THE DESIGN OF A CAMPUS ROAD

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

Henry D. Knapp

1947

THE DESIGN OF A CAMPUS ROAD

A Thesis Submitted to

The Facultity of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

By

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PREFACE

A Campus road is here designed to aid in the solution of the traffic problem and the shortage of parking area which has been created by the increased enrollment at Michigan State College.

The proposed road will decrease the congestion at the intersection of Kalamazoo and Harrison, provide married students, that are living in the apartment area, with better access to student parking lots; and aid in routing traffic around the Stadium and Field House during major athletic events.

Included in the design of the road is the removal of the hill just south of Demonstration Hall. This will provide fill dirt for the low area now occupied by the cavalry stables. The removal of the cavalry stables and leveling off of this area will provide greatly needed building or parking area.

The pine grove that covers the hill has long past the stage of being an experimental wood lot. Also it is no longer needed as a wind braker to stop blowing sand.

The Author has received helpfull suggestions during the designing and preparation of this thesis from Professor C. L. Allen and members of the Civil Engineering faculty of Michigan State College, T. B. Simons and members of the Buildings and Utilities Engineering Division, H. W. Lautner and members of the Landscape Archetecture Division, and D. W. Putman, Project Engineer, Michigan State Highway Department, for which thanks are hereby expressed.

SLAB DESIGN

The first consideration in the design of a concrete slab is the load which it is to carry. In the absence of a local traffic survey it will be assumed that the volume and character of traffic that the pavement will carry places it in the class of a Lightly Traveled Primary Route. Plate #1 shows the traffic volume and number and size of wheel loads characteristic of the class of road. The stress set up by these moving wheel loads are computed by the mathematical analysis developed by Dr. H. M. Westergaard.

$$S = \frac{3.36\,P}{d^2}\left[1 - \frac{\sqrt{\frac{a}{l}}}{0.925 + 0.22\,\frac{a}{l}}\right]$$

S = Maximum tensile stress in p.s.i. at the top of the slab in a direction parallel to the bisector of the corner angle, due to a wheel load of P lbs.

P = Wheel load in lb. placed on the slab corner. P is the static wheel load increased by a factor to pro- adequate allowance for the impact of moving loads.

TYPICAL TRAFFIC VOLUMES AND WHEEL LOAD DISTRIBUTION FOR LIGHTLY TRAVELED PRIMARY ROUTE

Average daily traffic					
	Automobiles		Commerical vehicles		
All vehicles	Number	Percent of total vehicles	Number	Percent of total vehicles	Number of Axles
1,310	1,090	83.2	220	16.8	469.2

Distribution of wheel loads on commerical vehicles Number of wheel loads per day and per cent of total commerical wheel loads.

Less than 4000 lb.	4,000 to 5,000 lb.	5,000 to 6,000 lb.	6,000 to 7,000 lb.	7,000 to 8,000 lb.	8,000 to 9,000 lb.	9,000 to 10000 lb.
No. 395	No. 25	No. 25	No. 12	No. 8	No. 3	No. 1.2
o/o 84.18	o/o 5.33	o/o 5.33	o/o 2.56	o/o 1.70	o/o .64	o/o .26

PLATE #1

d = Thickness in inches of a concrete slab at a corner (uniform thickness or equivalent thickness of a thickened edge slab).

a = radius in inches of the circular area equivalent to the contact of the tire with the pavement.

ℓ = radius of relative stiffness defined by the equation.

$$\ell = \sqrt[4]{\frac{Ed^2}{12(1-u^2)k}}$$

E = Modulus of elasticity of the concrete

u = Poisson's ratio for the concrete

k = Modulus of subgrade reaction in lb. per sq. inch per inch.

The stress given by the formula are for loads on the corners of the slabs. Stress due to loads in the interior of the slab or on the slab edge at some distance from the corner are not considered. Research and past experience has proven that the critical point in a pavement slab is the corner.

Slab thickness computations have been based on the assumption that the req uired life of the pavement is 30 years. Laboratory and field studies by the Michigan State Highway Department indicates that the value of subgrade reaction (k) for subbases in Michigan of sandy nature is 100 p.s.i. per inch. This value of (k) is used to find Westergaard's radius of relative stiffness

Concrete like other structural materials is effected more by repeated loads then by a single load of the same magitude. Application of the fatigue principle to pavements design is based on the facts that when a repeated stress does not exceed 50 per cent of the ultimate strength (safety factor not less than 2) the concrete will stand an unlimited number of stress repetitions without failure; when repeated stress is less than 50 per cent (safety factor greater than 2) the repetitions of stress is not harmful; when the repeated stress exceeds 50 per cent (safety factor less than 2) continued repetition of stress will cause failure.

Plate #2 shows the fatigue behavior of concrete in flexure. The relationship between the safety factor and the number of stress repetitions required to induce failure represents the best data available.

