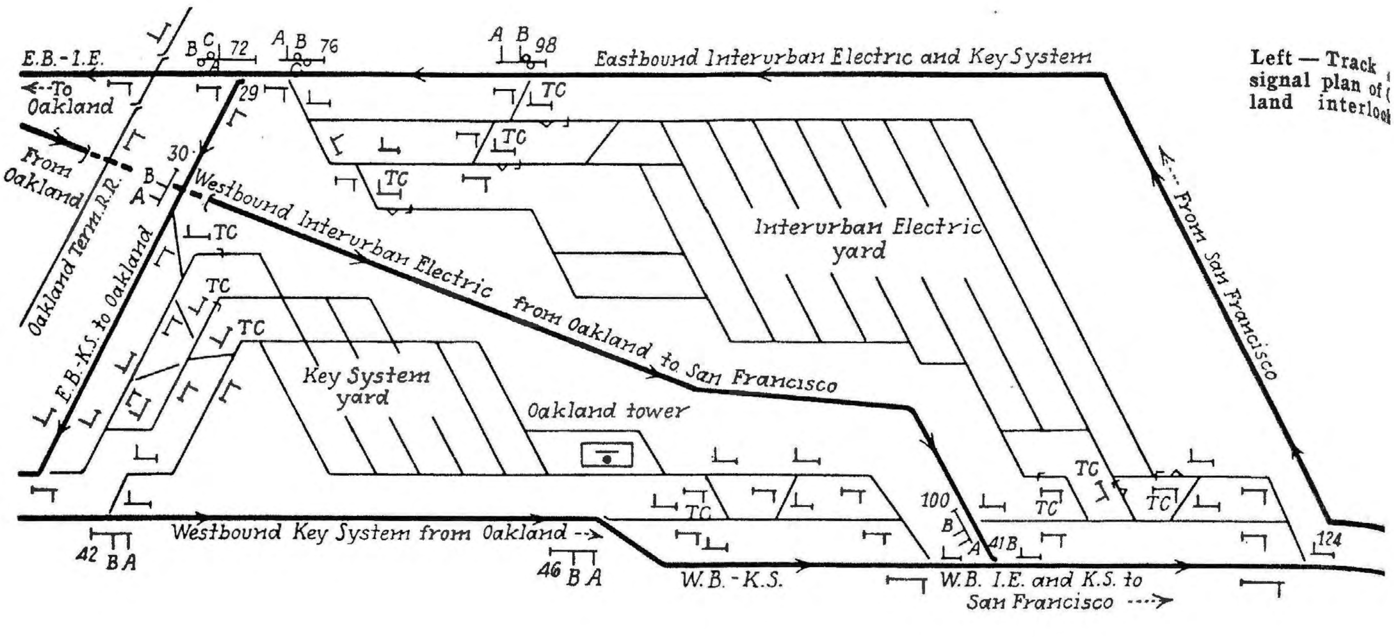


Left — Track signal plan of Oakland interlocking

San Francisco-Oakland Bay Bridge

Signaling and Interlocking

Cab signaling on bridge territory with route interlockings at each terminal provide maximum track capacity on a 63.5-sec. headway between trains

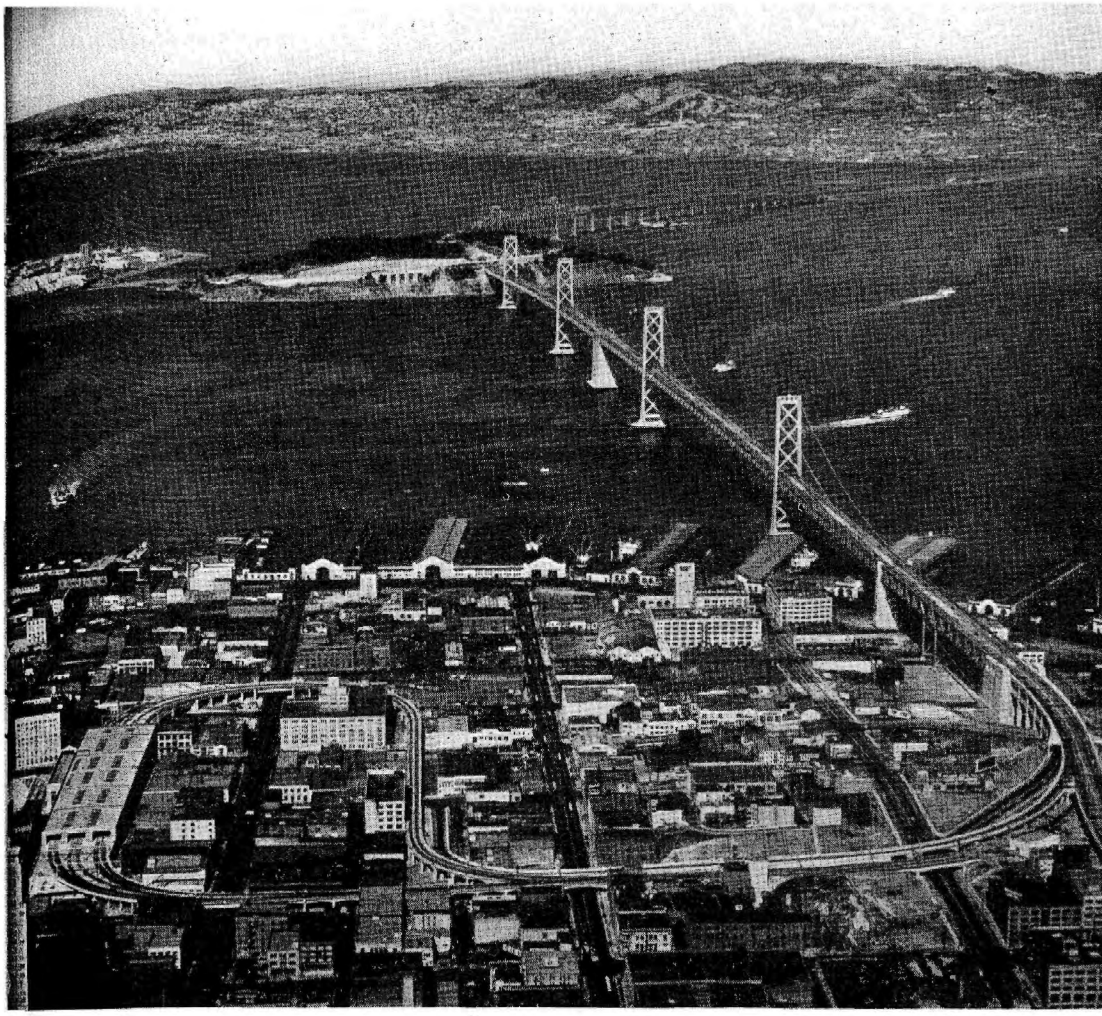
The cab signaling and automatic train control which have been installed in connection with the two tracks on the new 4.5-mile San Francisco-Oakland Bay Bridge, the NX interlockings at San Francisco, Cal., and Oakland, together with the train-describer system, all constitute an important signaling project.

