# Determination of Block Lengths on the San Francisco-Oakland Bay Bridge*

**By Chester Ross Davis,**

Resident Engineer in Charge of Signaling,
San Francisco-Oakland Bay Bridge

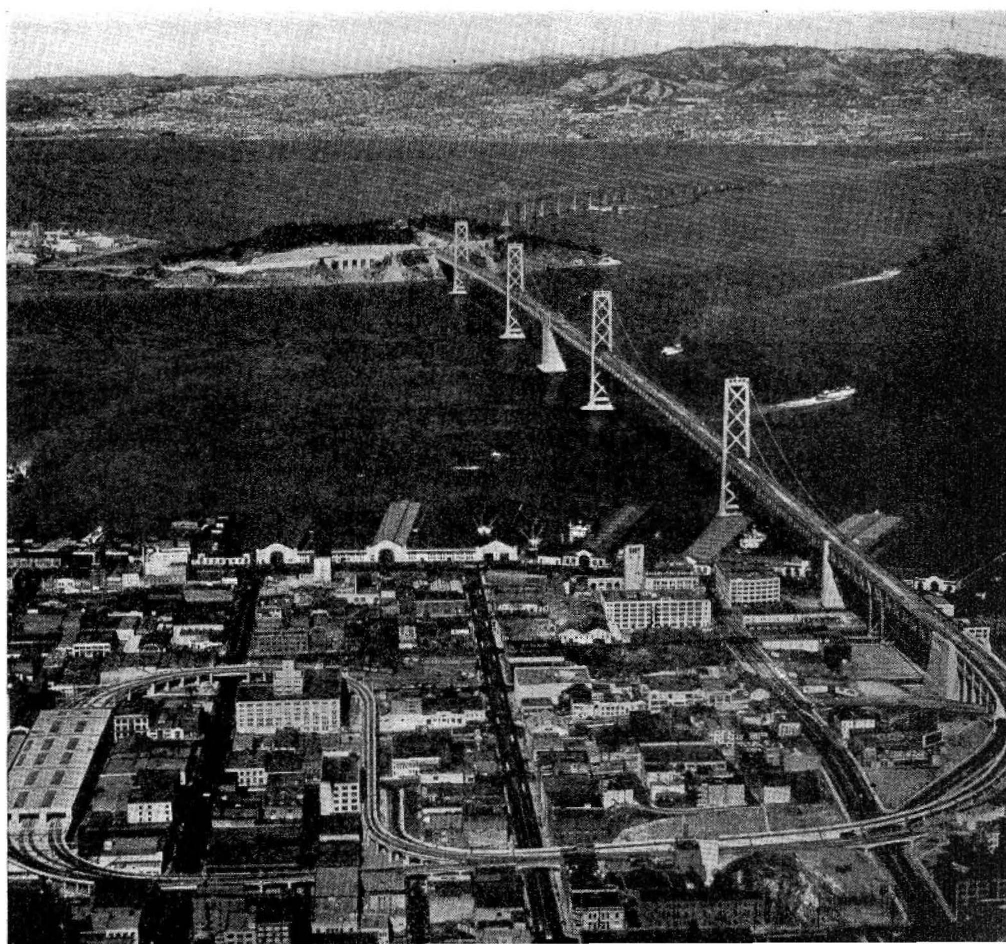
**Method used in calculating the lengths of signal blocks and safe braking distances for automatic train control system without wayside signals**

The extremely close headway between trains on the San Francisco-Oakland Bay Bridge Railway, together with the heavy grades and frequent changes in grade, necessitated an unusually careful and elaborate investigation to determine the correct layout of signal blocks throughout the length of the project. It is necessary that these blocks and their controls not only permit the desired headway, but also provide safe braking distances at all points and under all conditions. The investigation included tests of the equipment actually operated over the bridge, as well as studies of existing data.

To verify the headway the signal blocks were laid out in the usual manner on time-distance charts. Figure 1 shows a typical portion of one of these charts where the grade is descending 2.74 per cent and the speed is constant at 35 m.p.h. The line designated as "front end of train" is first calculated and drawn. Where the speed is not constant a step-by-step method is used for the calculation. Scaling the train length of 780 ft. to the left of this line, a second line is drawn parallel, representing the rear end of the same train at any instant. Still parallel to the first line, but scaling 65 seconds above it, a third line is drawn representing the front end of the following train.

A horizontal line drawn across these three lines will correctly represent the relative positions of the two trains at a given instant in time and, if the blocks are projected vertically from the track plan to this horizontal line, the arrangement of signal blocks between the two trains is shown. By drawing the horizontal lines at such points that the rear end of the train is shown as just having passed an insulated joint, the restrictive distance behind the train is at its minimum length. There must then be one full unrestricted block ahead of the following train, so that it may proceed through that block on a clear signal during the time that will elapse before the rear end of the leading train will pass beyond another insulated joint and thereby step the restrictive conditions another block forward.