The computations are tabulated in plate #3 to facilitate analysis of design. The wheel load groups taken from table #1 are tabulated in column (1). A 20 per cent allowance for impact is added to the maximum load in each group to give the loads actually used in this design and record in column (2). The anticipated number of vehicles per 24 hour period from plate (1)

FATIGUE OF CONCRETE

Number of stress repetitions to induce failure	Safety Factor
0	0.00
5,000	1.43
10,000	1.53
15,000	1.59
20,000	1.64
25,000	1.68
30,000	1.72
35,000	1.76
40,000	1.79
45,000	1.82
50,000	1.84
55,000	1.87
60,000	1.89
65,000	1.90
70,000	1.92
75,000	1.93
80,000	1.95
85,000	1.96
90,000	1.97
95,000	1.98
100,000	1.99

Plate #2

are going both directions. This total is divided by two to get wheel loads in one direction and recorded in column (3). The values in column (3) are multiplied by 10,950 days (30 year design period) to get the total number of anticipated load repetitions for each load group and the results are tabulated in column (4).

The accumulated number of wheel load repetitions for each load plus all heavier loads for the 30 year period are computed. The procedure is carried on until the accumulated number of wheel loads exceeds 100,000. Beyond this point a pavement will be adequate for an unlimited number of repetition of all lighter wheel loads. This is recorded in column (5). From plate #2 determine and inter in in column (6) the safety factor required for each accumulated total of load repetitions. The maximum wheel load, plus 20 per cent impact is multiplied by the anticipated load repetition for the 30 year period and recorded in column (7). Compute the allowable stress corresponding to each safety factor and wheel load by dividing the modulus of repture (700 p.s.i.) by the safety factor and record in column (8). Determine by the design formula the required thickness for each wheel load and record in column (9).

The pavement must be designed so that it is not

PAVEMENT DESIGN FOR LIGHTLY TRAVELED PRIMARY ROUTE

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Wheel load, lb.		Load repetitions							Analysis of design selected value of "d" 7.00 in.			
By groups static	Maximum for group plus 20 percent impact	No. per day one direction	Anticipated for 30-year peroid	Cumulated for each load plus heavier loads	required safety factor	Col. 2 Col. 4 for wheel loads having safety factor less than 2	Allowable stress 650 / S.F. P.S.I.	Required value of "d" inches	Actual stress p.s.i.	Actual safety factor 650 / Col 10	Actual allowable load repetition	Per cent fatigue resistance consumed by each load
Under 4,000	4,800	198	2,168, 100	....	2.00	....	325	......	.....	......	unlimited	....
4,000-5,000	6,000	13	142,350	....	2.00	....	325	......	.....	......	unlimited	....
5,000-6,000	7,200	13	142, 350	....	2.00	....	325	......	.....	......	unlimited	....
6,000-7,000	8,400	6	65,700	132,495	2.00	....	325	......	.....	......	unlimited	....
7,000-8,000	9,600	4.0	43,800	66,795	1.91	420,480,000	340	6.85	325	2.00	unlimited	....
8,000-9,000	10,800	1.5	16,425	22,995	1.67	177,390,000	389	6.67	360	1.80	42,000	39.1
9,000-10,000	12,000	0.6	6,570	6,570	1.47	78,840,000	442	6.50	390	1.87	23,000	28.6
Subtotal col 4, 7 and 13 (for wheel loads having S. F. less than 2	....	......	66,795	....	......	676,710,000	.....	......	....	....	....	67.7
Weighted average of wheel loads having S.F.less than 2	10,100	......	66,795	....	1.91	....	340	7.00	......	......	....	....

PLATE #3

only adequate for each wheel load group but also for the combined effect of all wheel load groups. The weight average of all these wheel load groups having a required safety factor of less than 2 is taken and treated as another group having the number of repetitions equal to the total number of repetitions of all the loads included in the weighted average. The weighted average wheel load is the total of column (7) divided by the total of column (4). This value is entered in column (2) and the corresponding number of load repetition is entered in column (4). The required safety factor for this accumulated total of load repetitions is taken from plate #2 and recorded in column (6). The allowable stress is computed and the corresponding value of "d" is recorded. It is now possible to select a design to meet these requirements. It is seen that the grestest required value of "d" is 7.00 inches.

The uniform as well as the thickened edge cross section have been considered here. Athough a pavement of uniform thickness slightly increases the concrete quantities it does not necessarily increase the cost, because subgrade preparation can be accomplished better and cheaper and it simplifies joint design and construcion. In this design it was decided to use a uniform thickness cross-section with "d" equal to 7 inches.

A check is made on the final design by recording in column (10) the actual stresses corresponding to each wheel load for the value of "d"= 7.00". The safety factors are computed and entered in column (11). Read from plate #2 the actual allowable number of stress repetitions for each safety factor and record in column (12).

From the actual allowable wheel load repetitions in column (12) and the anticipated wheel load repetitions in column (4) the percentage of the total fatigue resistance is determined and recorded in column (13). The limit of fatigue resistance used by the wheel losds is 100 per cent. The 7.00" uniform cross-section is satisfactory since not all of its fatigue resistance is used up by the anticipated loads.

