INSTALLATION OF FOG GUIDANCE LIGHTS ON AFTON MOUNTAIN

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY

The Afton Mountain fog guidance system was installed between May 15, 1974, and March 15, 1976, at a total cost of $1,997,748. It covers a distance of 5.819 miles, and consists of 841 pavement inset lights spaced at 200 ft. intervals on tangent sections and at 100 ft. on curved sections on the main line and a short distance down the exit ramps at the Afton Interchange; a short section of 50 low elevation roadway lights on ramp 'AB' at the Afton Interchange; six fog detectors strategically located throughout the system; and a building to house the power and control apparatus for the system.

All electrical wiring, whether control or power, is enclosed in conduit. The system comprises conduits buried along both edges of the road in each direction; 1,659 transformer housings located off the road shoulders below the surface set in concrete and in line with the conduit; 251 junction boxes; and 45 electrical splicing boxes.

The system is divided into three contiguous sections, and is automatically controlled by fog detecting devices that turn the lights on and off and adjust the intensity of the lighting to the proper brightness for the density of fog.

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INTRODUCTION

Fog is defined as a state of atmospheric obscurity that restricts visibility to less than 3,300 ft. (approximately 1,000 m) regardless of whether it is produced by water droplets or solid particles. If the obscurity permits visibility at distances greater than 3,300 ft. but is still restrictive, it is referred to as mist. If it restricts visibility to 660 ft. (200 m) or less, it is defined as thick fog.(1) The fogs of greatest concern to highway engineers are those that restrict visibility to the point where highway driving becomes difficult and dangerous. Even with a visibility of 800 ft. (243.84 m), the situation does not become critical; it does, however, become extremely critical when the visibility drops to 200 ft. (60.96 m) or less.

There is no doubt that extremely heavy fog impairs the safe and efficient operation of motor vehicles. Statistics reveal that in such fog (1) a slight reduction in accident frequency occurs, (2) there is an increased likelihood that an accident will result in a fatality, and (3) there is an increased chance that an accident will involve several vehicles.(2) Statistics often do not tell the whole story. Traffic volumes decrease in inclement weather, which accounts for the reduction in accident frequency; however, the shortcoming in the statistics is not in their accuracy, but the inability to describe the situation. Picture for a moment what could happen to a motorist who is driving along on a sunny day and suddenly, without warning, passes into a heavy bank of fog that reduces his visibility from unlimited to zero instantaneously. Anything could happen. The least serious is that he gets the fright of his life, or momentarily loses control of his vehicle without accident. The following two examples illustrate what did happen on the opposite end of the spectrum. The first is from an article in the September 1970 issue of Popular Mechanics, where it is described as follows:

> In November 1969, a car traveling at 45 mph (72.4 km/h) entered sudden dense fog on the New Jersey Turnpike. The driver slowed to 30 mph (48.3 km/h), and was overrun by a tractor and a tank-semitrailer that overturned and blocked both lanes and the shoulder. When other vehicles

entered the area, multiple collisions occurred, resulting in six fatalities and three serious and fifteen minor injuries. Some of the vehicles involved were trucks carrying gasoline or propane, so explosions and fires resulted. Five of the six fatalities resulted from burns, and the pavement was so damaged it had to be resurfaced. Twenty-nine vehicles were involved in this multiple vehicle accident; 20 cars were demolished and six trucks were destroyed or damaged. The Safety Board determined the cause of the accident to be vehicle penetration into a dense fog area with a visibility of 20 to 50 feet (6.1 m to 15.2 m), coupled with varying rates of speed that prevented appropriate evasive action.(3)

The second example was related in the Virginian Pilot of July 24, 1971, and consisted of traffic accidents that occurred in a heavy fog the previous day in the Norfolk area. The newspaper account stated in part:

> A series of fiery chain reaction collisions on fogbound Interstate 64 atop and near the high level draw span at Gilmerton early Friday left at least 53 vehicles damaged and 22 people injured, and traffic backed up for miles from both ends of the I-64 bridge over the southern branch of the Elizabeth River. Eight cars and a mail truck in the first pile-up "burned totally", State Police said. Wrecked vehicles were strewn for miles along the high-speed highway as oncoming cars and trucks plunged into those already stopped or slowed by the major collisions.

The study of traffic accident data suggests two processes that operate in fog: (1) a delay in responding, which is due to the inability to see ahead, and (2) a care exhibited by drivers that is related directly to their interactions with other vehicles. Many drivers appear to be aware of fog as a hazard but seem either not to know how to, or not to be willing to, respond in ways other than modest speed reductions. In emergency situations, they exhibit erratic behavior and some will plunge their vehicles into a fog bank where visibility is 20 ft. (6.1 m) or less at speeds in excess of 60 mph (96.6 km/h), while others will simply stop. Discussions of the causes of the various reactions could fill volumes. There are, however, two factors that apparently underlie motorist reactions: (1) the independent spirit of American drivers, and (2) the lack of proper driver attitudes. Until attitudes are changed, there will be a great possibility that multiple accidents will occur no matter what system of guidance or warning is installed.

In Virginia there are several areas that are subject to heavy fog and, unfortunately, some of these are traversed by high volume interstate highways. Of the two examples of multiple collisions previously cited, one occurred in such an area— namely, Norfolk. Perhaps the area in Virginia that has the heaviest fogs and the most frequent occurrences is the Afton Mountain area of the Blue Ridge chain. With the aim of improving the safety of highway travel in areas where heavy fog frequently occurs, in early 1972 the Maintenance Division of the Virginia Department of Highways and Transportation requested that the Research Council study the fog situation in Virginia, and perform a state of the art study of fog abatement and fog lighting systems then in use.

REVIEW OF THE LITERATURE

In response to the above cited request, a review of the literature was conducted. This review revealed that very little meaningful research had been done and that most of what had been performed related to airports. The review did turn up two approaches to increasing visibility in fog; namely, abatement systems and visual guidance systems. The abatement systems consisted of methods of either dispersing fog or blocking its movements. The major abatement method cited involves seeding fog with some type of moisture-attracting mineral, usually salt, which causes the fog to condense and fall as rain. Large helicopters are sometimes used to mix drier air from above with the fog below, which practice, under ideal conditions, will disperse the fog. Forest stands and vegetative barriers have been suggested as methods of blocking fog movement from high elevations to lower areas.

The methods mentioned in the literature all have serious disadvantages. Of the two methods of seeding fog— ground and air— the ground method has not been perfected to anywhere near the level that would make its use feasible. In regard to the air method, few, if any, highway departments have planes necessary for seeding, nor can they economically justify the costs necessary to purchase them. In addition, the seeding material (salt) used to condense the fog presents serious environmental questions. Some airports have successfully used large helicopters to draw dry air from above and mix it with the saturated air at ground level and disperse fog in this manner. For this method to work, the air above must be dry, which often is not the case. As is true with planes in seeding, highway departments don't usually have fleets of helicopters.

There is also great danger to personnel in mountainous areas with the seeding and air mixing methods. Forest stands and vegetative barriers were suggested as methods of blocking fog movement. This method must be considered hypothetical or at best applicable for only a few specific locations that have special conditions. All of the critical fog locations in Virginia are in heavily wooded areas, and observations have not indicated that the vegetation has any effect in stopping the movement of fog.

The second approach to increasing visibility turned up in the literature survey, the visual guidance systems, consist of different types of lighting and are categorized on the basis of where the lights are located. The active system has the lights moving with the vehicle (headlights) to illuminate the target, and it offers the most difficulty under dense fog conditions. Instead of the light penetrating the fog, the particles of moisture act as tiny prisms that scatter the light rays and prevent them from reaching the target. In the passive system, the road is lighted by fixed light sources (roadway lights) independent of the vehicle. If the roadway lighting is to produce maximum visibility, it must be mounted low to the ground so the light will have a minimum blanket of fog to penetrate. The lights should be rotated slighted in the direction of travel. There are two advantages of mounting lights in this manner; one, as previously mentioned, is to keep the blanket of illuminated fog thin, and the other is to keep to a minimum any glare that the driver may experience from the lights.

Signal systems are composed of lights that communicate messages to motorists, and they may be separated into (1) the lights contained on the vehicle, such as brake and turn signals, and (2) lights located on the road, such as traffic signals and illuminated delineators. The illuminated delineators, because of one-way transmission, give a high degree of contrast.

In summary, the literature search[4] revealed that–

1. fogs are significant contributors to multiple car accidents that often result in fatalities;

2. neither systems that adequately abate fogs nor lighting systems that provide minimum visibility requirements have evolved;

3. most abatement techniques stem directly from methods used at airports;

4. it is very improbable that a lighting system can be designed that will produce a visibility level equal to a fog-free condition;

5. fog abatement techniques have not progressed to the point that they are feasible for highway use; and

6. of the several lighting systems cited in the literature, the two that appear to hold the most promise are

   (a) a lineal guidance system employing lights inset in the pavement, and

   (b) a low level lighting system.

Using the information gained from the literature search as a basis, Research Council and Department personnel discussed the feasibility of providing some type of aid for motorists who would be traveling in fog on the soon-to-be opened portion of I-64 over Afton Mountain, one of the heaviest fog areas in Virginia. It was the author's contention that although fog abatement was most desirable, the technology for accomplishing it reliably and effectively had not advanced to the point where it was feasible. It also seemed that meaningful research with an active light system (vehicle headlights) was beyond the resources of the Research Council. With these two possiblities ruled out, only the passive and signaling systems were left. A decision was made to design a test section for Afton Mountain employing a combination of the last two systems.

EQUIPMENT

The lights to be tested were of two types; one was to be embedded in the pavement edgelines, nearly flush with the pavement surface, to provide a lineal guidance/road delineation system, and the second was to be mounted above the road surface at elevations between 2 ft. and 15 ft. (.61 m and 4.57 m). Lineal guidance systems employing the inset lights have been used effectively at many airports. Under poor conditions, the range of visibility of lighted lane lines is far greater than with any of the presently used paint markings and border striping materials. In general, it is approximately double that of reflective marking materials. (5)

An increase in sight distance under inclement or hazardous conditions is always desirable and was considered to be an objective of the research effort. In the case of heavy fogs, effecting significant increases in sight distance becomes very difficult; however, the literature suggests that sight distances can be increased by mounting roadway lights at elevations from 2 ft. to 3 ft. (61 cm to 91 cm). Consequently, this type of lighting was included as part of the experiment.

The procurement of equipment was the next step and proved to be very difficult. It was learned that no lights had been specifically designed for highway use in fog. Managers at airports were contacted to obtain information about airport lighting. It was found that only one company was making pavement inset lights, and the lights were designed with features that would never be required for highway usage. For example, because of the necessity of withstanding the landing impact of the largest jet, the light assemblies were much larger and heavier than necessary for highway purposes. Nevertheless, 12 unidirectional (one-way) airport runway lights were purchased for testing. The lights were weatherproof units having 200-watt, 6.6-ampere, long-life quartz filament bulbs. The assembly was contained in a ductile iron casting fastened to the base receptacle by 6 bolts and sealed with a rubber 'O' ring. They were 12 in. (30 cm) in diameter, and 3.5 in. (8.9 cm) deep, and weighed 50 lb. (22.7 kg) each. The unit is installed in the pavement with only about 0.25 in. (0.64 cm) of the dome above the surface. The lights are wired electrically in series as recommended by the manufacturer, which requires a transformer at each light to step down the voltage to the constant 30 volts necessary for operating the lights and to redirect the current around any lights that may burn out.

Many questions were raised about the advisability of using series circuits; however, electrical experts who design light systems for airports say that they are used because they are superior to parallel circuits in maintaining constant voltage through a long circuit. In parallel circuits, there are large voltage drops over great distances. An integral part of the light system is a constant current regulator that controls the intensity of the lights within the range of brightness required for operation under various conditions of visibility. Figure 1 shows the pavement inset light before and after installation. Note the small transformer in the left photograph that redirects the current upon bulb failure.

For the low level roadway lights a 500-watt quartz floodlight was selected that was designed for applications requiring a wide horizontal and relatively narrow vertical beam spread. Louvres were also ordered for the 10 lights to further control the vertical light cutoff. Figure 2 shows the low level light with the louvre attached.

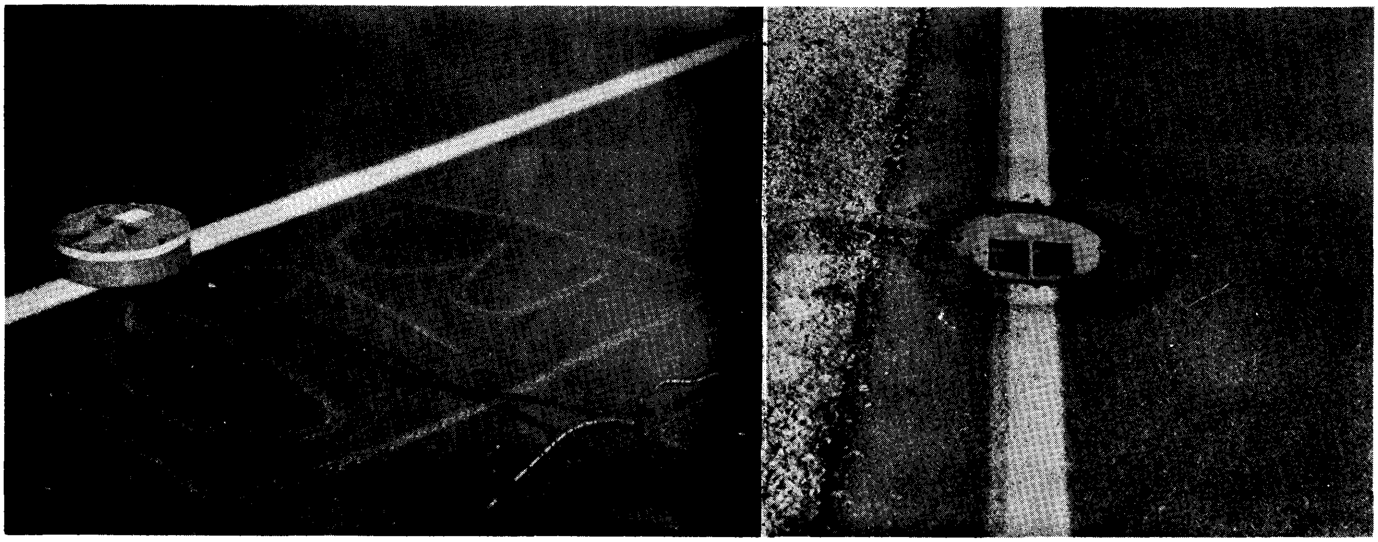

Figure 1. At left, unidirectional pavement inset light with transformer. At right, light installed.

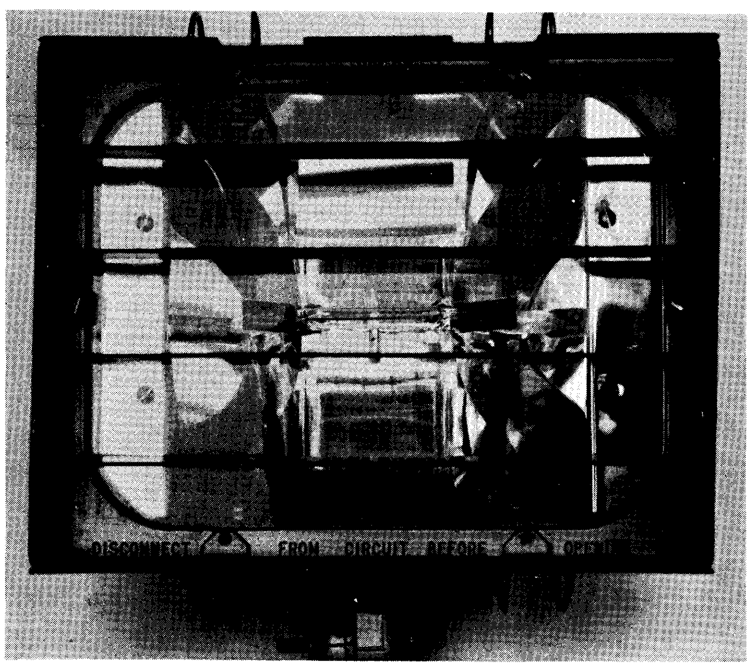

Figure 2. The 500-watt quartz floodlight selected for fog tests.

TEST SITE

The site selected for the initial testing was an unopened portion of the eastbound lanes of I-64 on Afton Mountain in central Virginia. This site was picked for the reasons cited below.

- The area frequently experiences heavy fog.
- If experimentation proved positive, an installation would be made on this section of road.
- The road was not open to traffic and hence provided a safe work area.
- The area was relatively close (25 miles [40 km]) to research headquarters, which permitted visits on short notice of the presence of fog.

