KISHI

A Study of the Characteristics & the Performance of Different Types of Steam Locomotives, by Means of Speed-Time & Speed-Distance Curves

Mechanical Engineering

M. E.

1909

A STUDY OF THE CHARACTERISTICS AND THE PERFORMANCE OF DIFFERENT TYPES OF STEAM LOCOMOTIVES, BY MEANS OF SPEED-TIME AND SPEED-DISTANCE CURVES

BY

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B. S. Tokio Technological College, 1899

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MECHANICAL ENGINEER

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1909

1309
1564-

UNIVERSITY OF ILLINOIS

THE GRADUATE SCHOOL

May 12, 1909

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

TERUO KISHI

ENTITLED A STUDY OF THE CHARACTERISTICS AND THE PERFORMANCE OF DIFFERENT TYPES OF STEAM LOCOMOTIVES, BY MEANS OF SPEED-TIME AND SPEED-DISTANCE CURVES

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

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A STUDY OF THE CHARACTERISTICS AND THE PERFORMANCE OF DIFFERENT TYPES OF STEAM LOCOMOTIVES, BY MEANS OF SPEED-TIME AND SPEED-DISTANCE CURVES

Train resistance and the acceleration of the train:

A STUDY OF THE CHARACTERISTICS AND THE PERFORMANCE OF DIFFERENT TYPES OF STEAM LOCOMOTIVES, BY MEANS OF SPEED-TIME AND SPEED-DISTANCE CURVES

(1) In the development of the problem assigned, it is proposed to assume an Atlantic type locomotive possessing definite characteristics, and then to determine the speed at which it can handle trains of several different weights over a course of 100 miles of straight level track. Modifications of the problem will also permit a study of the effects of stops on schedule speed.

(2) The locomotive to be employed is assumed to possess the following characteristics:

Cylinder	20 x 28 inches
Heating surface	2655 square feet
Diameter of driving-wheels	81 inches
Weight on driving-wheels	105,000 pounds
Weight on trucks	45,000 "
Weight on trailing-wheels	46,000 "
Weight of tender	164,000 "
Working pressure	200 "

These dimensions are characteristic of a class of locomotives built for the Southern Pacific Company by the Baldwin Locomotive Works of Philadelphia.

(3) It is proposed to assign successively to this locomotive, trains of 100, 200, 400, and 800 tons, respectively; and to determine the facility with which it can handle them.

(4) THE TRACTIVE POWER OF THE LOCOMOTIVE.- There are three elements which determine the tractive force of a locomotive, namely:

(a) Adhesive weight on drivers.

(b) Boiler capacity.

(c) Cylinder capacity.

(a) When a locomotive is running at low speed, the steam consumption per unit time is comparatively small, although the engine is driven in full gear and with wide-open throttle, and there is no question as to the ability of the boiler to supply the necessary quantity of steam to the cylinders. Consequently the adhesive weight on drivers alone determines the tractive force of an engine at low speed. The maximum tractive force at the driving-wheel is generally believed to be one-fourth of the weight on drivers; or maximum available tractive force at the driving-wheel equals total weight on drivers divided by 4.

(b) When the engine runs up to high speed, the demand for steam increases more and more, and at last the boiler capacity will become insufficient to supply the demands of the cylinders; then the cut-off must be gradually shortened, and the tractive force diminishes and becomes less than the adhesion.

Hence it is not necessary to consider the adhesive weight, and the boiler capacity is the only factor which determines the tractive force at high speed.

(c) It is clear that in any case the cylinder capacity is a necessary factor in the determination of the tractive force of an engine, no matter whether the engine is running at high speed or low speed; but in modern locomotive practice, the cylinder volume is always large enough, compared with boiler capacity and adhesive weight on drivers, and there is therefore no failure caused by insufficient cylinder volume; hence it will not concern us in this case.

According to item (a) (denoting the maximum tractive force at the driving-wheel by T' and the weight on drivers by W'), we have

$$T' = 1/4\ W'$$

To get the tractive force at the tender draw-bar, it is necessary to deduct the rolling and air resistance which acts upon engine and tender, from T'. The formula can be written as follows:

$$T = 1/4\ W' - W(2 + 1/6V) - 0.11\ V^2 \text{ ---------- } (1)$$

in which

W' = weight on drivers in pounds.

W = weight of engine and tender excluding the weight on drivers in pounds.

V = velocity of train in miles per hour.

and $W(2 + 1/6V)$ = rolling resistance offered by the truck and tender.

$0.11\ V^2$ = air resistance.

(See "Locomotive Performance" page 424)

T = tractive force at the tender draw-bar.

The values for T are given in Column 2, Tables 1, 2, 3, and 4 for all speeds which are below 15.96 miles per hour, and the upper part AB of the curve ABC, Fig. 1, was plotted from these values.

The tractive force at high speeds, which was explained in item (b), can be calculated by the use of a formula from "Locomotive Performance", page 424, which is as follows:

$$T'' = 161 \frac{H}{V} \qquad (2)$$

in which

T'' = tractive force in pounds, neglecting all loss in transmission from the cylinder to the draw-bar.

H = heating surface in square feet.

V = velocity of train in miles per hour.

Taking 2655 square feet for H and substituting various values for V, the following vales of T" were obtained:

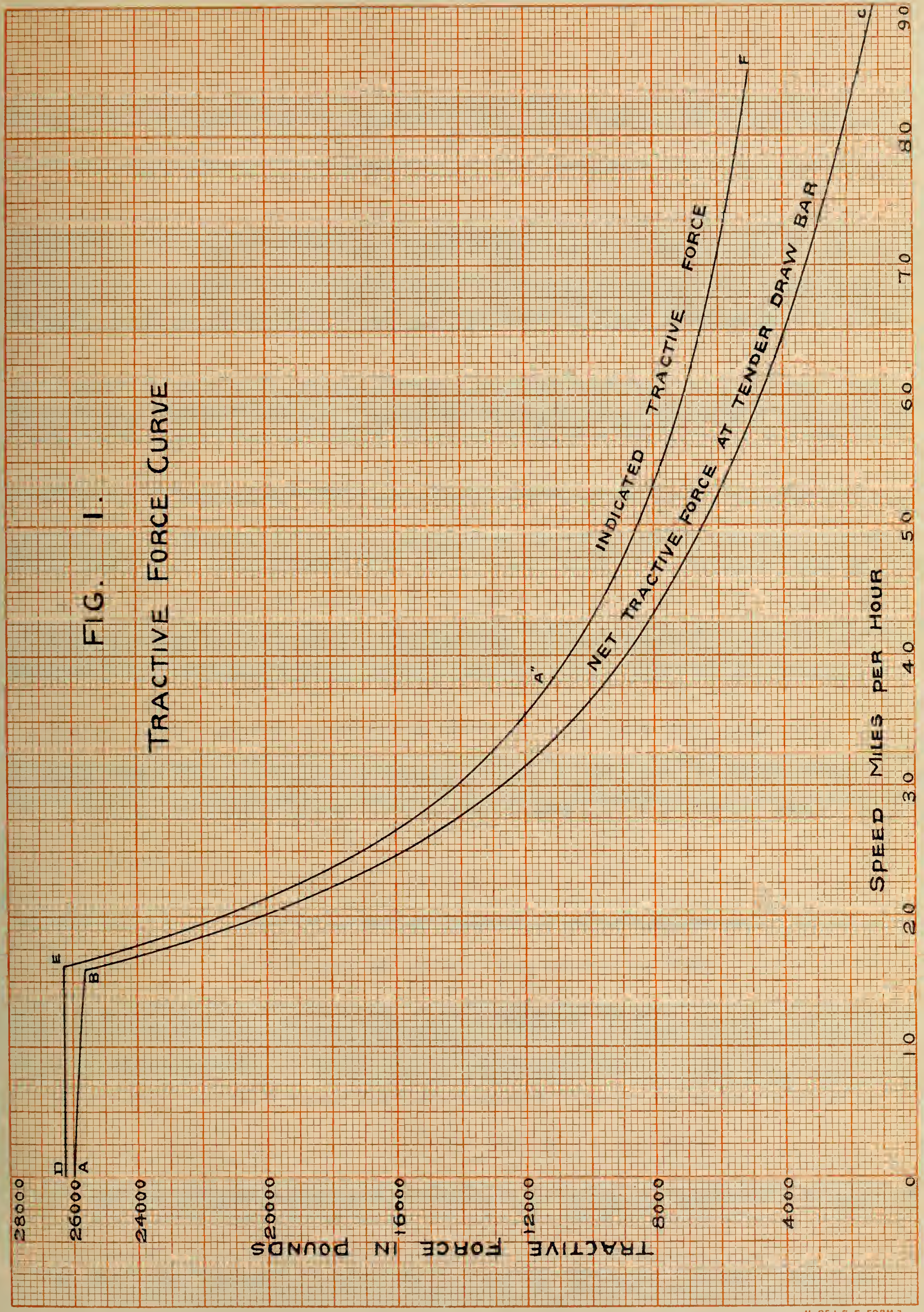


FIG. I.

TRACTIVE FORCE CURVE

V	15	15.96	20	25	30	35	40	45	50
T"	28497	26783	21373	17098	14249	12213	10686	9499	8549

V	55	60	65	70	75	80	85
T"	7772	7124	6576	6107	5699	5343	5029

Taking the values of T" as ordinates and the values of V as abscissae, the curve DEF in Fig. 1 was plotted.

The formula for calculating the tractive power at the tender draw-bar was also taken from "Locomotive Performance", page 424.

$$T = 161 \frac{H}{V} - 3.8 \frac{d^2 L}{D} - W(2 + 1/6V) - 0.11 V^2 \text{ --- } (3)$$

where

H = heating surface of the boiler in square feet.

V = velocity of train in miles per hour.

D = diameter of driving-wheel in feet.

d = diameter of cylinder in inches.

L = stroke of piston in feet.

W = weight of engine and tender in tons, excluding the weight on drivers.

and

$3.8\ \frac{d^2\ L}{D}$ = internal resistance of the engine in pounds.

$W(2 + 1/6V)$ = rolling resistance in pounds.

$0.11\ V^2$ = air resistance in pounds.