CROWN

The crown of the 30 foot pavement is 1 5/8 inch. This is the crown specified by the Michigan State Highway department for this type road. Concrete being of higher type surfacing requires very little slope to assure water run off. The crown is based on the modified parabolic curve.

JOINTS

Joints are used in concrete pavement to reduce stresses caused by changes in temperature and moisture content which cause changes in volume of the concrete. These changes in volume cause compression, tension and flexure in the slab. Expansion joints, contraction joints, and hinged joints are installed in pavement to keep those stresses to a minimum.

The question of joint spacing in concrete pavements is very debatiable. The spacing of expansion joints is dependent on the allowable compressive stress in the concrete and on the maximum compressive stress created by the expansion of the slab. It was assumed in the calculations for slab thickness that no forces are acting at the ends of slabs where the reinforcement is broken. This requires an expansion joint at every break in the reinforcement. This is impractical, however, and unnecessary because concrete is strong in compression. The average compressive strength of pavement concrete in Michigan is between 4,000 and 6,000 pounds per square inch. Suppose a pavement was laid during a temperature of 40°F. and the following summer reached a temperature of 140°F. If the pavement is fully restrained the maximum possible unit compressive stress would be 2,500 pounds per square inch computed by the following equation:

$$Sc = Eet$$

Sc = unit compressive stress in pounds per square inch

E = Modulus of elasticity assumed as (5,000,000 p.s.i.)

e = coefficient of expansion assumed as (.000005)

T = Temperature differential ($100^{\circ}F$)

It is obvious that expansion joints could be omitted in construction during the summer months without cause of any harmful effects, where as, during the colder months it would be desirable to place them at intervals of not more than 400 feet.

Expansion joints may by necessary to relieve undesirable horizontal pressures at bridge structures or at critical joints such as short horizontal and vertical curves and intersections.

It is recommended by the Michigan State Highway Department that a narrow expansion joint of 1 inch be used between 400 foot slab sections.during cold weather construction. This practice will be accepted as it will eliminate the undesirable features associated with contraction joints.

Contraction joints are installed in the pavement for the purpose of controlling cracking. Since the reinforcement must be broken at contraction joints, the joint is free to open. This presents a difinite mainteance problem, especially when they open more than 1/4 inch. The longer the slabs are constructed the wider the joints will open. Contraction joints are to be constructed every 100 feet. This gives an expansion or contraction joint at every 100 feet to create continuous reinforced 100 foot slab sections.

A tie joint is installed down the center line of the pavement to control longitudinal cracking.

JOINT FILLER

Since the primary purpose of the joint filler is to prevent infiltration of foreign matter when the slabs are contracting and to support the joint slabing compound at the top, the material best fitting the requirements is pre-compressed wood. The wood boards are precompressed in the dry state to approximately 70 per cent of their original thickness and are inserted in the pavement while still in this condition.

The Joint Sealer should be as soft as can be used without flowing from the joint in warm weather. Non-bituminous materials or combinations of bituminous and non-bituminous materials make the better sealers. An asphalte rubber compound used here offers the most satisfactory results.

REINFORCEMENTS

Steel reinforcement is generally employed in concrete pavements to control cracking, tie bars in longitudinal center joints, and slip dowels in transverse expansion and contraction joints. It in no way increases the resistance of an unbroken slab to flexural stress or adds to its strength. Its sole purpose is to hold together the fractured slabs after cracks formed so as to aid in load transmission and to prevent cracks from openning wide. Since steel does not perform its function until the concrete has cracked it is necessary to use enough steel to take all tension.

Tension in the steel members across any crack is equal to the force required to over come friction between pavement and sub-grade from the crack to the nearest free joint or edge. Steel bar mat is therefore designed to be adequate for a crack in the middle of a slab. Although the amount of steel may be reduced toward the ends of the slab the same weight is usually used through out the slab.

The area of steel required for 1 ft. width of slab is computed from the formula:

$$A = \frac{LfW}{2S}$$

A = Area of steel, running in the direction in which L is measured, in sq. in.

L = The distance in Ft. between free transverse joints when the equation is used to calculate longitudual steel of between free longitudual joints or edges when figuring transversal steel.

W = The weight in lb. of 1 sq. ft. of slab

f = The coefficient of friction between slab and subgrade

S = Allowable working stress in the steel in p.s.i.

The standard 1/4" bar mat will be used as it will meet these requirements.

Experience indicates that small bars or mesh are more effective than the same area of larger bars, because they can be distributed more uniformly in the slab. The position of the steel in the slab is not important except that it should be far enough from either surface to be adequately protected from corrosion.

Tie bars are used across longitudinal joints to insure firm contact between slab forces and to insure adequate load transfer. They are also used across longitudinal joints in order to prevent separation of the slabs at fills and curves.

The tension on the tie bars is equal to the weight of the slab between the joint to be tied and the free longitudinal joints or edges multiplied by the subgrade friction.

Expressed as a formula:

$$A = \frac{L\,b\,W\,f}{S}$$

A = total cross-section area of steel in all the tie bars across L ft. of longitudinal joint.

