DESIGN FOR A SUBWAY

Under Illinois Central Railroad Tracks,

UNIVERSITY AVE., CHAMPAIGN, ILL.,

BY

ROBBINS YALE MAXON.

THESIS

For the Degree of Bachelor of Science in Civil Engineering,

UNIVERSITY OF ILLINOIS.

1895.
Design for a Subway

Introduction. Any observant inhabitant of Champaign whose business relations are such as to necessitate his crossing the Illinois Central track several times daily is aware of the great inconvenience experienced from blocked crossings. As the volume of business on the east and west thoroughfares increases in the future, the hindrance to traffic caused by the present grade crossings of street and railway will be multiplied, that eventually a separation of the two will be inevitable. These considerations, coupled with the fact that the "Grade Crossing Question" in our large cities is one
of the great problems which confronts the engin-
neering profession today, determined the writer
to select as a subject for a thesis the design
do a structure that will obviate some of the
difficulties mentioned above.

Selection of the site. University Avenue was
selected as an available site for this structure
for two reasons, viz:

First. It is a much more frequented
thoroughfare than any of the other streets in the
vicinity.

Second. The Urbana and Champaign Street
Railway already has a franchise on this street.

Kind of Structure. A subway was found
to be the best form of structure to use as there
are relatively few tracks to cross. The advantage
of a subway as compared with a viaduct may be briefly summarized as follows:

(a) Less head room is required for a subway than for a viaduct. For the latter a clear head way of sixteen to eighteen feet is necessary, while for the former twelve to thirteen feet will accommodate the ordinary street traffic and give sufficient clearance for electric cars.

(b) A part of the momentum acquired on the descending grade of the subway is available in making the ascent, so that the hauling power of teams is not taxed as heavily as if the ascending grade came first.

Subways, Maps, etc. Plate I accompanying this thesis is a map of a portion of Lakehampshire in the vicinity of the intersection of
University Avenue and the Illinois Central tracks. Part of the data for the map was taken from a recent atlas of Champaign County, some from a map of the Illinois Central Railway. Also, made by students Bassett, Shawhan and Van Orstrand of the class of '96, but the greater portion of the data was obtained by a survey of the grounds made by the writer. The accompanying profile, from levels taken by the writer, shows the grade of University Avenue from Neil Street to the Bone Yard.

Head Room. A minimum head room of thirteen feet was decided upon, after an exhaustive search through the available literature and after considerable correspondence with
superintendents of various street car lines. Actual measurements were taken of some of the largest and tallest cars now used on the Urbana and Champaign Street Ry. line.

Gradient. The Special Commission on the Separation of Grade Crossings at Newton, Mass., in its report (1892) recommended 5% as the ordinary maximum gradient for the streets, although 7 to 8% was allowed in extreme cases. The maximum gradient in the Van Buren Street Tunnel in Chicago, used by a double track cable line, is 10%. In the Ninety-Third Street Subway under the Illinois Central tracks, in South Chicago, used by the Launnet Electric Street Ry., the maximum gradient is 4%. The present maximum grade on the
Urbana and Champaign Street Ry. is 4.1%. On the basis of the preceding, 6½% was adopted as the maximum gradient of the approach to this subway. The two governing considerations which led to the adoption of this particular gradient are; First, the maximum must not be so excessive as to form a serious hindrance to the operation of the street car line. Second, it is desirable that the rate of grade be so chosen that the grade of the east approach will begin at Water Street and that of the west approach at Market Street, in order to avoid changes in the present grades of these intersecting streets. In order to investigate the effect that a 6½% gradient would have on the operation of the Electric Street Ry. line, recourse was had
to several standard works on electric street railways, notably the one by Crosby and Bell. In this work 6 1/2% is given as the maximum grade for an ordinary 16 ft. car, equipped with a motor on each axle, starting from rest. For the same car in motion under the same conditions the maximum slipping grade is 8 1/2%. The conclusion arrived at was that no change in the rolling stock would be occasioned by using a maximum gradient of 6 1/2% in the proposed subway, except the equipping of all cars to be used on the University Avenue line with a motor on each axle (two cars are already so equipped) and with some device for bonding the rail in wet weather.
Cross section. The width of the subway, inside to inside of masonry at the line of the side walk, will be 42 ft., including two walks each 6 ft. in width. The total length of the subway and approaches will be 641 ft., as indicated on the longitudinal section shown on Profile "B". The clear roadway will be 30 ft., and will have a crown of 2 inches with a uniform slope to the gutter.