In the locomotive taken in this problem

$H = 2655$

$d = 20$

$L = 28 \div 12$

$D = 81 \div 12$

$W = 127.5$

Assuming several different speeds and substituting these values in equation 3, the values in Column 2 in Tables 1, 2, 3, and 4 for all speeds which are higher than 15.96 miles per hour, were obtained and the curve BC in Fig. 1 was plotted.

Two curves calculated by equations 1 and 3 will meet at the point B which corresponds to 25628 pounds of tractive force and the speed of 15.96 miles per hour. This means, therefore, that the tractive force for speeds less than 15.96 miles per hour is limited by the adhesive weight on drivers; while for higher speeds it is limited by the capacity of the boiler.

(5) TRAIN RESISTANCE AND THE ACCELERATION OF THE TRAIN.- To compute the train resistance we have a formula suggested by "The Engineering News".

$$R = 2 + \frac{V}{4}$$

in which

R = train resistance in pounds per ton.

V = velocity of the train in miles per hour.

This formula is generally used in American practice and gives generally reliable results; however, it is not theoretically correct, as it is an equation of a straight line, and the results obtained by experiment show that it is a curved line, also many authors believe it is not a straight line. Another equation, $R = 2.5 + \frac{V^{\frac{5}{3}}}{80}$, gives a curved line, and if a curve is plotted by this equation, it falls below that given by the equation $R = 2 + \frac{V}{4}$ with an average difference of about 3 pounds. Adding, therefore, this 3 to the constant in $R = 2.5 + \frac{V^{\frac{5}{3}}}{80}$, I obtained a formula which I believe to be more nearly correct in form, from the theoretical standpoint, and which is not greatly different in the results it gives from the "Engineering News" formula. The formula is as follows:

$$R = 5.5 + \frac{V^{\frac{5}{3}}}{80} \text{ -- } (4)$$

Substituting values for the several assumed speeds, as in the case of tractive effort, in equation 4, the several values for resistance given in Column 4, Tables 1, 2, 3, and 4, were obtained. These and the remaining columns of Tables 1, 2, 3, and 4 were determined as follows:

Column 1 = speed of train in miles per hour assumed.

Column 2 = tractive force at tender draw-bar calculated by equations 1 and 3.

Column 3 = available tractive force per ton of train = Column 2 ÷ weight of train.

Column 4 = resistance of train in pound per ton calculated by equation 4.

Column 5 = tractive force available for acceleration in pounds per ton = Column 3 - Column 4.

The general formula for acceleration is

$$a = \frac{F}{M}$$

where

a = acceleration, feet per sec. per sec.

F = force to produce acceleration in pounds.

M = mass of body.

Considering a mass weighing 1 ton

$$M = \frac{2000}{32.2}$$

$$\therefore \quad a = \frac{32.2}{2000} \times F$$

Assuming five per cent for the force needed to produce the acceleration of the rotating parts, we have:

$$a = \frac{32.2}{2000} \times \frac{F}{1.05} = \frac{F}{65.2} \text{ ---------------------- } (5)$$

If A denotes the acceleration in miles per hour per second,

$$A = \frac{F}{65.2} \times \frac{60 \times 60}{5280} = \frac{F}{95.6} \qquad \text{------------------} \quad (6)$$

The values in Columns 6 and 7 of Tables 1, 2, 3, and 4 were calculated by these equations, i. e.,

Column 6 = acceleration, feet per sec. per sec. calculated by equation 5.

Column 7 = acceleration, miles per hour per sec. calculated by equation 6.

Column 8 = the mean of two consecutive values of acceleration in Column 7.

$$= \frac{\text{the sum of two succeeding values in Column 7}}{2}$$

Column 9 = time in seconds required to produce the change in speed indicated in Column 1.

$$= \frac{\text{difference between two succeeding values in Col. 1}}{\text{corresponding values in Column 8}}$$

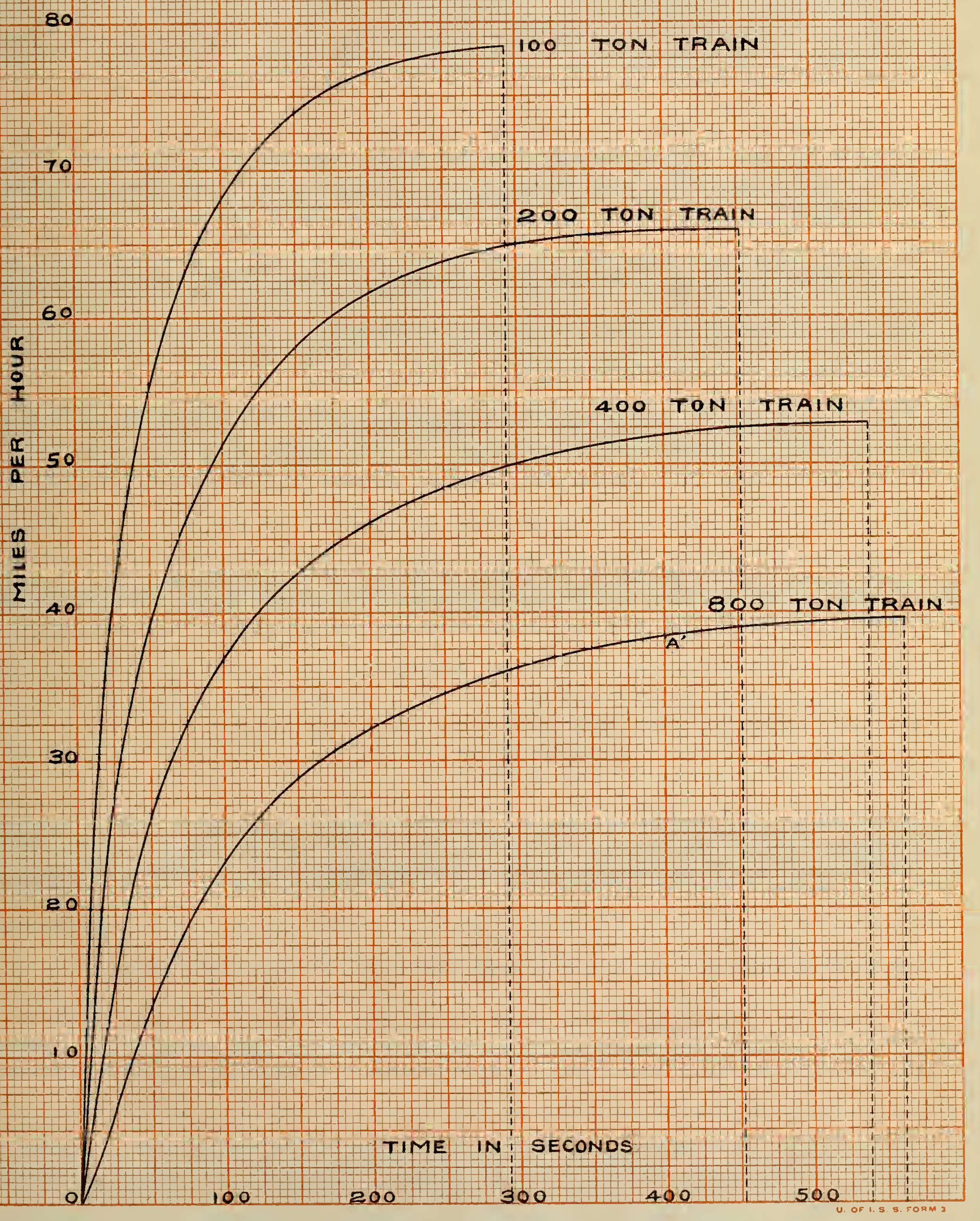
The acceleration curves in Fig. 2 were plotted by taking the speed of the train (i. e., the values in Column 1) as ordinates, and the time required to produce the change in speed (i. e., the values in Column 9) as abscissae.

It may be seen from this figure that the acceleration of the train is high at the start and low at high speeds; also that a heavy train requires more time to reach its maximum speed than does a light train, but that the increase of time for increasing weight will gradually decrease as the weight of the

FIG. 2.

SPEED TIME CURVE

DURING ACCELERATIOTION



train increases.

The work done during acceleration, the rate at which speed is increasing, and the distance which must be passed over in bringing the train from rest to its maximum speed are summarized in Tables 5-1 and 5-2. The derivation of Tables 5-1 and 5-2 is as follows:

Column 1 = time in second.

Column 2 = area under acceleration curve in Fig. 2 bounded by the lines of times, corresponding to Column 1, values determined by means of planimeter.

Column 3 = Average speed, miles per hour, for the time intervals in Column 1.

= (Column 2 ÷ corresponding base in inches) x 10.

Column 4 = total distance run over during the time interval in Column 1.

