REPORT UPON
TUNNEL VENTILATION OF BALTIMORE & OHIO RAILROAD TUNNELS
BETWEEN
GRAFTON AND PARKERSBURG - WEST VIRGINIA

BY

FRANK JEROME BACHELDER

A THESIS SUBMITTED

FOR THE DEGREE OF CIVIL ENGINEER

CIVIL ENGINEERING COURSE

UNIVERSITY OF WISCONSIN

1917

REPORT

to

THE PUBLIC SERVICE COMMISSION

STATE OF WEST VIRGINIA

upon

TUNNEL VENTILATION

BALTIMORE & OHIO RAILROAD TUNNELS

between

GRAFTON & PARKERSBURG, W. VA.

F. J. BACHELDER
Consulting Engineer

Chicago, Illinois
1916.

March
10th,
1916.

Honorable Chairman and Members of the
Public Service Commission,
State of West Virginia,
Charleston, West Virginia.

Gentlemen:

I respectively submit herewith, a report upon Tunnel Ventilation in connection with the Investigation of the Baltimore & Ohio Railway Tunnels, between Parkersburg and Grafton, West Virginia, in accordance with your request of February 4th, 1916.

It has been the endeavor to pursue such lines of investigation, as seemed necessary to a broad consideration of the subject.

I wish to express my appreciation of the valuable co-operation of Mr. Winters, of your staff, in carrying on this investigation.

Throughout this investigation, the Company and its employees have assisted and co-operated in the work whenever requested and I take this opportunity of acknowledging the courtesy extended by the Company and its employees towards solving the problem.

Respectfully submitted,

F. J. Bachelder
Consulting Engineer.

FJB/GAU

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INTRODUCTION

A complaint received by the West Virginia Public Service Commission from the employees of the Baltimore and Ohio Railroad, operating trains between Grafton and Parkersburg, states the natural ventilation in several of the tunnels is insufficient. This question was taken up informally by the Public Service Commission with the officers of the Railroad, without obtaining satisfactory working conditions, it is alleged by the employees.

The object of this study is to determine whether the complaint as to improper ventilation is just and what action should be taken to remedy the alleged conditions, should they be found unfit for the men to perform their duties with safety and reasonably free from the extreme discomforts from the heat and gases, said to exist.

HISTORICAL

Tunnels on the Baltimore & Ohio Railroad between Grafton and Parkersburg were constructed and put in service about 1866. These tunnels, as constructed, can be said to have made reasonable provision for sufficient space for the small locomotive then operated. Topography of the country through which the railroad is built is rather rough, and the grades, especially at that early date, were as good as could be reasonably built with the capital available and the traffic that was then to be handled. Since the construction, the sections of the tunnel have not been enlarged nor the grades improved.

Locomotives used in the early days in freight service did not exceed from 40 to 50 tons in weight and hauled 450 tons of freight, since which time phenomonal developments in the size of the locomotives have taken place. The size and tractive power of the locomotive has increased two fold or more until at the present time a 100 ton locomotive with a tractive power of 42,168 pounds, hauling 1000 to 1050 tons of freight, is operated in this district.

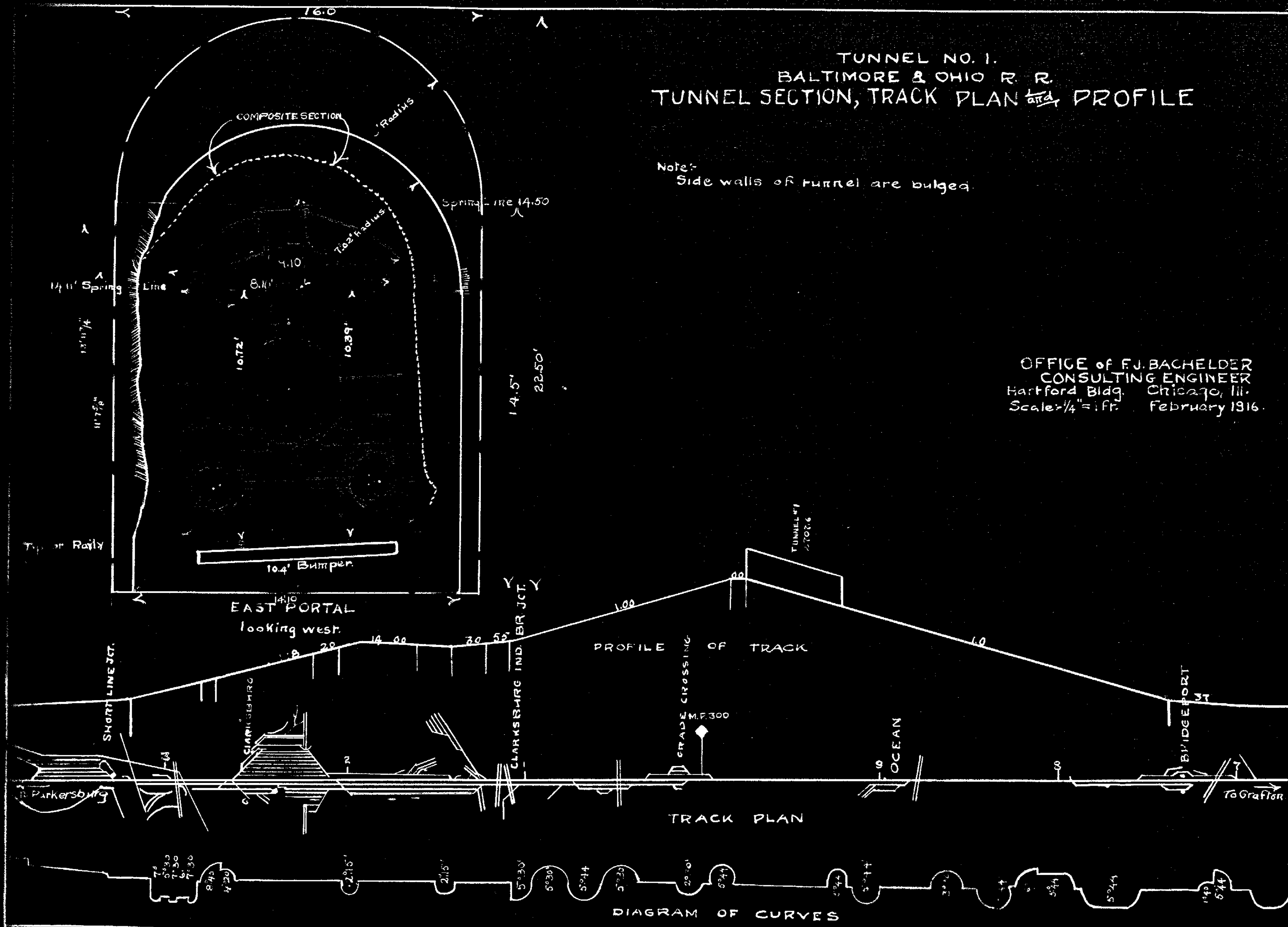
Tonnage handled by the freight trains has kept pace with the size of the locomotive. In the early days it was not a question of the capacity of the facilities of a railroad and the then small engines easily took care of the traffic offered. Modern methods of operation have brought about a maximum train load, until trains now are operated with two one hundred ton locomotives, one at the head and one at the rear.

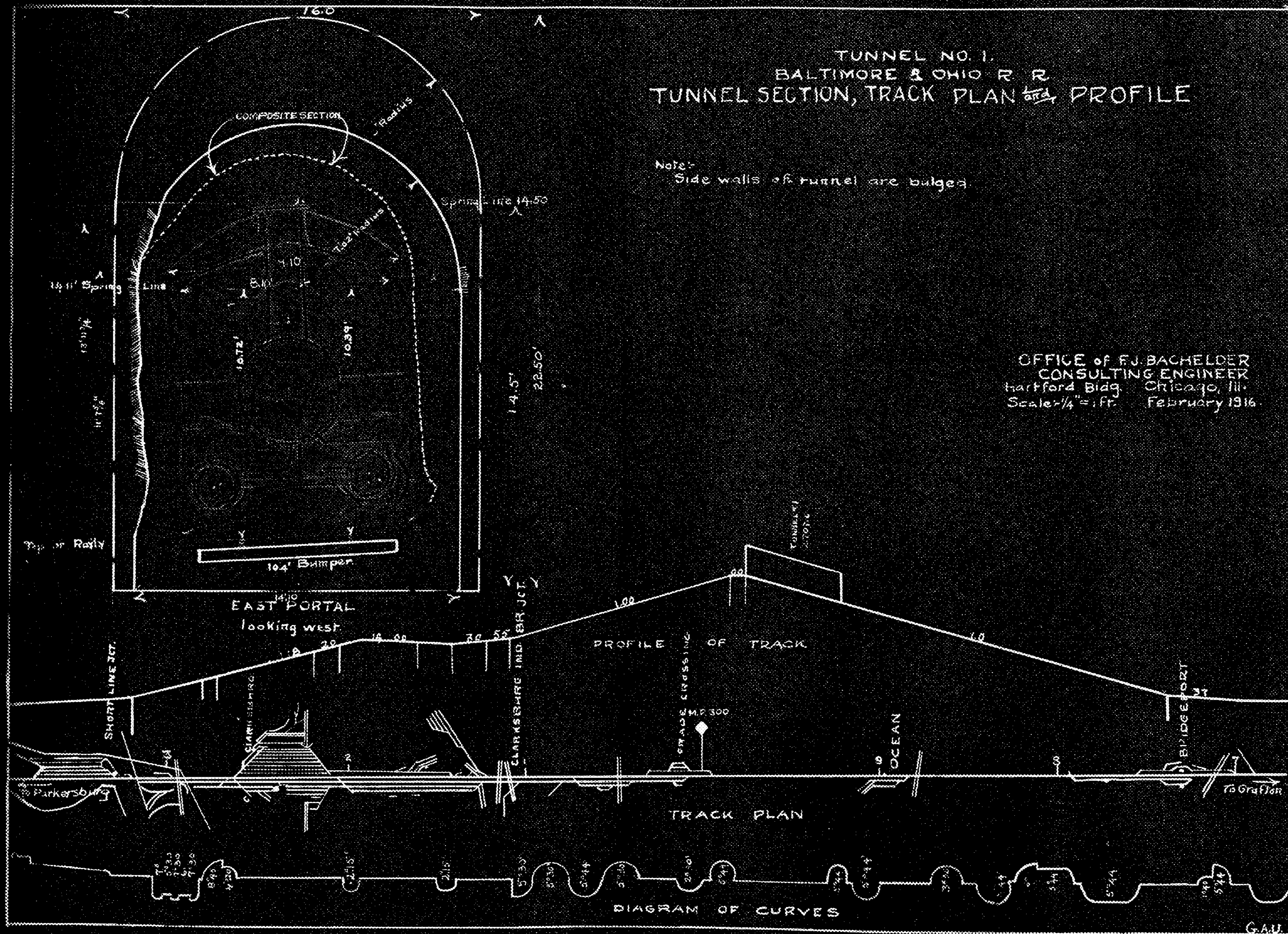
Such operation has increased the intensity of the heat on account of increased steam pressure and the amount of gas brought about by the greater consumption of fuel with less volume of space between engine and tunnel walls for the dilution of the gases.

In order to give some idea of the space occupied by the present day engine and some comparisons with the early day locomotives blue print figures 1 - 2 - 3 and 4, pages 4, 5, 6, and 7 show a section of four of the twenty three tunnels in which conditions were found poorer than the average, by the writer. The tunnels in question show the present day locomotive outlines in red and the early day locomotives in yellow. Locomotives now operated and the space they occupy will indicate to some extent the conditions produced in the operation of this modern motive power.

As a result of the growth of the train load and in the size of locomotives, methods of ventilation of tunnels have been undertaken, so that asphyziating gases are being removed and excessive temperature reduced. Steam Railway mechanical ventilation seems to have been first put in operation in 1901, in this country.

It will be noted that the space in the section of these tunnels has been almost wholly filled by the present day locomotive.


TUNNEL NO. 1.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE
Note:-
Side walls of tunnel are bulged.
OFFICE of F.J. BACHELDER
CONSULTING ENGINEER
Hartford Bldg. Chicago, Ill.
Scale 1/4" = 1 ft. February 1916.
16.0
COMPOSITE SECTION
Spring Line 14.50
14.11' Spring Line
10.72'
10.39'
14.5'
22.50'
Top of Rails
10.4' Bumper
EAST PORTAL
looking west.
PROFILE OF TRACK
TUNNEL #1
SHORT LINE JCT.
CLARKSBURG
CLARKSBURG IND. BR. JCT.
GRADE CROSSING
M.P. 300
OCEAN
BRIDGEPORT
TRACK PLAN
Parkersburg
To Grafton
DIAGRAM OF CURVES
G.A.U.



TUNNEL NO. 1.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE
Note:-
Side walls of tunnel are bulged.
OFFICE of F.J. BACHELDER
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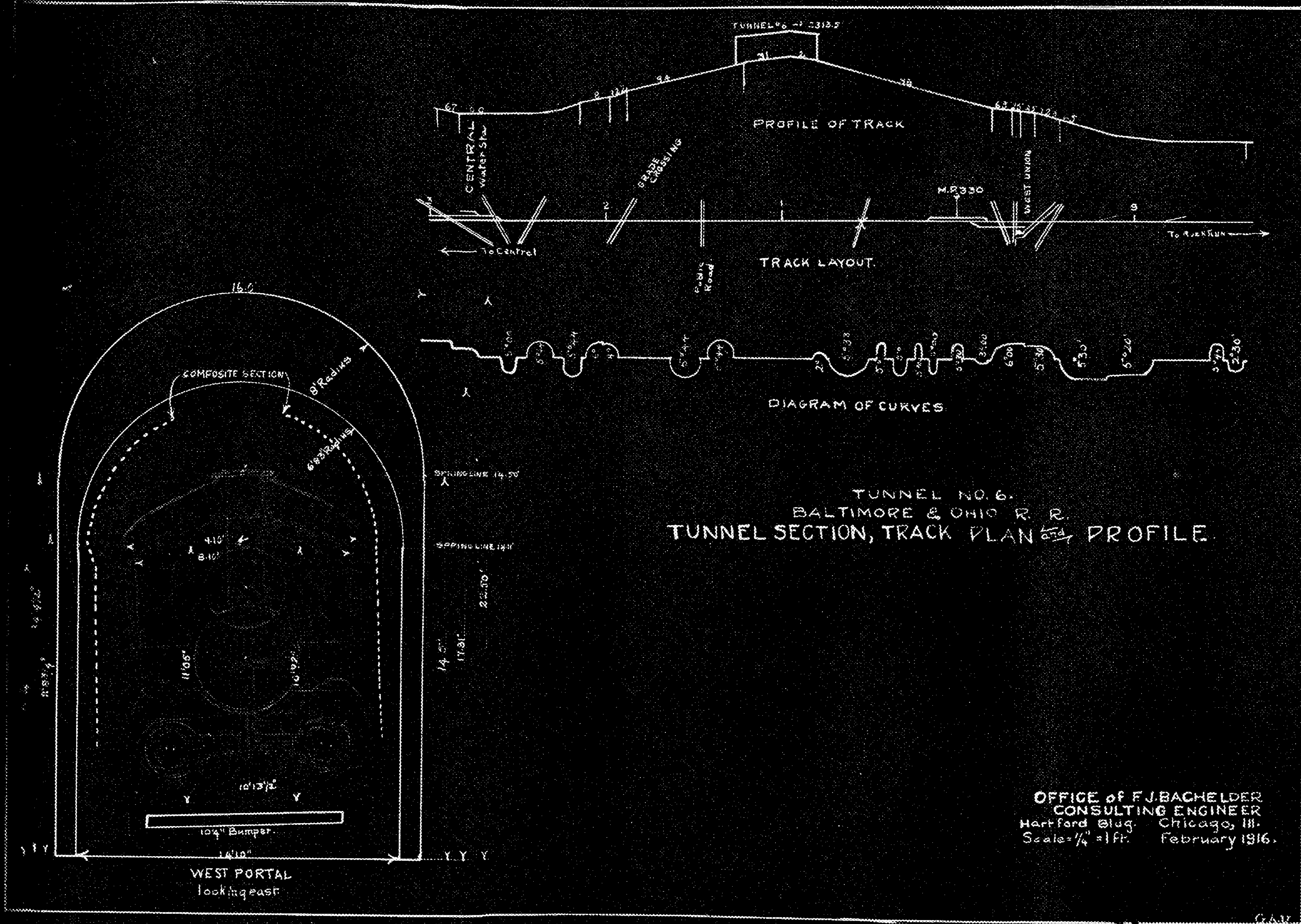
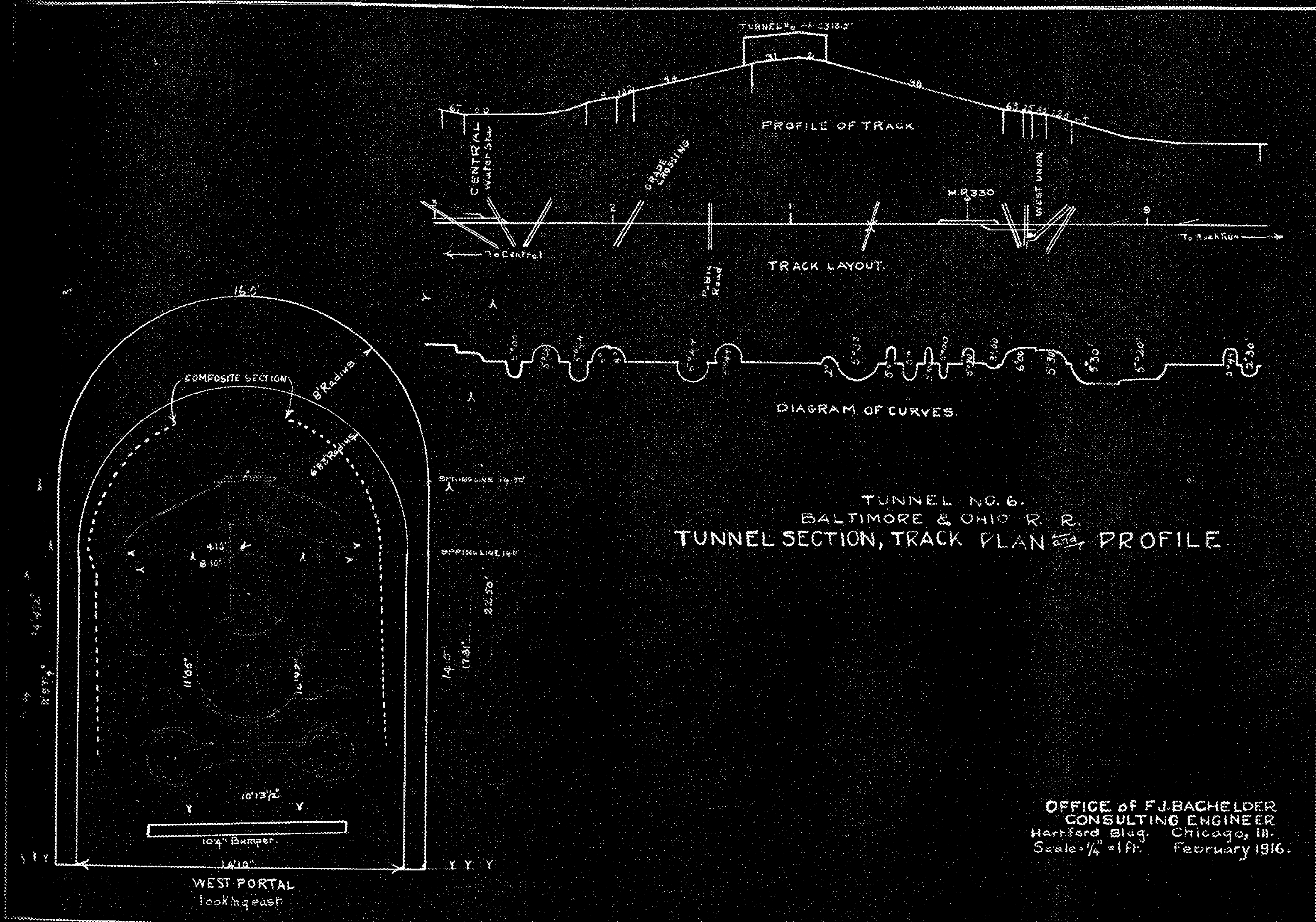
Hartford Bldg. Chicago, Ill.
Scale-1/4"=1ft. February 1916.
16.0
COMPOSITE SECTION
Spring Line 14.50
14.5'
22.50'
10.72'
10.39'
104' Bumper
Top of Rails
EAST PORTAL
looking west
PROFILE OF TRACK
SHORT LINE JCT.
CLARKSBURG
CLARKSBURG IND. BR. JCT.
GRADE CROSSING
M.P. 300
OCEAN
BRIDGEPORT
To Parkersburg
To Grafton
TRACK PLAN
DIAGRAM OF CURVES
G.A.U.



