footing performed similarly to the timber post embedded 38 in.

3. Comparisons of the static field test results with the analytical predictions indicate that the analytical model provides a useful means for predicting the response of guardrail posts to static loads.

4. The dynamic guardrail post tests conducted as part of this research study indicate that the steel guardrail post embedded 38 in. without a concrete footing performed similarly to the timber post embedded 38 in. Thus, based on the results of the limited field tests, the steel guardrail post embedded without a concrete footing performs satisfactorily as a traffic barrier system.

5. Comparisons of the dynamic field test results with the analytical model appear to provide a useful means for predicting the response of guardrail posts to dynamic loads. However, the analytical model is sensitive to the soil viscosity used in the dynamic model.

6. It should be emphasized, however, that these results and statements are based on a limited number of tests performed in the field on the steel and timber posts. Because of the limited time and resources available to the authors, repeatability of the test results was never verified. Therefore, it is recommended that another series of tests be performed in the future to check the repeatability of the results.

REFERENCES

1. Response of Guardrail Posts During Impact. Res. Report 03-9051. Southwest Research Institute, San Antonio, Tex., Oct. 1970.
2. J.F. Dewey, J.K. Jeyapalan, T.J. Hirsch, and H.E. Ross. A Study of the Soil-Structure Interaction Behavior of Highway Guardrail Posts. Res. Report 343-1. Texas Transportation Institute, Texas A&M University, College Station, July 1983.
3. T.M. Leps. Review of Shearing Strength of Rockfill. ASCE, Journal of the Soil Mechanics and Foundations Division, Vol. 96, No. SM4, July 1970.

Publication of this paper sponsored by Committee on Safety Appurtenances.

Encasement of Pipelines Through Highway Roadbeds: Synopsis of Final Report for NCHRP Project 20-7, Task 22

RAYMOND A. KOENIG, Jr.

ABSTRACT

Warrants for providing increased protection to pipelines crossing highways are discussed. The practice of using casing pipes to protect crossing pipelines is examined. Problems encountered with this practice, particularly related to interference with induced-current cathodic protection systems for pipelines, are presented. Two failures of pipelines, which the National Transportation Safety Board attributed to the use of casings, are documented. Results of a survey of state transportation departments, railroads, trade associations, utility companies, and pipeline operators are included.

In 1981 the Transportation Research Board, which administers the National Cooperative Highway Research Program (NCHRP), contracted Byrd, Tallamy, MacDonald and Lewis to conduct research addressing the need for encasing pipelines under highways. AASHTO sponsored the research in cooperation with the FHWA.

The objective of the research was to develop procedures for determining the need for pipeline encasement at highway crossings based on

1. A review of literature on underground pipeline design and performance,
2. Limited stress analyses of underground pipelines, and
3. An evaluation of field experience by highway, railroad, and utility agencies of encased and uncased pipelines.

The study was completed in late 1982, and the final report (1) has been accepted by NCHRP. Existing regulations concerning pipeline crossings are summarized, including those of the Office of Pipeline Safety, U.S. Department of Transportation. Forty-two publications relating to pipeline crossings are listed as references in the bibliography of the report. Results of a survey of state highway departments, utility companies, and pipeline operators regarding their encasement practices are presented. Problems encountered with the use of casings, particularly with regard to cathodic protection systems, are discussed. Warrants for providing increased protection at pipeline crossings are addressed, and limited stress analyses for design of both encased and uncased crossings are included.

AASHTO GUIDE

The AASHTO "Guide for Accommodating Utilities Within Highway Rights-of-Way" defines encasement as "structural element surrounding a pipe" (2). Although this definition includes jacketing, or encasement by concrete poured around a pipe, the term encasement is generally thought of as the practice of placing a carrier pipe within a casing pipe.

