A Study of Concrete Roads.
(Michigan Avenue between Lansing and East Lansing.)

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by

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Contents.

INTRODUCTION.

Introduction.

The problem of selecting a type of road to meet the peculiar conditions of the country through which it will pass is a real one and has caused many of the ablest road engineers to pause and think twice before going ahead with new construction. The highway departments of the majority of the states have made studies of the selection of road types,but it has not yet been reduced to a finality.

The first thing to be considered in making plans for a new road is if it will be satisfactory to the majority of users. A road which is unsuited to the needs of the traffic or which is not maintained in a manner which will enable it to meet the demands made upon it will cause the people of the community to become prejudiced against all roads of the same type. This will also cause them to give preference to high-cost roads in locations where low cost roads would have sufficed.

The Michigan State Highway Department finds that gravel roads will stand up under the average country road traffic,which is largely by automobile,but less than 400 vehicles per day. Such roads constitute 3,000 miles,or 60 per cent of the total improved mileage in the state today. It is estimated that in 85 per cent of the cases gravel roads are rendering satisfactory service, and that with uniformly good maintenance this figure could be bettered.

The Michigan State Highway Department advises that the ability of the community to pay for the road be considered in its selection. When in doubt,the cost and success of the different

types under similar conditions in other locations are good criterions to follow. The ability to pay depends upon the valuation of the adjacent country which is served by the road. In Michigan this valuation is divided by the number of miles of road to be built and the result is tabulated as the valuation per road mile.

It follows that the traffic increases with an increase in the road mile rate. For instance in Wayne county where the traffic is the greatest in the state the valuation per road mile is $609,000;in Kent county it is $16,950 and in Lake county $3,980 per road mile. In the latter county with its low road mile valuation,the traffic is less than 400 vehicles per day on the most highly traveled throughfares. The county road commission shows good judgment in restricting the road building to gravel construction costing $2,000 per mile.

Wayne county on the other hand can well afford to select an expensive type of road for it is 150 times as large as Lake county in point of road mile valuation. As a result concrete roads have been built extensively in this county at an average cost of $16,000 per mile. Kent county,Ottawa,and Ingham counties are now falling in with the concrete road idea and are constructing numerous roads of that type.All of these counties have sufficient road mile valuation to take up this type of road on a small scale.

Data secured from the Michigan State Highway Department shows that there is a practical traffic limit for 16 foot gravel roads. This is set at500 vehicles per day.If used for a greater number of vehicles per day,the maintenance costs more than is considered economical. The Highway Department data also shows that theoretically,if the traffic does

not exceed 800 vehicles per day, we can afford to spend $466 plus $150 (the assumed maintenance for gravel road below 500 vehicles per day), or about $600 per mile per year in the maintenance for a gravel road before it would be economical to build bituminous-surfaced macadam. Practically, however, a gravel road carrying 800 vehicles per day would be in a continual state of repair. When ever possible, therefore, if a community is financially able to build better road types, it should do so by all means, providing that indications point to a future increase in traffic. The highclass road type will eventually become economically suited to the traffic passing over it.

The road on Michigan Avenue between Lansing and East Lansing, Michigan affords a good illustration of the futility of trying to use the lower types of road surfaces for heavy traffic, especially of the automobile type. This road lies on the route of the Wolverine Pavedway, which is a much traveled through route from Detroit to Grand Rapids and other Western Michigan cities, as well as a most important market road. It is also the most traveled road from Lansing to the Michigan Agricultural College which results in considerable pleasure driving over it. The advent of the automobile has caused the traffic to more than triple since the first time the road was improved in 1906. The average number of vehicles passing over the road daily is now in excess of 1000, of which approximately 85% is motor driven.

Until 1906 the road had never been improved and travel over the dirt roadbed during the wet seasons was impossible. The traffic, though largely horse drawn by the year 1906, had assumed such porportions that some form of improvement was necessary. After considerable

parley, macadam was selected in the belief that it would serve for years to come. The improved section was two miles long and extended from Lansing through and beyond the limits of East Lansing. The road was constructed in two courses with a limestone base and a top of crushed fieldstone forming a compacted depth of six inches. The width of the macadam was 15 feet, and between side ditches 22 feet. The total cost was $13,485, or approximately $6,750 a mile. It was built according to the specifications of the State Highway Department and was among the earliest applied for, its application number being 27.

Two years of use, however, proved that this type of road was unsuited to the conditions for the surface became badly rutted. An experiment was tried. The road was scarified, reshaped and treated with asphaltic oil by the penetration process.

The new surface looked good for a time, but the period between 1908 and 1914 witnessed a large increase in traffic and a gradual change from horsedrawn to motor driven vehicles. The change in traffic conditions left the road in bad condition at the end of each season and in 1914 it was apparent that it must be resurfaced in some manner. An abundance of good gravel was available, and it was decided to resurface the road with this, since the lack of funds prevented extensive reconstruction. The gravel was placed to a greater depth at the center, to form a small crown, since the old surface had become worn quite flat. When the gravel had been throughly compacted and shaped, the surface was treated with glutrin.

It took less than two years for the gravel to become displaced and the road again became deeply rutted and full of holes. Traffic as a result could not proceed over it at a greater speed than ten miles per hour without discomfort to the passengers.

In 1916 it became evident that immediate steps must be taken to reconstruct the road with some form of permanent surface. Prominent business men of Lansing and East Lansing headed by W.K.Prudden suscribed heavily toward a fund for reconstruction. The state contributed it usual amount for good roads of permanent character and the county paid the balance. Concrete was selected as the most feasible type to build.

The writers of this thesis have undertaken to investigate the construction of the road in question to determine if it was done according to the best practice as recommended by the leading concrete road engineers and to determine if possible any defects in the finished road. The proceedings of the Second National Conference on Concrete Road Building held at Chicago,February 15-18,1916 have been used as a basis for comparison,it being assumed that a report of this nature resulting from an assimilation of ideas from America's most prominent road builders can be taken as an outline of good practice.

The following points were considered in the investigation:

1-Drainage and preparation of roadbed.

2-Design,thickness,crown and grade.

3-Aggregates.

4-Handling and hauling of materials.

5-Porportions of materials and consistency of concrete.

6-Mixing and placing of concrete.

7-Reinforcements.

8-Joint locations.

9-Expansion and contraction.

10-Finishing and curing.

11-Construction of shoulders and curbs.

12-Form of specifications.

13-Testing of samples taken from road.

14-Counting of cracks,classifying and learning the causes of each.

SECTION I

Drainage and Preparation of Roadbed.

Section 1.

Drainage.

The drainage of a roadbed is of vital importance for if the subgrade is not well drained, there is danger of unequal settlement or frost action, which will cause cracks. Local conditions will have to be taken into consideration when deciding on the method of drainage to be used. Lateral drains or ditches will provide suitable drainage for ordinary country roads. The drainage trenches if placed under a subgrade, should be completed before final rolling.