In checking braking distances, the leading train is considered stationary with its rear axle immediately ahead of an insulated joint. When closing up on a standing train, a restrictive block must be encountered at such a distance behind that insulated joint as



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Descriptive material covering the general layout, cab signaling and route-interlocking plants of the San Francisco-Oakland Bay Bridge installation was presented in the March, April and May, 1939 issues of *Railway Signaling*.

will enable the motorman to bring the train from its maximum possible speed to a safe stop. This required distance includes five items as follows:

1. Travel during time required for operation of signal equipment ($2\frac{1}{2}$ seconds).
2. Travel during allowed time for motorman's reaction ($2\frac{1}{2}$ seconds).
3. Travel from initiation of service-brake application until train is stopped.

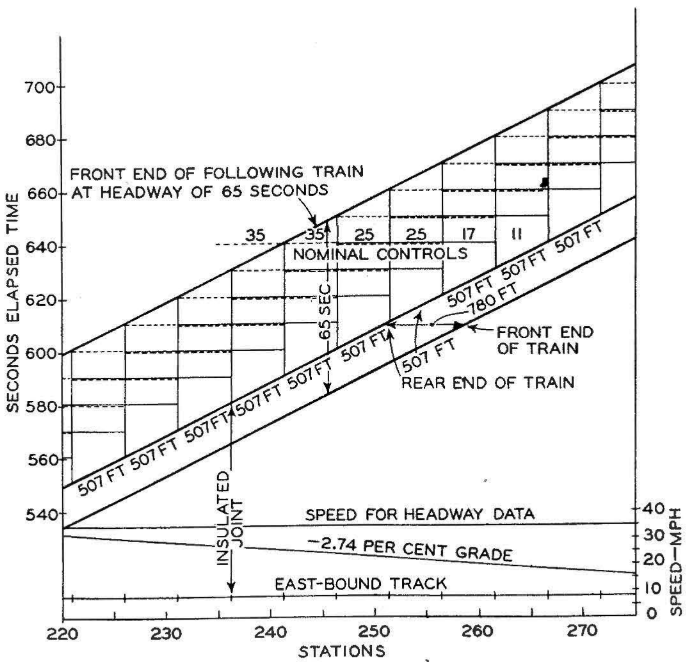


**Fig. 1—Typical time-distance chart**

4. Safety factor for defective brakes or slippery rails, 25 per cent of item 3.
5. Overhang of two trains beyond end axles (20 ft.).

Items 1 and 2 are taken together as the travel at the maximum possible speed for five seconds. The maximum possible speed under any control is the speed which would result in an automatic brake application, plus two per cent error for governor maladjustment. For the maximum fully loaded ten-car Interurban Electric train on level track the items are as follows:

| | |
|---|---|
| Items 1 and 2, $\frac{5 \times 37.74 \times 5280}{3600}$ = | 277 ft. |
| Item 3, level grade, from 37.74 m.p.h. | 1,329 ft. |
| Items 4, 25 per cent of Item 3 | 332 ft. |
| Item 5 | 20 ft. |
| Total | 1,958 ft. |

It will be seen that only Items 3 and 4 will vary with the grade and only Item 3 requires extensive investigation. The chief factors influencing the effect of brakes upon a railway train may be listed as follows:

1. The nominal pressure of the brake shoes against the wheels when the brake cylinders are at full operating pressure.
2. The efficiency of the brake rigging in transmitting this pressure.
3. The coefficient of friction which enables this pressure to effect a tangential force on the wheel rims.
4. The variation in effective brake pressure during the period of initial application before all brake cylinders are at their full operating pressures.
5. The weight of the train, including its load.
6. The inertia effects of rotating parts, such as wheels and axles and parts such as motor armatures which are geared to the wheels and axles.
7. The train resistance or those components of mechanical friction which oppose the motion of the train at a constant speed on tangent level track in still air.
8. The grade over which the train is moving.
9. Curvature of the track over which the train is moving.

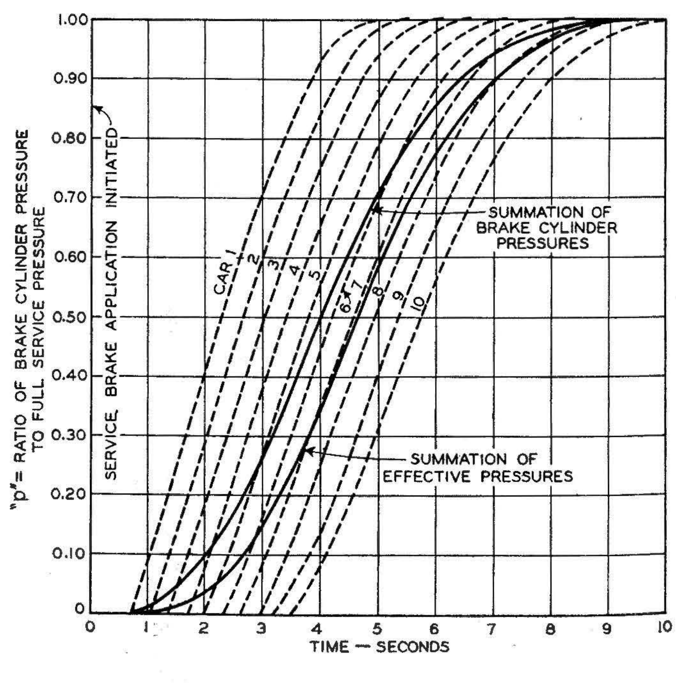


**Fig. 2—Initial rise in brake pressures**

These factors as they entered into our own particular problem were as follows:

1. Total nominal brake-shoe pressure (pounds):

| | |
|---|---|
| Interurban Electric ten-car train, six motor cars, four trailers, with equalization at 50 lb. | 942,000 |
| With equalization at 60 lb. | 1,130,400 |
| Key System seven-unit train with single brakes | 1,181,900 |
| With clasp brakes | 1,057,700 |

2. Brake rigging efficiency, taken in all cases as 85 per cent.
3. The most extensive records of the effect of railway brakes are of the very elaborate and lengthy series of experiments made by Captain Douglas Galton in 1878 on the Brighton Railway in England. As is true of most braking studies made since that date for speeds under 60 m.p.h., Galton's observations have been the basis for our studies and, together with the tests made with Key System and Interurban Electric equipment, comprise the data from which our friction formulas have been derived.

For use in our braking calculations the coefficient of brake-shoe friction is taken as continuously varying with the speed and with the distance through which the brakes have been applied. For clasp brakes our formula is $f_1 = \frac{36}{100+3V}$ in which $V$ is the speed in miles per hour. This gives a curve which approaches the maximum extremes observed by Galton without exceeding his maximum observation for any speed. Galton's tests were made with clasp brakes. For single brakes we have used values somewhat less than the mean of his observations, having found that such values agreed with our tests. The formula used for single brakes is

$$f_1 = \frac{9}{30+V}$$

The reduction factor for distance, $F$, is taken as equal to the ratio,

$$\frac{10{,}000+5d}{10{,}000+24d}$$

in which $d$ is the distance in feet through which the brakes have been fully applied.

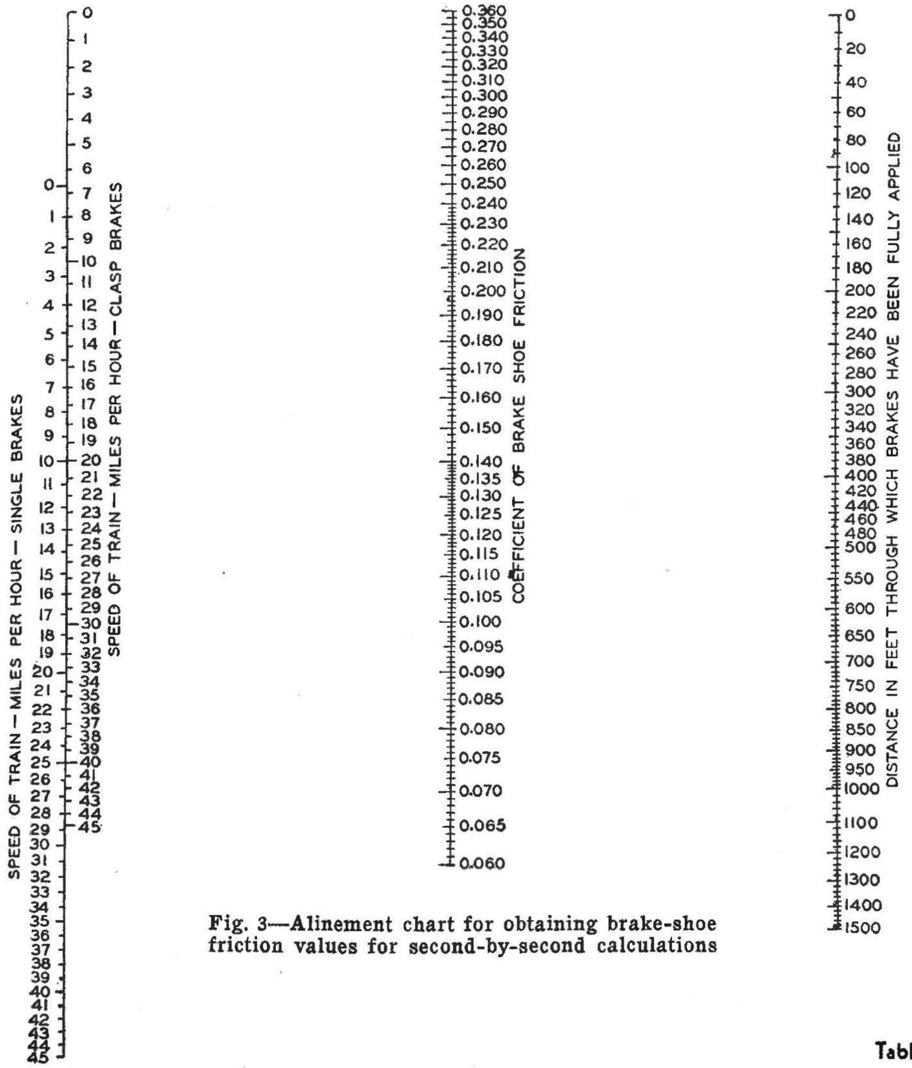


**Fig. 3—Alinement chart for obtaining brake-shoe friction values for second-by-second calculations**

The final coefficient is then given by the formula,

$f = Ff_1$

and the nomograph, Fig. 3, is designed for conveniently obtaining the resulting values.

The coefficient of friction at low partial pressures is assumed to vary as the square root of the pressure and this variation is included in the curve of summation of effective pressures in Fig. 2.