L = length of longitudinal joint in ft.

S = tension in the steel in p.s.i.

b = distance between the tied joint and the nearest free joint or edge

W = the weight of the pavement in p.s.i.

f = coefficient of friction between pavement and subgrade

$$A = \frac{100 \cdot 13 \cdot 84 \cdot 1.5}{2500} = 6.53$$

Using 40 tie bars in the 100ft of joint at maximum spacing of 30 inches. Each tie bar must have a cross section area of 6.53/40 = 0.163 sq. in. (1/2" bar dia. equals 0.196).

Tie bars are embedded far enough in each slab to develop the necessary bond. The maximum working stress for bond in deformed bars is taken as 200 p.s.i. Each bar will cary a total tension of

$$S = \frac{100 \times 13 \times 84 \times 1.5}{40} = 4450\#$$

and will need

$$\frac{4450}{200} = 22.25 \text{ sq. in. of area on each}$$

half of the bar to provide sufficient bond. As the circumference of a ½ inn. round bar is 1.5708 in., each half bar will need to be at least $\frac{22.25}{1.5708} = 14.3$ in. long. 40 tie bars 1/2" x 30" long will be used in the 100 ft. of longitudinal joint.

In view of the fact that there is insufficient factual data available upon which one can conclusively base design as to the proper size, type and spacing for dowel bars, it will be assumed that practice and experience is to be the deciding factor in selection of a suitable load transfer unit. The recommended 1" x 15" dowel at 12" centers with metal sleeves will be used. Usually the dowel nearest the pavement edge is placed 6" from the edge. This permits 12 dowels per 13 foot slabs.

WIDTH

The width of pavement used is 30 feet. This width of pavement is not only in keeping with the width of other campus roads but will allow two ordinary private passenger vehicles to pass each other safely with vehicles parked parallel along one curb. The actual width of roadway available is only 29 feet (see road cross-section illustration Plate #5). Michigan laws limit the gross width of vehicles to 8 feet. This leaves 21 feet for moving traffic.

STORM SEWER DESIGN

Preliminary to the design of a storm sewer system the amount of sewage that it must carry requires consideration. The rational method is used in analysis of the various factors effecting the amount of rainfall runoff. This method is expressed in the following equation:

$$Q = AIR$$

Q = the runoff in cubic feet per second

A = the area of the section to be served in acres.

I = the coefficient of runoff of the area

R = the rainfall rate in inches per hour.

The area of the section to be served can be measured from the map. The runoff coefficient is very largely dependent upon the per cent imperviousness of the area from which the runoff is derived. The percent of imperviousness for the whole area is derived after estimating or ascertaining the proportions of the various surfaces of the whole area. In this case very little water will be running on the pavement from the shoulders due to its construction. Therefore the greater part of the area in concern is the pavement itself.

Two considerations will inter into the rainfall intensity to be used. One being the time of rainfall duration and the other the expected rainfall intensity. Sufficient data can be obtained from prepared rainfall intensity curves and formulas to avoid guessing as to the expected intensities.

The combination curb and gutters illustrated in Plate #5 is used to carry off the surface water. Catch basins collect the surface water from the gutters at about every 500 feet along the roadway.

In the design of the pipe to take care of the water that has entered the catch basins the following assumptions were made:

1. The minimum size sewer to be used is 8 inches.
2. n is 0.013
3. the minimum allowable velocity is 2.5 ft. per second.
4. The minimum cover over the crown of the sewer is 5 feet.

5. Area to be served by each catch basin is 0.034 acres.

6. The time of concretration is 11 seconds.

7. The imperviousness is 50 per cent

8. The rainfall formula adopted is:

$$R = \frac{106}{t+27}$$

Substituting the time of concentration for

t, $R = \frac{106}{11+27} = 3.92$ inches per hour.

These quantities are substituted in the

formula: $Q = AIR$

$Q = .032\ (.50)\ 3.92 = .0666$ cu. ft per. sec.

The quantity of flow originating in the road area does not warrent laying a new sewer line. The existing storm sewers as shown on the plan will be used to carry off water collected in the catch basins. A 21" line crosses the pavement at station 6 + 40 and empties into 24" line in about 500 feet. The 24" line empties into the Red Cedar River back of the Jenison Field House. This line can easily take care of the additional load of 0.266 cu. ft. per second that it collects as it passes under the roadway. The 12" line that drains the tennis courts and empties into a 15" line that empties into the River will be used to drain the pavement from 6+40 to 15+35. This area of road way will produce a flow of 0.38 cu. ft. per second. The pavement Southwest of Demenstration Hall will drain its runoff into the 24" line running to the River.