The road under consideration is drained by a lateral system consisting almost entirely of open ditches. The drainage problem for this road is a big one because of the nature of the land, it being to a large extent marsh which in flood seasons is covered with water. Government reports show that once every ten years the Red Cedar river over flows its banks to such a depth that the road is inundated.

It is hard to advise whether or not the road should have been raised so as to get above the high water mark because of the economic problem involved. The cost of raising the road to such a level under present cost of labor and material would undoubtedly be more than the damage which will result to the road in event of another inundation. In our minds, however, there is no doubt that the present road level is inadequate to allow sufficient flow off of surface waters and to keep the road in the best of condition.

The interurban line abutting the road on the south side of the road prevents an adequate open ditch along that side. In place of the open ditch, an eight inch tile is used from station 17.9 to station 31.2 at which point a catch basin is located. The ramainder of the south side of the road is not drained the elevation of the interurban tracks making it impossible. Open ditches are used on the northside from

station 0 to catchbasin at station 31.2 . From station 31.2 to 42.7, a twelve inch tile is used. From there on to the end of the road an open ditch is provided.

This system of drainage we consider inadequate. Larger tiles should have been used where ditches were impossible because the land abutting is so near the same elevation of the road surface that there is very little opportunity for the water to run off. Inspections of the road during the flood season this year indicated that water stands under surface during those periods. This will cause the best of roads to deteriorate.

Sub-grade.

According to the best practice the fundamental requirement of the subgrade is that it should be of uniform density so that it will not settle unevenly,thus causing cracks in the surface of the pavement. No part of the work is more deserving of intelligent care and painstaking labor than the preparation of the sub-grade. The slight additional cost necessary to insure good results in abundantly justifiable. When the pavement is constructed on the natural soil , care should be taken to remove all soft spots so as to insure uniform density; and if constructed on an old roadbed,even greater care must be taken as the subgrade then is likely to be more compact in the center that at the sides. An old roadbed should be scarified,reshaped and rolled. The subgrade adjacent to the curb should be hand tamped.

The road under investigation was constructed on an old macadam road using the old macadam as a foundation. There are two practical methods of preparing an old macadam road as a foundation for a concrete road:1-Scarify the old macadam foundation,supply the necessary material to bring the road up to a practical grade from

an outside source and roll the excavated material over the subgrade; Such a procedure does not necessarily insure a uniform subgrade, but approaches it within practical limits. Its accomplishment will cost considerable money, amounting approximately to from $800 to $1,500 per mile when the surface of the new road is made parallel to the old macadam or when cuts and fills do not exceed about one or two feet.

The second method is that of merely removing the crown of the old macadam road and spreading and rolling this metal over the full new road width. This process reduces the cost approximately 70%, which saving could be used to maintain the cracks that subsequently occur in the pavement.

The latter method was used in the construction of the road under investigation with the exception that a small amount of dirt was adddd to fill in the extra road bed, and to provide shoulders. The old macadam was first scarified to a depth of six inches whereas it should have been scarified to a depth of one foot. This has already caused cracks, both horizontal and longitudinal. The subgrade was then rolled and dragged until it was thought to be of uniform density and capable of holding a concrete road.

SECTION II

Design, Thickness, Crown and Grade

Section 2.

Thickness.

Many factors have to be taken into consideration before deciding upon the thickness of a concrete road. The use of the heavy motor truck and bus makes it necessary that the thickness be not less than six inches at any point. In general pavements should be thicker at the center than at the sides. Wherever thickness can be increased without excessive cost, such increase is advisable.

The pavement under consideration is six inches thick at the outer edges and eight and one fourth inches at the center. Therefore we consider that the road is of proper thickness and in that respect has been constructed according to the best practice. (See cross section on blue print).

Width.

Ten feet is considered the desirable width for a single track concrete road. For a double track road the width should be at least eighteen feet. The total width of the roadway should not be less than twenty feet for single track pavements and not less than twenty-six feet for double track pavements.

The width of roads is based mainly upon the amount of vehicle traffic and should be chosen not only to accommodate the present traffic, but also any increase in future traffic. Roads which take only a horse drawn vehicle traffic can be made narrower than those which are subjected to both horsedrawn and motor car traffic. In the former case a width of 14 to 16 feet gives sufficient clearance between two passing teams. The width out to out of the average touring car is about six feet, while motor trucks are made as wide as eight feet. A wider road is therefore necessary for motor traffic

than for horsedrawn vehicle traffic.in order to allow the machines to pass each other at a fair rate of speed with proper clearance and still keep on the improved surface. If the width is not sufficient to allow machines to pass without running off the concrete into the earth shoulder,the edge of the road metal will be broken down.

The width of the road under investigation is eighteen feet ~~wide~~ with three foot shoulders making the total distance out to out twenty-four feet. The traffic census taken during the fall of 1916 indicates an average of 1,000 vehicles passing over the road each day. Another traffic census taken during April 1917, shows an average daily travel of 774 vehicles.The April census was taken under unfavorable weather conditions which undoubtedly accounts for the falling off of the traffic over that indicated by the fall survey. The average speed of the traffic is twenty-five miles an hour.

Since the width of the roadway out to out is two feet less than is recommended by good practice and since the traffic census shows that the travel over the road is largely by automobiles or motor truck we consider that the designers should have allowed for broader shoulders and that the shoulders should be constructed of gravel carefully rolled. The present width does not permit the motor vehicles to pass without danger of colliding. Several serious accidents have already resulted because of the narrowness of the roadway.

Crown

The crown of concrete roads should be not less than one one-hundredth nor more than one fiftieth of the total width. One one-hundredth of the total width is usually sufficient for country roads . The crown of the road under investigation is two and one fourth inches. Dividing 2¼"by 216"(width of pavement) we found that the crown is 1.04/100 of the width and is within the limits set by recommended practice.

Grade.

The determination of the proper grade for a concrete road is still in the experimental stage. The original practice was not to exceed 5%,but today we are building pavements on grades as steep as 8 % under certain conditions. The grade seems now to be limited only by the ability of the workmen to make the wet concrete run during the process of construction,by the character of the mix and the kind of traffic.

The Michigan Avenue road was constructed on a grade ranging from .21% to 1.96% . This is well within the limit set by recommended practice. The grade is fairly undulating,a feature which is considered of value to horsedrawn traffic since it is much easier to pull a load up a hill if you have a little momentum resulting from coming down an incline.

SECTION III

Aggregates.

Section 3.

Aggregates.

Imformation secured by the American Portland Cement Manufacturers Association indicates that the coarse aggregates used in concrete roads built in the United States todate may be classified as follows:crushed rock of all kinds,55 per cent;gravel 40 per cent;miscellaneous materials,5 per cent. Natural sands account for nearly all the fine aggregate.