EXPERIMENTS

Initial Testing

The equipment was received in November 1972 and experiments were begun immediately on a section of I-64 on Afton Mountain. The pavement lights were placed on top of the pavement surface along the edge line markings and were wired so as to allow the spacings to be varied. The determination of the most effective spacing was an objective of the experiment. Figure 3 is a diagram showing the component parts of the test section. Note that the lights are placed on each edge line and point toward the oncoming driver. This placement produces a lineal pattern or channel for a motorist to follow. From the diagram, the wiring in series, the individual transformers for each light, and the placement of the constant current regulator may be noted. The testing consisted of having motorists drive through the test section in fog under various spacings and intensities and then report what conditions they thought were best.

Another factor of utmost importance was whether these lights could withstand snowplowing. With the light installed as shown in Figure 1, a snowplow with a carbide tipped blade made 12 runs across it in a light snow, and an additional 10 runs over it on bare pavement. The only damage to the light was a slight shaving of metal on the dome.

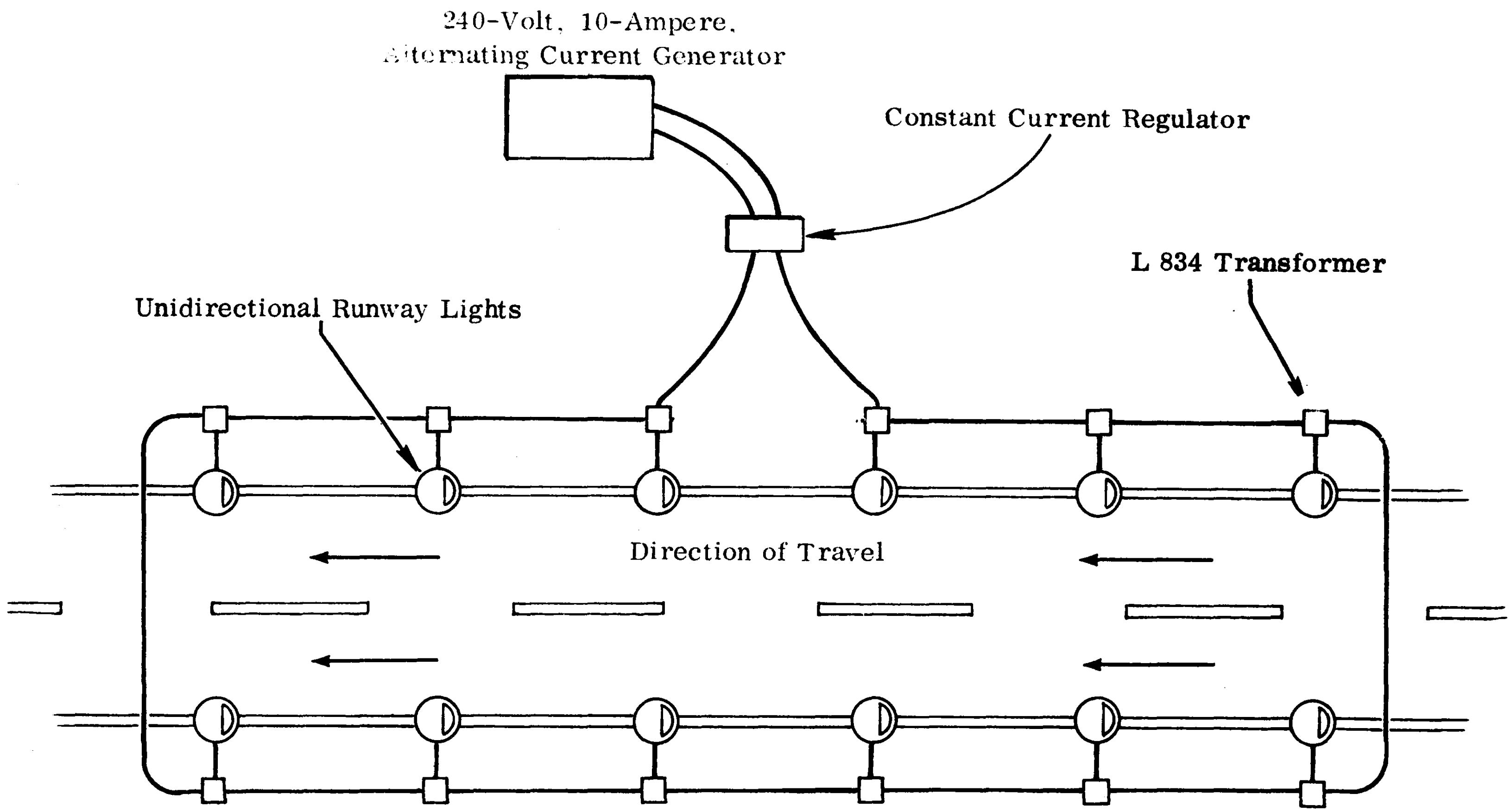

Figure 3. Diagram of a test section of lineal guidance lights.

The low level lights were tested by placing them on standards in such a manner that they could be adjusted in height between 2 ft. and 12 ft. (60.9 cm and 365.8 cm). They were positioned off the shoulder and behind any existing guardrails. Figure 4 shows the mounted low level light.

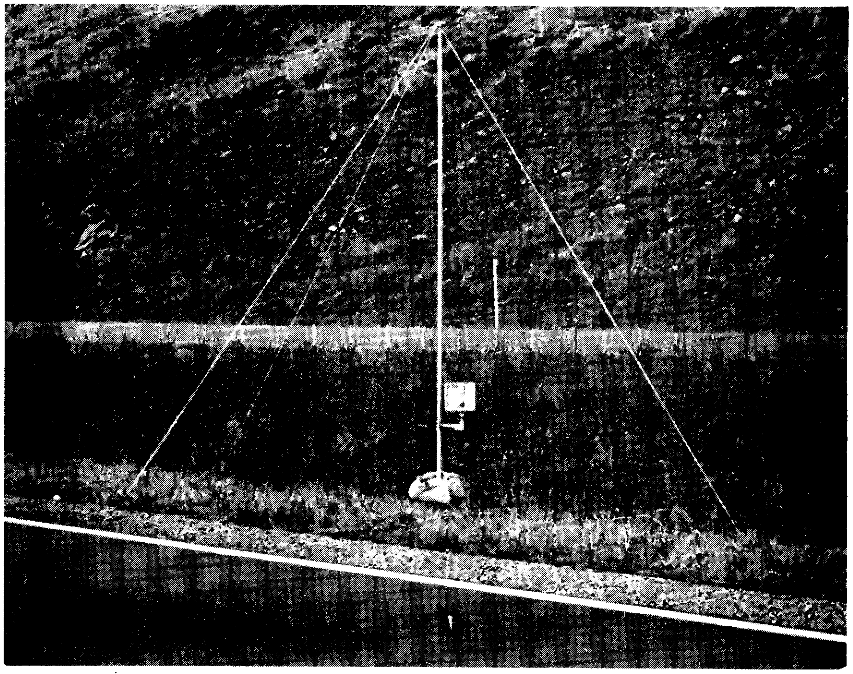

Figure 4. Low level light mounted by specially designed arm onto assembly consisting of 12-ft. (365.8 cm) pipe welded to automobile wheel, guy wires, and sand bags.

The pavement lights were tested first with the spacings and intensities being varied; then the low level lights were tested with heights and spacings being varied. When these optimums were determined, the lights were tested together. The testing was cut short by the opening of I-64 in December 1972.

From the testing it was determined that the pavement inset lights did an excellent job in delineating the road in the heaviest of fogs. It was also determined that varying intensities were needed for different fog conditions, and that intensities had to be lower for night conditions than during daylight. Spacings between 50 ft. and 300 ft. (15.2 m and 91.4 m) were tested. The closer spacings obviously give the best pattern, but when considering the cost of an installation, economics have to be considered.

The low level lights increased visibility, but a problem with glare was encountered, and the question of how to adequately protect the lights from damage was not solved.

Semipermanent Test Section

The author met with representatives of the Virginia Department of Highways and Transportation's Maintenance and Equipment Divisions and the Research Council to discuss the findings and to make a decision as to what further research, if any, was to be pursued. The recommendation was made to construct a semipermanent 1/2-mile (.8 km) installation of the pavement inset lights on the traveled portion of the eastbound lanes of I-64 on Afton Mountain from milepost 27.90 to milepost 28.40. The group recommended that the lights be installed on both edges of the road in line with the edge line markings. The semipermanent experimental section was essential before a decision could be made on whether to install the lights over the breadth of the Mountain. There were several reasons for this recommendation. The motoring public had not been exposed to the lights, and therefore the degree to which they would be accepted was a matter of speculation. Also it was realized that a sufficient amount of testing had not been performed to permit certainty as to the best spacings between lights; so, three spacings were recommended, 100, 200, and 250 ft. (30.5 m, 61.0 m, and 76.2 m). Further work on intensities was also necessary. For a permanent installation across the entire Mountain, an automatic fog sensing device would be a necessity to actuate the lights; so this had to be tested. All of the facts indicated that this more permanent test facility would be necessary to gain information essential for a decision about constructing a larger installation.

It was also recommended that testing of the low level lights be continued on a secondary road in the vicinity, but that they not be installed on I-64.

The 1/2-mile (.8 km) section of pavement inset lights was completed in March 1973. It consisted of 30 lights with three spacing patterns as follows:

1. A 500-ft (152.4 m) section with lights spaced 100 ft. (30.5 m) on centers;
2. a 1,400-ft. (426.7 m) section with lights spaced 200 ft. (61.0 m) on centers; and,
3. a 750-ft. (228.6 m) section with lights spaced 250 ft. (76.2 m) apart.

The light system was triggered by a fog-sensing device that set the daylight intensity of the lighting at 30% of the maximum of the unit with an output of 2,250 candelas and a hot spot of 3,600 candelas. For night lighting, where contrast is greater, the intensity setting was 10% of maximum, which produces an output of 750 candelas with a hot spot of 1,200 candelas. At the 30% setting, the light burns at 124-watts, and at the 10% setting at 84-watts. The system provided the potential for adjustments of the intensity.

The installation was made by state forces for an approximate cost of $15,000. After completion of construction, a subjective evaluation was performed between April and September 1973, in which information on motorists' reactions to the lights was obtained from various groups of individuals through the use of personal interviews and mailed questionnaires. In addition, a close check was kept on the equipment. The fog detector proved completely reliable and never failed to operate properly and the lights performed adequately with only a few bulbs needing replacement. The conclusions are given below.

1. The pavement inset lights clearly outlined a traffic pattern or channel to follow, in the opinion of approximately 66% of the motorists who responded to the questionnaire. An additional 33% thought the lights aided by outlining the road edges, although they did not think the lights produced a visual pattern to follow. (This information was to prove valuable at a later date.)

2. The lights did not cause a prohibitive glare, and with a more sensitive control system the glare could be almost completely eliminated.

3. The lights were effective in reducing driver anxiety and, to some degree, produced a feeling of security.

4. It was thought that perhaps the lights would produce a silhouette effect on cars ahead in the traffic stream. This was not the case, as only 25% of the motorists reported seeing cars outlined by the lights.[6]

The response to the lights was extremely positive and this fact along with other test results led to a decision to install the pavement inset lights over the full breadth of Afton Mountain, a distance of 5.8 miles (9.3 km).

INSTALLATION DESIGN AND CONSTRUCTION

To avoid repetition, the descriptions of the design and construction of the project have been combined in the following narrative.

The light system was designed by a committee made up of representatives of the Department's Equipment, Purchasing, Construction, Traffic and Safety, Maintenance, and Location and Design Divisions, its Staunton District, and the Research Council, as well as representatives from equipment manufacturers. The first task of the committee was to determine the boundaries of the system and whether it should be divided into sections. From the beginning of the experimentation, data had been collected on fog patterns and the extent of the fog. With these data, reinforced by information gained in discussions with construction personnel who had been on the Mountain during the construction of I-64, it was determined that a system of lights 5.819 miles (9.31 km) in length was necessary. It was also determined that fog often occurred in patterns such that the entire length of the lights need not be on at all times. Study of the fog patterns indicated that the system could be effectively divided into three sections: one large section on top of the Mountain, where low-lying clouds often engulf the Mountain and fog in general is heaviest, and two shorter sections, one on each side of the Mountain. The sections were to be contiguous and to be controlled separately by automatic fog detecting devices which would set the lights at the necessary levels of brightness. Portions of the system were located in the three counties of Augusta, Nelson, and Albemarle. Figure 5 shows the sectioning of the system.

With the length of the project, the sectioning, and the method of actuating the lights having been established, the actual design of the project began.

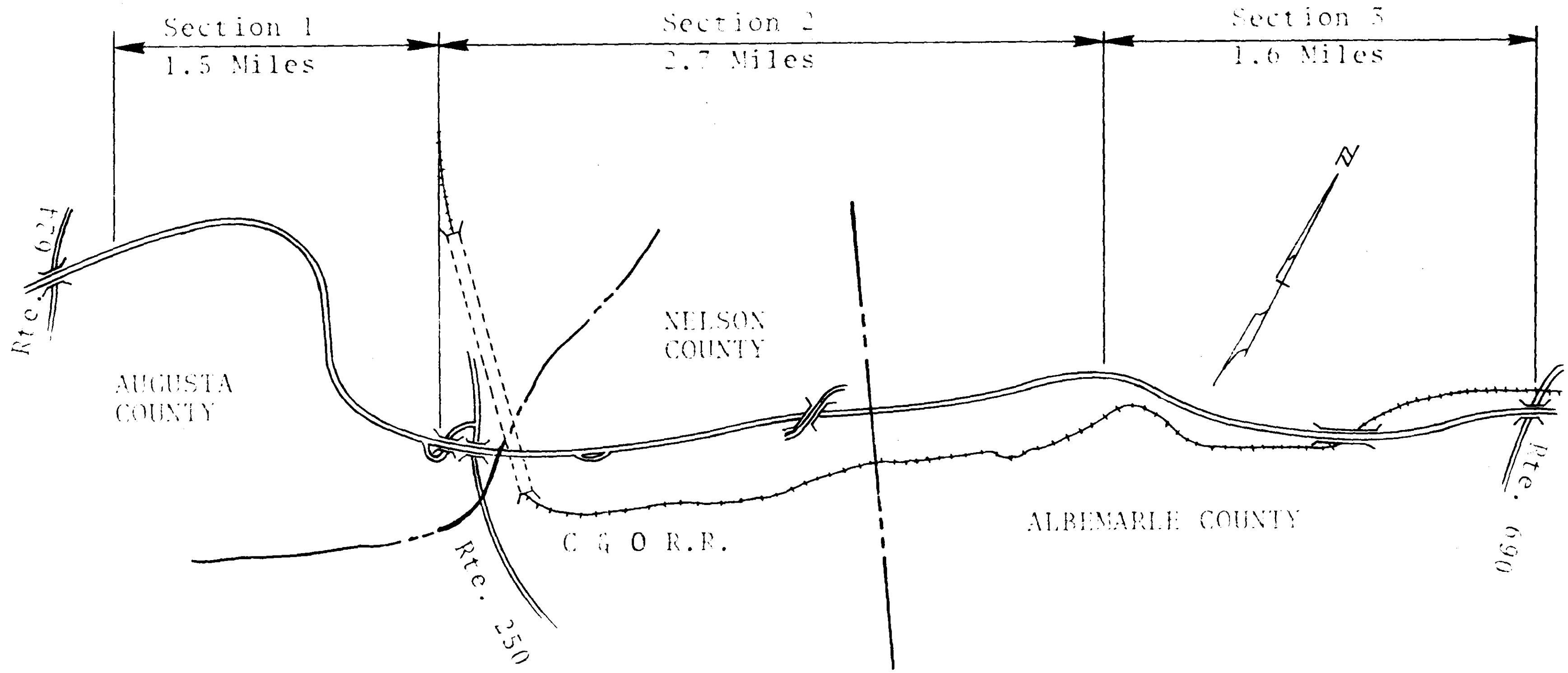

Figure 5. Site location– Interstate 64, Afton Mountain.
Note: 1 mi. = 1.6 km.

First consideration was given to the electrical circuitry and its component parts. The number of lights and length of each circuit were controlled by the capacity of a constant current regulator. The regulators selected for this project were designed to produce 2,300 volts with a maximum current output of 20.3 amperes and a minimum of 8.5 amperes. This output by the regulator is stepped down by the individual transformer at each light to 30 volts constant, with the current in a range from 6.6. to 2.8 amperes depending upon the brightness requirements of the lights due to the ambient conditions. The current coming from the regulator is reduced in a 3 to 1 ratio.

