# DESIGN

FOR A

## SUBWAY ON UNIVERSITY AVENUE

## CHAMPAIGN

BY

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# THESIS

FOR

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This is to certify that the thesis prepared under the
immediate direction of Assistant Professor F. G. Frink by

THOMAS YATES

entitled      DESIGN FOR A SUBWAY ON UNIVERSITY

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is approved by me as fulfilling this part of the requirements for
the Degree of Bachelor of Science in Civil Engineering.

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<center>THESIS.</center>

# DESIGN OF A SUBWAY IN UNIVERSITY AVENUE, CHAMPAIGN,ILL.

It is well known that the losses of life and property in
the operation of railroads in the United States are exceeding-
ly high. To lessen these great losses, railroad companies have
introduced safety devices such as the block system, the airbrake,
the automatic coupler, and scores of other devices.Notwithstand-
ing these improvements many accidents occur, due sometimes to
the failure of the appliance and sometimes to the neglience of
the operator.

Many of these accidents occur at street crossings. An ac-
cident at a grade crossing may be due to one of several causes.
A heavy fog or smoke may obscure an approaching train.A trolley
car may run past the gates due to wet or frosty rails or the
failure of the brake. The gateman may fail to lower the gates
in time. These are only a few of the many ways a disaster might
occur.

It is for the prevention of grade  crossing accidents that
track elevation and depression have been introduced. In isolat-
ed cases where there are a number of tracks to be crossed, as
in the case of a freight yard, it is more economical to build
a viaduct. Where a street crosses a freight yard of a railroad
which is being elevated,a subway is built. It is generally the
practice to construct undercrossings where there are only a few
tracks to be crossed unless the street or road has a rising
grade on each side of the tracks. When the grade crossing has

been eliminated by the construction of a subway or a viaduct, the only danger to traffic in the street is that due to the failure of the superstructure or to the derailment of a train. An advantage is gained in the operation of trains in that there is no speed limit and no limit to the lenght of train which may be hauled.

In the City of Chicago the railroads are compelled by city ordinance to construct subways and bear the cost of construction. The ordinance determines the location of the subway, the width of roadway, the width of sidewalks, the maximum grade of approach, and the final elevation of the base of rail over the center line of the street.

Since the city and not the railroad company decides on the location of a subway, it will not be undertaken in this thesis to show why a subway should be constructed at the crossing of the Illinois Central tracks and University Avenue. To decide this would necessitate an investigation to determine the amount of traffic at this point, the number of accidents which have occurred there, and other things, which is not the work of the engineer of the railroad company. It will be assumed that the City of Champaign has passed an ordinance compelling the railroad company to construct a subway in University Avenue,and that the width of subway,between faces of abutments, shall be sixty-four feet(64), the width of sidewalks ten feet (10), the width of roadway forty-four (44), and the clearance fourteen feet (14).These figures, with the exception of the clearance, are identical with the dimensions of subways constructed in Chicago in streets of the width of University Avenue. Where no

# PAGE FROM TRACK ELEVATION ORDINANCE, CHICAGO, ILL.

Railroad, Chicago and Northwestern Railway and Chicago Terminal Transfer Railroad. (Street, 66 Feet Wide.)

· The depression of street shall not exceed 6.05 feet below the present grade of street, making the elevation of the floor of the subway not less than 6.0 feet above city datum. This level shall extend on the south to the south line of Sixteenth street and on the north 10 feet beyond the north portal of subway. From this level the approaches shall extend on a grade of not to exceed 3.5 feet in 100 feet to a connection with the present surface of street, including the approaches into West Fifteenth place and Sixteenth street.

Width between walls of subway, 66 feet.

Width of roadway, 46 feet in subway.

Width of sidewalks, 10 feet each in subway.

Width of roadway and sidewalks outside of subway shall be the same as they now exist.

The depression of sidewalks shall be uniform with the roadway and about one foot above the level of the same. Two lines of posts may be placed in curb lines and inside thereof and one line of posts in the center of the roadway to support girders.

Clear head room, 12.5 feet.

———

Subway in South Union Street, Under the Chicago, Burlington and Quincy Railroad, Chicago and Northwestern Railway and Chicago Terminal Transfer Railroad. (Street, 66 Feet Wide.)

The depression of street shall not exceed 7.0 feet below the present grade of street, making the elevation of the floor of the subway not less than 5.0 feet above city datum. This level shall extend on the south to the south line of Sixteenth street and on the north 10 feet beyond the north portal of subway.

From this level the approaches shall extend on a grade of not to exceed 3.5 feet in 100 feet to a connection with the present surface of street, including the approaches into West Fifteenth place and Sixteenth street.

Width between walls of subway, 66 feet.

Width of roadway, 46 feet in subway.

Width of sidewalks, 10 feet each in subway.

Width of roadway and sidewalks outside of subway shall be the same as they now exist.

The depression of sidewalks shall be uniform with the roadway and about one foot above the level of the same. Two lines of posts may be placed in curb lines and inside thereof and one line of posts in the center of the roadway to support girders.

Clear head room, 12.0 feet.

———

Subway in Sixteenth Street, Under the Brown Street Tracks of the Chicago, Burlington and Quincy Railroad. (Street, 66 Feet Wide.)

The depression of the street shall be sufficient to make the elevation of the floor of the subway not less than 7.36 feet above city datum. This level shall extend on the east 10 feet beyond the east portal of subway and on the west to the west line of South Morgan street, south of Sixteenth street. From this level the east and west approaches shall extend on a grade of not to exceed 3.0 feet in 100 feet to a connection with the present surface of street.

