Pennsylvania R. R. Electrifies Philadelphia District

SYNOPSIS—A 15 to 20% gain in capacity of each suburban passenger line can be secured by changing from steam to electric traction. Single phase selected for possible trunk-line operations. Overhead construction on the Paoli line; changes in signal system and rolling stock.

The Pennsylvania R.R. is now operating the suburban line between Broad St. Station, Philadelphia, and Paoli—the first of its electrified lines in that district. This change and the proposed electrification of the other suburban lines have been undertaken to increase the capacity of the Broad St. Station and relieve congestion.

Change Made to Increase Capacity

This terminal is of a stub-end type, with 16 station tracks approached by six main-line and three yard tracks on an elevated structure. At West Philadelphia the main lines branch off, going north to New York, west to Pittsburgh and south to Washington. The suburban service extends over six different routes, as shown in the sketch, Fig. 1.

All the plans for relief by physical enlargement involved extensive reconstruction and much delay, and therefore the possibilities of electric traction were analyzed. It was found that the change on the Paoli line alone would increase its capacity by about 19%, giving for the station as a whole an increase of about 8%. A similar increase in capacity would result from the electrification of the other suburban routes, and work on the Chestnut Hill line has already commenced.

Although the work done on the Paoli line includes the most expensive part of electrifying the whole district—the Broad St. terminal, with its elaborate yards and restricted property lines—yet there will be sufficient saving in operating cost over steam to pay the interest on the additional investment; that is, the increased capacity will be largely self-sustaining, which would not be the case with physical enlargement.

Alternating-Current System Selected

The 11,000-volt single-phase 25-cycle alternating-current system was selected, power being supplied directly to the train from an overhead catenary-trolley system. The primary factor affecting this choice was the possibility of long-distance operation over the entire suburban division, rather than the requirements of present short suburban electric service. This is in marked contrast to the reasons for the selection of 600-volt direct current for the New York terminal zone some years ago.

Although the possible future electric traction may extend over several railway divisions and cover various classes of service, yet the present installation is for suburban passenger service only and involves about 43 trains each way between Philadelphia and Paoli, west on the main line of the Philadelphia division. From Broad St. Station the main tracks are electrified for 20 mi. A coach yard at West Philadelphia and a coach and repair yard at Paoli have been equipped. A total trackage of 93 mi. is affected.

Electric Power Is Purchased

Power will not be generated by the railway company, but will be purchased from the Philadelphia Electric Co. For the present power will be taken from only one phase of the power company's three-phase generating system. It is planned to supply future electrification from the remaining phases. Current is generated by the electric company at its main station on the east bank of the Schuylkill River and is delivered over four three-conductor armored submarine cables to the railroad company's Arsenal Bridge substation on the westerly bank. Here the current is stepped up from 13,200 volts to 44,000 and is distributed over four single-phase overhead transmission

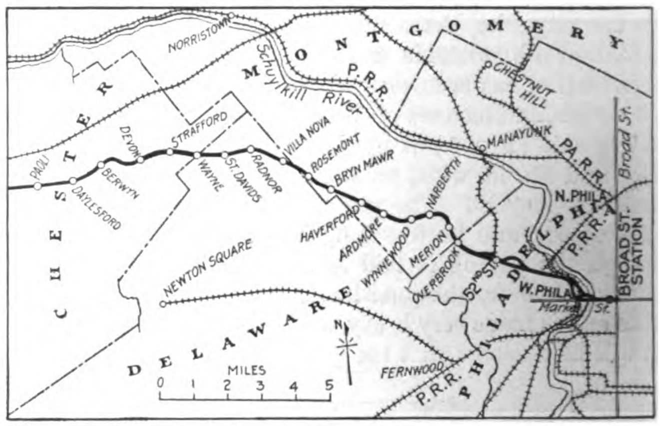


FIG. 1. MAP OF PENNSYLVANIA R.R. SUBURBAN LINES AT PHILADELPHIA

lines, two carried on each side of the track. All four transmission lines go to the West Philadelphia substation (Fig. 1); one pair continues to Bryn Mawr and Paoli and the other will later run to Chestnut Hill. The transmission-line insulators are tested for 250,000 volts puncture and 120,000 volts wet flashover. After erection the transmission lines were tested out at a potential of 66,000 volts to ground—three times working pressure (since the middle of the transformer secondaries is grounded the working potential is 22,000 volts above earth).

