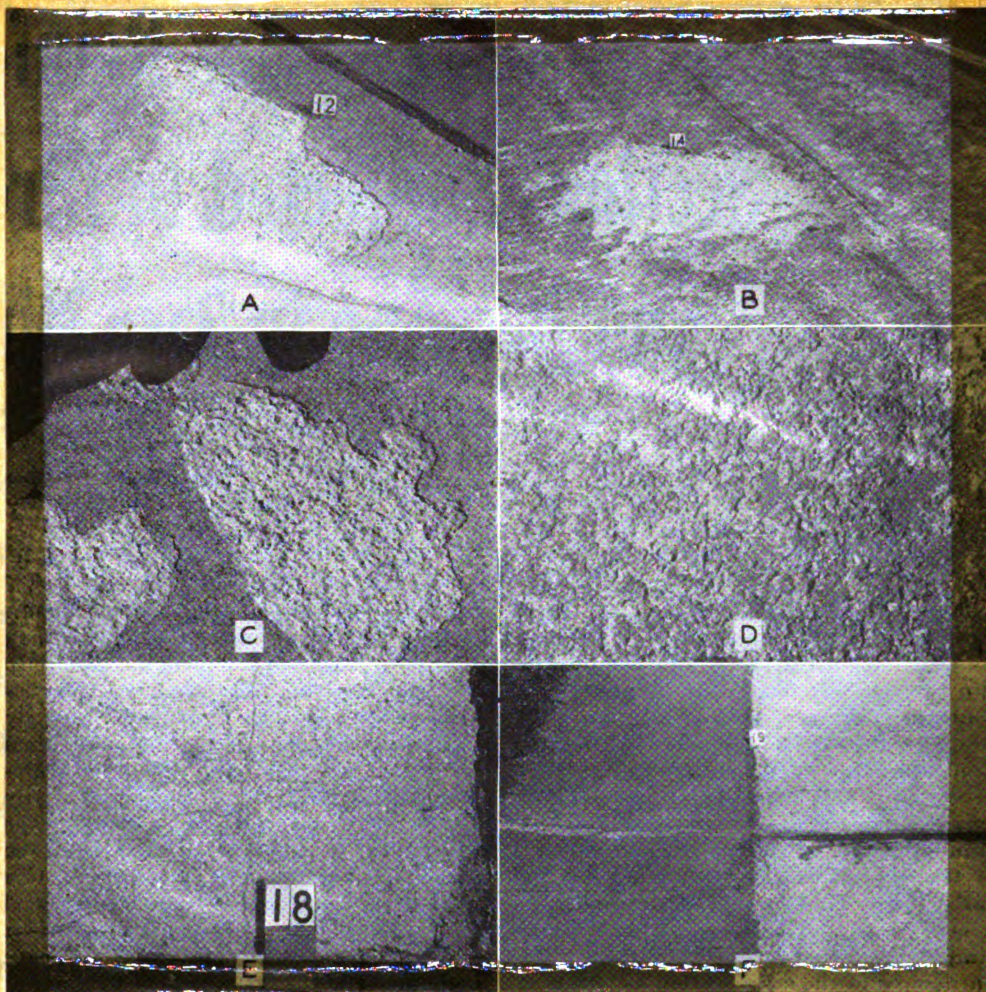


Figure 19

A-D. Surface scale occurred commonly on the Munchen-Salzburg route but only isolated cases elsewhere. E,F. Incipient disintegration, revealed by D lines, was found only at one place on the system.

This pavement, as well as many other portions of the system, had evidently been sprayed with bituminous material at some time, probably for camouflage purposes. The scale here is not deep enough to affect the riding quality of the surface.

Incipient disintegration of the concrete, as revealed by the formation of so-called D lines along the edges of the pavement and along joints, was found at only one place on the system; a point on the Munchen-Salzburg section where the worst scaling was found. The D lines in this case were found along the outside (north) lane and were very fine. The condition is shown in figures E and F. In the United States, cracks of this type have come to be associated with the beginning of disintegration due to accelerated weathering.

The general freedom of the motor roads from scaling and other troubles associated with severe weathering may be attributed to the following factors, the listing not necessarily being in order of importance:

1. The general excellent quality of the aggregates.
2. The low water-cement ratio (usually 0.45 or less, by weight).
3. The practice of designing mixtures and compacting concrete in such a manner as to avoid the formation of a heavy surface layer of mortar.
4. The comparatively mild winters.
5. The fact that chloride salts were not used for

ice removal.