4. When a service-brake application is made, the reduction in air pressure, followed by the operation of the triple valve, is first effective in the head car and then successively in the following cars of the train. Further, the normal pressure of the brake shoes on the wheels is not applied instantly, but rises gradually from zero to full pressure. For use in making braking calculations, standing tests were made of the rate of rise in brake cylinder pressures of an Interurban Electric ten-car train. These pressure rises were charted and, after consideration was given to the effect of reduced pressures on brake rigging efficiency and on coefficients of friction, a curve of summation of effective pressures was added to the chart, Fig. 2. Similar data were obtained for a Key System train of seven articulated units. The effective pressure factors for the first ten seconds of a service brake application as used in our calculations are as follows:

| Seconds | Factor for Interurban Electric Railway | Factor for Key System |
|---|---|---|
| 1 | 0.0 | 0.0 |
| 2 | 0.01 | 0.0 |
| 3 | 0.08 | 0.08 |
| 4 | 0.24 | 0.43 |
| 5 | 0.46 | 0.78 |
| 6 | 0.68 | 0.97 |
| 7 | 0.85 | 1.00 |
| 8 | 0.94 | 1.00 |
| 9 | 0.98 | 1.00 |
| 10 | 1.00 | 1.00 |

5. The weights in pounds of the various trains involved were as follows:

| | |
|---|---|
| Interurban Electric ten-car train | 970,000 |
| Maximum passenger load | 250,000 |
| Total weight | 1,220,000 |
| Key System train with clasp brakes | 952,000 |
| Maximum passenger load | 296,000 |
| Total weight | 1,248,000 |
| Key System train with single brakes | 910,000 |
| Maximum passenger load | 296,000 |
| Total weight | 1,206,000 |

6. We have found that the inertia of the rotating parts of either of our maximum trains is equivalent to the addition of approximately 100,000 lb. to the weight. This is the weight equivalent of the rotaing parts and, when this is added to the total weight of the train, the sum is the total weight-equivalent of the train.

7. Train-resistance data were obtained by drift tests on level track. From these

**Table I**

| Code Interruptions Per Minute | Cab Signal Aspect | Nominal Authorized Speed (MPH) | Speed Above Which White Light Is Lighted (MPH) | Speed Above Which Warning Signal Is Sounding (MPH) | Speed at Which EmergencyBrakes Are Automatically Applied (MPH) |
|---|---|---|---|---|---|
| 180 | Green | 35 | 35 | 36 | 37 |
| 120 | Yellow and green | 25 | 25 | 26 | 27 |
| 75 | Yellow | 17 | $16^1/_2$ | $17^1/_2$ | $18^1/_2$ |
| None | Red | 11 | $10^3/_4$ | $11^1/_4$ | $12^3/_4$ |

**Table II. Interurban Electric Railway Ten-Car Train, Test Condition, Braking From 30 Miles Per Hour, Level Grade**

| t | V | p | f | $R_b = 16.4pf$ | $R_t = \frac{V+45}{450}$ | $R = R_b + R_t$ | $V_a$ | D | SD | d | Sd | $Sd_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 30.00 | | | | | | | | | | | |
| 1 | 29.83 | 0 | | 0 | 0.17 | 0.17 | 29.92 | 43.9 | 43.9 | 0 | | |
| 2 | 29.64 | 0.01 | 0.150 | 0.02 | 0.17 | 0.19 | 29.74 | 43.6 | 87.5 | 0.4 | 0.4 | 0.2 |
| 3 | 29.27 | 0.08 | 0.150 | 0.20 | 0.17 | 0.37 | 29.46 | 43.2 | 130.7 | 3.5 | 3.9 | 2.1 |
| 4 | 28.52 | 0.24 | 0.150 | 0.59 | 0.16 | 0.75 | 28.90 | 42.4 | 173.1 | 10.2 | 14.1 | 9.0 |
| 5 | 27.24 | 0.46 | 0.149 | 1.12 | 0.16 | 1.28 | 27.88 | 40.9 | 214.0 | 18.8 | 32.9 | 23.5 |
| 6 | 25.44 | 0.68 | 0.147 | 1.64 | 0.16 | 1.80 | 26.34 | 38.6 | 252.6 | 26.2 | 59.1 | 46.0 |
| 7 | 23.26 | 0.85 | 0.146 | 2.03 | 0.15 | 2.18 | 24.35 | 35.7 | 288.3 | 30.3 | 89.4 | 74.2 |
| 8 | 20.86 | 0.94 | 0.146 | 2.25 | 0.15 | 2.40 | 22.06 | 32.4 | 320.7 | 30.4 | 119.8 | 104.6 |
| 9 | 18.36 | 0.98 | 0.147 | 2.36 | 0.14 | 2.50 | 19.61 | 28.8 | 349.5 | 28.2 | 148.0 | 133.9 |
| 10 | 15.80 | 1.00 | 0.149 | 2.42 | 0.14 | 2.56 | 17.08 | 25.0 | 374.5 | 25.0 | 173.0 | 160.5 |
| 11 | 13.16 | | 0.153 | 2.51 | 0.13 | 2.64 | 14.48 | 21.2 | 395.7 | 21.2 | 194.2 | 183.6 |
| 12 | 10.41 | | 0.160 | 2.62 | 0.13 | 2.75 | 11.79 | 17.3 | 413.0 | 17.3 | 211.5 | 202.8 |
| 13 | 7.52 | | 0.169 | 2.77 | 0.12 | 2.89 | 8.97 | 13.2 | 426.2 | 13.2 | 224.7 | 218.1 |
| 14 | 4.46 | | 0.180 | 2.95 | 0.11 | 3.06 | 5.99 | 8.8 | 435.0 | 8.8 | 233.5 | 229.1 |
| 15 | 1.12 | | 0.197 | 3.23 | 0.11 | 3.34 | 2.79 | 4.1 | 439.1 | 4.1 | 237.6 | 235.5 |
| 15.3 | 0 | | 0.210 | 3.42 | 0.10 | 3.52 | 0.56 | 0.3 | 439.4 | 0.3 | 237.9 | |

