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subject areas
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13 land acquisition
22 highway design

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CONTENTS

FOREWORD

The papers in this RECORD examine various aspects of utility and highway coordination.

Kaston examines the need for coordination and communication among utilities, local government agencies, state transportation agencies, and construction contractors in coordinating safe working conditions for construction workers and the welfare of the people in close proximity to construction sites. The author places the responsibility of communication on the utilities and states that they must constantly communicate their needs and wants for work-site safety and damage prevention. The author then lists methods by which a workable communications system may be established.

Hoffman examines the practices and problems involved in accommodating utilities in rights-of-way of public streets. The paper identifies the best current practices, indicates areas where further research and improvement are needed, and points the way toward alleviating some of the most widespread and serious problems.

White and Saylors are concerned with new design for uncased pipelines crossing transportation facilities and requirements by the U.S. Department of Transportation that all new pipelines be 100 percent cathodically protected. A number of new design features are presented in this paper.

Peacock compares the telephone network with the system of local, state, and national streets and highways in the United States and contends that there is a direct analogy between the various classes of roads and their counterparts in the Bell System network. He then examines the waveguide system now under development at Bell Laboratories and its effect on land use, suggesting that land use be minimized by placing waveguide on Interstate right-of-way where the routing is coincident and where the right-of-way is adequate to permit economic construction without disruption to highway usage or safety.

UTILITY AND HIGHWAY COORDINATION TO IMPROVE SAFETY

George Kaston, Consumers Power Company, Royal Oak, Michigan

Most utility facilities are buried in public rights-of-way and are vulnerable to damage during road improvements and construction. Utility companies in southeastern Michigan have begun a joint damage prevention program among utilities, local governmental agencies, state transportation agencies, and construction contractors. To communicate their needs and wants for work-site safety and damage prevention, the utilities must establish a workable communication system that involves obtaining knowledge of future road improvement projects, developing a consistent reciprocal information exchange between utilities and roadway design groups, attending and participating in prebid and preconstruction meetings, providing a 1-number telephone communication system for use in locating underground facilities, and launching a vigorous promotional program among governmental agencies and construction contractors on the theme that damage prevention is everyone's business. The American Public Works Association is promoting national acceptance of 1-number communication systems.

•ALL OF US in the gas utility business are concerned with the preservation of our underground systems because we are interested in the continuity of service to our customers and we are concerned with the hazards presented by our product when it is not contained safely within the pipes that carry it. This concern is also great with those in the electric and communications utilities.

Most utility facilities are buried in public rights-of-way. Each year road improvements in the form of drainage, paving, road widening, and expressway construction give construction contractors many opportunities to damage underground facilities. The utility companies in southeastern Michigan have begun a joint damage prevention program.

Communication among utilities, local governmental agencies, state transportation agencies, and construction contractors is the prime factor in coordinating safe conditions for construction workers and the public in proximity to construction sites and in providing less inconvenience to public use of rights-of-way.

To gain the attention and to earn the cooperation of roadway designers and construction contractors, the utilities must communicate constantly their needs and wants for work-site safety and damage prevention. Methods to accomplish a workable communications system are obtain knowledge of future road improvements projects, develop a consistent information exchange between utilities and roadway design groups, attend and participate in prebid and preconstruction meetings, provide a 1-number telephone system for use in providing information on the location of underground facilities, and promote the idea among governmental agencies and construction contractors that damage prevention is everyone's business. The American Public Works Association is promoting a national formula to encourage national acceptance of 1-number communication systems.

The gas distribution network of Consumers Power Company in the lower peninsula of Michigan has 17,000 miles of gas mains. There are 910,000 gas customers, about half located in the 3 counties surrounding the city of Detroit. In many of the suburbs, the first utilities are water wells and tile fields for sanitary purposes. Generally the next utilities are electric service and gas main extensions. Some years later water mains and sanitary sewerage facilities are installed. Roads must then be widened to keep pace with population expansion, and the excavation for these roadbeds gives opportunities for construction equipment to damage buried utility facilities.

In the greater metropolitan area of Detroit, there are more than 2,500 excavating contractors, all able to locate our facilities the "instant way" by using the fastest facility locater—backhoe, trenching machine, or dozer. How do we work with the contractor to prevent "dig-ups"? We must make it convenient for him to communicate his wants in the area of underground facility location. In the spring of 1970 a committee of enthusiastic utility people formed a Damage Prevention Committee as a joint venture to attack the problem of contractor damages.

In many areas of Michigan, ordinances have driven the electric and telephone companies underground. As they have jointly used poles, they will now jointly use trenches. Many miles of electric and telephone cable have been placed underground, and interest in damage prevention has risen sharply in these vital utility organizations. It has become apparent that all utilities have a common denominator called "underground damage prevention."

In November 1970 we formed the Utility Location and Protection Service on a trial basis in the South Oakland Division of Consumers Power Company. This area contains 138 square miles and has electric service by Detroit Edison, telephone service by Michigan Bell, some miles of transmission facilities of Michigan Consolidated Gas, and gas utility service by Consumers Power Company. Because the gas utility has the most to gain through a positive damage prevention program, Consumers Power Company felt that it should stimulate a joint venture.

The committee members from the 4 utilities who were engaged in this program thought that all the intricate details should be confined to a small and controllable area. At the outset, we wanted to make certain that our degree of success could be carefully measured and our program could be developed with positive results before we expanded to a larger area.

In February 1971, after 3½ months of successful experience, we held several open houses for municipal government people, contractors, and consulting engineering firms to acquaint them with our joint-utility Damage Prevention Program. People who attended realized that the southeastern Michigan utilities were sincerely asking for assistance in making the communication program successful.

Estimating costs of damages caused by dig-ups of underground facilities of the 4 utilities is difficult. Estimates can be made for costs of gas main and service repairs to damage caused by outside contractors, but are difficult to make for continuity of service, real or potential hazards, and public image.

Early in 1970 we appointed Division Construction Coordination Supervisors whose mission is to carry an appeal to various municipalities, contractor organizations, consulting engineering firms, and to whoever else might have occasion to excavate. We found that a positive and enthusiastic appeal to excavators to call before they dug was well received. Converted to numbers, MISS DIG becomes 647-7344, the phone number used. The convenience of a 1-call system to obtain the locations of facilities of all participating members was met with enthusiasm by contractors.

The telephone call is received on one of 7 private lines to the call center at the service center of the South Oakland Division of Consumers Power Company. These calls come in by private circuitry and not through the company switchboard. Teletype equipment at 55 individual sites is used to dispatch contractor excavation information selectively to the southeastern area of Michigan so that not only do utilities have information of pending excavation but many municipal public works departments as well receive the information on teletype terminals. Trained personnel can receive as many as 7 calls at once and transmit, within minutes, the excavation contractor's request for locating and staking underground facilities (Fig. 1).

Located in the call center is an 8-track tamper-proof tape recorder to maintain accurate information on the request. It is very easy for a caller to say that he is putting in a sewer lateral on North Alexander Street when he really meant South Alexander Street.

Each call is given a serial number for record purposes. The information obtained is the extent, location, and time of the work to be performed. When the order has been dispatched to the participating utilities and municipalities, the time is again noted by use of a time stamp machine (Fig. 2). In this manner we can exercise management controls relevant to rapid information transmission. High-speed teletype tape preparation machines are used to transcribe the contractor information for all program participants. The teletype tape machine prepares a tape that runs at the rate of 100 words per minute (Fig. 3). In the near future, computerized selection of member utility underground facilities will allow more rapid transmittal of information and will aid in further expansion of the system.

In designing the teletype network, the joint utility committee decided that the receiving units at the various participating headquarters would be able to receive but not to send messages to prevent the equipment from being used for purposes other than contractor damage prevention.

The next step in the communication system is to get the word of proposed excavation out to locating and staking crews. All 4 utilities, and most of the participating municipal groups, are in a position to locate their underground facilities if given a 24-hour notice.

Early in the program, we found it necessary to equip locating and staking crews with "instant" information. We also found it wise to select top-notch people from our Operating Group to do the locating and staking of gas facilities. The radio-equipped van type of vehicle, we have found, is the most flexible for our locating and staking program. These vehicles are equipped with the latest pipe-locating devices, microfilm records of all service leads into buildings, and all gas main record maps, including abandoned facilities. The 24-power viewer that is used in the locating and staking vans has been invaluable for instant information (Fig. 4).

We have felt for many years that the combination of good facility records and pipe-locating devices and training in the use of locating equipment has given us excellent pipe-locating abilities. Some of our sister utilities have taken the same approach as we have: The locating and staking personnel should not be selected from the "walking wounded." The sharp operator, given good tools, equipment, and encouragement, soon learns that he is the vital link in the Damage Prevention Program.