The National Conference on Concrete Road Building held at Chicago,February 15-18,1916 recommended granites and trap rocks, quartzite,conglomerates,hard linestones and dense blast furnace slag to be of proper chemical composition and excellent aggregates for concrete roads. This same conference warned against the use of soft limestones,inferior sands and gravels,and other questionable materials.

The specifications adopted by the conference for aggregates for one course concrete roads are as follows:

Fine Aggregate:Fine aggregate shall consist of natural sand or screenings from hard ,tough,durable crushed rock or gravel consist-of quartzitic grains of other equally hard materials graded from course to fine with the course particles predominating.

Fine aggregate,when dry,shall pass a sieve having four meshes per square inch;not more than 90 nor less than 50 per cent shall be finer than a sieve having eight meshes per linear inch,not more than 20 per cent shall be finer than a sieve having 50 meshes per linear inch,and not more than five per cent shall be finer than a sieve having 100 meshes per linear inch. The above-mentioned percentages shall be computed on the basis of weight. Fine aggregate

shall contain no vegetable matter or other deleterious materials and shall not more than three per cent of clay or loam,by weight.

Fine aggregates which give a mortar strength equal to or higher than the minimum values at any of the ages below,shall be considered as fulfilling the mortar strength requirements of this specification.

Age at Tests	Minimum Strength of 1:3 Fine Aggregate Mortar.
72 hours	1.25 time (A)
7 days	1.10 times(A)
28 days	1.00 times (A).

(A) equals the length of of 1:3 standard Ottawa sand mortar specimens of same form and size,and similar plasticity made by the same operator using the same cement.

The tests shall be made on mortars composed of one part Portland cement and three parts,by weight,of fine aggregate or standard Ottawa sand. The tests specimens shall be made,stored, and tested in the same manner. All mortar strength tests shall be made under laboratory conditions in accordance with recognized standards. Each value shall be the average from tests of not fewer than three specimens .

Coarse aggregates:Coarse aggregates shall consist of clean hard,tough,and durable crushed rock or gravel. Coarse aggregate shall contain no vegetable or other deleterious matter,and shall be free from soft,flat,or enlongated particles.

Coarse aggregates shall be graded from two inches down. The coarsest particles shall pass a two inch round opening. Not more than five per cent,by weight,shall be finer than a seive having four meshes per linear inch.

Ready mixed aggregates:Run of crushed stone ,run of bank gravel,or other ready prepared mixtures of fine and coarse aggregates shall not be used.

The Michigan Avenue road was constructed according to the Michigan State Highway specifications which agree, with one or two exceptions, with the specifications of the National Conference on Concrete Road Building. The coarse aggregate was obtained from the Standard Builders' Supply Company of Grand Rapids, Michigan and passed the examinations of the State Highway Department and Universal Portland Cement Manufacturers Association inspectors. We therefore believe that the aggregate used was suitable for the work.

SECTION IV

Handling and Hauling of Materials.

Section 4.

Handling and Hauling of Materials.

Handling and hauling of materials is one of the largest items of cost in constructing a new road. The quality of the road to a certain extent also depends upon the methods adopted in handling the materials.

The first essential from a standpoint of cost is that the method of hauling adopted be such as to insure an adequate supply of material for the mixer. Progress and cost depend upon there being at all times an adequate supply of concrete aggregates so that the mixer crew will work at a maximum capacity.

Since the quality of concrete depends largely upon the use of clean concrete aggregates, and although a method of hauling and handling may prove economical it may expose the aggregates to the danger of becoming mixed with dirt and consequently impair the character and quality of the road surface. If materials are dumped in piles along the road or on the subgrade, and wet weather delays the operations, a certain percentage of the material at the bottom of the pile will become mixed with dirt and must be left in the pile and hence wasted. Stock piles can be protected by placing them upon wooden platforms, and while this is possible and adequate for small work it is impracticable where large quanities of material are to be stocked in piles that are distributed along the length of the roadway. Inasmuch as considerable expense is invloved in properly washing aggregates, it is extremely poor economy to employ a method of hauling and handling that exposes the materials to the possibility of becoming mixed with foreign material.

There are four distinct types of equipment available for hauling concrete aggregate: 1-Horse-drawn wagons; 2-Motor trucks; 3-Steam or gas-tractor trains. For hauling in congested districts

and for city paving work, the team-drawn truck and the motor truck are suitable. Neither has an advantage over the other as regards keeping the aggregates clean. The mortar truck will prove more economical if the haul exceeds about two miles.

If the haul is over fairly good roads and exceeds one mile, the tractor train can be used economically. Its capacity is relatively small, and it is hampered by unfavorable conditions more than any other type of hauling equipment.

The industrial railroad is adapted to conditions where loading facilities are ample and where the haul exceeds about two miles. It is quite flexible as to capacity, is not hampered greatly by weather conditions and is probably the most economical method of hauling. Under suitable conditions materials can be transported by this method without danger of becoming dirty.

Aggregates can be most economically handled by unloading from the railway cars by means of the locomotive crane, the bucket elevator or the belt conveyor. Hauling is greatly facilitated when ample storage is provided of such a nature that the hauling equipment can be quickly loaded.

Available imformation regarding the cost of hauling and handling of materials is so incomplete and contradictory that it is impossible to submit a table of cost with the assurance that it will be accurate and of general application. The items which really enter into the cost of Hauling are: 1-Operating costs; 2-Maintenance of equipment; 3-Interest on investment in equipment; 4-Depreciation on equipment.

Water is another item of cost in constructing a concrete road. A system, however, should be devised which will insure an

abundance of water. A pipe line along the road is the most convenient means of distribution. If the water is piped for more than a mile the pipe should not be less than two inches in diameter; but in any case hydraulic computations can be made to determine the proper size. For ordinary purposes a two inch pipe seems adequate. The pump may be any suitable type designed to furnish not less than 250 gallons per minute. The power requirements will vary with the head, but the 5 or 6 HP gas engine is commonly employed, and is adequate except where the static head is excessive.

The materials for the road under investigation were shipped by railroad from Grand Rapids and hauled by wagon a distance of about two and one half miles to place where the supply piles were maintained. Evidently not enough care was taken to keep the material clean during transit for there are numerous holes in the finished road caused by the chipping out of particles coal, clay, sticks and other foreign matter.

SECTION V

Proportions of Materials and Consistency of Concrete.

Section 5.

Proportions of Materials and Consistency of Concrete.