PROFILE OF TRACK
TUNNEL No 6
CENTRAL Water Sta
GRADE CROSSING
WEST UNION
M.P. 330
To Central
To Ruckrun
Public Road
TRACK LAYOUT.
DIAGRAM OF CURVES.
COMPOSITE SECTION
8' Radius
SPRING LINE 14.50'
SPRING LINE 14.8'
10'4" Bumper
14'10"
WEST PORTAL
looking east
TUNNEL NO. 6.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE.
OFFICE of F. J. BACHELDER
CONSULTING ENGINEER
Hartford Bldg. Chicago, Ill.
Scale = 1/4" = 1 ft. February 1916.



PROFILE OF TRACK
CENTRAL Water Sta.
GRADE CROSSING
WEST UNION
M.P. 330
To Central
To Rush Run
Public Road
TRACK LAYOUT.
DIAGRAM OF CURVES.
COMPOSITE SECTION
8' Radius
SPRING LINE 14.50'
SPRING LINE 14.0'
10'4" Bumper.
14'10"
WEST PORTAL
looking east
TUNNEL NO. 6.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE.
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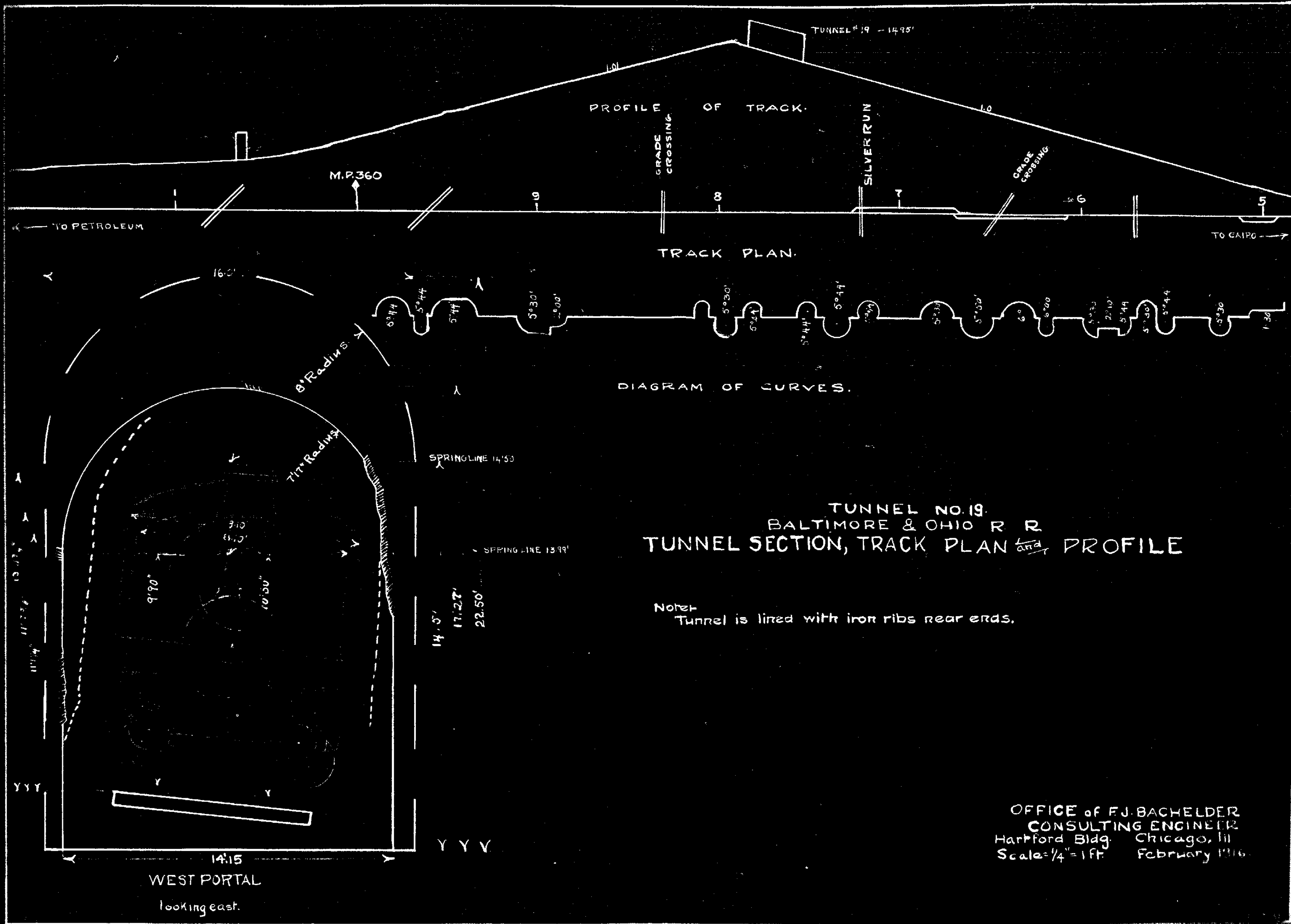
Scale-1/4" = 1 ft. February 1916.


TUNNEL # 19 – 1495'
PROFILE OF TRACK.
GRADE CROSSING
SILVER RUN
GRADE CROSSING
M.P. 360
TO PETROLEUM
TO CAIRO
TRACK PLAN.
DIAGRAM OF CURVES.
16'0"
8' Radius
7'1" Radius
SPRINGLINE 14'50
SPRINGLINE 13.99'
9'90"
10'50"
14.5'
17.27'
22.50'
14.15
WEST PORTAL
looking east.
TUNNEL NO. 19.
BALTIMORE & OHIO R R
TUNNEL SECTION, TRACK PLAN and PROFILE
Note:
Tunnel is lined with iron ribs near ends.
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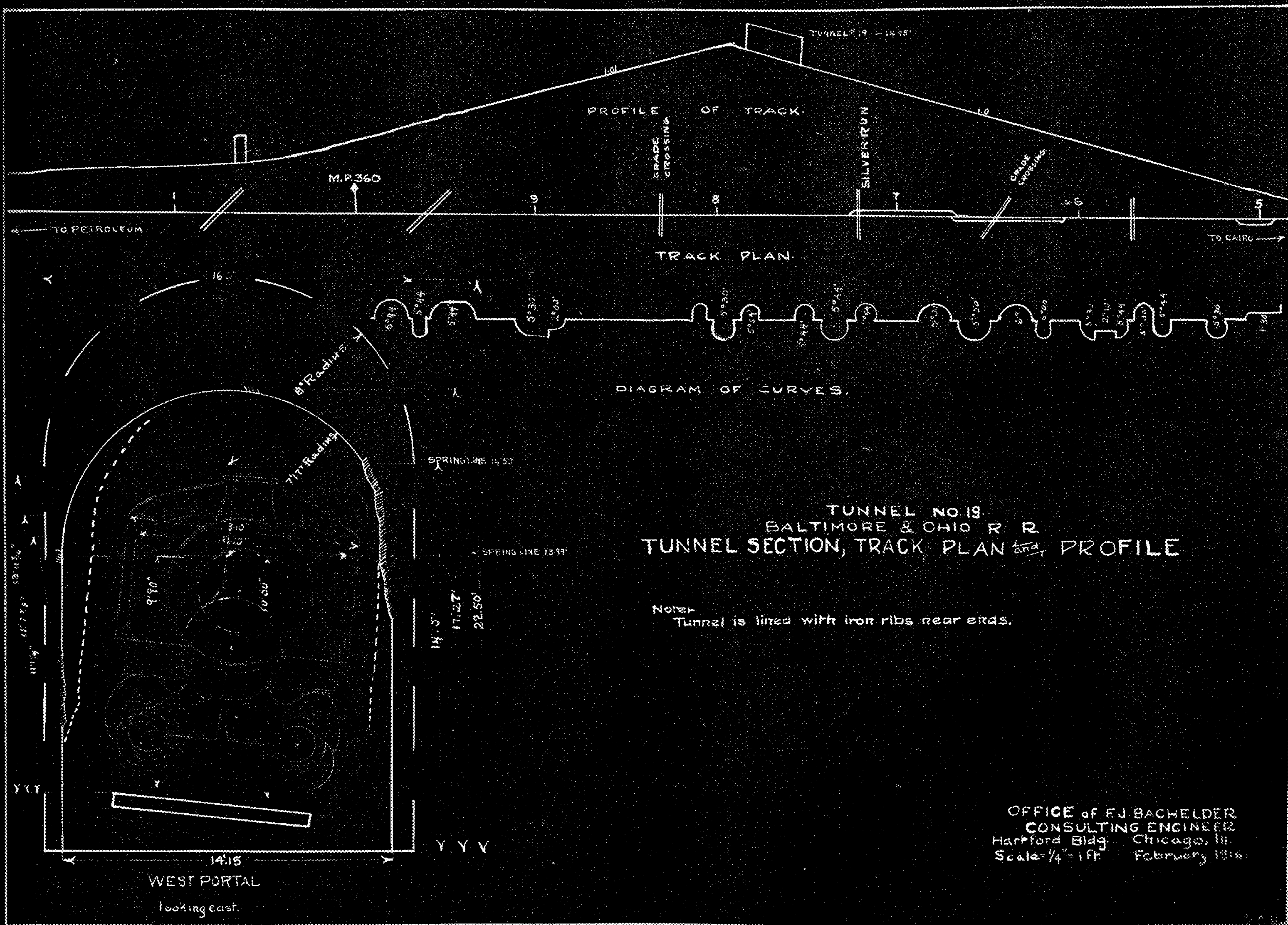
CONSULTING ENGINEER
Hartford Bldg. Chicago, Ill
Scale: 1/4" = 1 ft. February 1916


TUNNEL No. 19 — 1495'
PROFILE OF TRACK.
M.P.360
GRADE CROSSING
SILVER RUN
GRADE CROSSING
TO PETROLEUM
TO CAIRO
TRACK PLAN.
DIAGRAM OF CURVES.
8' Radius
7.17 Radius
SPRINGLINE
SPRING LINE 13.99'
14.5'
17.27'
22.50'
9.90'
10.00'
14.15
WEST PORTAL
looking east.
TUNNEL No. 19
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE
Note:
Tunnel is lined with iron ribs near ends.
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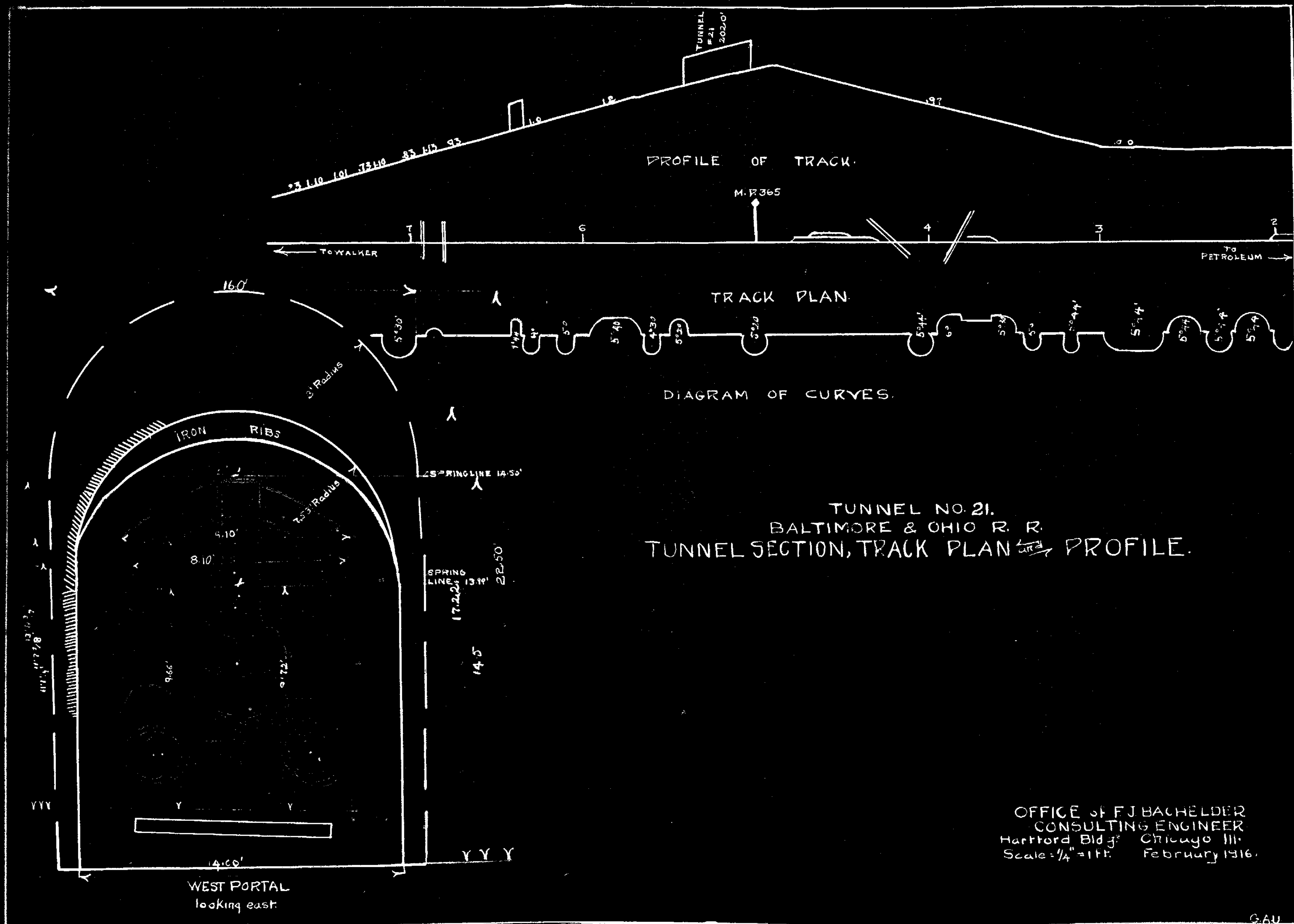
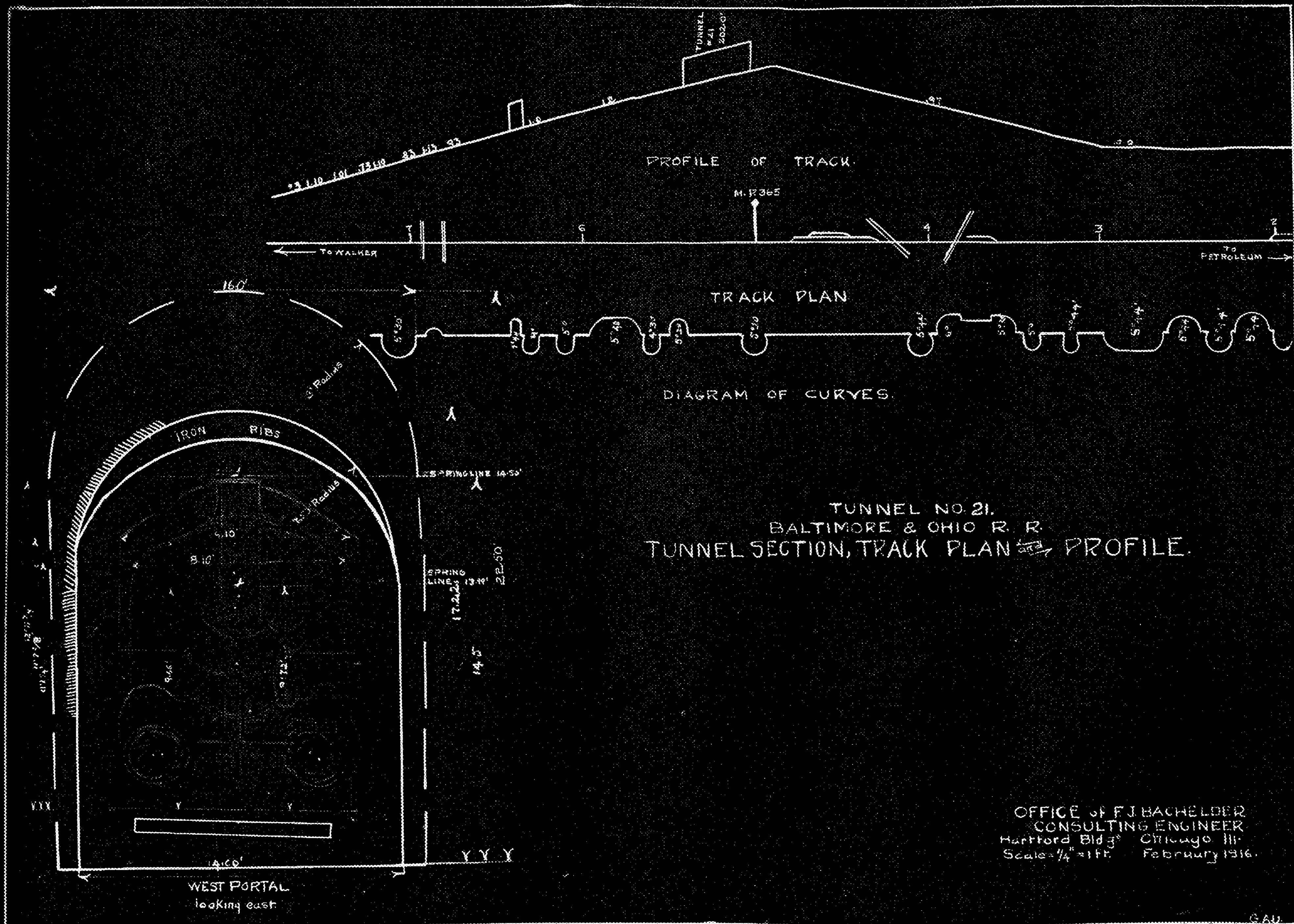
CONSULTING ENGINEER
Hartford Bldg. Chicago, Ill.
Scale 1/4" = 1 ft. February 1916.



TUNNEL #21 2020'
PROFILE OF TRACK.
M.P. 365
TO WALKER
TO PETROLEUM
TRACK PLAN.
DIAGRAM OF CURVES.
16.0'
3' Radius
IRON RIBS
SPRINGLINE 14.55'
7.53' Radius
SPRING LINE 13.99'
22.50'
17.22'
14.5'
14.00'
WEST PORTAL
looking east.
TUNNEL NO. 21.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE.
OFFICE of F. J. BACHELDER
CONSULTING ENGINEER
Hartford Bldg. Chicago Ill.
Scale: 1/4" = 1 ft. February 1916.
G.A.U.



PROFILE OF TRACK.
TUNNEL #21 202.0'
M. 12365
TO WALKER
TO PETROLEUM
TRACK PLAN
DIAGRAM OF CURVES.
160'
IRON RIBS
SPRINGLINE 14.55'
SPRING LINES 13.11'
22.50
14.5'
14.00'
WEST PORTAL
looking east
TUNNEL NO. 21.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN AND PROFILE.
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CONSULTING ENGINEER
Hartford Bldg. Chicago Ill.
Scale = 1/4" = 1 ft. February 1916.

TUNNEL SECTIONS

In order to give concise information as to the dimensions of the twenty-three tunnels under consideration, the statement given in Table #1, page 15, shows the tunnel number, location, area and grades, approaching the tunnels. A study of this Table shows that tunnels #1, #6 and #21, by their greater lengths, would have the poorer ventilation. Trips through these various tunnels on locomotives found these conditions to be verified and, in addition, tunnel #19 was also found to have unusual gas and heat conditions. By comparing the area of these tunnels, with published information regarding tunnels that have been ventilated, it is found that their sections are considerably smaller than other single track sections usually constructed. In addition to the area of the section of the tunnel, the sufficiency of the natural ventilation seems to be dependent on the length and percent of the grades approaching the tunnel and the grades through the tunnels.

Tunnel #1, east of Clarksburg, is 2707.6 ft. long, being the longest tunnel covered in this investigation. The area does not vary greatly from the other tunnels in this district, but it will be noted from Figure #5, page 11, that its area is considerably less than the area recommended for single track tunnels by the American Railway Engineering Association in their Manual of Recommended Practice of 1911. Cross section of tunnel #1 is shown by white lines: the section recommended for single track by the American Railway Engineering Association by dotted red lines. Area provided by the American Railway Engineering Association section is 31% greater than that provided by tunnel #1.