Field records of gas service lines, gas mains, and abandoned gas facilities are recorded on microfilm (Fig. 5). We have the ability to update changes of our field records on a weekly basis. In this manner our field crews have up-to-date knowledge of all gas facilities.

A very significant segment of our total damage prevention picture is the engineering function of preplanning and coordinating well in advance of paving, sewer construction, and water construction. In our division we have a civil engineer who devotes most of his time visiting consulting engineering firms, the state highway department, and municipal engineering departments to obtain information on forthcoming excavation work. Many times in the preplanning stages of municipal engineering work, we have been able to eliminate expensive relocation of our facilities and also to acquaint the design people with the location of our facilities so they can be inserted into the various civic construction plans.

Although we spend a considerable amount of time and effort on engineering planning coordination with the state highway department and the various county road commissions, we too often find ourselves running only 2 jumps ahead of a paving contractor who was awarded work not known to the utilities until almost the last hour. We realize that occasionally funding allocations are changed and priorities reassigned among civic improvement jobs, but we make an appeal to be given an opportunity to work ahead of roadway improvements in a coordinated fashion so that delays and economic losses can be minimized. Utility poles, underground cables, and gas facilities serve the same public for whom roadway improvements are constructed.

Since November 1970, when the MISS DIG program was launched, we have been constantly promoting the interest of various contracting agencies and municipal agencies in southeastern Michigan. We have had many meetings to discuss mutual problems in the prevention of damage to buried facilities. Communication is the key to a good damage prevention program, and MISS DIG is a communications method (Fig. 6).

The toughest hurdle in the development of our 1-call Damage Prevention Program was the preparation of an acceptable contractual agreement among the 4 primary parties.

Figure 1.

Figure 2.

```
WO 3-919
CITY  SOUTHFIELD   DATE  3-27-72   TIME REC  805 AM
LOCATION OF WORK  NINE MILE AND INKSTER AREA WORKING ON THE E SIDE
OF INKSTER RD IN THE 1 ST BLK S OF NINE MILE AND E OF SEMINOLE
ALSO ON THE N AND S SIDE OF SEMINOLE WITHIN 300 FT OF INKSTER RD
STARTING DATE AND TIME  3-28-72 8 AM
TYPE OF WORK  WATER MAIN AND SEWER
NAME  MR CAVALLORE
CONTRACTOR  CAVALLORE CONST CO
PHONE   KE 19320 X 26        BEST TIME TO CALL  8-5
EXTENT OF WORK   ATT ALL UTILITIES CONTRACTOR WOULD LIKE TO MEET WITH
YOUR REPRESENTATIVES ON JOB SITE 3-28-72 8 AM ASK FOR TONY COMPANY
SUPT PLEASE CALL IS UNABLE TO KEEP APPT
```

Figure 3.

Figure 4.

Figure 5.

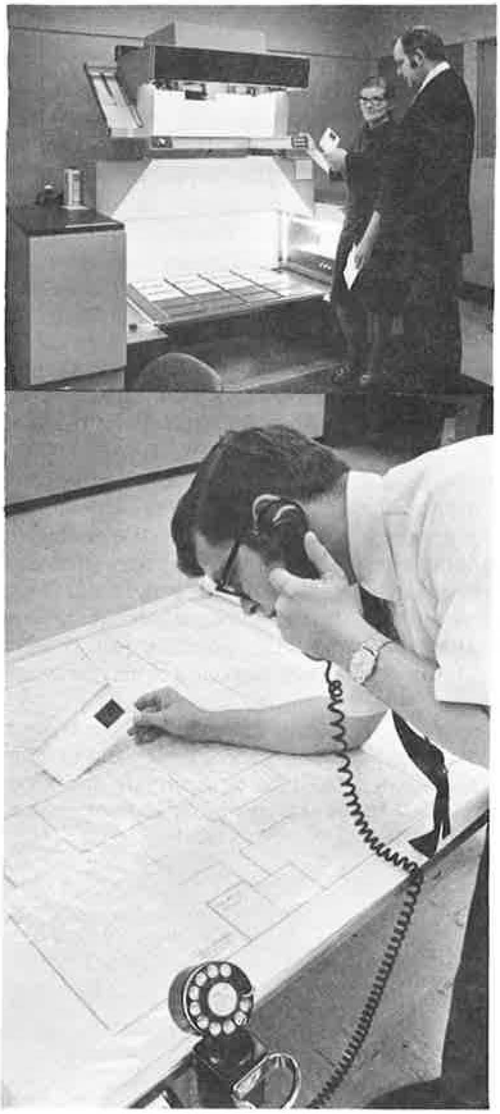


Figure 6.

Table 1. Gas lines damaged in southeast division of Consumers Powers Company in metropolitan Detroit.

Year	Units of Site Visits and Staking	Damages	Damage per 100 units[a]
1969	42,358	2,630	6.2
1970	100,389	2,065	2.1
1971	154,541	2,861	1.8
1972	212,390	1,910	0.9
1973	263,489	1,923	0.7

[a] Units of construction site visits to locate and stake (a) each main crossing or each 50 ft of parallel main and each gas service and (b) to inspect construction job in progress.

The Damage Prevention Committee of the 4 utilities found it prudent to develop the program and get a solid foundation under it before it was taken to the individual legal departments. It seemed that, for every statistic of safety and damage prevention that was given to the lawyers, they would find 3 or 4 ways to say "but the liability." After locking up a pair of attorneys for each of the participating utilities in 2 sessions, an agreement was hammered out to the satisfaction of all participants.

The MISS DIG Communication System is administered by members of each of the 4 primary participants. The committee comprises a working member from each and an alternate who is often a specialist in maintenance of plant facilities, a construction supervisor, a computer programmer, or a communication technician. The committee gives a great deal of latitude to its chairman who, for practical purposes, represents all 4 utilities under the title of Executive Secretary. The present secretary is Division Gas Supervisor of the South Oakland Division of Consumers Power Company and devotes all of his time to coordinating damage-prevention activities for all 4 utilities.

We have found it beneficial to have a knowledgeable, public-relations minded individual who can speak for all 4 utilities to contractor groups and municipal organizations and also act as a coordinator for this joint venture.

At present, the 4 utilities are sharing the expense of operating the call center. We are accepting negotiated fees from 26 secondary parties who have teletypes to receive information pertinent to their individual operating areas. A number of pipeline companies and municipal water systems have indicated an interest in participating in our 1-call system and will probably join the communication system in the near future. The negotiated fees from secondary parties help defray the expense of operating the call center.

As we increase the number of locating requests, we increase the number of locating and staking activities and construction site visits (Table 1). The refinements in staking techniques, up-to-date equipment, and an enthusiastic work force have allowed us to accept this increase in operating expenses of the Damage Prevention Program.

ASSESSMENT OF THE CURRENT STATE OF THE ART OF ACCOMMODATING UTILITIES IN PUBLIC STREET RIGHTS-OF-WAY IN THE UNITED STATES AND CANADA

Robert J. Hoffman, American Public Works Association, Chicago

This paper examines the practices and problems related to accommodating utilities in public street rights-of-way, identifies best current practices, indicates areas where further research and improvement are needed, and points the way toward alleviating some of the most widespread and serious problems. The paper is based on information derived from field interviews in 20 metropolitan areas, a comprehensive mail survey of practices in 222 municipalities, traffic delay tests in 16 areas, and a literature search conducted in the course of a research project. Some of the major conclusions and recommendations are as follows: Diffused utility ownership and control arrangements inhibit a total systems approach toward implementing improvements in the broadest possible public interest; local utility coordinating committees can be effective instruments for resolving conflicts; city planning and utilities planning are often carried on as independent efforts, and utility considerations are either ignored or subordinated to other concerns in the planning process; utility location record systems are generally inadequate; municipal inspection programs do not always ensure that pavement is properly restored over utility trenches; workable local utility location standards should be developed, and efforts should be made to develop models for optimum locational solutions; additional studies are needed to resolve controversy over the advisability of joint trenching; additional research is needed to improve utility delivery systems; and the effects of lane closures on traffic may be less than popularly believed.

•THE AMERICAN Public Works Association is conducting a comprehensive and intensive study of utility accommodation practices. In this study an extensive search of pertinent literature has been made, week-long interviews have been conducted among local governmental and utility company officials in 20 metropolitan areas, a comprehensive mail survey has been conducted with responses from 222 municipalities, and field tests have been performed by 16 municipalities to determine the effects of lane closures on traffic. This work will result in the publication of a state-of-the-art report and a manual of recommended practice, which will have the sanction of the American Public Works Association. This report was written during the data analysis phase of this project and represents only the preliminary personal views of the author.