The city of San Francisco is located on the west side of San Francisco Bay, just south of the Golden Gate, a strait which connects the bay with the Pacific Ocean. Oakland is located on the east side of the bay, the distance between the ferry piers of the two cities being slightly over three miles. Oakland has a population of 284,063*, and three adjacent suburbs, Berkeley, Alameda and Piedmont, have a total population of 126,475*. Many of the people who live in Oakland and the adjacent suburbs work in San Francisco, and, therefore, commute daily. The Key System operates electrically-propelled, multiple-unit cars on various lines serving Oakland and Berkeley. These lines formerly terminated at a ferry slip on a mole extending into the bay from the Oakland side, passengers being handled in each direction between Oakland mole and San Francisco by ferry boats. The Interurban Electric railway, a subsidiary of the Southern Pacific, also has suburban lines serving some sections of Oakland and Berkeley. These lines formerly terminated on the Southern Pacific mole at Oakland, and interurban passengers were handled to and from San Francisco by Southern Pacific ferry boats. Lines of the Southern Pacific which served the island of Alameda, terminated at a ferry slip on that island. The Sacramento Northern, which operates a suburban line to the north out of Oakland, used the tracks and ferries of the Key System. On the average week day, about 40,000 interurban passengers travel in each direction between San Francisco and Oakland. The passengers of these three interurban lines no longer use the ferries, because the multiple-unit electric cars are now operated over the new bridge directly into a new terminal in San Francisco.

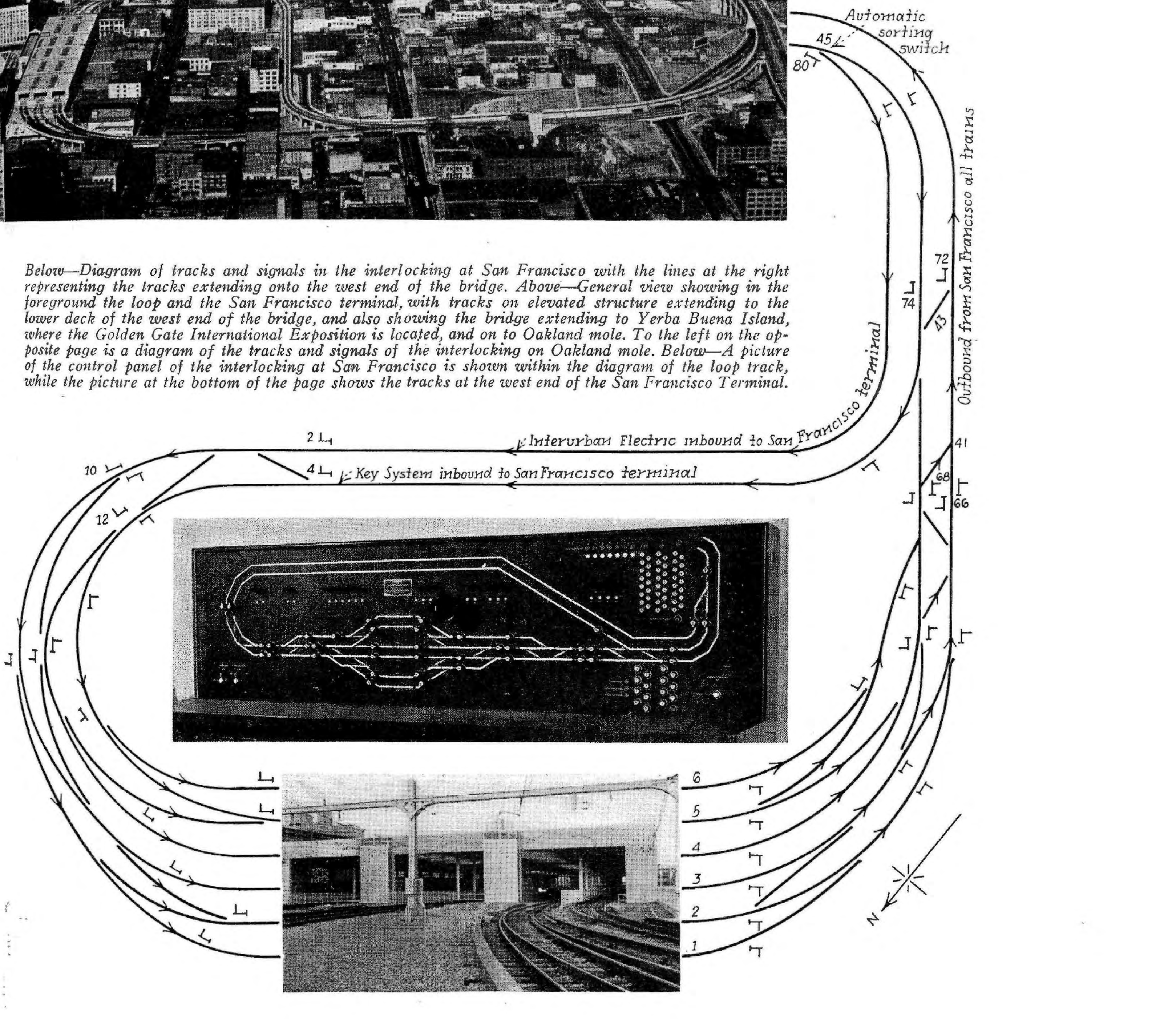
From the San Francisco interlocking limits at the west end of the main bridge structure on Rincon hill to Yerba Buena island, the length is 11,400 ft., and between the island anchorage and the Oakland interlocking limits at the east end of the main structure, 12,400 ft. Thus the total length of the main double-deck structure, which is also the length between interlocking plants, is 4.5 miles. The upper deck of the bridge has six lanes for passenger automobiles, while the lower deck has three lanes for trucks and buses, and two tracks equipped for electrical propulsion on which the interurban cars are operated.