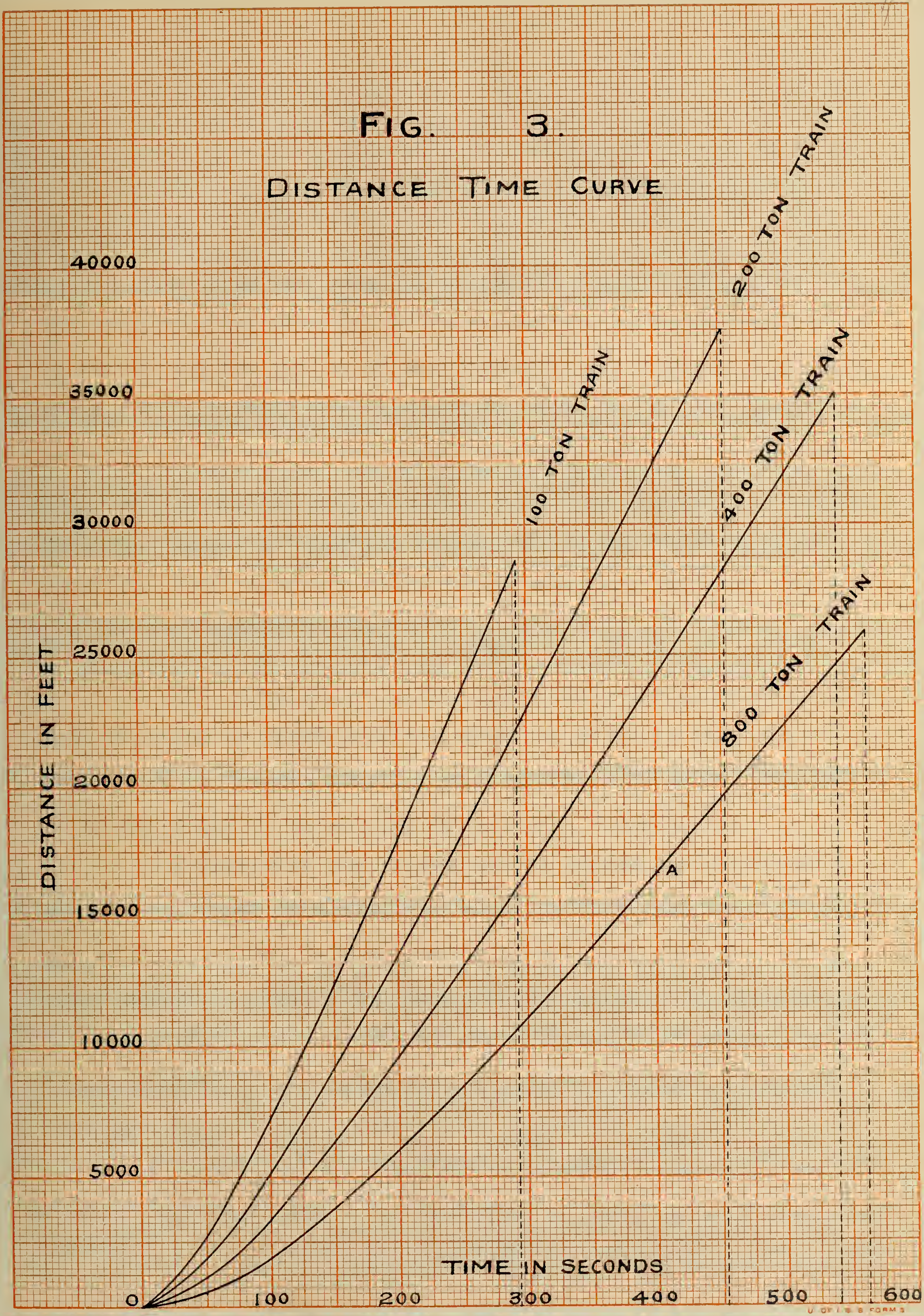
$$= \frac{\text{Column 3} \times 5280 \times \text{difference two consecutive times in Column 1}}{60 \times 60}$$

The distance curve in Fig. 3 was plotted by taking the values in Column 1 as abscissae and the values in Column 5 as ordinates.

The lightest or 100-ton train reached its maximum speed at a distance of about 28,600 feet from the start, while the 200-ton train required a distance of 37,577 feet, notwithstanding

FIG. 3.

DISTANCE TIME CURVE



the fact that its maximum speed is far lower than that of the 100-ton train.

Further increase in the weight of train leads to opposite results, that is, it decreases the distance required to be run during the period of acceleration; for example, a 400-ton train is required to run 34,958 feet, while an 800-ton train is required to run but 25,862 feet. Therefore within the limits which have thus far been studied, it may be stated that the distance in which the train can reach its maximum speed will be short for both light and heavy trains and comparatively long for the train of medium weight.

(6) BRAKING.- It is a well-known fact that the brake shoe friction is great when the speed of train is low, and at high speed it becomes small. This variation in the coefficient of friction can be calculated by the next formula.

A review of the report of the Master Car Builders' Association shows that when the speed is 70 miles, the coefficient of friction may be expected to be 0.1, and when the train comes almost to rest, the coefficient is about 0.3. Results of the tests show that such values are attained in service. Using these values for the purpose of making an equation, I get the formula

$$f = \frac{.3}{1 + .02857\ V} \quad \text{-------------------------} \quad (4)$$

where

f = coefficient of friction.

V = velocity of train in miles per hour.

This formula gives results which coincide approximately with the values for the average coefficient of friction determined by modern experiments.

The force applied at the wheel is 80 per cent of the load upon the wheel. Therefore the brake shoe pressure per ton of load is 2000 x .8 = 1600 pounds, and

f x 1600 = braking force.

Results obtained under these conditions are shown by Tables 1^B, 2^B, 3^B, and 4^B, derived as follows:

Column 1 = speed of train, miles per hour.

Column 2 = coefficient of friction calculated by formula 4.

Column 3 = friction per ton = Column 2 x 1600.

Column 4 = retardation in miles per hour per second, calculated by the formula $A = \frac{P}{95.6}$ as in the case of acceleration.

Column 5 = average retardation for each interval (the sum of two consecutive values in Column 4) ÷ 2.

Column 6 = time in seconds required to produce the change in speed indicated in Column 1.

$$= \frac{\text{difference between two consecutive values in Col. 1}}{\text{Column 5}}$$

The braking curves of Fig. 4 were plotted from the values in these tables, and the values in Table 6 were derived by the process employed in determining the values in Tables 5-1 and 5-2 in the case of acceleration.

As may be seen in Fig. 4, the four curves of retardation have quite similar shape, but the rate of retardation for the low speed train is greater than that of the high speed train. In order to compare these four curves, the average retardation for each case was calculated as follows:

Average retardation in miles per hour per second:

$$\text{For 800-ton train} = \frac{39.5}{12.4} = 3.18$$

$$\text{" 400-ton "} = \frac{52.7}{18.4} = 2.86$$

$$\text{" 200-ton "} = \frac{65.9}{25.4} = 2.57$$

$$\text{" 100-ton "} = \frac{78.3}{33} = 2.37$$

Thus the average retardation in miles per hour per second for the 800-ton train is 34 per cent greater than that for the 100-ton train, due to the fact that the lighter the train, the higher the initial speed.

The schedule speed of the train is an average speed for the entire trip, including the dead time of stops. Therefore each stop of the train lowers the schedule speed on account of

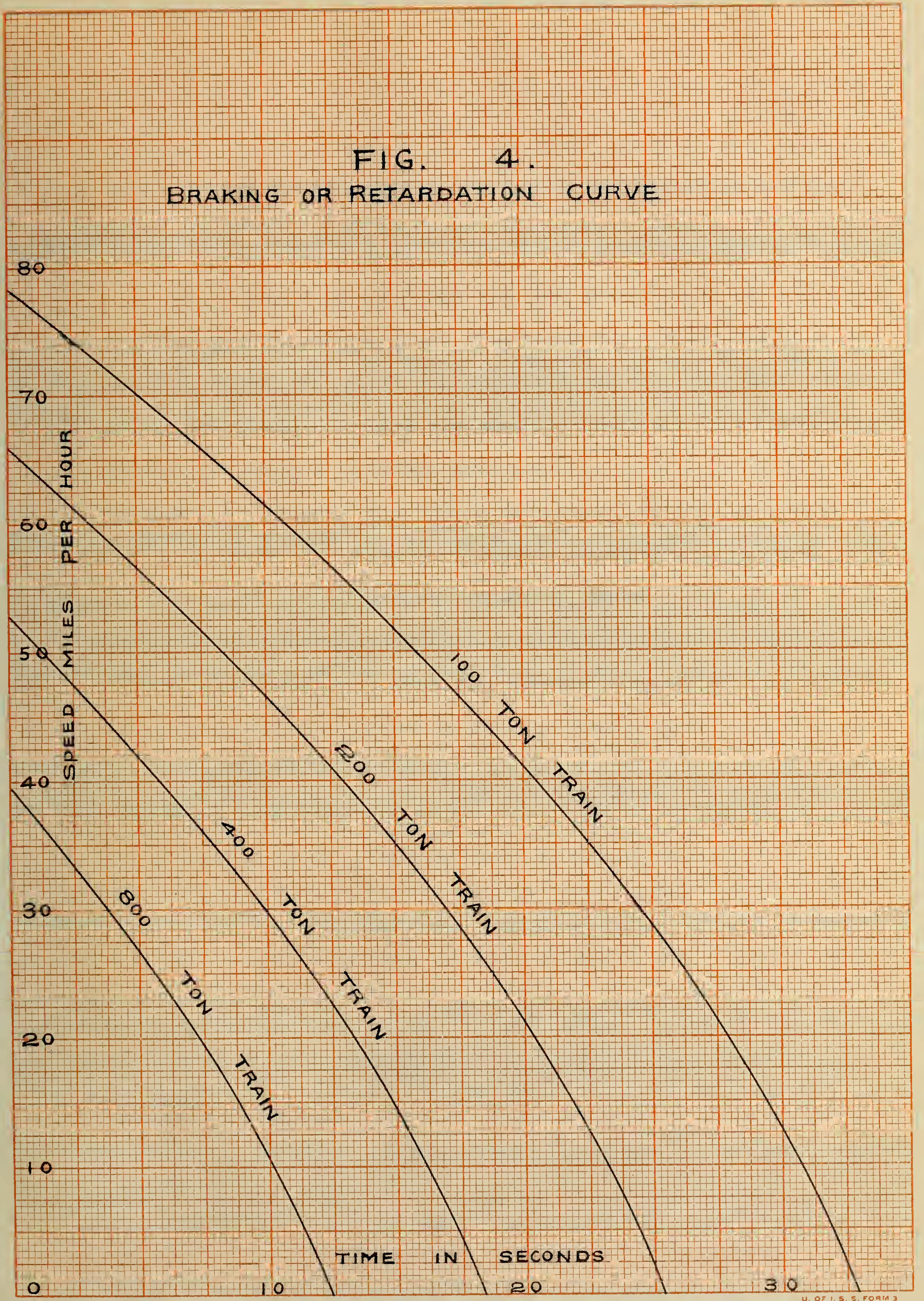


FIG. 4.

BRAKING OR RETARDATION CURVE

dead time and the low average speed during acceleration and retardation.

(7) THE TIME REQUIRED FOR THE ENTIRE TRIP OF 100 MILES WITH VARYING NUMBER OF STOPS AND DIFFERENT WEIGHTS OF TRAIN.- The data and equations which are necessary to find out the times are tabulated in Table 7, the explanation of which is as follows:

Column 1 = weight of train assumed.

Column 2 = distance run during acceleration and retardation = sum of Column 5, Tables 5-1 and 5-2, plus sum of Column 5, Table 6.