Practices for accommodating utilities in public street rights-of-way vary widely among communities in the United States and Canada. There are, however, a set of organizational arrangements, regulatory and control mechanisms, and problems common to most communities. An examination of these practices and problems can identify best current practices, indicate areas where further research and improvement are needed, and point the way toward alleviating some of the most widespread and serious problems.

A series of utility networks lace all urban communities with webs of cables and pipes that provide essential energy, communication, water, waste disposal, drainage, and other services and commodities that make modern urban life possible. For the most part, these utility networks are superimposed over, and coincident with, the network of urban roads and streets. Most of the existing electric power, telephone, and other cable-transmitted services are strung overhead on poles located in street rights-of-way and rear-lot easements although there is a noticeable trend toward placing new distribution systems underground and converting existing aerial facilities to underground.

This trend, compounded by continued urbanization of the country, population growth, increased per capita demands for utility services, and the advent of new utility services such as cable TV (and perhaps others such as pneumatic tubes and vacuum waste collection systems), will increase the congestion of subsurface space and the problems attendant to this congestion.

Accidental utility line "dig-ups"—a serious nationwide problem—are but one manifestation of the problem. The crowding of subsurface space, the haphazard location of many older utility lines, and the lack of reliable utility location information complicate the problems of installing and maintaining underground utility systems. The need to protect workmen, pedestrians, vehicles, and neighboring utilities; to minimize traffic delays and inconvenience to abutting properties; to reduce noise; and to prevent other environmental detriments has made utility work in street rights-of-way difficult and costly, and adverse side effects still occur in spite of efforts to minimize them. The number of different types of utilities found in most city streets and the diffuse pattern of utility ownership and management responsibilities make coordination of utility work in street rights-of-way difficult.

Many governmental agencies have developed mechanisms to alleviate these problems and to provide for more efficient and orderly use of space. Some of these approaches appear to be working well. Agencies not now employing these proven practices would do well to adopt them. In other instances, however, the identification of "best" practice is not so clear-cut—only subjective judgments are available to assess the relative costs and benefits. Even when assessible, practices that work well under one set of circumstances may not work so well under others. Not enough is known about the effects of institutional and environmental differences among communities to predict the successful transferability of particular arrangements from community to community. Local adaptations may be necessary to implement identifiable "good" practices. In some areas, no models appear to exist. Better approaches must be conceived. Additional research and development would be useful, particularly to improve product reliability, reduce size, and decrease cost. Following are some observations about the state of the art of utility accommodation practices and what is needed to improve it.

A TOTAL SYSTEMS CONCEPT

In the United States, and to only a slightly lesser extent in Canada, the provision of the array of utility services is characterized by a pattern of diffused ownership. Water and sewage service is usually provided by a publicly owned agency—municipality, special district, or authority—although there are a number of investor-owned water utilities. Electric power, telephone, and natural gas are typically investor-owned utilities although there are a number of municipal and other publicly owned electric and gas utilities. Street lighting and emergency signal systems may be owned and operated either by public agencies or investor-owned companies.

Twelve different types of utility services are provided in most urban areas. In a recent APWA survey, the following percentages of respondents indicated the presence of the named utility in their communities.

Utility	Percentage
Water	99+
Sanitary sewers	96
Storm sewers	97
Gas	98
Electric power	99+
Telephone	99+
Telegraph	67
Cable TV	51
Street lighting	97

Utility	Percentage
Traffic signal cable	92
Police signal cable	53
Fire signal cable	69
Combined sewers	41
Steam lines	18
Chilled water	6
Other	5

Typically, 1 municipal department, 2 other governmental agencies, and 4 investor-owned companies provide utility service in a municipality although the total number of different utility agencies reported in one community runs as high as 27.

A number of different agencies and municipal departments are involved in the utility regulatory, planning, or control process. Typically, a state public utilities commission or a public services commission regulates utility rates and may prescribe certain practices such as undergrounding. The state legislature or city councils or both may grant utility franchises and impose certain restrictions. A local planning commission may establish subdivision regulations and zoning districts that affect utilities. The public works department or city engineer may regulate street openings. The traffic engineering or police departments may regulate lane closings and traffic protection measures. A state agency may prescribe safe work practices. A state highway department may regulate utility work in state rights-of-way passing through municipalities.

Each of these regulatory agencies, and each utility service agency (investor-owned or public), has its own clientele to serve, its own interests to protect, and its own limited perspective on the problem of utility accommodation. One wants to maximize the return on investment, one wants to minimize rates, one wants to protect workmen, one wants to reduce traffic congestion, one wants to prevent damage to the pavement, one wants to beautify the community, and so on. Measures designed to optimize one of these objectives often conflict with others. Each resolution of a problem ultimately has an effect—real, but not measured—on a variety of groups: the utility company and its customers, the municipality and the taxpayer, the motorists, the abutting property owner or resident, and a number of other affected groups.

Under present diffused ownership and control arrangements, there is no incentive (and plenty of disincentives) to look at total systems costs—the sum total of the effects of accommodation practices on all affected parties. Consequently, the net total effect of existing practices is unknown; neither is it known whether proposed changes will have a net beneficial or negative effect.

There are immense theoretical and practical problems to be overcome both in determining total system costs and in applying this concept to real-world situations. Where to draw the boundaries of the system, i.e., what costs to include, and how to measure or recognize certain environmental and social effects are both problems. Minimum total system cost solutions, which result in the redistribution of immediate costs and benefits among affected parties, may be difficult to implement because of the political and economic power of the affected groups. In spite of these difficulties, it seems advisable to develop mechanisms for providing a broader perspective on the problems, for evaluating trade-offs, for resolving conflicts, and for implementing solutions in terms of the broadest possible public interest.

UTILITY PLANNING AND COORDINATION

Utility coordinating committees, composed of representatives of investor-owned utility companies, governmental utility agencies, regulatory bodies, and other interested groups, have been formed in a number of communities in the United States and Canada to coordinate their plans and programs for their mutual benefit. The composition, structure, legal status, authority, activities, and effectiveness of these organizations vary from place to place. In most cases, these committees are organized on an informal basis, meet on call as an occasion arises, and have no powers, responsibilities, or continuing programs except to serve as a focal point for the exchange of information and the resolution of problems through the mutual consent of the participants.

In a minority of cases, the committees are formally organized with officers and by-laws, meet on a regularly scheduled basis, employ a staff, have an operating budget (financed from assessments levied on participating agencies), have authority to recommend decisions to some higher authority (in a very small number of cases, to make binding decisions), and carry out some on-going programs that may include centralized record keeping, public information campaigns, "1-call" and "locate-and-stake" programs, the development of utility location guidelines or standards, and the coordination of plans and programs of the participating agencies.

These voluntary utility coordinating committees clearly perform a useful service and should be formed where they do not exist. (Forty-six percent of the communities in the United States and Canada have no utility coordinating committee, either formal or informal.) Although the structure and programs of these committees should reflect local needs and circumstances, the successful groups tend to be organized on a formal basis with adequate staff and fiscal resources.

Although utility coordinating committees can be effective coordinating instruments and may be able to focus attention on various planning problems, in most cases they do not have the authority to determine certain public policies and plans that directly bear on the utility-accommodation process. In too many cases overall city planning and utility planning are carried on as independent efforts. City plans are developed—and changed—often with little regard for the effects of those decisions on the utility networks. Rezonings and unplanned high-density developments can have major impacts on the utility system, requiring the installation of miles of new trunk facilities and the attendant street openings and traffic disruptions. Vacating existing street or alley rights-of-way can eliminate necessary access to utilities in those rights-of-way. The granting of building encroachments into the subsurface space within rights-of-way can preempt an alignment needed for utility purposes.

Thoroughfare plans are developed primarily to meet transportation needs; little attention is given to utility space requirements. Right-of-way widths are set to accommodate traffic and parking lanes, sidewalks, and planting strips. Utilities must then fit into available space as best they can. Little thought is given either to providing adequate space for utilities or to organizing space utilization in a manner that will minimize conflicts in using that right-of-way for both transportation and utility purposes.

When highway grades, alignments, or widths are changed, utilities are usually required to relocate at their own expense. Too little thought is given to planning for this eventuality. Many municipalities do not have long-range capital improvement plans for streets and municipal utilities and do not adequately coordinate development plans to avoid the cutting of new pavement for utility work. When acquiring additional right-of-way for street improvements, most municipalities do not obtain extra right-of-way that is needed for either municipal or investor-owned utilities.