Width between walls of subway, 66 feet.

Width of roadway and sidewalks in subway shall be the same as they now exist.

The depression of sidewalks shall be uniform with the roadway and about

street cars pass through the subway, the clearance is usually
made twelve feet.Where street cars pass through a subway, it is
the practice to make the clearance 13'-6". In this case it is
necessary to make the clearance 14'-0" to provide for inter-
urban cars. The Test Car of the Electrical Eng. Dept. of the
University of Illinois was measured for the purpose of ascer-
taining the clearance required. The distance from the top of
the knuckle at the base of the trolley to the top of rail was
found to be 13'-10". This is also the clearance of the door
of the car barn which admits the largest cars in the service.
The grade of approach and the proposed base of rail will be as-
sumed after a consideration of physical conditions.

The thesis shall consist of five parts as follows;

(1) A plat of that part of the city near the crossing,for
use in determining the grade of approach and the length of the
subway.

(2) A Filing Plan, or General Plan similar to a plan
which is filed with the Department of Track Elevation in the City
of Chicago. It shows the general plan of the subway, a profile,
and a cross-section.  There are also shown, the location of
water pipes, sewers, gas mains and catch basins. It must be ap-
proved by the Commissioner of Public Works,the Superintendent
of Track Elevation, the Superintendent of Streets,the Engineer
of Water Pipe Extension, and the Engineer of Sewers.

(3) A general plan of the bridge superstructure which is
made to submit, with specifications, to bridge companies or con-
struction companies, who desire to bid for the contract.

(4) A masonry plan of one abutment.

(5) An estimate of the cost of the subway.

# PART ONE.

## DETERMINATION OF LENGTH OF SUBWAY AND GRADE OF APPROACH.

To discuss the possible length of the subway and the grade of approach reference must be made to Sheet 1. Before proceeding, it will be explained how this plat was drawn up.

As a general thing sufficient data for making a plat may be obtained at the office of the County Recorder. In this case the data was not obtainable. A gentleman employed in the office of the County Recorder, who had been in the abstract business several years, informed the writer that he had never been able to obtain the dimensions of fractions of lots made by the vacation of property for the extension of University Avenue between First Street and Neil Street. In the following books in the Recorder's office, data was obtained from which that part of the city could be plotted before University Avenue was extended:

Book H,    Page 33.
"    T,      "    49.
"    4,      "    96.
"    U,      "    548.

After the plat had been made from this data, furthur information was found in the office of the City Engineer from which University Avenue was located.The plat was checked up in the field by running the center lines of University Avenue and First South Street,and a base line along the right of way of the Illinois Central Railroad, thus forming a triangle. After the base line had been plotted, the lengths of the sides of the triangle, by scale, were checked with the computed lengths from

the notes taken in the field. The plat was found to be suffi-
ciently accurate for the purpose here intended. In track eleva-
tion work in Chicago the right of way and street lines are lo-
cated by a competent surveyor before work is begun on the plans.
It would be necessary to do the same in this case. The location
of the tracks, depot, freight house, etc., were obtained from a
survey in which all distances and plusses were referred to the
base line along the Illinois Central right of way.

In this design it will be assumed that the tracks shall
remain at their present elevation for the following reasons;

First; The station is located near the crossing. To ele-
vate the tracks would make it necessary to elevate the station.

Second; If the passenger tracks were to be elevated, the
freight tracks and the freight house would have to be elevated
or relocated.

Third; To raise the tracks to any great extent would neces-
sitate changes in the round house layout and the existing sub-
ways, probably including the Green Street subway.

In order to have the grade as light as possible, a shallow-
floored bridge will be considered.By a shallow floor is meant
a floor without ballast, the rails resting on rail plates which
rest on a deck plate supported by I beams between the girders.
Such a floor will have a distance of about 1'-9" between the
clearance line and the top of rail.(See article by A. F. Rob-
inson in Journal of Western Society of Engineers, Vol. X, No.3
page 239.) The distance between the top of rail and the crown
of the street below would be 1'-9" plus the clearance, 14'-0",
or 15'-9". Considering the ground as being practically level,

the length of an approach on a 5% grade would be about 316 ft.
The length of an approach on a 3.5% grade ( the grade usually
specified for subways in Chicago) would be about 450 feet.

Refering to Sheet 1, it will be seen that there are two
team tracks or switch tracks crossing University Avenue about
150 feet from the passenger tracks. It is thought necessary to
cut these tracks for the reason that an approach with a grade of
5%, designed to provide clearance under these tracks would make
it necessary to depress Market Street and Water Street consider-
ably. With these tracks cut the heads of the approaches would
come near the intersections of these streets with University
Avenue and little depression would be necessary.  These team
tracks are connected with the main line north and south of Un-
iversity Avenue and switching would not be seriously interfered
with. Moreover, a considerable saving in the cost of the sub-
way would be made by eliminating bridges for these tracks. The
writer has in mind an instance where the tracks in a coach yard
were run into ladder tracks on each side of the street rather
than pay the cost of bridging over the street.

It will be seen that if the tracks remain at their pres-
ent elevation and the team tracks be cut, a subway constructed
on a grade of 5% would interfere only with Oak Street on the
east and Chestnut Street on the west. These streets have little
traffic and are used mostly for teaming purposes. It would not
interfere with teaming to any great extent if these streets
were not continuous across University Avenue.Material to be
hauled to Urbana could be switched on the east track and mater-
ial for Champaign on the west track.  The approach to the freight

house could be constructed as shown on Sheet 2.

