DESIGN AND COST ESTIMATE OF A PEDESTRIAN UNDERPASS UNDER SAGINAW STREET, EAST LANSING, MICHIGAN

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

W. M. Thatcher

1938

Design and Cost Estimate of a Pedestrian Underpass Under Saginaw Street, East Lansing, Michigan

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

OF

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by

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Candidate for the Degree of

Bachelor of Science

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INTRODUCTION

The School Board of the City of East Lansing, Michigan feel that there will be a need for a school in the northwest part of the city in the very near future. There are two possible sites for this school. One site is five acres of land in the southwest corner of the intersection of Saginaw Street and Harrison Avenue, which could be obtained at the price of $1500 an acre. The other site, on the north side of Saginaw Street, is five acres in the southeast corner of the former Inter City Golf Course, which has been offered to the City of East Lansing gratis for use as a school site. However if the latter site were chosen it would necessitate the construction of a pedestrian underpass, because the majority of the school children would be coming from the south side of Saginaw Street, Michigan trunk line route number seventy-eight, which carries all of the traffic from Flint, Saginaw, Bay City, and other northeastern Michigan cities to Lansing. The problem before the School Board then, is whether it is cheaper to take five acres of free land on the north side of Saginaw Street and build an underpass, or to buy the five acres of land on the south side in which case an underpass is not needed.

In this paper, I am going to design and estimate the cost on a underpass under Saginaw Street to serve a school, if built, on the five acres of land in the southeast corner of the former Inter City Golf Course.

The logical location for the underpass is at the Touraine Avenue crossing of Saginaw Street. After making a survey of the territory around this intersection, I fixed the location of the underpass as shown on the map which is in the pocket on the inside of the back cover of this book. The sewer and water main were located from maps in the East Lansing Engineering Department. They will be cut by the underpass. This will necessitate putting in a sump pump for the sewer. The water main can be lowered.

The computations will be given in the first part of the book. The drawings of the completed design are in the pocket on the inside of the back cover of the book. The cost estimate, including cost of materials, construction costs, and engineering costs, will appear in the second part of the book.

DESIGN

The underpass will slope from a floor elevation at the south entrance of 52.0 feet at a rate of three percent to a floor elevation of 54.7 feet at the north entrance. It will be skewed by an angle of 30 degrees under Saginaw Street, but the entrances will be parallel to the Saginaw Street sidewalks. The inside dimensions will be 7 feet by 7 feet.

A 2500 pounds per square inch concrete composed of one part cement, two parts of fine aggregate, and four parts of coarse aggregate will be used. The allowable unit concrete stresses in flexure, shear, and bond will be in accordance with the American Concrete Institution Specifications. These specifications will be followed likewise for the unit stresses in the reinforcement and will, in general, govern the design throughout.

The dead load will consist of the weight of the structure, the weight of the pavement slab, and the weight the earth topping.

Earth pressure will be acting on the side walls and will be calculated from Rankine's formula $P= C_e wh^2/2$ where the constant C_e equals 0.27. Weight of earth will be assumed at 100 pounds per cubic foot and weight of concrete 150 pounds per cubic foot.

For live load, I shall assume the H_{20} class of highway loading. Therefore, I shall use a typical truck of

20 tons (as shown in figure 1a page 5). As only one set of wheels can be over the structure at one time, the live load on the structure will come from the effect of a concentrated load of 22,080 pounds, which is the load of one rear wheel of 16,000 pounds plus impact equal to 50/1+125 times 16,000 pounds. The effect of this load on the structure will be in accordance with the empirical formula for distribution of loads set up by the Michigan State Highway Department, which says, that for every foot of depth, from the pavement surface to the structure, the load will be spread over a square area of depth plus three feet on a side. The effect of two trucks over the underpass at the same time (figure 1 b) will give the maximum loading and the effect shown in figure 2 page 6. From this diagram it can be seen that the section of maximum loading will be the one foot longitudinally of the underpass where the distribution of two wheel loads overlap. The live load on this section will be:

$$\frac{22,080}{(\text{area of distribution})^2} \times 2 = \frac{22,080}{(5.1)^2} \times 2 = 1700\#/\text{ft.}$$

for a length of 5.1 feet moving across the width of the underpass. This will be the live load used in design of the structure.

The rigid frame type of underpass was selected because it has proved to the most economical type as far as quantity of materials and excavation are concerned.