The AASHTO guide gives three reasons for providing encasement of pipeline crossings (2):

> (1) As an expediency in the insertion, removal, replacement, or maintenance of carrier pipe crossings of freeways, expressways, and other controlled access highways and at other locations where it is necessary to avoid trenched construction.
> (2) As protection for carrier pipe from external loads or shock, either during or after construction of the highway.
> (3) As a means of conveying leaking fluids or gases away from the area directly beneath the traveled way to a point of venting at or near the right-of-way line or to a point of drainage in the highway ditch or a nature drainage way.

CASINGS

Industry is all too familiar with problems caused by casings. Casings can create problems both during and following construction. Improper design and installation (i.e., insufficient clearance between pipe and casing), inadequately designed encasement pipes and insulators, or improper installation and inspection procedures have sometimes resulted in crossing failure (see Figure 1).

During construction it is difficult to maintain the necessary separation between the casing and carrier pipeline. Typically, for an encased crossing, the casing pipe is installed first, either by boring, jacking, or open-trench construction. Once the casing is in place, greased insulators are strapped to the carrier pipe at regular intervals and the carrier is inserted into the casting by pushing it from one end of the casing to the other. Irregular casing line or grade, displacement at casing joints, or defects in the casing cross section will sometimes cause the carrier to bind inside the casing. Often excessive force is applied to drive the carrier through its casing, which can result in damage to the carrier pipe or casing insulators or both. Because it is impossible to visually inspect the carrier within the casing, the damage goes undetected. When repairing short circuits and extending casings, pipeline companies and their contractors have many times found the insulators stacked together at the end of a casing.

CATHODIC PROTECTION

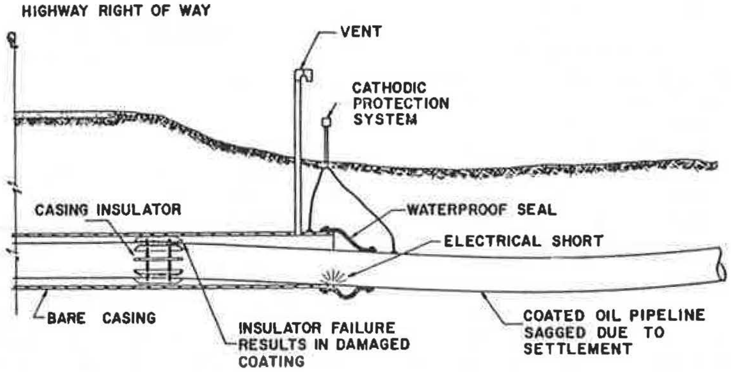
When the separation between a carrier and casing is not maintained, as often happens during construction, metal-to-metal contact between the carrier and casing results. The most serious implications of this contact are in the area of cathodic protection.

Pipeline Safety Regulations (3) promulgated by the Office of Pipeline Safety require underground pipelines that carry gas and petroleum products to be 100 percent cathodically protected. A typical external cathodic protection system consists of a buried anode and rectifier from which current flows through the soil to the pipeline surface being protected. This external system reverses the natural potential between a pipeline and surrounding soil that causes corrosion.

When a casing and carrier come into contact, a short circuit in the cathodic protection system results. The short circuit drains protective current from the remaining pipeline and can actually increase the corrosion potential at the point of contact.

Sometimes a casing short circuit develops after construction. If fill inside bore pits at the casing ends is not sufficiently compacted during installation, the pipeline outside the casing will settle. This settlement causes the pipeline inside the casing to deflect, in some cases to a point where it comes into contact with the casing pipe.

Short circuits are not the only problem with regard to cathodic protection systems caused by casings. Perhaps the more basic problem is that the carrier pipe is shielded from effective cathodic protection by a casing. Inside a casing a carrier pipeline is not in contact with surrounding soil, the medium through which current from a buried anode flows to the surface of a pipeline. In addition, because many states do not permit coated casing pipes, the bare metal surface of the casing attracts much of the current that an external cathodic protection



Source: National Transportation Safety Board

FIGURE 1 Possible failures in cased crossings.

system provides. As a result the carrier pipeline, for which the cathodic protection system is designed, is left unprotected.