The proper proportions of materials for concrete is a subject which has been discussed considerably, but in spite of the apparent necessity for using scientific methods, it is still common practice to proportion by the method of "arbitrary selection". Its general use has seemed to be justified by the facility with which the work can be handled under existing conditions. It is evident, however, that unless the character of the aggregates to be used and the quality of concrete made with the specified porportions of the concrete carefully determined, this method should not be used, for a 1:2:3 mixture in one case may be identical in quality with a 1:2:4 mixture, or even a 1;2½:5 mixture of another, on account of the variation in the size of aggregates.

The National Conference on Concrete Road Building reports that unsatisfactory concrete will result from the best aggregates if they are not properly proportioned and that therefore a careful investigation of aggregates may mean the difference between the success and failure of the road. The general adoption of a more scientific method of proportioning the materials is very much to be desired.

H. Eltinge Breed of the New York State Highway department recommends the following proportions based upon his observations of 201 miles of second class concrete pavement, 1:2½:5 mix, a type

no longer constructed ;and upon the actual construction of of 364 miles of concrete pavement ,1:1½:3 mix,built in the last four seasons:

One volume of cement to 4½ volumes of sand and broken stone or gravel,the porportions of the fine and coarse aggregate to be varied slightly to give the greatest density.

The National Conference on Concrete Road Building offers the following recommendations for porportioning materials for concrete:

One-Course Concrete. For a one course concrete pavement the materials should be mixed in the proportions of one sack of Portland cement,two cubic feet of fine aggregate,and three cubic feet of coarse aggregate; and a cubic yard of the resulting concrete in place should contain no fewer than six and eight tenths sacks of Portland cement.

Two -Course Concrete. For the base of a two-course pavement the material should be mixed in the proportion of one sack of Portland cement,two and one-half cubic feet of fine aggregate,and five cubic feet of coarse aggregate;and a cubic yard of the resulting concrete in place shoudd contain not fewer than five sacks of cement.

If the base is to consist of cement and fine aggregate, the materials should be mixed in the proportions of one sack of Portland cement to not more than four cubic feet of fine aggregate;and a cubic yard of the resulting concrete inplace should contain not fewer than eight and two tenths sacks of cement.

For the wearing course of a two-course pavement the materials should be mixed in the proportions of one sack of Portland cement to not more than two cubic feet of fine aggregate; and ard cubic yard of the resulting concrete in place should not contain not fewer than eleven and eight-tenths sacks of cement.

According to these specification,the proportions of the coarse aggregate used in the road under investigation was a little to large.This apparently will not affect the durability of the pavement,because tests made of samples of concrete made of these proportions showed sufficient strength when properly mixed,

SECTION VI

Mixing and Placing of Concrete.

Section 6.

Mixing and Placing of the Concrete.

Arguments against hand mixing need not be considered in road building, for it was long ago settled that the proper method of mixing concrete for big construction is by the machine. There are two kinds of mixers in use, namely the batch and the continuous mixers. The former is preferable because all materials can be accurately measured and can be mixed a predetermined length of time. Each batch therefore may be considered as uniform in composition with the preceding and succeeding batches.

One of the most important items in mixing is the amount of water to use. Good practice calls for concrete which will flow readily in order that it may be properly spread and consolidated. In attempting to attain this end it is easily possible to use more water than is desirable.

The National Conference on Concrete Road Building went on record as believing that with the average amount of moisture found in concrete materials the water to be used in roadmaking should not exceed six pounds per cubic foot of concrete [illegible], this meaning the cement, sand and stone used, measured loose. This is approximately one gallon of water for each cubic foot of concrete in place. Dry materials in hot weather require more water and rain soaked sand and stone require less water. The most needed reform in the mixing and placing of concrete for roads is less water than is generally used.

Time is the big factor in the placing of concrete and as a result the equipment used is of utmost importance. The use of horse carts in distributing concrete should be condemned and the use of wheelbarrows and hand carts discouraged, as the latter require more time to complete the work than is consistent with good practice.

The Engineering Record has made an attempt to gather some dats which would lead to improvement in the mixing and placing of concrete in roads. Numerous prominent engineers were consulted, but the views received were as numerous as the men questioned. The engineers questioned differed as to best types of distributers to use, namely the open-chute as against the boom-and-bucket.

The National Conference of Concrete Road Building agreed that they could see no reason for favoring one method above the other. They did agree, however, that buckets are used the preferable type is one that dumps by overturning. Many users reported that buckets discharging by the opening of flap doors in the bottom had to be watched so closely that stones would not lodge so as to prevent closing. Unless the bottom is closed completely there is serious leakage of thin rich material . The committee recommends the chute for distributing concrete and specifies that the pitch of the chutes should be steep enough to deliver concrete of a proper consistency readily.

An angle of 20 degrees is the minumum to be used as a pitch for the chutes and the maximum amount of water should be as stated above. It is better to increase the pitch than to increase the amount of water

Tests made at the plant of the T.L.Smith Company,mixer manufacturers,Milwaukee,Wis.,in the presence of a score of leading engineers caused the National Conference on Concrete Road Building to recommend the following points to be observed in mixing concrete for road work:

1-The mixer drum should revolve at a speed not exceeding sixteen revolutions per minute. It has been suggested that the speed of the drum be expressed in travel per minute per foot of circumference.

2-The minimum number of revolutions for each batch to be ten.

3-The minimum length of time for mixing each batch to be one minute.

The reason for fixing the minimum in the tests at one minute is that experiments indicate that the water does not work through a mass of concrete in less than one minute. This is a point which has not been mentioned to any extent in concrete experiments,but is of importance. A much smaller quanity of water can be used with long-time mixing than with short-time mixing,and the same degree of fluidity obtained.

A batch mixer was used in the construction of the concrete road under investigation. Only short chutes were necessary for the mixer was pushed along the road. Narrowness of the pavement made it possible to deposit the concrete almost directly from the mixer spout.

The specifications under which the road was built called for a minimum of eighteen turns which is well with in the limits

recommended by the National Concrete Road Builders Conference. Tests made of samples taken from the road, however, indicate that the the builders did not live up to this specifications. This will be taken up in a latter section of this thesis under the heading of Testing of Samples Taken from the Road.

SECTION VII

Reinforcements

Section 7.

Very little information is available on methods of reinforcing concrete pavements, since this type of pavement is a comparatively new form of construction. Little attention has been paid to reinforcements of concrete pavements in the past in spite of the fact that engineers long ago realized that the use of a reinforcement is the only sure preventive of cracks and most necessary to insure durability and wear.

Several types of reinforcements are on the market, of which the woven wire fabric seems to be the most popular. When this type is used the mesh should be laid directly upon the base immediately after the same has been finished to proper grade and it should be lightly tamped so that at least fifty percent of the wires are imbedded therein. The longitudinal wires should be so placed as to be parallel to the center line of the pavement (Note:-If the expansion joints are spaced not to exceed fifty feet, longitudinal wire may be placed at right angles to the center line of the street). All laps at the sides of the sheets should be at least one inch and all laps at the ends should be at least twelve inches. The reinforcement should cover the entire pavement area between expansion joints. If reinforcement is required because of unsatisfactory foundation, it should be placed in the base course at a distance of at least one inch above the bottom surface.