In practice, utility considerations are practically ignored in the planning process, and utility rights in public rights-of-way are definitely subordinated to other interests. The result is not in the public interest. Better understanding needs to be developed of the interrelations between city and utility planning. Utility concerns should be better represented in the planning process, better capital improvement planning should be undertaken, and additional efforts should be made to communicate and coordinate decisions and plans with affected parties.

RECORD SYSTEMS

The comprehensiveness, accuracy, currency, and accessibility of utility location maps and records vary from municipality to municipality and from utility to utility. There are some excellent record-keeping systems, but most are deficient in one or more respects. Common deficiencies include failure to record as-built conditions (field changes are often made from planned alignments and not noted), out-of-date records (locations may be referenced to original features such as curbs that may subsequently have been relocated), delays in updating maps (months of field notes may be backlogged), errors in field measurement or in plan dimensioning, incomplete records (no records exist for many older systems), and failure to show service connections.

Generally each utility is responsible for keeping records of the location of its own facilities. Central repositories of information on the location of all utilities in public street rights-of-way are uncommon, and most of these are incomplete.

The vast majority (99 percent) of municipal location records exist in the form of engineering drawings or utilities maps. Microfilm records are kept by about 23 percent of the municipalities, and only 1 percent of all municipalities use computerized records. Five percent of all municipalities use a geocoding coordinate system for storing utility data.

Improvements are clearly needed in utility record-keeping systems and procedures. Greater care and effort should be devoted to gathering and recording utility location information; available technology for information storage, processing, and retrieval should be more widely utilized; and mechanisms should be developed and implemented for facilitating the compilation of all utility location information in a particular area either through centralized record-keeping arrangements or through the use of modern telecommunication links to the individually maintained record systems of all utility agencies.

FIELD LOCATION AND SUBSTRUCTURE DAMAGE PREVENTION

Most utilities are actively engaged in substructure damage prevention programs. Eighty-seven percent have a "call-before-you-dig" program, although in only 35 percent of the communities is there a central telephone number to reach all utilities. Almost all (95 to 98 percent) of the water, sewer, gas, telephone, and power utilities provide a field service to locate buried facilities. However, a sizable portion (30 to 50 percent) of these programs depend entirely on records to mark the location of buried utilities (as indicated previously, record systems are not always reliable). Instruments are used about 50 to 60 percent of the time, and in only about 13 to 15 percent of the cases are the lines actually uncovered by test digging.

Additional efforts are needed in this area. Call-before-you-dig and locate-and-stake programs should be installed in all areas; more intensive public and contractor education programs should be undertaken; convenient 1-call systems should be developed to encourage public cooperation; less reliance should be placed on records to locate underground utilities, and more use should be made of instruments and hand digging to verify locations; and better instruments should be developed, particularly for locating nonmetallic conduits.

PERMIT AND INSPECTION PROGRAMS

In almost all communities the use of street rights-of-way for utility purposes is regulated by the municipality. Permits are normally required to cut street pavement except in emergencies. Fees are normally charged for each permit, and performance or surety bonds are normally required from private contractors and frequently required from utility companies. Municipal departments are often exempt from these permitting requirements.

Permits normally regulate or specify the extent and method of work (open cutting is prohibited under certain circumstances), hours of work, signing and barricading, vehicular and pedestrian safety measures, protection of other utility facilities, backfilling, pavement restoration, cleanup, and others.

Although permit requirements are often very stringent, field inspection is often less than adequate to enforce these requirements. Backfilling, compaction, and pavement restoration are most likely to be less than adequately controlled as evidenced by the number of settled utility trenches that exist in most communities.

Generally, municipal permit systems for utility work in street rights-of-way work fairly well. Improvements are needed in the areas of simplifying administrative procedures and making it more convenient for the permittee to obtain a permit; subjecting municipal departments to the same necessary and reasonable procedures and standards required of other utility agencies and contractors; and providing better field inspection, particularly for backfilling and pavement restoration.

PAVEMENT RESTORATION

About 36 percent of the municipalities surveyed performed pavement restoration work with their own forces. Nevertheless, almost all permit the utility company or its contractor to backfill the trench, make the temporary pavement restoration, and maintain the temporary pavement. Municipalities that have chosen this method maintain that it works well for them, although restoration by municipal forces is no guarantee of superior work. Other cities, which have good pavement restoration standards and adequate inspection, report satisfaction with the restoration work performed by utility companies or their contractors. Each municipality must judge the adequacy of its own procedures, identify the cause of any deficiencies, and apply its own remedies. One improvement that might prove of general benefit, however, is in the area of backfill materials. Some cities have experimented with "unshrinkable" fills (a weak soil-cement mixture) and mixtures of crushed pavement and excavated spoil with good results.

UTILITY LOCATION STANDARDS

A number of communities have developed guidelines to standardize the location of utilities in street rights-of-way and to use scarce space more efficiently. These standard locations vary from community to community, and clear-cut patterns are not easily discernible. Each local standard appears to be a product of a number of organizational, technical, traditional, environmental, and other considerations unique to that community so that transferability to other areas is indeterminate. There is little documentation to indicate why, or by what process, the final determinations were made. The rationale for supporting particular locational preferences is weak in many cases.

Although there undoubtedly is no one best arrangement for all circumstances, there probably is one best arrangement for each particular set of circumstances. To formulate a model by which optimum locational arrangements can be developed for each set of circumstances may be useful. This, however, is a most complex undertaking because of the difficulty in identifying all the relevant constraints, requirements, and variables; the difficulty in identifying and measuring the effects of various locational alternatives on total system costs or some other indicator of overall system effectiveness; and the lack of uniform data on utility installation and maintenance costs, among others.

The potential benefits of this approach, however, would seem to warrant the pursuit of this model. If "optimum" utility arrangements cannot be identified, "workable" arrangements that provide for some regularity and predictability in utility locations within a community would be of considerable benefit and should be developed.

JOINT-USE FACILITIES

The joint use of utility poles by 2 or more utilities is widely practiced to cut costs and minimize street clutter. Joint trenching, however, is not so widespread. It is common practice in only 22 percent of municipalities surveyed, and an exceptional practice in 37 percent of these municipalities. It is not practiced at all in 41 percent of the municipalities. The most common joint trench combinations place water and sewer lines in the same trench and electric and telephone lines in the same trench in various combinations with telegraph, cable TV, and other signal cables.

There is much controversy over whether joint trenching is advantageous or detrimental from a cost, safety, and compatibility standpoint. It is encouraged in some places and discouraged in others, and there is no clear-cut consensus. Additional studies are needed to resolve this question.

EFFECTS OF LANE CLOSURES ON TRAFFIC

The opinion is widely held that lane closures for utility work in street rights-of-way have a major impact on traffic and create congestion, delay, increased travel costs, and environmental pollution.

A number of measures, such as limiting the amount of street to be closed at one time or restricting the hours of work to off-peak hours, have been devised to minimize these problems and are widely used. These measures, which significantly increase the cost of performing utility work in street rights-of-way, have been developed in response to public pressures and are assumed to be justified. However, studies have not determined the costs of such lane closures and the costs of such palliative measures or compared the two.

Some field testing performed by a number of municipalities on city streets for the American Public Works Association supports the conclusion that controlled lane closures on the majority of municipal streets during off-peak hours have a minimal effect on traffic. Additional testing is required to determine the effects of severe lane closures on streets operating at or near capacity. Such testing would provide valuable information for developing optimum regulations and procedures for traffic controls at work sites and should be undertaken.

MATERIALS AND PROCEDURES

During the years, a number of improvements have been made in pipe, joints, cable, and other materials used in utility installations. Such improvements, which increase reliability and extend the useful life of facilities, can pay dividends in reduced maintenance and other costs during the life of these installations. Continued product improvements should, of course, be encouraged. However, more economic studies that use a total systems cost approach should be performed to determine to what extent higher first costs for improved products can be justified over the long term. Once determined, these analyses should guide engineering practice.

Technological innovations such as the telephone "wave-guide" transmission system, which greatly increases the number of messages that can be sent through a limited space, could produce dramatic improvements in the utilities field. Procedural innovations, such as direct burial of cable, could also be useful. The delivery systems of many utilities, however, remain essentially unchanged from earlier technological eras. More research is needed, and should be undertaken, to improve these delivery systems.

CONCLUSION

This paper has sought to analyze the current state of the art of accommodating utilities in street rights-of-way, to identify best known practices, and to indicate ways in which improvements might be made. A more extensive analysis of the state of the art and a manual of recommended practice are available from the American Public Works Association.