Column 3 = time required during acceleration and retardation, i. e., for 100-ton train

(sum of Col. 9, Table 1) +
(sum of Col. 7, Table 1^B)

for 200-ton train

(sum of Col. 9, Table 2) +
(sum of Col. 7, Table 2)

for 400-ton train

(sum of Col. 9, Table 3) +
(sum of Col. 7, Table 3^B)

for 800-ton train

(sum of Col. 9, Table 4) +
(sum of Col. 7, Table 4^B)

Column 4 = Maximum number of stops between which the train can reach its maximum speed = 100 ÷ Col.2.

Column 5 = time required for whole trip through 100 miles with no stops. The processes are as shown by the equation in each line, for instance, in the case of 100-ton train:-

100 - 5.845 = distance in miles for full speed run.

78.3 = full speed, miles per hour.

$\frac{100 - 5.845}{78.3}$ = time in hours for full speed run.

$\frac{(100 - 5.845) \times 60 \times 60}{78.3} + 326$ = total time for whole trip in seconds.

Column 6 = time in seconds increased by each stop. In the case of 100-ton train:-

326 = time required during acceleration and retardation.

$\frac{5.845 \times 60 \times 60}{78.3}$ = time in seconds required to cover at full speed, the distance required for acceleration and retardation.

$326 - \frac{5.845 \times 60 \times 60}{78.3}$ = additional time (in seconds) required for each stop.

Calculations for the three other trains are similar.

The Tables 1^c, 2^c, 3^c, and 4^c were derived from this table, i. e., assuming n = number of stops.

Column 1 = number of stops.

Column 2 = time in seconds required for entire trip with no dead time at stops.
(Col. 5, Table 7) - n x 58

Column 3 = Average speed for above trip.
= 100 ÷ Col. 2 ÷ 60 x 60

Columns 4, 6, 8, and 5, 7, 9 are similar to Columns 1 and 2 respectively.

By inspection of Tables 1^c, 2^c, 3^c, and 4^c, it can be easily understood how the number of stops affects the schedule speed, and Table 7 shows that a heavy train loses more time for each stop than the light train, due to the fact that the acceleration of the heavy train is far lower than that of the light train.

(8) THE STEAM CONSUMPTION AND COAL CONSUMPTION.- In order to find the water consumption, it is necessary to calculate the horse-power developed during the trip. For this purpose it will be convenient to plot a tractive force-distance curve.

Take the tractive force which is given in Fig. 1 as ordinates, and the distances which are given in the distance curve in Fig. 3 as abscissae, and by referring to the accelera-

tion curve, Fig. 2, we may construct a tractive force-distance curve as shown in Fig. 5. For instance, assume a point A in the distance curve. It corresponds to 16630 feet of distance and 400 seconds of time; therefore mark a point B as the abscissa in Fig. 5 equal to 16630 feet. Now draw an ordinate at 400 seconds on the acceleration curve of Fig. 2. This ordinate meets the 800-ton curve at the point A', whose corresponding speed is 38.3 miles per hour. Referring to Fig. 1, we find that a speed of 38.3 miles per hour corresponds to a tractive force = 10880 pounds. At B in Fig. 5 we may now erect an ordinate equal to 10880 and we have determined one point on the desired curve. By repeating the same process for the several points, the tractive force-distance curves of Fig. 5 were plotted. The area under these curves shows the work done during acceleration, and if it is multiplied by some constant, it will also denote the horse-power consumed during acceleration; and we can thereby compute the water consumption and coal consumption. The procedure is as shown in Table 8.

In constructing Table 8 the following values were assumed:

32 lb. = water consumption per 1 h.p. per hour during acceleration.

28 lb. = water consumption per 1 h.p. per hour at full speed.

4.5 lb. = coal consumption per 1 h.p. per hour.

FIG. 5.

TRACTIVE FORCE – DISTANCE CURVE DURING ACCELERATION

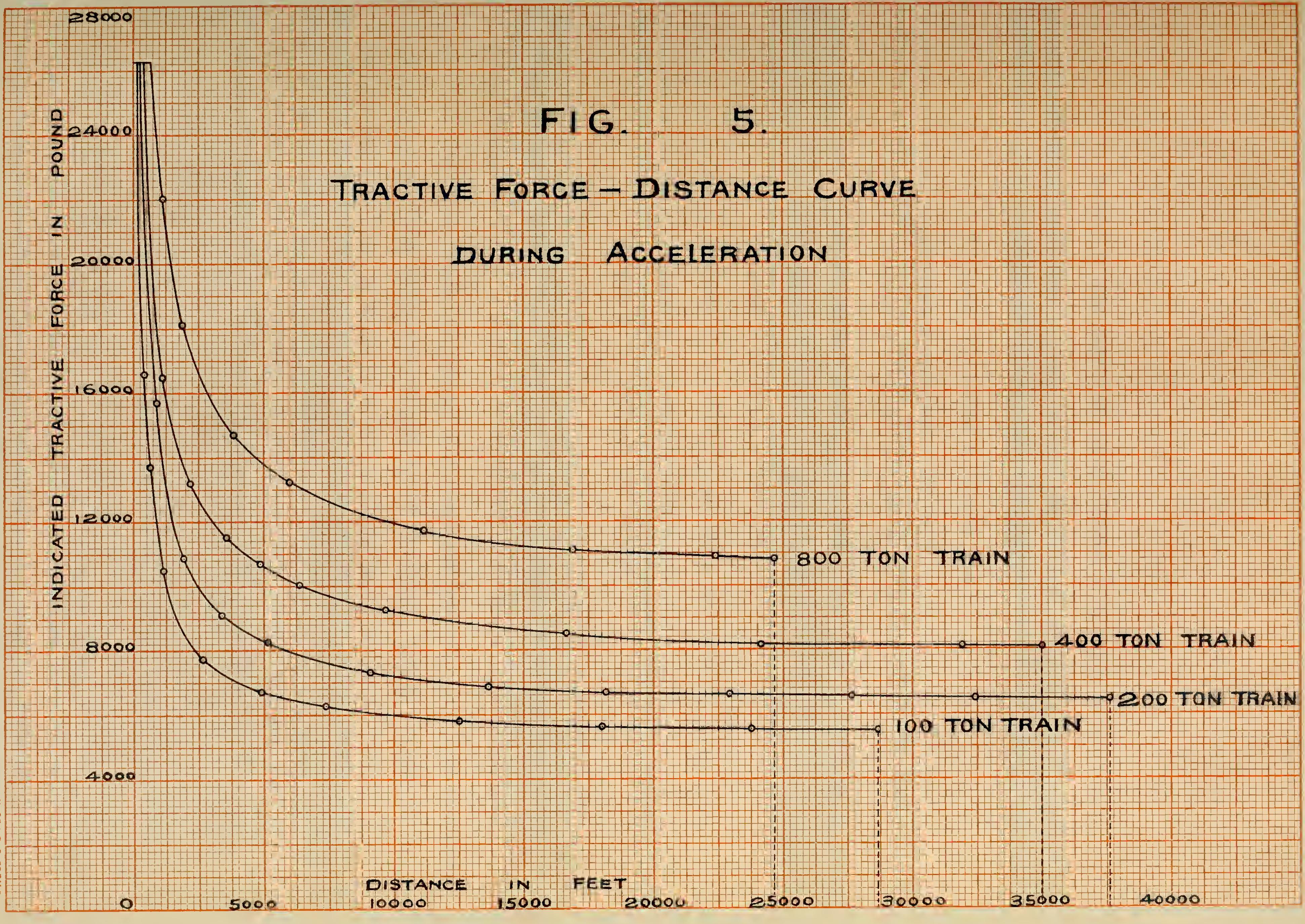


Table 9 was derived from Table 8 by the following processes:

Column 1 = number of stops

Column 2 = 4963 + 72.94 x n

Column 3 = 6588 + 38 x n

Column 4 = 5927 + 117.45 x n

Column 5 = 7848 + 66 x n

Column 6 = 7409 + 143.6 x n

Column 7 = 9819 + 86 x n

Column 8 = 9707 + 129.56 x n

Column 9 = 13059 + 71 x n

Where n = number of stops

It will be seen by Fig. 5 that during acceleration, the distance over which the engine can exert its maximum tractive force is only a small portion of the whole distance required for the train to reach its maximum speed. At the instant of starting, the tractive force is a maximum, after which it falls rapidly for a time and afterwards more slowly.

The rate of decrease of tractive force, as shown by the power distance curves, is greater for light trains than for heavier trains, due to the higher rate of acceleration of the lighter trains.

As an aid to the investigation of the water and coal

consumption as affected by the weight of the train and the number of stops, Figs. 6, 7, and 8 have been plotted.

The water consumption as shown by the black line of Fig. 6 was plotted from the values in line 10 in Table 8, and the curve for one ton of train was plotted from the same values divided by the values of corresponding weights of train. The coal consumption curves in Fig. 8 were plotted from the values in line 12 in Table 12 by the same method as that employed for the water consumption curve. The relation of weight of train to coal consumption is similar to that defined for the water consumption, as shown by the similarity in shape of the curves in Figs. 6 and 7.

The amount of water represented in Columns 2, 4, 6, and 8 of Table 9, plotted as ordinates upon Fig. 8, and the number of stops as abscissae, give the relation between water consumed and number of stops.