The substation equipment is housed in substantial fireproof brick buildings adjacent to the track. Lightning arresters and high-tension feeder section switches are located on the roof. Busbars and switching equipments are on the second floor and transformers on the first. At Arsenal Bridge (Fig. 1) there are three 5,000-kv.-a. step-up transformers and at the three other substations there are two 2,000-kv.-a. step-down units. Space is provided for 100% increase in capacity. In each station there are two small transformers stepping down to 440 and 220 volts for operating circuit-breakers for lighting and miscellaneous purposes. Sixty-cycle power is also provided in all substations to operate circuit-breakers in case of loss of 25-cycle traction power. There are no attendants in the substations, except at West Philadelphia. For the control of the other substations switchboards are provided in nearby signal towers.

The overhead-line construction in many ways resembles that worked out by the same engineers for the Norfolk & Western Ry., Elkhorn grade, as noted in *Engineering News* of June 24, 1915. The principal feature is the tubular-pole cross-catenary bridge supporting the longitudinal catenary and running wires. As shown in Fig. 2, a tubular steel pole is set in concrete foundations on either side of the track and double-guyed away from the track. Between the poles over the tracks are two cross-wires forming the cross-catenary bridge. Where there is no room for back-guying, self-supporting structural-steel posts have been used.

Details of Overhead System

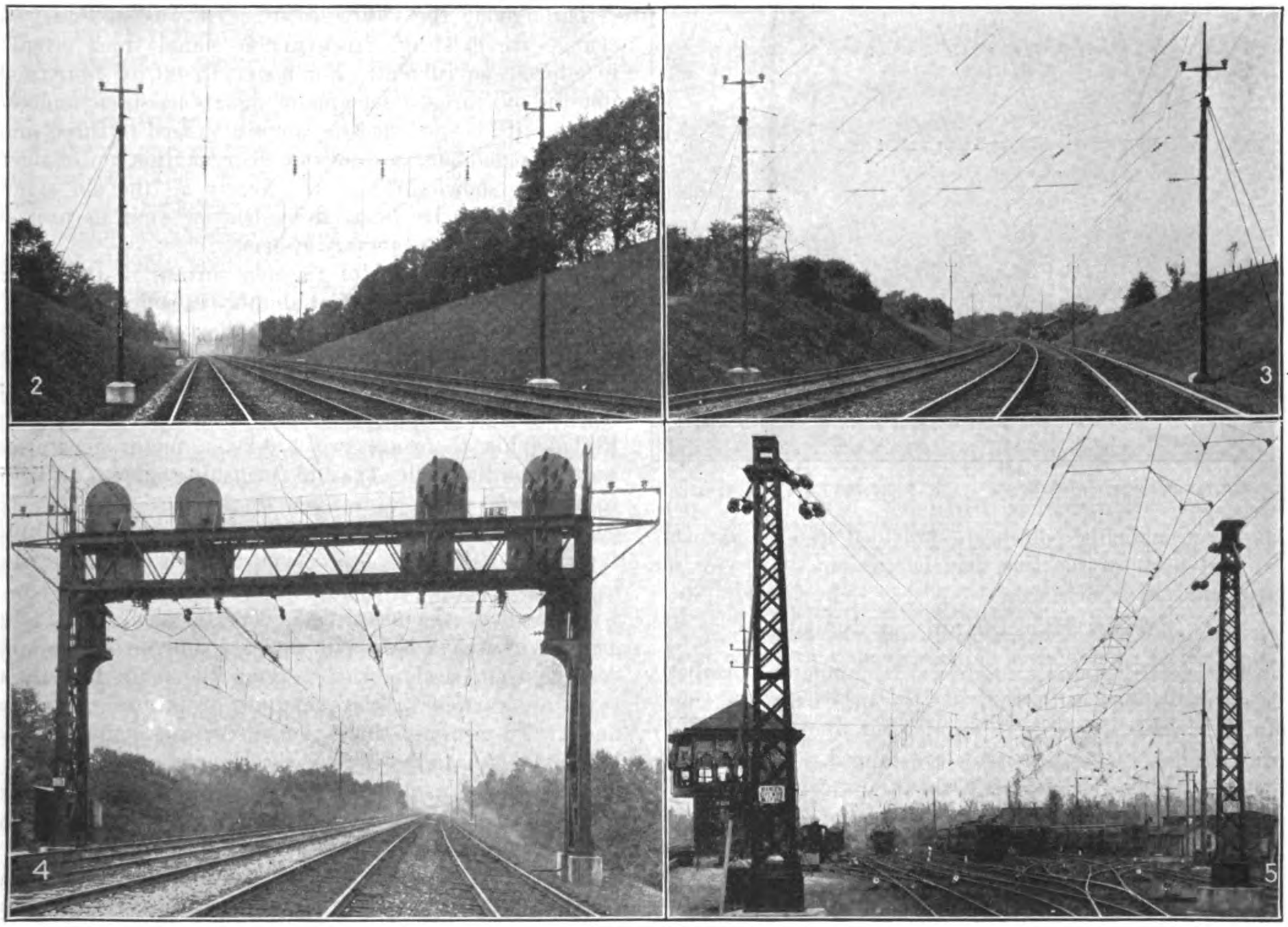
The tubular poles are built up of various lengths, sizes and weights of steel pipe welded together to meet the varying conditions of different locations. The guys are solid-steel rods, with a heavy turnbuckle near the ground end to permit of adjustment. The anchors are of the dead-weight type, consisting of a concrete slab reinforced with old rails. Where the guy rods pass up through the soil they are protected by steel pipe filled with grout. Each steel structure is grounded by connecting to a copper plate buried in coke.