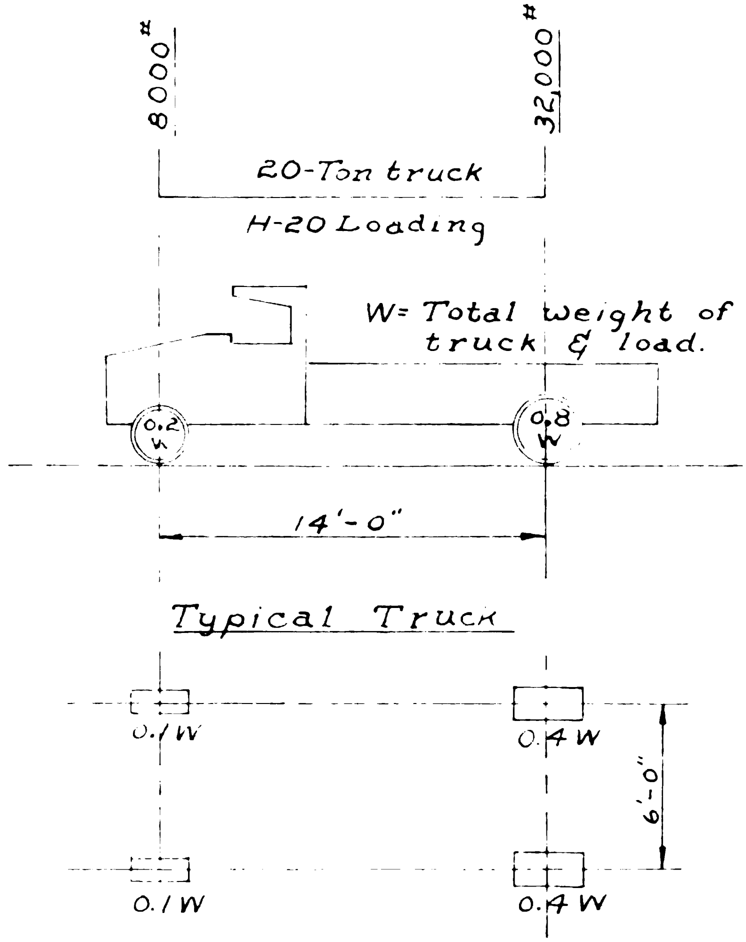


Fig. 1 a.

Clearances on 20' Pavement

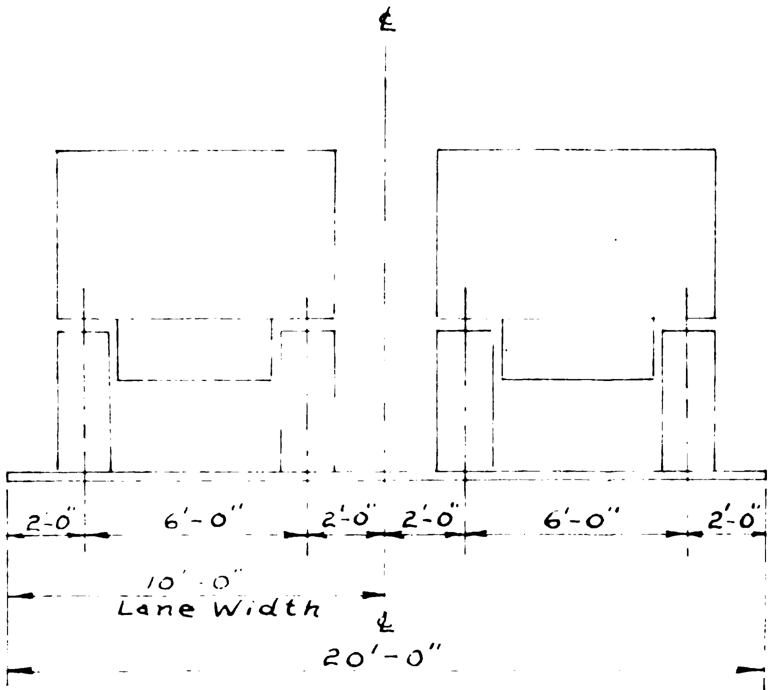
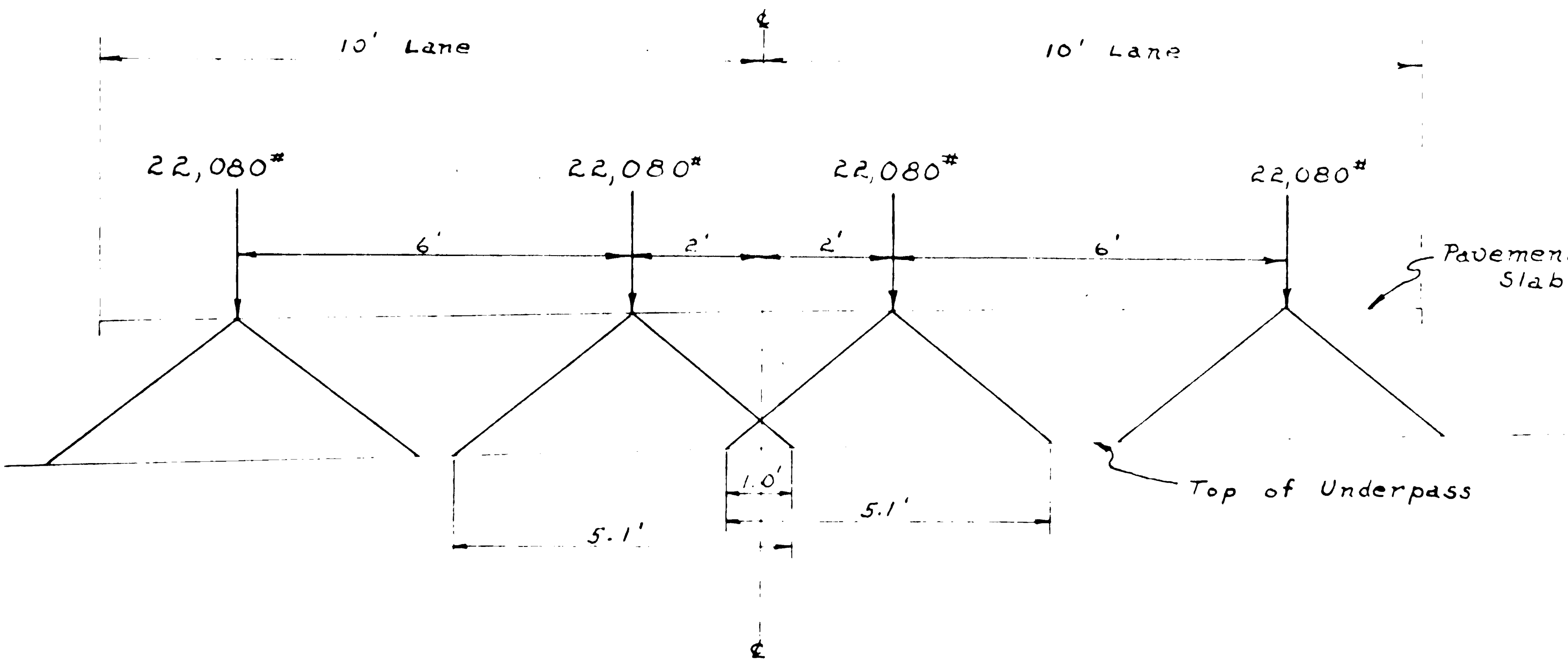