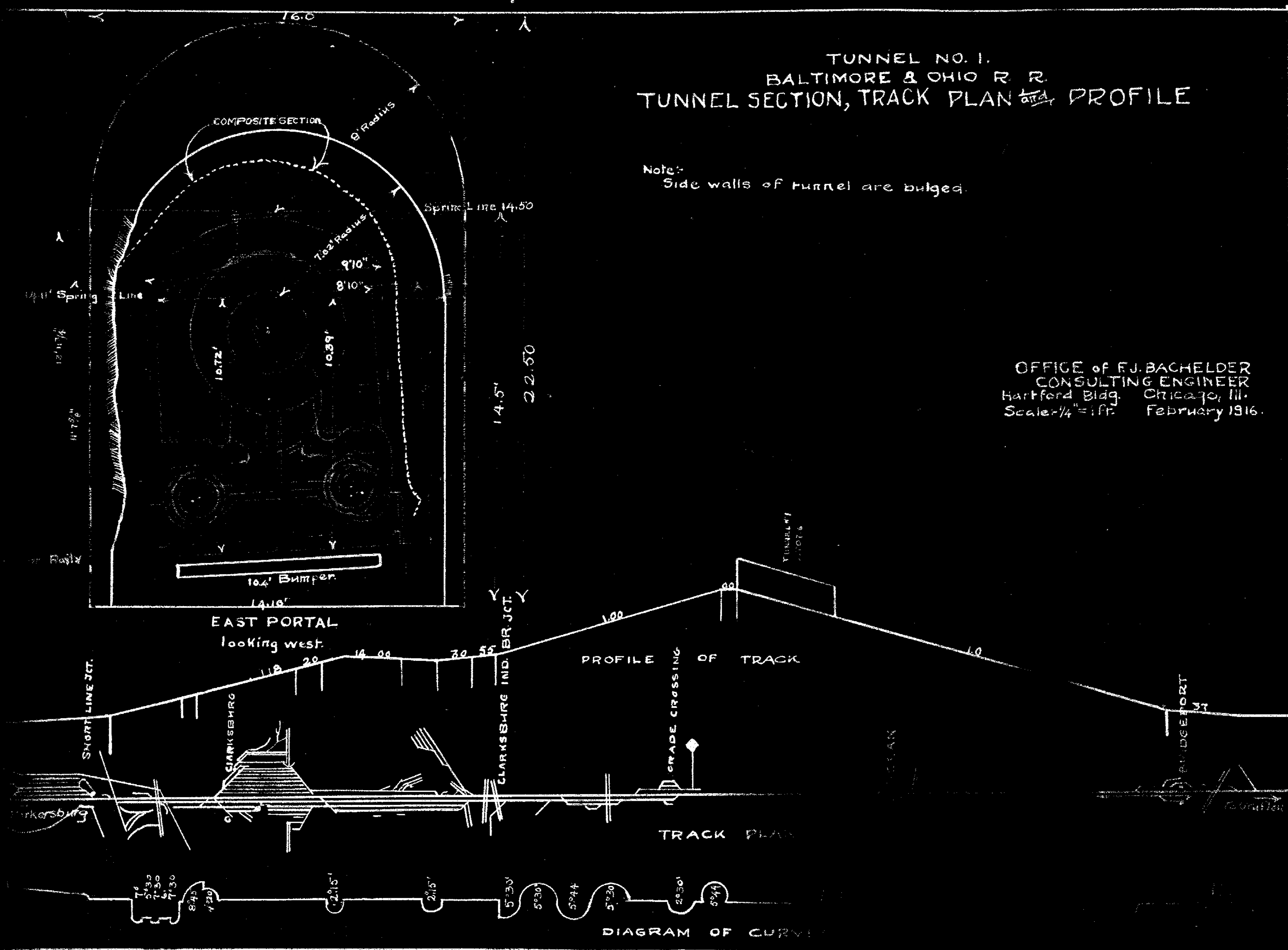
Tunnel #1 is located at the summit of a 1% grade, west bound, the grade being approximately two and one half miles in length. This grade is one of the ruling ones for the whole district and on account of its length heavy tonnage trains have considerable difficulty handling their trains and consume more time in passing through the tunnel at reduced speed, on account of its location at the summit of the grade.

Tunnel #6, it will be noted, is 2313.5 ft. long and is at the summit of a grade varying from .77% to 1.28%. In fact, the summit of the grade meets in the tunnel, which no doubt, contributes to the poorer natural ventilation than would otherwise be obtained. The section of the American Railway Engineering Association is 31% greater than that provided by tunnel #6, as shown by Figure #6, page 12.

Tunnel #19, commonly known as Silver Run Tunnel, is 1495 ft. long and is at a summit of a three mile 1% ascending grade, west bound. The American Railway Engineering Associations recommended area is 32% larger than that of tunnel #19, as shown by Figure #7, page 13.

Tunnel #21, commonly known as Eaton Tunnel, is at the summit of another ruling grade, approximately three miles in length, the grade varying from .5% to a 1.2% ascending grade, east bound. The American Railway Engineering Association Sectional area is 32.5% greater than the sectional area of tunnel #21, as shown by Figure #8, page 14.

It is considered that the section of the four tunnels above mentioned with information regarding grades and other dimensions, is sufficiently representative of the conditions met with when supplemented by information under Table #1, page 15, showing tabulated information regarding all the tunnels.



TUNNEL NO. 1.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE
Note:-
Side walls of tunnel are bulged.
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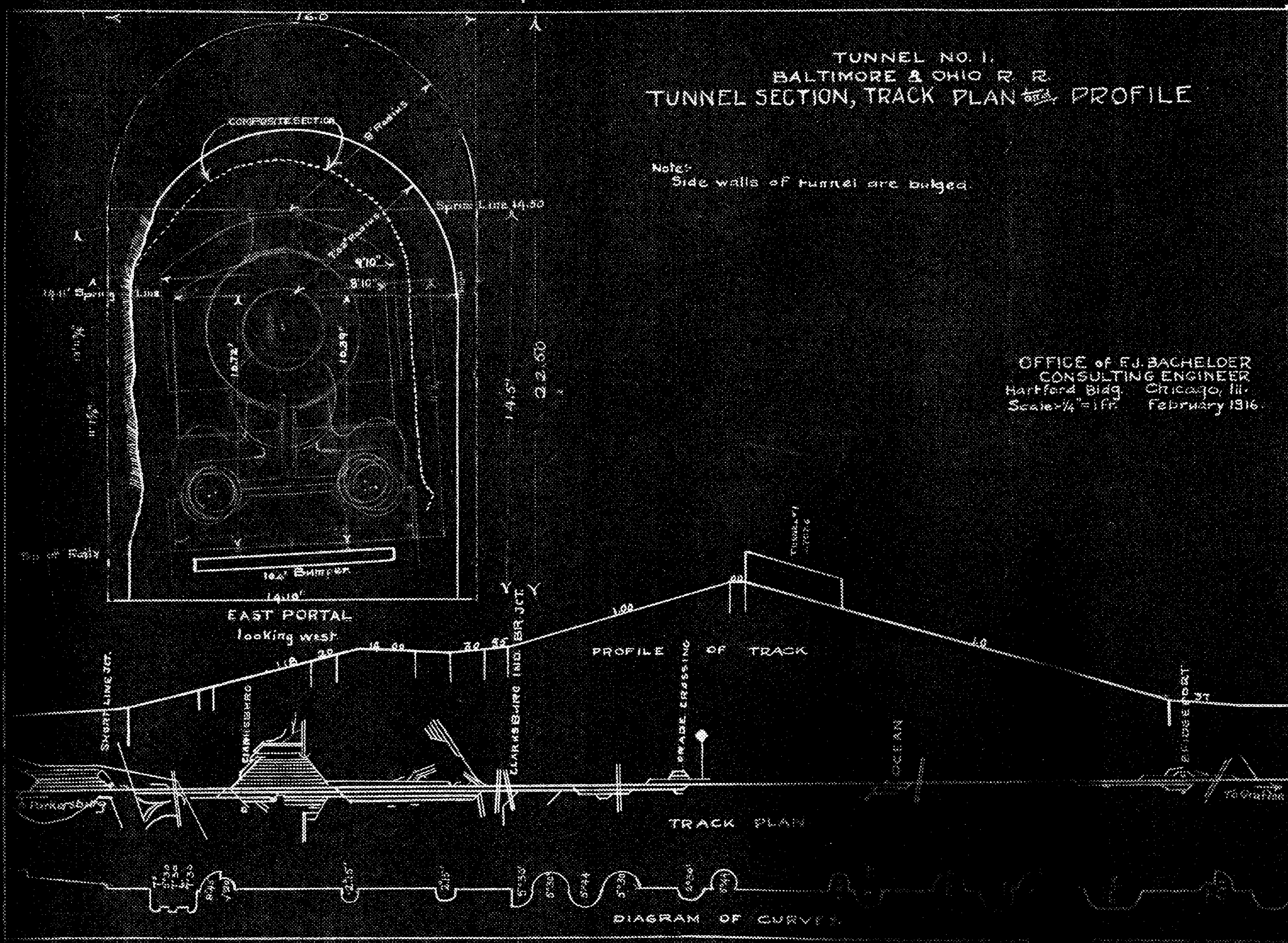
Hartford Bldg. Chicago, Ill.
Scale-1/4"=1ft. February 1916.
16.0
COMPOSITE SECTION
8' Radius
7.02' Radius
Spring Line 14.50
Spring Line
9'10"
8'10"
10.72'
10.39'
14.5'
22.50
10.4' Bumper
14.10'
EAST PORTAL
looking west.
PROFILE OF TRACK
SHORT LINE JCT.
CLARKSBURG
CLARKSBURG IND. BR. JCT.
GRADE CROSSING
BRIDGEPORT
TRACK PLAN
Parkersburg
DIAGRAM OF CURVES
2°15'
5°30'
5°44
2°30'


TUNNEL NO. 1.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE
Note:-
Side walls of tunnel are bulged.
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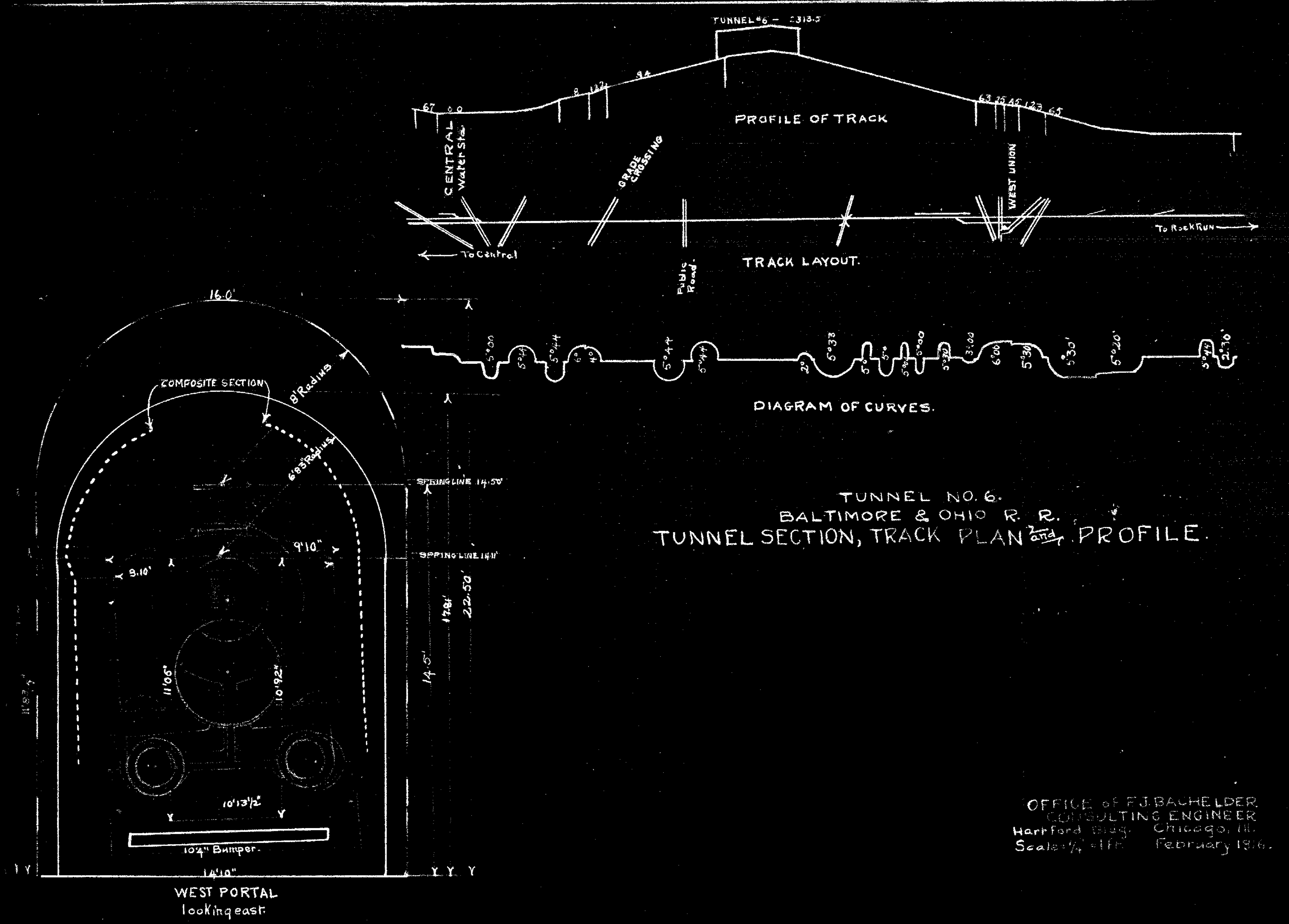
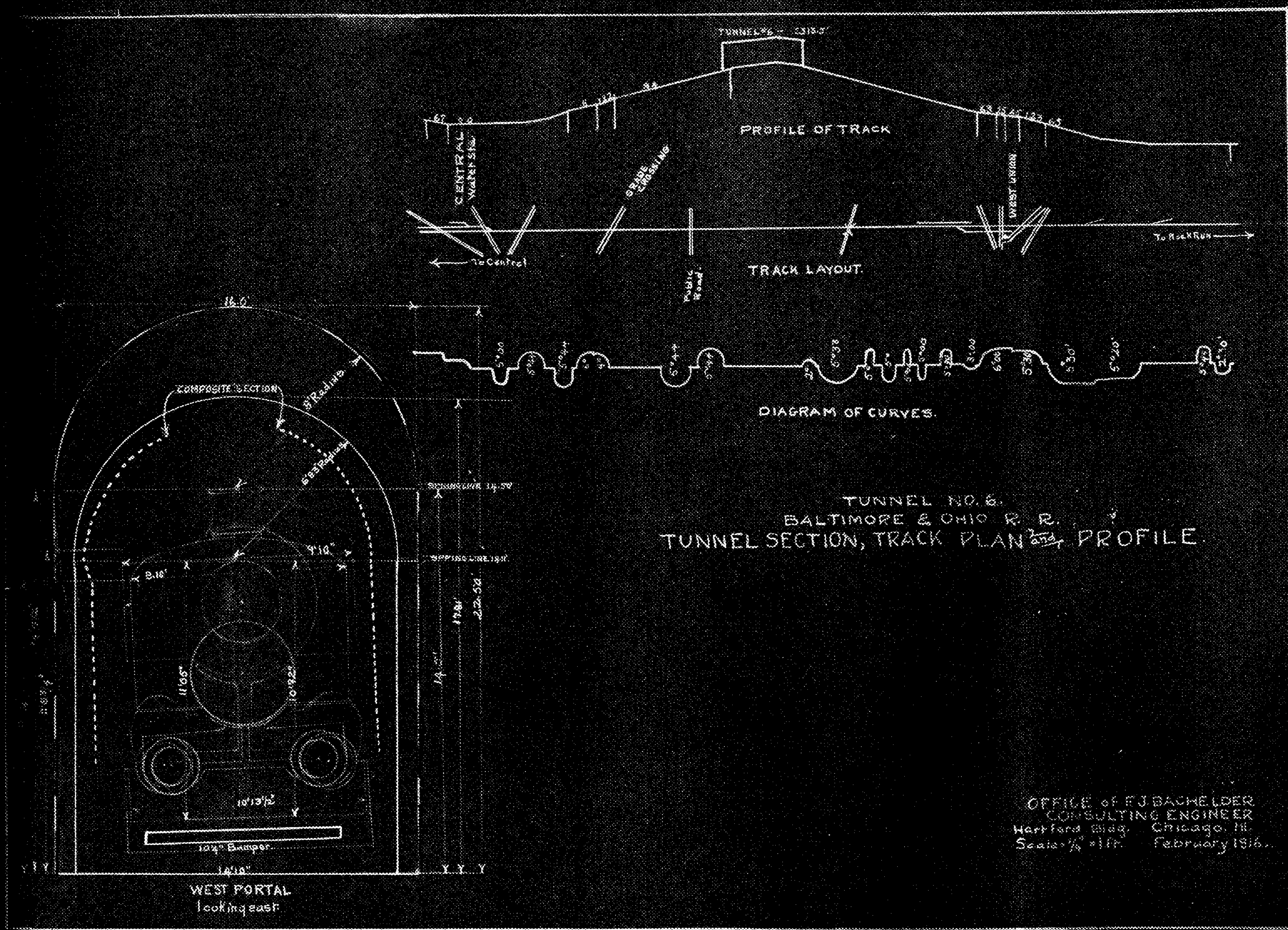
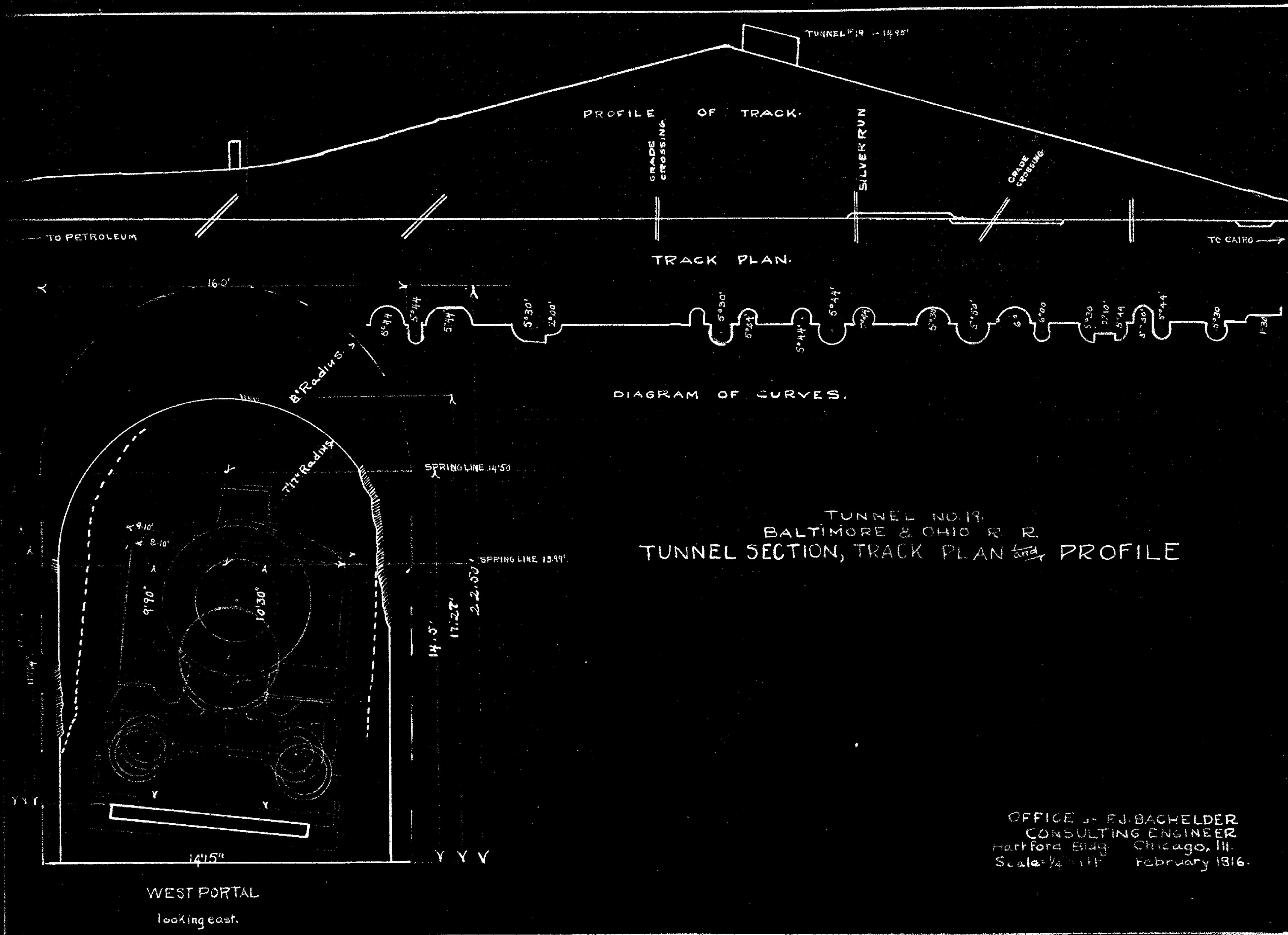
CONSULTING ENGINEER
Hartford Bldg. Chicago, Ill.
Scale-1/4"=1 ft. February 1916.
COMPOSITE SECTION
Spring Line 14.50
14.0' Spring Line
Top of Rails
10.4' Bumper
14.0'
EAST PORTAL
looking west
14.5'
22.60
PROFILE OF TRACK
SHORT LINE JCT.
CLARKSBURG
CLARKSBURG IND. BR. JCT.
GRADE CROSSING
OCEAN
BRIDGEPORT
TRACK PLAN
To Parkersburg
To Grafton
DIAGRAM OF CURVES


TUNNEL #6 – 2313.5
PROFILE OF TRACK
CENTRAL Water Sta.
GRADE CROSSING
WEST UNION
Public Road.
To Central
To Rock Run
TRACK LAYOUT.
DIAGRAM OF CURVES.
16.0'
COMPOSITE SECTION
8' Radius
6'83 Radius
SPRING LINE 14.50'
SPRING LINE 14.1'
9'10"
9.10'
11'06"
10'92"
14.5'
17.81'
22.50'
10'13 1/2"
10'4" Bumper.
14'10"
WEST PORTAL
looking east.
TUNNEL NO. 6.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE.
OFFICE of F. J. BACHELDER
CONSULTING ENGINEER
Hartford Bldg. Chicago, Ill.
February 1916.