The cross-catenary bridges are about 300 ft. apart on tangents but closer on curves, the spacing depending upon the degree of curvature. The insulators holding the longitudinal wires are over the center of each track, being offset on curves toward the outside.

The cross-wires are of galvanized-steel cable, the upper one usually $3/4$ in. and the lower one usually $1/2$ in. in diameter. Both are socketed at each end with a turnbuckle at one side. The top and bottom wires are joined by vertical $3/4$-in. rods and malleable-iron clamps at the points where insulators supporting longitudinal wires are located. The insulators are of the three-disk suspension type. Each disk is 8 in. in diameter.

The main longitudinal messenger is a $1/2$-in. seven-strand double-galvanized steel cable, strung with a sag of 5 ft. in a normal span of 300 ft. Every mile or two this cable is socketed and dead-ended on one of the structural signal bridges spaced about half a mile apart (Fig. 4). The messenger is insulated from the bridge by two or more sets of three-disk suspension insulators.

Every 15 ft. on curved track and 30 ft. on tangent track two wires are supported from the messenger. The top wire—called the auxiliary—is of No. 0 round copper, giving proper current-carrying capacity to the overhead system. The lower wire is a No. 000 grooved bronze alloy ("phono-electric"). Both wires are about 22 ft. above the top of rail, except where they pass under certain highway bridges



FIGS. 2 TO 5. OVERHEAD LINE CONSTRUCTION OF PENNSYLVANIA R.R. AT PHILADELPHIA
Fig. 2—On typical tangent. Fig. 3—On typical curve. Fig. 4—Signal and anchor bridge. Fig. 5—In Paoli yard

Provision Against Corrosion

In the terminal and along the first 5 mi. out, where the steam-locomotive traffic is dense and there is much smoke and corrosive gas, a noncorrodible tube hanger and hanger clips of monel metal and bronze are used. Where the steam traffic is not dense wrought-iron strap hangers 1 in. wide by $\frac{3}{16}$ in. thick are employed. The main messenger cable is protected from corrosion at brass or monel-metal hanger clips by an inside zinc collar.