In view of the number of cases where 5% grades exist it is thought that such a grade would not be objectionable in this design.At 16th Street, in Chicago, the Wentworth Avenue cars, which are fully as large as the Danville and Champaign Interurban cars, runder the tracks of the Illinois Central Railroad and over the tracks of the Chicago & Western Indiana Railroad with a grade of 5% between.Moreover, the grade is all on one side and the alignment is such that a car cannot gather momentum for the ascent. This would not be the case in the University Avenue Subway where the approaches are of the same grade and about the same length. The momentum of the car would assist greatly in carrying it up the approach. The approach to the team tracks in the Englewood Yard of the Chicago & Western Indiana Railroad is on a grade of 5%. Some of the approaches to the bridges and viaducts in Chicago are between 4% and 5%. The west approach to the subway in Green Street, Champaign, is on a grade of 5%. A lighter grade could not be obtained for the University Avenue subway without elevating the tracks or depressing Market Street and Water Street.

It will be assumed then, that the grade of the approaches shall be 5%. Sufficient information is given in the preceding pages to proceed with Part 2, the General Plan of the Subway.

# PART TWO.

## GENERAL PLAN OF SUBWAY.

LOCATION OF STREET CAR TRACKS:

The clearance required for subways in streets without car tracks is 1/2 or 2 feet less than that required for subways having car tracks. It would be desirable then, to locate the car tracks on one side of the subway and the roadway on the other, each having the required clearance.  Such an arrangement applied in the design of a subway in University Avenue would reduce the grade of the roadway about 0.7%, if the clearance of the roadway were made 11'-6". A similar design was carried out in the construction of the subway in Clark Street, near 16th. Street, Chicago. The street at that point is however, 80 feet wide.

Let such an arrangment be considered for a subway in University Avenue. The street is 64 feet wide and the width of the sidewalks, say, 8 feet each. Adding about 2 feet for posts and footings, there is left 46 feet for roadway and car tracks. The clearance required for two car tracks would be about 26 feet. It will be seen that there is left about 20 feet for the roadway, which is not enough. It is the opinion of the writer that the best location for car tracks is in the middle of the street, one track on each side of the center line. With the tracks in this position, vehicles may use the space occupied by the tracks and the traffic on each side of the street will be in the same direction, i.e., traffic keeping the right hand side of the street.

SIDEWALKS:

It is not necessary to have a clearance of more than 8 feet

for the sidewalks. This is the clearance provided in the Green
Street subway. The slope should not be more than one- half inch
in one foot. Refering to Sheet 2, it will be seen that a side-
walk continued on this slope each side of the bridge would meet
the present sidewalk some distance beyond Oak Street on the east
and Chestnut Street on the west. If the sidewalk were to be
constructed without steps it would be necessary to build prop-
erty walls at the north-east and south-east corners of Univer-
sity Avenue and Oak Street, and at the north-west corner of Un-
iversity Avenue and Chestnut Street. Entrance into the subway
from Oak Street and Chestnut Street would be cut off. To avoid
the construction of property walls and to provide entrance into
the subway from Oak Street and Chestnut Street, steps are located
as shown in Sheet 2. The difference of elevation made up by
the steps would be about five feet. A flight of steps of this
height is not thought to be intolerable. A similar case came
up in the construction of the C. R. I. & P. subway in Archer
Avenue, Chicago. Steps were used to avoid interference with ex-
isting structures and to give the sidewalk less slope.
ROADWAY:

The crown of the street will be 9" above the gutter line
except at a point in the middle of the subway, where the gutter
line is made 6" to drain the water into the catch basins. A
vertical curve forty feet long is provided at the bottom of each
approach. A curve of this lenght will provide clearance for
street cars if the point of intersection of the grade lines is
located 20 feet outside the center line of the outside girder.

RETAINING WALLS:

Walls are shown on Sheet 2. It is not necessary to construct a wall on the street line between the abutment and the steps since there is nothing to prevent the earth from running back on its natural slope from the sidewalk. The retaining wall under the bridge is buttressed to support the column. Details are shown on Sheet 4. This method of construction was used in the 63rd. Street subway, Chicago, under the tracks of the Illinois Central Railroad.

DRAINAGE:

It was found that the bottom of the proposed subway is at the same elevation as the bottom of the Boneyard Branch where it crosses University Avenue. Drainage into this then, would be impossible. Neither would it be possible to drain the subway into any of the present sewers. It becomes necessary to pump the water out of the subway. The drainage plan shown on Sheet 2 consists of four catch basins drained by a 9" pipe which is run under the south abutment into a sump which may be located wherever convenient. The cost of constructing the sump and installing pumping machinery will add considerably to the cost of the subway but it appears to be the only way out of the difficulty. Catch basins should be built near the head of each approach to prevent the water from running into the subway.

WATER AND GAS MAINS:

The present mains, an 8" water main and a 6" gas main, are placed under the sidewalk as shown on Sheet 2.

In a subway constructed by the C. M. & St. P. R'y. at Mason City, Ia., the mains were arranged in the same way.

# PART THREE.

## DESIGN OF BRIDGE.

Where there are no limiting conditions it is becoming the practice to use ballasted floor bridges in track elevation. A ballast floor is desirable for the freedom from noise and the ease of maintaining the alignment of the track. In Part 1 the advantage of a shallow floor was shown for this particular case. 12" I beams will be used in the floor system. The floor could be made with less depth by the use of built up sections but it would not be as economical.

The bridge will be designed for Cooper's "E 50" loading and in accordance with the specifications of the Chicago & Western Indiana Railroad, one of the roads which has done considerable track elevation in Chicago.