OPERATIONS

When water enters a casing through defective end seals, casing joints, or external vents, and mixes with soil and other foreign material inside, an electrolytic solution results. The solution conducts current from the casing to the carrier, which would not be a problem if the entire carrier were submerged. However, typically a casing is only partly filled, and the corrosion potential of the pipeline is again increased. Likewise, the wet environment inside a casing, combined with oxygen entering through casing vents, promotes atmospheric corrosion of the carrier pipeline.

Casings have proved to be difficult to extend in highway widening projects, particularly when there are horizontal and vertical bends in the pipeline. Not only is it difficult to initially construct and maintain separation between carrier and casing at these locations, but it also becomes extremely difficult to extend a casing through bends.

FAILURES

The NCHRP report (1) contains case histories for two pipeline failures at highway crossings that the National Transportation Safety Board (NTSB) attributed to the use of casings.

The first involved failure of a 30-in.-diameter gas transmission pipeline in a 34-in.-diameter casing under State Highway 124 near Monroe, Louisiana. The accident occurred at approximately 11:10 a.m. on March 2, 1974, when the carrier pipe ruptured at a girth weld located approximately 6 ft inside the casing end. According to the NTSB report (4):

> Gas escaped instantly at a pressure of 797 psig and filled the annulus between the carrier pipe and the casing. It blew off the casing vents and seals, ripped open and flattened 40 feet of the casing pipe and blasted a hole, 100 feet long, 30 feet wide and 25 feet deep, through State Route 124. The gas, which ignited almost immediately, burned 10 acres of forest and scorched the soil for 700 feet along the pipeline right-of-way.

The NTSB report cited two reasons for the failure: First, settlement of earth fill immediately adjacent to the ends of the casing pipe, together with "swells and heaves" of the surrounding soil, caused the carrier pipe to "flex" in its unrestrained condition inside the casing pipe. Second, a substandard weld, subjected to the "flexing" repetitions, failed.

The NTSB report (4) further stated:

> Soil stress alone might not have caused this pipe to fail, but because it was encased with 34-inch pipe for 90 feet, the carrier pipe was unrestrained. It is possible that if the wall thickness of the pipeline had been greater, and if it had not been cased underneath the highway, it would not have failed. Even if that same weld had been poorly made, there would have been little opportunity for flexing, because the backfill would have been tight around the pipe and there would be little space in which to flex. The weld, although poor hypothetically, would have had more weld metal applied because of the heavier wall and would have been stronger. In this instance it is probable that the use of casing contributed to the failure of the carrier pipe.

Finally, with regard to the history of the general practice of the encasement, the NTSB report (4) stated:

> Casting was used to permit the repair and replacement of a failed pipe by cutting and removing the pipe from the casing without disrupting the traffic. The theory was good, but the seemingly easy task of removing and replacing the leaking pipe within the casing sometimes became difficult. Often, the casing seals had broken and the annulus had become plugged with dirt and debris. The problems of casing seal failures and coating failures within the casings remained. It was difficult, even under ideal construction conditions, to obtain a perfect casing installation. Once the carrier pipe came in contact with the steel casing, an electrical short developed which made it difficult to protect the carrier pipe against corrosion.
>
> Recently many arguments have been presented to discontinue the use of casing because of all the problems associated with it, and to use double-coated carrier pipe with greater wall thickness instead. Welds would be 100 percent x-rayed, an outer coating of concrete would be added, and the pipe would be buried deeper below the road.

The second failure documented in the report involved a 32-in.-diameter petroleum products transmission pipeline within a casing under Route 234 near Manassas, Virginia. The accident occurred on March 6, 1980, at approximately 3:30 p.m. when a pressure surge in the line caused an 11-ft-long rupture in which 8,000 barrels of aviation-grade kerosene gushed from a 5-ft-high geyser created at the casing end. The kerosene poured into a roadside ditch, through major storm drainage systems, into the Bull Run River, and eventually contaminated the Occoquan Reservoir, which supplies drinking water to more than 500,000 persons in northern Virginia. No personal deaths or injuries resulted, but fish and waterfowl populations were severely affected.