PROFILE OF TRACK
CENTRAL Water Sta.
GRADE CROSSING
WEST UNION
To Rock Run
To Central
TRACK LAYOUT.
Public Road
DIAGRAM OF CURVES.
COMPOSITE SECTION
14.0'
WEST PORTAL
looking east
TUNNEL NO. 6.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE
OFFICE of F. J. BACHELDER
CONSULTING ENGINEER
Hartford Bldg. Chicago. Ill.
February 1916.


TUNNEL #19 - 1495'
PROFILE OF TRACK.
GRADE CROSSING
SILVER RUN
GRADE CROSSING
TO PETROLEUM
TO CAIRO
TRACK PLAN.
DIAGRAM OF CURVES.
16.0'
8' Radius
7'7" Radius
SPRING LINE 14.50
SPRING LINE 13.99'
9.10'
8.10'
9.90'
10.30'
14.5'
17.27'
22.50'
14'5"
WEST PORTAL
looking east.
TUNNEL NO. 19.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE
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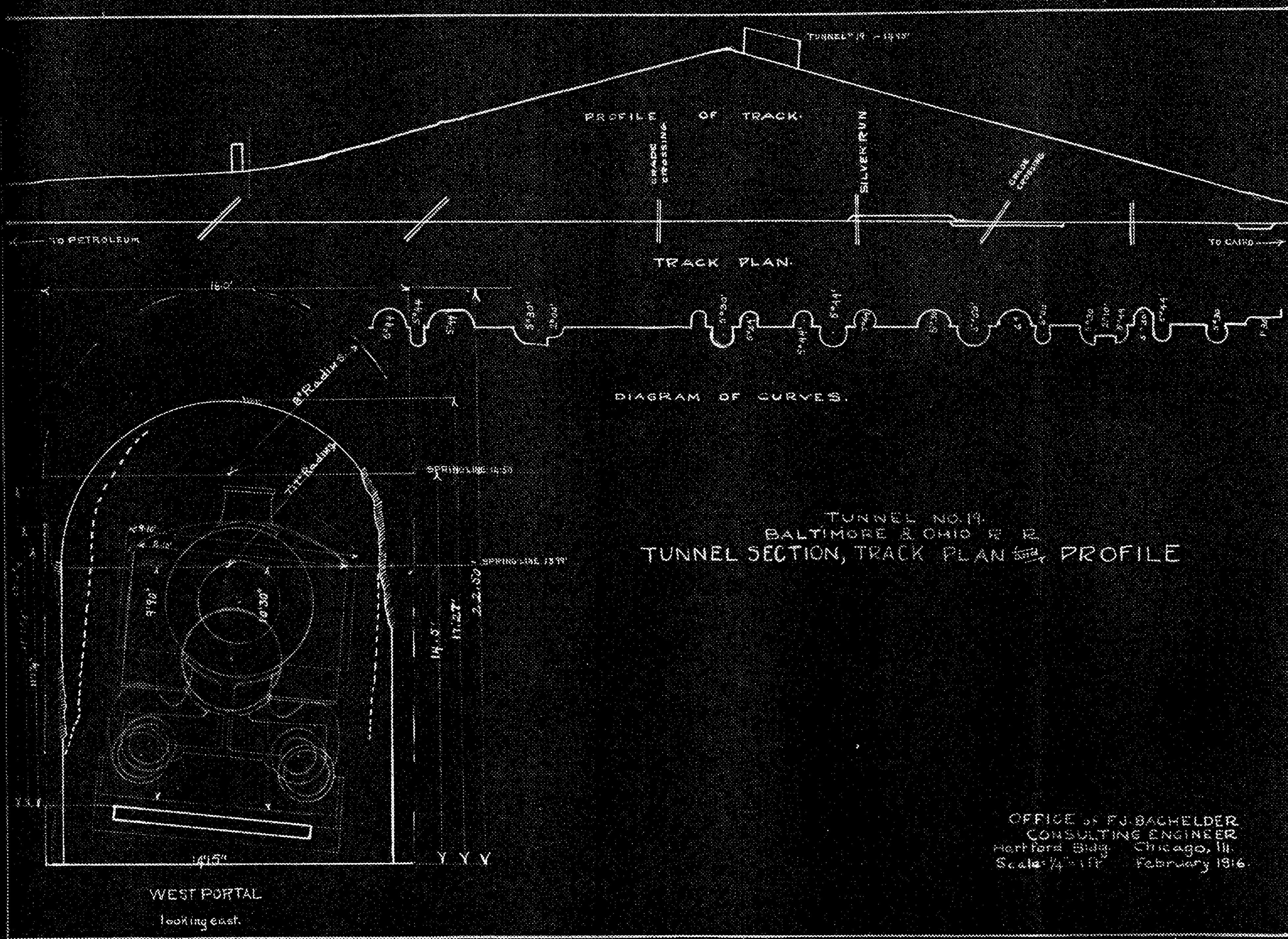
Scale 1/4" = 1 ft. February 1916.


TUNNEL No. 19 - 1345'
PROFILE OF TRACK.
GRADE CROSSING
SILVER RUN
GRADE CROSSING
TO PETROLEUM
TO CAIRO
TRACK PLAN.
DIAGRAM OF CURVES.
SPRING LINE 14.50
SPRING LINE 13.9'
16.0'
8' Radius
7.1' Radius
14.5'
17.27'
22.50
14'5"
TUNNEL No. 19.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN AND PROFILE
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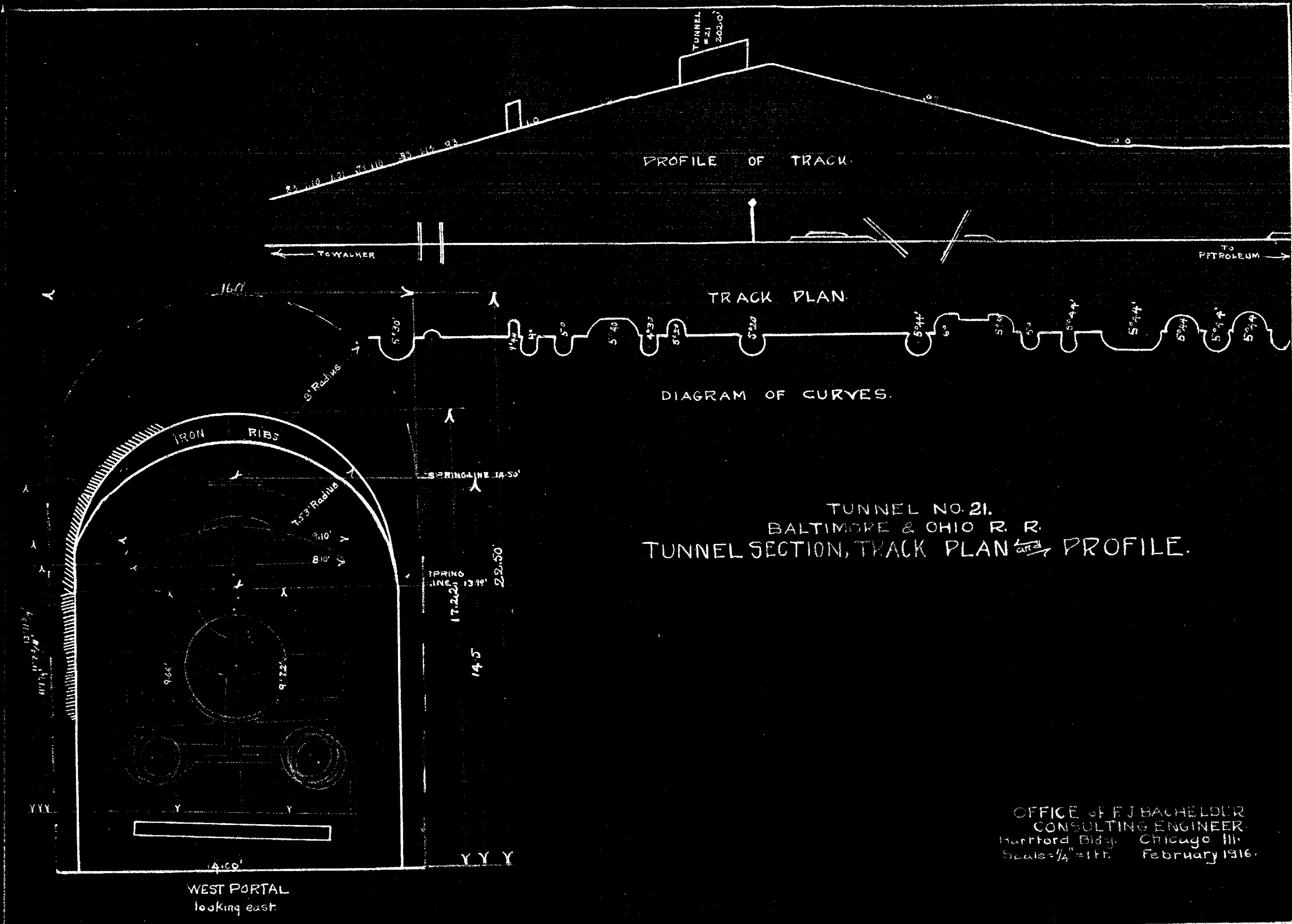
CONSULTING ENGINEER
Hartford Bldg. Chicago, Ill.
Scale 1/4" = 1 ft. February 1916.
WEST PORTAL
looking east.


TUNNEL #21 202.0'
PROFILE OF TRACK
TO WALKER
TO PETROLEUM
TRACK PLAN
DIAGRAM OF CURVES.
8' Radius
IRON RIBS
7.53' Radius
SPRINGLINE 14.50'
SPRING LINE 13.99'
22.50'
17.22'
14.5'
14.00'
WEST PORTAL
looking east
TUNNEL NO. 21.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE.
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Hartford Bldg. Chicago Ill.
Scale=1/4"=1 Ft. February 1916.

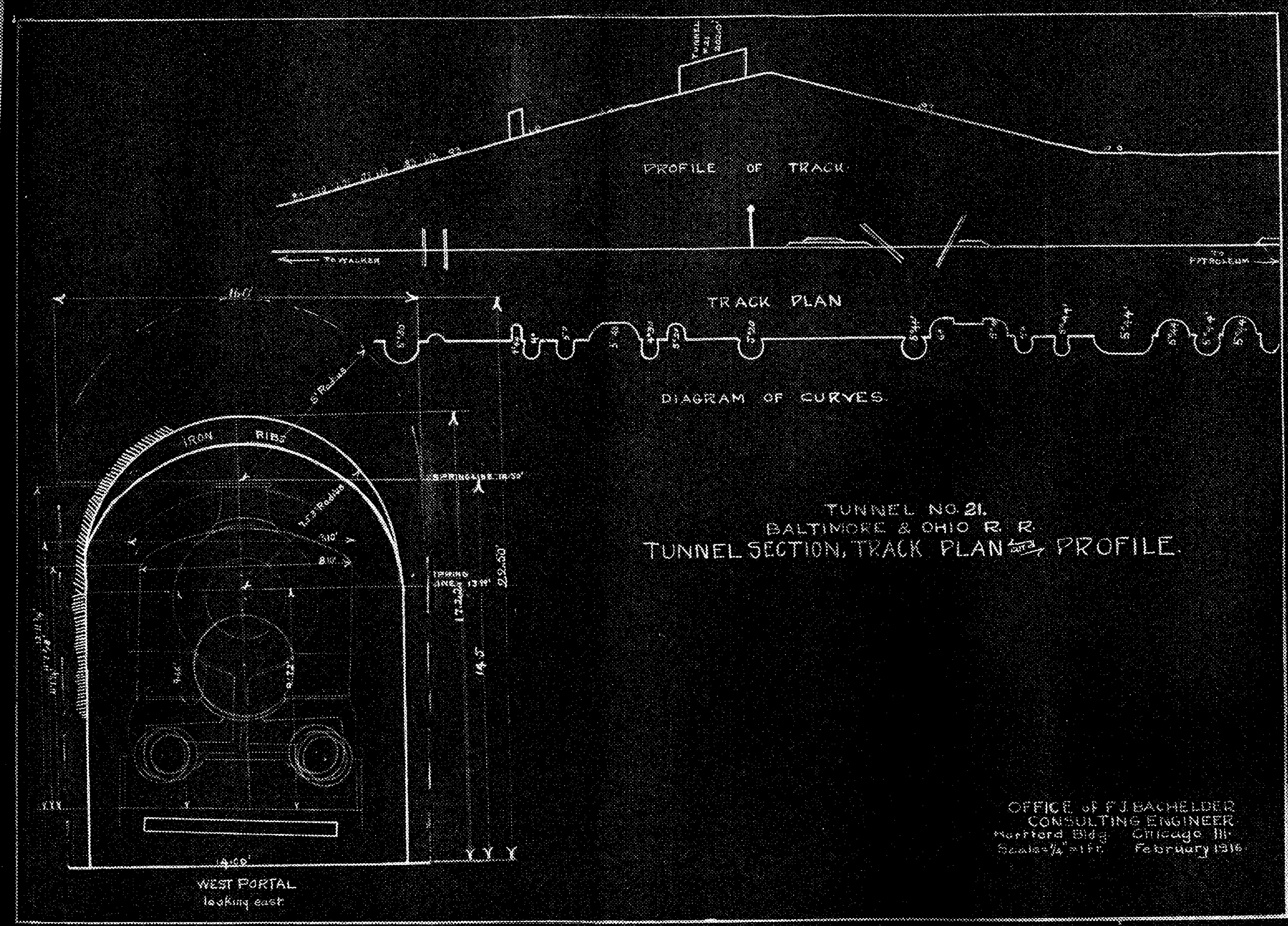

PROFILE OF TRACK
TO WALKER
TO PETROLEUM
TRACK PLAN
DIAGRAM OF CURVES
IRON RIBS
5' Radius
7.53' Radius
SPRING LINE 13.50'
22.50'
14.5'
14.00'
WEST PORTAL
looking east
TUNNEL NO. 21.
BALTIMORE & OHIO R. R.
TUNNEL SECTION, TRACK PLAN and PROFILE.
OFFICE of F J BACHELDER
CONSULTING ENGINEER
Hartford Bldg. Chicago Ill.
Scale=1/4"=1 Ft. February 1916

TABLE # I.

DESCRIPTION OF B. & O. R. R. TUNNELS

between

PARKERSBURG AND GRAFTON, WEST VIRGINIA.

Number & Location	Length in Feet.	Grade Per-cent	Length of Grade Miles	Width Feet	Heighth of High Rail to Spring Line.	Heighth - Top Rail to Center Arch of Tunnel	Section Area in Square Feet.
#1 - E. of Clarksburg	2707.6	1.00	2.60	14.1	10.39	17.57	227.94
#2 - E. of Salem	1086.0	0.81	0.60	13.44	11.25	18.20	227.05
#3 - W. Long Run	282.0	0.30	0.01	13.91	10.27	17.15	217.65
#4 - E. Morgansville	846.0	0.40	1.10	14.27	10.40	17.56	228.70
#5 - W. Smithburg	359.0	0.41	0.25	14.03	11.16	17.57	220.92
#6 - E. Central	2313.5	(1.10 0.31)	1.40	14.10	10.92	17.81	228.77
#7 - E. Pennsboro	789.8	0.43	1.10	14.02	9.97	17.06	218.97
#8 - W. "	587.8	1.00	0.50	14.23	10.89	18.15	237.51
#9 - W. "	855.1	0.85	0.60	14.12	10.05	17.48	229.10
#10- W. Ellenboro	337.0	0.55	1.00	16.36	8.51	16.69	244.82
#11- E. Cornwallis	175.5	0.11	0.25	14.76	10.11	17.73	239.97
#12- E. "	748.5	0.53	0.80	14.44	10.45	17.94	239.24
#13- "	352.5	0.04	0.40	14.18	10.50	17.52	225.84
#14- W. Cornwallis	183.0	0.05	0.20	13.94	9.67	17.18	223.14
#15- "	478.0	0.08	none	14.10	9.29	16.56	213.53
#16- "	221.0	0.20	none	14.09	9.76	17.10	222.36
#17- "	451.0	0.07	0.50	14.15	9.70	16.94	219.80
#18- E. Cairo	965.0	0.07	0.50	14.18	10.00	17.31	225.50
#19- W. Silver Run	1495.0	1.00	2.20	13.94	9.90	17.27	222.85
#20- E. Petroleum	254.2	0.34	0.40	14.60	10.12	17.31	229.20
#21- W. Eatons	2020.0	..83-1.30	3.00	13.99	9.66	17.22	224.67
#22- W. "	338.0	1.00	2.10	13.94	10.10	17.35	223.34
#23- E. Kanawba	286.0	.04	0.15	14.12	9.77	16.60	211.65
American Railway Engineering Association Tunnel (Recommended Section for Single Track)				16.0	14.50	22.50	332.50

TABLE # I.

DESCRIPTION OF B. & O. R. R. TUNNELS

between

PARKERSBURG AND GRAFTON, WEST VIRGINIA.

Number & Location	Length in Feet.	Grade Per-cent	Length of Grade Miles	Width Feet	Heighth of High Rail to Spring Line.	Heighth - Top Rail to Center Arch of Tunnel	Section Area in Square Feet.
#1 - E. of Clarksburg	2707.6	1.00	2.60	14.1	10.39	17.57	227.94
#2 - E. of Salem	1086.0	0.81	0.60	13.44	11.25	18.20	237.05
#3 - W. Long Run	282.0	0.30	0.01	13.91	10.27	17.15	217.65
#4 - E. Morgansville	846.0	0.40	1.10	14.27	10.40	17.56	228.70
#5 - W. Smithburg	359.0	0.41	0.25	14.03	11.16	17.57	220.92
#6 - E. Central	2313.5	(1.10) (0.31)	1.40	14.10	10.92	17.81	228.77
#7 - E. Pennsboro	789.8	0.43	1.10	14.02	9.97	17.06	218.97
#8 - W. "	587.8	1.00	0.50	14.23	10.89	18.15	237.51
#9 - W. "	855.1	0.85	0.60	14.12	10.05	17.48	229.10
#10- W. Ellenboro	337.0	0.55	1.00	16.36	8.51	16.69	244.82
#11- E. Cornwallis	175.5	0.11	0.25	14.76	10.11	17.73	239.97
#12- E. "	748.5	0.53	0.80	14.44	10.45	17.94	239.24
#13- "	352.5	0.04	0.40	14.18	10.50	17.52	225.84
#14- W. Cornwallis	183.0	0.05	0.20	13.94	9.67	17.18	223.14
#15- "	478.0	0.08	none	14.10	9.29	16.56	213.53
#16- "	221.0	0.20	none	14.09	9.76	17.10	222.36
#17- "	451.0	0.07	0.50	14.15	9.70	16.94	219.80
#18- E. Cairo	965.0	0.07	0.50	14.18	10.00	17.31	225.50
#19- W. Silver Run	1495.0	1.00	2.20	13.94	9.90	17.27	222.85
#20- E. Petroleum	254.2	0.34	0.40	14.60	10.12	17.31	229.20
#21- W. Eatons	2020.0	..83-1.30	3.00	13.99	9.66	17.22	224.67
#22- W. "	338.0	1.00	2.10	13.94	10.10	17.35	223.34
#23- E. Kanawba	286.0	.04	0.15	14.12	9.77	16.60	211.65
American Railway Engineering Association Tunnel (Recommended Section for Single Track)				16.0	14.50	22.50	332.50

VENTILATION

Atmosphere contains only one constituent that is useful to living things and that is oxygen. Gases may perform other uses in nature and yet not be immediately necessary.