From Fig. 6 it can be seen that the curve which represents the water consumption for the whole train, is not of uniform curvature; its radius of curvature decreases as the train weight increases. This means that the increase in weight of train does not increase the water consumption in the same proportion. On the other hand, it may be seen by curve CD that the water consumption per ton of train decreases as the weight

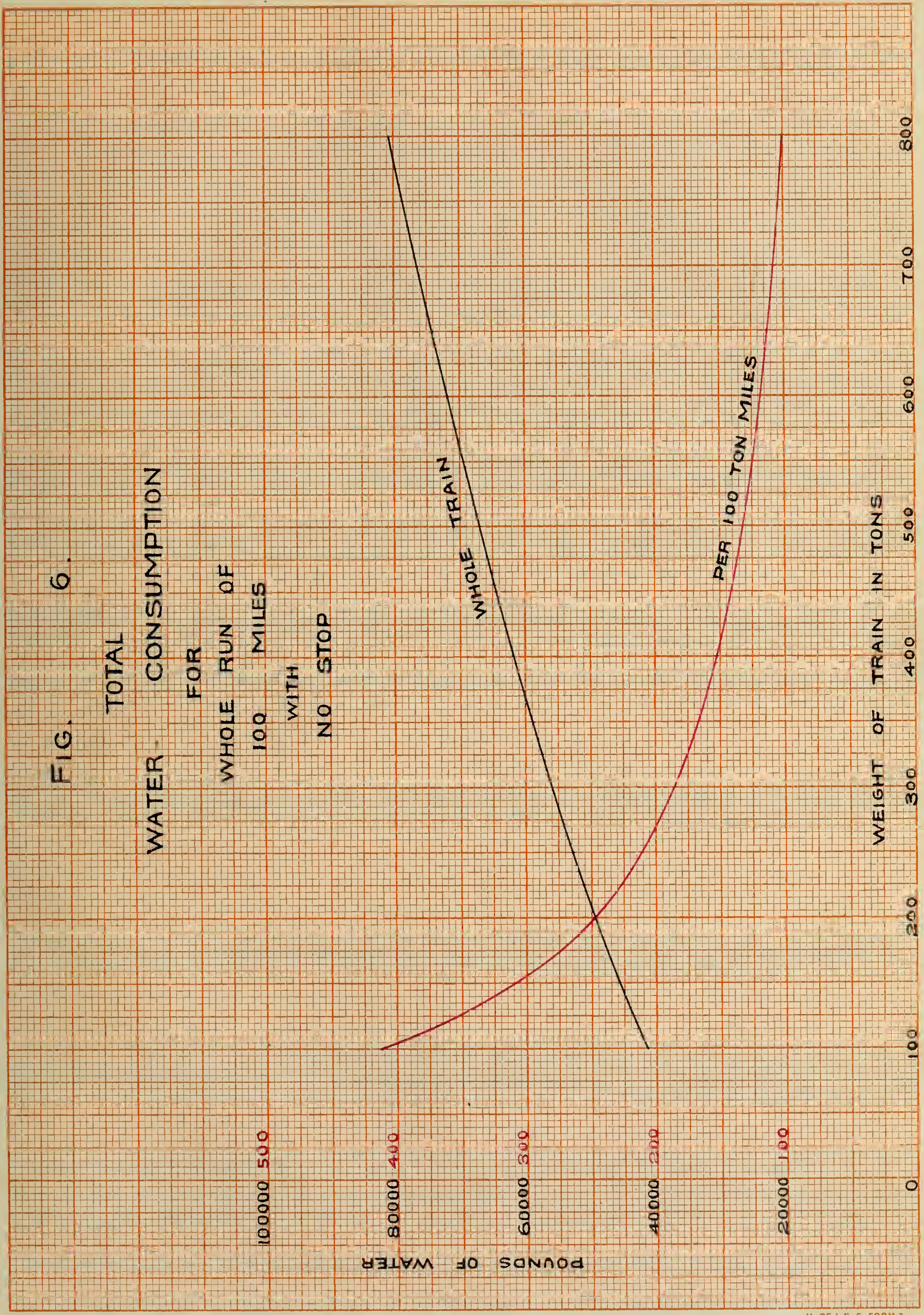


FIG. 6. TOTAL WATER CONSUMPTION FOR WHOLE RUN OF 100 MILES WITH NO STOP

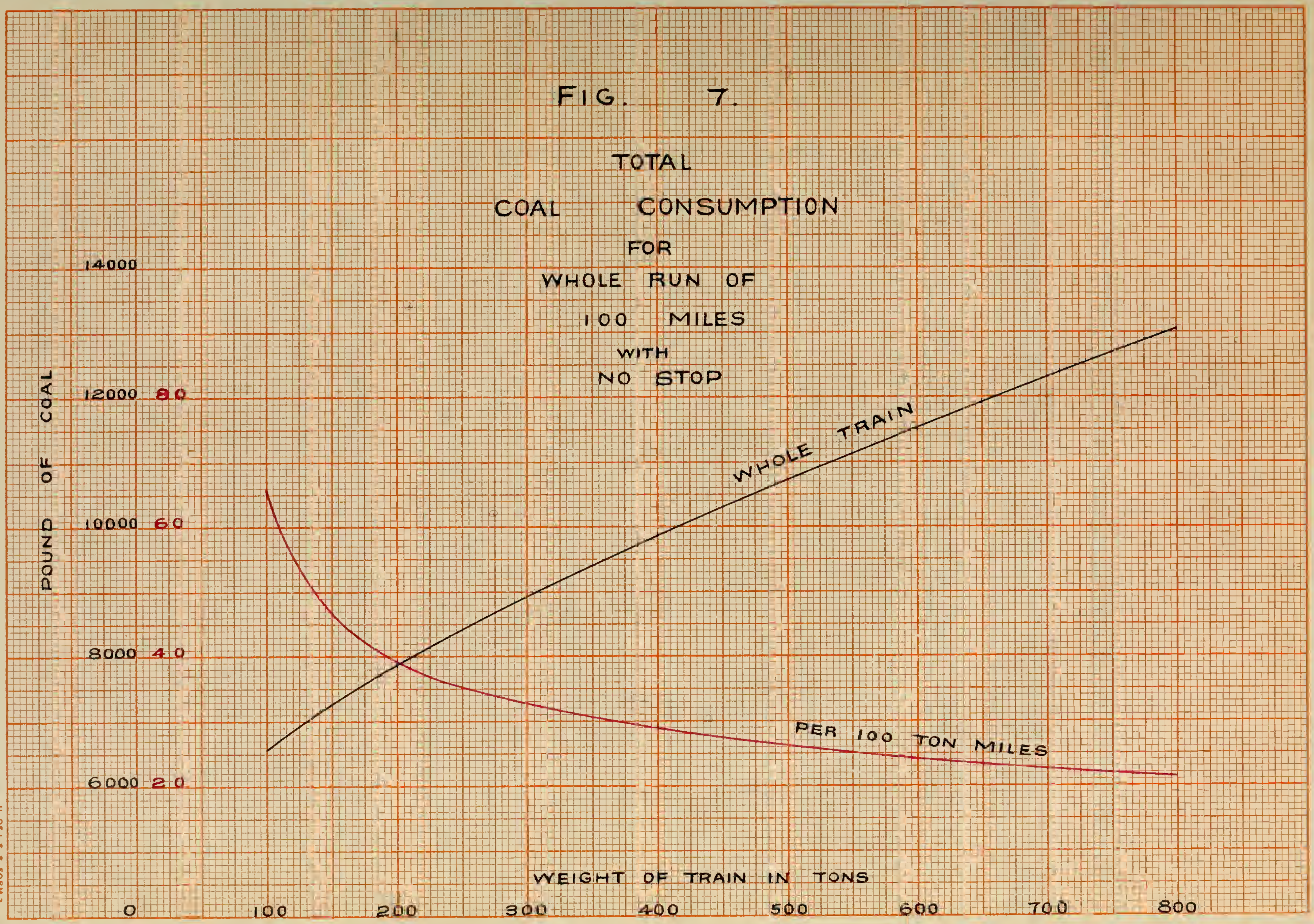


FIG. 7.

TOTAL
COAL CONSUMPTION
FOR
WHOLE RUN OF
100 MILES
WITH
NO STOP

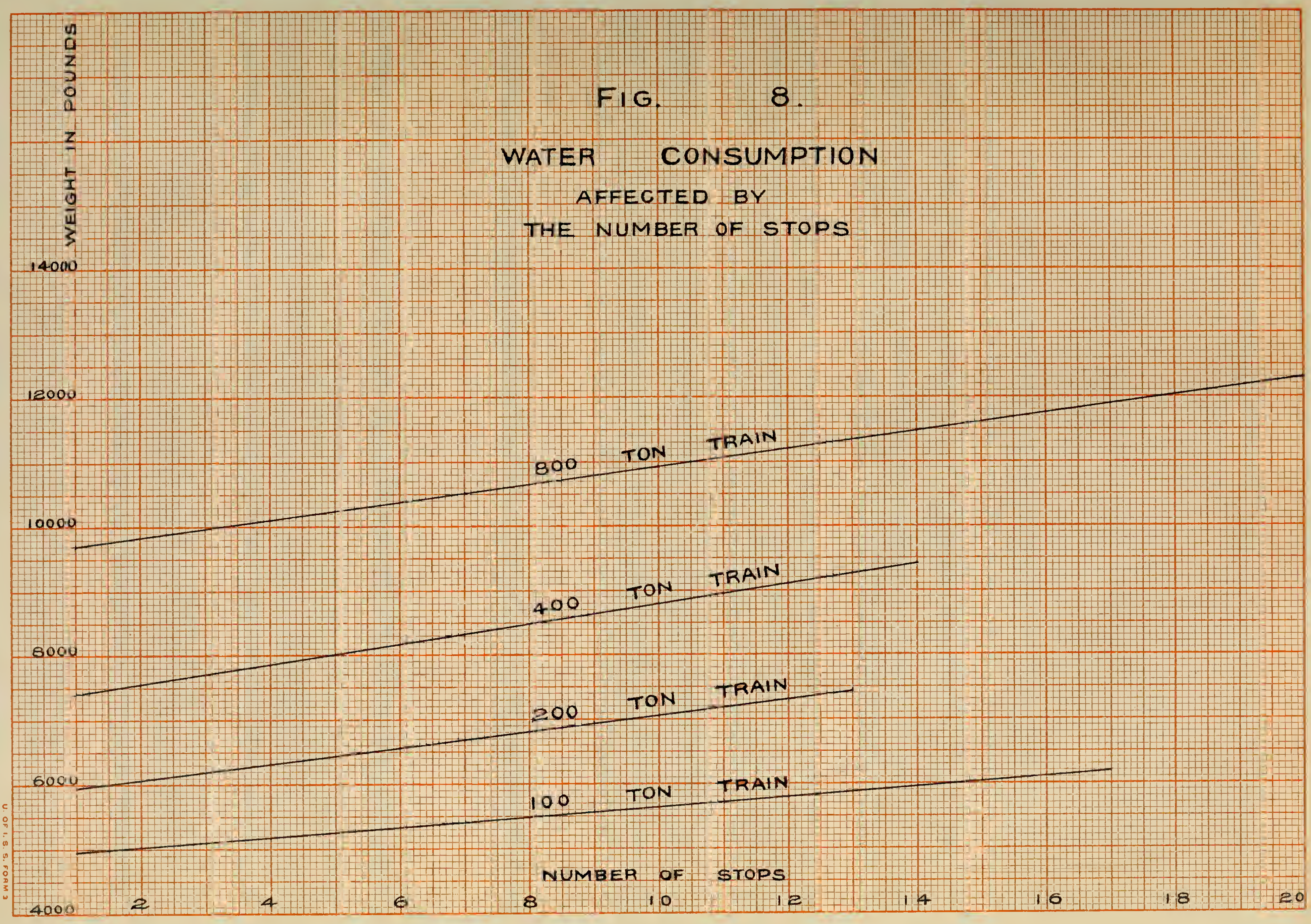


FIG. 8.