The NTSB report (5) concluded that the carrier pipe coating had been damaged during installation of the carrier pipe within the casing. Corrosion had thinned the pipe wall and created a weakened pipe section. Although the pressure in the pipeline exceeded the maximum operating pressure, because of a surge created by an operator malfunction, the weakened point at which the failure occurred was created by corrosion resulting from casing-carrier pipe contact.

The NTSB report (5) quoted a Battelle Institute report on the failure:

> The failure occurred at an area near the bottom of the pipe that had been thinned by corrosion. Apparently the corrosion resulted from ground water leakage past the pipe-to-casing seal and into the annular space between the pipe and casing, where the shielding effect of the casing

would mitigate against obtaining adequate cathodic protection....

In addition, the NTSB report (5) stated:

> Corrosion resulting from damaged coating on a carrier pipe inside its casing is, unfortunately, common in pipeline systems. An electrical shorting of the pipe can occur when the pipe coating has been damaged and the separators which position the pipe away from the casing have been broken. This allows the pipe metal to touch the casing metal and a short circuit results. Cathodic protection applied to the pipe by anodes or rectifiers cannot effectively protect the pipe under this condition and with the entrance of water in the casing an electric cell is formed and corrosion results.

SURVEY

As part of the research effort, state transportation departments, railroads, trade associations, utility companies, and pipeline operators were contacted for input into the study. Of the 21 states that responded to the survey, most indicated that they consider pipeline crossings on a case-by-case basis. Most states will consider methods besides casing pipes for providing increased protection at pipeline-highway crossings.

Of the 22 pipeline operators and utility companies that responded to the survey, 19 indicated that they preferred uncased crossings. The three companies that use cased crossings do so for different reasons. One cited protection of their pipelines from external damage, particularly from highway construction and maintenance activities. Another used casings because of damage that occurs during construction when uncased crossings are attempted in rocky or adverse subsurface soil conditions. The third company indicated that it has been their longstanding policy to use casings, that casings have served them well in the past, and that they will continue to use casings in the future.

Five railroads were also contacted during the study and each referred to Chapter 1, Part 5, of the American Railway Engineering Association (AREA) Manual for Railway Engineering (6), which presents recommended practices for pipeline crossings. Each indicated that the manual's practice of providing casing pipes for crossing pipelines is a good one, and that they will continue to follow it.

DESIGN

Methods to size both cased and uncased crossings currently exist and design formulas are presented in the NCHRP report (1). The equations, developed by Barlow, Spangler, Marston, and others while considered conservative by some, are all time tested and widely used by both pipeline and highway industries.

PROTECTION AT CROSSINGS

A matrix developed during the research compares warrants for providing increased protection for pipelines crossing highways with available methods (see Table 1). The distinction between transmission and distribution pipelines is made because the sizes and operating pressures of transmission lines normally distinguish them from distribution lines. Six general methods for providing protection are listed:

1. A sleeve, which not only includes casing pipes but also includes tunnels or galleries, where multiple pipes crossing a highway are placed in a single box-culvert-like structure;
2. Concrete encasement, which includes a variety of techniques, all of which involve placing concrete around a pipe;
3. Cathodic protection, including coatings, wrappings, or external systems;
4. Concrete protective slab (usually precast), which is placed over, but not in contact with, the carrier pipe; this procedure is widely used by pipeline companies in areas other than highway rights-of-way where external damage, particularly from plows or other farm machinery, is likely;
5. Thickened wall carrier pipe; and
6. Leak-proof joints.

When the matrix is examined, two conclusions can be drawn. First, transmission pipelines are not normally removed from their casings to facilitate maintenance or repair. In fact, this is probably an understatement, because in the course of this research not a single reported instance involving removal of a transmission pipeline from its casing for maintenance or repair was found. Second, for each of the other warrants presented, mainly protection from a spill, protection from external loading or damage, or corrosion, more than one method is available to protect the pipeline.