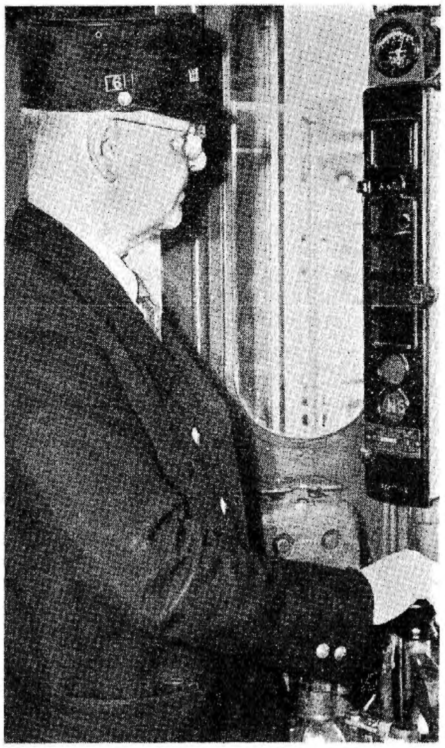
No provisions have been made to operate through passenger trains over the bridge. The bridge was not designed to carry steam locomotives or heavy passenger equipment; furthermore, the operation of the suburban trains taxes the track capacity to the limit. The main-line trains of the

*By 1930 census.



Below—Diagram of tracks and signals in the interlocking at San Francisco with the lines at the right representing the tracks extending onto the west end of the bridge. Above—General view showing in the foreground the loop and the San Francisco terminal, with tracks on elevated structure extending to the lower deck of the west end of the bridge, and also showing the bridge extending to Yerba Buena Island, where the Golden Gate International Exposition is located, and on to Oakland mole. To the left on the opposite page is a diagram of the tracks and signals of the interlocking on Oakland mole. Below—A picture of the control panel of the interlocking at San Francisco is shown within the diagram of the loop track, while the picture at the bottom of the page shows the tracks at the west end of the San Francisco Terminal.





Cab signal in a Key System car

Southern Pacific and Western Pacific to and from points east are terminated at the Oakland mole, as formerly, and passengers, baggage, mail and express are being handled by ferry boat to and from San Francisco.

The new installation of tracks in San Francisco, including the terminal, is elevated on a structure above street level. The bridge ends on Rincon hill near Bryant street, about five blocks south of Market street. From the end of the bridge, the two tracks curve to the north and, together with a third track, extend two blocks to Folsom street, at which point the tracks form a large loop with a six-track, double-end station on the north side of the loop. This station faces Mission street, which is one block south of Market street, the principal business thoroughfare of the city. All trains normally run counter-clockwise in this loop, thus arriving from the east end and departing from the west end of the six station tracks, which are 700 ft. long. Interurban Electric trains use the three tracks on the north side of the station, while the Key System and Sacramento Northern trains use the other three tracks. Ordinarily, Interurban Electric trains, inbound to San Francisco, are diverted to the third track at the switch on the end of the bridge, there being two inbound tracks between this switch and the station tracks to compensate for the reduced track capacity where lower train speeds are necessitated by the 20-deg. curves. The 10 single switches, 13 crossovers, and 40 signals on this layout are controlled by the General Railway Signal Company's NX interlocking system, the control machine being located in a tower near the west end of the station.