Fig. 1 b.



Scale:- 1"=2.5'
Fig. 2

Underpasses of this type have proved very successful in Grand Rapids and Lansing.

The slope deflection method of analysis of rigid frames will be used as the basis of design. It consists briefly of a series of simultaneous equations set up and solved, each equation expressing a relation between certain of the bending moments at the ends of the several members of the structure under consideration and giving as a result the value of all these end moments. The relation most commonly used, and the one I will use, is the equilibrium existing between all the end moments at any one of the rigid joints. The determination of the shears and stresses, completing the solution of the structure, is a simple matter once these moments are determined. The computations of the end moments are as follows:

The general slope-deflection equation is
$M_{near} = 2EK\ (2\theta_{near} + \theta_{far} - 3R\ ) \pm C_{near}$ the end of the beam for which the moment is written being designated near end.

θ = slope at section designated

E = modulus of elasticity $\qquad$ $K = I/L$

I = moment of inertia $\qquad$ $R = d/L$

d = deflection

L = distance between near and far section

C_{near} = the moment caused at the near end of an identical fixed-ended beam carrying the same load as the given beam.

The top slab will be assumed 12 inches thick, the side walls 10 inches thick, and the footing 12 inches thick. The loading will then be as shown in figure 3 page 9, this section being the one foot longitudinal section calculated as the maximum loaded section.

Refer to figure 3 throughout the calculations of the end moments.

ab = 12" thick d = 10" L = 7.44'	ad = 10" thick d = 7" L = 7'
$k_{ab} = .375$	$k_{ad} = .375$
kd = 3.75"	kd = 2.63"
$A_{st} = .0094 \times 12 \times 10$	$A_{st} = .0094 \times 12 \times 7$
$A_{st} = 1.13$ sq. in.	$A_{st} = 0.80$ sq. in.
$I_{ab} = 2897$	$I_{ad} = 1844$
$K_{ab} = \frac{2897}{7.44}$	$K_{ad} = \frac{1844}{7}$

$$n = \frac{1844}{7} \times \frac{7.44}{2897} = 0.68$$

$$2EK = 2 \times \frac{2897}{(7.44)(12)^2} \times 2{,}500{,}000 = 13{,}520{,}000$$

By symmetry: $\theta_a = -\theta_b$; $\theta_d = -\theta_c$

There are no deflections to consider, so R= 0 in all cases.