Gases are not chemically combined with one another in the atmosphere, but are mechanical mixtures. Oxygen may be used or taken from a sample without effecting the other constituents. Other constituents may be added and yet not effect the oxygen. When oxygen is taken up in breathing a production of carbon dioxide takes place.

The atmosphere has been found the same on the ocean, at various elevations and in country districts.

The following composition, by volume, of pure atmospheric air, free from aqueous vapor, may be taken to have the following composition.

TABLE # 2

* Oxygen	2094	per	ten	thousand	parts
Nitrogen	7800	"	"	"	"
Argon	94	"	"	"	"
Carbonic Acid	03	"	"	"	"
Hydrogen	09	"	"	"	"

In a study of ventilation the gases to be considered most seriously are oxygen, carbon dioxide, carbon mono-

*See report of a Parlimentary Committee on Ventilation of Factories and Workshops, London, 1912, Page #93 xide and water vapor.

Carbon dioxide is a product of respiration and of combustion of fuels and at the same time varies little in uncontaminated air. Little difference of carbon dioxide is found in pure country air whether in forests or over the ocean.

Accurate analysis made in Scotland of country air shows 3.13 to 3.36 volumes of carbon dioxide per 10,000 volumes.*

In the parks of London, Angus Smith found 3.01 volumes of carbon dioxide per 10,000 volumes and 3.80 in the streets. In the differentparks of London averages of his samples were 4.39, from Manchester, 4.03, and from Glasgow, 5.02.

Records kept of the amount of carbon dioxide in the air of Paris since 1890 was found to be as follows:

TABLE # 3.

Carbon Dioxide in the Air of Paris During Day & Night: 1891 to 1900(Inclusive)

	Mountsouris Park	Center of City
Day	3.10	3.34
Night	3.18	3.21
24 Hour Average	3.14	3.27

In the streets of New York City, George A. Soper made some observations for the Rapid Transit Commission of New York and found the carbon dioxide was 3.67 parts per 10,000, as a result of 309 analyses.

From a study of the above results, the amount of carbon dioxide met with, where air has a free circulation, can be taken to vary from 3.0 to 4.0 parts by volume per 10,000.

*See report of Angus Smith, J.S. and E.B. Haldane and G.F. Armstrong. (PHYSIOLOGICAL MAGAZINE OF 1890, page 306)

In order to show the effects of respiration in producing carbon dioxide, the following table, taken from Foster Physiology Text Book, 1906, page 440, shows the difference between the principal gases in inspired and expired air, per 10,000 parts:

TABLE # 4

	Inspired Air	Expired Air
Oxygen	2081.0	1600.3
Nitrogen	7915.0	7958.9
Carbon Dioxide	0004.0	438.0

*"This gas exists both as natural and artifi-fial product. As the former, it is found in volcanic caves and mines of all kinds, where, occurring with marsh gas, it is known as "Choke damp", at the bottom of deep wells, in sewers and tunnels."

SYMPTOMS OF CARBON DIOXIDE POISONING

Symptoms of carbon dioxide (CO_2) poisoning may be acute or chronic. In acute cases where the victim has been suddenly exposed to a large volume of the gas, he falls to the ground unconscious with complete muscular relaxations, deep, difficult breathing, a deep blue color and a feeble quick pulse.

CARBON MONOXIDE GAS

Carbon monoxide is an extremely poisonous gas and is known to cause death by destroying the oxygen carrying power of the blood by entering the blood corpuscles in the lungs. Most common of the deaths caused by this gas have been from ordinary illuminating gas, where such gases have been accidently or purposely left turned on. Carbon monoxide

*"THE OCCUPATIONAL DISEASES" by W. Gilman Thompson, M.D. Professor of Medicine, Cornell University in New York City, 1914.

forms 7 to 10% of the ordinary illuminating gas.

*The statement following gives information regarding the amounts in parts per 10,000 of the various gases that effect the life of animals.

TABLE #5.

PARTS PER TEN THOUSAND

Names of Gases	Rapid and Dangerous Injury	Bearalbe for 30 to 60 minutes without grave effects.
Hydrochloric Acid	1.5 to 2.0	0.05 max. 0.1
Sulphurous Acid percent	0.4 to 5.0	0.05
Carbonic Acid percent	about 30.0	6 to 8
Ammonia	2.5 to 4.5	0.3
Chlorine Bromine	.04 to .06	.004
Iodine	----------	.003
Hydrogen Sulphide	0.5 to 0.7	.2 to .3
Carbon Disulphide	0.1	.002
Carbon Monoxide	2 to 3	.5 to 1.0

Composition of pure atmospheric air is as follows:

TABLE #6.

PARTS PER TEN THOUSAND

Oxygen	2094
Nitrogen	7800
Argon	94
Carbon Acid	3
Hydrogen	9
	10,000

*LEHMAN METH. PRACTICAL HYGIENE, 1901, page 174.

SYMPTOMS OF CARBON MONOXIDE POISONING

*"Presence of such small quantities as 0.1% cause unpleasant symptoms such as headache. When the percent rises to 0.4%, the atmosphere becomes dangerous to animal life.

Carbon Monoxide gas had the following effect

on two blast furnacemen:

"In the case of these men there was at first great sleepiness and headache, followed by incomplete loss of power in the lower limbs and on subsidence of the acute symptoms it was observed that speech was effected much in the same way as in general paralysis. There was a distinct articulation defect when I examined the men, two or three months after the commencement of their illness. The power of walking properly had not been regained, the gait was slow and stepping, the grasp of the hands feeble and the pupils dilated. One of the patients would burst into hilarious laughter now and again without the slighest provocation. The simplest question addressed to him seemed to cause amusement. Although the general physique of these men is good, their nervous system has been so thoroughly poisoned by the blast furnace gas, that they are likely never to do any further work. In confirmation of this statement I have recently learned that the mental condition of these men remains the same, although it is now fully two years since their illness began. That the particular constituent of the blast furnace gas which poisoned these men was carbon monoxide, there is little doubt, when attention is given to the analysis of the gas.

Analysis of the gas on two occasions from the blast furnaces at which the men worked, showed large quantities of carbon monoxide.

	A.	B.
Carbonic Acid	4	7
" Monoxide	36	32
Hydrogen	2	5
Arsenic	00.1	
Sulphur	trace	
Nitrogen	58	55.3

In severe cases there may be convulsions and loss of consciousness and when the gas enters a bedroom and is inhaled by the persons who are asleep, the sleep only becomes deeper. In many instances there is no awakening.

*DISEASES OF OCCUPATION" by Thomas Oliver, M.D. Physician Royal Victoria Infirmary, New Castle on Tyne. Professor of Physiology, Dunham University, 1908 Edition.

One of the most important effects is alteration or loss of speech."

Poor ventilation in tunnel construction has been found to not only reduce the working capacity of the laborers, but many have died, where the air was not skillfully supplied. The construction and maintenance of some of the modern tunnels has been possible only by a proper air supply. During the construction of the St. Gothard Tunnel, 800 of the workmen died through defective air supply, while the Simplon Tunnel was constructed under much more serious conditions, with the hospitals empty.

Many employers have found in mine and tunnel construction work that the indirect savings that can be made by supplying fresh air for the men to work in, have been considerable, as much more work is done on account of the better health of the employees.

On account of the increased size of the fire box, the increased steam pressure and the almost complete filling of the tunnel by the increased cross section of the locomotive, the conditions have gradually changed in the tunnels. Heat that is radiated from the locomotive has increased very materially with the size of the locomotive, so that the heat met with in passing thru the tunnel is a very important factor, in addition to the poisonous gases. Steam pressures of the early locomotives operated were 150 pounds, the steam being at a temperature of 358° Fahrenheit. Present day locomotives operated in this district carry 200 pounds steam pressure with a temperature of steam of 381.9° Fahrenheit. As will be shown later from tests conducted while passing through the tunnels and later in the labratory, the normal temperature in the engine cab was raised from 55° Fahrenheit to from 128 to 142° Fahrenheit, and, on a hot summer day, the rise in temperature probably reached a maximum of 150° Fahrenheit.

Ventilation has also become necessary in railway tunnels on account of excessive heat from the greater volume and higher temperatures of the steam from the exhaust, as well as from the heat radiated from the much larger boiler and fire box surfaces. Heat has become more intense from the above causes and on account of less volume of air between the locomotive and tunnel walls, through which medium the heat is radiated and is thus reduced.

In this country the Boston and New York subways have been ventilated, although electric motor cars have been operated. Subways have been ventilated as follows:

I. By the introducing or exhausting air at various points by means of fans.

2. By forcing a current of air from one end to the other of the whole line by fans.

3. By so called natural ventilation.

4. By piston action of trains.

Beneficial results have been produced by this method of ventilation by doing away with disagreeable odors and conditions have been produced in subways very nearly approaching the atmosphere outside the subway.

Steam railway tunnels in America have been ventilated as follows:

I. By blowing the current of air with a fan in the direction the train is moving and with sufficient velocity to remove the smoke and other combustion gases ahead of the engine.

2. By blowing with a fan, a current of air against the direction of the train with velocity and volume sufficient to dilute the smoke and combustion gases to such an extent as not to be uncomfortable to the operating crews.

Steam railway tunnel ventilation, while not as difficult as subway ventilation, is much more serious to those subjected to the gases. On the one hand, it is a problem largely of removing disagreeable odors, requiring constant renewal of the air, while on the other hand, a sufficient volume of air is necessary to reduce the high temperatures and remove sufficient of the gases so they will not be dangerous to the health and lives of the employees.

The list of tunnels ventilated under the plans of Charles S. Churchill and C. C. Wentworth are given in the statement following and it is understood in most cases with good results.

TABLE # 7.
RECORD OF TUNNEL VENTILATION.

UNDER PLANS OF CHAS.S. CHURCHILL & C.C. WENTWORTH

Location of Tunnel	Date of Installation	Rate of Grade	Location of fans	Length of Tunnel	Section Square Feet.
N. & W. Ry. Elkhorn, Coaldale, West Virginia	6 - 1901	*1.4%E 2/3 length	Lower End	3000	S. 235
C. & O. Ry. Big Bend, E.Hinton, West Virginia	12 - 1902	*0.4% E	Upper End	6500	S.T.250
P. R. R. Washington, D.C. Station	12 - 1907	*0.13%S	Upper End	Tubes 4050 Track 760 2-6 tracks	S.T.260
P. R. R. Callitzin, Altoona Pennsylvania	4 - 1905	*0.5% W	Lower End	3600	S.T.324
Penn., North & East Rivers, New York	9 - 1910	Special installation of 14 fans for emergency uses of tubes that are 4135 ft. and 4357 ft.			Vent. 225
B. & O. R. R. Kingwood, Tunnleton, West Virginia	12 - 1910	*1.0% E	Lower End	4138	S.T.352
C. & O. Ry. Lewis, Allegheny, Virginia	6 - 1911	*0.14%W	Lower End	4026	S.T.318
N. Y. C. Line Weehauken, N.J.	9 - 1911	*0.25%E	Lower End	4365	D.T.469
P. R.R. Tunnel Baltimore, MD.	9 - 1911	*1.32%S	Upper End	4963	D.T.432

RECORD OF TUNNEL VENTILATION CONT'D.

Location of Tunnel	Date of Installation	Rate of Grade	Location of Fans	Length of Tunnel	Section Square Feet.
C.G.W.R.R. Winston, Ill.	5 - 1911	*1.00%E	Lower End	2500	S.T.282
Va. Ry. Allegheny Tunnel	in progress	*1.22%E	Lower End	5148	S.T.369
N.P. Ry. Mullen, Mont.	in progress	*2.00%W	Lower End	3899	S.T.283
N. & W. Ry. Horseshoe	in progress	*0.18%E	Upper End	3291	S.T.300
N.P.Ry. Stampede, Washington	in progress	*0.74%E *0.20%W	Lower End	9844	S.T.310

Plans for ventilating steam railway tunnels by Charles S. Churchill and C. C. Wentworth are extensively used in the ventilation of American railway tunnels, and where adopted, have given good relief.

Designs of the fans in most general and recent use, are the multivane type of blade, arranged as shown in the side and end views on page 26-7, Figures 9-10-and 11. It will be noted that the fan is made up of a large number of narrow blades, riveted to the side of the plates. Inlet area obtained by narrow blades, it will be noted by the arrows, is large and would seem to bring about most efficient results. The direction of the outlet to the air duct is indicated by the vertical arrows.

Blades of the fan are made up of plates of steel, curved radially, which contain several cup shaped depressions which tend to confine the air until the blades reach the outlet.