ALTERNATIVES

The data in Table 1 present various methods available for providing protection at pipeline crossings. If removal of the carrier pipeline is unnecessary or impractical, as it is for transmission pipelines, then other methods, besides casing pipes, can pro-

TABLE 1 Warrants and Methods for Providing Protection at a Highway-Pipeline Crossing

	Methods	
Warrants	Transmission	Distribution
To facilitate carrier removal	—[a]	1
To prevent a spill or to mitigate its effects	2, 3, 5, 6[b] 1, 2, 3, 5, 6[c]	1, 2, 3, 5, 6
To protect from external loads and/or from excavation damage	1, 2, 4, 5	1, 2, 4, 5
To prevent corrosion or to mitigate its effects	3, 5	3, 5

Note: The methods are as follows: 1 = sleeve (including casing pipe, tunnel, or gallery), 2 = concrete encasement (including grouting, precast concrete covering, cradling, walling, boxing, capping, or jacketing), 3 = cathodic protection (including coating, wrapping, or induced-current systems), 4 = concrete protective slab, 5 = thickened-wall carrier pipe, and 6 = leak-proof joint. Note that the following methods are used for trenched construction only: tunnel, gallery, cradling, walling, boxing, capping, jacketing, and concrete protective slab.

[a]Not normally removed.
[b]High pressure.
[c]Low pressure.

vide the necessary protection. These methods include jacketing of carrier pipe with reinforced concrete, thickened pipeline walls, cathodic protections, or capping the pipe with a protective concrete slab. Figure 2 (2), taken from the AASHTO guide, illustrates several methods for providing pipeline protection in addition to the use of casing pipes.

Pipeline crossings exist where these other methods of protection have been used successfully. A case history included in the NCHRP report (1) documents more than 200 such crossings in Georgia, Mississippi, and Tennessee.

In 1971 the Colonial Pipeline Company petitioned the Georgia Department of Transportation to permit uncased crossings associated with the construction of a new 158-mile-long transmission pipeline. Uncased pipeline carriers, ranging in size from 10 to 36 in. in diameter, were installed at 121 highway crossings.

Figure 3 (7) illustrates the cross section for a typical, uncased, 36-in.-diameter transmission petroleum products pipeline. Pipeline walls are 3/8-in. grade X52 steel, which is approximately one-third greater in wall thickness than normal line pipe. The surface of the pipe is double coated with asphalt or coal tar emulsion, and a 1-in.-thick concrete coating with steel wire mesh provides additional protection.

The pipe is placed with greater-than-normal earth cover below highway ditches, and cathodic protection test points are located at the highway right-of-way line.

The external diameter of the assembly is approximately 39 in. The concrete-coated carrier pipe is inserted during the same process that the crossing is bored. In this case the space between the coated pipe and the bored hole is filled with urethane foam to minimize settlement and prevent water damage to the highway subgrade.

Following the uncased construction in Georgia, Colonial Pipeline Company was permitted to install uncased crossings in Mississippi and Tennessee. In 1972 more than 60 uncased crossings of 10-in.-diameter transmission pipeline were constructed in Tennessee. To date there have been no reports of pipeline failures at any of the more than 200 uncased pipeline crossings.