$$C_{ab} = \frac{1700}{12(7.44)}(7.44^3 - 6x1.3^2x7.44 + 4 \times 1.3^3) +$$

$$\frac{400\ (7.44)^2}{12} = 6625 - 1845 = 8470'\#$$

LOADING

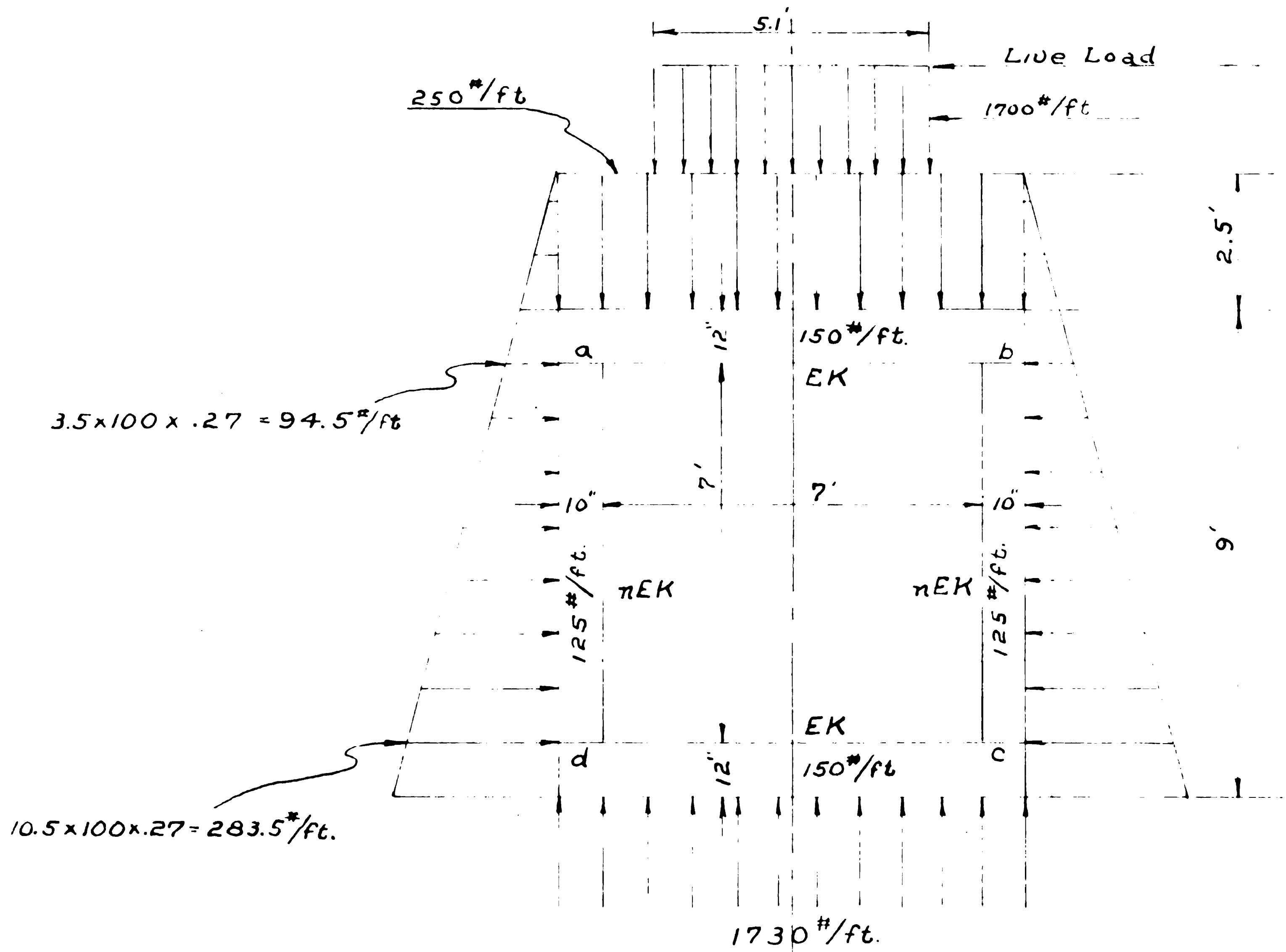


Fig. 3

$$C_{ad} = \frac{661.5 \times 7}{12} + \frac{661.5 \times 7}{15} = 386 + 309 = 695'\#$$

$$C_{da} = \frac{661.5 \times 7}{12} + \frac{661.5 \times 7}{10} = 386 + 463 = 849'\#$$

$$C_{dc} = \frac{1730 \times 8.83}{12} = 11,240'\#$$

$$M_{ab} = 2EK\theta_a - 8470$$

$$M_{ad} = 2EK\,(1.36\,\theta_a + 0.68\,\theta_d) + 695$$

$$M_{da} = 2EK\,(1.36\,\theta_d + 0.68\,\theta_a) - 849$$

$$M_{dc} = 2EK\,\theta_d + 11,240$$

The above expressions contain two unknowns, θ_a and θ_d, and two equations for finding these unknowns are obtained by the condition of equilibrium existing at each joint.

$$M_{ab} + M_{ad} = 0$$

$$M_{da} + M_{dc} = 0$$

$$2.36\,\theta_a - .68\,\theta_d = \frac{7775}{13,520,000} = .0005751$$

$$.68\,\theta_a - 2.36\,\theta_d = \frac{-10,391}{13,520,000} = -.0007686$$

$$5.5696\,\theta_a - 1.6048\,\theta_d = .0013572$$

$$.4624\,\theta_a - 1.6048\,\theta_d = -.0005226$$

$$5.1072\,\theta_a = .0018798$$

$$\theta_a = .0003681$$

$1.6048\,\theta_a + .4624\,\theta_d = .0003911$

$1.6048\,\theta_a + 5.5696\,\theta_d = -.0018137$

$5.1072\,\theta_d = -.0022048$

$\theta_d = -.0004317$

$M_{ab} = 13,520,000\ (.0003681) - 8470 = -3493'\#$

$M_{ad} = 13,520,000\ (1.36 \times .0003681 + .68 \times -.0004317) + 695$

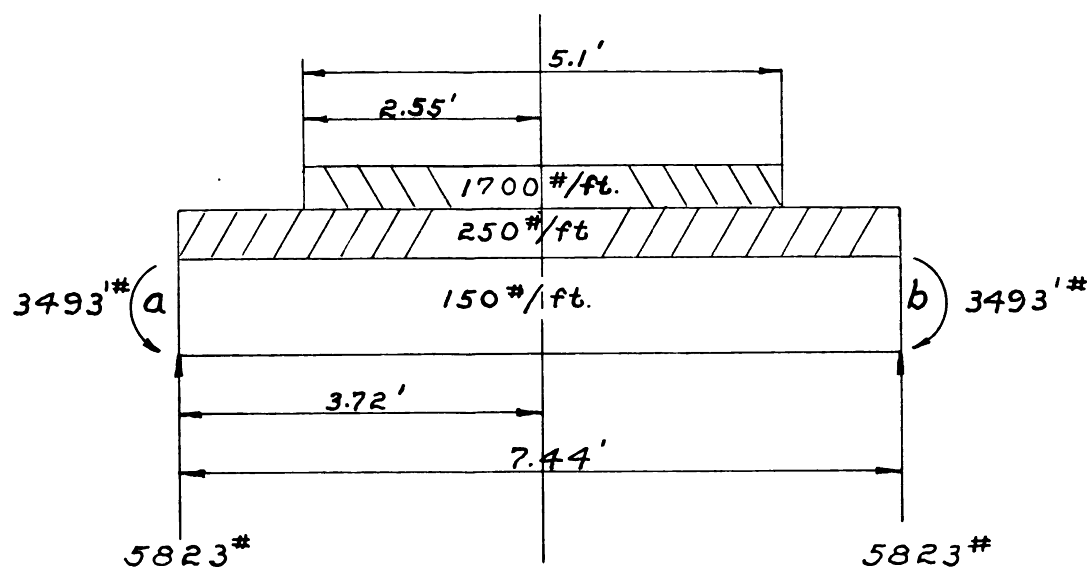
$= 13,520,000\ (.000207) + 695 = 3494'\#$ --------Check