The system was designed to have seven electrical circuits as shown in Figure 6. Circuits 1-6 were designed to be powered by 30-kilowatt regulators and circuit 7 by a 50-kilowatt regulator. From Figure 6 it may be noted that there are three circuits in section 1; three in section 2; and one in section 3. This particular configuration of circuitry was selected for convenience. This figure also shows the number of lights in each circuit.

The system was designed to have lights spaced at intervals of 100 ft. (30.48 m) on curved sections and 200 ft.(60.96 m) on tangent sections in both edge lines. The design included aiming the lights so they would converge at a point 200 ft. (60.96 m) up the road. The need for this aiming was realized on the test section when it was observed that considerable light was lost off the edge of the road. As previously mentioned, the lights point toward the oncoming driver. Section 1 was to be controlled by two automatic fog detectors, section 2 by three detectors, and section 3 by one detector. The detectors were to be set to sense five levels of fog. The detectors are backscatter devices that contain their own source of light and measure the amount of light reflected into their sensors. One of the major reasons for the selection of the type being used was its reliability. Figure 7 is a wiring diagram of circuit 3. The other six circuits are essentially the same.

The electrical circuits were designed to be carried in polyvinyl chloride conduit, except for three special cases where metal conduit was used. Table 1 gives summary information on the conduit used on the project. The table contains the types of conduit, the sizes, the quantity, the outside and inside diameters, the thickness of the wall, the minimum crushing strength, the class, and a column headed remarks. The remarks section includes information on where the conduit was used. Obtaining the conduit was one of the big holdups of the project, which resulted in a shutdown of 49 days at the beginning of construction. When the specified grade could not be obtained, the specifications were waived and the installation altered as described in the note to Table 1.

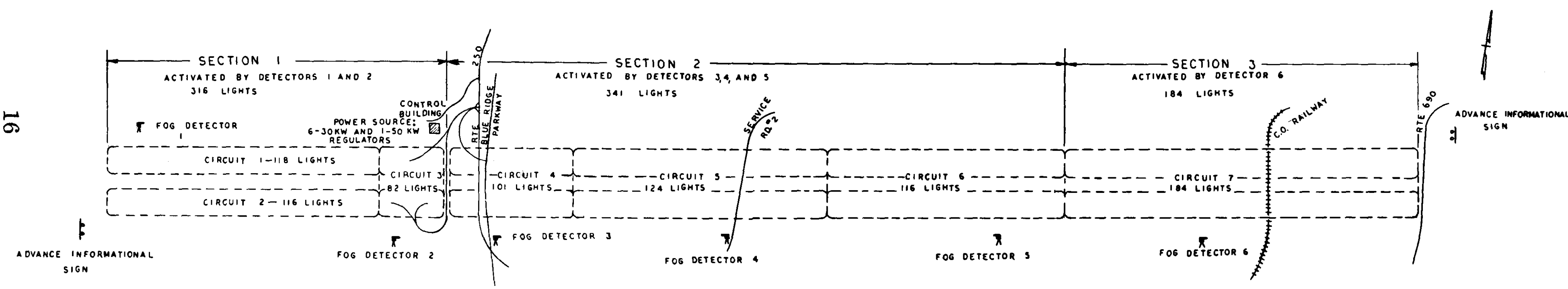

Figure 6. Circuitry and components of system.

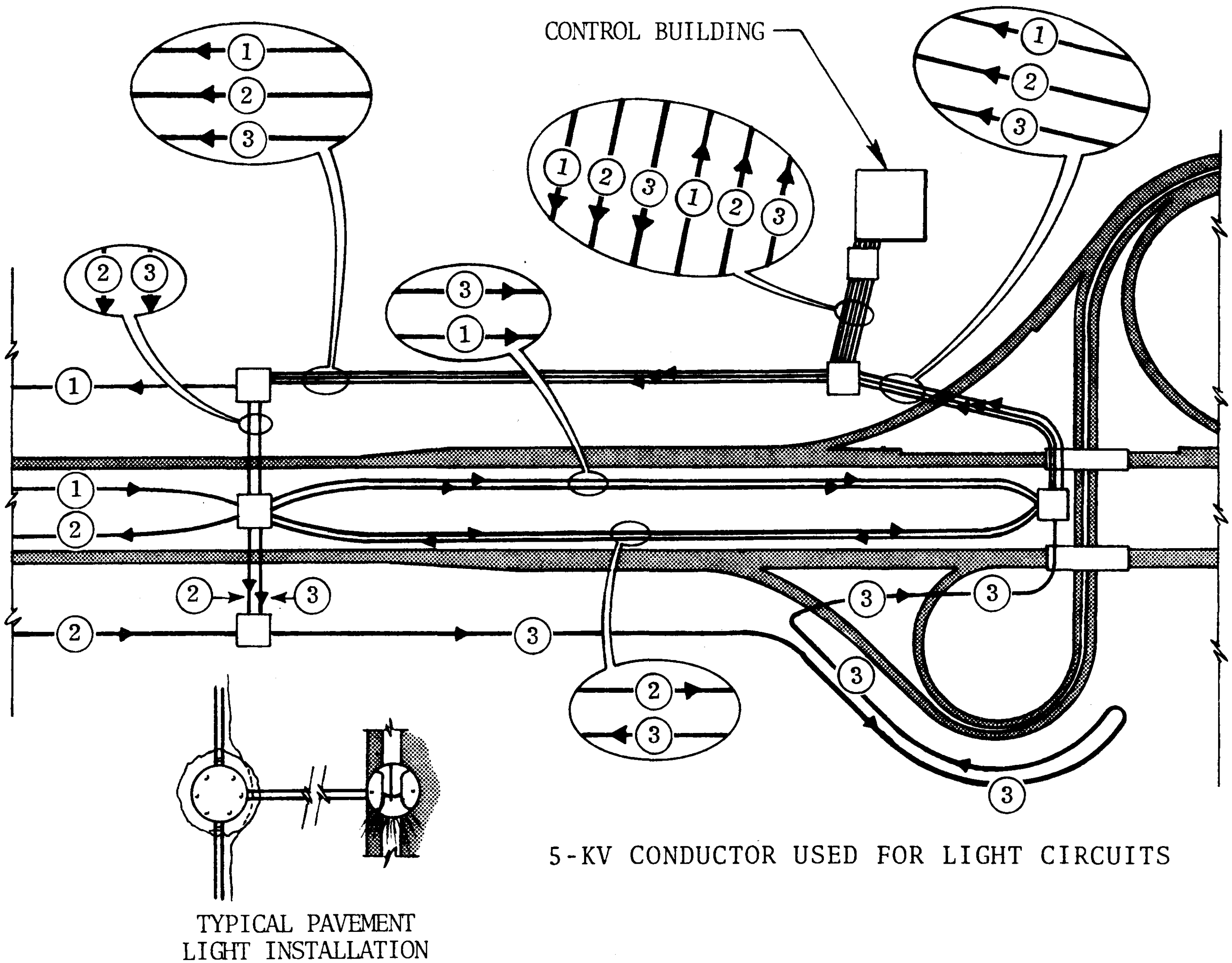

Figure 7. Wiring diagram for circuit 3 with inset showing wiring to light.

Table 1. Summary data on conduit.

TYPE	SIZE	LINEAR FEET USED ON PROJECT	O.D.	MIN. I.D.	MIN. WALL	MINIMUM CRUSHING STRENGTH P.S.I.	CLASS	REMARKS
P.V.C.	1"	10,849	1.315	1.000	.060	300	*Thin wall DB (Direct Burial)	Used to carry conductors between bypass transformer located in transformer housings to pavement light located in edge of pavement.
P.V.C.	2"	140,689	2.375	2.000	.100	450	*Thin wall DB (Direct Burial)	Used to carry conductors for roadway lights, signs, and fog detectors.
P.V.C.	3"	636	3.500	3.000	.216	1,000	Heavywall	Used to carry conductors from control building to low level lights.
P.V.C.	4"	17,217	4.500	4.000	.237	900	Heavywall	Used to carry conductors for roadway lights, signs, and detectors.
Galvanized metal	1"	308	1.315	1.049	0.133	---	Electrical	Used to carry conductors to low level lights on exposed concrete median lt Ramp 'C'; to signs from junction boxes and raceways in control building.
Galvanized metal	2"	270	2.375	2.067	0.154	---	Electrical	Used to carry conductors under bridge structures, to sign from junction boxes and raceways in control building.
Galvanized metal	1 1/4"	129	1.660	1.380	0.140	---	Electrical	Used to carry telephone service to control bldg.

*The Virginia Department of Highways and Transportation Road and Bridge Specifications required P.V.C. conforming to Federal Specification W.C.– 1094, TYPE I. Due to the difficulty encountered in securing P.V.C. conduit to meet these specifications and in order to expedite the project, the following changes were made: (1) Use 1" type DB conduit, which conforms to the requirements of the spefications, (2) Use 2" type DB conduit with the specifications waived, (3) Use 3" and 4" type heavy wall, which conforms to the requirements of the specifications.

The 2", 3", and 4" P.V.C. is installed at an 18" depth in lieu of the 14" depth as specified, with no additional cost to the Virginia Department of Highways & Transportation.

Note: 1" = 2.54 cm; 1' = 0.30 m; 1 psi = 6,895 Pa.

Where conduit had to go under the roadway, it was placed in metal pipe sleeves to protect it and the electrical wiring inside it. These pipe sleeves, for which summary information is given in Table 2, were installed in holes bored under the road.

Nine types of electrical conductors were used as listed in Table 3. The #2 and #8 wires were used in the high voltage circuits carrying power to the signs and pavement lights. The balance of the wiring was either signal cable or types used to supply power to the low voltage equipment.

An idea of the magnitude of the project is given by the fact that the total length of wiring used, excluding ground wire, was 376,721 ft. (114.82 km), or 71.35 miles. In addition, 130,681 ft. (39.83 km) of copper ground wire was used. It was connected to all pavement lights, transformer cans, junction boxes, and fog detectors, making a complete loop of the project.

Control and electrical junction boxes were designed into the system. Both types are 3 ft. 8 in.(1.12 m) in length, 2 ft. 2 in.(.67 m) wide, and 3 ft. 3 in.(.99 m) in depth. Each box has a two-piece galvanized cast iron cover with lettering designating whether it is a control junction box or an electrical junction box. The boxes were designed with inserts so the needed number of cable racks could be attached. A total of 186 control junction boxes are spaced approximately 200 ft.(61 m) apart in the control lines. As can be noted in Table 3, the control junction box contains #10 cable for the fog detector and #16 shielded cable for the signs. It could also be used as a pull or splice box. Sixty-five electrical junction boxes were located where required for splices and pulling the high voltage conductors. These boxes contain the 5-kilovolt #8 conductors to each pavement light circuit and the 5-kilovolt #2 conductors to various sign locations.

Each pavement light has a transformer, protected with a metal can (housing). These cans, buried behind the guardrails, served as pull boxes. The Department, anticipating that someday the distance between lights might need to be changed, instructed the designers to include transformer cans at the midpoints between lights.

A section of low level lights was designed for entrance ramps A and D as shown in Figure 8. The lights are under the guardrail and are protected by a chain link fence in front. The lights are installed three to a circuit, and if damaged, only the lights in the damaged circuit will go out. They are controlled by fog detectors in the vicinity of the ramp and burn at 500 watts. Each light has a louvre to dampen the effect of glare. They are spaced 20 ft. (6.1 m) center to center on the left-hand side of the entrance ramp up to the vicinity of the gore area, where they are spaced on 10-ft. (3 m) centers on both sides. In the gore, raised markers are installed in the pavement. The electric current for these lights is 110-120-volt, 60-cycle alternating current. This small section of low level lights is considered to be experimental.

The building housing the electrical control equipment is of brick and cinderblock construction with a concrete floor. It measures 24 ft. x 36 ft. (7.3 m x 10.9 m), and is partitioned into areas 24 ft. x 12 ft. (7.3 m x 3.7 m) and 24 ft. x 24 ft. (7.3 m x 7.3 m). The larger area houses the primary high voltage equipment consisting of seven regulators, a master oil switch, and a bus bar system in the ceiling. The smaller room contains the master control and low voltage equipment. The building temperature is thermostatically controlled. It is cooled by a special exhaust fan system in the roof and is electrically heated.

Table 2. Summary data on pipe sleeves.
Note: 1" = 2.54 cm.

Size	Linear Feet Used On Project	Method of Installation	Ft. Inches Of Boring	Remarks
12"	266.2	Bored	3,194	Used to carry conduit lines under roadway at: (1) Ramps C & D, (2) Rte. 250, (3) Overlook off Ramp, (4) Overlook on Ramp.
6"	49.0	Bored	294	Used to carry conduit lines under roadway WBL.
*4"	1,030.3	Bored	3,833	Used to carry conduit lines under roadway for: ends of lighting circuits, sign locations, and detector locations.
*2"	1,176.4	Bored	1,859	Used to carry 1" P.V.C. conduit from Type II transformer cans to roadway pavement lights on entrance and exit ramps.

*Part of 2 in. and 4 in. sleeves were installed by open cutting where possible.

Table 3. Summary data on electrical conductors.

Type and Size AWG	Number of Strands	Nominal Diameter Inches	Insulation Thickness	Construction	Linear Feet Used On Project	Remarks
#2 (5 kv)	7	.53	110 mils	Annealed copper with crosslinked polyethylene (XLP) insulation	46,670	Used to supply power to the "Advance Informational Signs" and the 16 variable speed signs to be installed after further evaluations. Comes directly off the bus bar system.
#8 (5 kv)	19	.38	110 mils	Annealed tinned copper with crosslinked polyethylene (XLP) insulation	202,287	Used to supply power to roadway pavement lights coming from a constant current regulator that is fed off the bus bar system.
#10 cable (12 conductor) 600 volts	19 per conductor	.87 per cable	.02 inch per conductor	Annealed copper with P.V.C. insulation	53,674	Used to supply power to the 6 fog detectors located throughout the project and to return the signal from the detectors to the alarm unit of the control building.
#16 Shielded Cable (2 conductor)	26/30	.240 per cable	.016 inch	Tinned copper with polyvinychloride P.V.C. insulation	36,238	Used to carry signal from control equipment to the 2 Advance Information Signs and variable speed signs.
#6 THHN (600 volts)	19	.26	.035 inch	Copper with vinyl insulation and nylon jacket	2,823	Used to supply power to low level lights and bridge mounted sign on Blue Ridge Parkway bridge.
#10 THHN (600 volts)	19	.17	.024 inch	Copper with vinyl insulation and nylon jacket	2,185	Used to supply power to low level lights.
#12 THHN (600 volts)	19	.13	.019 inch	Copper with vinyl insulation and nylon jacket	3,534	Used to supply power to individual circuits of low level lights; runs from bypass transformer on the secondary side to each pavement light. Used in wiring of control building.
#2 XHHW	7	.39	45 mils	Copper with crosslinked polyethylene (XLP) insulation	11,082	Used to supply power to low level lights from control building to left ramp 'D'.
#4 XHHW	7	.33	45 mils	Copper with crosslinked polyethylene (XLP) insulation	18,228	Used to supply power to low level lights from control building to left ramp 'D'.

Note: 1 mil = 2.54×10^{-3} cm; 1" = 2.54 cm; 1' = 0.30 m.