Oakland and Bridge Tracks

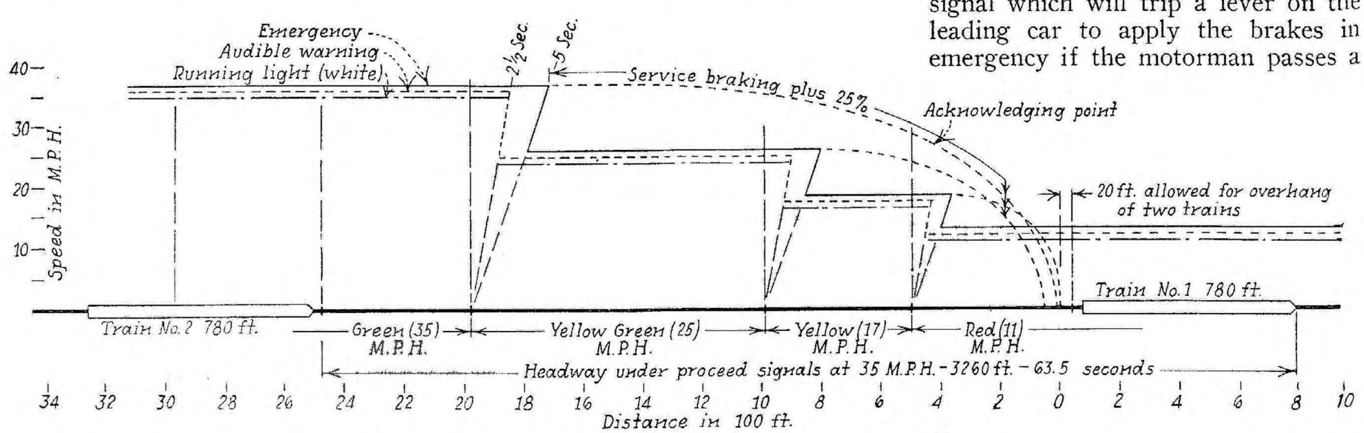
At the Oakland end of the bay bridge, the existing Key System track layout was entirely rebuilt with extensive additions, not only to provide connections from the bridge tracks to inbound and outbound tracks of both roads, without crossings at grade, but also to provide a yard for each road where trains can pick up or set out cars without interfering with the movement of other trains. These yards and tracks were constructed on the mole formerly used by the Key System. New track connections were constructed to connect with the tracks of the Interurban Electric lines. The various junctions and yard connections on the Oakland mole form a track layout about two miles long. The 14 single switches, 11 crossovers, and 62 signals in this interlocking layout are also controlled by the General Railway Signal Company's NX interlocking system, the control machine being located in a tower near the center of the yard. The details of the construction and operation of the interlockings will be explained in detail in a subsequent article.

When making the preliminary plans for the bridge it was thought that it might be necessary to provide three tracks in order to handle the peaks of traffic westbound in the morning and eastbound in the evening. The final plan providing only two tracks, thus allowing a third lane for trucks, was adopted because a signal and train control system could be devised which would safely handle trains on the close headway required. Each track is cab signaled for train movements in one direction only, all reverse movements being made under the most restrictive control.

A total of 520 scheduled trains are run into and out of the San Francisco terminal each week day. Each set of the Key System articulated units seats 134 people, and each Interurban Electric car seats 116 people. Each suburban train is made up of from 1 to 10 cars, or 1 to 7 articulated units, each consisting of two permanently connected cars. In order to provide a seat for each of 17,000 people to be handled in one direction in or out of San Francisco in a 20-min. period, it is necessary to operate 16 trains, each consisting of 10 cars or 7 articulated units, on a 75-sec. headway. Headway is defined as the period from the time the head end of one train passes a given point until the head end of the next train passes that point. In order to allow for irregularities and increases in traffic, the specifications to which the signal system was designed called for facilities to operate 10-car trains, each 780 ft. long, at a 63.5-sec. headway, at running speeds up to 35 m.p.h.

Why Train Control and Cab Signaling Was Used

In order to visualize the outstanding advantages of the system developed for use on the San Francisco-Oakland project, a brief reference is made to systems installed previously to solve somewhat similar problems. In the subways of New York, train movements are controlled by wayside signals with a mechanical arm at each signal which will trip a lever on the leading car to apply the brakes in emergency if the motorman passes a

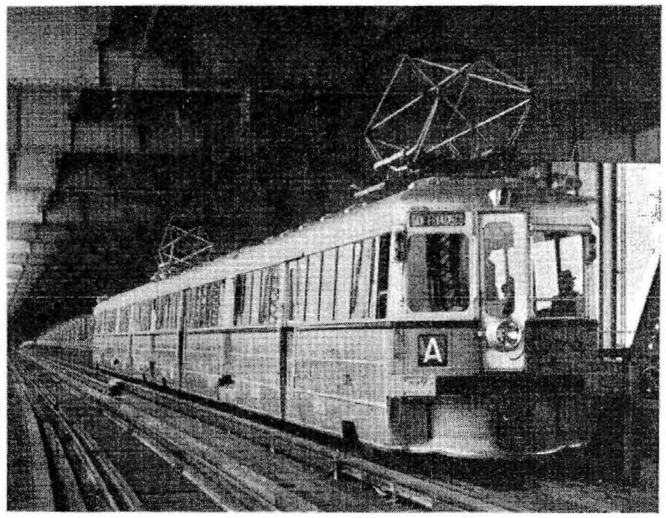


Arrangement of blocks and speed curves for *descending* grade signal indicating stop. With such a system, there are always two signals indicating stop in the rear of a train in order that a following train, if the brakes are automatically applied at the first stop signal it encounters, will always have ample braking distance before reaching the entrance of the occupied block. Furthermore, this system requires that the stopping distance be sufficient to take care of the highest speeds which trains can attain in the respective territories.