DESIGN OF CONCRETE MIX

The design of concrete mixtures is based principally upon the net quantity of mixing water used per sack of air-intrained cement. The selection of a water-cement ratio involves a consideration of both the degree of exposure to which the pavement is to be subjected and the strength requirements of the pavement. In determining the proportions of A. E. cement, water, and aggregate it is desirable to arrive at those proportions which will give the most economical results. The relative proportions of fine and coarse aggregates and the total amount of aggregate that can be used with fixed amounts of A. E. cement and water will depend not only on the consistency of the concrete required but also on the grading of each aggregate. A modification of the Mortor Void Method for the design of air-entraining concrete mixes has been used by the Michigan State Highway Department since 1940. Their specifications and classifications are here used in design of a Grade "A" pavement concrete mix with a cement content of 5.5 sacks per cubic yard.

The materials to be used are:

Cement-----------A. E.

Fine aggregate ---------2NS

Coarse aggregate ------4A

Coarse aggregate ------10A

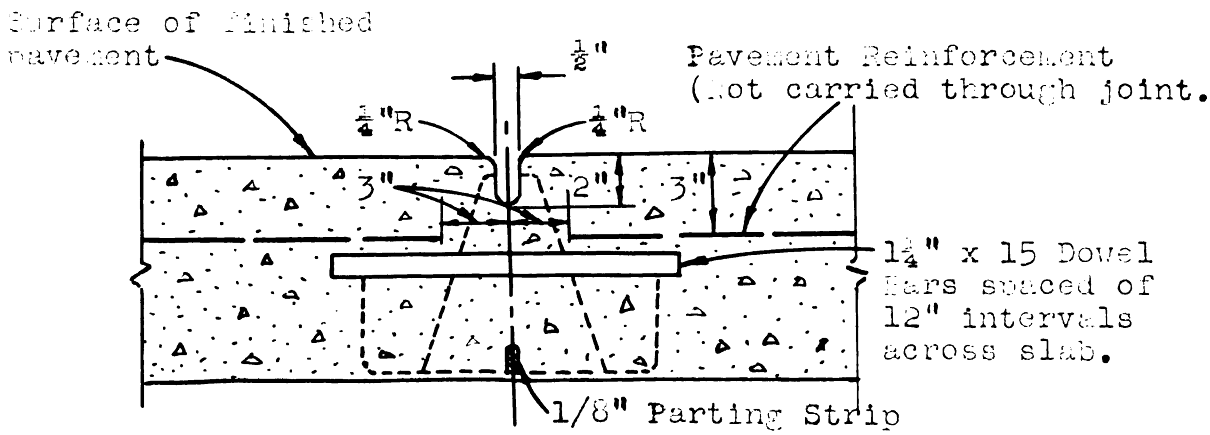
In a 1-bag batch there will be 1 cubic foot of cement, 1.87 cubic foot of sand, 3.83 cubic feet of coarse aggregate (combined 4A and 10A using half and half of each) and 0.8 cubic foot of water.

ROAD LOCATION

The preliminary survey was made with transit and tape, the angles and distances being carefully measured and recorded. The Topography was fully noted together with any details that would effect the final road location.

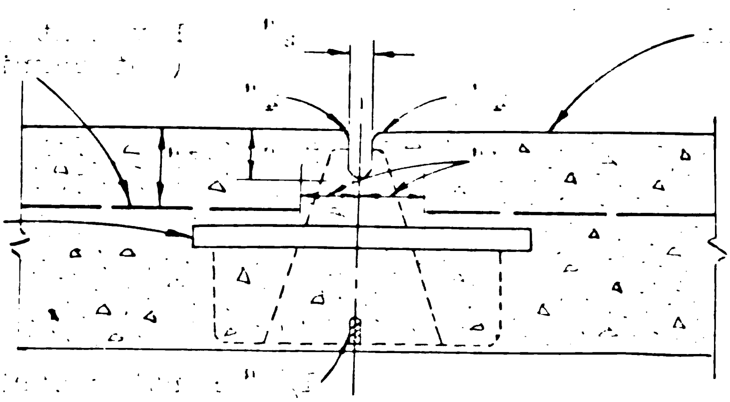
The data from the preliminary survey was plotted to scale and the road location determined. Center line stations were established at 100 feet stations and cross sections taken at each station, or fraction there of, if ground elevation meet an abrupt change. The center line profile data was plotted on profile paper and the road grades determined.