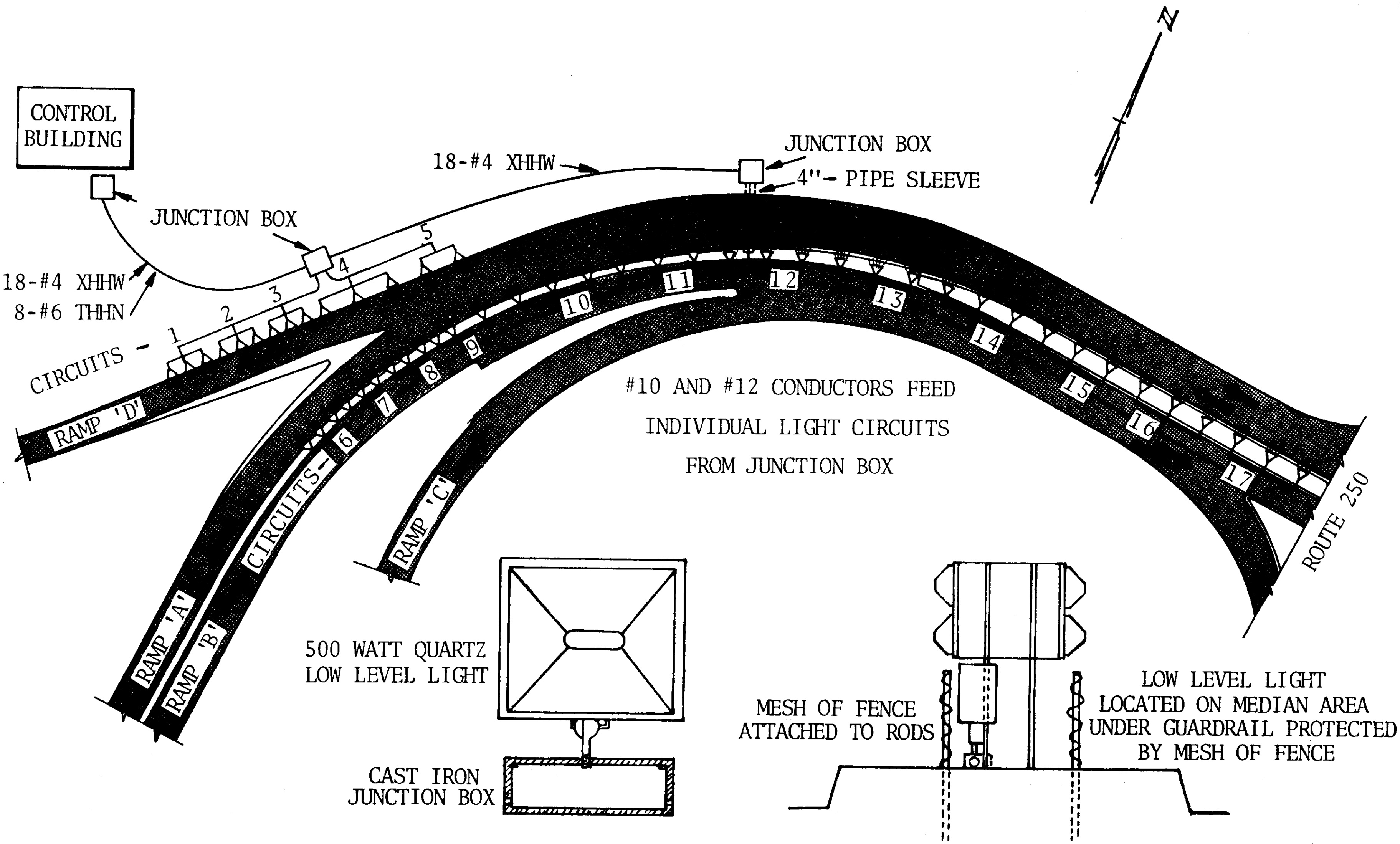

Figure 8. Circuitry and layout of low level lights on entrance ramps'A'and'D'at the Afton interchange.
Note: 1" - 2.54 cm.

The control equipment consists primarily of switching and amplifying apparatus. It receives the signal from the fog detectors and switches on the light sections at the correct intensity levels. A console provides indications as to whether the equipment is functioning properly. The control equipment is capable of adjusting the intensity of the light to five levels of fog. Included in the system are strip chart recorders to record the fog density as read by the detectors. Figure 9 is a simplified schematic showing how the control equipment works. Figure 10 shows a layout of a control circuit, including the fog detectors, the electrical wiring, and the sign.

Additional features designed into the system were circuitry for the information signs at each end of the project advising motorists of the upcoming pavement lights, circuitry for 8 pairs (16) of variable message speed signs, and a satellite information console to be located at the Staunton District office.

Specifications for the pavement inset light equipment were those used by the Federal Aviation Administration. Copies of these specifications may be obtained by writing the Virginia Highway and Transportation Research Council.

To expedite construction, the Department purchased the pavement lights, constant current regulators, transformers and transformer housings, low level lights, and fog detectors. The construction was let to contract with the contractor supplying all other equipment and the materials and labor.

The contract for construction, which stipulated a time limit of 180 calendar days, was awarded April 22, 1974, and the notice to proceed was issued May 13, 1974. Problems were encountered in obtaining the designated polyvinylchloride conduit and the contractor requested a shutdown. When the recommended conduit could not be obtained a lesser grade was approved and the burial depth was increased from 14 (356 mm) to 18 inches (457 mm). Trenching was done as shown in Figure 11 and the conduit was laid by direct burial. Refer to Table 1 for summary information on the conduit used on the project.

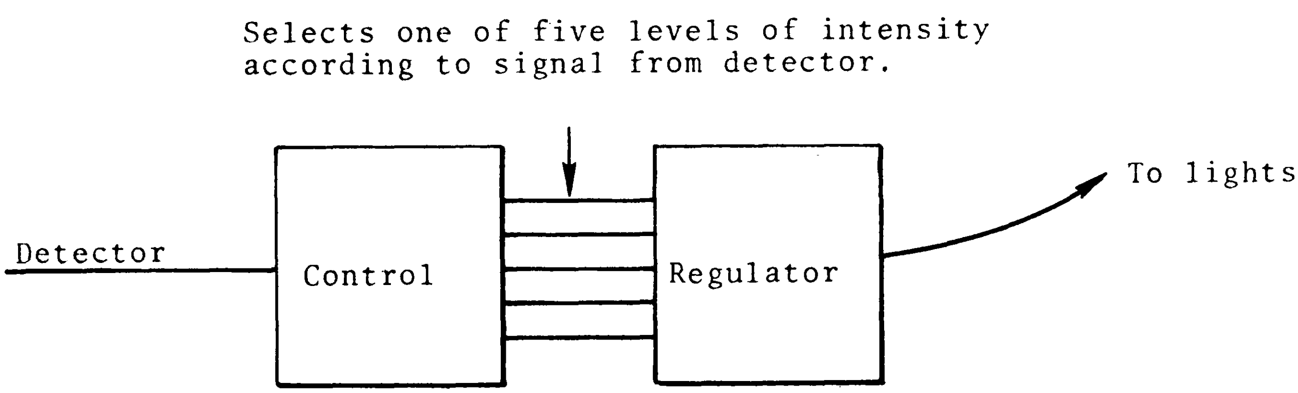

Figure 9. Simplified schematic of control equipment.

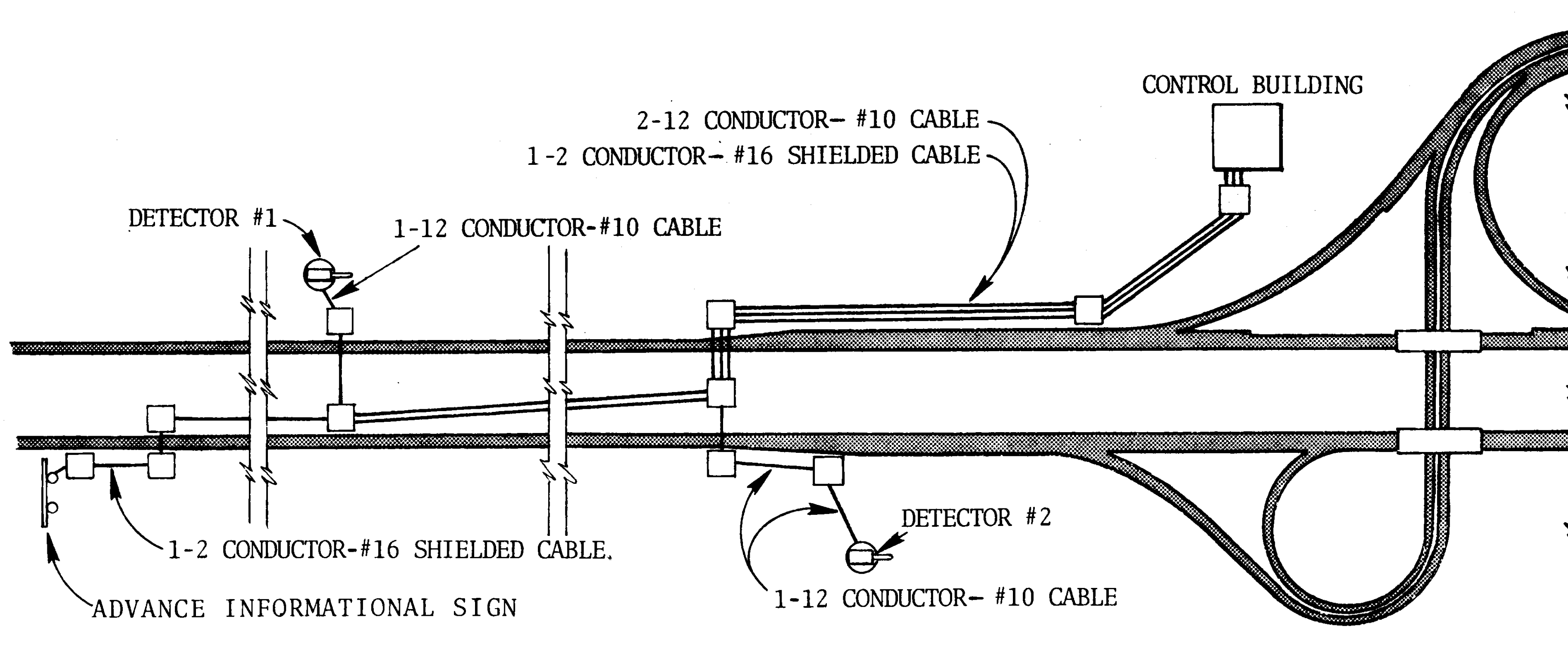

Figure 10. Typical layout of control circuits on Afton Mountain fog guidance system.

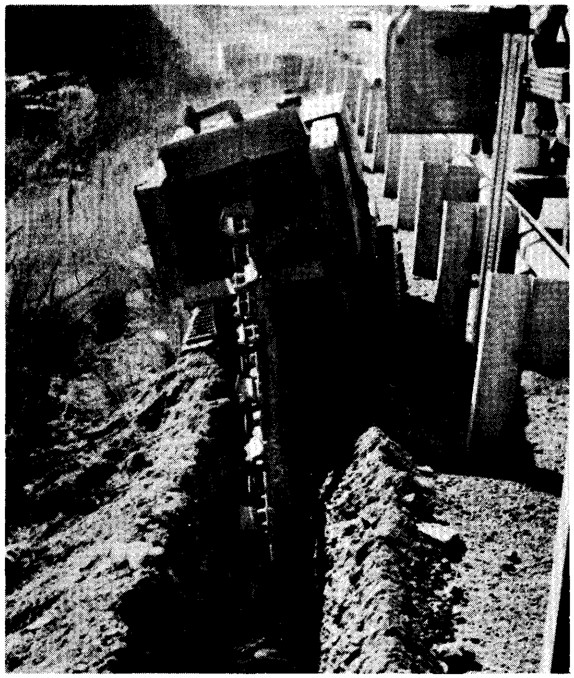

Figure 11. Trenching for placement of conduit. Trench depth was a minimum of 18 inches (457 mm).

The galvanized transformer housings (cans) measuring 12 in. (305 mm) in diameter and 13 in. (330 mm) in height and having a metal top secured by 6 bolts were installed in line with the conduit and were placed on 4 in. (102 mm) of porous material for drainage. The holes for the transformer cans were bored with an earth auger using a rock bit. Figure 12 shows the placement of the transformer housing and conduit within the trench. The smaller conduit to the left goes to the light. After the housings were placed and the conduit was attached, the trench was backfilled and compacted, and the hole around the housing was partially filled and compacted as shown in Figure 13. Concrete was then poured around the housing to stabilize and protect it. The trenching and laying of conduit progressed with no major problems, except that rock was encountered at a few places. This phase of construction was performed from the beginning of the project until it was approximately three-fourths finished, at which time the laying of conduit was completed.

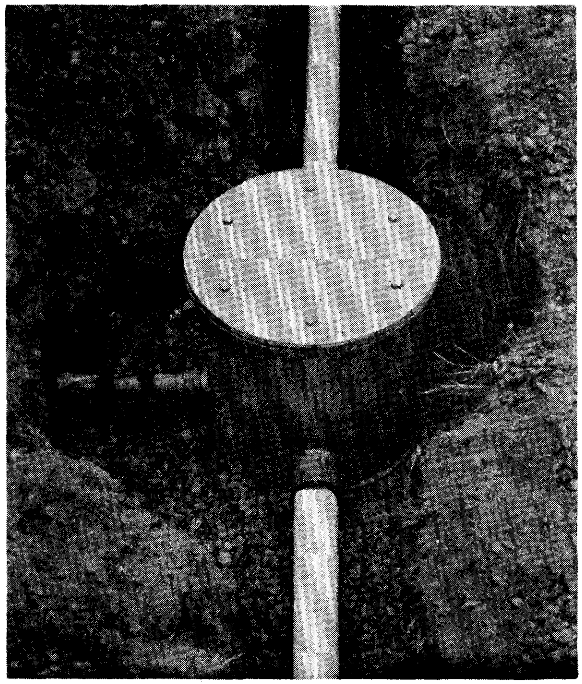

Figure 12. Transformer housing and conduit in trench.

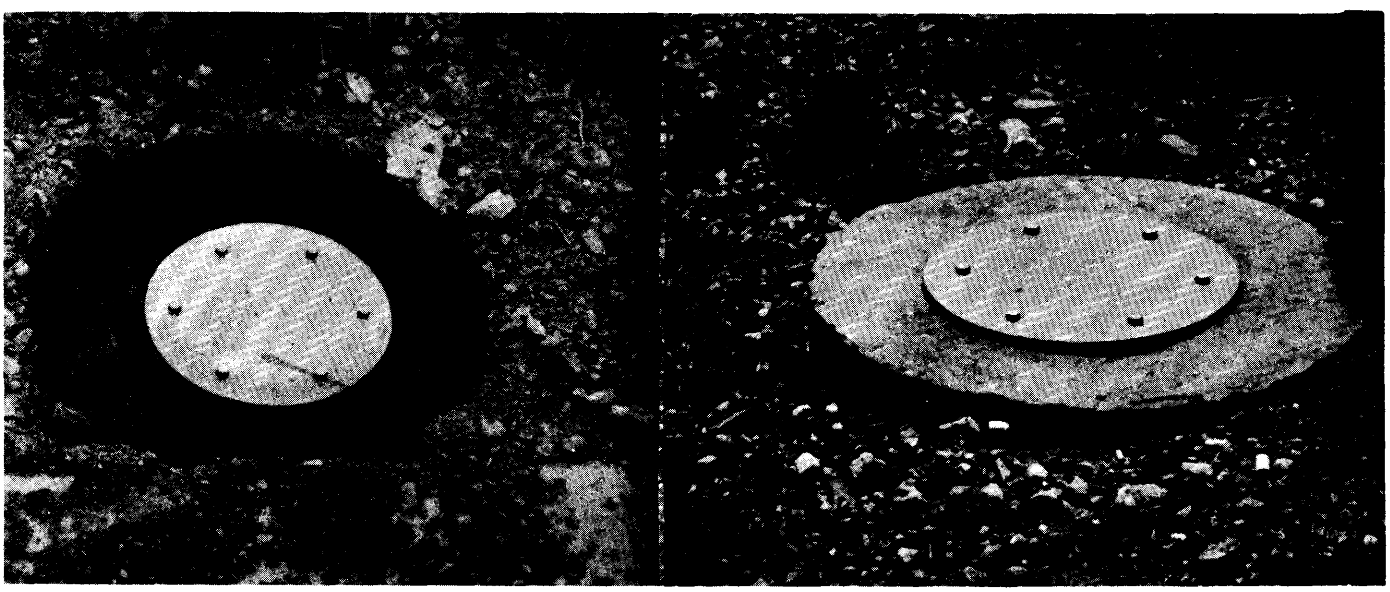

Figure 13. Transformer housing before and after concrete was poured.

Along with the conduit and transformers, 251 junction boxes were installed. Excavating for the boxes, which were in line with the conduit, was done with a rubber tired backhoe at a rate of about five boxes per day. The bottom of each hole was compacted with a tamper and hand leveled. A hole was dug in the bottom of the excavated area and filled with 2 $ft.^3$ of crushed stone for drainage. After the box was placed and leveled, the backfill material was brought up to just below the holes for the conduit. The conduit was brought into the box and cement grout was used to seal the spaces around it. After the grout cured, the area around the box was backfilled and compacted to within 1 in. (25.4 mm) of grade. A .75 in.(19 mm) diameter rod 10 ft.(3.0 m) in length was driven through the drainage materials into the underlying soil to serve as an electrical ground. A copper ground wire was attached to the rod and to the cast iron cover of the box. Figure 14 shows a junction box with the conduit grouted into place, and one after construction was completed. The conduit going around the junction box in left photo carried control cable.