In regular practice, the motorman of a subway train does his braking in the second block behind the preceding train, and stops his train at the first stop signal he encounters; in other words, there is always one full block of overlap. A study of the speed-time-distance curves covering the bridge railway operation showed that it was not possible to obtain the specified headway for full length trains with a system of wayside signals and trip stops. This is true even with very closely spaced signals and with wayside time-element control of the signals on the down grades, the headway limitations being due to the length of overlap required for safe operation of trains at 35 m.p.h. on the down grades. Another consideration leading to the adoption of cab control rather than wayside signals was the extremely dense fogs that occasionally occur.

In order to obtain the required headway, a system of continuous cab signals with suppressed braking and speed control was installed. This arrangement requires the motorman to make a service brake application as the train approaches a restrictive block, (if running over the restrictive speed limit), and eliminates the use of the overlap; thus making it possible to obtain the required headway on the down grades. At the same time, the speed governor on the car permits continuous control of train speed depending upon the distance to the preceding train, as indicated in the accompanying chart.

In the block occupied by the rear end of a train, and in an area or "block" which may consist of one or more track circuits immediately in the rear of that occupied, a "no code" condition is set up and a train entering therein will receive a "Red 11" restriction. In the "Yellow 17" area, which likewise may consist of one or more track circuits, a train entering in the direction of traffic will receive a coded current of 75 interruptions per minute. In the "Yellow-Green 25" area, the received code will be 120 per minute. In the "clear" blocks in the rear of the "YG25," a train operating in the direction of traffic will receive a coded current of 180 interruptions per minute, resulting in a "Green 35" aspect of the cab signal and a corresponding speed control. The basic features of the code train control system used on this installation are explained in Bulletin No. 171, of the General Railway Signal Company. The details of the construction and operation of the installation will be explained in a subsequent article, the following discussion being devoted primarily to an explanation of how the cab signaling and train control system are used to accomplish the specified results in track capacity on the San Francisco-Oakland project.



A Key System train on the bridge, note the letter "A" marker on end

Car Equipment for Cab Signaling and Train Control

Motorman's train control equipment is provided in each end of each single car (except non-controlled trailers) and at the extreme ends of each articulated unit, and each car or unit was equipped with speed-measuring apparatus geared to an axle, automatic brake control valves, etc. This equipment was installed on 88 Key System articulated units, on 110 Interurban Electric cars, and on 17 Sacramento Northern cars.

As shown in one of the illustrations, each cab signal consists of a metal case 4¼ in. wide and 22 in. high, with 6 indication lamps, 4 lenses being rectangular and 2 circular. The top lens displays green and the figures "35" outlined on the lens; the next lamp is half green and half yellow, marked "25"; the third is yellow, marked "17"; and the fourth is red, marked "11." The figure in each instance indicates the maximum miles per hour at which a train is authorized to operate in accordance with that indication. No wayside automatic signals are used, and under the red "11" aspect a train is authorized to proceed at that speed prepared to stop short of train or obstruction.

At the interlockings, wayside signals are used, as locations must be marked where a "stop and stay" indication must be given to trains. The cab signaling and train control in the normal direction of traffic is in effect throughout the interlockings as well as on the bridge tracks.

The cab signal lamp (second from the bottom) which has a white lens and no figures, is lighted when a train is running at or above the maximum speed permissible by one of the colored aspects. Should the speed rise a mile above the authorized speed, a bell, in the upper part of the cab signal housing, will sound on a Key System car, or a whistle will blow on an Interurban Electric car. When he receives this warning, the motorman must take action to reduce the speed of the train to the maximum permissible speed. If he does not take such action, the speed continues to increase, the brakes are automatically applied, and the power is cut off. Each time the aspect of the cab signal is changed to one more restrictive, the audible indication is given, and the motorman has 2½ seconds to suppress, i.e., shut off power and initiate a service brake application. Of course, if he is running below the new speed limit, no audible indication is given and he takes no action whatever. When a "Red 11" is received, an additional distinctive signal is sounded, and the motorman is required to press an acknowledgment lever within 2½ seconds thereafter, or before moving the brake handle from the full service position. A special feature of the system is that operation of the brake handle to the service position is checked by a contact which is closed only when the handle is in the full service position. This contact is included in circuits which, in effect, forestall an emergency application. In case the brakes are applied automatically in emergency, the train must be allowed to stop before the brakes can be released.

When a train passes out of train control-cab signaling territory, the lamps in the cab signal are extinguished, and a purple lamp at the bottom marked "NS" for "no signal" is illuminated. The speed-control equipment is automatically cut out as a train passes into non-signaled territory, and is cut in automatically when it enters such territory.

Braking Distances Vary

On days when football games are scheduled at the University of California in Berkeley, some trains leaving San Francisco are loaded to seating capacity and all standing room is occupied. Therefore, braking distances were figured on the basis of these maximum loads.