On tangents the hangers hold only the auxiliary messenger and the running wire is supported at mid-span. On curves where the two lower wires do not hang directly beneath the messenger both wires are supported at the same point from the hanger. Rigidity is here prevented by the chance for upward swing.

The tension in all cables is selected so that in hot weather there will be no sagging of the running wire, while in cold weather the contraction will not cause stresses beyond the elastic limit.

The running-wire catenary system for each of the four main tracks is separated electrically from the others, and sectionalizing points are provided at all crossovers so that parts of the line may be cut out of service for repair.

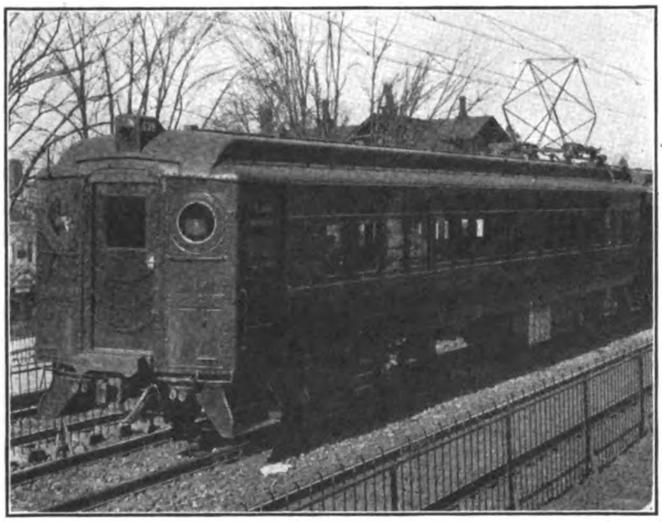


FIG. 6. STEEL MOTOR CAR, PENNSYLVANIA R.R.

Wires Under Highway Bridges

The electrified route is crossed by numerous overhead highway bridges with limited clearance over the track. In such cases where it is impractical to raise the highway bridge, the trolley wires are dipped. The catenary bridges are so located that the highway bridges come in the center of the span and where the vertical height necessary to clear the catenary system is at a minimum. The overhead line is steadied by being held with post-type insulators on brackets on the bridge structure. Transmission lines on either side of the track are also carried down underneath the bridge.

To prevent curious pedestrians from coming in contact with the wires solid wooden fences, either vertical or inclined, and of sufficient height to shut out all view of the wires, have been erected. To protect trainmen general orders have been issued that no men be allowed on top of the cars in the electric zone.

Bonding Rails; Preventing Induction Interference

Each rail of the main-line track is double bonded throughout with No. 0 copper. Through interlockings only one rail of each track is bonded, but all the traction rails are connected together. The bonds have pin-expanded terminals, one being welded and the other soldered on, after the bond has been slipped under the fishplate. At each signal block the track rails are sectionalized by insulating joints. The traction current is led through impedance bonds connected around the insulated joints (allowing the 25-cycle traction current to flow, but preventing the 60-cycle signal current from passing).

Minimum inductive effect of traction currents on adjacent telephone and telegraph wires has been secured in much the same way as on the Norfolk & Western Ry. Series transformers are located about a mile apart along the line and the full traction current is led through the primary windings. The secondary coils are connected across insulated joints in the track so that at this point all returning traction current must pass through the rails. These transformers are shown in place on tower brackets of a signal and anchor bridge in Fig. 4.

Changes in Signal System

Throughout the electrified lines it was necessary to change the existing direct-current signal track circuits to alternating current. For about 15 mi. of four-track line the old form of semaphore signals has been replaced by one with hooded electric lamps arranged in three rows like the semaphore positions of clear, caution and danger. These are shown in Fig. 4. Nearly all the old signal bridges had to be replaced by heavier ones to provide anchorages for the catenary system.