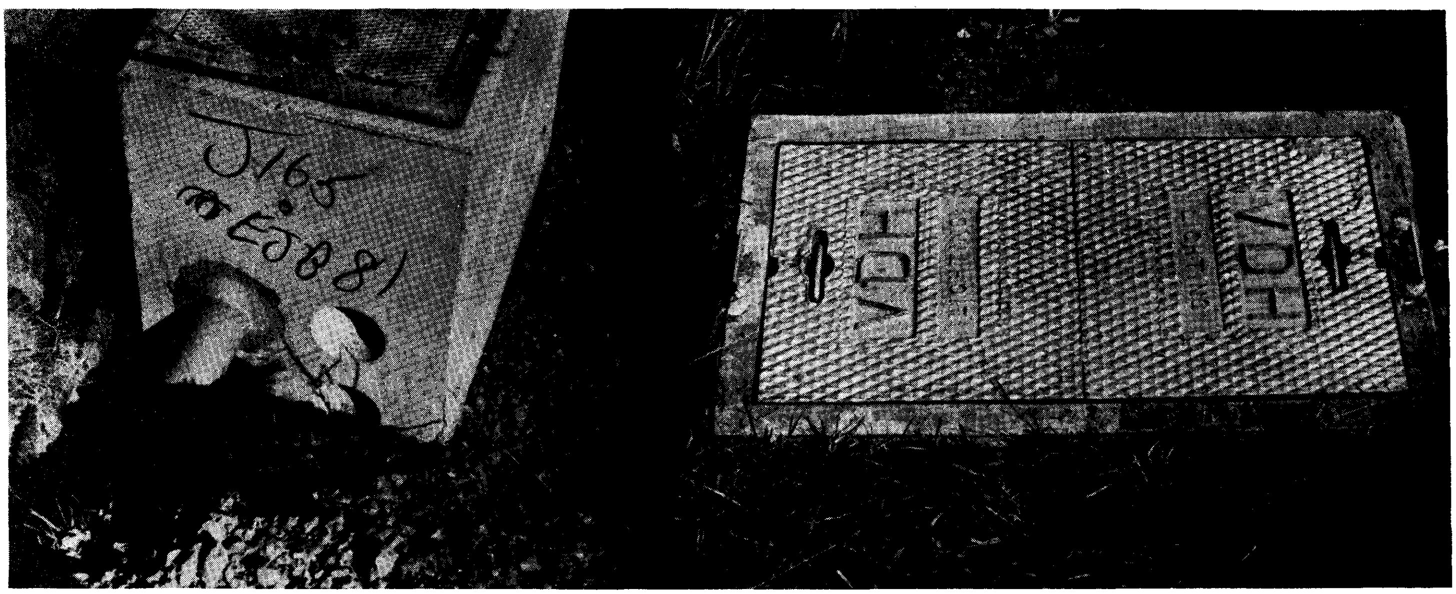

Figure 14. Electrical junction box during construction and after construction was completed.

Pipe sleeves were used to protect the conduits carrying electrical conductors under the road. The Department strongly discourages cutting pavement surfaces on the traveled way, so boring under the road was necessary. The largest size sleeve installed under the road was 12 in.(304.8 mm) in diameter and the smallest 2 in.(50.8 mm). This boring consumed a great amount of time and effort. Figure 15 shows the equipment employed to drill under the road and a pipe sleeve after installation.

Simultaneously with other construction on the project, the building for housing the control and electrical power equipment was constructed. The location of each piece of equipment to be housed in it was predetermined and conduit was placed accordingly. Figure 16 shows part of the conduit under the floor. The conduit used in the building was listed in Table 1. Since the building is of conventional construction, the construction procedures are not detailed here. Figure 17 shows the completed building, and Figure 18 shows some of the equipment. Construction took approximately two months and was done under a subcontract.

Also located in the power room are two master switches. One is a 2,400-volt master oil fuse switch that feeds high voltage current to the pavement lights through the bus bar system and constant current regulators. The second master switch supplies low voltage current to the equipment in the building, to the low level lights, bridge-mounted signs, and control equipment. Figure 19 shows these switches.

The smaller room contains the fog guidance light control system. The control equipment receives the signal from the fog detectors, determines the level of visibility the detector is monitoring, and sends a signal to the appropriate regulators, which switch on the correct section of lights at the desired intensity. During daylight, the equipment provides for five levels of intensity while at night, due to more contrast, three levels of intensity are provided. This is accomplished by a photoelectric cell that distinguishes between day and night. When more than one detector activates a section of lights, the control equipment selects the reading of the one recording the heaviest fog. A display panel provides an indication of what is happening throughout the system. The fog detectors are monitored with their levels of detection, the operation of the constant current regulators is indicated by on-off lights, and the operation of the variable speed signs will be indicated if they are installed. There are failure indicators as well as test switch circuits for each detection level from the fog detectors to test the operation of the equipment in the control room. A remote display panel in the Staunton District shop gives the same information as that in the control room. Figure 20 shows the master control equipment for the entire installation.

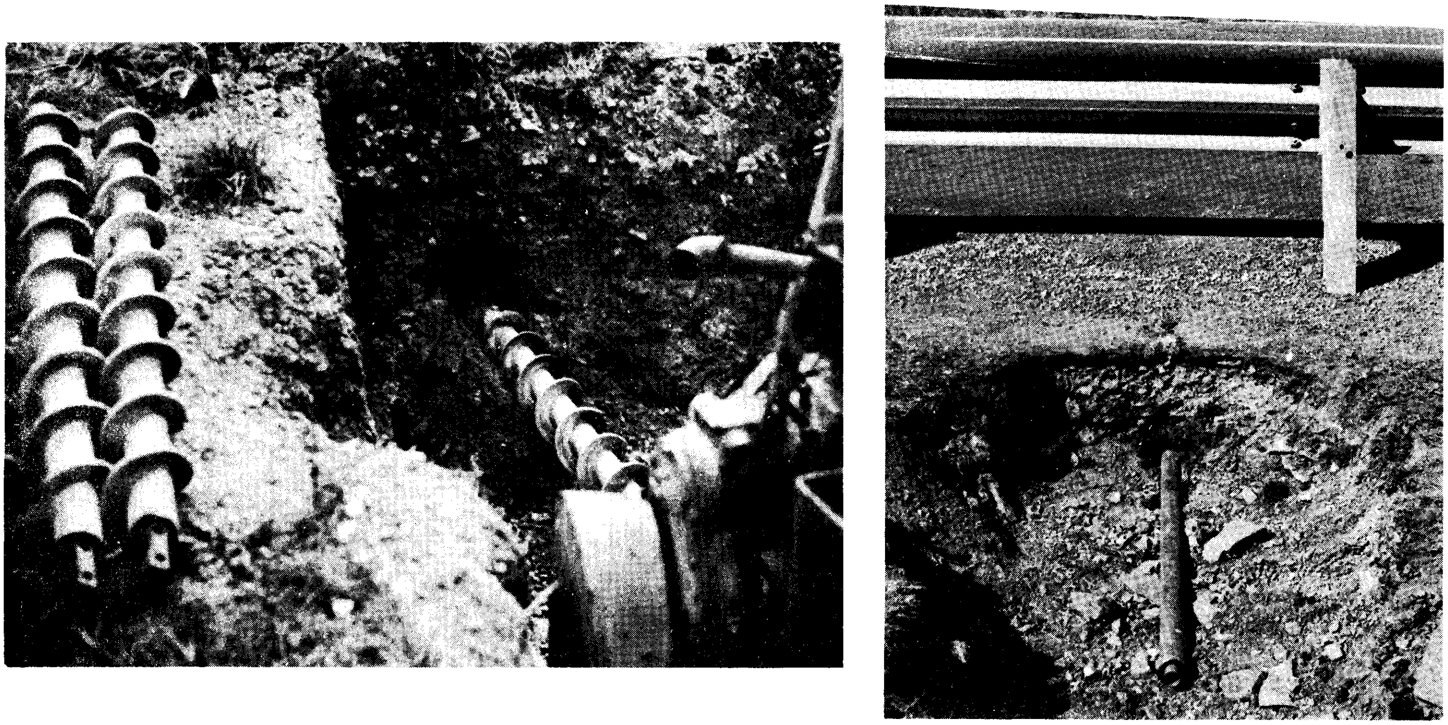

Figure 15. Equipment used to bore under the road and an installed pipe sleeve.

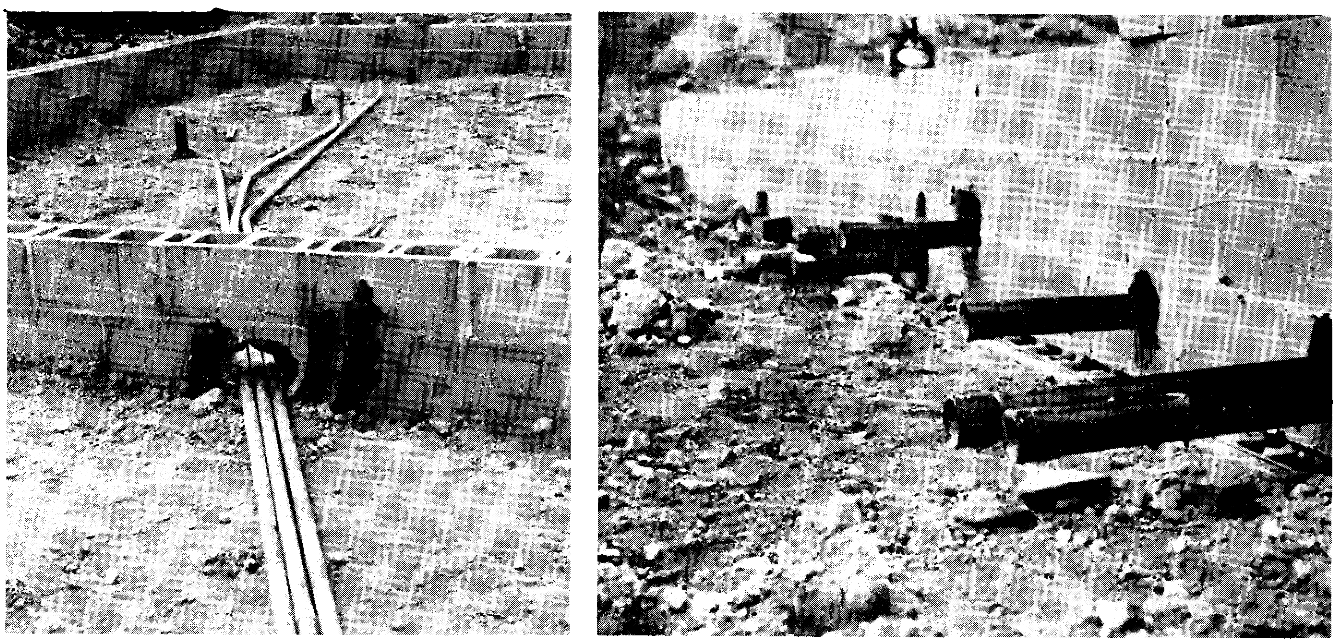

Figure 16. Part of conduit placed before concrete floor was poured.

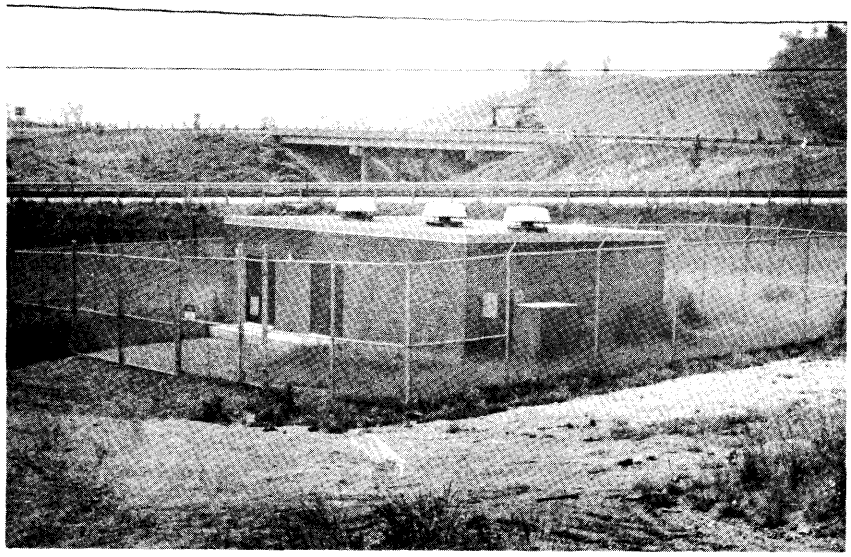

Figure 17. View of building. Note the three exhaust fans on top for cooling.

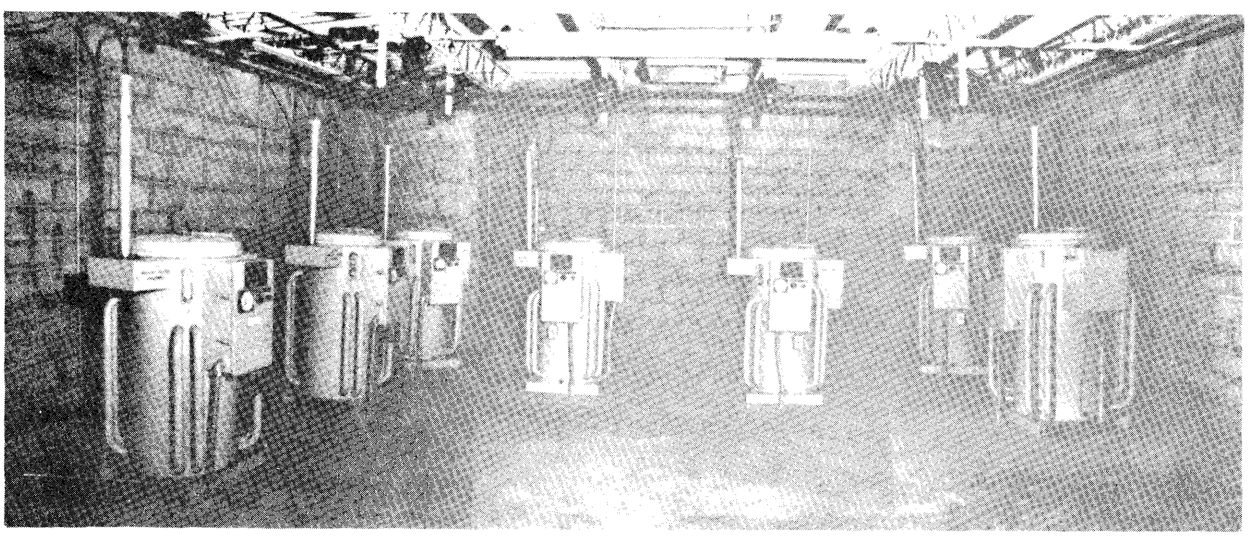

Figure 18. View of completed power room showing the seven constant current regulators and the overhead bus bar system.

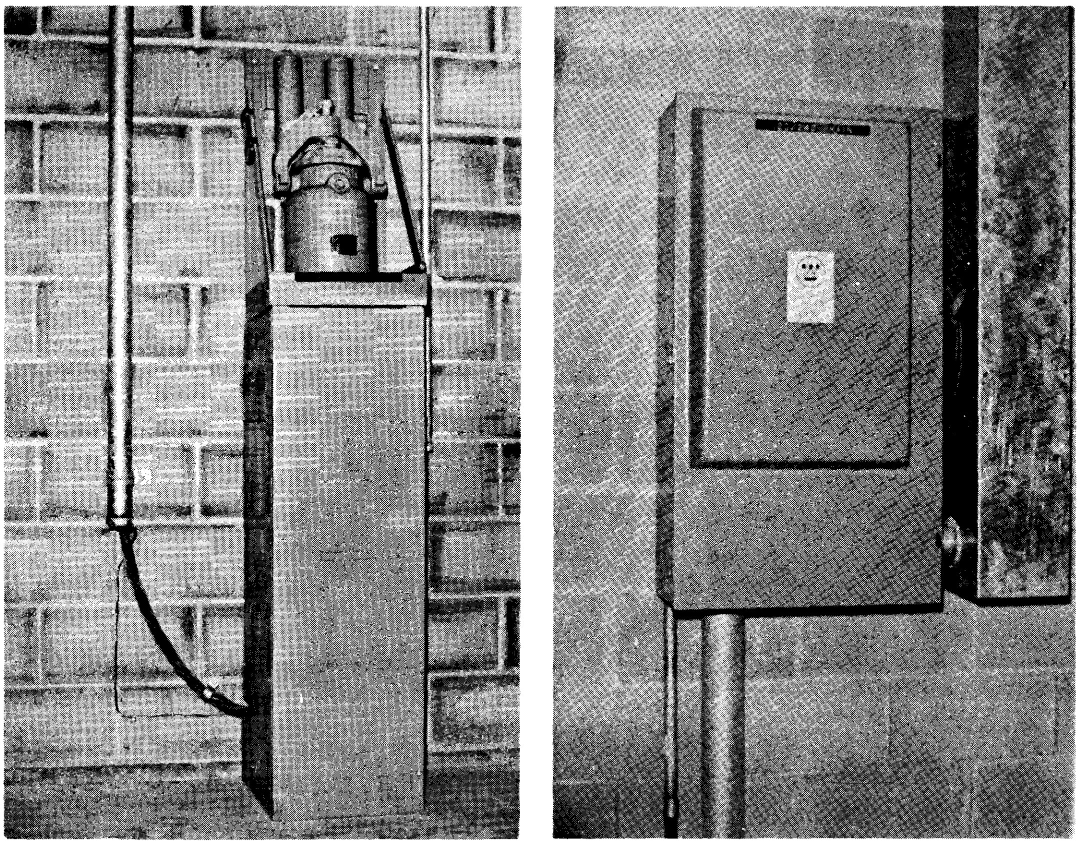

Figure 19. Master switches in the power room. High voltage oil switch on left and low voltage breaker on right.