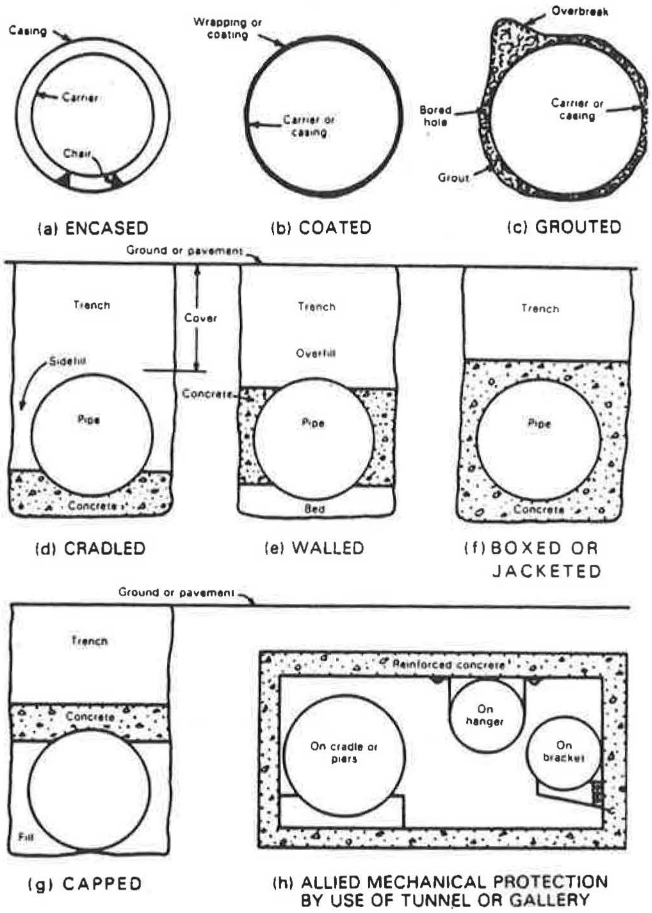


FIGURE 2 Alternate methods for protecting pipelines at highway crossings *(2)*.

SUMMARY

Recognition of the importance of both freeway and pipeline networks suggests that they should be protected from each other at freeway crossings. Just as crossings should be designed to minimize the utilities' interference with traffic and highway operations, so too should the impacts on utility operations of highway maintenance and future highway expansion be taken into account.

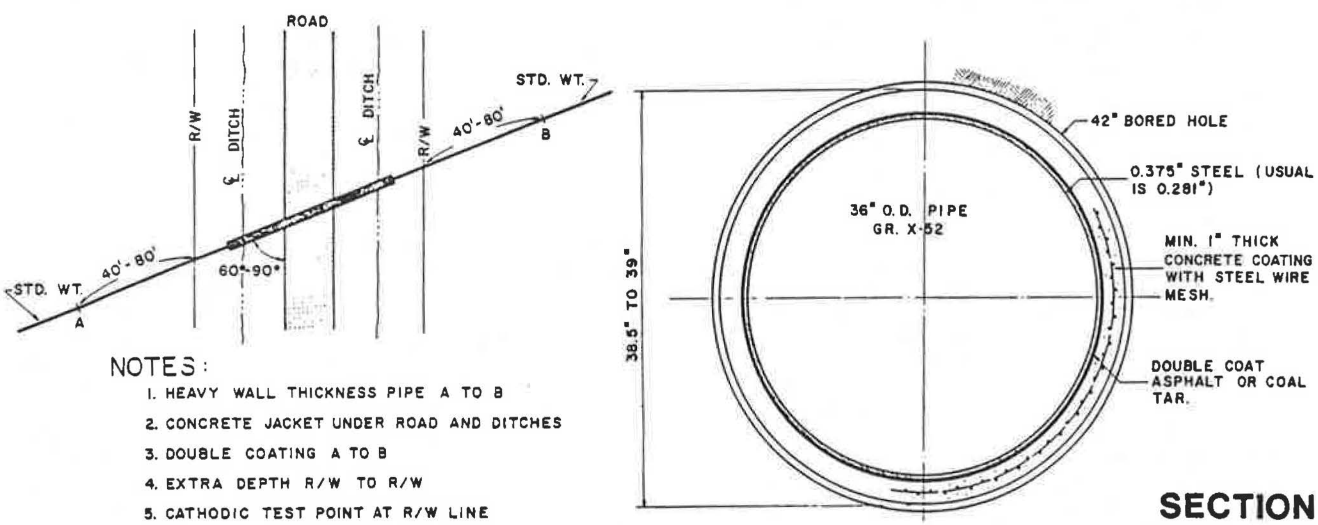


FIGURE 3 Typical uncased road crossing *(7)*.