STRESSES IN LONG GIRDER OR GIRDER BETWEEN THE CURB AND THE CENTER LINE OF THE STREET:

The span is 23.5 divided by the sine of 72$^{\circ}$ = 24.7 feet. The angle between the center line of the bridge and the center line of the street is approximately 72$^{\circ}$. It might vary a few minutes with the re-alignment of the track but the stresses would not be materially affected. Where a bridge comes on a flat curve as in this case, it is the practice to make the center line of the bridge a straight line. With a straight center line the cost of the work in the shop is greatly lessened.

The maximum moment occurs when wheel 3 is 3.75 feet to the left of the middle of the girder (Johnson's Framed Structures, page 76.) With the loads in this position, the live load reac-

tion at the left end is 55 060 lbs. The maximum moment will be
under wheel 4 and will be equal to,

$$(55\ 060 \times 13.60 - (25\ 000 \times 10 + 25\ 000 \times 5\ )) \times 12,$$

or 4 485 000 in. lbs.

For an interior girder or girder between tracks, the moment will be,

$$2 \times 4\ 485\ 000 \quad \text{or} \quad 8\ 971\ 000 \text{ in. lbs.}$$

IMPACT; As required by the specifications, "add 25% to live
loads in figuring stresses in spans 10 feet long or under, and
reduce this per cent in proportion as the length of span increas-
es, until at 85 feet no additional stress is added."

The stress due to impact is 20% (for a span of 24.7 feet)
of the maximum live load moment or 1 794 000 in.lbs.

For an exterior girder the stress due to impact is one
half of this or 897 000 in.lbs.

DEAD LOAD; The dead load per foot of track is estimated at
1 000 lbs. as follows;

Metal floor, including brackets, plates and
connections, ---------------------------------------------600 lbs. per foot

Deck Plate, 5-16",-----------------------------------150 "  "  "

Web Plate, 31" x 1-2",--------------------------- 53 "  "  "

Four Angles, 6" x 6" x 3-4"-----------------------114 "  "  "

Rails,------------------------------------------------ 50 "  "  "

Cover Plates,----------------------------------------- 33 "  "  "

1000 "  "  "

The dead load moment is,

$$\frac{1000 \times (24.7)^2 \times 12}{8} \qquad 915\ 000 \text{ in.lbs.}$$

For an exterior girder the dead load moment is one half

of this or, 457 500 in. lbs.

END SHEAR; LIVE LOAD,   The maximum end shear will occur when
wheel 2 is about to pass over the center line of the columns.
With the loads in this position the left reaction is 70500 lbs.

For an interior girder the end shear is twice this or,
141 000 lbs.

IMPACT:   The end shear due to impact is 20% of  141 000 or,
28 000 lbs.

The end shear due to impact for an exterior girder is
14 000 lbs.

DEAD LOAD; The dead load end shear is ,

$$\frac{1\ 000 \times 24.7}{2}$$   or,   12 000 lbs. foran interior

girder,    and

$$\frac{1\ 000 \times 24.7}{2}$$   or,   6 200 lbs. for an exterior

girder.

STRESSES IN SHORT GIRDER OR GIRDER BETWEEN COLUMN AND
ABUTMENT.

For short spans the maximum load generally applied is
two loads of 32 000 lbs. each 7 feet apart, for one rail.

The length of the span over the sidewalk is 10 feet divid-
ed by the sine of 72° or 10 ft. 6 in.

MAXIMUM MOMENT; LIVE LOAD,  The maximum live load moment occurs
when one of the axle loads is in the middle of the span, and is
equal to ,

16 250 x 5.25 x 12   or   543 600 in. lbs.

For an interior short girder the maximum moment is,

2 x 543 600   or   1 087 200 in. lbs.

IMPACT;  The moment due to impact is

543 000 x 0.25   or   135 000 in. lbs. for an exterior girder, and

1 087 200 x 0.25   or 271 800 in. lbs. for an interior girder.

DEAD LOAD;   The dead load moment is,

$$\frac{1\ 000\ \times\ (10.5)^2\ \times\ 12}{8}$$

or,

165 000 in. lbs.

For an exterior girder the dead load moment is one half of this or, 82 700 in. lbs.

END SHEAR; LIVE LOAD,  The maximum end shear occurs when one of the axle loads of 32 500 lbs. is about to pass off the girder. The other load will be 7 feet from the end of the girder. With the loads in this position, the left reaction or end shear is 43 300 lbs.

The end shear for an interior girder is twice this amount or 86 600 lbs.

IMPACT;  The end shear due to impact is,

0.25 x 43 600 or 10 800 lbs. for an interior girder and

0.25 x 86 600  or, 21 600 lbs. for an exterior girder.

DEAD LOAD;   The dead load end shear is,

$$\frac{(10.5\ +\ 24.7\ )\ \times\ 1\ 000}{2}$$

or,

17 600 lbs.

For an exterior girder the end shear is one half this amount or,  8 800 lbs.

## STRESSES IN COLUMN ON THE CENTER LINE OF THE STREET.

LIVE LOAD; The maximum load on a column on the center line of the center line of the street will occur when wheel 4 is over the column. With the loads in this position, the unit load on the left of the column is $\frac{62.5}{24.7}$ or 2.5, with wheel 4 directly over the column, or, $\frac{87.5}{24.7}$ or 3.5, with wheel 4 a little to the left of the column. The unit load on the two middle spans is $\frac{145.5}{49.4}$ or 2.9. The condition conforms to the criterion for maximum column or floor beam reaction. (Johnson's Framed Structures, page 76.) With the loads in this position the column reaction is 93 900 lbs.