A coating of light rust will not be detrimental to satisfactory results, but care should be exercised that no excessive rust, paint or other coating are present to interfere with proper bond. Care should also be exercised to see that the reinforcement is so stored prior to use, that it is not coated with mud or clay when placed in

the pavement. Reinforcement left on the job when when the contract is completed should be collected and stored so that it will be protected from the elements. Occasional tensile and bending stress tests should be made to see that the requirements of the specifications are fulfilled.

No reinforcements were used in the road under investigation, and while the officials of the Michigan State Highway Department assert that that none are necessary, we believe that much better service could be expected from the road if reinforcements had been provided. The State Highway Department does not include reinforcements in any of specifications for concrete roads.

SECTION VIII

Joints and Joint Locations.

Section 8.

Joints and Joint Locations.

Engineers differ as to the proper placing of joints. The Michigan State Highway Department specifies that all concrete roads to receive state rewards shall have vertical transverse expansion joints across the entire width perpendicular to the center line where work is stopped for more than thirty minutes and that all joints shall extend through the entire thickness of the pavement and shall be perpendicular to the surface.

The National Conference on Concrete Road Building recommends that traverse joints be placed across the road perpendicular to the center line about fifty feet apart.

There seems to be a tendency to widen the distance between joints and to make them extend entirely through the pavement, as well as through the curb if integral curbs are used.

Longitudinal joint filler should be staked or otherwise securely held. Joint material should also be placed around the manholes, catch-basins, etc. The tendency of the present practice is toward omission of metal protection plates for joints, the need of protection plates being dependent somewhat upon the character of the aggregate used, and it is considered that they are more essential in street pavements than in country highways.

Plates for protected joints should be wired together with the joint filler in place and securely held in the installing bars. When short sections of joint filler are used they should

likewise be wired together. Supports for the joints should be used when pavements are of such width that the installing bar deflects. On wide roads every joint should be checked as to crown with sighting T's. As the joint plates do not usually fit tight to the installing bar, a quarter-inch shim is placed under each end of the installing bar, to insure that the plates are not covered by the concrete.

The road under investigation does not have many joints, due to the specifications under which it was built. The joints were placed only where the work was stopped for more than thirty minutes . The State Highway Department officials maintain that it is just about as cheap to fill in cracks with joint filler when they appear as it is to construct joints during the original construction. This method of placing joints appears to be in the nature of an experiment and the results will be awaited with interest by concrete road engineers.

SECTION IX

EXPANSION AND CONTRACTION.

Section 9

Expansion and Contraction.

Expansion and contraction of concrete is due to three causes;temperature changes,hardening and moisture changes. The rate of expansion and contraction under the former condition is fairly well established by laboratory tests which give an average value of about .000006 per degree F. The tests were made on well cured concrete.

It has been shown that in general concrete hardened in air will shrink markedly while concrete hardened under water or moist conditions will expand slightly. A.T.Goldbreck of the U.S. Office of Public Roads found that specimens allowed to dry out immediately after molding contracted .05 per cent in three months,and that wet specimens ,when allowed to dry out,contracted about the same amount as the air-hardened specimens. Assuming the usual coefficient of expansion,the contraction in hardening was about the same as that produced by a change of 90 degrees in temperature. Professor A.H.White.of the University of Michigan made similar tests which corroborated the results of Mr Goldbreck.

Experiments conducted at the Iowa Experiment Station,C.S. Nichols and C.B.McCollough give results of measurements of temperature effects,and effects of shrinkage due to hardening in concrete arches. They found that the shrinkage due to setting and hardening to be about .04 per cent in 100 days,in 1:2:4 concrete. They also found the actual rise and fall of the arch due to

temperature changes to correspond approximately to the calculated value based on a coefficient of expension of .000005 (Engineering and Contracting,November 12,1913.)

The British Concrete Institute finds that the coefficient of contraction due to hardening is from .02 per cent to .05 per cent for one month,and .04 per cent to .06 per cent for one and one half years ,the value depending upon the richness of the mix and the amount of water. The Cement and Engineering News for November,1913 states that a dry mixture of concrete shrinks less than a wet mixture,and concrete richer in cement more than lean mixtures.

The Engineering Record for January 3,1914 contains the results of tests made by Henry S.Spackman on concrete hardened in water for 14 weeks,the concrete containing about 10 per cent of hyrdated lime . The test showed that the effect of adding the lime to the cement appeared to reduce somewhat the shrinkage in setting which took place the first day or two. According to the Engineering News for March 11,experience on concrete roads in Maryland indicates that the use of 10 per cent of hydrated lime reduces the tendency to crack.

That a change in the moistute content of hardened concrete will cause expansion and contraction is corroborated by experiments hade by Goldbeck,already mentioned, and by other observations. The effect of a change in moisture content

on concrete of considerable age is not well determined.

The report on expansion and contraction of concrete roads from observations made by the Bureau of Standards in cooperation with the Association of American Portland Cement Manufacturers indicates that the expansion of concrete during December and March is due to the absorption of moisture, as there was no marked change in temperature; from March to May the expension was due to an increase in temperature assisted by further absorption of moisture during March.

Between May and August the contraction was due to loss of moisture, while the constant condition of the concrete during the interval from August to December, while the temperature falls 50 degrees Fahrenheit is explained by the absorption of moisture.

Form this information it is apparent that concrete laid in June does not behave the same as concrete laid in December, as it does not show the same magnitude of contraction at the early period nor equal movement at subsequent periods up to six months. There was no marked contraction during the period from July to September, apparently due to the fact that there was considerable rainfall to prevent the concrete from drying out.

Between September and October the contraction is probably due to a marked drop in temperature, and from October to December the concrete remains constant due to absorption of moisture although there is a drop in temperature.

The following conclusions have been drawn from the foregoing by the National Conference on Concrete Road Building:

That contraction and expension are caused by temperature changes and by by chanees in moisture conditions,and that under cilmatic conditions similar to those at Washington,D.C.,the effect from these two factors in concrete road surfaces are approximately of the same magnitude.

That in concrete roads,contraction and expansion are sufficient to cause frequent transverse cracks unless joints are provided.

That the actual movement in any particular case depends upon the character of the concrete and of the sub-grade. A sloppy concrete shows greater movement than concrete mixed only moderately wet. No more water should be used than necessary to permit of convenient placing and forming.

From the foregoing discussion we believe that the concrete road which we are investigating will not withstand contraction and expension as well as though it had been laid in June. The cilmatic conditions during the fall of 1916 when the road was constructed alternated between rainy to frosty. Expansion joints were only placed where the work was stopped for a period of thirty minutes or more. The contraction due to absorption of moisture with insufficient allowance for it in the joints has already caused numerous cracks both transverse and longitudinal. The appearance of cracks will be discussed in a latter section.