The inductive effect of traction current in the signal circuits is killed by resonant shunts (capacity and resistance in series, adjusted so that they present zero impedance for the 25-cycle current).

Power for the operation of the signals is supplied by the West Philadelphia and Paoli substations. At West Philadelphia there are two 150-kv.-a. motor generators running on the trolley bus and furnishing current at 3,400 volts and 60 cycles over three single-phase feeders. An emergency transformer carried on an outside supply furnishes single-phase, 60-cycle current for signal lighting in emergency.

Throughout the electrified zone, telephone and telegraph wires have been put underground on account of damage from sleet storms. Along the main line these wires are carried in clay conduits or bituminized fiber ducts. To minimize induction disturbances the conduit is located as near the edge of the right-of-way and as far from the tracks as possible. The main signal-power cable is lead-sheathed and carried in a pitch-filled pump log run on top of the main bank of conduits.

Besides the usual telephone facilities between substations and between the power director and train dispatchers, there are permanent telephone boxes on every signal bridge—approximately half a mile apart.

Steel Rolling Stock

The traffic is carried entirely by motor cars. The standard steel suburban coaches have been used without structural changes. This was possible, since the requirements for mounting electric apparatus were considered at the time when the car was introduced. Each car carries two 225-hp. single-phase air-cooled motors, mounted on one truck. The other truck does not drive. Each motor car is complete with one 11,000-volt pantograph trolley, oil circuit-breaker, main transformer, switch group and limit switch, resistance, and two master controllers, one motor-generator set for supplying the control energy, one control battery, four nine-point train-line receptacles and one train line jumper, one combined blower and compressor unit, and one complete air-brake equipment. All of the main pieces of electrical apparatus are mounted on one end of the car and the air-brake equipment is mounted at the other end. This puts approximately 60% of the total car weight on the driving wheels. The cars are fitted for double-end control and operation.

The motors are connected in series and are started and operated up to about 15 mi. per hr. as repulsion motors with the auxiliary field, armature and main field in series. The running steps for higher speeds place the auxiliary field on one part of the car transformer and the armature and main field on the other portion. Subsequent steps are obtained by increasing the motor voltages. Between the motor shaft and the driving wheels are flexible gears, each made up of a rim, a center and intermediate springs, which equalize the rapidly pulsating torque of the single-phase motor and prevent unpleasant vibration in the car frame.

The air-brake equipment is electro-pneumatic (the Westinghouse U. C., which has been generally adopted by the Pennsylvania R.R.). The application is made simultaneously on all the cars by electrically controlled release, service and emergency sections of a "universal valve" which replaces the "triple valve" of the older air-brake systems. This equipment may be used with either steam or electric traction.

Engineering and Construction

The design and construction described were carried out by Gibbs & Hill, of New York City, as consulting engineers for the railroad company, but in coöperation with the engineering department and officials. All construction except for substation buildings and inspection buildings (which were built under outside contracts) was carried on by specially organized force. The motor-car equipment and important electrical apparatus was furnished by the Westinghouse Electric and Manufacturing Co., but the mounting of the car equipment was carried out by railroad forces under the motive-power department. The signal equipment and changes in telephone and telegraph lines were designed and installed under the direction of the signal and telegraph departments, the equipment being made by the Union Switch and Signal Co. Tubular poles were made by the National Tube Co., structural material by the McClintic-Marshall Co. and Belmont Iron Works; overhead wires by J. E. Roebling's Sons Co., Waclark Wire Co. and Bridgeport Brass Co.