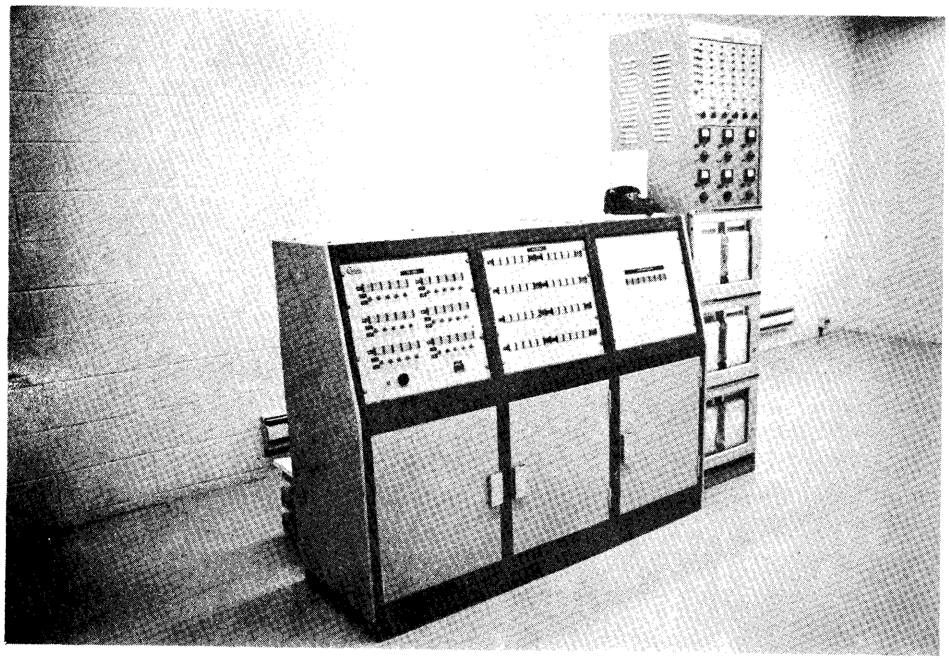

Figure 20. Master control for fog lighting system.

Installation of the pavement edge inset lights consumed a great quantity of time. There was one type of light but two types of transformer housings, referred to as Type I and Type II. The Type I housings are those located away from the lights and installed in line with the conduit; the Type II are installed under the light. The majority of the lights have the Type I housings, with only those lights installed in the acceleration and deceleration lanes having the second type. However, the installation of the lights on these lanes proved very difficult. The lights with their housings attached are 20 in. (508 mm) high, which required a much deeper hole in the pavement than is required for main line lights. Since the pavement could not be cut, and these lights were located out on the lane lines separating the acceleration and deceleration lanes from the main line traffic, boring under the roadway to the location of the lights had to be performed. It is impossible to be exact in boring under the road due to the deflection of the drill steel by rock or aggregate; so, the drilling was performed out to where the light should be placed, the sleeve was installed, and the pavement was then removed with a pavement breaker. A larger hole than necessary for the light had to be made to facilitate locating the end of the pipe sleeve. This usually required a hole approximately 24 in.(609.6 mm) in diameter. Concrete was placed in the bottom of the hole and the light base was placed on top of it and attached to the conduit. The hole was then filled with concrete, which was vibrated while the light was held in place. As could be expected, this operation was tremendously time-consuming. It took approximately four days to bore for the pipe sleeves, take out the pavement with a pavement breaker, install the light, and allow the concrete to cure. Figure 21 shows the light installed.

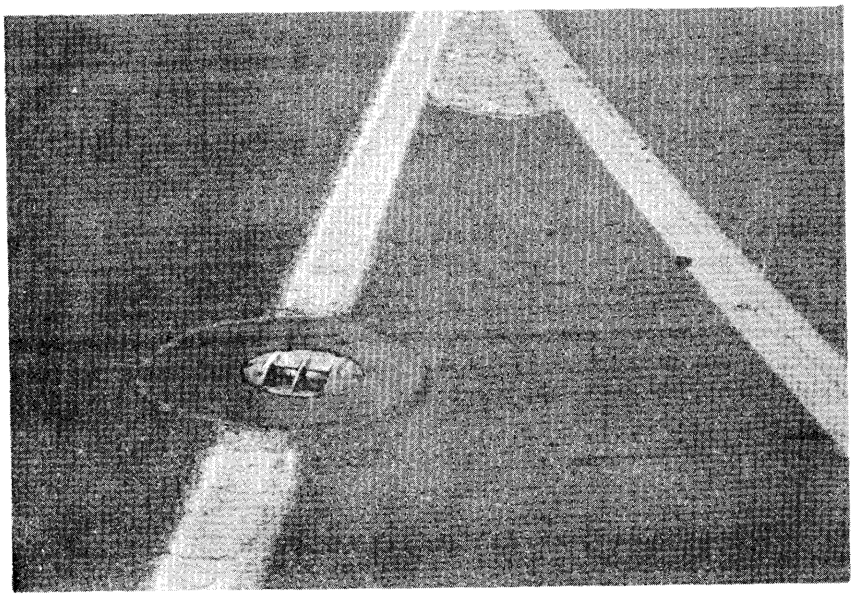

Figure 21. Light installed on acceleration lane.

The majority of the lights were located on the main line. Holes for these lights were punched with a modified pile driver. A hollow, circular steel die, 12.5 in.(317.5 mm) in diameter was driven at least 3.5 in.(90 mm) into the pavement to make a hole as shown in Figure 22. In most cases the plug came out when the die was removed; if this didn't happen, hand tools were used to remove it and even up the bottom.

After the hole was prepared, the light was suspended in a blanket of cold tar epoxy that was allowed to cure. If the light is properly installed and the epoxy grout is permitted to fully cure, the light will withstand snowplowing without being dislodged.

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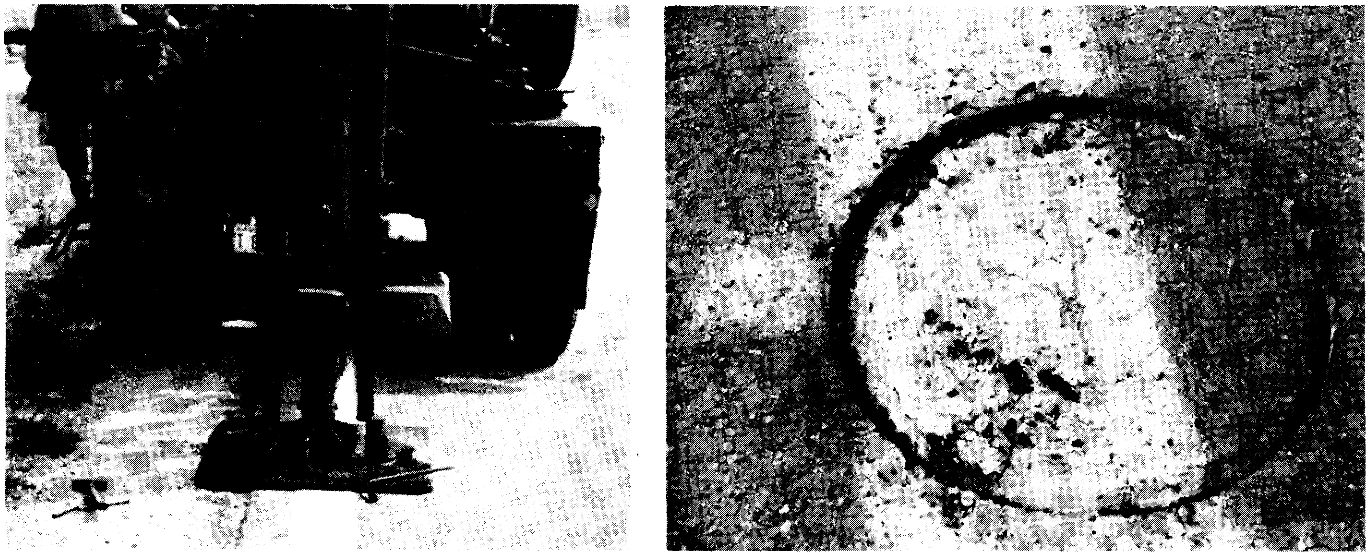

Figure 22. Equipment used to punch holes for light installation and the hole punched.

The lights on the main line were aimed to come to a point 200 ft.(61 m) distant on the centerline. This aiming, as previously mentioned, was to give a good target value to the motorist, and therefore give a clear road delineation, and to prevent the loss of light off the shoulder edge. Figure 23 shows the light being set and being aimed by the stringline method.

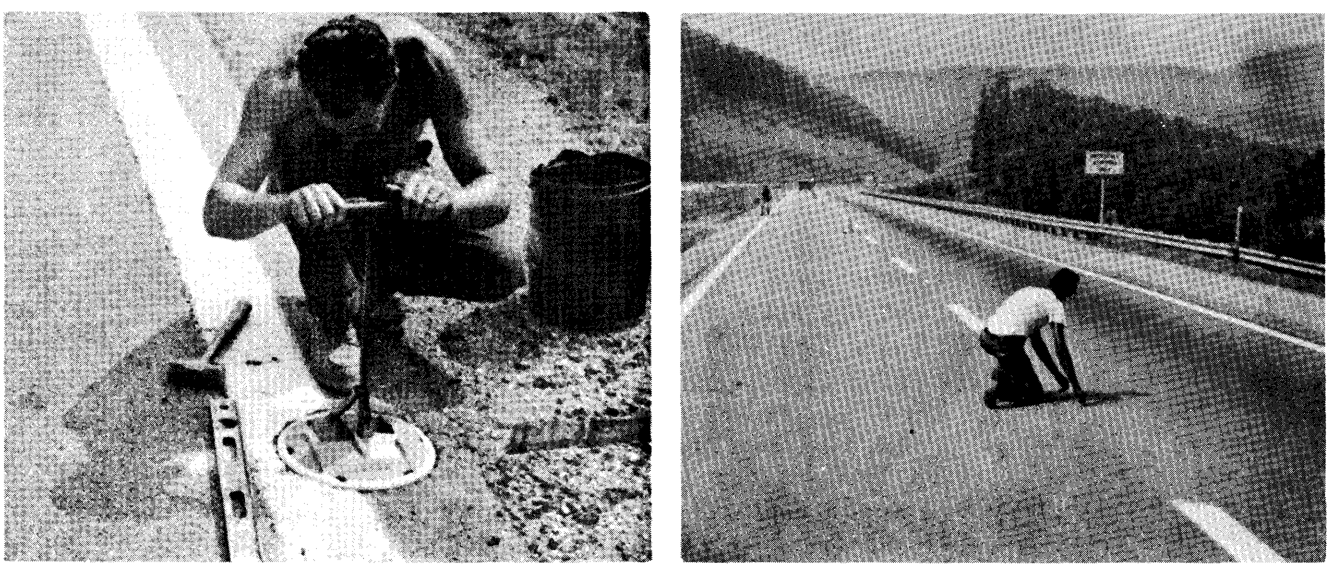

Figure 23. Pavement light being set and being aimed with a stringline.

In order to place the 1-in.(25.4 mm) conduit to the lights from the transformer housings located outside the shoulder, trenches approximately 5 in.(127 mm) wide and 4 in.(102 mm) deep were cut in the paved shoulders from each light using a pavement breaker. Figure 24 shows the trench being cut and the conduit placed in it. Note the ground wire running along the conduit from the light. After the installation was made, the trench was filled with S-5 bituminous plant mix.

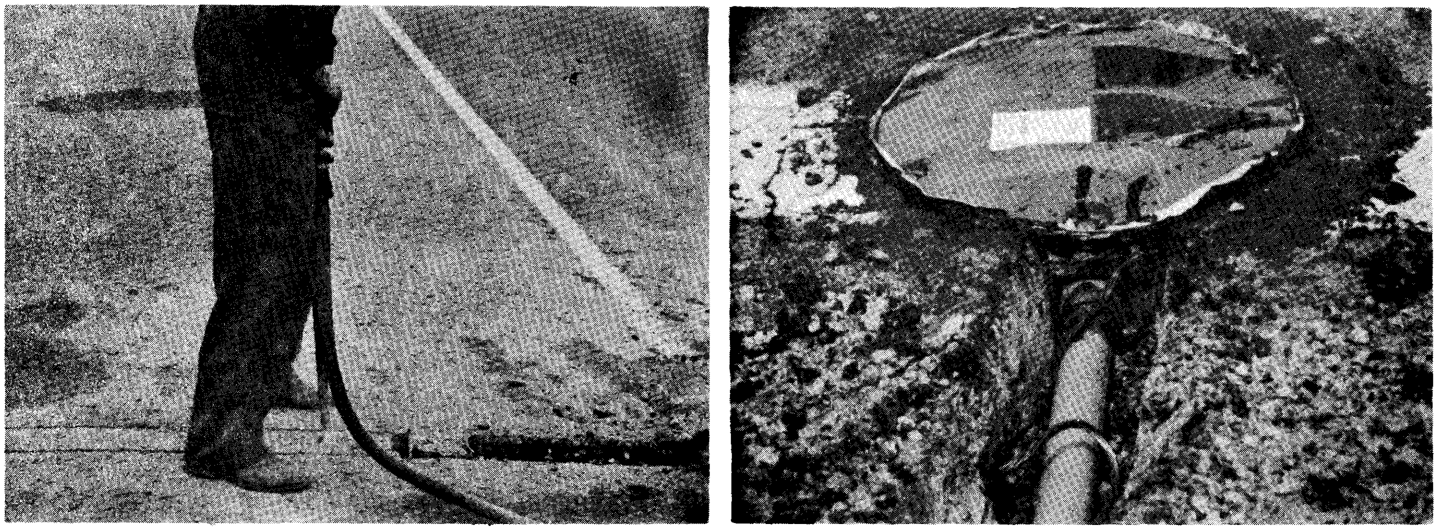

Figure 24. Cutting trench for conduit at left, conduit in trench at right.

The system of 50 low level lights was installed with three lights to a circuit, except that the one circuit in the gore area has only two lights. Referring to Figure 8, page 22, circuits 1-8 have the lights spaced 10 ft.(3.0 m) apart and circuits 10-17 have the lights spaced on 20 ft.(6.1 m) centers. All of the lights are perpendicular to the roadway and are installed behind the guardrail. From Figure 8 it may be noted that in the gore area the lights are installed on both sides of the road on 10 ft.(3.0 m) centers, because it is important that the gore be lighted as well as possible under heavy fog conditions. Since there was no way to protect the lights in the gore area, raised markers were installed in the pavement. The lights are actuated by fog detectors 2 and 3 on top of the Mountain.

The low level lights are installed below the guardrail on two types of surfaces; a concrete median and an aggregate surface. Each light has a junction box. On the concrete median the junction box rests on top of the median, and on the aggregate median it is set in concrete with its top flush with the surface. The lights are protected by a continous chain link fence. The installation of these lights took approximately three weeks. Figure 25 shows details of the construction and installation.