**Note:** Two tests made under the above conditions resulted in measured distances of 429 feet and 431 feet, respectively.

**Table III. Interurban Electric Railway Ten-Car Train, Braking From 37.74 Miles Per Hour, Minus Three Per Cent Grade**

| t | V | p | f | $R_b = 16pf$ | $R_t = \frac{V+45}{450}$ | $R = R_b+R_t -0.61$ | $V_a$ | D | SD | d | Sd | $Sd_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 37.74 | | | | | | | | | | | |
| 1 | 38.17 | 0 | | 0 | 0.18 | −0.43 | 37.95 | 55.6 | 55.6 | 0 | | |
| 2 | 38.57 | 0.01 | 0.132 | 0.02 | 0.19 | −0.40 | 38.37 | 56.2 | 111.8 | 0.6 | 0.6 | 0.3 |
| 3 | 38.82 | 0.08 | 0.130 | 0.17 | 0.19 | −0.25 | 38.70 | 56.8 | 168.6 | 4.5 | 5.1 | 2.8 |
| 4 | 38.75 | 0.24 | 0.128 | 0.49 | 0.19 | +0.07 | 38.79 | 56.9 | 225.5 | 13.6 | 18.7 | 11.9 |
| 5 | 38.26 | 0.46 | 0.124 | 0.91 | 0.19 | +0.49 | 38.50 | 56.5 | 282.0 | 26.0 | 44.7 | 31.7 |
| 6 | 37.40 | 0.68 | 0.119 | 1.29 | 0.18 | 0.86 | 37.83 | 55.5 | 337.5 | 37.7 | 82.4 | 63.5 |
| 7 | 36.29 | 0.85 | 0.113 | 1.54 | 0.18 | 1.11 | 36.85 | 54.0 | 391.5 | 45.9 | 128.3 | 105.3 |
| 8 | 35.10 | 0.94 | 0.108 | 1.62 | 0.18 | 1.19 | 35.70 | 52.3 | 443.8 | 49.2 | 177.5 | 152.9 |
| 9 | 33.91 | 0.98 | 0.103 | 1.62 | 0.18 | 1.19 | 34.50 | 50.6 | 494.4 | 49.5 | 227.0 | 202.2 |
| 10 | 32.75 | 1.00 | 0.100 | 1.60 | 0.17 | 1.16 | 33.33 | 48.9 | 543.3 | 48.9 | 275.9 | 251.4 |
| 11 | 31.64 | | 0.097 | 1.55 | 0.17 | 1.11 | 32.20 | 47.2 | 590.5 | 47.2 | 323.1 | 299.5 |
| 12 | 30.58 | | 0.094 | 1.50 | 0.17 | 1.06 | 31.11 | 45.6 | 636.1 | 45.6 | 368.7 | 345.9 |
| 13 | 29.55 | | 0.092 | 1.47 | 0.17 | 1.03 | 30.07 | 44.1 | 680.2 | 44.1 | 412.8 | 390.7 |
| 14 | 28.55 | | 0.091 | 1.45 | 0.16 | 1.00 | 29.05 | 42.6 | 722.8 | 42.6 | 455.4 | 434.1 |
| 15 | 27.56 | | 0.090 | 1.44 | 0.16 | 0.99 | 28.06 | 41.2 | 764.0 | 41.2 | 496.6 | 476.0 |
| 16 | 26.59 | | 0.089 | 1.42 | 0.16 | 0.97 | 27.08 | 39.7 | 803.7 | 39.7 | 536.3 | 516.4 |
| 17 | 25.63 | | 0.088 | 1.41 | 0.16 | 0.96 | 26.11 | 38.3 | 842.0 | 38.3 | 574.6 | 555.4 |
| 18 | 24.69 | | 0.087 | 1.39 | 0.16 | 0.94 | 25.16 | 36.9 | 878.9 | 36.9 | 611.5 | 593.0 |