$M_{da} = 13,520,000\ (1.36 \times -.0004317 + .68 \times .0003681) - 849$

$= 13,520,000\ (-.0003368) - 849 = -5403'\#$

$M_{dc} = 13,520,000\ (-.0004317) - 11,240 = 5403'\#$ -----Check

Design of Top Slab:



Max. $M = 5823 \times 3.72 - 400 \times 3.72 \times 3.72/2 - 1700 \times 2.55 \times 2.55/2 - 3493$

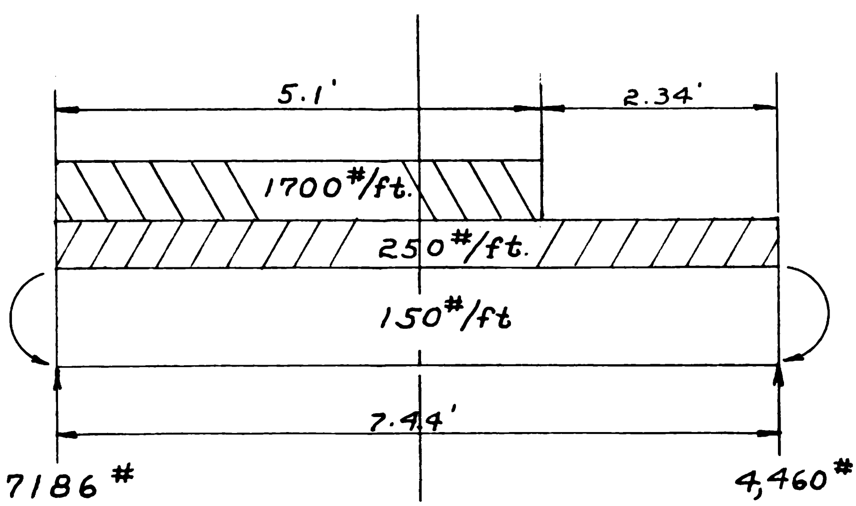
$= 21,662 - 2768 - 5525 - 3493 = 9,876'\#$

d = effective depth = $\frac{M}{K\,b}$ K = 164

$$d = \sqrt{\frac{12 \times 9{,}876}{164 \times 12}} = \sqrt{60.2} = 7.8'' \quad \text{Use } 10''$$

d = 8" would be okay, but a check for shear will show that web reinforcement would be necessary in this case. Therefore, I used 10" for d which made it possible to get away from using web reinforcement as will be shown when I check for shear in the next step.

Protective Covering = 2"   Therefore Total Depth = 12"



Loading for Maximum Shear

$$\text{Max. V} = \frac{400 \times 7.44}{2} + \frac{5.1/2 + 2.34}{7.44} \times 8670$$

$$V = 1488 + 5698 = 7186\# \qquad v = \frac{V}{bjd} \qquad j = .875$$

$$v = \frac{7186}{12 \times .875 \times 10} = \frac{7186}{105} = 68.4 \ \#/\text{sq.in.}$$

68.4 is less than 75 which is the allowable without web reinforcement, but with special anchorage. Therefore, I shall use special anchorage.

A_{st} (required) = pbd = .0094 x 12 x 10 = 1.13 sq. in.

Bond required ------- $\text{Perimeter (total)} = \dfrac{V}{\text{Allowable bond stress} \times j \times d}$

$$\text{Total Perimeter} = \frac{7186}{125 \times .875 \times 10} = 6.6 \text{ inches}$$

Try 3 - $\frac{3}{4}$ inch round bars at 4 inch spacing

Total Area = 1.33 sq. inches ------ O.K.

Total Perimeter = 7.06 inches ------ O.K.

Shrinkage and Temperature Steel:

A_{st} = pbd with p = .0025

A_{st} = .0025 x 12 x 10 = .30 sq. in.

Use $\frac{1}{2}$ inch square bars at 10 inch spacing

Therefore for the top slab use:

12" total thickness

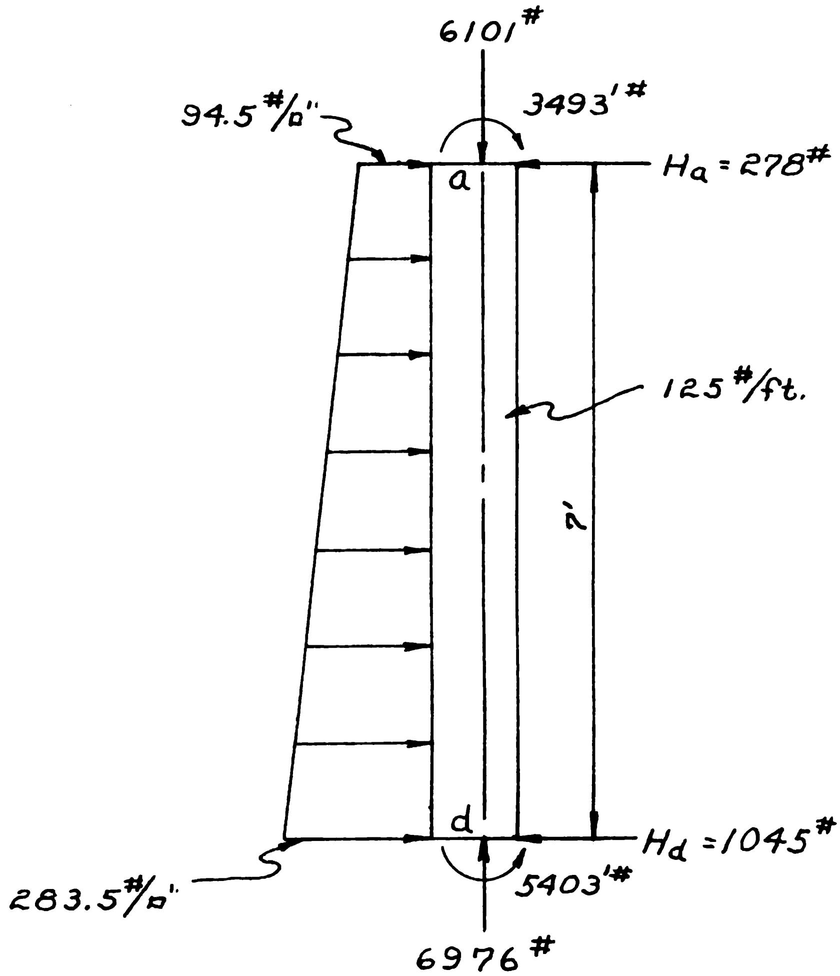
10" effective depth

3 - $\frac{3}{4}$" round bars for main reinforcement at 4" spacing

special anchorage of main reinforcement

$\frac{1}{2}$" square bars at 10" spacing for shrinkage and temperature steel.

Design of Walls:



Loading on Wall

Assumed a 10" Wall

Calculation of the horizontal forces at the ends (H_a and H_b).

Summation of the moments at either end (a or b) equals zero.

$$7\ H_a = 94.5 \times 7 \times 3.5 + 189 \times 7/2 \times 7/3 + 3493 - 5403$$

$$7\ H_a = 2315 + 1544 + 3493 - 5403$$

$$H_a = 278\#$$

$7\ H_d = 94.5 \times 7 \times 3.5 + 189 \times 3.5 \times 14/3 + 5403 - 3493$

$7\ H_d = 2315 + 3088 + 5403 - 3493$

$H_d = 1045\#$

Check:

Summation of horizontal forces equal zero.

$94.5 \times 7 + 189 \times 7/2 = 1045 + 278$

$661.5 - 661.5 = 1323$

$1323 = 1323$ --------- Check

Maximum moment = 5403'#

$$d = \sqrt{\frac{12 \times 5403}{164 \times 12}} = \sqrt{32.9} = 5.8''$$

Use $3\frac{1}{2}''$ protective covering

Therefore total depth = $5.8 - 3.5 = 9.3$

Use 10" wall effect depth = $6\frac{1}{2}''$

Check for Shear: Maximum $V = 1045\#$

$$v = \frac{1045}{12 \times .875 \times 6.5} = \frac{1045}{68.25} = 15.31\#/\text{sq.in.}$$

15.31 is less than 50 the allowable. Therefore no web reinforcement or special anchorage is required.

$A_{st} = .0094 \times 12 \times 6.5 = .73$ sq.in.

Use 2-$\frac{3}{4}''$ round bars 6" spacing

Area = .88 sq.in. ---------- O.K.

Perimeter = 4.71 inches

Check for Bond:

$$\text{Unit bond stress} = \frac{V}{\text{Perimeter} \times j \times d}$$

$$= \frac{1045}{4.71 \times .875 \times 6.5} = \frac{1045}{26.8}$$

Unit bond stress = 39#/sq.in. --------- O.K.

Shrinkage and Temperature Steel:

A_{st} = pbd = .0025 x 12 x 6.5 = .20 sq. in.

Use ½" square bars at 12" spacing

Therefore for the walls use:

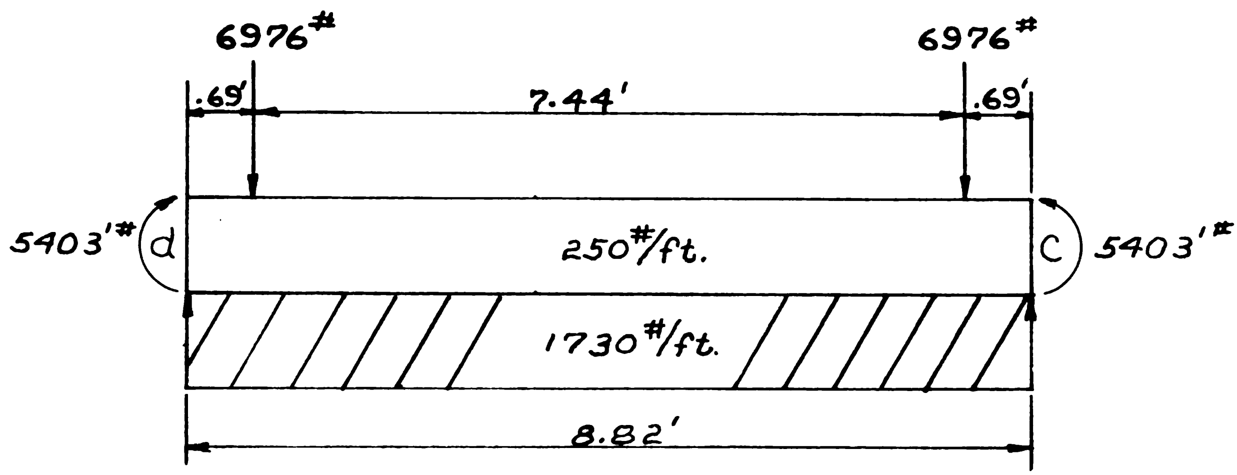
10" total thickness

6½" effective depth

2-¾" round bars for main reinforcement --- 6" spacing

½" square bars at 12" spacing for shrinkage and temperature steel.