WATER CONSUMPTION
AFFECTED BY
THE NUMBER OF STOPS

of train increases, and the rate of decrease is greater for light trains than for heavy trains.

In Fig. 7 the coal consumption curves are similar to Fig. 6 in all respects, and the effect upon coal consumption of changes in the weight of train is also the same as in the case of water consumption. The greater economy of train operation would be secured by hauling heavy trains, the minimum limit of train weight for highest efficiency being somewhat beyond the range of conditions assumed.

The increase of water consumption as affected by the number of stops can be represented by a straight line as in Fig. 8, as the rate of increase is always constant for a definite weight of train; but the rate of increase varies somewhat for different weight of train. This variation can be seen by the inclination of water consumption lines in Fig. 8, that is, the angle made by the line which represents the water consumption and the abscissa is 7.5° for 800-ton train, and those of 400, 200, and 100-ton trains are respectively 9°, 7.2°, and 4.7°, showing that, in these four cases, the 400-ton train is more influenced by the increase in the number of stops than the others, a thousand pounds of coal being required for every 6.5 stops.

Reference to Fig. 3 will suggest a close coincidence between the distance run during the acceleration and the increas-

ing water consumption as affected by the number of stops, i. e., the train which covers a long distance during acceleration, requires more water for each stop than one which covers a short distance during acceleration.

TABLE 1.

PERFORMANCE DURING ACCELERATION TRAIN 100 TON.

Speed Miles per hour	Tractive force at tender Draw bar pounds	Available tractive force per ton of train Col 2 ÷ 100	Resistance of train pounds per ton	Tractive force available for acceleration lb. per ton; Col. 3 - Col. 4	Acceleration per second		The mean of two consecutive values in Col. 7	Time in seconds required to produce the change in speed indicated in Col. 1
					Ft. per second	Miles per hour		
1	2	3	4	5	6	7	8	9
0	25995	259.95	18.00	241.95	3.712	2.531	2.575	.388
1	25974	259.74	9.46	250.28	3.840	2.618	2.630	.380
2	25952	259.52	7.00	252.52	3.874	2.641	2.646	.378
3	25930	259.30	5.97	253.33	3.887	2.650	2.650	.377
4	25908	259.08	5.73	253.35	3.887	2.650	2.649	.378
5	25886	258.86	5.68	253.18	3.884	2.648	2.646	.378
6	25864	258.64	5.75	252.89	3.879	2.644	2.643	.378
7	25841	258.41	5.82	252.59	3.876	2.642	2.640	.379
8	25818	258.18	5.90	252.28	3.871	2.639	2.637	.379
9	25795	257.95	5.99	251.96	3.867	2.636	2.634	.380
10	25771	257.71	6.08	251.63	3.861	2.632	2.623	1.906
15	25651	256.51	6.64	249.87	3.835	2.614	2.612	.329
15.96	25628	256.28	6.76	249.52	3.828	2.610	2.319	1.742
20	20124	201.24	7.34	193.90	2.975	2.028	1.794	2.787
25	15718	157.18	8.17	149.01	2.287	1.559	1.397	3.597
30	12732	127.32	9.12	118.20	1.813	1.236	1.117	4.476
35	10554	105.54	10.18	95.36	1.463	.997	.904	5.531
40	8880	88.80	11.35	77.45	1.188	.810	.733	6.821
45	7540	75.40	12.62	62.78	.964	.657	.592	8.446
50	6431	64.31	13.98	50.33	.772	.526	.470	10.638
55	5490	54.90	15.44	39.46	.606	.413	.362	13.812
60	4673	46.73	17.00	29.73	.456	.311	.264	18.939
65	3950	39.50	18.64	20.86	.320	.218	.175	28.571
70	3300	33.00	20.36	12.64	.194	.132	.092	54.348
75	2706	27.06	22.18	4.88	.075	.051	.026	126.923
78.3	2341	23.41	23.41	0.0				

TABLE I^b

PERFORMANCE DURING RETARDATION TRAIN 100 TONS.

Speed miles per hour	Coefficient of friction	Friction per ton Col. 2 x 1600	Retardation in miles per hour per second $A = \frac{P}{95.6}$	The mean of two consecutive values in Col. 4	Time in seconds required to produce the change in speed indicated in Col. 1	The sum of times in Col. 6
1	2	3	4	5	6	7
78.3	.093	149	1.56	1.58	2.09	
75	.095	152	1.59	1.63	3.07	5.16
70	.100	160	1.67	1.71	2.92	8.08
65	.105	168	1.76	1.81	2.76	10.84
60	.111	178	1.86	1.91	2.62	13.46
55	.117	187	1.96	2.02	2.48	15.94
50	.124	198	2.07	2.13	2.34	18.28
45	.131	210	2.20	2.27	2.20	20.48
40	.140	224	2.34	2.43	2.06	22.54
35	.150	240	2.51	2.61	1.92	24.46
30	.162	259	2.71	2.82	1.77	26.23
25	.175	280	2.93	3.06	1.63	27.86
20	.191	306	3.20	3.36	1.49	29.35
15	.210	336	3.51	3.71	1.35	30.70
10	.233	373	3.90	4.14	1.21	31.91
5	.262	419	4.38	4.70	1.06	32.97
0	.300	480	5.02			

TABLE I^{c}

TIME REQUIRED TO TRAVEL 100 MILES AND THE AVERAGE SPEED DURING THE RUN AS INFLUENCED BY THE NUMBER AND THE LENGTH OF STOPS. TRAIN 100 TONS.

No. of stops	No dead time		1 minute dead time in each stop		2 minutes dead time in each stop		5 minutes deadtime in each dead stop	
	Time in seconds	Average speed in miles per hour	Time in seconds	Average speed miles per hour	Time in seconds	Average speed miles per hour	Time in seconds	Average speed miles per hr.
1	2	3	4	5	6	7	8	9
0	4655	77.34						
1	4713	76.38	4773	75.42	4833	74.49	5013	71.81
2	4771	75.46	4891	73.60	5011	71.84	5371	67.03
3	4829	74.55	5009	71.87	5189	69.38	5729	62.85
4	4887	73.66	5127	70.26	5367	67.08	6087	59.41
5	4945	72.80	5245	68.64	5545	64.92	6445	55.87
6	5003	71.96	5360	67.16	5723	62.90	6803	52.92
7	5061	71.13	5482	65.67	5901	61.01	7161	50.27
8	5119	70.33	5599	64.29	6079	59.22	7519	47.88
9	5177	69.54	5717	62.97	6257	57.54	7877	45.70
10	5235	68.77	5835	61.70	6435	55.94	8235	43.72
11	5293	68.01	5953	60.47	6613	54.44	8593	41.89
12	5351	67.28	6071	59.30	6791	53.01	8951	40.22
13	5409	66.56	6189	58.17	6969	51.66	9309	38.67
14	5467	65.85	6307	57.08	7147	50.37	9667	37.24
15	5525	65.16	6425	56.03	7325	49.15	10025	35.91
16	5583	64.48	6543	55.02	7483	48.11	10383	34.67
17	5641	63.82	6661	54.05	7681	46.87	10741	33.52

TABLE 2.

PERFORMANCE DURING ACCELERATION—TRAIN 200 TONS.

Speed miles per hour	Tractive force at tender Draw bar pounds	Available tractive force per ton of train Col. 2 ÷ 200	Resistance of train pounds per ton	Tractive force available for acceleration lb. per ton Col. 3 - Col. 4	Acceleration per second: Feet per second	Acceleration per second: Miles per hour	The mean of two consecutive values in Col. 7	Time in seconds required to produce the change in speed indicated in Col. 1
1	2	3	4	5	6	7	8	9
0	25995	129.98	18.00	111.98	1.718	1.171	1.216	.822
1	25974	129.87	9.46	120.41	1.848	1.260	1.272	.786
2	25952	129.76	7.00	122.76	1.884	1.284	1.288	.776
3	25930	129.65	5.97	123.68	1.897	1.293	1.294	.773
4	25908	129.54	5.73	123.81	1.900	1.295	1.294	.773
5	25886	129.43	5.68	123.75	1.898	1.294	1.293	.773
6	25864	129.32	5.75	123.57	1.895	1.292	1.292	.774
7	25841	129.21	5.82	123.39	1.894	1.291	1.290	.775
8	25818	129.09	5.90	123.19	1.891	1.289	1.288	.776
9	25795	128.98	5.99	122.99	1.888	1.287	1.286	.778
10	25771	128.86	6.08	122.78	1.883	1.284	1.278	3.912
15	25651	128.26	6.64	121.62	1.866	1.272	1.271	.755
15.96	25628	128.14	6.76	121.42	1.863	1.270	1.123	3.598
20	20124	100.62	7.34	93.28	1.432	.976	.856	5.841
25	15718	78.59	8.17	70.42	1.081	.737	.654	7.645
30	12732	63.66	9.12	54.54	.838	.571	.509	9.823
35	10554	52.77	10.18	42.59	.654	.446	.396	12.626
40	8880	44.40	11.35	33.05	.508	.346	.304	16.447
45	7540	37.70	12.62	25.08	.384	.262	.226	22.124
50	6431	32.16	13.98	18.18	.279	.190	.158	31.646
55	5490	27.45	15.44	12.01	.185	.126	.096	52.083
60	4673	23.27	17.00	6.27	.097	.066	.039	128.205
65	3950	19.75	18.64	1.11	.018	.012	.006	150.000
65.9	3828	19.14	19.11	0.00				

TABLE 2^b

PERFORMANCE DURING RETARDATION TRAIN,200 TONS.