The load on an interior column is twice this amount or 187 800 lbs.

IMPACT. The stress due to impact will be taken as 13% of the live load stress. This percentage was used in designing bridges for the C. & W. I. R. R. Track Elevation.

For an interior girder, the stress due to impact is,

0. 13 x 187 800 or 24 400 lbs.

For an exterior girder the stress due to impact is,

0.13 x 93 900 or 12 200 lbs.

DEAD LOAD; The dead load stress for an exterior girder is,

$\frac{1\ 000\ x\ 24.7}{2}$ or 12 400 lbs.

The dead load stress for an interior girder is,

$\frac{1\ 000\ x\ 24.7}{2}$ or 24 700 lbs.

## STRESSES IN COLUMNS AT THE CURB LINE.

LIVE LOAD; The maximum load on a column at the curb will occur when wheel 3 is over that column. With the loads in this position the unit load is, $\frac{35}{10.5}$ or 2.4, with wheel 3 direct-

ly over the column, and $\overline{\dfrac{50}{10.5}}$ with wheel 3 a little to the left

of the column. The unit load on the two end spans is $10.\overline{\dfrac{132.5}{5+24.7}}$

or 3.7. This condition conforms to the criterion for maximum

column concentration. With wheel 3 over the column the column

reaction is 77 100 lbs.

For an interior column the reaction is twice this amount

or 152 200 lbs.

IMPACT; The stress due to impact is,

0.13 x 77 100   or   10 000 lbs.,

for an exterior column and,

0.13 x 154 200   or 20 000 lbs.

for an interior column.

DEAD LOAD;   The dead load reaction for an exterior column is,

$$\frac{(10.5 + 24.7) \times 1\ 000}{2 \times 2}\ \text{or}\ \ 8800\ \text{lbs.}$$

The dead load reaction for an exterior column is twice

this amount   or   17 600 lbs.

<div align="center">SUMMARY.</div>

For the summary see Sheet 3.

<div align="center">DESIGN OF INTERIOR LONG GIRDER.</div>

The depth of the girder should not be less than one tenth

of the span. ( Johnson's Framed Structures. ) In designing gir-

ders for a subway bridge, another condition must be taken into

consideration, which is the distance of the subway from the

station. Where a subway is to be built close to a station, there

will be great danger of a passenger being caught between the

girder and the car if a deep girder is used. At the 63rd. St.

subway of the C. & W. I. R. R.  it was found necessary to remove

the deep girders and replace them with shallow girders support-

ed on posts, thus eliminating all danger from this source.

One tenth of the span of a long girder is about 2'-6". To give a little greater area for shear the web plate will be considered as being 31" deep, or 31" back to back of flange angles.

Let a section made up as follows be considered.

Web Plate, 31" x 3-4",

Flange angles, 6" x 6" x 3-4",

Cover Plates,

      Top Flange,  Top plate, 14 1-2" x 1-2",

                 Middle plate, 14 1-2" x 1-2",

                 Bottom plate,  14 1-2" x 5-8",

Bottom Flange;  Same as top flange, excepting the plate next to the flange angles, which is made 20" wide to provide for riveting the I beams of the floor.

The distance between the neutral axes of the flanges is 30.46 in.

The flange stress is,

$$\frac{11\ 680\ 000}{30.46} \quad \text{or} \quad 383\ 450 \text{ lbs.}$$

The gross area of the flange is 40.44 sq. in. Deducting for two rivets in each cover plate and one in each flange angle (rivets staggered in flanges), and adding 1-8 of the gross area of the web, there is left the net area of 38.59 sq.in. Dividing the flange stress by the net area, the unit stress is found to be 9 940 lbs. per sq. in.

The maximum end shear is 181 400 lbs. The gross area of the web is 23.25 sq.in. The net area, deducting for two rivets is 21.75 sq.in. Dividing the maximum end shear by the net area the unit shear is found to be 8 340 lbs. per sq. in.

Using a section made up as described on the preceding page, it is seen that the unit stresses are not excessive and the section will be adopted.

### DESIGN OF LONG GIRDER (EXTERIOR)

The depth of the web will be made the same as that of an interior girder, 31 in.

Let a section made up as follows be considered.

Flange angles, 6" x 6" x 1-2"

Web Plate, 31" x 3-8"

Cover Plates;

Top Flange, Two plates 14 1-2" x 3-8"

Bottom Flange, Same as the top flange except the plate next to the flange angles, which is made 17 1-2" wide to provide for rivets for the I beams in the floor.

The distance between the neutral axes of the flanges is 29.64 in. The flange stress is,

$$\frac{5\ 839\ 500}{29.64} \qquad \text{or 197 000lbs.}$$

The gross area of the flange is 22.42 sq.in. Deducting for two rivets in each cover plate and one in each flange angle, and adding 1-8 of the gross area of the web, there is left the net area of 21.35 sq.in.

The unit stress is the flange stress divided by the net area or about 9200 lbs. per sq. in.

The maximum end shear is 90 700 lbs. The gross area of the web 11.63 sq.in. The net area, deducting for two rivets 10.97 sq.in. The unit shear is the maximum shear divided by the net area or 8 300 lbs. per sq. in.

The above section for a long exterior girder gives safe

unit stresses and the section will be adopted.

### DESIGN OF SHORT GIRDER.( INTERIOR )

The depth of the short girder will be made the same as the depth of a long girder for the sake of appearance.

Let a section made up as follows be considered.