UNCASED PIPELINE CROSSING TRANSPORTATION ARTERIES

J. E. White and W. F. Saylors, Colonial Pipeline Company

The U.S. Department of Transportation now requires all new pipelines to be 100 percent cathodically protected. However, the use of casing pipe around carrier pipe obstructs the successful application of cathodic protection. Although once necessary because of materials and methods of construction, casing can now be eliminated because of better materials and manufacturing methods, welding procedures, and quality control and inspection methods. In 1971, 3 state highway departments allowed uncased pipes to be used at highway crossings. The following features were incorporated in this new design: Nominal pipe wall thickness increased by a minimum of 20 percent, heavier wall pipe extended 40 to 80 ft on either side of the highway right-of-way, complete X-ray examination of girth welds within right-of-way, pipe coated and wrapped to provide adequate protection and electrical insulation, 1-in. thick reinforced concrete jacket installed on the pipe to be pulled, cathodic protection of pipeline at all times, 3-ft minimum cover provided between pipe and ground surface within right-of-way, and hydrostatic pressure test at 125 percent of maximum operating pressure level for a 24-hour period.

•THIS PAPER will acquaint those persons actively engaged in the design, construction, and maintenance of transportation arteries or in the legislation and writing of rules and regulations governing the installation of pipeline crossings under these arteries with the methods employed by Colonial Pipeline Company in crossing paved roads. This report presents reasons for our favoring the uncased pipeline construction over the encased construction.

METHODS EMPLOYED IN 1971-1972

In 1971 the Colonial Pipeline Company requested and received permission from 3 state highway departments to use a new type of uncased pipeline in highway crossings constructed in those states. The new design incorporated the following features:

1. Increase the nominal pipe wall thickness by a minimum of 20 percent over that used in cross-country pipe,
2. Extend this heavier wall pipe 40 to 80 ft on either side of the right-of-way to provide for future widening of the highway,
3. Perform complete X-ray examination of all girth welds at time of construction,
4. Apply a coating of primer and enamel and wrap the pipe in glass and felt to provide adequate protection and electrical insulation (Fig. 1),
5. Install a 1-in. thick concrete jacket reinforced with wire mesh on the pipe to be pulled to protect the coating during installation (Fig. 1),
6. Maintain complete cathodic protection,
7. Provide a minimum of 3 ft cover between the top of pipe and the ground surface within the right-of-way, and
8. Conduct a 24-hour hydrostatic pressure test at 125 percent of maximum operating pressure level.

The crossings were bored in the usual manner by an auger machine on which was fastened a cutting head on the end of the auger. When the carrier pipe was bored into position, a section of mandrel pipe was welded to the front end of the carrier pipe in which the cutting head could work during the boring procedure (Figs. 2 and 3). When the bore was completed, the cutting head was taken off and the auger removed from the pipe. A specially built pulling head was then tacked to the end of the mandrel section of pipe (Fig. 4), and the concrete-coated pipe was pulled forward and positioned under the highway (Fig. 5). Once the pipe was positioned, the mandrel joint was removed and reused at another crossing. Additional heavy wall pipe then was welded to both ends of the concrete-coated pipe to extend beyond the right-of-way on both sides of the crossing (Fig. 6).

CASING REQUIREMENTS OF THE PAST

In earlier days, casing was necessary for a variety of reasons, the most important of which was the use of mechanical methods for joining sections of pipe. The joints were a constant source of leaks because of corrosion at the joints, uneven settlement of the pipe, or strain that could cause the seal of mechanical pipe joints to break. The casing pipe acted as a conduit that allowed the carrier pipe to be shoved through the casing joint by joint, thus minimizing the danger of damaging the joints (Fig. 7).

Pipe used in the early days was inferior to that of today. The earlier pipe was manufactured from steel of low yield strength, and the longitudinal seam was joined by the butt-weld or lap-weld process. In most cases, the pipe had little or no protection against corrosion, and leaks were quite probable. Thus, the use of casing was necessary, for in the event of a leak the pipe could be withdrawn from the casing and repaired at minimum cost and with little or no inconvenience or hazard to the public.

MORE RECENT DEVELOPMENTS

Many improvements have been made in construction methods, pipe quality, and means of pipe protection. In the early 1900s, joints were welded by the oxyacetylene method; in the 1920s they were electrically welded, and "bare" rods came into use. Although these joining procedures were great improvements over threaded ends and collars, the methods of welding left much to be desired.

In 1930, shielded or coated electrodes or both were used experimentally, and from that time electric welding gained rapid acceptance as strides were made in its development. Beginning in 1946, the use of X-ray offered a means for control of welding quality. This method of checking the deposited weld material locates defects of a significant nature that might affect the strength of the completed joint.

The installation of pipe has further been improved in recent years by close inspection of all phases of construction, improved welding techniques, availability of large and powerful construction equipment, and increased use of nondestructive testing of welds.

The manufacture of pipe also has greatly improved. In the 1920s, seamless pipe was introduced, and electric resistance welded pipe became available in the 1930s. Pipe manufacturers have continually improved the quality of the pipe by various means such as improved quality control, carefully controlled alloying elements, closely controlled rolling temperatures, oxygen injection in open-hearth steel furnaces, and improved weld and test equipment.

The increased use of centrifugal pumps and pressure control and safety equipment in recent years has further reduced the number of leaks occurring from equipment failure and operational causes. Centrifugal pumps develop a constant pressure at a given flow in contrast to reciprocating pumps that produce a variable flow and pressure with each stroke of the piston. Modern equipment accurately controls discharge pressure to a set maximum. If there is an upset in the system, such as power loss at a station or an unexpected valve closure, the control equipment will maintain a maximum discharge pressure by reducing flow, and the backup safety equipment will shut down the pump units on high pump case pressure or the complete station on high discharge pressure if the controller malfunctions.

Figure 1. Uncased pipe.

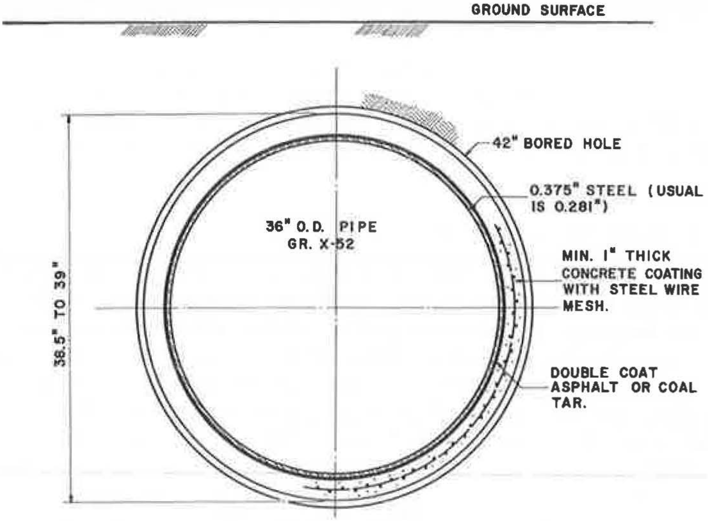


Figure 2. Road-boring equipment and procedure.

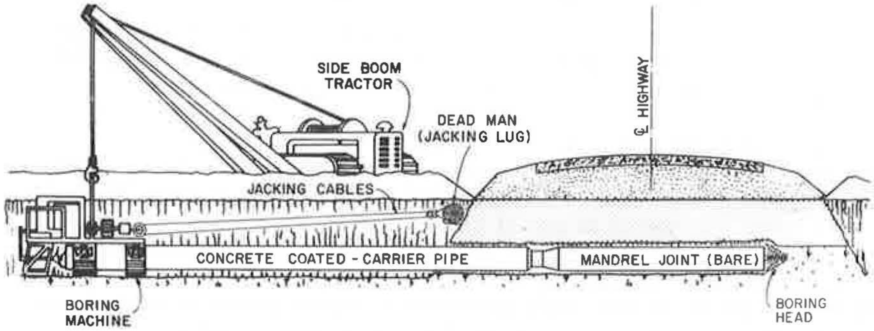
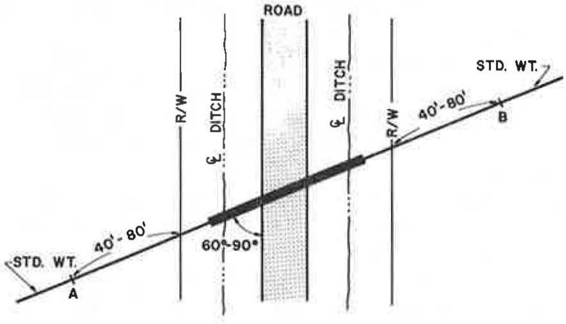


Figure 3. Road-boring equipment in operation.

Figure 4. Pulling head being tack-welded to pipe for positioning of pipe.

Figure 5. Uncased pipe in place before foam is applied to annular space.