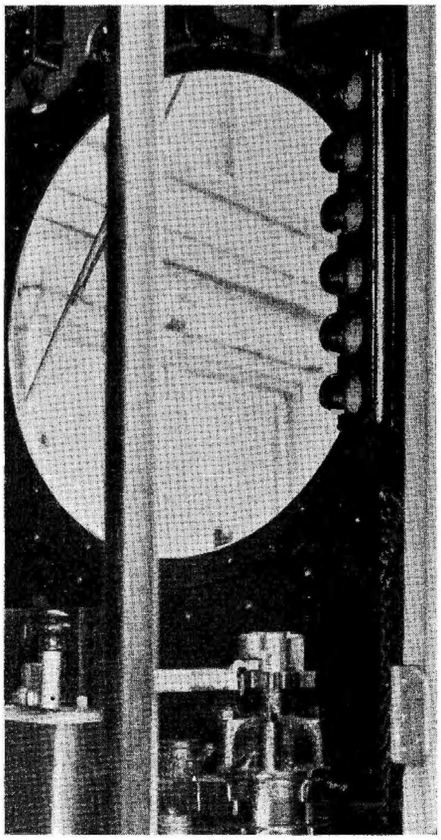
The grades of tracks on the mole at Oakland are nearly level, but practically all of the tracks on the bridge are on grades. Starting at the west end of the Oakland interlocking, the tracks to the west ascend on a grade of 2.74 per cent to a vertical curve in the middle of the cantilever span over the east channel. From this point, the grade is descending at about 2.5 per cent to the tunnel through Yerba Buena island, then ascending at about 3 per cent to a vertical curve over the center anchorage of the two suspension bridges, then descending at about 3 per cent to the west anchorage, and continuing on the elevated structure at varying descending grades to the station tracks in San Francisco, which are on a slight ascending grade (0.5 per cent). Loaded trains operate on a 3 per cent ascending grade at a balanced speed of a little over 20 m.p.h., and must be held to a running speed not exceeding 35 m.p.h. when on level track or on descending grades.

In order to determine the length and location of track circuits and speed zone controls throughout the bridge tracks, speed-time-distance curves were prepared to indicate the operation of loaded trains on all sections of these tracks. Based on these curves and the headway requirement of 63.5 seconds for maximum speed, the track circuit locations and zone controls were laid out to provide service-braking distances at all times between moving trains, with a margin of 25 per cent. On the 3 per cent ascending grades, track circuits are about 370 ft. long, while on descending grades of 2.74 and 3 per cent, where the speed limit is 35 m.p.h., track circuits are approximately 500 ft. long. Near the west end of the bridge, where the westbound trains, when descending the 3 per cent grade, are reducing speed on account of the curve, the track circuits are about 250 ft. long. Considering the tracks on the bridge only, between the interlockings, there are 67 track circuits on the eastward track, and 64 track circuits on the westward track.

The distinctive feature of the system is that the occupancy of any one track circuit establishes the location and length of the three successive speed zones to the rear of the train. The location of the leaving end of any speed zone is far enough in the rear of the occupied track circuit to permit a motorman of a following train to reduce the speed of his train by a service brake application, and to bring it to a stop with the proper margin of safety. Thus, as a train proceeds, the controls are established for three speed zones to the rear, and these zones may vary in length or the total length of the three may vary depending on whether the track is an ascending or descending grade. In effect, the protection moves along behind the train in short jumps of from 250 to 500 ft. each.

Emergency Crossovers on Bridge

In order to provide for emergencies, a set of two hand-operated crossovers, one facing in each direction between the two main tracks, are located at five places on the bridge.



Cab signal in an Interurban Electric car

Two-aspect, color-light dwarf signals, known as switch-position markers, are located in the approach to each set of crossovers. These signals normally display a green aspect, but if any of the four switches in a layout are open more than 1/4 in., the signals display red, and an approaching train receives reduced-speed cab aspects and automatic train control speed restrictions.

Eliminating Congestion at Terminals

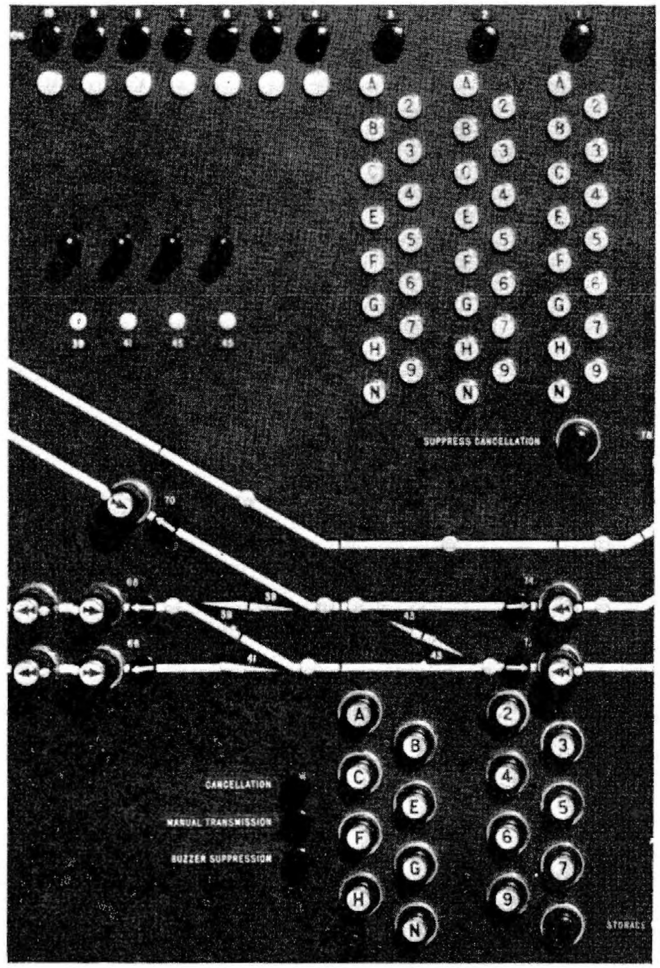
Granting that one track can handle 18 trains in 20 min. past any one point on the bridge where the maximum speed is 35 m.p.h., the next question is how to get these trains out of the way of one another as the speed is necessarily reduced when negotiating the curves and being brought to a stop in the station tracks in San Francisco. This problem was solved by the addition of the third track from the switch on Rincon hill north and around the loop to the throat of the station, thus providing double the capacity of one track in this section. The Key System and Sacramento Northern trains are routed over the center track, and Interurban Electric trains are diverted at switch 45 to the third track.