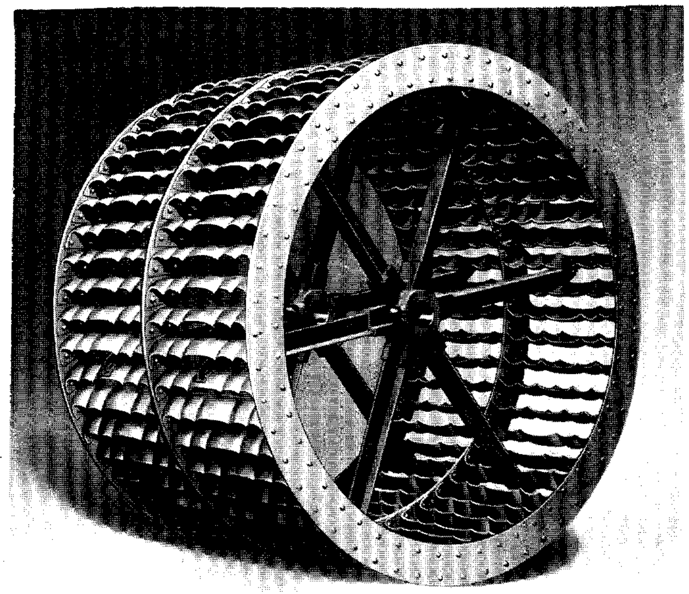


Figure 9

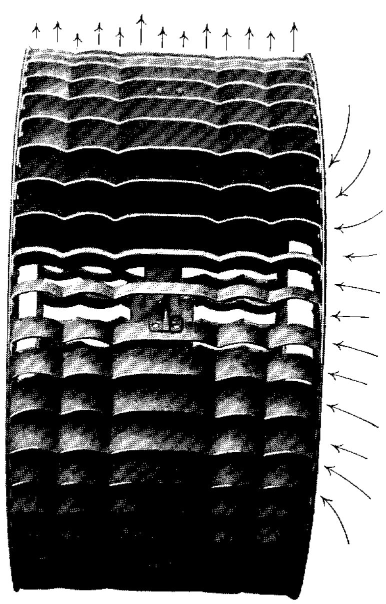


Figure 10

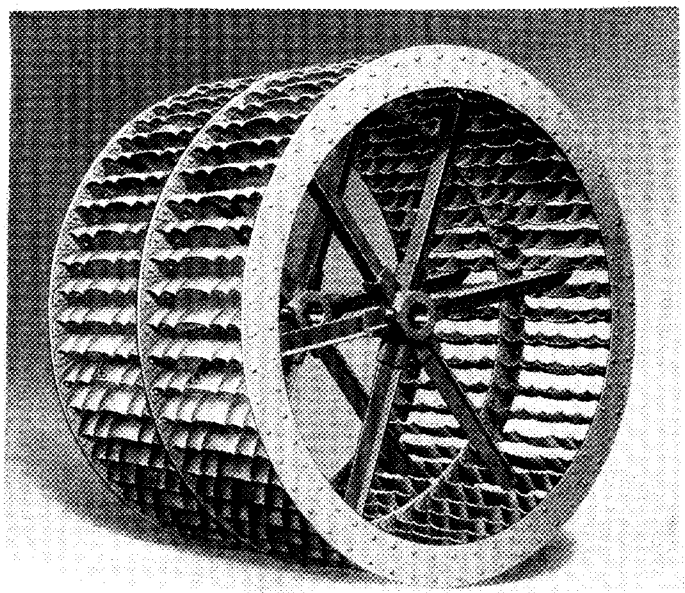


Figure 9

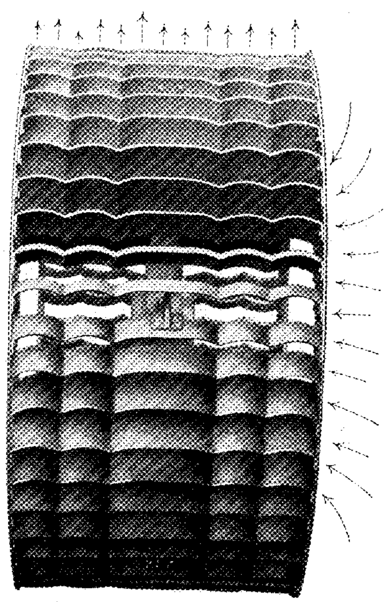


Figure 10

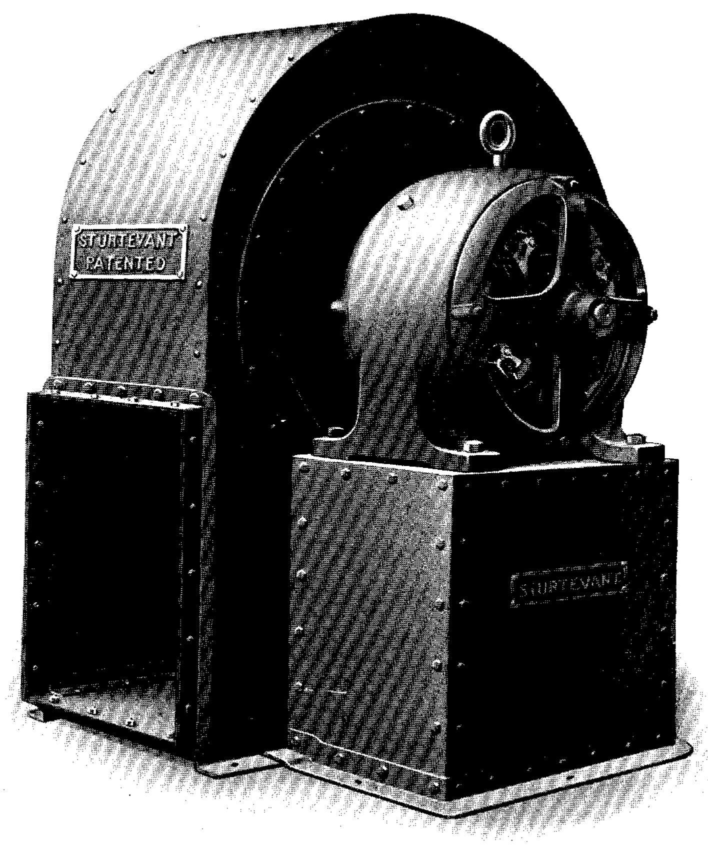


Figure 11

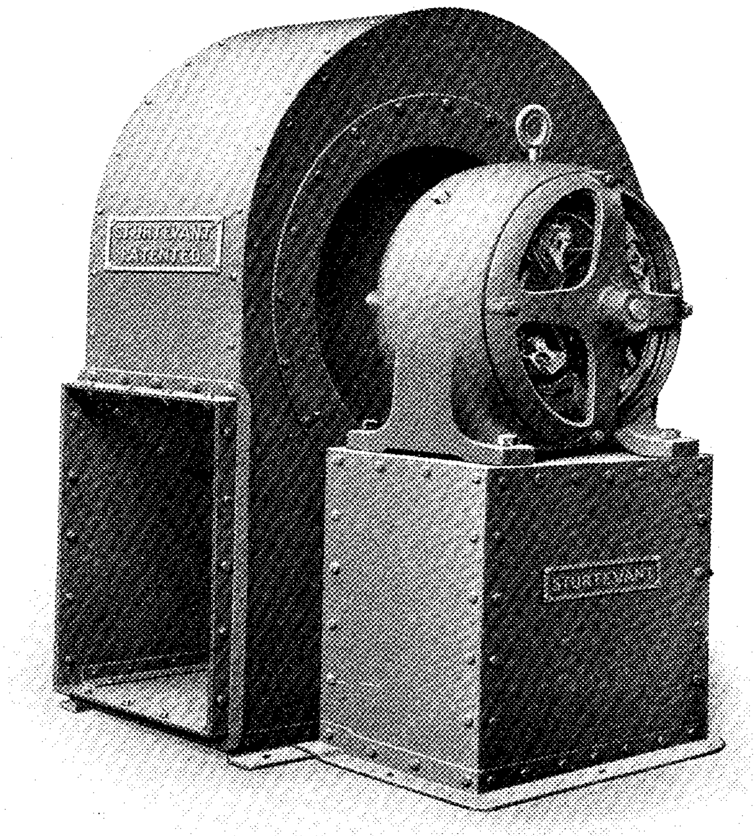


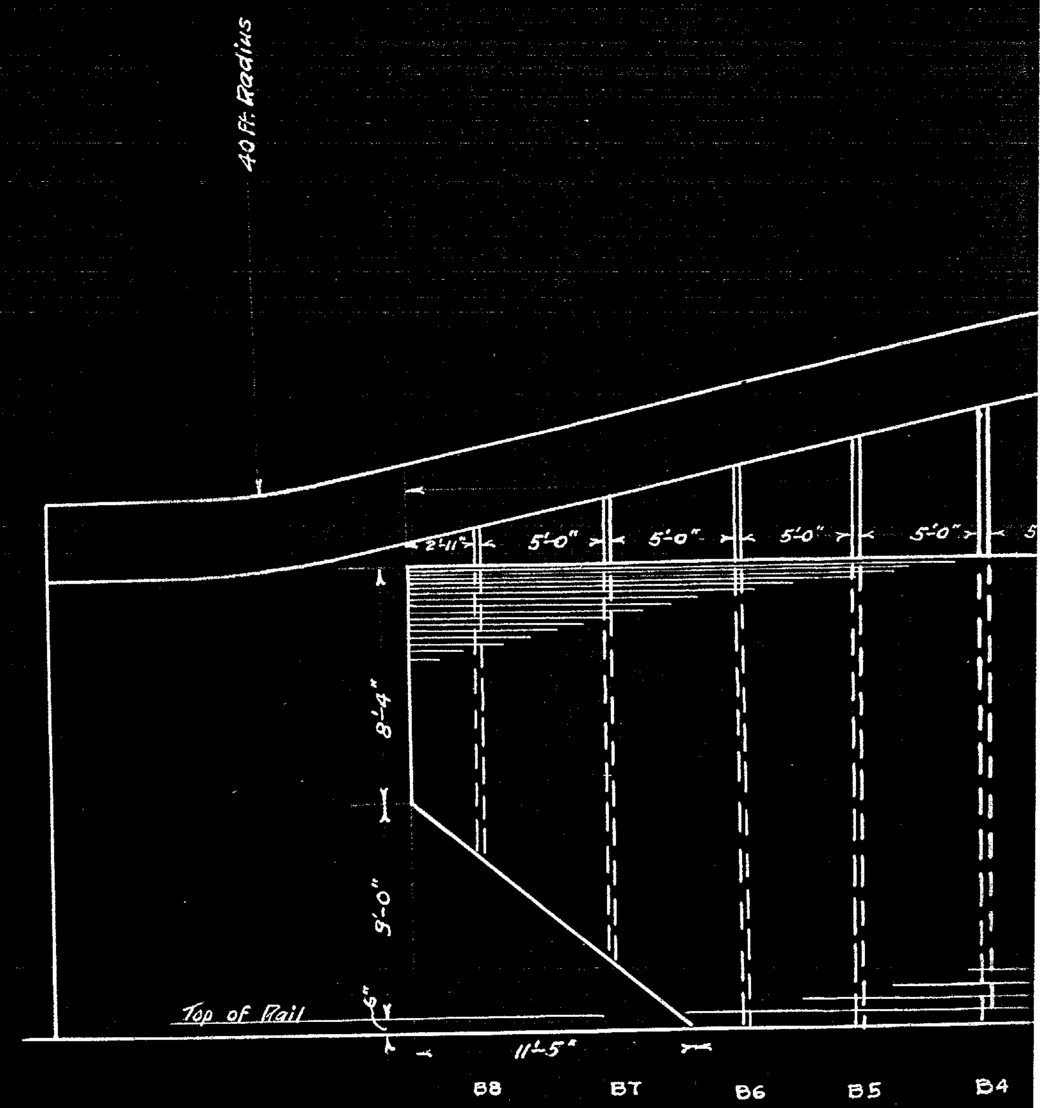
Figure 11

Air is delivered by the fan to an air duct, which delivers the air into the tunnel through a nozzle. The nozzle is also designed by Messrs. Churchill and Wentworth, general lines of which are shown by Figure 12, page 29. Air delivered through the nozzle takes the direction indicated by arrows and, of course, attaining very high velocity at the nozzle. Average velocity of the air, judging from the speed of trains that follow the gases through the tunnel, is from ten to twelve miles per hour. The ventilation of the tunnel is caused by blowing the current of air in the direction in which the train is moving on the ascending grade, thus blowing the gases ahead of the engine.

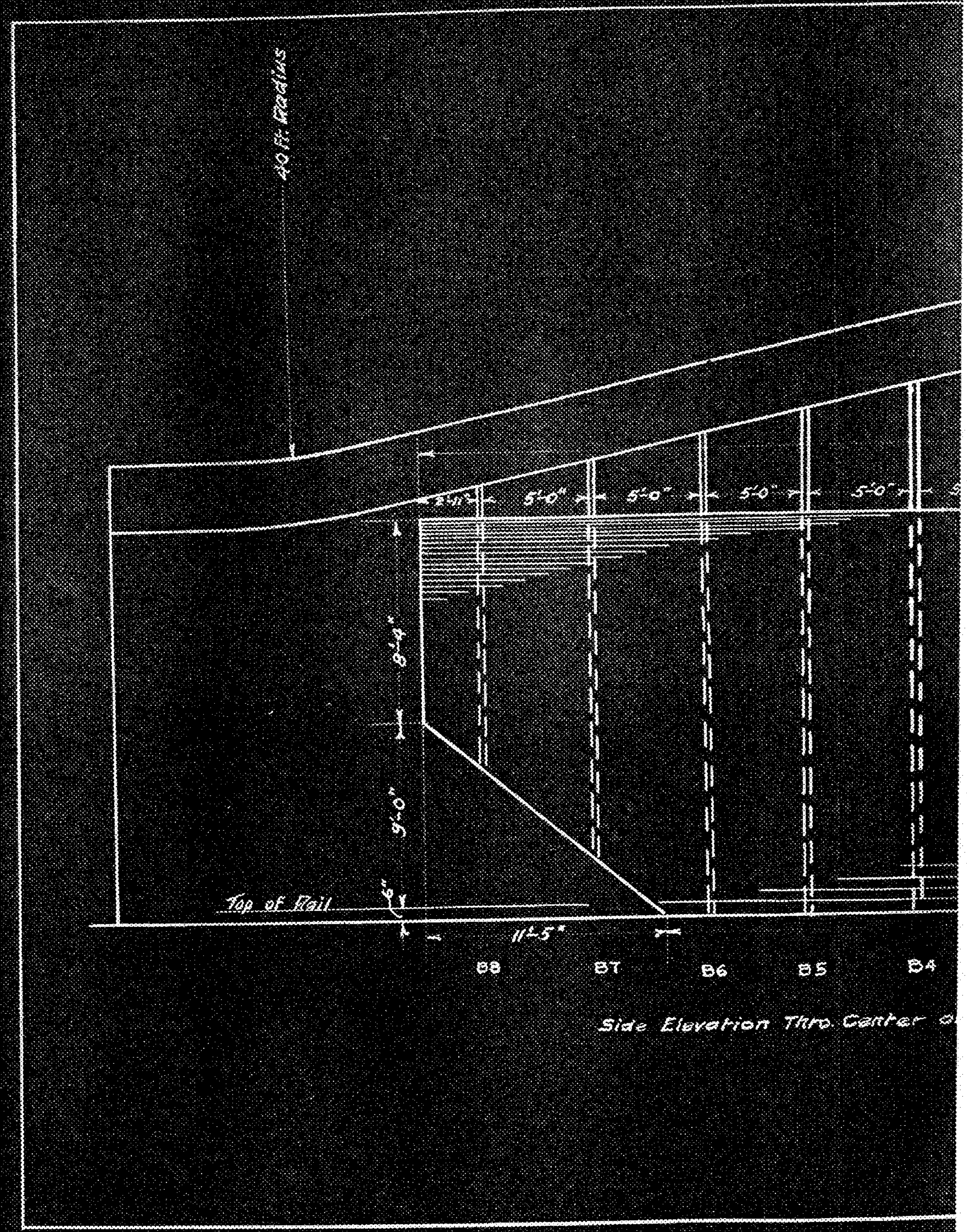
Previously described fans are similar to one that has been installed for the ventilation of a tunnel some 4,000 ft. long, that has been investigatedby the writer. Fans used for ventilating are 9 ft. 8½ in. in diameter, propelled by a 250 H.P. alternating current motor. The fans are operated at 180 revolutions a minute with a motor capable of making 580 revolutions a minute.

A night and day operator is on duty and the fans are only operated while tommage freight trains operated on a long 1.14% ascending mountain grade, with Mallet locomotives carrying 200 pounds steam pressure.

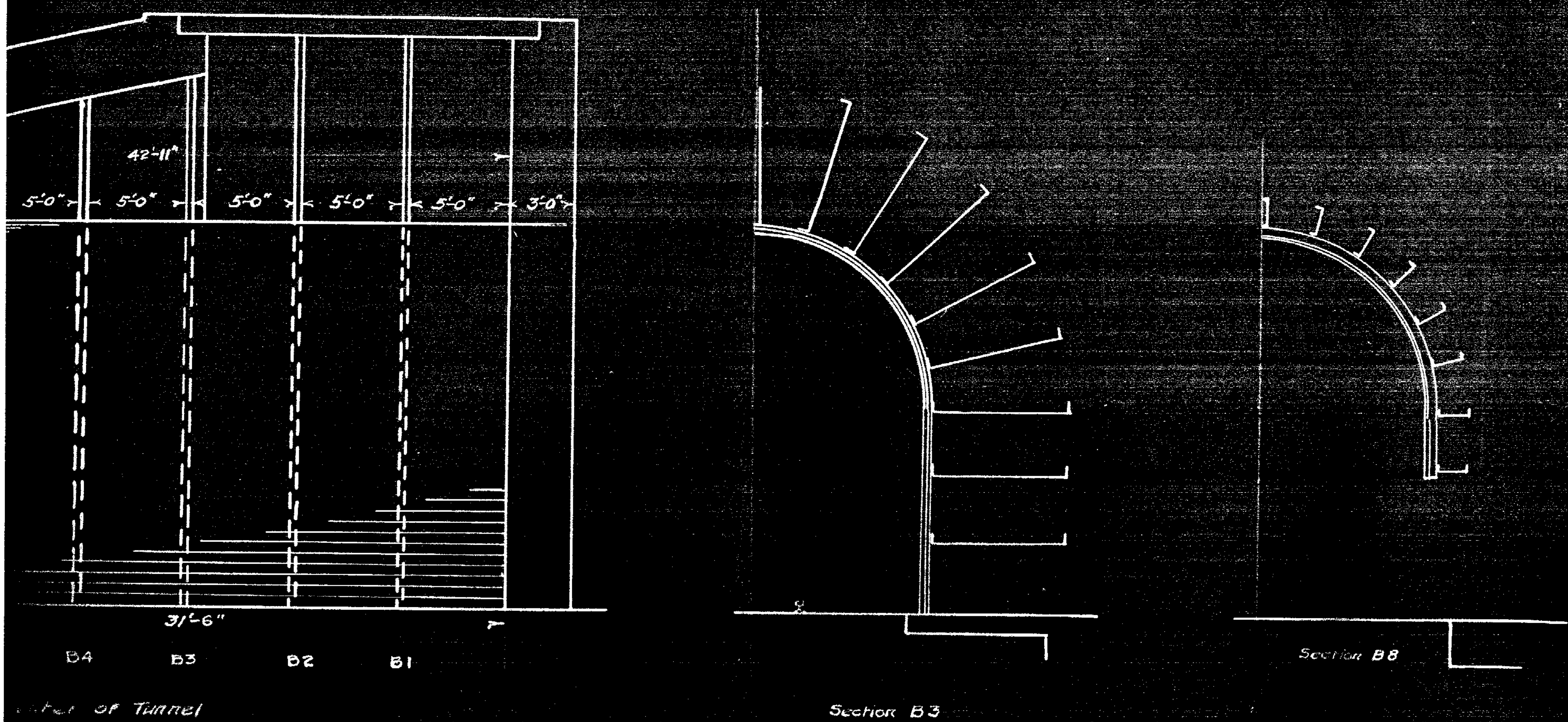
These Mallet locomotives have a tractive power of 79,626 pounds, use super-heated steam, which at a steam pressure of 200 pounds reaches a temperature much higher than saturated steam. In addition, these locomotives have automatic stokers, so that there is continuous firing during the time the locomotive passes through the tunnel. In the case of hand fired locomotives, it is the practice not to do any firing while the locomotive is passing through



Side Elevation Thro. Center o

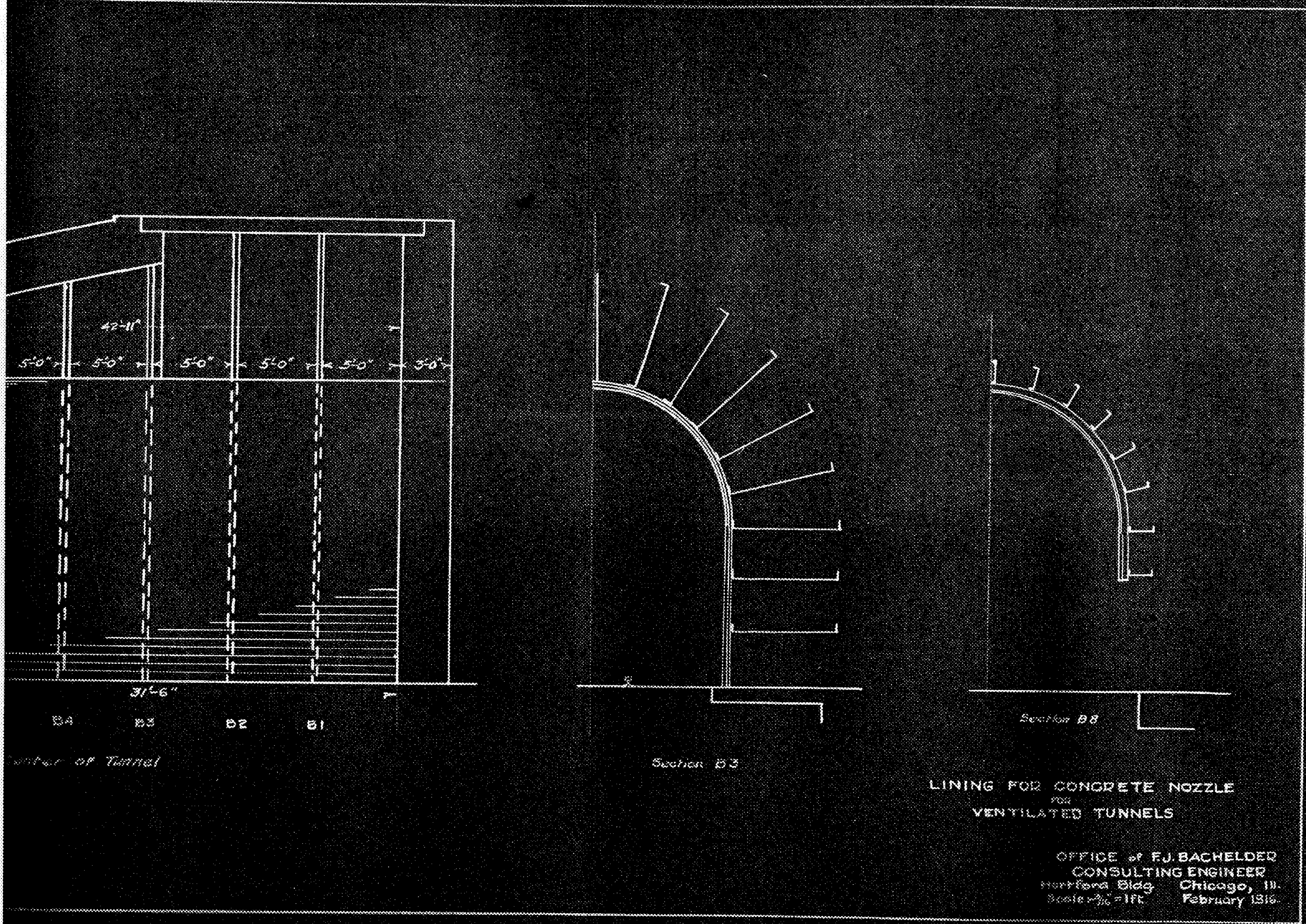


Side Elevation Thro. Center o



LINING FOR CONCRETE NOZZLE
FOR
VENTILATED TUNNELS

OFFICE of F.J. BACHELDER
CONSULTING ENGINEER
Hartford Bldg. Chicago, Ill.
Scale 1-3/16" = 1 ft. February 1916.



42'-11"
5'-0"
5'-0"
5'-0"
5'-0"
5'-0"
3'-0"
31'-6"
B4
B3
B2
B1
of Tunnel
Section B3
Section B8
LINING FOR CONCRETE NOZZLE
FOR
VENTILATED TUNNELS
OFFICE of F.J. BACHELDER
CONSULTING ENGINEER
Hartford Bldg. Chicago, Ill.
Scale 3/16" = 1 ft.
February 1916.

or just previous to entering the tunnel, but with these automatic stokers the firing, of course, is continuous. Fan operators receive instructions as to trains that need ventilation from the operator at the telegraph office, near approach to tunnel, by telephone.

Observations made by the writer, 925 ft. from the lower end of the tunnel, between the train and wall of tunnel, at a height of 6 ft. above the top of rail, while the train was passing, showed a very excellent result obtained by the ventilating fans. Diluted gases blown ahead of the locomotive seemed about normal temperature of the air in the tunnel before the locomotive entered and the gases were not as extremely obnoxious as experienced in some naturally ventilated tunnels. The atmosphere in which the locomotive actually travels, just following the gases are not at all obnoxious. Temperature changes observed while locomotive was in the tunnel, showed only 2° above the normal and the analysis of the sample of the gas taken just as the truck wheel of the engine passed shows result as follows:

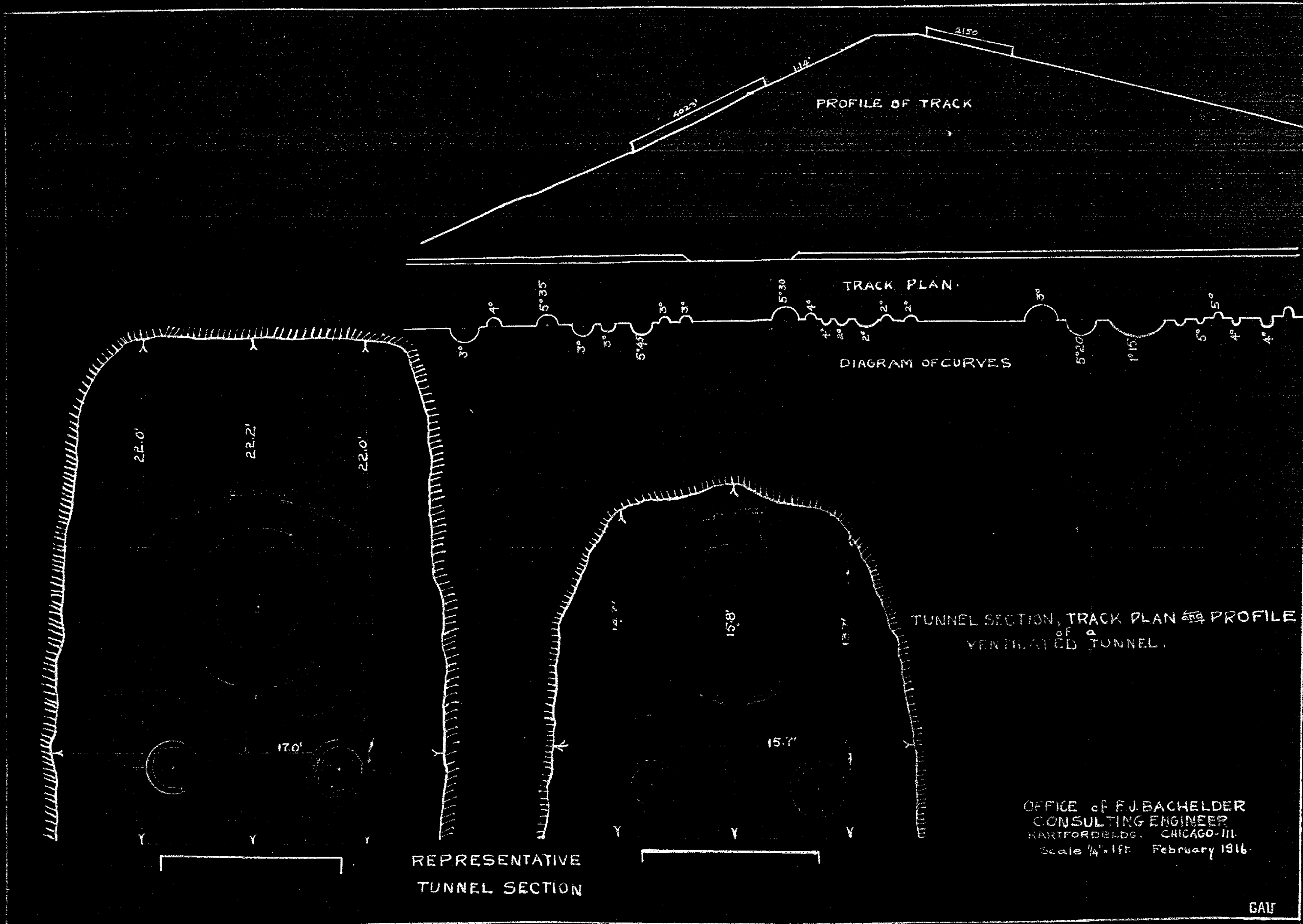
TABLE # 8.