Web Plate, 31" x 1-2",

Flange Angles, 6" x 6" x 1-2"

Cover Plates;

Top flange, 14 1-2" x 3-8",

Bottom Flange, 20" x 3-8", to provide for rivets for I beams in the floor.

The distance between the neutral axes of the flanges is 28.84 in.

The flange stress is,

$$\frac{1\ 524\ 400}{28.84} \quad or \quad 52\ 600\ lbs.$$

The gross area of the web is 16.96 sq.in. Deducting for two holes in the cover plate and one in each of the flange angles, and adding 1-8 of the gross area of the web, there is left the net area of 16.65 sq.in.

The unit stress is the flange stress divided by the net area or about 3200 lbs. per sq. in.

The maximum end shear is 125 800 lbs. The gross area of the web is 15.50 sq.in. Deducting for two rivets, the net area is 14.62 sq. in.

The unit shear is 8 600 lbs. per sq. in, which is within the allowable limit.

## DESIGN OF SHORT GIRDER.(EXTERIOR)

It was found that with the same flange sections as the interior girder and a web plate 31" x 3-8", the unit stresses were well within the allowable limit.

## DESIGN OF INTERIOR COLUMN.

It is desirable to have a wide column, since each column must support one end of each of two adjoining girders. A column made up of Z bars will give a wider bearing at the top than one built up of channels to carry the same load.

It is necessary to have the radius of gyration greater about one axis than it is about the other on account of the lateral bracing between the columns.

Let a section made up as follows be considered.

    4 Z Bars, 6" x 3 1-2" x 3 1-2" x 3-8",

    1 Plate,  11" x 1-2",

The radius of gyration about an axis through the center of the column and parallel to the plate is 3.51.  The radius of gyration about an axis thruogh the center of the column at right angles to the plate is 5.05.  The length of the column below the lateral bracing is 91 inches and the length of the column neglecting the lateral bracing is 158 in.

In designing columns the specifications require the use of the following formula,

$$\underline{P} \text{ is equal to } 1 + \frac{\frac{10\ 000}{L}}{40\ 000\ R}$$

where L is the length in inches and R the radius of gyration.

The column may fail by bending about the axis parallel to the plate, which will be called for convenience, Case 1, or, it may fail about the axis at right angles to the plate, which will be called Case 2.

CASE 1; Substituting for L and R the values 91 and 3.51, $\underline{P}$ is found to be 9993 lbs. per sq. in.

CASE 2; Substituting for L and R the values 158 and 5.05, $\underline{P}$ is found to be 9992 lbs. per sq. in.

In either case the area required is the maximum load, 236 900 lbs., divided by the allowable unit stress $\underline{P}$

The area required in each case is 23.71 sq. in. The gross area of a section of the column is 23.86 sq. in.

It is seen that the column is equally strong about both axes.


DESIGN OF EXTERIOR COLUMN ON THE C. L. OF THE STREET AND ALL COLUMNS AT THE CURB LINE.

The section for the above columns will be made the same as the section for an interior column on the center line of the street except the plate which will be made 11" x 3-8" instead of 11" x 1-2".

# INVESTIGATION OF I BEAMS IN FLOOR.

The size and the spacing of the I beams is the same as that used in a number of cases in Chicago track elevation. The beams used are 12" I beams at 45 lbs. per foot, and the spacing is about 1'-3" center to center. The loading applied is one of the axle loads of 32 500 lbs. for one rail.

With the above spacing it may be safely assumed that an axle load is distributed over three I beams which would make the load on one I beam,

$$\frac{2 \times 32\ 500}{3} \quad \text{or 21666 lbs.,}$$

which is concentrated at two points, one under each rail. The span is the distance center to center of flange angles or 12'-5". The moment due to the above loading is 474 500 in.lbs., making the extreme fibre stress about 10 000 lbs. per sq. in. A maximum fibre stress of 16 000 lbs. per sq. in. is considered safe and the dead load is not sufficient to bring the extreme fibre stress up to this amount.

## PART 4, DESIGN OF ABUTMENT.

Abutments are sometimes built with the face vertical and sometimes with a face having a batter. The object in giving a batter to the face is to give greater stability against earth pressure and to bring the center line of bearings approximately over the middle of the footing. Low abutments are usually built with vertical faces. In this design, since the distance from the sidewalk to the bridge seat is only about 7'-3", the face will be made vertical.

The bottom of the footing should come below the frost line. On account of the protection of the earth under the sidewalk, there is no danger from frost and the bottom of the footing is made Elev. 712.50, one foot below the crown of the street. If it were made higher there would be danger of the pressure of the abutment forcing the curb wall out. The elevation of the bottom of the footing of the curb wall is made 709.00, four and one half feet below the crown of the street. With the depth of footing 3 feet, sufficient space is provided for the paving.

The elevation of the bridge seat was determined as follows;

| 713.50, | Elevation of crown of street. |
| 14.00, | Clearance. |
| 1.32, | for rivet heads, cover plates, flange angles, I beams, deck plate, and rail plate. |
| 728.82, | Elev. base of rail at C. L. of street. |
| 0.17, | Difference of elev. due to grade of 0.5%. |
| 728.65 | |
| 1.99, | for deck plate, rail plate, I beams, and sole plates |
| 726.66, | Elevation of bridge seat. |