Flat or Adjustable Bearings in Brick Tests—Ordinary flat (rigid) bearings for testing brick in compression are nearly as good as self-adjusting bearings, according to an extended series of tests just reported in the October "Journal" of the Association of Engineering Societies. E. L. Baker and A. F. Suss, students in Washington University, made the tests. The series included about 300 tests. To get comparative values, each brick was first broken in cross-bending and then the two pieces tested in crushing, each by a different method. The bearing surfaces were chipped flat with cold-chisel and hammer, but were not bedded. Two forms of spherical bearing were used—(1) a one-piece bearing, consisting of a rocker shoe the curved surface of which rested on the platen of the testing-machine, while the other (flat) face supported the brick; and (2) a ball-and-socket bearing. The comparison values of crushing strength obtained in the tests are: One-piece spherical bearing to flat-plate bearing, 1.03; ball-and-socket bearing to one-piece bearing, 1.12. The ball-and-socket bearing gave the highest average crushing strength, 9.340 lb. per sq.in. These brick averaged 2,600 lb. per sq.in. in modulus of rupture.

Load Distribution on Concrete Slab Floors

The Highway Department of the State of Ohio (Clinton Cowen, Commissioner) has issued as Bulletin No. 28 a résumé of a long series of tests made to determine the distribution of concentrated loads to the beams and girders under a reinforced-concrete floor slab. The tests were both on laboratory specimens and on the floor of an actual bridge. The pamphlet is too long to abstract here, but as an indication of its contents the summary of the results is given below. The object of the tests was to obtain, if possible, a sufficient knowledge of the distribution of loads through and by concrete floor slabs to enable the designer rationally to proportion the joists of a slab floor, and also the slab itself to carry concentrated loads.

Practically all heavy loads on highway-bridge floors except the dead-load are concentrated on small areas, such as the wheels of a road roller or heavy motor truck. In the design of reinforced-concrete floors, therefore, there are two assumptions which must be made:

(1) In designing the supporting joists or stringers, how much of a concentrated load on the slab is carried by the joist immediately below it and how much is distributed by the slab to other joists? (2) In designing the floor slab itself, what width of slab may be considered as carrying a concentrated load resting upon it?

A satisfactory theoretical solution of these questions is impossible, as it involves the elastic properties of both concrete and steel in flat slabs and beams with multiple supports, and requires so many assumptions that any results thus obtained would be little better than assuming the distribution at once.

The following conclusions regarding the distribution of concentrated loads on a reinforced-concrete slab to the floor joists seem to be warranted by these tests:

1. The percentage of reinforcement has little or no effect upon the load distribution to the joists so long as safe loads on the slab are not exceeded.
2. The amount of load distributed by the slab to other joists than the one immediately under the load increases with the thickness of the slab.
3. The outside joists should be designed for the same total live-load as the intermediate joists.
4. The axle load of a truck may be considered as distributed uniformly over 12 ft. in width of roadway.
5. If the slab has ample grip on the upper flange of the I-beam and is continuous over the floor-beams, and the joists are riveted to the web of the floor-beams, the live-load stress in the joist may be but one-half as great as for a similar load on the bare I-beam supported at its ends.
6. Under these favorable conditions the axle load in a panel of not more than 20 ft. may be assumed as uniformly distributed over two-thirds of the length of the joists considered as simple I-beams supported at the ends. Without these conditions the load may be assumed as uniformly distributed over a length of at least 5 ft.

In a slab of a certain span and indefinite width there is some width symmetrical with the load beyond which a single concentrated load will have no effect. The stresses in this slab will be a maximum under the load and will decrease in each direction from it.

The "effective width" of a slab is that width used in designing over which a single concentrated load may be considered as uniformly distributed on a line down the middle of the slab parallel to the supports.

The tests of slabs seem to warrant the following conclusions:

1. The "effective width" is affected very little by the percentage of transverse reinforcement (parallel to supports).
2. The "effective width" decreases somewhat as the load increases.
3. The "effective width" in percentage of the span decreases as the span increases.
4. The following formula will give a safe value of "effective width" where the total width of slab is greater than $1\frac{1}{3}S + 4$ ft.: $e = 0.6S + 1.7$ ft., where e is effective width in feet and S is the span in feet.

Tests and studies of the same problem are being made by Philadelphia, but so far without results.