6. Thorough curing.

The possible influence of all of these factors is fairly obvious. The role of the cement is not so apparent. According to Swayze's report, mentioned in Chapter V, the cements used in the Autobahn were distinctly inferior to those manufactured in this country. However, the concrete is good and from this fact we can conclude at least that it is possible to make good concrete with the German cements provided the other conditions are right. Whether these cements would perform any better than the American cements under conditions that prevail in the Northern part of the United States is another matter. An intensive research program would be necessary to answer this question.

The Autobahn was damaged little during the war aside from its bridge structures. The Germans demonstrated stupidity in destroying the fine bridges of the network in their retreat. Whereas destruction of one span would have rendered a bridge completely useless to the Allies, the Germans demolished the entire structure in most cases. The roads themselves were not damaged to any extent; however, railway lines were almost completely destroyed. Reconstruction of these bridges has been in progress since shortly after the end of the war. Some have been completed but others are still in the process. Transportation as a whole was ruined and decades will probably elapse before it equals the once efficient system which existed.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

As mentioned in the body of this report, the comparatively light traffic on the German motor roads, particularly as regards the movement of heavily loaded vehicles, as well as the comparatively mild climate, make comparisons with the performance of concrete pavements in this country difficult. This is especially true if we attempt to compare the Germany primary roads with the heavy-duty concrete pavements of the industrial States of the north and middle west. Many of these roads undoubtedly carry a far heavier volume of truck traffic than any of the motor roads in Germany. The question therefore is: How would the German roads perform under similar climatic and traffic conditions? It is, of course, impossible to say definitely. However, these two factors -- the low volume of heavy truck traffic and the relatively mild climate -- probably account for the comparative freedom of the German motor roads from structural defects and that, under comparable climatic and traffic conditions, the structural performance of the German roads would be about the same as the average concrete pavement in this country. This opinion is borne out by the fact that structural failures such as joint spalling, faulting, etc., were found to be more numerous and, in general, more serious on sections of the system where the indications pointed to the heaviest traffic.

We must also recognize the beneficial effect of using a layer of granular material under the pavement, particularly with respect to the control of mud pumping at joints, a condition which was not found anywhere on the system.

The quality of the German concrete was excellent. Although the design strengths were not unusually high as compared to standards in use in the United States, the indications were that a high degree of uniformity was obtained. This may possibly be due to the care used in proportioning mixes, as, for example, the use of several sizes of aggregate and the practice of limiting the maximum size in the top course to about 1 inch. Reference was also made to the general absence of the relatively heavy mortar top which we see so often on our roads, and to the fact that this might have reduced the tendency to scale. It is believed that the principle of consolidating the pavement slab by vibration is good although the Germans may have gone too far in their effort to use excessively dry concrete. This is indicated by the rather rough surface with occasionally noted evidence of grinding off of high spots. However, the principle of using as dry a mix and as low-sanded a mix as can be consolidated properly by the effective use of vibratory equipment is good and should be encouraged in this country.

The uniformly excellent durability of the concrete is probably also due, in part at least, to the excellent quality of the aggregates generally used. This is also a factor to which we might give more consideration in the United States.

The probable influence of long continued and thorough curing also should not be ignored. Whether the elaborate precautions for protecting the fresh concrete from sun or wind were always necessary is problematical. However, the practice of thorough water curing, although old-fashioned in terms of modern American practice, is still, in the opinion of the author, the preferred method.

Regardless of the quality of the cement used, the quality of the concrete was excellent; concrete containing Eisenportland (portland-blast-furnace slag cement) was, on the average, as good as concrete containing straight portland cement. Although it was impossible to determine on just what portions of the Autobahn the Eisenportland was used, it was stated to have been used on about one-third of the total mileage. This fact would seem to warrant the statement that its performance was satisfactory.

As a result of a study of methods and practices employed during the construction of the Autobahn and also of its present conditions, the author recommends that steps be taken to initiate a comprehensive program of research on each of the following subjects:

1. Study of the possibility of insuring greater

uniformity in pavement concrete by reducing the maximum size of the coarse aggregate.

2. Development of more effective methods of compacting concrete in pavements by mechanical means, such as vibration, tamping, etc.

3. Study of the effects of variations in the chemical composition of cements and the methods of manufacturing cements on the properties of concrete.

With the initiation and completion of these studies, perhaps the super highways, which this country will continue to build in the future, will be free of many or all of the defects so common to concrete pavements now.

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