| 19 | 23.76 | | 0.087 | 1.39 | 0.15 | 0.93 | 24.23 | 35.5 | 914.4 | 35.5 | 647.0 | 629.2 |
| 20 | 22.83 | | 0.087 | 1.39 | 0.15 | 0.93 | 23.30 | 34.2 | 948.6 | 34.2 | 681.2 | 664.1 |
| 21 | 21.90 | | 0.087 | 1.39 | 0.15 | 0.93 | 22.37 | 32.8 | 981.4 | 32.8 | 714.0 | 697.6 |
| 22 | 20.97 | | 0.087 | 1.39 | 0.15 | 0.93 | 21.44 | 31.5 | 1012.9 | 31.5 | 745.5 | 729.7 |
| 23 | 20.04 | | 0.087 | 1.39 | 0.15 | 0.93 | 20.50 | 30.1 | 1043.0 | 30.1 | 775.6 | 760.5 |
| 24 | 19.10 | | 0.088 | 1.41 | 0.14 | 0.94 | 19.57 | 28.7 | 1071.7 | 28.7 | 804.3 | 790.0 |
| 25 | 18.16 | | 0.088 | 1.41 | 0.14 | 0.94 | 18.63 | 27.3 | 1099.0 | 27.3 | 831.6 | 818.0 |
| 26 | 17.21 | | 0.089 | 1.42 | 0.14 | 0.95 | 17.69 | 25.9 | 1124.9 | 25.9 | 857.5 | 844.6 |
| 27 | 16.26 | | 0.089 | 1.42 | 0.14 | 0.95 | 16.74 | 24.6 | 1149.5 | 24.6 | 882.1 | 869.8 |
| 28 | 15.30 | | 0.090 | 1.44 | 0.13 | 0.96 | 15.78 | 23.1 | 1172.6 | 23.1 | 905.2 | 893.7 |
| 29 | 14.31 | | 0.092 | 1.47 | 0.13 | 0.99 | 14.80 | 21.7 | 1194.3 | 21.7 | 926.9 | 916.0 |
| 30 | 13.30 | | 0.093 | 1.49 | 0.13 | 1.01 | 13.80 | 20.2 | 1214.5 | 20.2 | 947.1 | 937.0 |
| 31 | 12.28 | | 0.094 | 1.50 | 0.13 | 1.02 | 12.79 | 18.8 | 1233.3 | 18.8 | 965.9 | 956.5 |
| 32 | 11.22 | | 0.096 | 1.54 | 0.13 | 1.06 | 11.75 | 17.2 | 1250.5 | 17.2 | 983.1 | 974.5 |
| 33 | 10.14 | | 0.098 | 1.57 | 0.12 | 1.08 | 10.68 | 15.7 | 1266.2 | 15.7 | 998.8 | 991.0 |
| 34 | 9.03 | | 0.100 | 1.60 | 0.12 | 1.11 | 9.59 | 14.1 | 1280.3 | 14.1 | 1012.9 | 1005.8 |
| 35 | 7.89 | | 0.102 | 1.63 | 0.12 | 1.14 | 8.46 | 12.4 | 1292.7 | 12.4 | 1025.3 | 1019.1 |
| 36 | 6.70 | | 0.105 | 1.68 | 0.12 | 1.19 | 7.30 | 10.7 | 1303.4 | 10.7 | 1036.0 | 1030.6 |
| 37 | 5.47 | | 0.108 | 1.73 | 0.11 | 1.23 | 6.09 | 8.9 | 1312.3 | 8.9 | 1044.9 | 1040.4 |
| 38 | 4.18 | | 0.112 | 1.79 | 0.11 | 1.29 | 4.83 | 7.1 | 1319.4 | 7.1 | 1052.0 | 1048.4 |
| 39 | 2.82 | | 0.116 | 1.86 | 0.11 | 1.36 | 3.50 | 5.1 | 1324.5 | 5.1 | 1057.1 | 1054.5 |
| 40 | 1.39 | | 0.121 | 1.94 | 0.10 | 1.43 | 2.10 | 3.1 | 1327.6 | 3.1 | 1060.2 | 1058.6 |
| 40.9 | 0 | | 0.127 | 2.03 | 0.10 | 1.52 | 0.70 | 0.9 | 1328.5 | 0.9 | | 1060.6 |