SECTION X

Finishing and Curing.

Section 10-

Finishing and Curing.

A concrete pavement which will successfully answer the requirements of modern traffic must have a hard dense surface which will wear uniformly. The surface must be true to grade and cross section, and free from waves, depressions and irregularities. Such a surface can be obtained only by using proper methods and appliances in striking off, finishing and curing the pavement.

The American Concrete Institute held at Chicago, February 8-10, 1917 give the following suggestions for proper finishing and curing a concrete road:

The surface of a concrete road should be screeded by means of a templet drawn with a short sawing action at a right angle to the axis of the road, The heavy screed should be used, and at the same time it should not be necessary to move this screed over the concrete surface more than once. Following this a "Smoother" should be used. This is frequently referred to as a float. The real intention is to smooth the surface so it will conform with the finished cross section. This smoothing tool should always be made of wood.

Sprinkling with hand pots should be started as soon as the concrete surface will stand it. Hand pots should be used because the pressure from a hose on the first sprinkling is usually to severe on the surface. This should be done from one to two

hours after the concrete is placed. In this connection it is very essential that the hand sprinkling should be done several times before sod or earth protection is placed over the surface, and then after it is placed the pavement should be sprinkled at least twice during the day and once at night. A heavy split float should be used for taking care of the joints, The use of a long-handled float, will enable the operator to always work in a normal position over the bridge. This will eliminate an additional man who is necessary when hand floats are used.

The finishing should always be within 10 to 15 feet of the screed, and this is impossible if the concrete is too wet. Some engineers advocate the brooming of a concrete road for the reason that the marks which the broom makes in the pavement aid in holding the moisture during the curing season. Care should be taken, however, to see that the broom marks are not to deep so as to start spalling and impede surface drainage.

The National Conference on Concrete Road Building advised that the protection and curing of concrete roads and pavements should be given careful attention in order that the maximum strength and wearing qualities may be obtained. They also maintain that the best concrete may be damaged by too rapid drying out of the surface in hot weather or by wind, by early exposure to low temperatures or by being opened to traffic at too early a period.

The Conference recommended that during hot or windy weather it will usually be found necessary to cover the surface of the finished pavement with canvas as soon after the floating as possible, and to keep this canvass sprinkled for several

hours. This will help to prevent the formation of shrinkage cracks.

When the concrete has had sufficient time to harden the canvass should be removed and the pavement covered with earth or other water retaining material. This covering should be at least two inches thick and should be kept throughly wet for a period of from ten to fourteen days.

Another method of curing which has been successfully used and at a cost considerably less than that of earth covering and sprinkling,is known as "ponding". The pavement is flooded so that the water stands about two inches deep over the crown at the shallowest point. If there are no curbs,light dikes or banks of clay or earth about 8 or 10 inches wide will retain the water.

In event that a storm occurs before all the concrete pavement is sufficiently hardened to prevent pitting,it becomes necessary to protect the surface. The use of canvass as previously described for curing in hot weather,taking care to lay the canvass strips so that the covering will shed the water readily ,is a satisfactory way to meet this condition.

It is advisable to omit the earth covering during the fall months in order that the warmth of the sun during the day may hasten the hardening of the concrete rather than expend its heat in drying out the wet earth cover. The pavement should be sprinkled if the temperature is high during the middle of the the day,but when there is danger of frost or freezing weather

at night,sprinkling should be omitted on work only a day or two old.

When there is danger of frost or light freezing,the pavement should be protected by means of a canvass. A canvass covering is much easier handled and placed than building or tar paper, and is much more efficient and economical. It should be removed the day after placing to give the pavement the full benefit of the heat from the sunshine. Should it be necessary the following night to cover the concrete again to protect it from freezing, at least three inches of straw,marsh hay,or other similar material should be used,covering the fresh concrete with canvas. Enough earth should be placed upon the straw to keep it from being blown away.

If the concrete is laid when the temperature is,or there is a probility that it will withing 24 hours drop to 35 degrees Fahrenheit or below,specifications usually contain a clause requiring the water and aggregates to be heated and precautions taken to protect the work from freezing for at least ten days.

Work done under such unfavorable conditions can not be expected ~~to done~~ for the same money as if placed during warm weather. It will be cheaper for the contractor to go to the slightly increased expense of heating water and aggregates rather than be compelled to remove and replace pavement damaged by freezing. In no case should concrete be deposited upon a frozen sub-grade.

The length of time necessary to keep the pavement clear

to traffic depends entirely upon weather conditions. During warm weather the pavement should be kept closed to traffic for at least fourteen days and preferably three weeks. When a concrete pavement has been laid in the late fall,it is sometimes necessary, owing to peculiar conditions to open the road to traffic before it is actually safe to do so. It is hard to determine in the fall just when it is safe to open a road to traffic. Under such conditions if about three inches of straw is placed upon the pavement and this covered with three inches of earth,the surface of the pavement will be protected sufficiently against abrasion to allow the opening of the road sooner than could be safely done without such protection. This will,however,not minimize the danger of damage by heavy loads. Many concrete roads have been utterly ruined by opening to traffic to soon.

The road which we are investigating was not protected from freezing except for a small section adjoining the city limits of Lansing which was laid during the month of November . The major portion of road was cured according to the essentials outlined in the above discussion and should therefore be commended in that respect. The portion adjoining the city limits,however, was opened to traffic to soon,those in charge evidently assuming that it was sufficiently hardened when in reality the hardness was due to being frozen. A warm spell in December thawed out the surface and soon numerous cracks appeared.An attempt was made to check the breaking up of the surface by covering it with

clay and closing the road to traffic. Later the road was again opened to traffic, but the vehicles were required to drive over the rough clay covering.

With the arrival of spring the road appears to have hardened, but the surface is badly cut up due to the cutting and abrasion of the traffic during the period it was used before having sufficiently hardened.

SECTION XI

Construction of Shoulders and Curbs.

Section 11

Construction of Shoulders and Curbs.

The design of shoulders and curbs depends largely upon the nature of the traffic to pass over the road, the availablity of suitable material for the shoulders and local conditions. The National Conference on Concrete Building divided the subject into four parts, namely: shoulders for one-track roads -grades not exceeding three or four percent; shoulders for two track-roads-grade not exceeding four percent; shoulders for one-track roads; grades of five percent and over; shoulders on two-track roads-grades of five per cent and over. Since single-track roads constructed of concrete are in the minority and are seldom built except for courts, alleys, etc., we will consider only the two-track design in this discussion. We will quote the recommendations of the Conference which is as follows:

Two-Track Road-Grades Not Exceeding Three or Four Per Cent: Where a two-track concrete road has been constructed, that is, one not less than sixteen feet wide, it will not be necessary to provide shoulders for traffic purposes, but rather for occasional turning out. In this case the shoulders may be constructed of earthen materials, excluding all vegetable or other matter likely to decay. The slope of the shoulders to the gutter should be continuous. Deep open ditches should not be constructed. The slope of the shoulders for two three feet out from the concrete should be

but slightly greater than that of the concrete,and then should increase gradually as the gutter is approached.