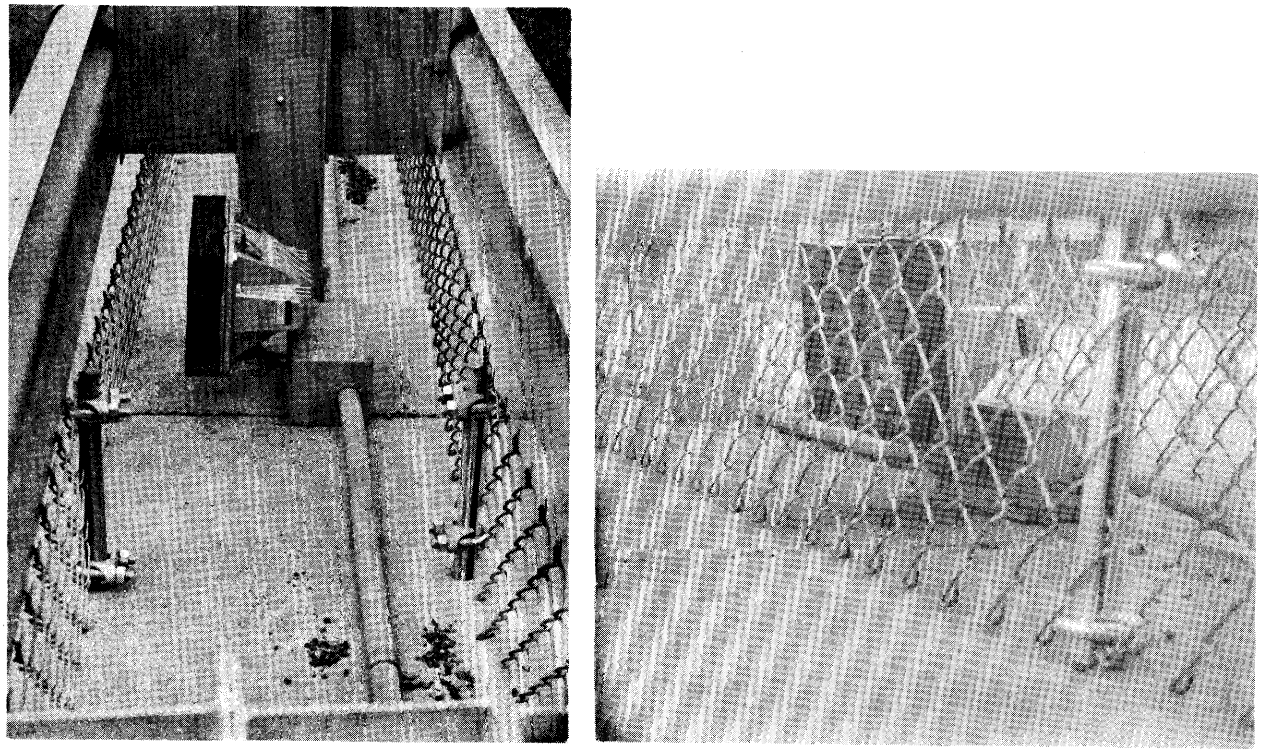

Figure 25. Low level light assembly on a concrete median. Note the individual junction boxes, the chain link fence in front and back.

After installation of the pipe sleeves, conduit, transformer housings, junction boxes, splice boxes, and inset lights, the electrical wiring was pulled and connected to the equipment. For short sections (200 ft. [61 m] or less) a steel wire was fed through the conduit and the electrical conductor was attached and pulled. For longer lengths (greater than 200 ft. [61 m]) a device similar to a badminton birdie attached to a nylon or hemp cord was blown through the conduit with compressed air and the conductors were hooked to the cord and pulled. All wire pulling was manual and was performed over a period of three months. A lubricant was used to make pulling easier and to prevent damage to the insulation. Figure 26 shows a lubricant being applied as the wire was being pulled from a splice box(left), and (right) the wire being drawn through a transformer housing.

Splices of cable were made at the transformer housings where the lights were hooked into the system, at splice boxes, and in junction boxes. Special conductor kits (splice kits) supplied by the light manufacturer were used to hook the lights into the circuits. For high voltage wires, a special splice kit was used, while the low voltage wiring was spliced manually. For the electrical circuits, 45 splice boxes, differing from the junction boxes only by having concrete covers, were installed for pulling and splicing the wires. The left portion of Figure 25 shows a splice box.

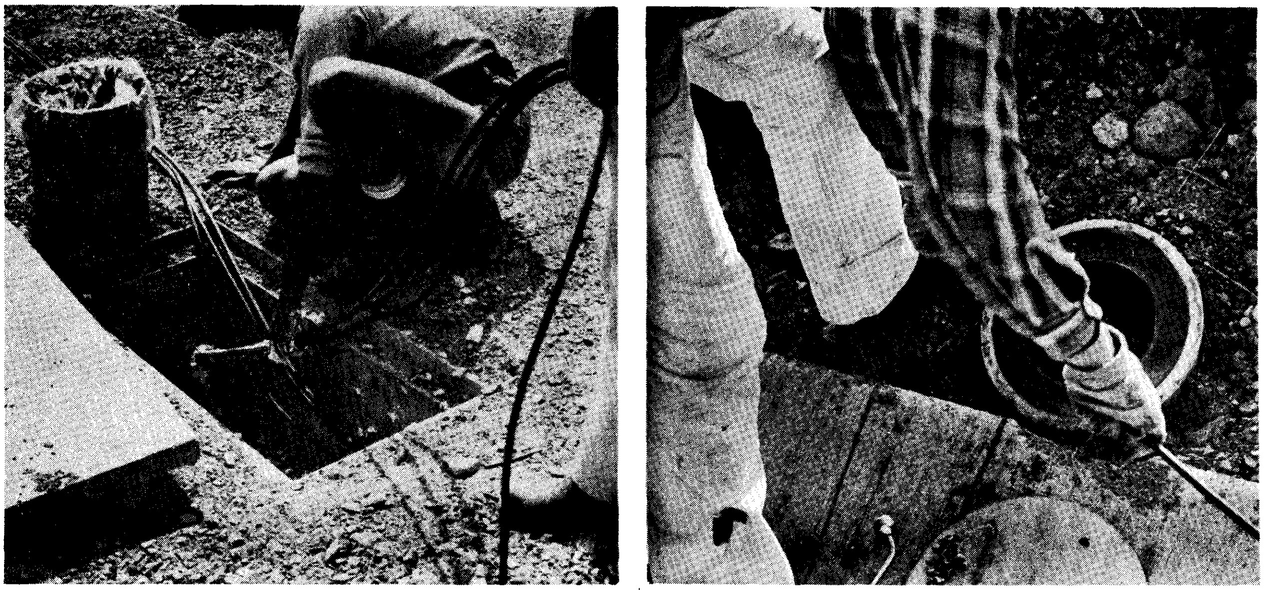

Figure 26. Wire pulling.

The fog detectors were installed in the locations shown in Figure 6. They were installed at least 20 ft.(6.1 m) above the roadway and they were pointed away from the rising and setting sun to avoid damage to the photodiode tube from direct exposure to the sun. The detectors were pointed so as to have at least 300 ft.(91.4 m) of open visibility. They were installed on a 33 in.(838.2 mm) square concrete base set at least 24 in. (609.6 mm) into the original slope. In several cases, the thickness of concrete was 3 ft.(.914 mm) or more. The galvanized conduit to the detector was cast in the base as were the three 12 in. (304.8 mm) long anchor bolts for attaching the detector. The left portion of Figure 27 shows the detector attached to its base. Note that the slots for the anchor bolts allow the detector to be rotated ± 15° for aiming purposes. The three other bolts are for leveling the detector, and the stud in the foreground is the end of the ground rod. The center portion of Figure 27 shows the rear of the detector and its mounting stand, and the right portion is a front view.

The final two items that need discussing are the sign and the raised pavement markers on the bridges and in the gore area. On each end of the project, 500 ft.(152.4 m) in front of the lights there are signs with the message "Pavement Edge Guidelights Ahead". These are matrix signs with horizontal louvres that present a black matt face when the lights are not on. On top of the signs are two 12-in.(304.8 mm) 100-watt alternating amber flashing lights with a frequency of 60 flashes per minute. The signs operate on 115-volt, 60-cycle alternating current. These information signs are activated when any detector in the system senses fog. The signal to turn the signs on is transmitted by a tone generator. The letters in the message are of the 8 in.(203.2 mm) series D type. Figure 28 shows the sign in the non-activated and activated stages.

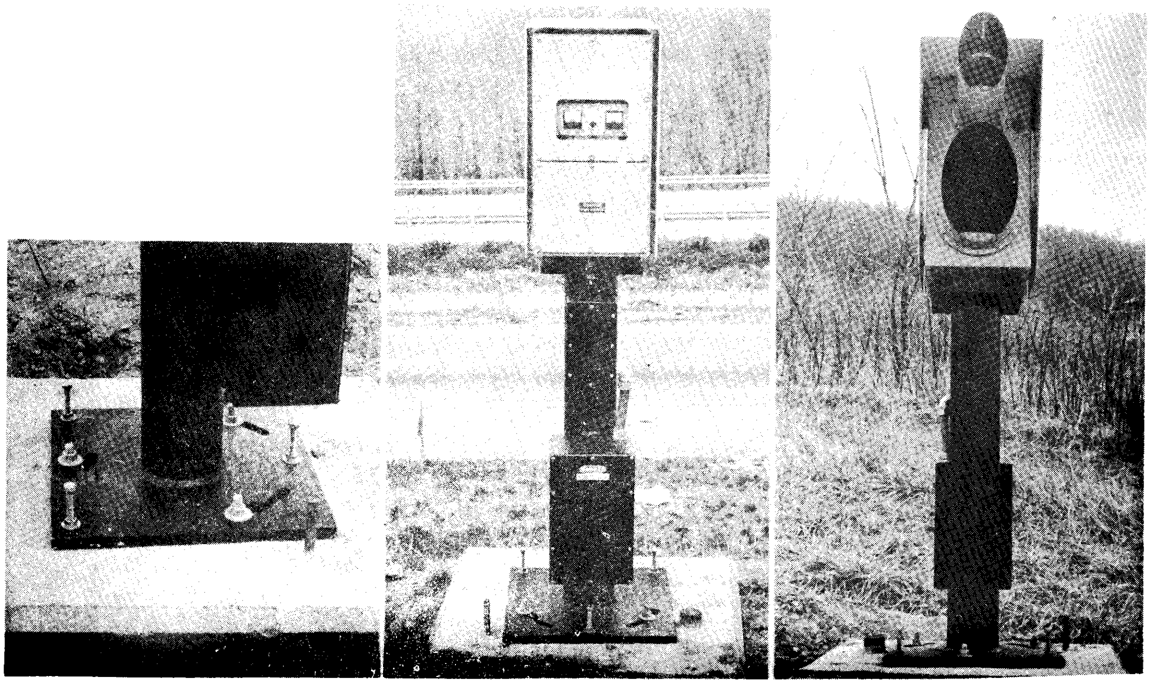

Figure 27. Mounting details and rear and front views of fog detector.

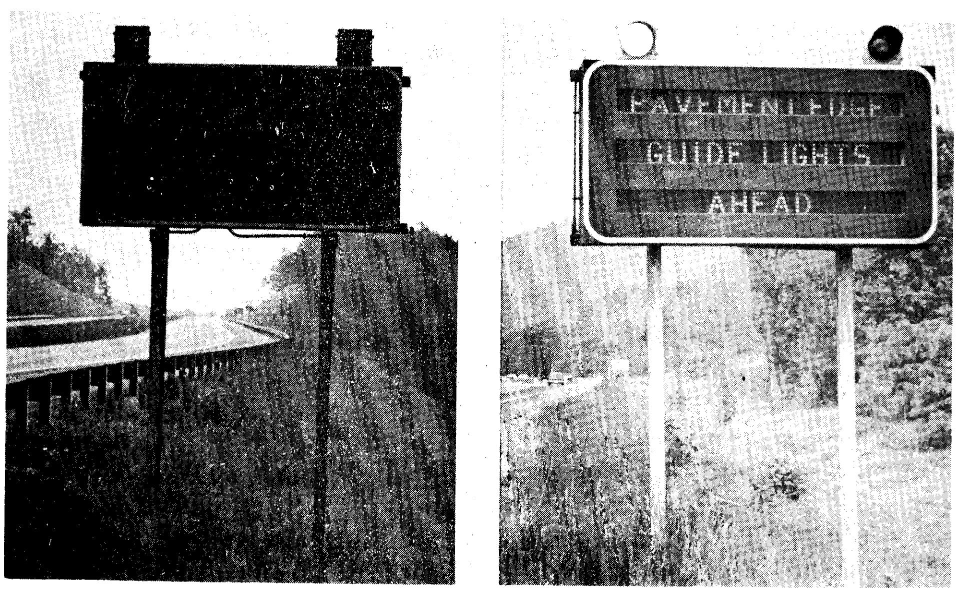

Figure 28. Advance information sign.

Incorporated in the electrical wiring of the light system is the potential for 8 pairs (16 signs) of remote controlled (by the fog detectors) variable message speed signs. These variable signs, of which only one has been installed and must be considered experimental until proven effective, are capable of displaying speeds of either 15,25,35,45, or 55 mph, depending upon the density of fog as determined by the fog detectors. In a given section, the signs are designed to be controlled by the detector recording the heaviest fog. The 48-in.(1219 mm) diamond matrix sign displays the word "Fog" with the speed limit beneath it. As is the case with the information signs, the speed signs are topped with flashing amber lights.

No lights were installed on the bridges due to the difficulty involved and a reluctance to cut deeply into the bridge surfaces. Instead, raised reflectorized markers were installed in the pavement on 10-ft.(3 m) centers by cutting two slots for the legs as shown in Figure 29 and epoxing them into place. An installed marker is shown to the right in Figure 29. These markers were also installed in the gore areas on the ramp.

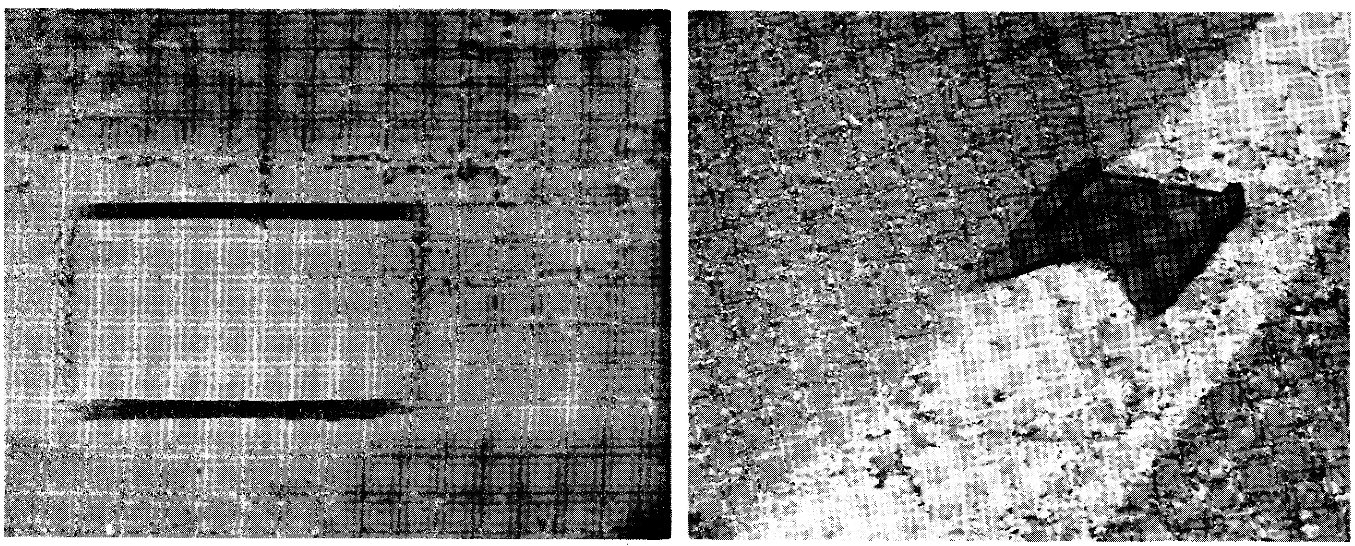

Figure 29. Installation of reflectorized pavement markers.

The length of the construction contract was specified as being 180 calendar days, which included Sundays, holidays, and nonworking days, but excluded all days for which the contractor was granted a shutdown by the engineer in charge. Shutdowns were granted for inclement weather and when work could not be performed due to a shortage of critical materials. The contractor was issued a notice to proceed on May 13, 1974, and the job was completed and accepted on March 15, 1976. A total of 321 shutdown days were allowed, a major portion of which were due to the contractor not being able to obtain the designated conduit for the job and a holdup in delivery of the control equipment. In the first case, after it became apparent that an indefinite wait would be involved in obtaining the conduit in the specifications, the specifications were waived and thin walled was used in lieu of heavy walled with deeper burial. In the case of the control equipment, the manufacturer went into recieversship and this held up its delivery. Figure 30 shows the anticipated work schedule as compared to actual work performed. It may be noted that the contractor adhered relatively closely to the schedule until September 20, 1975. The contract was extended by work orders by a number of days equal to the total amount of work orders divided by the daily rate. The daily rate was calculated by dividing the contract amount by the number of days in the contract. The extension time amounted to 10 days. Negotiations are now under way between the Department and contractor about the overrun not covered by contract, shutdown, or work orders.

Throughout construction, problems occurred due to the purchase of equipment by the Department and installation under contract. Since all of the control equipment was not furnished by the Department, or even the same manufacturer, compatibility between component parts became a difficulty. This and other problems, such as the acquisition of shop drawings, led to the conclusion that a future contract could probably best be done entirely by one party.