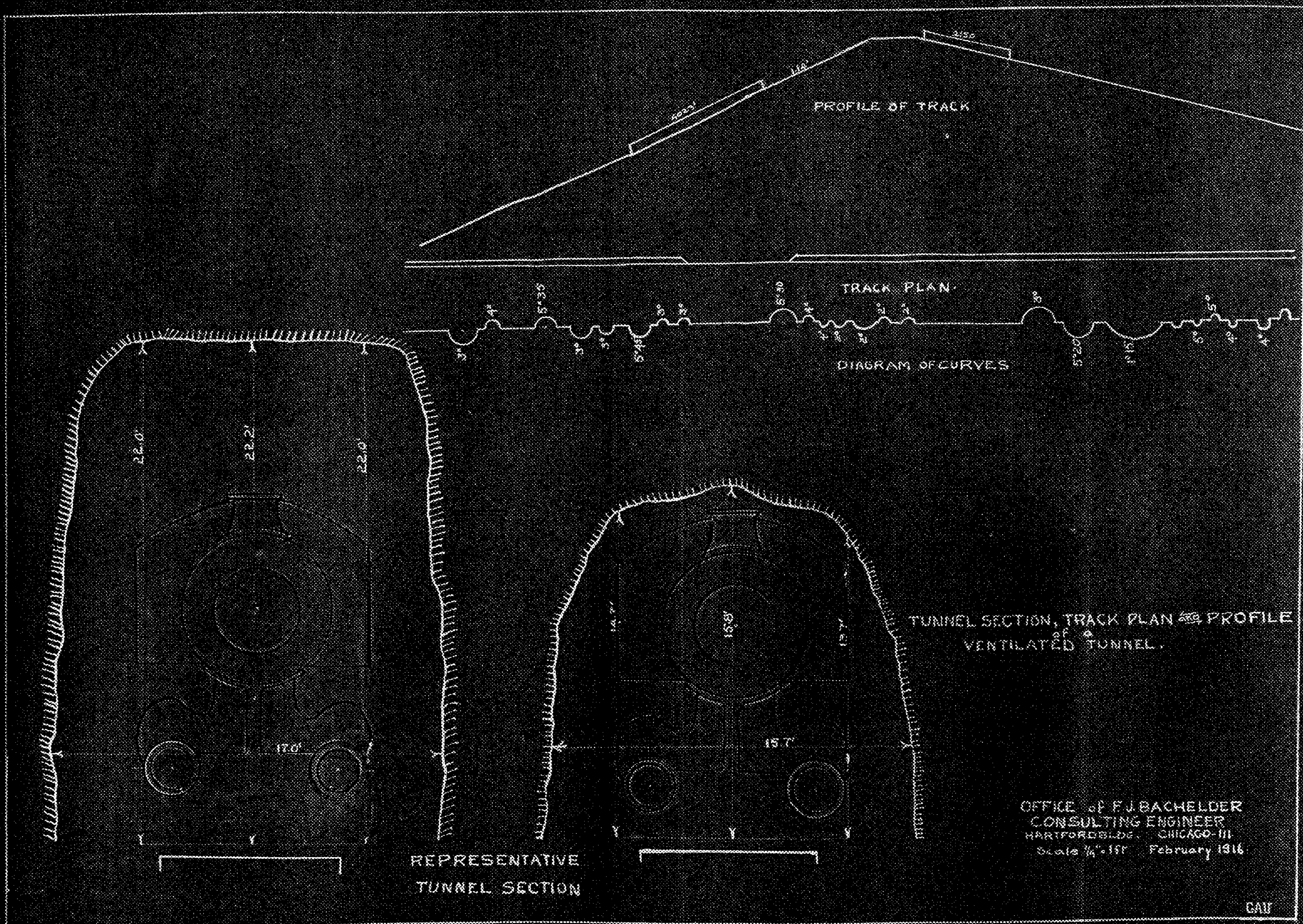
	Sample of Gas in Ventilated Tunnel, Engine #700	Composition of Pure Atmospheric Air.
Carbon Dioxide	20	
Carbon Monoxide	none	
Oxygen	1990	2094
Hydrogen	trace	9
Nitrogen	7990	7800
Argon		94
Carbonic Acid		3

In the second column, the composition of pure atmospheric air is given and it will be noted that the analysis of the composition of the gases in this tunnel shows practically the same proportion of oxygen, nitrogen and hydrogen, with no carbon monoxide and some carbon dioxide gas and confirms the impression had while in the tunnel as the train passed, that it was almost an ideal condition for train operation, with one of the heaviest locomotives with a train load of tons, on a mountain grade.

A sample of gas taken where the method of ventilation was by blowing current of air to the opposite direction that the train was moving, thus diluting the air, provides relief from the poisonous gases and heat. Apparent advantages seen in this system of operation is that it is more economical. This is especially true where the section of the tunnel is large, requiring larger volumes of air, with larger fans and more power to operate. Where the section of the tunnel is small, it is probable that this method would not prove more economical than the method of blowing the gases ahead of the locomotive.

Blue print, page #32, Figure #13, shows the cross section and grades approaching the ventilated tunnel and in which the Mallet engine is operated. Outline of the locomotive is shown in red and the smaller section shows a rather restricted area. Yet the results from the mechanical ventilation was good, as can be seen by consulting Table # 8, Page 30.


PROFILE OF TRACK
4023'
1.14'
2150
TRACK PLAN.
DIAGRAM OF CURVES
3°
4°
5°35
3°
3°
5°45
3°
3°
5°30
4°
4°
2°
2°
2°
2°
3°
5°20
1°15
5°
5°
4°
4°
22.0'
22.2'
22.0'
17.0'
14.7'
15.8'
13.7'
15.7'
REPRESENTATIVE
TUNNEL SECTION
TUNNEL SECTION, TRACK PLAN AND PROFILE
of a
VENTILATED TUNNEL.
OFFICE of F.J. BACHELDER
CONSULTING ENGINEER
HARTFORD BLDG. CHICAGO-ILL.
Scale 1/4"=1Ft. February 1916.
GAU


PROFILE OF TRACK
TRACK PLAN
DIAGRAM OF CURVES
22.0'
22.2'
22.0'
17.0'
15.8'
15.7'
REPRESENTATIVE
TUNNEL SECTION
TUNNEL SECTION, TRACK PLAN AND PROFILE
of a
VENTILATED TUNNEL.
OFFICE of F. J. BACHELDER
CONSULTING ENGINEER
HARTFORD BLDG. CHICAGO-ILL
February 1916
GAU

A sample of gas from a tunnel having only natural ventilation, on the Chicago & North Western Railroad, known as tunnel #3, at Summit, Wisconsin, was taken by the writer and the analysis of the composition showed the following:

TABLE # 9

	Parts per 10,000
Carbon Dioxide	20.00
Carbon Monoxide	30.00
Oxygen	1925.00
Hydrogen	10.00
Nitrogen	8015.00

It will be noted that both of the dangerous gases, carbon dioxide and carbon monoxide, were found in this tunnel, the carbon monoxide being in sufficient quantity to produce serious effects, and the carbon dioxide in sufficient quantity to be near the danger point. This can be seen by comparing the quantities given as dangerous, Table 5, page 19. The sample was taken July 8th, 1915, during the passing of an east bound passenger train, hauled by one locomotive, at a height of 7 ft. 6 in. above the top of rail, between the train and wall of the tunnel, at a distance of 1500 ft. from the east portal of the tunnel.

This investigation was instigated as the result of a locomotive engineer in the service of the Chicago & North Western R. R., having been overcome while on the second engine of a double header passenger train, while passing through the tunnel on the ascending grade.

There seems little doubt but what the overcoming of the Chicago & Northwestern locomotive engineer was what might be expected from the gases found in this tunnel, and probably resulted in his death.

CONSTRUCTION COSTS OF TUNNEL VENTILATING PLANTS

The kind of power to be adopted for operation of ventilating plants largely depends upon local conditions. If the tunnel to be ventilated is in a district where cheap electric power may be obtained from a hydro-electric plant relatively nearby, electric power would seem to be most advisable. Except where a very heavy and dense traffic may exist, a steam power plant is not economical for operation, as it is necessary to keep a head of steam and fire in the boiler at times when it is not necessary to operate the ventilating apparatus. Even where low priced fuel is available it has been found that electric power from hydro-electric developments was more economical than the steam power plant, this for the reason that in addition to the power not being used, it was possible to operate the plant with less labor, as the fireman was done away with. By this reduction in force it was possible to make a reduction in operating expenses.

It is deemed advisable to have two units, whether steam or electric power is used, which makes it possible to keep the plant in operation while repairs may be necessary on one of the fans or engines.

Where the cost of electric power equals the cost of operation by steam, an electrically operated fan requires a smaller construction cost. The following is the approximate cost of an installation complete with steam plant and fans, compared with the cost of an electrically operated plant complete with fans.

These costs represent complete cost of the steam power with all connections to the boiler in the one case, and the cost of motors, switchboard and apparatus necessary for taking power from the transmission line, including necessary transformers and regulators.

Total cost of steam power plant, including engines and steam connections from boiler to engines, for the operation of two units of ventilating fans, 9'x8½" in diam. and operated at 180 revolutions per minute	$23,845.00
Total cost of installation of fans including fittings and nozzle	30,900.00
GRAND TOTAL	$53,745.00

Total Cost of Electrically Operated Ventilating Fans

Total cost of installation of two direct connected, 250 H.P. alternating current motors with necessary switchboard and regulators for operation of two ventilating fans, 9'x8½" in diam. operated at 180 revolutions per minute	$10,890.00
Total cost of installation of fans including fittings and nozzle	30,900.00
GRAND TOTAL	$41,790.00

Local conditions may make some variation in the cost of installation of the plants, but the above figures are considered reasonable for the average conditions met with.

OPERATING COSTS OF MECHANICAL VANTILATION

Consideration of the expense of correcting conditions investigated by Public Bodies and required by law, does not necessarily involve strict attention to the cost, except to determine the reasonableness of the method to be pursued in correcting the conditions.

Data available as to the cost of operating fans for ventilating tunnels, varies somewhat with the kind of power used and the number of trains, especially since in most cases, the fans are only operated for heavy tonnage trains, operating in the direction of the ascending gardes and therefore, are only operated for a portion of the time.

Statistics available show an average cost of $23.70 per day using electric power, supplied by a utility company at 2½¢ per kilowatt hour and including all labor and material for maintenance and operation. Cost of operation, using a steam plant at this same point, averaged $28.00 per day, coal costing $1.00 per ton. This does not include the depreciation or investment charges in either case. Electric power, where available at reasonable rates per kilowatt hour, from some power utility company, seems to usually prove to be most economical, especially where traffic through the tunnel is light, as fuel would not then be burned when the tunnel was not used by the trains.

RESULTS

In making the study of the conditions in these tunnels it has been the endeavor to know conditions and the facts by observing first hand from personal experience in making the trips through the tunnels. In addition to observations, data gathered was studied in connection with labratory analysis and experiments. To obtain actual operating conditions, was the aim, in carrying on the investigation. Tonnage handled and the make up of the trains was noted, tests were made on head engine and rear engine of double header train, as well as on light tonnage trains. Trips were also made on an engine equipped with a locomotive ventilator provided in a few cases to supply better ventilation to the engineer. Respirators, for sale and available to all members of the train and engine crews were also used. These devices are said to provide relief from heat and the gases.

One of the principle features of the complaint by the employees has been the excessive heat. From a study of the effects described by the men in these tunnels, it occurred to the author that poisonous gases given off, as a result of combustion, might have a greater effect in cuasing them to be overcome than the temperature.

Gas samples were, therefore, taken in the engine cab while locomotives were passing through the tunnels. Containers for taking gas samples, filled with distilled water and provided with a valve on each end, were used in taking samples of gas. After the locomotive had entered the tunnel, both valves were opened and a sample of the gas was drawn into the container, as the water ran out. Use of the distilled water eliminated any possibility of the gas sample being contaminated. Samples of gas as taken, are fairly representative of the conditions under which the men have to work. As the sample was taken in the engine cab, with all the available windows and doors closed, conditions obtained in the engine cab would not represent the extreme conditions which would be encountered in case the engine should be stopped on account of breaking in two, or having been stalled. Considerable protection is afforded by the engine cab. In case it became necessary for a member of the crew to get out in the tunnel to examine the train, conditions met with would be more serious.

In order to have absolute knowledge of the quality of the coal being fed into the fire box at the time of passing through the tunnel, a sample of the coal being used was taken in three cases. This with the view of determining any unusual fuel conditions, which might be surmised was the cause for excessive amounts of certain gases. A representative sample of the coal was taken for labratory analysis.

GAS ANALYSIS

The following Table gives the results of the analyses of the samples of gases taken in the tunnels in which conditions observed were in need of more complete investigation. In addition to these results of analyses, additional information is given of the analysis of ordinary atmospheric air. One of the samples of gas taken in #6 tunnel, it will be noted, corresponds very closely with the analysis of atmospheric air. The seal on this container was broken and may have been tampered with by some one curious to know about the apparatus. It will also be noted that this train was a quick dispatch train, handling light tonnage.

TABLE # 10

	PARTS PER TEN THOUSAND.					
	Analysis of Pure Atmospheric Air	Analysis of Principle Gases of Expired Air	Sample taken 2/9/16 on engine #2885 in tunnel #6 of B&O R.R.	Sample taken 2/6/16 on engine 2832 in Eaton Tunnel, #21	Sample taken 2/8/16 on engine #2737 in Silver Run Tunnel, #19	Sample taken 2/5/16 on engine #2824 in Eaton Tunnel, #21
Tonnage Hauled by Locomotive Adjusted Tons			816*	1890	1042	1910
Carbon Dioxide	3	438.0	10	10	10	150
Oxygen	2094	1600.3	2050	1650	1390	1890
Carbon Monoxide	none		none	10	20	30
Hydrogen	9		trace	7	13	13
Nitrogen, etc	7800	7958	7940	8323	8567	7917
Argon	94					

* A quick light dispatch tonnage train.

Results of analysis of gases from tunnel #19, commonly known as Silver Run Tunnel, the percentage of oxygen was found to be the lowest of any test samples, with double the amount of carbon monoxide and the same quantity of carbon dioxide as found in tunnel #6 and sample taken from locomotive operating single train through tunnel #21. These smaller quantities of carbon dioxide and carbon monoxide gas, however, are in sufficient quantities to result in rapid and dangerous injury.

When riding through this tunnel, the writer placed a handkerchief saturated with water over his nostrils and mouth and a very uncomfortable trip was experienced. Breathing was difficult, but not as difficult as when riding on pusher engine #2824, while passing through tunnel #21, but the trip was decidedly uncomfortable.

A sample of gas taken from Tunnel #21, known as Eaton Tunnel, on the engine #2824, of a double header train, shows very unusual condition with exceptionally large comparative quantities of carbon dioxide and a larger proportion of carbon monoxide than usually met with. The percentage of oxygen in the sample was more favorable in Eaton than in Silver Run tunnel, in tests previously mentioned. Parts of carbon monoxide gases were in sufficient quantity to cause rapid and dangerous injury, according to information given by Table 5, page #19. Tests described later in this report of a canary bird being placed in an actual sample of this tunnel gas, confirms results found by various investigators. In fact, the writer in passing through this tunnel experienced conditions that were as nearly unbearable as it was possible for him to realize. Although, before entering the tunnel, he had saturated a handkerchief with water and placed same over his nose and mouth, by the time he was half way through the tunnel, he was gasping for breath and felt as if there was a question whether he would survive the ordeal. Breathing was exceptionally difficult and he fells he would not care to undertake a trip on a double header engine more often than could possibly be avoided. Men should not be asked to work under such conditions, as it is about the limit of human endurance. At the time this test was made, the writer was free from colds or any apparent physical condition that would aggravate his breathing and there were no other unusual conditions that would not be met with in ordinary operation of a double header train. Coal furnished on this trip was excellent, being almost entirely free from slack and dirt and from its analysis it will be seen, and the later discussion will show it to be an excellent grade for such purposes. There was a full head of steam upon entering the tunnel, no firing being done just previous nor while passing through the tunnel. Condition of the fire in the fire box was good. Speed attained through the tunnel, according to records was at the rate of 7.6 miles per hour, which I believe is as fast as is usually made by a tonnage train. It will be noted that steam pressure only dropped 3 pounds while passing through the tunnel, which would indicate a good condition of the steaming qualities of the boiler.

Representative samples of coal were taken in order to determine from the usual coal analysis, the value of the coal as a fuel and whether there were any unusual ingredients in the coal, which might made it unfit for use in a locomotive operating thru a tunnel. Results of the analysis of the three samples taken are given in Table #11, page 43.

TABLE # 11.

COAL ANALYSIS OF SAMPLES

	Sample Coal of Engine Tender #2824 2/5/16. Eaton Tunnel, #21.	Sample Coal of Engine #2885 2/9/16, Tunnel #6	Sample Coal Engine #2832 2/6/1916 Eaton Tunnel
Moisture	Elim.	Elim.	Elim.
Volatile Combustible Matter	39.14	40.15	41.02
Fixed Carbon	52.19	53.58	51.06
Ash	7.95	6.27	7.92
Sulphur	2.97	2.66	4.23
Heat Value (B.T.U.)	14026	14281	14004

Analysis shows the coal to be uniform in quality and as having a high comparative heat value. Percentage of ash in the coal is low, which would tend to allow of keeping a good fire and the volatile matter is not so high but what good combustion can be obtained in an ordinary fire box.

The coal supplied engine #2824 on February 5th, when it made the trip through tunnel #21, appeared to be an exceptionally good coal, as it was unusually free from dust, dirt, slate and slack, better than usually obtained where run of mine coal is used.

Coal supplied engine #2832 on February 6th, while passing through tunnel #21, known as Eatons Tunnel, would run about one third slack and would be considered only fair coal where run of mine is supplied.

Coal supplied engine #2885, Feb. 7th, while passing through Eatons Tunnel, would be considered good coal where run of mine is used.

TEMPERATURE

In the collection of data regarding temperature, normal outdoor temperatures, normal temperatures in the engine cab and temperatures while passing through the tunnels on the locomotive, were taken. There was a certain error involved in reading of the temperatures in the tunnels, owing to the fact that the temperatures could not be read until after leaving the tunnel on account of the steam and gas interfering with seeing the mercury. The error involved, account of not being able to read the thermometer until reaching daylight outside of the tunnel, would tend to get lower than the actual temperatures. These temperatures were taken with thermometers whose readings were checked with the reading of the U. S. Weather Bureau at Parkersburg, W. Va., as well as compared with a calibrated labratory thermometer. Comparisons of these readings are given in Table 15, page 64 , of the appendix. On account of the comparatively short time consumed in passing through the tunnel, it was the opinion of the author, confirmed by the following labratory tests that the maximum temperature was not obtained on account of insufficient time elapsing in which the change of temperature of from 37° to 53° could be registered while the engine was passing through the tunnel.

TABLE #_12.

Time in Minutes	Steam Calibrated Labratory Thermometer (Fahrenheit)	Temperature of Field Thermometer (Fahrenheit)
0	32 °	36°
30	46 °	
1:00	53 °	56°
1:30	61 °	65°
2:00	65 °	72°
3:00	71 °	77°
4:00	75 °	78°
5:00	77	

It will be noted that the calibrated labratory thermometer gave almost identical results with the hermometer used in taking most of the temperatures in this study. It also apprars from this test, that the maximum emperature of the tunnels was not registered in the time consumed in passing and it seemed to the writer the temperature as actually raised considerably higher than indicated by the thermometer readings, after passing through the tunnels.