It is recommended that where practicable they should be sown with grass and thereafter kept mowed. This will effectually protect them from any cross wash and add much to the road side appearence . The shoulder slope and gutter slope should be made gradual so that a mowing machine may be utilized to cut the grass.

Two-Track Road on Grades of Five Per Cent and Over: The width of concrete for two-track roads should be not less than sixteen feet,and preferably eighteen feet. In cut, arrangements should be made to afford the road proper protection. It will be necessary to construct a macadam shoulder and in addition a paved gutter.

On fills the shoulders be provided with curbs if on a grade, and if the fill is over five or six feet deep,and can not be made w wide,vertical curbs are to be recommended. It is recommended that that the curbs be an integral part of the pavement,and that the whole section of the road,including the face of the curb,shall be struck with a single template. But if the road is to be greater than eighteen feet wide,then vertical curbs may be used which can be placed ahead of the construction of the pevement proper, and used as guides for striking the surface. Integral curb construction is recommended on pavements not over twenty feet wide.

The construction here recom ended,to do away with the shoulders and gutters on heavy grades in cuts and allow the whole roadway to take care of the storm water,suggests a type

of construction to be used on hills where the remainder of the road is of macadam or gravel, but where this form of construction on the hill would have excessive cost of maintenance and comparative high first cost of construction as well.

The shoulders on the road under investigation have not been fully developed, but the plans call for six feet of earth carefully packed. In their present condition they do not meet the needs of the traffic for turning out, for several accidents have already occured as a result of overturning in the soft built up shoulders. We recommend that the advice of the National Conference on Concrete Road Building be followed and that the shoulders be rolled, packed and sown with grass. If the funds were available macadam should be used on the shoulders. This would provide a means for vehicles to pass with out slowing down being in danger of over turning in the soft shoulders thus greatly eliminating danger of accidents.

SECTION XII

Form of Specifications.

Section 12.

Form of Specifications.

The form of specifications for concrete roads vary in different parts of the country. The National Conference on Concrete Road Building, however agreed upon a form which should meet with popular approval for they seem to cover all the essentials of good construction. In outlining this form of specifications, we will not discuss the items to be considered under each head for they have been already covered in the several sections of this thesis. The essential matters which should be incorporated in a form of specifications are proposals, contracts, and specifications for construction. The form follows:

I- Proposal

1-Instruction to bidders;2-Location;3-Estimate of quanities; 4-Certified checks;5-Beginning and completion of work;6-Plans and specifications;7-Extra work;8-Price sheet.

II-Contract.

9-Contract;

III-General Clauses.

10-Work to be done:Materials and tools;11-Notice of beginning and completion of work;12-Laws and ordinances;13-Protection of work during construction;14-Payments;15-Bond;16-Incompetent or disorderly workmen;17-Workmen's quarters;18-Duties of inspector; 19-Definitions,(a)Party of the first part;(b)Party of the second part,(c)Inspector;(d)Engineer;20-Plans are a part of the contract;

21-Engineer's grade stakes;22-Engineer as referee;23-Imperfect work or material;24-Changes in plans and quanities;25-Contractor's liability;26-Guarantee;27-Subletting contract;28-Preserving monuments and land marks;29-Instructions to superintendents;

IV-Specifications for One or Two Course Concrete Pavement.

30-Materials,(a)Cement,(b)Coarse aggregate for lower course,(c) Fine aggregate for lower course,(d)Aggregate for wearning course, (e)Water,(f)Bituminous filler for expension joints,(g) Bituminous material for surface coating,(h)Protection plates for expension joints,(i)Reinforcing metal,(j)Gravel or chips for bituminous surfacing;31-Machinery,(a)Concrete mixer,(b)Roller;32-Earthwork;33-Road-bed;34-Shoulders and side roads;35-Under drains and lateral drains; 36-Side forms;37-Thickness of concrete;38-Proportion of concrete; 39-Proportion of concrete for lower and upper courses; 40-Placing contraction and expension joints;41-Mixing and placing of concrete; 42-Placing concrete for lower course;43-Placing concrete for upper course;44-Finishing the surface;45-Beveled edges;46-Curing the concrete;47-Placing the macadam or gravel shoulders;48-Cleaning up;49-Preparing surface for bituminous coating;50-Spreading bituminous material;51-Dressing the surface;Placing reinforcing materials.

The specification under which the road under investigation was constructed are those of the Michigan State Highway Department and as far as form is concerned are near enough to that outlined above to be considered good practice.

SECTION XIII

Tests of Samples Taken From Road.

Section 13.

Tests of Samples Taken From Road.

The National Conference on Concrete Road Building specifies that sixteen turns of the mixer be required for road work and that ten turns be set as the minimum. The report of the conference gives data and results of tests made at the Structural Materials Research Laboratory, Lewis Institute, Chicago which shows that the average compressive strength of concrete fit for road work should be as follows:

Compressive Strength lb.per sq.in. 1 mo.	2 mo.	Remarks.
3380	4920	(Consistency pronounced ideal for road work. Slope of chute 25 degrees)
4120	5160	(Consistency pronounced ideal for road work. Slope of chute 20 degrees)
3280	4290	(Consistency pronounced ideal for road work. Slope of chute 15 degrees).

The above data would indicate that concrete placed through a chute inclined 20 degrees and using 16 turns of the mixer produces the best concrete as shown by compressive tests. As heavy loads are the greatest sources of ruin and wear, attention should be paid to producing concrete which will withstand heavy compressive loads.

In investigating the Michigan Avenue road we took samples of concrete for 5,8,11,14,18,20,24 turns of the mixer and also for road run. The slope of the mixer was approximately 20 degrees. The samples were tested in the laboratories of the Michigan

Agricultural College and the University of Michigan. For road run we found the average compressive strength to be 1,401.5 pounds per square inch.which is about one fourth that given in the Lewis Institute tests. For eighteen turns of the mixer,the average compressive strength was 4,483 pounds per square inch which is still less than the strengths given of concrete for roads at the Lewis Institute,

The specifications under which the road was built called for eighteen turns of the mixer and the falling off the compressive strength of the road run from that of the eighteen turn specimens indicates that the concrete was not sufficiently mixed. The road run,however,has sufficient compressive strength to withstand ordinary usage. The results of the tests follow:

No.of Revolutions.	Total Load. In.pounds.	Average. lb.per sq.in.	Mix.
5	25,000 20,440	631.2	1:2:3½
8	27,680 42,830	984.5 0	1:2:3½
11	100,000 115,000	2,986.5	1:2:3½
14	120,000 168,180	4,002.0	1:2:3½
18	162,260 167,860	4,581.5	1:2:3½
20	182,190 193,770	4,2175	1:2:3½
24	197,630 199,810	4,520	1:2:3½

The tests of road run concrete showed the following compressive strength.