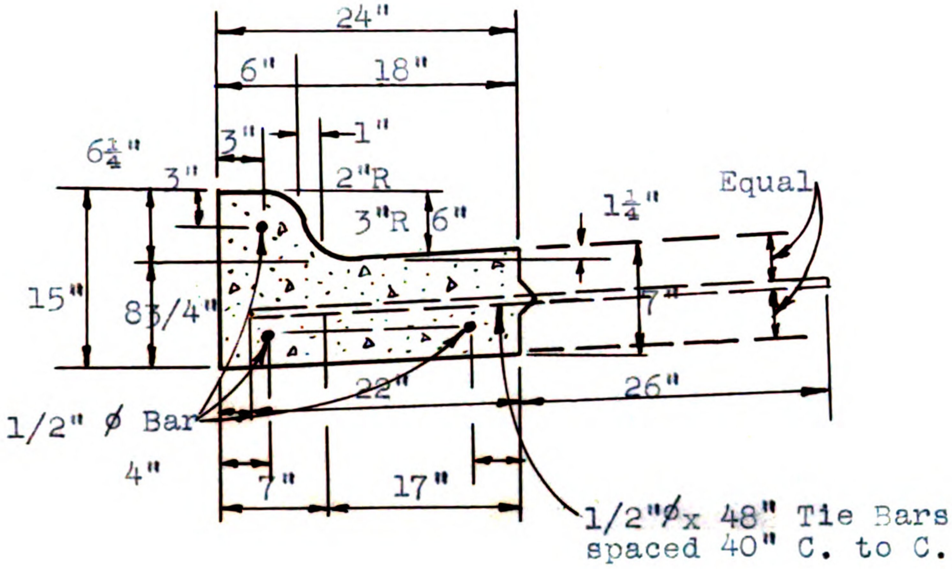
TRANSVERSE CONTRACTION JOINT



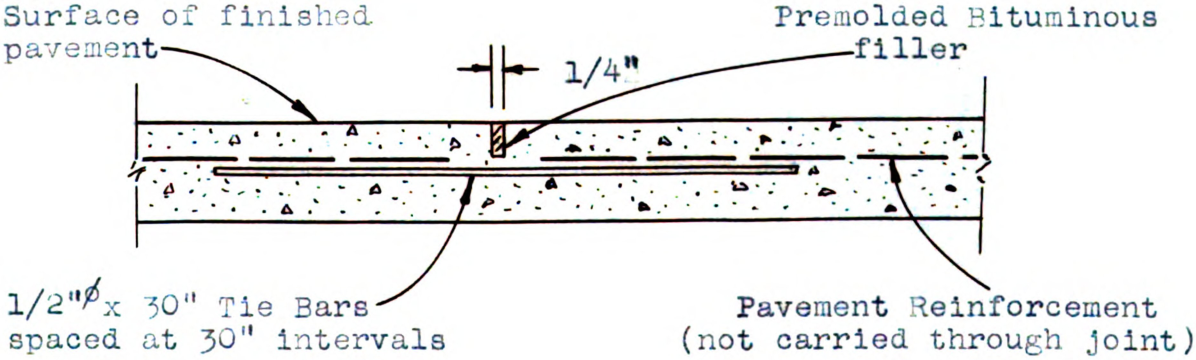
The joint forming strip on the load transfer device shall be removed and the joint formed while the concrete is still fresh and shall be true to position and line.

The joint shall be filled with hot poured, Rubber Type compound. The compond shall be poured so as to completely fill and seal the joint without overflowing the pavement.