**Table IV. Interurban Electric Railway Ten-Car Train, Braking From 18.87 Miles Per Hour, Minus Three Per Cent Grade**

| t | V | p | f | $R_b = 16\ pf$ | $R_t = \frac{V+45}{450}$ | $R = R_b+R_t -61$ | $V_a$ | D | SD | d | Sd | $Sd_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 18.87 | | | | | | | | | | | |
| 1 | 19.34 | 0 | | 0 | 0.14 | −0.47 | 19.10 | 28.0 | 28.0 | | | |
| 2 | 19.78 | 0.01 | 0.182 | 0.03 | 0.14 | −0.44 | 19.56 | 28.7 | 56.7 | 0.3 | 0.3 | 0.2 |
| 3 | 20.02 | 0.08 | 0.180 | 0.23 | 0.14 | −0.24 | 19.90 | 29.2 | 85.9 | 2.3 | 2.6 | 1.5 |
| 4 | 19.81 | 0.24 | 0.178 | 0.68 | 0.14 | +0.21 | 19.92 | 29.2 | 115.1 | 7.0 | 9.6 | 6.1 |
| 5 | 18.98 | 0.46 | 0.177 | 1.30 | 0.14 | +0.83 | 19.40 | 28.5 | 143.6 | 13.1 | 22.7 | 16.1 |
| 6 | 17.54 | 0.68 | 0.176 | 1.91 | 0.14 | 1.44 | 18.26 | 26.8 | 170.4 | 18.2 | 40.9 | 31.8 |
| 7 | 15.61 | 0.85 | 0.177 | 2.40 | 0.14 | 1.93 | 16.58 | 24.3 | 194.7 | 20.7 | 61.6 | 51.2 |
| 8 | 13.42 | 0.94 | 0.178 | 2.67 | 0.13 | 2.19 | 14.52 | 21.3 | 216.0 | 20.0 | 81.6 | 71.6 |
| 9 | 11.03 | 0.98 | 0.183 | 2.87 | 0.13 | 2.39 | 12.23 | 18.0 | 234.0 | 17.6 | 99.2 | 90.4 |
| 10 | 8.48 | 1.00 | 0.190 | 3.04 | 0.12 | 2.55 | 9.76 | 14.3 | 248.3 | 14.3 | 113.5 | 106.3 |
| 11 | 5.77 | | 0.200 | 3.20 | 0.12 | 2.71 | 7.13 | 10.4 | 258.7 | 10.4 | 123.9 | 118.7 |
| 12 | 2.87 | | 0.213 | 3.40 | 0.11 | 2.90 | 4.32 | 6.3 | 265.0 | 6.3 | 130.2 | 127.0 |
| 12.9 | 0 | | 0.232 | 3.71 | 0.10 | 3.20 | 1.43 | 1.9 | 266.9 | 1.9 | | 131.0 |

| | |
|---|---|
| **Five seconds at 18.87 miles per hour** | **= 138 feet** |
| **Calculated braking distance** | **= 267** |
| **25 per cent of braking distance** | **= 67** |
| **Overhang** | **= 20** |
| **Minimum length of one block** | **492 feet** |
| **Actual block on minus 3 per cent grade** | **507 feet** |

tests formulas were derived as follows:

For Interurban Electric, $R_t = \frac{V+45}{450}$

For Key System, $R_t = \frac{V+40}{1,000}$

in which $R_t$ is the retardation in miles per hour per second caused by train resistance and $V$ is the speed in miles per hour. The low train resistance of Key System equipment is a result of the installation of roller-bearing journals in all trucks.

8. Grades on the bridge railway vary from three per cent descending to four per cent ascending and lengths of blocks vary accordingly.

9. Resistance caused by track curvature was a factor in the calculation of our speed-time-distance charts, but its effect on braking was not of great importance and will not be discussed here.

To calculate the distance traveled from the initiation of a service brake application until the train is stopped, a second-by-second method is used. The retardation of the speed of a train, caused by the application of the brakes during a period of one second, is obtained by the formula

$R_b = G \cdot r \cdot e \cdot p \cdot f$

in which

$G$ is the constant of acceleration caused by gravity in miles per hour per second, taken as 21.93

$r$ is the nominal braking ratio, the ratio of the total nominal brake shoe pressures to the total weight-equivalent of the train

For the Interurban Electric fully-loaded ten-car train

$$r = \frac{1,130,400}{1,220,000+100,000} = 0.856$$

For the ten-car light train of the preliminary tests

$$r = \frac{942,000}{970,000+100,000} = 0.880$$

For the Key System fully loaded train with clasp brakes

$$r = \frac{1,057,700}{1,248,000+100,000} = 0.785$$

and with single brakes

$$r = \frac{1,181,900}{1,206,000+100,000} = 0.905$$

For the Key System light train with clasp brakes

$$r = \frac{1,057,700}{952,000+100,000} = 1.006$$

with single brakes

$$r = \frac{1,181,900}{910,000+100,000} = 1.170$$

$e$ is the braking rigging efficiency taken as 0.85

$p$ is the ratio of total effective presure to total full presure

$f$ is the coefficient of friction for the second involved and is obtained by means of the nomograph. Fig. 3, after the average speed for that second and the average distance through which the brakes have been applied have been estimated

In the formula for $R_b$, $G$, $r$, and $e$ are constant for a given train condition. For the fully loaded Interurban Electric train

$G \cdot r \cdot e = 21.93 \text{x} 0.856 \text{x} 0.85 = 16.0$

and the formula for this train may be simplified to

$R_b = 16 \cdot p \cdot f$

The total retardation per second is equal to the retardation caused by braking, plus that caused by train resistance, plus that caused by grade, or

$R = R_b + R_t + R_g$

$R_g$ is positive or negative in accordance as the grade is ascending or descending. The formula is

$$R_g = s \cdot G \cdot \frac{W}{W_e}$$

in which $s$ is the grade, $G$ is the gravity acceleration constant, $W$ is the total weight, and $W_e$ the total weight-equivalent of the train. For the loaded ten-car train on a three-per-cent descending grade

$$R_g = -0.03 \times 21.93 \times \frac{1{,}220{,}000}{1{,}320{,}000} = -0.61$$

miles per hour per second.