The width of the neatwork at the footing is made one half of the distance between the top of the footing and the base of tie. (C. & W. I. R. R. Standard.)

```
728.65,  Base of rail.
   .50
728.15,  Base of tie.
715.50
2) 12.65
   6.33,  or 6'-4", width of neatwork at footing.
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The projection of the footing beyond the neatwork was made 1'-6" in front and 6" in back, which moves the middle of the footing nearer the C. L. of bearings of the girders.

The wings were designed for a slope of 1 1/2 to 1, beginning at a point on a level with the base of rail and 9'-0" from the center line of track. (C. M. & St. P. Standard.) The wings were made inclined instead of stepped to fit the slope better and to give a better appearance in the front elevation.

The sidewalk elevation was determined as follows;

728.65,  Base of rail.

1.19,  for rail plate, deck plate, I beams, flange angles, cover plate, and rivet heads.

727.46

8.00,  Clearance.

719.46

0.26,  for slope of sidewalk in 8'-6" at 3/8" per foot.

719.20,  Elev. of sidewalk at inside edge of top of curb wall.

The batter of the front of the curb wall was made one and one-half inches per foot. The top of the column footing was made three feet square, which is about twice the area required to give a pressure of 350 lbs. per sq. ft. as required by the specifications. It was made large to give greater stability and, with the batter, to give the necessary spread for the foundation.

The load per sq. foot for the abutment is about one ton and includes the weight of the concrete, the weight of half the side-walk spans, and a live load of 10 000 lbs. per lineal foot of track.

The load per square foot for the column footing is about one and one-quarter tons.

## PART 5, ESTIMATE OF COST.

The cost of a subway for three proposed tracks, instead of one for the four present tracks, is made for the reason that the present track could be made to turn out from the freight-house lead at a point south of the street and the cost of a bridge for this track avoided.

The following is a detailed estimate of the cost;