Each of the six platform tracks in the station at San Francisco will hold one 10-car or 7-unit train. As all trains are starting from the station and encounter the same curves and grade on the way to the bridge, one outbound track is adequate, in contrast with two inbound tracks. It should be noted, however, that the track layout is so designed that two tracks can be used over a certain distance for outbound trains in a rush period. During rush hours, trains are scheduled to arrive and depart on 75-sec. headway.

With all functions normal, to route a train out of track 1, two single switches must be reversed and four signals cleared. If the next train departs from track 6, three single switches must be reversed and three signals cleared. By the time this first train has passed the last switch, No. 43, it has consumed about 47 sec. This leaves only 22 sec. for the towerman to line up three single switches and a signal for the next train to depart from track 6.

This problem was, in part, solved by arranging the tracks so that while an Interurban Electric train is pulling out on the north lead, a Key System train can depart and be proceeding on the south lead toward signal 68 which is cleared after the Interurban Electric train has passed switch 41 and it has been reversed. Regardless of these advantages effected by the track layout, the rapidity with which line-ups must be changed at this plant was considered by the bay bridge engineers as being beyond the limits of practicable operation with the use of the lever-type of interlocking machine in which each switch, crossover and signal is controlled by a separate lever. For this reason, the route-control interlocking was installed, by means of which the switches, crossovers and signals in a route are lined up within a period of a few seconds merely by pushing one button at the point on the diagram representing the entrance to a route and then pushing a second button representing the exit of the route. With this type of machine, the towerman can not only line the routes for departing trains at the rate of one every 63.5 sec., but also may line the routes for trains coming in at the east end of the station layout at the same spacing.

As a general rule, each train is scheduled to make a five-minute station stop at San Francisco to allow time to unload and load passengers. The departure of every train from San Francisco is scheduled to the second. Between 4:50 p.m. and 6 p.m., a train departs every 75 sec. As the time for a train to depart approaches, the conductor operates a button at a departure station on the platform; this causes a green light to appear on the control machine in the line representing that track. The towerman lines the route and clears the signal. In the meantime, the conductor boards the train, closes the last car gate, and signals the motorman to start. An electric clock, with a second hand, is located at each conductor's departure signal station. In case of a delay or unusual circumstance, a conductor can call the towerman by using a telephone located at the conductor's starting station, these telephones being connected to a loud speaker and microphone above the machine.



Section of the panel showing the train describer system with indicating lamps at upper right and sending buttons at the bottom

Layout at Oakland

The entrance-exit interlocking at Oakland is more extensive and includes more switches, crossovers and signals than the one at San Francisco. However, during the rush period, neither westbound nor eastbound trains stop to pick up cars, and, therefore, the trains in the direction of the preponderance of traffic move through at maximum speed. For this reason, the operating problem is confined to operation of the junction crossover No. 41, junction switch No. 29, and the signals governing these movements. In the morning, while the rush of westbound traffic is gradually reducing, the eastbound trains are setting out cars, and, likewise, in the late afternoon westbound trains pick up cars while the eastbound rush of traffic is increasing through Oakland. Thus, the towerman at Oakland has different types of line-ups to handle in rapid sequence.

The Train-Describer System

When arriving at San Francisco, the Interurban Electric trains must be routed to the three station tracks on the north side, and the Key System and Sacramento Northern trains to the other three tracks. Likewise, at Oakland yard, the trains must be sorted and diverted to separate routes. The leverman at each interlocking must, therefore, be informed as to the identity of each train before it arrives within his view. To provide this advance information, a train-describer system was designed and developed especially to fit the operating conditions encountered in this installation.

Each Key System and Sacramento Northern car is marked on the front end with a large-sized letter A, B, C. etc., which designates the route in Oakland or Berkeley which this train serves. Each Interurban Electric train is marked with a numeral 1, 2, 3, etc. The indicator lamps, for receiving the descriptions of trains, and the combination indicator and push buttons for transmitting descriptions are arranged in groups in the face of the panel of the NX interlocking machines.

When the leverman at Oakland is about to send train "A" to San Francisco, he presses his train-describer push button "A" on his control panel, at which time the lamp behind the center of this button is illuminated. Operation of the train description sending button acts also as the equivalent of the exit button to complete the route line-up. As the train leaves the Oakland interlocking, the "A" description is automatically transmitted by coded electrical impulses over two wires to San Francisco. This causes the lamp in the Oakland push button to be extinguished and at the same time lights the "A" train-describer lamp in the first row at the right at San Francisco.

When train "A" approaches the San Francisco interlocking, its arrival is indicated by the illumination of the approach track light on the track diagram. As the train enters the interlocking the "A" light in the train describer is extinguished. The train-describer arrangement has lights enough to indicate 10 trains en route.

The three nearest trains approaching the plant are fully described by an illuminated letter or number in the first three sets of indicators, each set of which consists of two vertical rows of lamps, the first row being lettered indicators and the second numbered indicators. The fourth to tenth trains, inclusive, are indicated by plain white lamps. When a train arrives, its description is extinguished, and the description of the next or second train, which had been shown in the second set of lamps, is moved up automatically to the first set; the third train's description is moved up to second, etc., and the fourth train, which had been indicated only by a single white lamp, is transferred to the third set where it is completely described.