Speed miles per hour	Coefficient Of friction	Friction per ton Col. 2 x 1600	Retardation in miles per hour per second $A = \frac{P}{95.6}$	The mean of two consecutive values in Col. 4	Time in seconds required to produce the change in speed indicated in Col. 1	The sum of times in Col. 6
1	2	3	4	5	6	7
65.9	.104	166	1.74	1.75	.51	
65.	.105	168	1.76	1.81	2.76	3.27
60	.111	178	1.86	1.91	2.62	5.89
55	.117	187	1.96	2.02	2.48	8.37
50	.124	198	2.07	2.13	2.34	10.71
45	.131	210	2.20	2.27	2.20	12.91
40	.140	224	2.34	2.43	2.06	14.97
35	.150	240	2.51	2.61	1.92	16.89
30	.162	259	2.71	2.82	1.77	18.66
25	.175	280	2.93	3.06	1.63	20.29
20	.191	306	3.20	3.36	1.49	21.78
15	.210	336	3.51	3.71	1.35	23.13
10	.233	373	3.90	4.14	1.21	24.34
5	.262	419	4.38	4.70	1.06	25.40
0	.300	480	5.02			

TABLE 2^c

TIME REQUIRED TO TRAVEL 100 MILES AND THE AVERAGE SPEED DURING THE RUN AS INFLUENCED BY THE NUMBER AND THE LENGTH OF STOPS. WEIGHT OF TRAIN 200 TONS.

No. of	No dead time		1 minute dead time in each stop		2 minutes dead time in each stop		5 minutes dead time in each dead stop	
stops	Time in seconds	Average speed in miles per hour	Time in seconds	Average speed miles per hour	Time in seconds	Average speed miles per hour	Time in seconds	Average speed miles per hour
1	2	3	4	5	6	7	8	9
0	5447	66.09						
1	5522	65.19	5582	64.49	5642	63.70	5822	61.83
2	5597	64.32	5717	62.97	5837	61.68	6197	58.09
3	5672	63.47	5852	61.52	6032	59.68	6572	54.78
4	5747	62.64	5987	60.13	6227	57.81	6947	51.82
5	5822	61.83	6122	58.80	6422	56.06	7322	49.17
6	5897	61.05	6257	57.54	6617	54.41	7697	46.77
7	5972	60.28	6392	56.32	6812	52.85	8072	44.60
8	6047	59.53	6527	55.16	7007	51.38	8447	42.62
9	6122	58.80	6662	54.04	7202	49.99	8822	40.81
10	6197	58.09	6797	52.96	7397	48.67	9197	39.14
11	6272	57.40	6932	51.93	7592	47.29	9572	37.61
12	6347	56.72	7067	50.94	7787	46.23	9947	36.19
13	6422	56.06	7202	49.99	7982	45.10	10322	34.88

TABLE 3.

PERFORMANCE DURING ACCELERATION. TRAIN 400 TONS.

Speed miles per hour	Tractive force at tender Draw bar pounds	Available Tractive force per ton of train Col. 2 ÷ 400	Resistance of train pounds per ton	Tractive force available for acceleration lb. per ton: Col. 3 - Col. 4	Acceleration per second		Mean of two consecutive values in Col. 7	Time in seconds required to produce the change in speed indicated in Col. 1
					Feet per second	Miles per second		
1	2	3	4	5	6	7	8	9
0	25995	64.99	18.00	46.99	.722	.492	.536	1.866
1	25974	64.94	9.46	45.48	.851	.580	.593	1.686
2	25952	64.88	7.00	57.88	.888	.605	.610	1.639
3	25930	64.83	5.97	58.86	.904	.616	.617	1.621
4	25908	64.77	5.73	59.04	.906	.618	.618	1.618
5	25886	64.72	5.68	59.04	.906	.618	.617	1.621
6	25864	64.66	5.75	58.91	.904	.616	.616	1.623
7	25841	64.60	5.82	58.78	.902	.615	.615	1.626
8	25818	64.55	5.90	58.65	.901	.614	.613	1.631
9	25795	64.49	5.99	58.50	.898	.612	.611	1.637
10	25771	64.43	6.08	58.35	.895	.610	.606	8.251
15	25651	64.13	6.64	57.49	.882	.601	.600	1.600
15.96	25628	64.07	6.76	57.31	.879	.599	.524	7.710
20	20124	50.31	7.34	42.97	.659	.449	.388	12.887
25	15718	39.30	8.17	31.13	.478	.326	.282	17.731
30	12732	31.83	9.12	22.71	.349	.238	.204	24.510
35	10554	26.39	10.18	16.21	.249	.170	.142	35.211
40	8880	22.20	11.35	10.85	.166	.113	.089	56.180
45	7540	18.85	12.62	6.23	.095	.065	.044	113.636
50	6431	16.08	13.98	2.10	.032	.022	.011	245.455
52.7	5906	14.76	14.76	0.0		.000		

TABLE 3^b

PERFORMANCE DURING RETARDATION TRAIN 400 TONS.

Speed miles per hour	Coefficient of friction	Friction per ton Col. 2 x 1600	Retardation in miles per hour per second $A = \frac{P}{95.6}$	The mean of two consecutive values in Col. 4	Time in seconds required to produce the change in speed indicated in Col. 1	The sum of times in Col. 6
1	2	3	4	5	6	7
52.7	.120	192	2.01	2.04	1.32	
50	.124	198	2.07	2.13	2.34	3.66
45	.131	210	2.20	2.27	2.20	5.86
40	.140	224	2.34	2.43	2.06	7.92
35	.150	240	2.51	2.61	1.92	9.84
30	.162	259	2.71	2.82	1.77	11.61
25	.175	280	2.93	3.06	1.63	13.24
20	.191	306	3.20	3.36	1.49	14.73
15	.210	336	3.51	3.71	1.35	16.08
10	.233	373	3.90	4.14	1.21	17.29
5	.262	419	4.38	4.70	1.06	18.35
0	.300	480	5.02			

TABLE 3^c

TIME REQUIRED TO TRAVEL 100 MILES AND THE AVERAGE SPEED DURING THE RUN AS INFLUENCED BY THE NUMBER AND THE LENGTH OF STOPS. WEIGHT OF TRAIN 400 TONS.

No. of stops	No dead time		1 minute dead time in each stop		2 minutes dead time in each stop		5 minutes dead time in each stop	
	Time in seconds	Average speed in miles per hour	Time in seconds	Average speed miles per hour	Time in seconds	Average speed miles per hour	Time in seconds	Average speed miles per hour
1	2	3	4	5	6	7	8	9
0	6926	51.98						
1	7021	51.27	7081	50.84	7141	50.41	7321	49.17
2	7116	50.59	7236	49.75	7356	48.94	7716	46.66
3	7211	49.92	7391	48.71	7571	47.55	8111	44.38
4	7306	79.27	7546	47.71	7786	46.24	8506	42.32
5	7401	48.64	7701	46.75	8001	44.99	8901	40.44
6	7496	48.03	7856	45.82	8216	43.81	9296	38.73
7	7591	47.42	8011	44.94	8431	42.70	9691	37.15
8	7686	46.85	8166	44.09	8646	41.64	10086	35.69
9	7781	46.27	8321	43.26	8861	40.63	10481	34.35
10	7876	45.71	8476	42.47	9076	39.67	10876	33.10
11	7971	45.26	8631	41.71	9291	38.75	11271	31.94
12	8066	44.63	8786	40.97	9506	37.87	11666	30.86
13	8161	44.11	8941	40.26	9721	37.03	12061	29.85
14	8256	43.60	9096	39.58	9936	36.23	12456	28.90

TABLE 4.

PERFORMANCE DURING ACCELERATION TRAIN 800 TONS.

Speed miles per hour	Tractive force at tender draw bar pounds	Available tractive force per ton of train Col. 2 ÷ 800	Resistance of train pounds per ton	Tractive force available for acceleration lb. per ton Col. 3 - Col. 4	Acceleration per second		Mean of two consecutive values in Col. 7	Time in seconds required to produce the change in speed indicated in Col. 1
					Feet per second	Miles per hour		
1	2	3	4	5	6	7	8	9
0	25995	32.49	18.00	14.49	.223	.152	.197	5.076
1	25974	32.49	9.46	23.01	.354	.241	.254	3.937
2	25952	32.44	7.00	25.44	.390	.266	.272	3.676
3	25930	32.41	5.97	26.44	.406	.277	.278	3.597
4	25908	32.39	5.73	26.66	.409	.279	.279	3.584
5	25886	32.36	5.68	26.68	.409	.279	.278	3.597
6	25864	32.33	5.75	26.58	.408	.278	.277	3.610
7	25841	32.30	5.82	26.48	.406	.277	.276	3.623
8	25818	32.27	5.90	26.37	.405	.276	.275	3.636
9	25795	32.24	5.99	26.25	.403	.275	.274	3.650
10	25771	32.21	6.08	26.13	.400	.273	.270	18.519
15	25651	32.06	6.64	25.42	.390	.266	.265	3.985
15.96	25628	32.04	6.76	25.28	.387	.264	.225	17.955
20	20124	25.16	7.34	17.82	.273	.186	.153	32.680
25	15718	19.65	8.17	11.48	.176	.120	.096	52.083
30	12732	15.92	9.12	6.80	.104	.071	.051	98.039
35	10554	13.19	10.18	3.01	.045	.031	.015	300.000
39.5	9031	11.29	11.23	.06		.00		

TABLE 4^b

PERFORMANCE DURING RETARDATION TRAIN 800 TONS.

Speed miles per hour	Coefficient of friction	Friction per ton Col. 2 x 1600	Retardation in miles per second per second $A = \frac{P}{95.6}$	The mean of two consecutive values in Col. 4	Time in seconds required to produce the change inspeed indicated in Col. 1	The sum of times in Col. 6
1	2	3	4	5	6	7
39.5	.141	226	2.36	2.44	1.84	
35	.150	240	2.51	2.61	1.92	3.86
30	.162	259	2.71	2.82	1.77	5.63
25	.175	280	2.93	3.06	1.63	7.26
20	.191	306	3.20	3.36	1.49	8.75
15	.210	336	3.51	3.71	1.35	10.10
10	.233	373	3.90	4.14	1.21	11.31
5	.262	419	4.38	4.70	1.06	12.37
0	.300	480	5.02			

TABLE 4^c

TIME REQUIRED TO TRAVEL 100 MILES AND THE AVERAGE SPEED DURING THE RUN AS INFLUENCED BY THE NUMBER AND THE LENGTH OF STOPS. WEIGHT OF TRAIN 800 TONS.