Following is a statement giving the temperatures, steam pressures and other data, taken while pasing through the tunnels, in this investigation:-

TABLE # 13

COMPARISON OF NORMAL AND TUNNEL TEMPERATURES.

ate	Train	Number of Engine	Time	Tunnel Number and Location	Temperature (Fahrenheit) Normal Out doors	In engine cab	Temperature In Tunnel	Difference in Temperature	Temperature of Steam & Steam Pressure: Entering Tunnel Pressure	Entering Tunnel Temperature	Leaving Tunnel. Pres-(F)ure	Leaving Tunnel. Temperature (F)
/5/16	46	2824	3:00	#21 W. Eaton	41o	55°	92°	37°	200#	381°.9	197#	380 92
/6/16	88	2832	2:30	#21 W. Eaton	48°	68°	112°	44°	200#	381°.9	165#	366°
/7/16	50	2885	1:45	#21 W. Eaton	30°	58°	100°	42°	200#	381°.9	195#	380o
/8/16	88	2845	2:04	#21 W. Eaton	28°	54°	110°	56°	200#	381°.9	175#	371°
/8/16	43	2737	1:30	#19 Silver Run	43°	58°	102°	44°	200#	381°.9	180#	373°
/9/16	2nd 96 Q.D.	2885	1:20	# 6 E. Central	41°	48°	94°	46°	190#	377°.6	180#	373°
/9/16	2nd 49	2832	2:30	# 1 E. Clarksburg	45°	52°	105°	53°	200#	381°.9	180#	358°.5

It will be noted while ranges in the temperature, with a maximum range of 56 degrees was registered, d a maximum temperature of 112 degrees was reached, these maximum temperatures would not seem to indicate the actual temrature encountered. However, as previously stated, the heat seemed to be much greater than the thermometer recorded and the labratory test was made to determine the real temperature. A study of Table 14, page 47, readily indicates that at the range in temperature cannot be accurately registered in the time the trains were in the tunnels.

It will be noted that the calibrated labratory thermometer gave almost identical results with the thermometer used in taking most of the temperatures in this study. It also apprars from this test, that the maximum temperature of the tunnels was not registered in the time consumed in passing and it seemed to the writer the temperature was actually raised considerably higher than indicated by the thermometer readings, after passing through the tunnels.

Following is a statement giving the temperatures, steam pressures and other data, taken while passing through the tunnels, in this investigation:-

TABLE # 13

COMPARISON OF NORMAL AND TUNNEL TEMPERATURES.

Date	Train	Number of Engine	Time	Tunnel Number and Location	Temperature (Fahrenheit) Normal Out doors	In engine cab	Temperature In Tunnel	Difference in Temperature	Temperature of Steam & Steam Pressure — Entering Tunnel Pressure	Entering Tunnel Temperature	Leaving Tunnel Pres(F)ure	Leaving Tunnel Temperature (F)
/5/16	46	2824	3:00	#21 W. Eaton	41o	55°	92°	37°	200#	381°.9	197#	380 92
/6/16	88	2832	2:30	#21 W. Eaton	48°	68°	112°	44°	200#	381°.9	165#	366°
/7/16	50	2885	1:45	#21 W. Eaton	30°	58°	100°	42°	200#	381°.9	195#	380o
/8/16	88	2845	2:04	#21 W. Eaton	28°	54°	110°	56°	200#	381°.9	175#	371°
/8/16	43	2737	1:30	#19 Silver Run	43°	58°	102°	44°	200#	381°.9	180#	373°
/9/16	2nd 96 Q.D.	2885	1:20	# 6 E. Central	41°	48°	94°	46°	190#	377°.6	180#	373°
/9/16	2nd 49	2832	2:30	# 1 E. Clarksburg	45°	52°	105°	53°	200#	381°.9	180#	358°.5

It will be noted while ranges in the temperature, with a maximum range of 56 degrees was registered, and a maximum temperature of 112 degrees was reached, these maximum temperatures would not seem to indicate the actual temperature encountered. However, as previously stated, the heat seemed to be much greater than the thermometer recorded and so the labratory test was made to determine the real temperature. A study of Table 14, page 47, readily indicates that that the range in temperature cannot be accurately registered in the time the trains were in the tunnels.

In order to obtain temperatures that were actually existing in the locomotive cab, a series of tests were conducted in which the range of temperature found in the locomotive cab, were used, the thermometers being placed in a furnace whose temperature could be maintained at any desired degree. The furnace consisted of a metal box, lined with asbestos, the insulation assisting in maintaining uniform temperature. Heat was supplied by a Bunson Burner and a calibrated thermometer immersed in mercury recording the temperature of the furnace. Field thermometer as well as the labratory thermometer were brought to the normal temperature of the engine cab and then placed in the furnace and the time was recorded in which the range of temperature, experienced in the tunnel, was taken. By a number of trials, the temperature of the furnace was brought to such a degree that the range of temperature in the engine cab as taken in the tunnel was recorded in the same time that it took the locomotive to pass through the tunnel. By this means the temperature of the furnace would represent the temperature actually reached in the engine cab.

In the following table, results of the labratory tests made are recorded.

TABLE # 14.

STATEMENT OF RESULTS OF LABRATORY TESTS TO DETERMINE CORRECT TEMPERATURES IN TUNNEL INVESTIGATIONS.

Test Number	Time Consumed	Temperatures (Fahrenheit) Initial	Final	Furnace
1	3 min.0 sec.	55°	82°	179°.6
2	2 " 0 "	55°	97°	142°.5
3	3 " 0 "	55°	92°	128°.0
4	2 " 30 "	80°	106°	130 to 131°
5	2 " 30 "	80°	106°	131°
6	2 " 30 "	80°	104°	124 to 126°
7	2 " 30 "	80°	112°	141 to 142°

Note:
An initial temperature of 80° Fahrenheit was used in tests 4 to 7 inclusive, as the thermometer was brought to that temperature just before entering the tunnel, with the endeavor of obtaining nearer the actual temperature in the tunnel.

It will be noted in tests #3 and #7 the conditions met with as to range of temperature and time consumed in the tunnel, were duplicated and the resulting temperature of the furnace of 128° and 142° respectively, represent the temperatures experiencedin the engine cab while in the tunnel. Just what temperature would be recorded on the hottest day in summer is, of course, something of conjecture, but it is the opinion of the writer that at least a temperature of 150° would be met with on a hot summer day. Such a temperature is very near the maximum temperature which can be inhaled without danger to the party inhaling same. A temperature of 167° Fahrenheit usually causes inflammation of the skin of an adult.

RESPIRATOR.

Respirators are furnished members of the engine and train crew desiring them at a cost of $1.00 each with the view of relieving the employees while operating trains through the tunnels. The respirator consists of a rubber mask which fits over the nose and mouth, provided with a sponge which is intended to be saturated with water before entering the tunnel through which the gases of the tunnel are inhaled. Exhaled breath passes out through a small valve, shown on photograph at point marked A. The whole apparatus is strapped around the head, shown by Figure 15, page 51.

One of these respirators were furnished for test in this investigation and provided relief in breathing to a considerable extent. To the parties using same it affords relief from the particles of soot and cools the temperature of the gas before being inhaled.

Water does not absorb carbon monoxide or carbon dioxide gases, therefore, the effect of inhaling gases through the wet sponge would not reduce any effects of the poisonous gases except when solutions were used that would absorb the gases. It might be possible to use a solution that would absorb carbon dioxide gas, but cuprous chloride, the absorbent of carbon monoxide gas, is a deadly poison and could not be inhaled with safety. So it would seem that this respirator would only afford partial relief, inasmuch as the carbon monoxide gas cannot be removed by the respirator, it only partially serves as a relief to the employees.

Fig. 14.

ENGINE VENTILATOR

Ventilators have been provided on several of the locomotives. These ventilators consist of two funnels connected by a pipe, the center of the lower funnel being located about 16 inches from the top of the rail on the engineer's side of the locomotive. This funnel is connected with the other funnel, located in front of the engineer's seat by a two inch pipe which delivers air, taken from the lower part of the tunnel, to the engineer. Air supplied from the main air reservoir and tapped into the apparatus sets up a current through same. The engineer can obtain a supply of air from the bottom of tunnel by opening the valve when he needs fresh air. The device described is shown in a photograph on page 49 , Figure 14 . Funnels shown at A and B on the photograph are $8\frac{1}{2}$ and $7\frac{1}{2}$ inches in diameter respectively. Experience of the writer, in trying one of these ventilators through the tunnel, was to obtain considerable relief by securing much better air, but along with it came considerable dust and dirt which was distributed by the moving train and thrown into ones face through the ventilator.

This, we are advised, could be eliminated by providing a screen with 1/16 inch holes. Whether sufficient air would be provided is not known, but in any event this only provides relief for the engineer. In case the train breaks in two, no relief is provided by this device to employees who must walk along train in the tunnel to investigate. No provision, as yet, has been made for firemen or head-brakemen of helper engines. Further, in case of trouble, which may occur when the train is

Fig. 15.

broken in two or stalled, no provision is made for relief from gases even in the engine cab. Carbon monoxide is heavier than the other gases and after the engine had stopped, the ventilator would supply this heavier gas.

LABRATORY TESTS OF EFFECT OF TUNNEL GAS ON BIRDS.

It is quite a common practice for exploring parties to carry a canary bird in mines where dangerous gases are encountered, as an indication of gas becoming dangerous to man. As a canary bird has a very much greater lung capacity and consequently greater absorption of poisionous gases than man, it is especially adaptable to serve as a warning to men working in mines for they show symptoms of poisoning far sooner.

In order to determine whether the samples of gas taken in this study were dangerous, a sample of gas from the Eaton Tunnel, taken on February 5th, on a pusher engine #2824, was transferred into a glass container having a capacity of 515 cubic centimeters. A canary bird was placed in the container and after one minute and fifteen seconds showed evident signs of distress; after two minutes and fifteen seconds the bird was gasping for breath having its mouth open continually. In seven minutes the bird was very much exhausted and distressed and weak. Usual evidence of livliness was not shown by the bird after the first minute, but it dropped down on the bottom of the container and partially closed its eyes, altho it was not wholly overcome.

When air was allowed to enter the container, the bird revived in a short period of time and seemed to return to normal condition in from five to ten minutes. After normal condition was again reached the bird was placed in a container having a capacity of 515 cubic centimeters with ordinary atmospheric air and remained in the closed container for eleven minutes without showing any distress for want of air, which indicates that the container was of sufficient size for the time consumed in this test.

After the bird had again revived, gas samples, taken from Silver Run Tunnel, from engine #2737, train #43, were placed in the container. While the effect of the gases on the bird were indicated by the unusual breathing, it did not open its beak and gasp for breath until after nine minutes had passed, which indicates that the gases were less dangerous than test made with the bird when samples from Eaton Tunnel were used.

TONNAGE

It may be somewhat beyond the scope of this investigation to make a study of the economies of operation, as the question involved is as to whether the conditions complained of are unsafe and unreasonable and to determine the most reasonable and just means of overcoming these conditions.

Operation of heavy tonnage trains, no doubt, has increased the intensity of the heat and gases.

Previous to this complaint, the tonnage of a double header train for an E 27 B class engine was 2100 adjusted tons. A reduction to an adjusted tonnage of 1900 tons has been taken since the ventilation question has been at issue.

It has been stated that by operating trains without using the helper engine would eliminate to a considerable extent, the serious effects from the gases, as the helper engine at the rear of the train undergoes much worse conditions than the head engine of the train. There is no doubt that the effects of the gases are much worse in the second engine than in the head engine, as is shown by the analysis of the gases in each case. This can be seen by an examination of Table 10, page 40. It is also customary for the firemen and head brakeman on the head engine to get out on the engine pilot while passing through the tunnel and thus obtain good air, which air cannot be obtained on the second engine of a double header train. Of course, the engineer cannot leave his post at any time while his train is in operation and cannot get away from the gases and heat.

Operatingmen in the past have not been agreed as to the economy of operation to be brought about by handling higher tonnage on their trains. No stated rule can be applied to all conditions as the extent of the facilities such as the amount of double track, number of passing sidings, amount of business offered and terminal and yard capacities and other local conditions, must be considered in each individual case. A railroad, in order to continue to obtain new business must operate its passenger trains on time, make quick and prompt delivery of freight offered for time or Quick Dispatch movement, move its slow freight with reasonable regularity as offered so as to make reasonable deliveries. The percantage of each class of commodities it is necessary to handle, requires consideration in each individual case so that the business may be handled with the facilities at hand and with the dispatch that has been represented, will be given the commodity and as desired by the shipper.

In connection with the freight rate hearing before the Interstate Commerce Commission, representatives of the Commission contended in some of the earlier hearings that the railroads were not applying all the efficiency that it was possible to attain and one of the points brought out strongly emphasized in the decision of this high tribunal was that the railroads had not produced the economies and efficiences that it was possible to bring about by loading the locomotives and cars to nearer their capacity. It is a known fact that steam engine works at its greatest efficiency when loaded to its fullest capacity. Since the decision by the Interstate Commerce Commission, railroads that have increased their train loads are actually increasing their earnings per ton-mile.

Some reasonable method should be adopted promptly of correcting the unsafe and extreme discomforts from gases and heat without reducing the train load, if such a method is available.

CONCLUSIONS.

1. Tunnels considered in this investigation served very well for a number of years after their construction, but their cross section is not sufficient to answer present day conditions.

2. Locomotives have increased in size until the cross sectional area of the tunnel is about taken up by the locomotives operated at present, leaving a comparatively small space for the reducing of the temperature of the steam and the dilution of the gases by natural ventilation.

3. Steam pressures have increased as well as the area and intensity of the radiating surfaces, thus causing the temperatures reached to be higher.

4. Grate areas have been considerably increased with greater fuel consumption and so producing a greater volume of gases.

5. Intensities of heat and gas in these tunnels is partly dependent upon the length of the tunnel and upon the percent of the ascending grade and its length approaching the tunnel.

6. Amount of tonnage hauled together with lengths and percent of ascending grades cause trains to consume unusual lengths of time in some of the tunnels, with increasing effects of heat and gases on the employees. Heavy tonnage trains more often break in two, making it necessary for crews to couple up trains, exposing them to the gases.

7. Results of field and labratory tests, show temperatures were attained in four of the longest tunnels of from 128°to 142° Fahrenheit, when the normal outdoor temperature ranged from

41° to 48° Fahrenheit. Probably temperatures of 150° to 160° are reached in these tunnels during the hottest summer days.

8. Analysis of coal being fired on several of the locomotives, the gases from which were sampled while passing thru the tunnels, showed the coal to be good uniform quality and would not be directly responsible for the conditions found to exist.

9. Experiences while riding locomotives through the tunnels, analysis of the gases, tests on a bird in the labratory, using actual samples of the gases, and the fact that employees have been actually overcome and incapacitated in operating trains, all indicate that the gases are dangerous.

10. Tests with the respirators which employees can purchase from the Railway Company, afford relief from the excessive heat, which is cooled by the water in the sponge and particles of soot in the gases are separated from the air in passing through the sponge. Water does not absorb either carbon dioxide or carbon monoxide gas. Cuprous chloride, which absorbs carbon monoxide gas, is a deadly poison and would be extremely dangerous if inhaled. The respirator cannot be said to be effective in preventing men from being overcome by the gases.

11. Engine ventilators provide purer air for the engineer on the trains operated with a single engine, but dust and dirt on those in use made them unsatisfactory. Proposed improvement by adding a fine wire screen in the ventilator may be effective in preventing dust entering the ventilator, but its effectiveness in providing air after the screen is applied is doubtfull. In either case, on the helper engine of a double header train, little improvement in the air could be obtained, on account of the head engine filling the tunnel with gases. In case it would be necessary to examine the train, while in the tunnel with train stalled or broken

in two, train or engine crew would be little benefitted.

12. Mechanical ventilation of tunnels where conditions require such action, involves considerable expense for power, labor, interest on investment and depreciation. However, sufficient economies may be possible through operating heavier power and made possible by the ventilating systems, to provide additional earnings.

13. Mechanical ventilation has proven effective in reducing heat conditions approaching the normal, and diluting the gases to very near that of atmospheric air.

RECOMMENDATIONS

1. It is recommended that tunnels #1, #6, #19 and #21, be ventilated by forced draft furnished by fans, the gases to be blown ahead of the engine when pulling its train on an ascending grade.

2. Until tunnels #1, #6, #19 and #21, are ventilated by mechanical forced draft, double header freight trains shall not be operated through these tunnels, except when a locomotive shall, through some failure while on the line of road, be unable to handle its train.

3. Single tonnage freight trains shall handle such a tonnage that the heat and gas conditions shall not be injurious or dangerous until such time as mechanical forced draft is provided in tunnels #1, #6, #19 and #21.

4. Ventilation shall be provided by blowing a current of air with a mechanical forced draft in the direction the train is moving. Sufficient velocity shall be provided to remove the smoke and other gases ahead of the locomotive.

5. Six months is considered a reasonable time in which to complete installation of ventilating apparatus.

APPENDIX

Employees met with, while making this investigation, were questioned regarding their experience while operating trains through the various tunnels and the following statements give in substance the conditions experienced:

1. One engineer was overcome in #21 tunnel, commonly known as Eatons Tunnel, when his train was broken in two in the tunnel. This engineer had no recollection when he came out of the tunnel, but regained consciousness at east switch at Eatons. He was relieved and taken into Grafton by a passenger train. Three days elapsed before he was able to leave his bed, being off duty for seventeen days. At seven p. m. of the day he was overcome his temperature was 104° Fahrenheit. Symptoms of the effects of the gases were that his arms and legs were numb for about 15 minutes after regaining consciousness, he was nauseated, very nervous and his muscles were very sore and stiff and he was unable to walk upon arriving at Grafton. A statement made by the conductor with this engineer was that he staggered while moving about after recovering consciousness. The engineer felt the effects of being overcome for three years. He was also overcome in tunnel #1, east of Clarksburg. His skin was blistered on his face, even though he had his coat over his head, in addition to some wet waste over his mouth and nostrils.

2. Another engineer, while pulling his train through tunnel #21, known as Eatons Tunnel, had a much more serious experience than any of the others. His train had stalled in the tunnel on account of something wrong with the air. Before the trouble

was corrected, the engineer was overcome and the engine was cut off from the train, and engineer was taken out of the tunnel on the engine. As a result, this engineer has worked very little since being overcome. He is very pale and has lost considerable weight and has been drawing employees' insurance benefits for over a year. On the day this occurred, it was extremely hot but otherwise the man was in a normal condition. He is a man about 35 years of age

3. Another engineer was overcome in #6 tunnel, while a fireman. When he was brought out of the tunnel, blood was oozing from pores of his scalp. This engineer has given up his road run and is working in one of the yards.

4. Another engineer was overcome in Eatons Tunnel, (#21) on account of the train stalling. It was necessary to cut off the engine to get him out of the tunnel. He has permanently given up his engine.

5. Information furnished indicates that another locomotive engineer had to give up his run, as he could not stand the gases.

6. Another engineer was overcome and made sick in Eatons Tunnel (#21) when his train was stalled.

7. Another employee was overcome in tunnel #1, east of Clarksburg.

8. A conductor advised that it is quite common for trains to break in two in Silver Run Tunnel, making it necessary to couple up trains, where gases test ones endurance.

9. During hot weather, a brakeman was overcome in #1 tunnel, on account of engine not being able to handle train and engine drivers slipping on rail, causing unusual heat and gas conditions.

10. A west bound train, some time last summer, was stalled in Silver Run Tunnel, with 1050 tons, about 10 p.m. Fireman was overcome and engineer thought he was dead, he was so completely overcome by the heat and gases.'

TABLE #15.

TEMPERATURES COMPARED WITH WEATHER BUREAU RECORDS AT PARKERBURG, W. VA.

Out of Door Temperatures - Fahrenheit.

Date	Test Thermometer	Weather Bureau Record
Feb. 5th, 1916	41°	44°
" 6th, "	48°	44°
" 7th, "	30°	29°
" 8th, "	28°	28°
" 9th, "	41°	34°

TABLE #16.

STATEMENT OF INFORMATION TAKEN IN TUNL INVESTIGATION.

Date	Train Number	Engine Number: Head Engine	Engine Number: Rear Engine	Tunnel Number	Location	General Weather Conditions	Temperature (F): Normal Outdoor	Temperature (F): Normal in Engine Cab	Temperature (F): In Tunnel	Steam Pressure: Entering Tunnel	Steam Pressure: Leaving Tunnel	Loading: Loads	Loading: Empties	Tonnage: Adj. Tons
2/5/16	46	2716	2824	#21	W. Eaton	Cloudy	[illegible]	[illegible]	92°	200#	197#	41	0	1910*
2/6/16	88	2832	2450	#21	" "	Rain	48°	68°	112°	200#	165#	37	0	1890
2/7/16	50	2885	none	#21	" "	Fair & Cold	30°	58°	100°	200#	195#	16	0	1020
2/8/16	88	2845	"	#21	" "	" "	28°	54°	110°	200#	175#	19	1	1006
2/8/16	43	2737	"	#19	W. Silver Run	Cloudy	43°	58°	102°	200#	180#	7	25	1042
2/9/16	2nd 96 QD	2885	"	#6	E. Central		41°	48°	94°	190#	180#	18	0	816
2/9/16	2nd 49	2832	"	#1	E. Clarksburg		45°	52°	105°	200#	150#	20	0	1050⊥

* A check of the tonnage from the card bills showed 1730 tons.
⊥ A check of the tonnage from the card bills showed 1148 tons.

INDEX OF TABLES

INDEX TO DRAWINGS AND ILLUSTRATIONS.

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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