Design of Floor Slab:



Loading on Floor Slab

Assumed 12" Thickness

$$\text{Max. } M = 6976 \times 3.72 - 1730 \times 8.82/2 \times 8.82/4$$

$$= 25{,}951 - 16{,}861$$

$$= 9{,}090'\#$$

$$d = \sqrt{\frac{12 \times 9{,}090}{164 \times 12}} = \sqrt{55.4} = 7.45''$$

Covering = 1" for drainage groove plus 2" protective covering

d = 8" would be okay, but a check for shear will show that web reinforcement would be necessary in this case. Therefore, I used 9" for d which made it possible to get away from using web reinforcement as will be shown when I check for shear in the next step.

With d = 9"   The total depth = 12"

Check for Shear:

Max. V = 7186 (see diagram for max. loading of ab for shear --page 12) + 875 - 1730 x .69

= 6867#

$$v = \frac{6867}{12 \times .875 \times 9} = \frac{6867}{94.5} = 72.6\#/\text{sq.in.}$$

72.6 is less than 75 which is the allowable without web reinforcement, but with special anchorage.

Therefore, I shall use special anchorage.

A_{st} (required) = pbd = .0094 x 12 x 9 = 1.06 sq. in.

Bond required:

$$\text{Total Perimeter} = \frac{6867}{125 \times .875 \times 9} = \frac{6867}{984} = 6.95''$$

Try 3-$\frac{3}{4}$" round bars at 4 inch spacing

Total Area = 1.33 sq. inches -------- O.K.

Total Perimeter = 7.06 inches -------- O.K.

Shrinkage and Temperature Steel:

A_{st} = pbd with p = .0025

A_{st} = .0025 x 9 x 12 = .27 sq. in.

Use $\frac{1}{2}$ inch square bars at 10 inch spacing

Therefore for the floor slab use:

12" total thickness

9" effective depth

3-$\frac{3}{4}$" round bars for main reinforcement --- 4" spacing

special anchorage of main reinforcement

$\frac{1}{2}$" square bars at 10" spacing for shrinkage and temperature steel.

Other features of the design:

The stair slab for the entrance at each end will be eleven inches thick allowing an effective depth of eight inches with a three inch covering. The main reinforcement shall consist of three-quarter inch round bars at six inch spacing. The shrinkage and temperature steel shall consist of one-half inch square bars at ten inch spacing.

The steps shall consist of safety tread iron grating one to one and one-quarter inch in thickness, and supported at each end by six inches of concrete to which it is to be bolted. The grates are to be close enough together to prevent a ladies heel from catching and causing damage. The rise shall be seven and one-quarter inches and the tread eleven inches.

A railing consisting of two inch round pipe shall be placed on each side of the stairway. For safety purposes, a two-rail guardrail of the same material shall also be placed around the top of the entranceway and in front of the entrance at a distance of five feet. The latter guardrail is to keep children from running at top speed into the entrance and possibly falling down the stairs.

A sump compartment with an automatic sump pump to pump water from it was provided. The sump and pump were necessary to carry the water from a short sewer line, which was to be cut by the underpass, underneith the underpass. It was also needed to care for drainage of the underpass inside and out.

Cast iron floor drains are to be placed at the bottom of the stairs at each entrance to keep the underpass dry inside. These floor drains will drain into the sump, where the water will be pumped into the sewer system of the city.

Drain tiles are to be placed on each side of the underpass at the floor slab depth so as to prevent water accumulation in the soil, which would increase the earth pressure considerably. They would also decrease frost action, which would produce cracks in the walls that would allow water to seep into the underpass. These drains also deposit their water into the sump.

The fixtures for lighting the underpass shall consist of the standard type for lighting underpasses. Lights are so placed in the concrete of the top slab as to be flush with the ceiling, providing maximum head room and still giving ample light.

The drawing, showing the completed design, is in the pocket on the inside of the back cover of this book

COST ESTIMATE

Item	Quantity	Unit	Unit Price	Amount
Concrete (as specified)	150	c.y.	$20.00	$3000.00
Reinforcing Steel	22,200	lbs.	.05	1110.00
Earth Excavation	680	c.y.	.60	408.00
Gravel Backfill	125	c.y.	2.25	281.25
Removing Pavement	37	s.y.	.75	27.75
Concrete Pavement Replaced	37	s.y.	4.00	148.00
Removing South Sidewalk	9	s.y.	.50	4.50
Concrete Sidewalk Replaced	9	s.y.	2.25	20.25
Relocating Saginaw Street				
Water Line				150.00
Automatic Sump Pump	1	each	200.00	200.00
6" C.I. Pipe	27	feet	2.00	54.00
8" C.I. Pipe	16	feet	2.15	34.40
6" Clay Tile	270	feet	.60	162.00
Cast Iron Floor Drain	2	each	4.00	8.00
Stair Treads & Fittings	20	each	11.00	220.00
Floor Drain Grate	2	each	14.00	28.00
2" Pipe -- Handrails & 2-Rail				
Guardrails	218	feet	.65	141.70
Lighting Equip. Complete				100.00
Bit. Material, Tar	1,200	gal.	.12	144.04
Sub Total				6,241.89
Eng. & Contingencies (approx. 10%)				624.11
Total				$6,866.00