TROUBLESHOOTING AND DEBUGGING

Almost all of the problems with the system have come from the control equipment. From the beginning of automatic operation, the signal conductors from the detectors picked up extraneous voltage. The exact source(s) could not be determined, but indications were that it came from either one or a combination of adjacent electrical conductors, ground electricity, or atmospheric electricity. In addition, transient voltage from the roadway lights during activation of the system was measured in the signal lines. Considering the fact that the signal from the fog detector was 1 milliampere or less and the voltage was 5 volts, it is not difficult to see how a problem arose. The signal from the detector was cancelled by the extraneous voltage. The problem might have been avoided by the use of shielded cable in the control circuits.

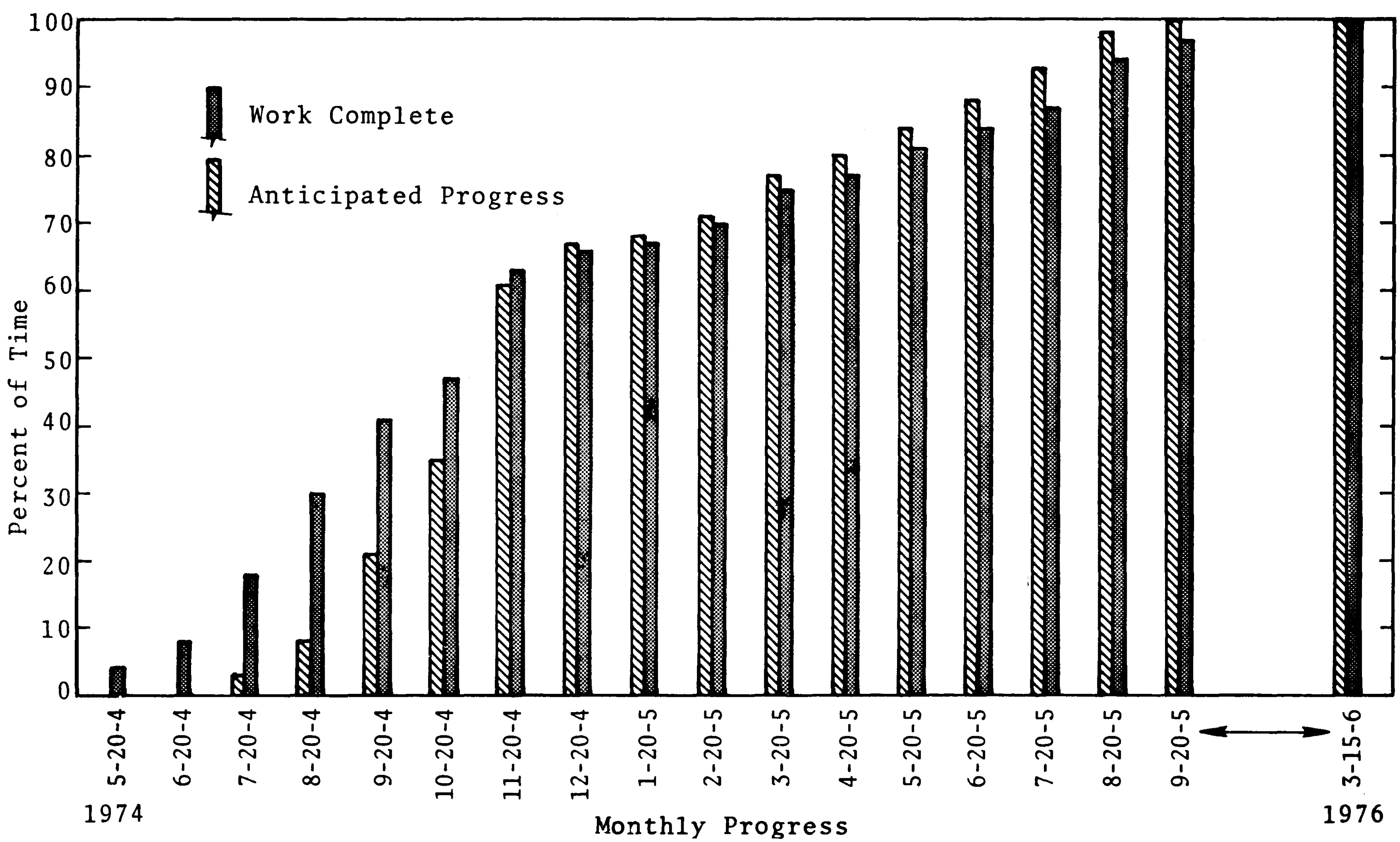

Figure 30. The anticipated work schedule compared to performance.

The first approach to solving the problem was to connect a capacitor across the input conductors in the control room from each detector to bleed off the induced electricity. This scheme worked at the control room end but burned out circuits in the detectors due to the high initial charging current drawn by the capacitors; so this method was abandoned.

A second approach was to connect an operational amplifier in the control circuit between the detectors and the control equipment at the control building. The operational amplifiers were supposed to cancel all except the signal voltage. To further protect the detector circuits, they were fused with 10 milli-ampere fuses and later zener diodes were added to the circuits to protect the fuses from transient voltages. These steps solved the problem for a period of time, but when a severe electrical storm occurred, the system was rendered inoperative. Part of the detector and control equipment was redesigned to further protect the signal circuits and reduce the transient voltage from the roadway lights.

Although the above actions appear to provide a partial solution to the problem, malfunctions do still occur in the control equipment and are most often the result of electrical storms. There have been instances in which the system has been activated by atmospheric electricity turning the lights on with no fog present. Once activated under these circumstances with the operational amplifier blown, the signal from the detector to shut the lights off is blocked. The system then has to be turned off manually. Discussions are now being held regarding plans for a major redesign of part of the control system and methods of protecting the system from electrical storms.

The system operates reliably in all cases on manual operation, which simply means that a technician, through a series of switches, turns the lights on at the correct level for a fog, and when it dissipates, he turns them off. Under manual operation the system cannot adjust itself for changing densities of fog.

Under the debugging, two constant current regulators malfunctioned and were repaired, one splice was found defective, units in detectors had to be replaced, and a schedule of replacing bulbs was set up. All bolts attaching the lights to their bases and all seals were replaced, because the original bolts were of the wrong hardness and subject to shear and and the seals were of the wrong size.

Also it was decided that snowplows used on the installation would be equipped with rubber blades, since they produce less impact and potential damage to the lights.

COST OF INSTALLATION

The total cost of the installation was $1,997,748, of which the state of Virginia bought and supplied equipment in the amount of $313,561. This was a federal aid 90-10 project. A listing of each item and its cost is given in Tables 1-A and 2-A of the Appendix.

RECOMMENDATIONS

1. Complete protection against atmospheric electricity (lightning) should be sought.
2. In projects such as the one reported, the entire project should either be let to contract or be done by state forces. Conflicts sometime arise when portions are done by the two working in conjunction.
3. All control electrical cable should be of the shielded type.

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GLOSSARY OF TERMS FOR THIS REPORT

Bus Bar System- Copper tubing used to distribute electricity to the constant current regulators in the control building.

Cable Racks- Metal arms with porcelain saddles for hanging of cables in junction boxes.

Cement Grout- A mixture of one part portland cement and 2 parts fine aggregate with water to obtain the required consistency. Used to seal the conduit holes in the junction boxes.

Coal Tar Epoxy- A thermosetting resin used to concrete and seal the roadway pavement light in place.

Conduit- Pipe used to carry and protect electrical conductors.

Constant Current Regulator- A floating coil constant current transformer that will vary the load current from 20 to 8.5 amperes. This regulator can be operated by a remote control station or can be controlled manually by a potentiometer.

Control Building- Building used to house the control and electrical equipment.

Control Equipment- Equipment in the control building which will digest the information received from the fog detector and, in turn, control appropriate signs and guidance lights.

Fog Guidance Light/ Pavement Inset Lights- For this report unidirectional airport runway lights 12 inches in diameter installed in the pavement surface on each side and pointed toward the oncoming driver in such a manner as to form a channel for his vehicle to follow.

F.I. of Boring- Method for payment of installation of pipe sleeves. Multiply total length of pipe installed by the nominal diameter.

Junction Box- A box at an intersection point or tie in of conduits and used for the pulling of electrical cables and making of splices on electrical conductors.

Low level light– A 500-watt quartz floodlight used to light the entrance ramp on I-64 and Route 250, Afton Interchange.

Modified Pile Driver– A guardrail post driver with a circular die attachment used for cutting holes in asphalt pavement in the installation of the roadway pavment lights of the type with the type I transformer housings.

Operational Amplifier– High gain, dc amplifier whose performance is determined by the value and stability of connected resistors rather than by the characteristics of the amplifier. Typically an op-amp will contain 20 transistors, 12 resistors, and a capacitor on a single silicon op-amp side.

P.V.C.- Polyvinylchloride conduit– Plastic pipe used for carrying electrical conductors.

Pavement Breaker– A spade-like piece of equipment having a wide chisel end operated by air and controlled manually. Used to remove asphalt or other hard objects in construction.

Pipe Sleeve– Pipe installed under the roadway by means of boring an opening and then forcing a casing into the opening. Usually the sleeve is larger than the required item that will be installed through it.

Shutdown– Authorized suspension of work.

THHN Conductor– Electrical wire with a thermoplastic insulation and a nylon jacket. Has definite temperature characteristics and is resistant to gasoline and oil.

Transformer Housings– A galvanized can used for housing the step-down transformer at each light location; the pulling of conductors and making of splices required for the roadway pavement lights.

XHHW Conductor– Electrical wire with cross-linked thermosetting polyethylene insulation. Highly weather resistant.

Zenor Diode– A semiconductor diode characterized by a high impedance to current flow in one direction and low impedance in the other direction. When its rated voltage is reached, it thus serves to limit the voltage which can be reached across the circuit in which it is connected.

A P P E N D I X

Table A-1

Costs of state supplied equipment for fog guidance system

Description of Item	Quantity	Each	Unit Price	Amount
Regulator, 50 kw constant current	1	each	$5,275.00	$ 5,275.00
Regular, 30 kw constant current	6	each	4,600.00	27,600.00
Light base & transformer housing combination, type II, 20" deep, 12" outside diameter	70	each	37.00	2,590.00
Transformer housing, type I 12" outside diameter 1.1" opening	1,600	each	24.60	39,360.00
Transformer housing, type I 12" outside diameter, 2.1" opening	60	each	25.85	1,551.00
Transformers, Insulating Type 20/66	850	each	32.00	27,200.00
Primary connectors, male and female primary to match insulating transformer	860	each	4.10	3,526.00
Secondary connectors, to match with secondary leads on insulating transformers, (includes a female kit to attach to light and a male kit to attach to transformer)	860	each	7.00	6,020.00
Pavement Inset Light complete with plug and receptacle kit	845	each	150.00	126,750.00
Optical assemblies(includes film dis. cutout)	60	each	120.00	7,200.00

Table A-1 cont.

Description of Item	Quantity	Each	Unit Price	Amount
Loctite, grade AV needed to install pavement inset light (24 bottles with 10 cc per bottle)	1	each	55.00	55.00
'O' Rings- Between pan and head of pavement inset light (for maintenance)	200	each	.50	100.00
Lamps for pavement inset lights (for maintenance)	200	each	8.95	1,790.00
Seals- Between base and head of pavement inset lights	200	each	2.40	480.00
Misc. Material- Loctite, silcone, lubricant, fuses, other materials	---	---	---	2,000.00
Fog detectors with pedestal for 220 vac operation	5	each	7,300.00	36,500.00
Fog detector with pedestal for 110 vac operation	1	each	7,300.00	7,300.00
Control equipment consisting of 6 separate channels of 5 levels each with adjustable 0-5 minutes on and 0-8 minutes off	1	each	5,660.00	5,660.00
Receiver chassis for maintenence of existing detectors (spare)	1	each	3,265.00	3,265.00
Lamps for maintenance of detectors	12	each	306.00	3,672.00
Graph recorders, 0-1 ma input with scale calibrated from 1/16 to 6 miles with sufficient paper (72 rolls) to last for 1 year	6	each	845.00	5,070.00
Power supply boosters, w/detector voltage monitors	6	each	76.00	456.00
Relay rack, to contain detector alarm devices, graph recorders and power supply boosters	1	each	141.00	141.00
TOTAL				$313,561.00

Table A-2

Contract costs for fog guidance system

Description of Item	Quantity	Each	Unit Price	Amount
Moblization, preparatory operations	Lump sum	100%	$71,250.00	$ 71,250.00
Install fog detector	5	each	500.00	2,500.00
Reset existing fog detector	1	each	560.00	560.00
Install pavement lights	809	each	150.00	121,350.00
Reset existing pavement lights	34	each	225.00	7,650.00
Install Type I transformer housing	1,595	each	90.00	143,550.00
Install Type II transformer housing	66	each	200.00	13,200.00
1 inch P.V.C.	10,849.2	L.F.	3.56	38,623.16
2 inch P.V.C.	140,689.1	L.F.	1.9336	272,036.44
3 inch P.V.C.	636.0	L.F.	5.00	3,180.00
4 inch P.V.C.	17,216.5	L.F.	3.00	51,649.50
1 inch galvanized metal conduit	307.5	L.F.	4.50	1,383.75
2 inch galvanized metal conduit	1,371.5	L.F.	5.30	7,268.95
2 inch pipe sleeve	1,176.4	L.F.	1.50	1,764.60
4 inch pipe sleeve	1,030.3	L.F.	4.00	4,121.20
6 inch pipe sleeve	49.0	L.F.	9.50	465.50
12 inch pipe sleeve	266.2	L.F.	21.00	5,590.20
Pipe jacking or boring	9,180.4	F.I.	3.00	27,541.20
Install low level flood lights	50	each	160.00	8,000.00
#2 conductor (5 kv)	46,699.5	L.F.	1.00	46,699.50

Table A-2 cont.

Description of Item	Quantity	Each	Unit Price	Amount
#8 conductor (5 kv)	202,287.1	L.F.	.40	80,914.84
#10 cable(12 conductor)	53,673.6	L.F.	1.50	80,510.40
#16 shield cable(2 conductors)	36,237.9	L.F.	.30	10,871.37
#6 bare copper wire (stranded)	130,680.8	L.F.	.50	65,340.30
#6 conductor (THHN) (stranded)	2,823	L.F.	.60	1,693.80
#10 conductor (THHN) (stranded)	2,185	L.F.	.25	546.25
#12 conductor (THHN)	3,534	L.F.	.60	706.80
Junction box	251	Each	825.00	207,075.00
Control building electrical system	Lump sum	100%	226,588.82	226,588.82
Field office, Type I	Lump sum	100%	6,500.00	6,500.00
Unidirectional reflectorized markers	399	each	8.80	3,511.20
Sign w/text Number 1	2	each	11,200.00	22,400.00
Bridge mounted sign	Lump sum	100%	6,500.00	6,500.00
Remove existing overhead sign structure	Lump sum	100%	2,500.00	2,500.00
Post 10"	73.4	L.F.	30.00	2,202.00
Remove existing guardrail	536.0	L.F.	1.50	804.00
Reset existing fence	30.5	L.F.	6.00	183.00
Remove existing fence	123.7	L.F.	1.50	185.55
Fence, FE-2 mod.(9' h)	224.2	L.F.	12.00	2,690.40
Corner brace unit, FE-2 mod.	4	each	200.00	800.00
Gate FE-2 mod. 20' Dbl. Swing	1	each	400.00	400.00

Table A-2 cont.

Description of Item	Quantity	Each	Unit Price	Amount
Gate FE-2 mod. 3'6"	1	each	150.00	150.00
Fence, FE-2 mod. 1' height	1,414.0	L.F.	6.00	8,484.00
Aggr. Base Mat'l Type I, No. 21 or 21A	43.50	Ton	20.00	870.00
FE-3C Fence	1,404.0	L.F.	2.475	3,474.90
FE-3C line brace	2	each	133.75	267.50
FE-3C corner brace	2	each	150.71	301.42
Stub out spare transformer housing	796	each	7.30	5,810.80
A-3 encasement concrete	4.031	C.Y.	132.25	533.10
Splice box	45	each	533.53	24,008.85
Sign with text Number 2 and remote receiver	1	each	17,728.24	17,728.24
6 WF 15.5 I beam post	18.7	L.F.	74.33	1,389.97
1 1/4 inch galvanized metal conduit	218.5	L.F.	4.70	603.95
#4 XHHW conductor	18,227.7	L.F.	.8832	16,098.70
#2 XHHW conductor	11,712.0	L.F.	1.0625	12,444.00
Duplex receptacles	Lump sum	100%	6,994.15	6,994.15
Remove existing sign	Lump sum	100%	500.00	500.00
Control building,	Lump sum	100%	33,220.00	33,220.00
TOTAL				$1,684,187.31

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