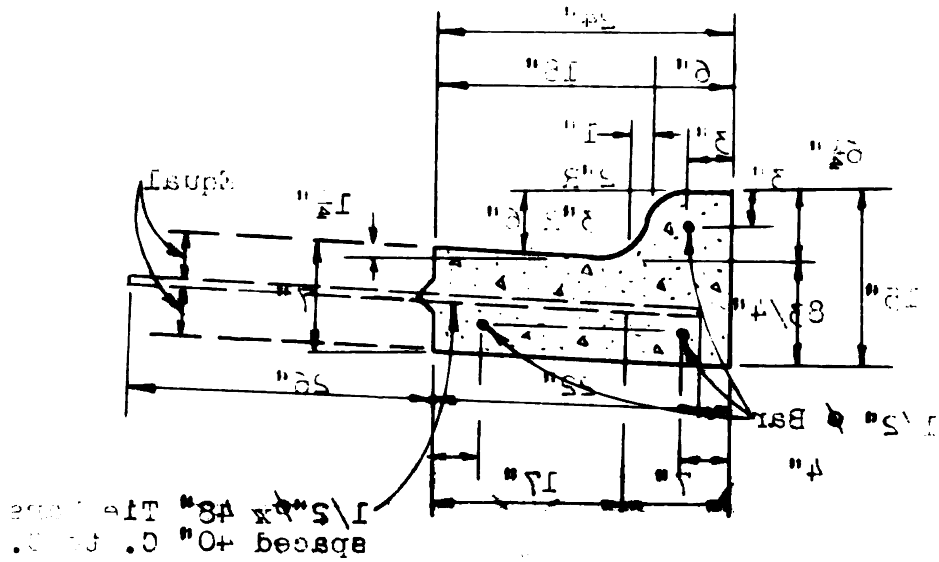


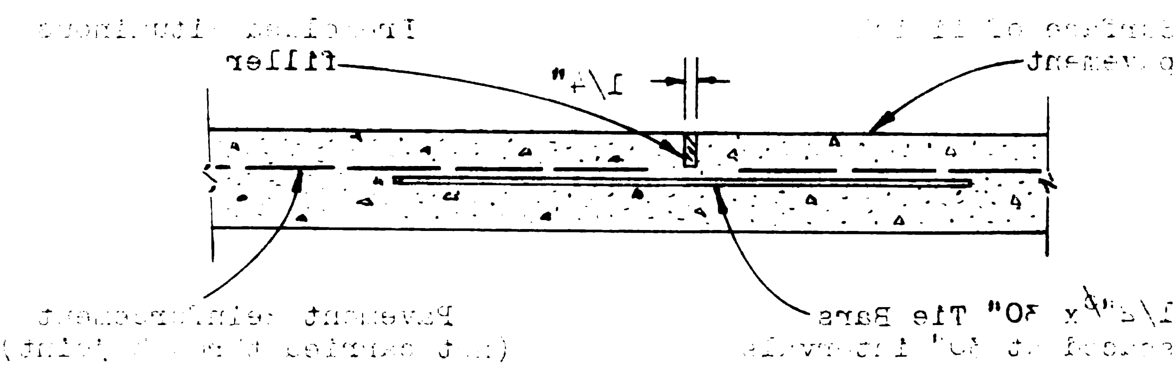


CURB AND GUTTER

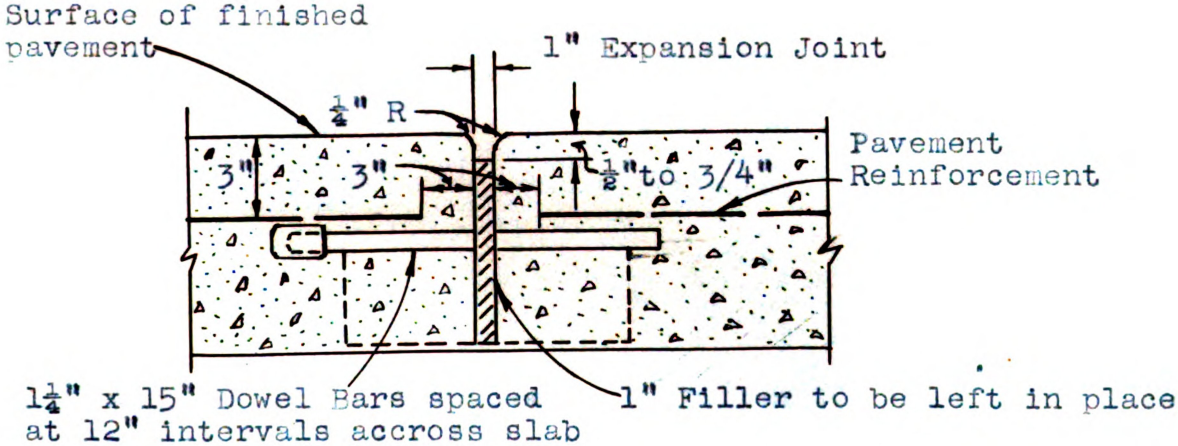


LONGITUDNAL LANE TIE JOINT

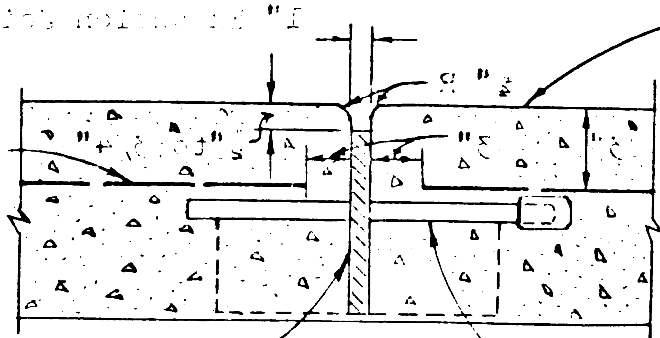

24"
18"
6"
1"
3"
3"
2"R
3 1/2"
Equal
1 1/4"
8 3/4"
15"
26"
12"
1/2" ϕ Bar
4"
17"
7"
1/2"ϕx 48" Tie
spaced 40" C.