Even industry does not suggest that casing pipes be eliminated all together. They acknowledge that there are certain instances when a casing pipe may provide optimum crossing protection. When evaluating a specific pipeline crossing location, all methods available to provide protection to both pipeline and highway should be considered.

ACKNOWLEDGMENT

Research conducted by Byrd, Tallamy, MacDonald and Lewis, a division of Wilbur Smith and Associates, has been summarized in this paper. The research was sponsored by AASHTO, in cooperation with the FHWA, and was conducted in the NCHRP, which is administered by the Transportation Research Board of the National Research Council.

REFERENCES

1. Encasement of Pipelines Through Highway Roadbeds, Final Report. NCHRP, Project 20-7, Task 22. TRB, National Research Council, Washington, D.C., March 1983.
2. A Guide for Accommodating Utilities Within Highway Rights-of-Way. AASHTO, Washington, D.C., 1982.
3. Pipeline Safety Regulations. U.S. Department of Transportation, April 1, 1982, Title 49, Parts 192, 195.
4. Michigan-Wisconsin Pipeline Company, Monroe, Louisiana. Pipeline Accident Report NTSB-PAR-75-1. National Transportation Safety Board, Washington, D.C., March 2, 1974.
5. Colonial Pipeline Company Petroleum Products Pipeline Failures, Manassas and Locust Grove, Virginia. Pipeline Accident Report NTSB-PAR-81-2. National Transportation Safety Board, Washington, D.C., March 6, 1980.
6. Manual for Railway Engineering. American Railway Engineering Association, Washington, D.C., 1972, pp. 1-11.
7. J.E. White and W.F. Saylors. Uncased Pipeline Crossing Transportation Arteries. In Transportation Research Record 483, TRB, National Research Council, Washington, D.C., 1974, pp. 14-23.

Publication of this paper sponsored by Committee on Utilities.

Determination of Cost-Effective Roadway Treatments for Utility Pole Accidents

CHARLES V. ZEGEER and MICHAEL J. CYNECKI

ABSTRACT

The purpose of this study was to determine the cost-effectiveness of alternative utility pole treatments. The study involved a large-scale data-collection and analysis effort to quantify benefits and costs associated with the following countermeasures: (a) placement of utility lines underground, (b) relocation of poles further from the roadway, (c) reducing the number of poles, (d) combinations of pole relocation and reducing pole density, and (e) use of breakaway poles. Expected accident benefits were computed for various countermeasures based on an in-depth analysis of accident and roadway data in four states. Countermeasure costs were obtained from telephone and electric utility companies around the country. Placing the utility lines underground and pole relocation were found to be cost effective for telephone and electric distribution lines for a variety of traffic and roadway conditions. Reducing pole density through multiple pole use was also cost effective in some instances, but increasing pole spacing was generally not cost effective. No countermeasures involving large transmission poles and lines were cost effective within the limits of the analysis. General guidelines were developed for selecting cost-effective countermeasures under various combinations of pole offset, traffic volumes, pole density (spacing), roadside conditions, and type of utility poles and lines.

Considerable emphasis has recently been given to the development of countermeasures to reduce or eliminate accidents involving fixed objects. Utility poles have been identified as a major roadside hazard. In 1976 Graf et al. (1) estimated that utility pole accidents accounted for more than 5 percent of the nationwide accidents, more than 5 percent of the nationwide traffic fatalities, and more than 15 percent of the deaths resulting from fixed-object accidents. In 1980 NHTSA reported that 1,840 of 10,329 fatal fixed-object accidents (17.8 percent) involved a utility pole, which was second only to trees and shrubbery (2). Jones and Baum (3) analyzed more than 8,000 single-vehicle, fixed-object accidents in urban and suburban areas in 1980 and found that util-