Automatic Sorting at San Francisco

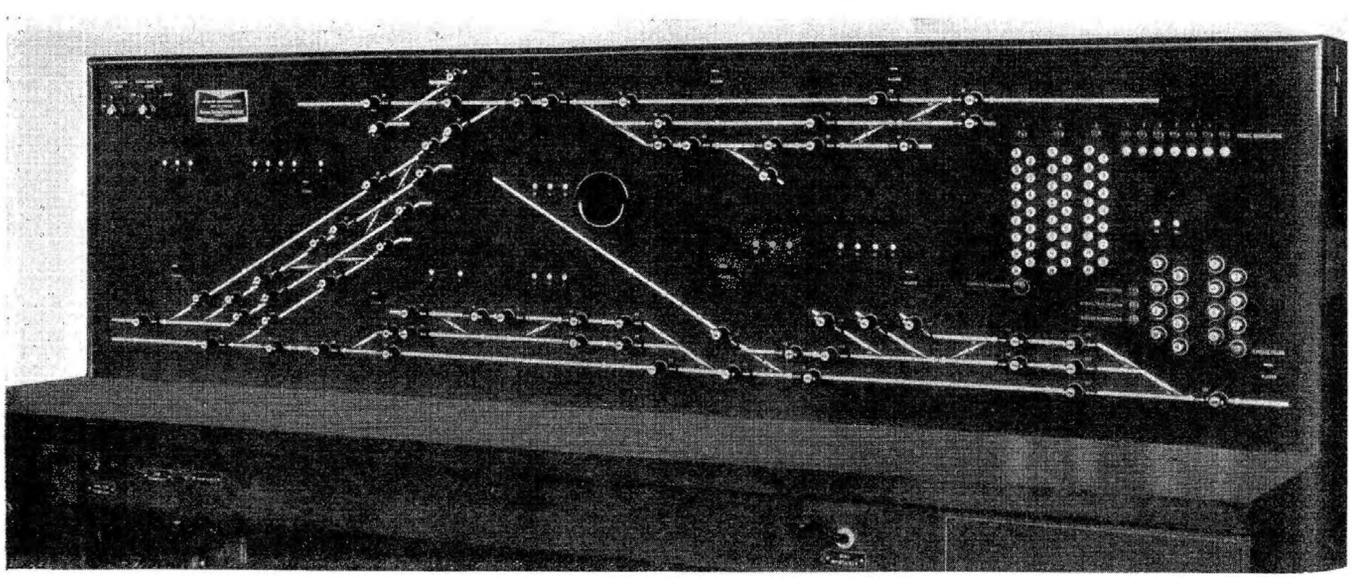
As mentioned previously, two tracks are provided from switch No. 45 northward around the loop to the station tracks for use of incoming trains to San Francisco. As the trains come from the bridge, the Interurban Electric trains which carry numbered markers are diverted at switch No. 45 to the third track and Key System or Sacramento Northern cars which carry lettered markers continue on the center track. The control of this switch is included as a part of the NX interlocking system and can be so controlled, but the towerman, by operating a special lever at the lower right of the panel can place the control of switch No. 45 and signal No. 80 on "automatic sorting," a feature operated by the train-describer system. If the description set up for the next arriving train is a "number" description, switch No. 45 will be reversed to divert the train to the outer loop track and the signal will clear. If the description set up for the next train is a "letter" description, the switch will be lined normal and the signal will be cleared for the move to the center track. When making such a change in line-up, the detector locking is released as soon as the previous train clears the switch points, and then the switch is operated at once so that the signal clears as soon as the previous train clears the fouling point. All of this operation, including the switch, its controlling and indicating relays, is accomplished in less than 9 sec., so that the cab signal for the following train will not impose speed restrictions that will require the motorman to shut off power or to reduce speed when approaching signal 80.

Plans and Specifications

The railway facilities on the bridge, terminals and connections were financed by the California Toll Bridge Authority by bonds sold to the Reconstruction Finance Corporation. The railway cost approximates $18,000,000 which is to be repaid by the railroads to the authority by tolls of 2½ cents per passenger, which are assessed against the respective railways and collected as a part of the regular fares. The operation of the trains over the bridge will save each passenger an average of 15 min. time.

The installation of the interlockings and the cab signal and train control system were made under the jurisdiction of the State of California, Department of Public Works, San Francisco-Oakland Bay Bridge Division, of which C. H. Purcell is chief engineer, Charles E. Andrew, bridge engineer, Glenn B. Woodruff, engineer of design, and C. R. Davis, resident engineer in charge of signaling. The specifications for the cab signaling, train control and interlocking prepared by the bay bridge authorities, was the ultimate outcome of a series of informal conferences held daily by a committee for several weeks in September and October, 1934. The members of this committee included C. R. Davis, R. D. Moore, signal engineer of the Southern Pacific, W. H. Evans, signal and electrical supervisor of the Sacramento Northern, D. L. Babcock, electrical engineer of the Key System, and representatives of each of the signal manufacturers. The contract drawings were prepared by the engineers of the San Francisco-Oakland Bay Bridge.

The detailed plans for the wayside cab signal and interlocking controls were prepared by the General Railway Signal Company, which furnished all wayside signaling and interlocking equipment and performed the construction work under contract. The train control and cab signal equipment on the Key System units and the Sacramento Northern cars was also furnished by the General Railway Signal Company and installed by the respective railroads. The train control and cab signal equipment on the Interurban Electric cars and the materials for the additions to interlockings on the Southern Pacific approaches at Oakland were furnished by the Union Switch & Signal Company and installed by the railroad forces. Signaling on the Key System approaches, including cab signal and train control apparatus to replace wayside signals on two miles of double track, was furnished by the General Railway Signal Co. and installed by the Key System. Train service over the bridge was placed in operation on Jan. 15.



The control panel for the interlocking at Oakland