Masonry. The retaining walls will be built of squared-stone masonry of the form and dimensions shown on the detail drawings. The abutments will be constructed of first-class ashlar masonry in accordance with the specifications in Baker's Masonry Construction section, 207, page 142.
Paving and Sidewalks. In the subway proper the roadway will be paved with a single layer of brick laid on a bed of concrete, 5\(\frac{1}{2}\) inches thick at the gutter and 7\(\frac{1}{2}\) inches thick at the prows. The roadway of the approaches will be paved with two layers of brick without the concrete foundation. The sidewalks will have a foundation of 5 inches of concrete and a wearing surface \(\frac{3}{4}\) inches thick composed of a mixture of one to one Portland cement and sand.

Drainage. An inspection of the profile shows that the low water level of the Bone Yard is but 2 ft. below the lowest point of the subway with a fall of only 2 ft. in 1200 ft. the gradient is far too flat to permit of a gravity flow into
the "Bone Yard."

There are two possible ways of draining the subway. The first and best method is to connect a catch-basin in the subway with the new sanitary sewer of Champaign, in case the sewer line is laid at a sufficient depth below the bottom of the subway to give the necessary fall.

The second and more expensive method is to construct a sump large enough to hold the accumulation of water from a storm of average duration and then pump the water into the "Bone Yard."

It is necessary to know the extent of the drainage area and the rate of maximum rainfall in order to decide upon the size of pipe to put in if the first method is employed.
on the capacity of the sump if the second method is used.

The grades of the streets near the approaches of the subway slope away from its mouth so that very little surface water from that source could find entrance into the subway. The drainage question then involved only the taking care of the storm water which falls on the exposed surface of the subway about 0.95 of an acre. This will be taken as the drainage area in the subsequent computations.

The Bulletins of the Agricultural Experiment Station, covering the years 1888 to 1894 inclusive, were consulted for data on the rate of maximum rainfall for this locality.
A single instance in which 1.64 inches of rain fell in one hour, occurred on July 28, 1889. Barring this unusual case, the duration of the majority of the storms in which the rate of rainfall exceeded one inch per hour, was seldom longer than half an hour. Assuming that a rain fall of one inch per hour produces a flow of one cubic foot per second from an acre, and that the rate of rainfall is 1 1/4 inches per hour, a sewer capable of discharging at the rate of 1.2 cu. ft. of water per second must be provided if the first method is adopted.

If the second method is adopted, the pumps must be large enough to hold at least 2,100 cu. ft. of water, that being the amount which would accumulate from the drainage area if the rate of rainfall was 1 1/4 inches per hour and the duration of the storm was thirty minutes.

Temporary operation of railway. To provide
for the operation of the Illinois Central Ry. during construction, temporary trestles shown in Plate 4 will be put up in sections, the lateral timbers being only long enough to span one track and being spiked to the sections adjoining after erection. The ties are 23 ft. long and will be capped by 12" x 14" timbers upon which will be laid the track stringers (8" x 16") in sections, four being placed under each track.

The street Railway line will be operated during construction by moving a portion of the tracks now on University Avenue to First South Street and Water Street as shown by the dotted line on the map.
DESIGN OF SUPERSTRUCTURE.

General Description. Since the Illinois Central track crosses University Avenue at an angle of 71° 30', it becomes necessary to take account of this skew in the design of the superstructure. In order to save as much headroom as possible, a type of through plate girder with a shallow floor was adopted. The four railroad tracks are to be carried by five girders spaced 14.75 ft. c.to c. measured parallel to the street. In the design of the girders, 48.2 ft. was taken as the length c.to c. of bearing plates, and one track only was taken as fully loaded, the assumed loading being equivalent to Haddell's Class X engine. The structural work of the subway was designed in accordance with the specifications in Johnson's Modern Framed
Structured pages 485 to 500 inclusive, the material used being soft steel unless otherwise noted.

**Live Loads.** One track was assumed to carry a live load equivalent to Maddello class X engine. For a span of 48.2 ft., the uniformly distributed live load from the diagram for plate girders is 5975 lbs. per linear foot of track, or 2987 lbs. per foot of length of girders.