In the typical calculations shown, symbols which have not been fully discussed are as follows:

*V*, speed, miles per hour, at the end of each second
$V_a$ average speed during the second
*D*, distance in feet traveled during the second
*SD*, total distance traveled since brake handle was placed in service position
*d*, equivalent distance $(D \cdot p)$ brakes were fully applied during the second
*Sd*, total equivalent distance brakes have been fully applied to end of second
$Sd_a$ total equivalent distance brakes have been fully applied to middle of second

After the final braking distance for a given speed and grade has been calculated and the required over-all length of the restrictive blocks obtained, the minimum length of a single block is found. On descending grades we have four restrictive blocks in the rear of the occupied block and three restrictive blocks where the grade is level or ascending. Our standard rail length is 39 ft. and where practicable the block length is a multiple of 39 ft. or of one-half of 39 ft.

In order to check the length of two blocks for braking from the 25 control, and of one block for the 17 control, calculations must also be made for braking from 27.54 and 18.87 m.p.h. For the project under discussion, braking distances were calculated for level grade, one, two, and three per cent descending, and one, two, and three per cent ascending grades.

In the typical tabulations shown, all calculations were made with slide rule. The formulas given herein for various functions of speed are not considered applicable to train speeds greater than 50 m.p.h.

# Mechanical Plant Modernized

*(Continued from page 493)*

The electric lever locks on levers 6, 13 and 24 are controlled by the usual circuit arrangements to prevent placing these levers normal when approach, route or detector locking is in effect due to track occupancy by trains, or by signals displaying an improper aspect. The lock controls include contacts in directional control stick relays, track and plant repeater stick relays, time element stick relays, track relays, etc., in the usual manner. In order to reduce battery consumption, the circuit for the coil of each electric lock is connected through contacts in a floor-push, which the leverman must step on when the lock is to be energized.

The clockwork time release, mounted on the lower panel on the illuminated track diagram, serves to effect a release of any of the three electric lever locks when approach locking is in effect.

## Control of Call-On Signals

In some instances cars are set out and picked up in interchange at Cold Springs, and in such moves, proceed aspects must be displayed while certain track circuits within home signal limits are occupied. For these reasons, a third "arm" is provided on the home signals, this arm in each instance being used to display a "call-on" aspect. When a call-on aspect is to be displayed, the switches and F.P.L. in a route must be lined up, the signal lever reversed, and the corresponding push-button operated. The push-buttons for these controls are mounted on the panel below the illuminated diagram. Operation of one of these push-buttons completes a circuit to energize a corresponding push-button stick relay, which sticks up as long as the corresponding signal lever is reversed. Contacts in these stick relays open the control circuits for the upper "arm" aspects of signals. Through a front contact in the stick relay a circuit is completed to feed a lamp in the illuminated track diagram as a warning to the leverman that a call-on aspect is being displayed.

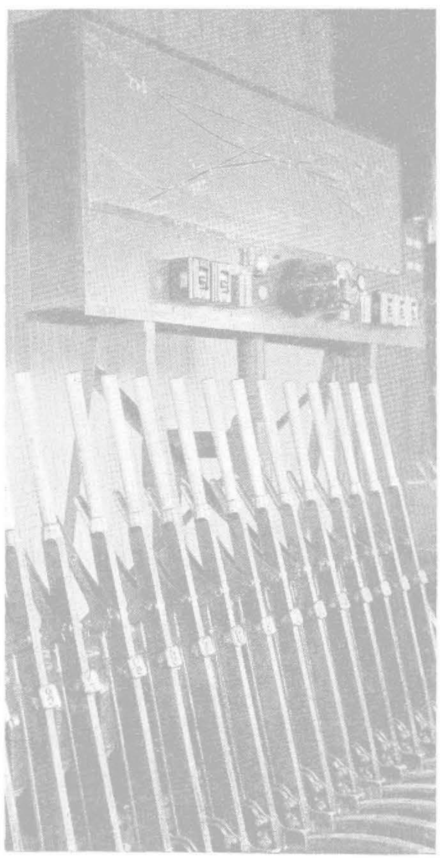

Diagram on angle-iron frame

## Train-Order and Manual Block Signals

Also mounted on the panel below the illuminated diagram are three drum-type rotary switches, each of which is used as the equivalent of a non-interlocked lever to control a manual block signal. Signals A-61 and A-53 are manual block signals, which are located as shown in order that trains can be run through the interlocking and then held until a manual block is clear. If these trains were held in the sections approaching home signals, routes for other trains would be obstructed. Signal D3 is a combination distant signal and also is used as a "hold-out" signal to stop westbound trains when the old Springfield Division branch line trains are using the portion of the Erie track between Cold Springs and the hand-operated junction switch.

When the handle, or rather lever, of one of these drum controllers is in the center position, the corresponding signal displays the Stop aspect, when the lever is thrown to the left, the 45-deg. aspect is displayed, and when thrown to the right, the 90-deg. aspect is displayed.

## Remote Switch Control

The switch at the west end of the passing track on the Big Four is operated by a G. R. S. Co. Model 5A low-voltage switch machine, and this switch together with the signals for directing train movements, is controlled by a desk-type circuit controller unit. This arrangement was in service prior to the modernization program, and the only changes with respect to this equipment was to mount the controller on the right end of the new illuminated track diagram as shown in the illustration.

The rehabilitation and modernization of the Cold Springs interlocking was planned and constructed by the signal forces of the C. C. C. & St. L. under the direction of B. J. Schwendt, assistant signal engineer, the major items of new equipment being furnished by the General Railway Signal Company.