Specimen No.	Total Load lb. pounds.	Strength lb.per sq.in.	Average lb.per sq.in	Mix.
19	53250	1480		
20	57420	1590		
21	41860	1164		
22	34750	965		
23	57290	1590		
24	58320	1620	1,401.5	1:2:3½

(Note-Tests were made on six inch cubes).

SECTION XIV

Classification of Cracks and Causes of Each.

Section 14.

Classification of Cracks and Causes of Each.

In previous sections of this thesis we have discussed causes for cracking of concrete road beds, namely improperly prepared sub-grade, expansion and contraction, etc. The Michigan State Highway Department made a survey of the Michigan Avenue road, which we are investigating, during the fall of 1916 and found a total of 12 longitudinal cracks, no diagonal cracks and no traverse cracks, and four small holes, making a total of 16. The number of defective slabs was ten.

During the spring of 1917 we surveyed the road and found 26 longitudinal, 7 transverse cracks, 5 diagonal cracks, and 118 small holes making a total of 149. The number of defective slabs was 43. The total length of the road is one and one-eight miles with a total of 54 slabs varying in length from 35 to 200 feet. The increase in holes and cracks from December 1916 to May 1917 totaled 137.

This big increase is due no doubt to the use of the old macadam road as a sub-grade and the effects of the first winterin which always causes more cracking than suceeding years as explained in the section on expension and contraction and on preparation of subgrade.

SECTION XV

Cost of Laying Concrete Roads.

Section 15

Cost of Laying Concrete Roads.

Methods of computing costs of constructing concrete roads vary. Some engineers compute the cost upon a cubic yard basis, while others use the square yard as the basis of comparison. The cubic yard system has the disadvantage of preventing ready comparison with the costs of other types, but possesses other advantages which counter balance the disadvantage. The square-yard basis, on the other hand, is not definite, for it neglects the thickness of pavement, making comparison between two concrete slabs of different thickness difficult. The cubic-yard method of reporting gives repeated checks on the amount of stone and aggregate used and on the thickness of pavement itself.

The average cost per square yard of constructing concrete roads, reported to the Association of American Portland Cement Manufacturers, 1913 to 1915 by inspectors of the association follow:

	1913	1915		1913	1915
Connecticut	$1.32	$1.13	Missouri	$1.17	$1.09
Illinois	1.01	1.03	New Jersey	1.12	1.23
Indiana	1.23	0.98	New York	----	0.98
Iowa	1.11	1.19	Ohio	1.22	1.09
Kansas	1.08	1.28	Pennsylvania	1.16	1.01
Maryland	1.21	1.08	Texas	----	1.15

	1913	1915		1913	1915
Massachusetts	$1.29	$0.95	West Virginia	$1.32	$1.03
Michigan	1.27	1.10	Wisconsin	1.06	1.02
Minnesota	1.05	1.11			

The cost of the materials used together with the labor and miscelaneous expenses for the Michigan Avenue road which we investigated was as follows:

1-Gravel	$3,030.28
2-Cement	6,261.52
3-Labor	12,402.38
4-Miscelaneous	3,426.59
Total	$25,131.82

*Dividing the total cost by(1⅛ x 5,280 x 18÷ 9) we found the cost per square yard to be $2.12

*Length of road-1 1/8 miles. One mile-5,280 feet.
Width of concrete-18 feet. One square yard-9 square feet.

The above data shows that the Michigan Avenue road cost nearly twice as much per square yard as the average cost per square yard from 1913 to 1915 in Michigan and other states. This increase is due largely to the increased cost of labor and materials, but it is more than probable that the same road could have been constructed much more cheaply by private interests on a contract basis. The percentage basis works out much more satisfactory on private contracts than on state or institutional work. In making this statement we are making no reflections on the Michigan State Highway Department officials, for we believe that they constructed the road to the best of their ability under the present conditions. There is no doubt in our minds, however, that a corporation or individual could build the same road for a much smaller figure.

CONCLUSION.

Conclusion.

The construction of the Michigan Avenue Road attracted the attention of road builders in all parts of Michigan, because it was the first concrete pavement built under the supervision of the Michigan State Highway Department in Ingham county, the seat of the state capital and the Highway Department offices. The fact that the Highway Department officials had ready access to the road being within what might be termed a stones throw of the construction and could make frequent inspections, sometimes as often as a dozen times a day if necessary, caused road builders to believe that the road would be model of construction and a sample to be pointed to with pride and satisfaction and that at least one road in Michigan had been properly constructed.

The result, however, has been rather disappointing for the road in several respects does not meet the requirements laid down by what is considered good practice, as has been explained in previous sections of this thesis. This can not be attributed to negligence on the part of the Highway Department officials, for we believe that they did the best they could under exisiting conditions. The fault lies, we believe, in the system used, the road having been constructed on the force system by private suscription, backed by county and state funds. If there had been centralization of authority and responsibility, the several items in the specifications would have been more closely carried out. Lack of conformity of the State Highway Specifications with specifications

laid down by good practice is no doubt partially to blame for the criticism which we are making on the road.

To summarize we believe:That the drainage is inadequate and that the old macadam was not scarified deeply enough;That the thickness of the road pavement is O.K.;That the width is two feet less than is recommended by good practice; That the crown and grade are O.K.;That the aggregate used is O.K. and agrees with the recommendations of good practice;That in the handling and hauling of materials not enough care was taken to keep the materials clean;That the proportions of cement,and fine aggregate were O.K.,but that the proportion of coarse material was a little to large;That the concrete was not mixed enough before placing;That some form of reinforcement should have been used;That the method of spacing joints is open to criticism;That the road will not withstand expansion and contraction without serious cracking due to the season of the year in which it was built and the failure to properly scarify the old macadam;That the portion of the road adjoining the city limits was opened to traffice to soon thereby causing a breaking up of the surface;That the shoulders should be developed further as outlined in section 11;That the form of specification used was adequate;That the road will not stand up as well under heavy loads as others of the same type because of the poor results attained in tests of samples taken from road run concrete; That the number of cracks in the road indicates that the surface will be in bad shape in a short term of years and that

careful attention must be given the road in order that the cracks may be repaired as fast as they appear to prevent a general breaking up of the surface; that the cost of the road was excessive being nearly twice as much as roads of similar nature constructed in other parts of Michigan and in other states.