**Dead Loads.** The dead loads were computed on the basis of the data given below, viz:

- Weight of rail = 72 lbs per yd.
- 8" x 10" x 8' oak ties spaced 20" c. to c.
- Weight per sq. ft. of box floor = 65.7 lbs
- " foot of one girder = 272"
- Dead load end dead = \( \frac{1378 \times 48.2}{2} \) lbs.

Weights per linear ft. used:

- Raile = 48 lbs.
- Tie = 138 lbs.
- Box Floor = 920 lbs.
- Girder = 272 lbs.
- Total = 1378 lbs.
Floor System. The section of the box floor shown below was designed to resist the bending moment produced by Waddell's Class U engine loading.

Diagram of Wheel Weights. Waddell's Class U Loading
Total weight of one engine and tender = 136 tons.

The actual bending moment produced by the above load acting on the section considered as a beam 14.75 ft. between supports, is 522,400 inch lbs.

The section as designed is capable of resisting a bending moment of 551,200 inch lbs.
Economical Depth of Girder. The economical depth was computed by the following formula, in which the moment of resistance of the web is neglected,

\[ x = 1.27 \sqrt{\frac{m}{f t}} \]

in which \( x \) = depth of girder in inches, \( f \) = allowable fiber stress 7200 lbs. per sq. in. on gross area, \( t \) = thickness of web 7/16 inch, \( m \) = center moment in inch lbs. from live and dead loads.

Dead load per linear foot = 1378 lbs.
Live “ “ “ “ = 2987”

\[ W = 4365” \]
\[ m = \frac{1}{8} W l^2 = 15,211,400 \text{ in. lbs.} \]

\[ x = 1.27 \sqrt{\frac{15,211,400}{7200 \times \frac{7}{16}}} = 88\frac{1}{2} \text{ inches} \]

85 inches will be taken as the economical depth.

*Johnson's Modern Framed Structures, Sec 28, page 300
Length of Flange Plates. The flange plate next to the angles will extend the entire length of the girder, 50 ft 6 ins.

In computing the length of the outside flange plate the following formula from Johnson's Modern Framed Structures, sec. 284, page 302, was used. \( x_2 = l \sqrt{\frac{a}{A}} \) where \( x_2 \) is the theoretical length of the first plate, \( a \) the area of the first plate, \( A \) the total flange area and \( l \) the length of the girder c to c of bearing plates. \( x_2 = 48.2 \sqrt{\frac{1.75}{18.50}} = 24 \text{ ft.} \) theoretical length. In order to get some rivets beyond the theoretical length the plate will be taken 25 ft. long.

Pitch of Rivets. The total shear at the end of the girder 117, 210 pounds and at the center 22650 pounds. The pitch of rivets in the flange...
was determined by the formula \( \rho = \frac{r \times h}{5} \) where 
\( \rho = \) distance c. to c. of rivets, \( r = \) bearing value of 
one rivet in the web plate, \( h = \) distance between 
the rivet lines of the top and bottom flange 
angles, and \( 5 = \) shear at the point considered

\[ \rho = \frac{4590 \times 8\frac{1}{2}}{117210} = 3.18 \text{ ins. spacing at ends of girder.} \]

\[ \rho = \frac{4590 \times 8\frac{1}{2}}{22650} = 16.50 \text{ " " center " " } \]

Knowing the rivet spacing at the center and at 
the ends, a diagram was constructed similar 
to the one described in section 288 page 305 of 
Johnson's Modern Framed Structures and the points 
at which the spacing could be changed were 
determined.

ESTIMATE OF COST.

SUBSTRUCTURE.

11900 cu. yds. excavation @ 20 cents = $2380.
374 " ashlar masonry for abutments $8.50 = 3179.
1070 " squared stone " retaining walls $7.00 = 7490.
98 " concrete (for footings & found. for paving) $4.75 = 465.
854.5 cu. yds. cement wall 6" thick $1.60 = 408.31
1937 " brick paving (2 layers) $1.44 = 2789.28
200 " " " (1 layer) $ .96 = 192.00
16903.59

SUPERSTRUCTURE.

278250 lbs. metal @ 2½ cents = 6956.25
 Erecting 139.5 tons metal $12.00 = 1669.44
 Painting " " $2.70 = 375.62
 9001.31
16903.59
25904.90

Engineering and contingencies 15% = 3885.73
Grand total $29790.63