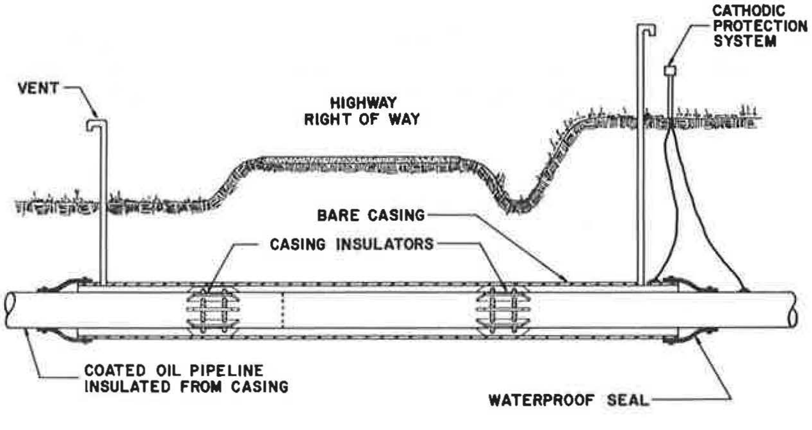
Figure 6. Typical uncased pipe crossing road.



NOTES:

1. HEAVY WALL THICKNESS PIPE A TO B
2. CONCRETE JACKET UNDER ROAD AND DITCHES
3. DOUBLE COATING A TO B
4. EXTRA DEPTH R/W TO R/W
5. CATHODIC TEST POINT AT R/W LINE

Figure 7. Cased pipe under highway.



REASONS FOR CHANGE

In earlier days, pipelines had little or no protection against corrosion. Today, however, new pipelines have good protective coatings that are supplemented with cathodic protection. According to requirements of the U.S. Department of Transportation, they must be checked at least once a year.

The use of casing pipe around carrier pipe has long been recognized by pipeline corrosion engineers as being undesirable and an obstruction to the successful application of cathodic protection. The U.S. Department of Transportation now requires that a buried pipeline be electrically isolated from the casing pipe or that the casing be interconnected to the carrier pipe and cathodically protected as a single unit. The former is often impossible, and the latter more often is impractical.

A short in a casing results in a number of corrosion control problems (Fig. 8). It is supposed that a carrier pipe inside a casing pipe, which is short-circuited to it, receives no cathodic protection current because of the shielding effect of the casing. In addition, the shorted casing pipe absorbs a disproportionate amount of the cathodic protection current. Recently, on a 3-mile section of 12-in. pipeline, a 42-ft section of 18-in. casing shorted to the carrier pipe, resulting in an increase in current requirements of 1,500 times the normal.

Colonial Pipeline Company has been spending $60,000 to $70,000 per year repairing these shorted casings that impose electrical drainage on cathodic protection systems. The idea that repairs could be made easier and, in the event of a leak, the casing, acting as a conduit, would bring this leakage to the vents near the edge of the right-of-way was valid where diameters were small and lines had little protection against corrosion. Today, however, the casing and spacer blocks are more likely to cause trouble than prevent it in that they sometimes dent the carrier pipe, harm the pipe coating, and short the corrosion protection system. Any such damage increases the possibility of leaks. In most cases, the large-diameter pipe in use today makes it faster and more economical to bore a new crossing beside the old one and change the line over rather than remove the damaged pipe and repair or replace it.

There are also initial costs to consider. A larger hole, which is bored under the road when casing pipe is used, creates a larger void that might possibly result in later settlement, although Colonial Pipeline Company has not experienced this problem. At any rate, the larger hole, the casing pipe itself, vents, seals, insulators, and the labor to install these are of considerable cost. For example, the cost of a typical 100-ft-long crossing for a 36-in. diameter pipeline would be approximately $2,000 to $3,000 less for Colonial's uncased pipe than for the typical cased pipe. A no-casing-required policy when existing roads are widened would result in savings to the highway departments, for the work required by the existing pipelines is reimbursable. In 1968, 1969, and 1970, various state highway departments reimbursed Colonial Pipeline Company more than $200,000 per year to adjust cased crossings for highway widening and alterations.

TECHNICAL SUPPORT DATA AND CALCULATIONS

The stated 20 percent minimum increase in pipe wall thickness for uncased pipelines crossing highways translates into the data given in Table 1.

API Bulletin RP 1102 entitled "Recommended Practice for Liquid Petroleum Pipeline Crossing Railroads and Highways" sets out the design criteria used by the pipeline industry. The formula used for calculating the circumferential stress resulting from external loads is the Spangler Iowa formula.

$$S = \frac{6K_b WERT}{ET^3 + 24K_z PR^3}$$

where

P = internal pressure, psi,
R = outside radius, in.,
T = wall thickness, in.,

Figure 8. Possible failures in cased pipes.

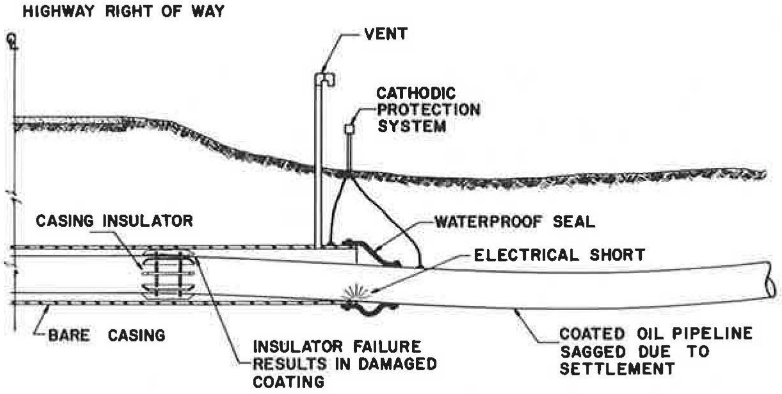


Table 1. Comparison of pipe normally used cross country to that proposed to be installed at road crossings.

Cross Country				Road Crossings		
Outer Diameter (in.)	Wall Thickness (in.)	Grade Pipe 5LX	Max Pressure[a] (psi)	Wall Thickness (in.)	Percent of Specified Min Yield Strength[b]	Percent of Ultimate Strength[b]
$6^{5}/_{8}$	0.188	X-42	1 716	0.250	69	48
$8^{5}/_{8}$	0.188	X-42	1 318	0.250	71	50
$10^{3}/_{4}$	0.219	X-46	1 349	0.279	70	51
$12^{3}/_{4}$	0.219	X-52	1 286	0.281	67	53
16	0.250	X-52	1 170	0.312	68	53
20	0.250	X-52	936	0.312	67	48
24	0.250	X-52	780	0.312	66	48
30	0.281	X-52	702	0.344	66	48
32	0.281	X-52	658	0.344	66	47
36	0.281	X-52	585	0.344	65	47
40	0.312	X-52	585	0.375	66	47

[a] 72 percent of specified minimum yield strength.
[b] Combined maximum internal and external loading.

Figure 9. Composite distribution of yield strength and thickness.

$$\text{FREQUENCY DISTRIBUTION OF } X = \frac{T_{MEAS}\ (YS_{MEAS})}{T\ (YS_{SPEC})}$$

WHERE T = NOMINAL WALL THICKNESS, INCHES
T_{MEAS} = MEASURED WALL THICKNESS, INCHES
YS_{SPEC} = SPECIFIED MINIMUM YIELD STRENGTH, PSI
YS_{MEAS} = MEASURED YIELD STRENGTH, PSI

K_b = bending parameter (0.138 for bored hole),
K_z = deflection parameter (0.089 for bored hole),
S = stress due to external loads, psi,
E = modulus of elasticity of metal (30×10^6), and
W = total vertical load (dead, live, and impact), lb/lin in. using Coopers E-72 loading for railroads and 15,000-lb single-wheel loading for highways. Impacts of 1.75 for railroad and 1.50 for highways were used, each decreasing 0.03/ft below 5 ft of cover.

An excerpt from the foreword of API Bulletin RP 1102 follows:

> The performance of casings and uncased carrier pipe installed since 1934 and operated in accordance with API code 26 and API code 1102 has been excellent in that there is no known record in the history of the petroleum industry of a structural failure due to imposed earth and live loads of either a casing or carrier pipe under a railroad or highway. API RP 1102 has been expanded to include highway crossings and has been improved by utilizing more recent research experience measuring actual performance of externally loaded pipelines under various environmental conditions, including the use of new materials and construction techniques developed since API 1102 was last revised.
>
> This edition of API RP 1102 incorporated the knowledge gained from the consideration of known applicable data on carrier pipe and casing design and the performance under dead and live loads as well as internal pressures. Extensive computer analysis was performed using M. G. Spangler's Iowa Formula to determine the stress in uncased carrier pipe and wall thickness of casing pipe. The stresses were determined covering a range of pipe sizes from 2 inches to 60 inches in various soil conditions and under fill heights from 1 foot to 30 feet.