247 650 lbs. of steel at 3 3/4 cents,....................$9 287.00

  5 700  "    " castings, at 2 cents,.....................   114.00

15 780 cu.yds. of excavation at 40 cents,............. 6 312.00

   970  "  "  " concrete at $6.00,.................... 5 820.00

  2 300 sq. yds. of brick paving at $2.00,.............. 4 600.00

  7 200 sq. ft. of cement sidewalk at 13 1/2 cents,....   972.00

   700 lin.ft. of 8" water pipe relocated at $1.00,...   700.00

   700  "  " of 6" gas pipe     "     " $0.75,...   525.00

     8 catch basins rebuilt at $10.00,.................    80.00

  1 240 lin. ft. of pipe railing at 25 cents,..........   310.00

   240  "   "   " temporary bridge at $5.00,.......... 1 200.00

      Pumping Machinery and Sump,.....................   500.00

                                  $30 420.00

      Engineering and Superintendence, 5%,........... 1 521.00

      Total,.........................................$31 941.00
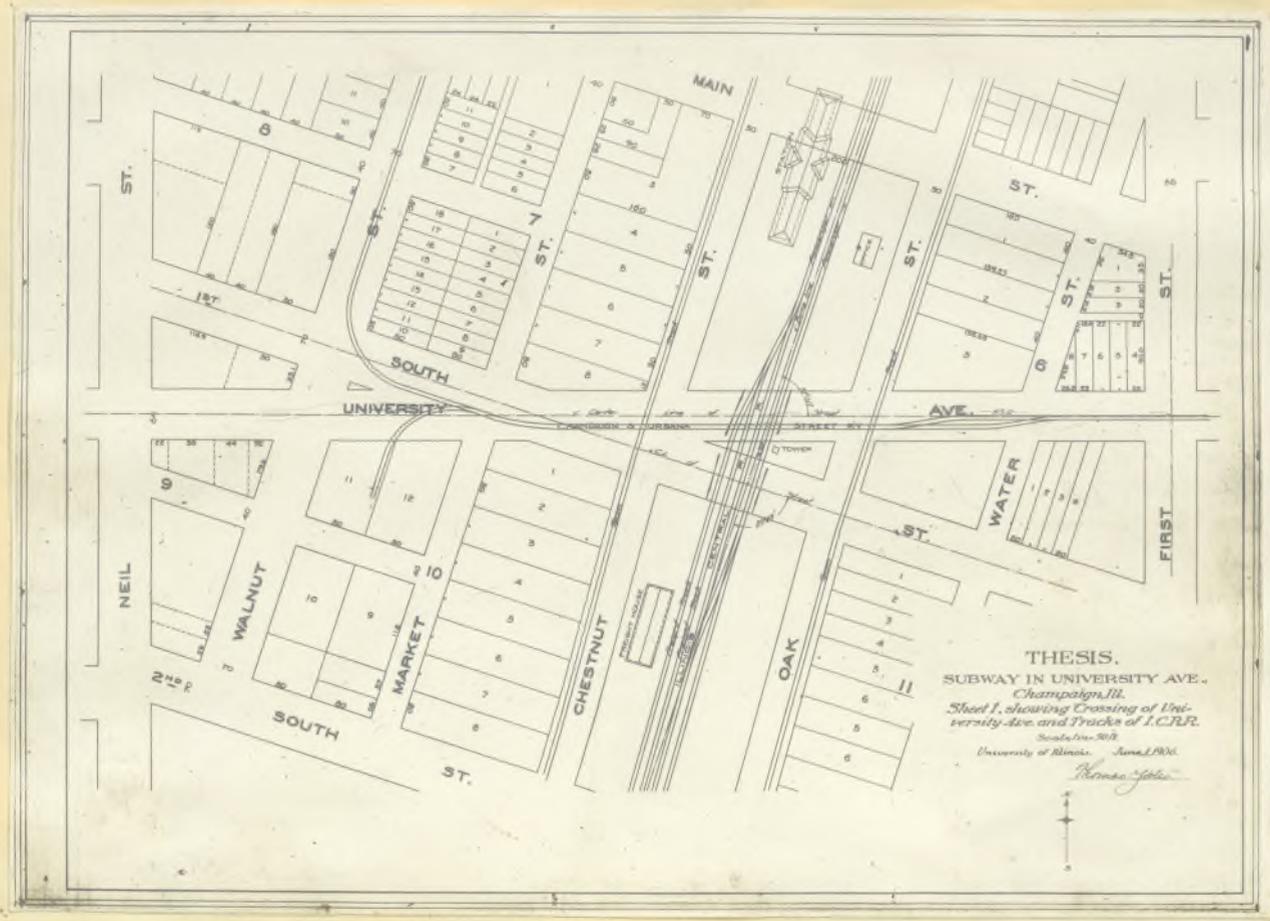
THESIS.
SUBWAY IN UNIVERSITY AVE.
Champaign, Ill.
Sheet 1, showing Crossing of University Ave. and Tracks of I.C.R.R.
Scale 1 in. 50 ft.
University of Illinois.   June 1, 1906.

THESIS.
SUBWAY IN UNIVERSITY AVE.,
Champaign, Ill.
Sheet 2, General Plan of Subway.
University of Illinois, June 1, 1906.
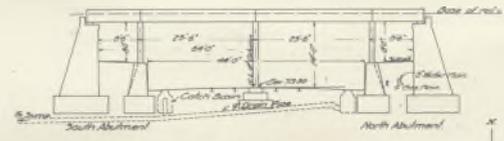
CROSS SECTION.
Scale 1in = 4ft
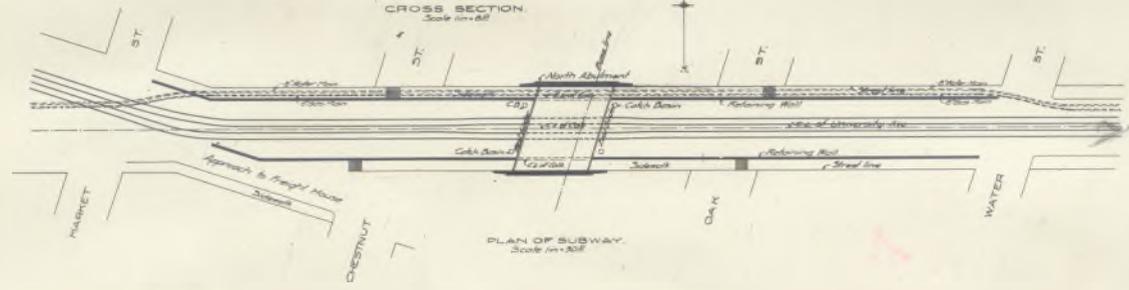
PLAN OF SUBWAY.
Scale 1in = 30ft

PLAN

COOPER'S E 50 LOADING
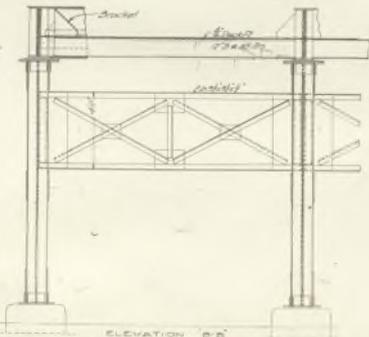
SECTION "A-A"

ELEVATION "B-B"

ELEVATION PERPENDICULAR TO C.L. OF BRIDGE.

END ELEVATION
ABUTMENT.

NOTE.
Bench Mark, Bolt S.W. Cor. City Hall, Elev 711.00
Grade on Bridge, 0.8% rising north, falling
south from C.L. of Street.
Load per sq ft.
Abutment, 1 ton.
Col. Footing, 1½ tons.

END ELEVATION
COLUMN FOOTING.

PLAN OF ABUTMENT AND COLUMN FOOTINGS.

ELEVATION OF COLUMN FOOTINGS.

E ——— W
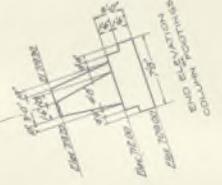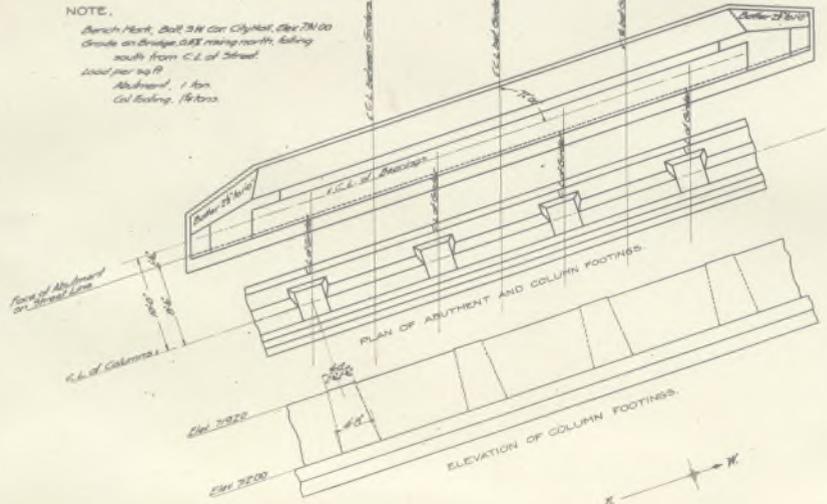
THESIS.
SUBWAY IN UNIVERSITY AVE.
Champaign Ill.
Sheet 4, Design of South Abutment.
University of Illinois, June 1, 1906.
Scale ¼=1'0"
Thomas Yolks