filler
1/4"
pavement
1/2"ϕx 30" Tie Bars
Pavement reinforcement

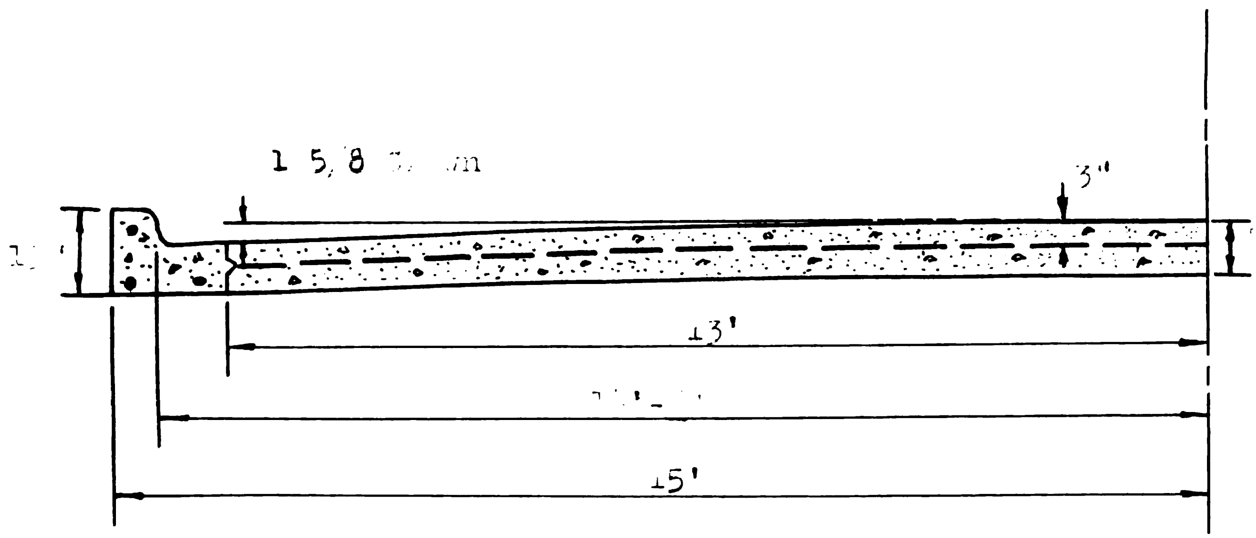
TRANSVERSE EXPANSION JOINT WITH LOAD TRANSFER



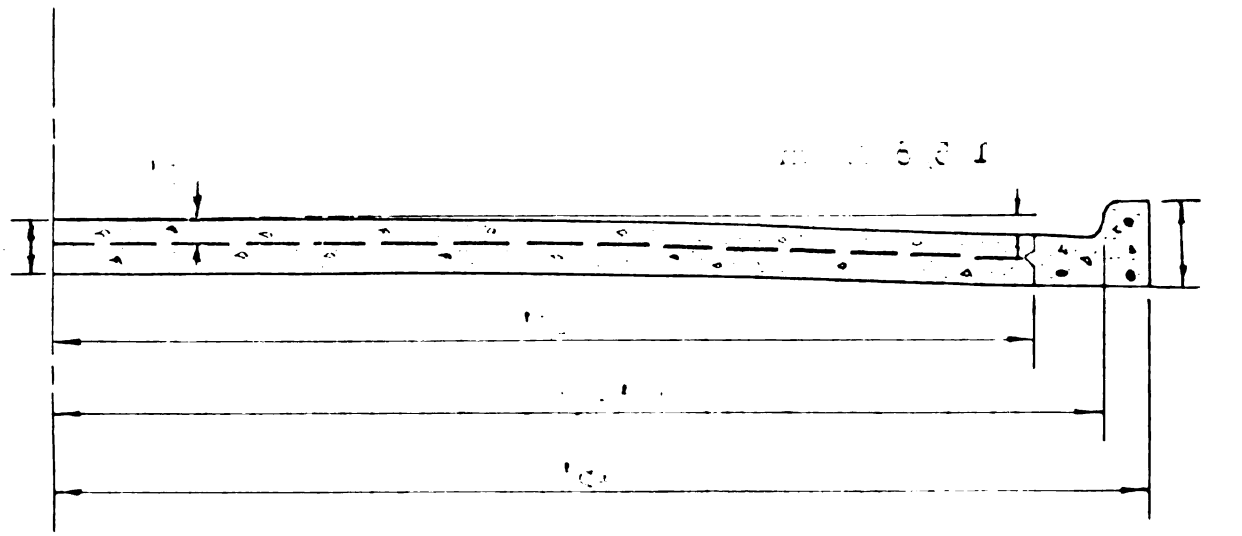
The filler strip shall be left in place and the joint formed while the concrete is still fresh and shall be true to position and line. The joint shall be filled with hot poured, Rubber Type compound. The compound shall be poured so as to completely fill and seal the joint without overflowing the pavement.



The filler strip shall be left in place and the joint formed while the concrete is still fresh and shall be true to position and line. The joint shall be filled with hot poured, rubber type compound. The compound shall be poured so as to completely fill and seal the joint without overflowing the pavement.



PAVEMENT CROSS-SECTION



QUANTITY ESTIMATE

Items of Work	Quantities
Clearing ----------------------------------	2 Acres
Grubbing ----------------------------------	1.58 acres
Earth excavation ------------------------	27,963 cyds
Steel reinforcement ---------------------	77,927 lbs
8" Culvert ------------------------------	720 lin. ft.
Catch Basins ----------------------------	10 each
Curb and Gutter -------------------------	6,370 lin. ft.
Concrete pavement, 7" uniform -----------	9,167 syds

COST ESTIMATE

Items of Work	Unit Price	Amount
Clearing ----------------	$150.00 / acre ------	$ 300.00
Grubbing ----------------	300.00 / acre ------	474.00
Earth excavation --------	0.40 / cyds ------	10,185.20
Steel reinforcement -----	0.10 / lb ------	7,793.00
8" Culvert --------------	1.00 / lft ------	720.00
Catch Basins ------------	100.00 / each ------	1,000.00
Curb and Gutter ---------	2.50 / lft ------	15,925.00
Concrete pavement, 7" ---	8.00 / syds ------	73,336.00
	Total -	109,733.20

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