Unit prices given in the eight issues of the Engineering News-Record from March 31, 1938 to May 19, 1938 along with a general knowledge of local prices were used as a basis for the unit prices listed in the estimate. These prices include material costs, transportation costs, and installation or construction costs. Therefore, the amount listed for each item is the total cost of that item as an integral part of the completed structure.

CONCLUSION

The rigid frame type of underpass was used because it was economical. As can be seen from the cost estimate, the total cost of this underpass will be $6,866.00 which for an underpass of such size is a very reasonable figure.

The School Board of East Lansing could save approximately $634.00 by taking the five acres of free land on the north side of Saginaw Street for a school site and building this underpass in preference to buying five acres of land on the south side where an underpass would not be required. Therefore, the School Board would be wise in accepting the free land and build this underpass.

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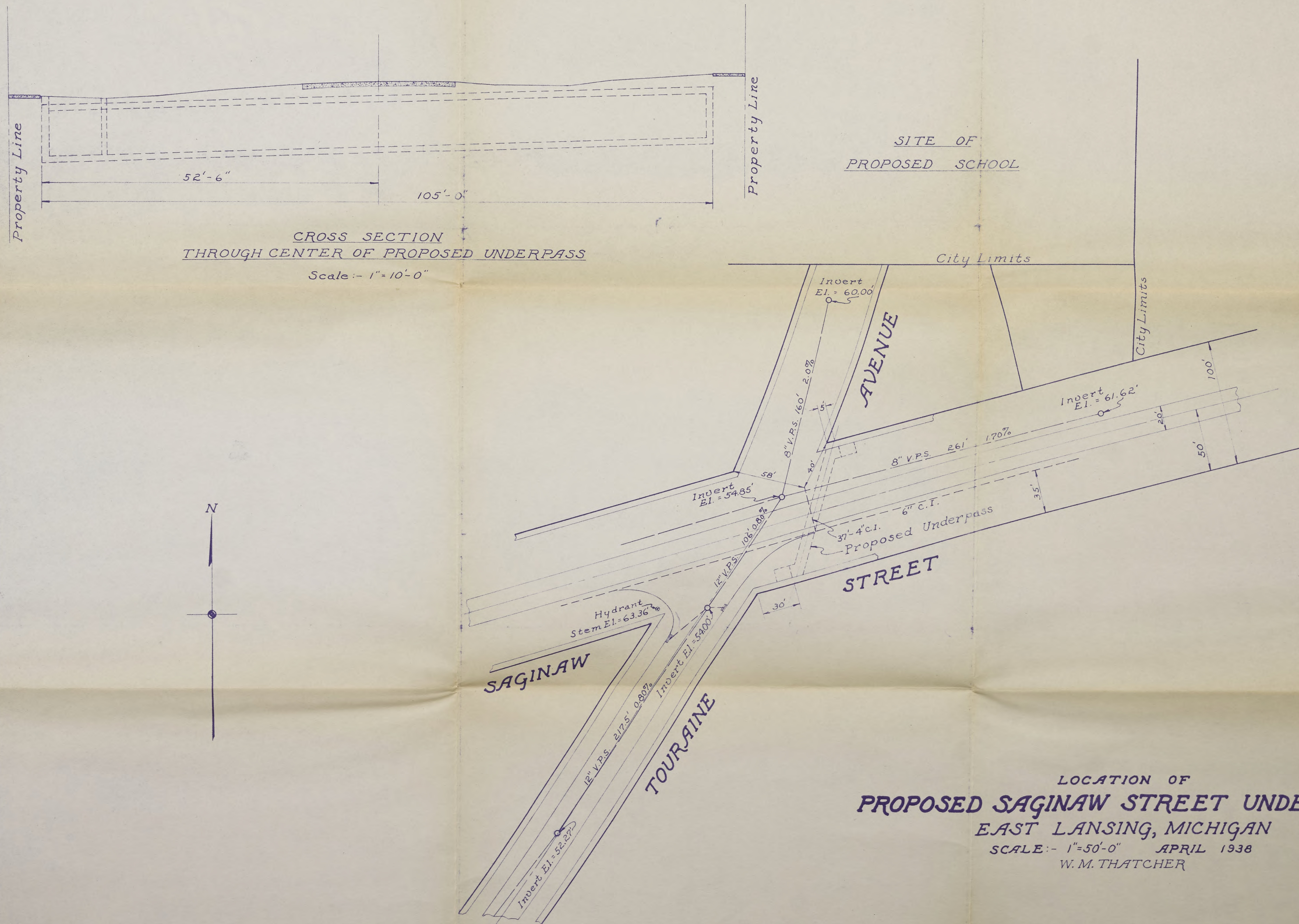

LOCATION OF

PROPOSED SAGINAW STREET UNDERPASS

EAST LANSING, MICHIGAN

SCALE:- 1" = 50'-0"   APRIL 1938

W. M. THATCHER

Pocket has: 2 maps