API Bulletin RP 1102 contains graphs and nomographs for determining the stresses due to external loading by using the Iowa formula. The total circumferential stress is the sum of the stresses created by internal and external loading. The formula used for calculating stress due to internal loading is Barlow's formula.

$$P = \frac{2St}{D} \quad \text{or} \quad S = \frac{PD}{2t}$$

where

P = internal pressure, psi;
D = outside diameter of pipe, in.; and
t = nominal wall thickness of pipe, in.

An example calculation for determining the circumferential stresses and percentage of specified minimum yield (SMY) is as follows:

P = 702 psi (72 percent of SMY of 30 × 0.281-in. X-52 line pipe),
D = 30 in.,
T = 0.344 in. (wall thickness of pipe used for road crossings),
H = 6 ft (minimum cover as specified by Colonial Pipeline Company), and
W = 180 lb (from graph 1 of API RP 1102).

$$S = \frac{6K_bWERT}{ET^3 + 24K_zPR^3}$$

$$S = \frac{6(0.138)(180)(30 \times 10^6)(15)(0.344)}{(30 \times 10^6)(0.344^3) + 24\ (0.089)(702)(15)^3} = 3{,}673 \text{ psi (stress due to external load)}$$

$$P = \frac{2st}{D} \quad \text{or} \quad S = \frac{PD}{2t} = \frac{702 \times 30}{0.688} = 30{,}600 \text{ psi (stress due to internal pressure)}$$

Total stress = stress due to external loads and stress due to internal pressure
= 3,673 + 30,600 = 34,273 psi

Percentage of SMY = 34,273/52,000 = 66 percent

Percentage of ultimate bursting pressure = 34,273/72,000 = 48 percent

Calculations were made of all sizes of pipe given in Table 1, and the percentage of specified minimum yield strength of the pipe is shown in the next to last column.

The specified minimum yield strength (52,000 psi in the previous example) is the minimum strength for the pipe specified. Yield strength is probably the property most difficult to control within narrow limits, and the manufacturers are forced to aim for an average considerably higher than the minimum to avoid rejections. The result is an increase, on the average, of the actual safety factor above that specified.

There is usually a misconception regarding pipe thickness tolerance. The API Standards permit an undertolerance of 8 to 12.5 percent on thickness of individual length depending on type and diameter of pipe. However, the standards also have a weight tolerance requiring that each length of pipe be weighed and not be more than 3.5 to 5.0 percent (depending on nominal thickness category) under the tabulated weight. In addition, each carload lot is weighed and must not be underweight by more than 1.75 percent of the nominal weight. This weight specification, when combined with the uniformity of thickness of plate used for welded pipe, results in a preponderance of pipe wall thicknesses significantly above those permitted by the tolerance on thickness of individual lengths (3, p. 47).

The combined distributions of yield strength and thickness almost never result in a figure below the equivalent of nominal wall at specified minimum yield strength (Fig. 9). The average strength is about 15 percent above specifications (3, p. 47).

It should also be remembered that the aforementioned calculations are made on the maximum steady-state operating pressure allowed, which occurs only at the discharge side of a pump station. Any other point on the line would be subjected to less pressure.

The effect of the road crossing being at any other point on the line is shown in Figure 10. The percentage of maximum design working pressure for various points based on percentage of distance between pump stations is shown. Figure 10 also shows the factor of safety that is based on both yield strength and tensile strength as the distance increases from the discharge of one pump station to the suction of the next station.

All these things combine to make the resulting stress calculations given in Table 1 ultraconservative.

CONCLUSIONS

Some of the states have recently been more lenient concerning casing requirements. In Georgia, Tennessee, and Mississippi, Colonial Pipeline Company has recently installed pipes without casings under county roads or state and federal highways: 30 installations of 36-in. diameter pipe, 21 of 12-in. pipe, and 70 of 10-in. pipe in Georgia; more than 50 of 36-in. pipe in Mississippi; more than 60 of 10-in. pipe in Tennessee. In these installations, the bored hole was kept to a minimum size and the annular space between the pipe and hole was filled with urethane foam near the ends of the bored hole to block any possible water channelization (Fig. 11).

Colonial Pipeline Company proposes, where practical, the design and construction of uncased pipelines in lieu of casings in the crossing of all transportation arteries. We believe these uncased crossings will offer the following advantages:

1. The increased thickness of the pipe over normal pipe will result in lower stress levels and higher strength.
2. There is no problem of shorting the cathodic protection system.
3. The concrete jacket protects the pipe coating during installation.
4. There are no insulating spacers that could cause dents in the carrier pipe or damage the protective coating.
5. Vent pipes are eliminated; therefore, vandalizing of the pipeline by dropping explosives or pouring acid down the vent pipe is eliminated.
6. There is no annular space in which moisture can collect because of the breathing action through the vents or leakage at the casing-to-pipe seals.
7. Initial cost is reduced.
8. Because of the heavy pipe extending on both sides of the right-of-way, there would be no need to rework the crossing should a highway be widened. This would save the highway department from having to pay nonbetterment expense to the pipeline company as is done when cased pipes have to be extended.

Figure 10. Effect of road crossing on points on the pipeline.

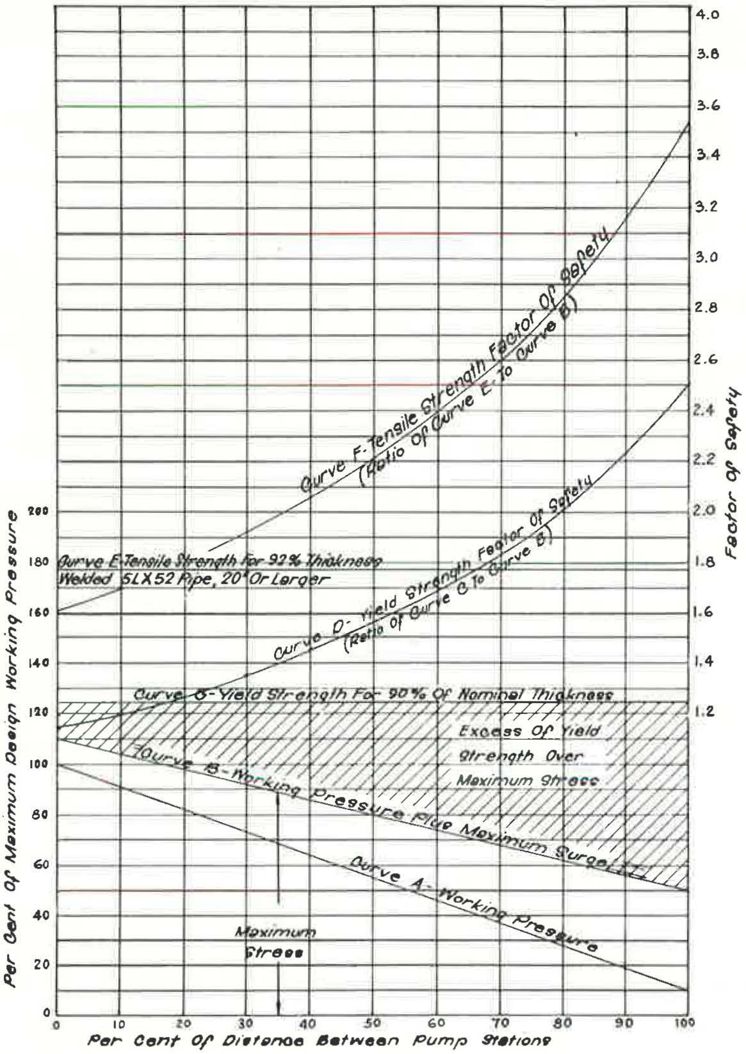
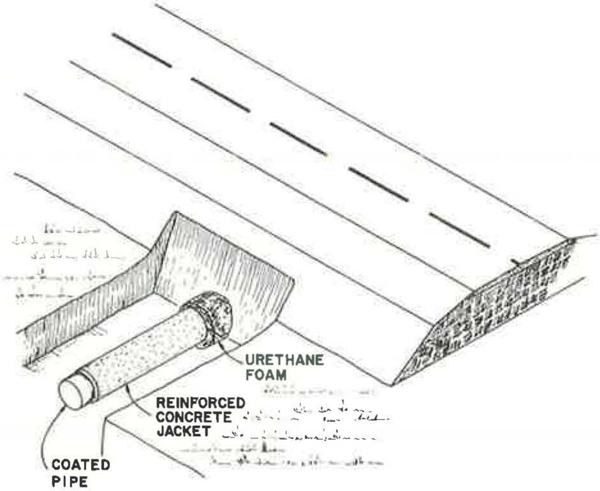


Figure 11. Use of urethane foam to fill annular space.