No. of	No dead time		1 minute dead time in each stop		2 minutes dead time in each stop		5 minutes dead time in each stop	
stops	Time in seconds	Average speed in miles per hour	Time in seconds	Average speed miles per hour	Time in seconds	Average speed miles per hour	Time in seconds	Average speed miles per hour
1	2	3	4	5	6	7	8	9
0	9234	38.98						
1	9354	38.48	9414	38.24	9474	38.00	9654	37.29
2	9474	38.00	9594	37.52	9714	36.06	10074	35.74
3	9594	37.52	9774	36.83	9954	36.17	10494	34.31
4	9714	37.06	9954	36.17	10194	35.31	10914	32.99
5	9834	36.61	10134	35.52	10434	34.50	11334	31.76
6	9954	36.17	10314	34.90	10674	33.73	11754	30.63
7	10074	35.74	10494	34.31	10914	32.99	12174	29.57
8	10194	35.31	10674	33.73	11154	32.28	12594	28.58
9	10314	34.90	10854	33.17	11394	31.60	13014	27.66
10	10434	34.50	11034	32.63	11634	30.94	13434	26.80
11	10554	34.11	11214	32.10	11874	30.32	13854	25.99
12	10674	33.73	11394	31.60	12114	29.72	14274	25.22
13	10794	33.35	11574	31.10	12354	29.14	14694	24.50
14	10914	32.99	11754	30.63	12594	28.58	15114	23.82
15	11034	32.63	11934	30.17	12834	28.05	15534	23.17
16	11154	32.28	12114	29.72	13074	27.54	15954	22.56
17	11274	31.93	12294	29.28	13314	27.04	16374	21.99
18	11394	31.60	12474	28.86	13554	26.56	16794	21.44
19	11514	31.27	12654	28.45	13794	26.10	17214	20.91
20	11634	30.94	12834	28.05	14034	25.65	17634	20.42

TABLE 5 - 1

TRAIN 100 TONS.

Time in seconds	Area under the acceleration curve	Average speed miles per hour, for the time intervals in Col. 1	Distance run during the time interval in Col. 1, in ft.	Total distance in feet
1	2	3	4	5
0	1.84	36.8	2699	
50	3.13	62.6	4591	7290
100	3.57	71.4	5236	12526
150	3.77	75.4	5529	18055
200	3.86	77.2	5661	23716
250	3.33	78.0	4885	28601 =
292.7				5.42 miles
TRAIN	200 TONS			
0	1.23	24.6	1804	
50	2.29	45.8	3359	5163
100	2.76	55.2	4048	9211
150	3.00	60.0	4400	13611
200	3.13	62.3	4569	18180
250	3.22	64.4	4723	22903
300	3.27	65.4	4796	27699
350	3.28	65.6	4811	32510
400	3.455	65.8	5067	37577 =
452.5				7.12 miles

TABLE 5 - 2

TRAIN 400 TONS.

Time in seconds	Area under the acceleration curve	Average speed miles per hour, for the time intervals in Col. 1	Distance run during the time interval in Col. 1, in ft.	Total distance in feet
1	2	3	4	5
0	.74	14.8	1085	
50	1.59	31.8	2332	3417
100	2.00	40.0	2933	6350
150	2.23	44.6	3271	9621
200	2.38	47.6	3491	13112
250	2.45	49.0	3593	16705
300	2.54	50.8	3725	20430
350	2.58	51.6	3784	24214
400	2.61	52.2	3828	28042
450	2.626	52.5	3850	31892
500	2.09	52.6	3066	34958 =
539.74				6.62 miles

TRAIN 800 TONS.

Time in seconds	Area under the acceleration curve	Average speed miles per hour, for the time intervals in Col. 1	Distance run during the time interval in Col. 1, in ft.	Total distance in feet
0	.33	6.6	484	
50	.93	18.6	1364	1848
100	1.32	26.2	1921	3769
150	1.54	30.8	2259	6028
200	1.69	33.8	2479	8507
250	1.79	35.8	2625	11132
300	1.85	37.0	2713	13845
350	1.90	38.0	2787	16632
400	3.88	38.8	5691	22323
500	2.41	39.4	3539	25862 =
561.24				4.9 miles

TABLE 6.

PERFORMANCE DURING RETARDATION.

WEIGHT OF TRAIN	Time in seconds	Area under braking curve	Average speed miles per hour, for the time interval in Col. 1	Distance run during the time interval in Col. 1, in ft.	Total distance
	1	2	3	4	5
100 TONS	0	7.44	74.4	546	
	5	6.60	66.0	484	1030
	10	5.67	56.7	416	1446
	15	4.66	46.6	342	1788
	20	3.49	34.9	256	2044
	25	2.09	20.9	153	2197
	30	.40	6.7	49	2246 =
	32.97				.425 miles
200 TONS	0	6.15	61.5	451	
	5	5.17	51.7	379	830
	10	3.59	35.9	263	1093
	15	2.82	28.2	207	1300
	20	1.23	11.4	84	1384 =
	25.4				.262 miles
400 TONS	0	4.74	47.4	348	
	5	3.59	35.9	263	611
	10	2.21	22.1	162	773
	15	.50	7.5	55	828 =
	18.35				.157 miles
800 TONS	0	3.31	33.1	243	
	5	1.91	19.1	140	383
	10	.27	5.7	42	425 =
	12.37				.0805 miles

TABLE 7.

Weight of train tons	Distance run during acceleration and retardation in miles	Time required during acceleration & retardation in second	Maximum No. of stops between which the train can reach its maximum speed	Time required for whole trip of 100 miles with no stop	Lost time for each stop (acceleration and retardation) compared with full speed run
1	2	3	4	5	6
100	5.845	325.67 say 326.	17	$\frac{(100-5.845) \times 60\times60}{78.3}$ $+ 326$ $= 4655$ sec. $= 1^h\ 17^m\ 35^s$	$326 - \left(\frac{5.845\times60\times60}{78.3}\right)$ $= 58^s$
200	7.382	477.9 say 478.	13	$\frac{(100-7.382)\times60\times60}{65.9} +$ $478 = 5447^s$ $= 1^h\ 30^m\ 47^s$	$478-\left(\frac{7.382\times60\times60}{65.9}\right)$ $= 75^s$
400	6.777	558.09 say 558.	14	$\frac{(100-6.777)\times60\times60}{52.7} +$ $558 = 6926^s$ $= 1^h\ 55^m\ 26^s$	$558-\left(\frac{6.777\times60\times60}{52.7}\right)$ $= 95^s$
600	4.981	573.61 say 574.	20	$\frac{(100-4.981)\times60\times60}{39.5} +$ $574 = 9234^s$ $= 2^h\ 33^m\ 54^s$	$574-\left(\frac{4.981\times60\times60}{39.5}\right)$ $= 120^s$

TABLE 8.

DESCRIPTION.	Line No.	Train 100 ton	Train 200 ton	Train 400 ton	Train 800 ton
Distance run during acceleration, in feet	1	28601	37577	34958	25862
Distance run during retardation, in feet	2	2246	1384	828	425
Tractive force during full speed run	3	5459	6486	8111	10822
Time required during acceleration, in second	4	292.7	452.5	539.7	561.2
Area under the curve in Fig. 5, in sq. in.	5	9.248	14.087	16.404	15.788
Horse power during acceleration (5) x $\frac{4000 \times 5000}{33000 \times ((4) \div 60)}$	6	1149.5	1132.	1105	1023
Water consumption during acceleration, in lb $(6) \times \frac{32}{60} \times (4) \div 60$	7	2989	4553	5302	5103
Increase in water consumption for each stop, in lbs. $(7) - \frac{((1) + (2)) \times (3) \times 28}{33000 \times 60}$	8	608	979	1197	1080
Increase in water consumption for each stop, in gallons (8) ÷ 8.3356	9	72.94	117.45	143.6	129.56
Water consumption for whole 100 mile trip with no stop in lbs. $(7) + \frac{(100 \times 5280 - (1) - (2)) \times (3) \times 28}{33000 \times 60}$	10	41367	49408	61759	80915
Water consumption for whole 100 mile trip with no stop, in gallons (10) ÷ 8.3356	11	4963	5927	7409	9707
Coal consumption for whole 100 mile trip with no stop, in lb. $\left(\frac{(6) \times (4)}{60} + \frac{(100 \times 5280 - (1) - (2) \times (3)}{3300}\right) \times \frac{4.5}{60}$	12	6588	7848	9819	13059
Increase in coal consumption for each one stop in lbs. $\left(\frac{(6) \times (4)}{60} - \frac{((1) + (2)) \times (3)}{33000}\right) \times \frac{4.5}{60}$	13	38	66	86	71

TABLE 9.

Weight of train	100		200		400		800	
No. of stops	Water con-sumption in gallons	Coal con-sumption in lbs.	Water con-sumption in gallons	Coal con-sumption in lbs.	Water con-sumption in gallons	Coal con-sumption in lb.	Water con-sumption in gallons	Coal con-sumption in lbs.
1	2	3	4	5	6	7	8	9
0	4963	6588	5927	7848	7409	9819	9707	13059
1	5036	6625	6044	7914	7553	9905	9837	13130
2	5109	6664	6162	7980	7696	9991	9966	13201
3	5182	6702	6279	8046	7840	10077	10096	13272
4	5255	6740	6397	8112	7983	10163	10225	13343
5	5328	6778	6514	8178	8127	10249	10355	13414
6	5401	6816	6632	8244	8271	10335	10484	13485
7	5474	6854	6749	8310	8414	10421	10614	13556
8	5547	6892	6867	8376	8558	10507	10743	13627
9	5619	6930	6984	8442	8701	10593	10873	13698
10	5692	6968	7102	8508	8845	10679	11003	13769
11	5765	7006	7219	8574	89[illegible]9	10765	11132	13840
12	5838	7044	7336	8640	9132	10851	11262	13911
13	5911	7082	7454	8706	9276	10937	11391	13982
14	5984	7120			9419	11023	11521	14053
15	6057	7158					11650	14123
16	6130	7196					11780	14195
17	6203	7234					11910	14266
18							12039	14337
19							12169	14408
20							12298	14479