When the advantages of uncased pipelines crossing highways are weighed against the disadvantages of cased pipelines, it is readily apparent that the uncased pipelines are more advantageous both to the pipeline company and to the governing agency of the transportation artery being crossed.

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PLANNING THE TELEPHONE HIGHWAYS

John M. Peacock, American Telephone and Telegraph Company

Organization of the telephone network in the United States has much in common with the system of local, state, and national streets and highways. There is a direct analogy between the various classes of roads and their counterparts in the Bell System network. Circuits are bundled together into blocks of various sizes depending on traffic demand. Telecommunications transmission is based on a hundred years of technological innovation. The millimeter waveguide system now under development at Bell Laboratories is expected to go in service in 1980 as the next stage of evolution beyond coaxial cable. It has a capacity of ¼ million voice channels and will become the backbone of the long-distance network. Waveguide resembles a rugged steel pipe. It has important advantages over coaxial cable from the standpoints of increased capacity, reduced need for maintenance access, and improved reliability. Virtually all coaxial cable routes are on private right-of-way. Land use and environmental impact might be minimized if waveguide were located on freeway right-of-way where the routing is coincident and where the right-of-way is adequate to permit economic construction without disruption to highway usage or safety. A joint study is proposed to evaluate the feasibility of this alternative.

•THE ORGANIZATION of the communication network in this country is remarkably analogous to that of the transportation system. There are many similarities in physical structure. Also, both fields are continually changing and evolving as new technology and new constraints are introduced.

This paper briefly reviews the history and present state of the art in telephone transmission. This background sets the stage for a description of the new waveguide transmission system, which is in advanced development now and scheduled for commercial service in the 1980s. This is a very high-capacity system for major long-haul routes.

Can waveguide routes share right-of-way with limited-access highways? A joint study is proposed to evaluate this alternative.

EVOLUTION OF THE TELEPHONE NETWORK

The first telephone call in 1876 was from one room to another room just a few steps away. For several decades thereafter the major thrust was to extend the feasible transmission distance. Range extension was achieved during the years through a series of inventions such as the vacuum tube amplifier and improved transmission lines. In 1915, after 40 years of telephone development and a lot of hard work, the first transcontinental line was completed. This line had 3 circuits!

In the years since, major emphasis has been on technological innovation to improve the traffic-handling capability and economy of the system. It is a giant stride from a few dirt roads to the 40,000-mile Interstate highway network. Exactly the same thing could be said about the communication highways. The first circuits were hard-pressed to carry intelligible conversation; today long-haul telecommunication systems have capacities in the hundreds of thousands of channels. Human voices can be intermingled with music or computer talk at will just as midget cars can share the highways with tractor trailers. The carrier techniques that make it possible to stack the signals up in this way represent the most advanced state of the art in electronic technology. Table 1 gives the dramatic increases that have been achieved in capacity.

Table 1. Transmission system capacities.

	Voice Channels		
Decade	Cable	Microwave	Waveguide
1930	480	–	–
1940	1 800	–	–
1950	5 400	3 000	–
1960	32 400	22 800	–
1970	108 000	25 800	–
1980	–	72 000	250 000
1990	–	–	500 000

So far we have discussed only the development of transmission technology. Of equal importance are the strategies for physically organizing and interconnecting the network so that any of the 125 million telephones in the United States can reach any other one in a matter of seconds. The circuits originate at those places where customers request service. The individual telephones are connected to the exchange network, which converges on the local switching center through a well-organized system of distribution and feeder cables. These are the local and connector streets.

The switching centers are then interconnected in a complex of local, intercity, and interstate trunk transmission links. These are carefully organized to provide the necessary flexibility and redundancy for the system and to take maximum advantage of economies of scale that result from bundling together large blocks of traffic.

The analogy need not be belabored any further, for it is evident that, for any class of street or highway one can name, its counterpart in the Bell System network can be identified.

Local telephone transmission is over pairs of wire carefully bundled together into cables of various sizes up to a few thousand pairs. Coaxial cable is used for long-distance, high-capacity systems. Coaxial cable was invented at Bell Laboratories in the 1930s. The first commercial installation was made just before the war, in 1938. We now have a network of 20,000 miles of buried coaxial cable that, together with the microwave radio system, carry the bulk of our long-distance traffic. The first coaxial cable system could carry about 500 voice channels; today it can carry 100,000. The implementation of these higher and higher capacity coaxial and microwave radio systems has been carefully planned to keep pace with the growth in communication traffic demand. Present-generation systems will accommodate the demand through the end of this present decade.

CONTINUING TECHNOLOGICAL DEVELOPMENTS

About 1980, the new millimeter waveguide system will be phased in as the next stage beyond coaxial cable in the continuing exploitation of new technology. In view of the importance of waveguide in future long-haul transmission plans, a brief description of this new communication medium is appropriate.

The initial waveguide transmission system will have a capacity of almost ¼ million 2-way voice circuits, several times the capacity of the largest coaxial cable transmission system. It will be used on the backbone long-haul routes.

The waveguide itself is a highly precise steel pipe with various special linings. It is a little more than 2 in. in diameter and has a wall thickness of a little more than ⅛ in. The waveguide is supported by an elastic suspension system and inserted in the field inside a second steel pipe about 5½ in. in diameter buried 4 ft underground. The manufactured lengths of both waveguide and sheath will be joined in the field by precision automatic welding. Thus the completed structure will be extremely rugged and highly resistant to mechanical injury. Corrosion protection will be provided for the sheath, and a dry nitrogen atmosphere will be maintained inside both waveguide and sheath.

In operation, electromagnetic waves are propagated through the waveguide. In most conventional transmission lines, the transmission loss increases as the frequency increases, but in waveguide the opposite is true. To take advantage of this, we are using frequencies in the extremely high frequency (EHF) range, from 40 to 110 GHz (1 GHz is 1 billion cycles per second). At these frequencies the wavelength is just a few millimeters. This gives rise to the term "millimeter waveguide" which is sometimes used to describe the system.

The bandwidth is enormous—70 GHz—which accounts for the large capacity of the system. At these frequencies the attenuation or transmission loss of the system is very low indeed. This permits repeater spacing at intervals of about 25 miles. This compares to repeater spacing of 1 mile on the highest capacity coaxial system.

Service reliability is particularly crucial in the high-capacity transmission systems because of their importance in the communication network. No effort is spared to minimize service disruption. The coaxial cables are shielded to improve their immunity to lightning. Helicopters among other things are used to patrol the routes where "dig-up" damage is likely. Complex automatic switching capabilities are built into the system to divert traffic when a failure does occur.

Current experience indicates that there will be about 3 service-affecting coaxial cable failures per 1,000 miles per year. Typical causes are lightning, nearby construction work, trenching, and even farmer's fence posts. There is a continuing program to reduce this rate to the bare minimum. Selection of suitable right-of-way is one obvious means.

Engineering estimates of the inherent reliability of the waveguide medium indicate reduced trouble rates by at least an order of magnitude as compared to coaxial cable. The objective is fewer than 0.3 service-affecting failures per 1,000 miles per year, or fewer than 1 failure per year on a transcontinental system. We believe this estimate to be realistic. It is based on extrapolation of the trouble history on coaxial cable as it would relate to the more rugged waveguide. The estimate is consistent with pipeline experience. Test work at our field laboratory confirms that waveguide is difficult to damage, even with the heaviest construction equipment.

RIGHT-OF-WAY PRACTICES

As a result of technological innovation, we have greatly minimized the amount of right-of-way needed to handle the country's communication traffic. Typically the newer, higher capacity systems have been retrofitted on existing routes without major new outside plant construction. About 90 percent of the new long-haul circuit mileage is being added in this manner. Nonetheless, as the country develops and as demand grows and shifts into new regions, we project a continuing need to extend the system on new right-of-way.

In planning for new routes, we try to ensure that our system dovetails with other public and private utility and transportation systems. We recognize the essential need to arrive at a well-conceived master plan for the utility complex as a whole. The public interest demands no less. We simply must find ways to reduce the demand on limited natural resources such as real estate.

The common features of the transportation and communications networks have made possible the extensive sharing of right-of-way from the very beginning. A large fraction of the telephone network is on public right-of-way by virtue of the franchise rights granted by the various jurisdictions. These rights-of-way are shared not only with transportation systems but with other utilities. Some 70 percent of the utility poles used by the Bell System are jointly occupied with power. The same policies are being promoted to share space and trenches in underground installations. The Bell System is cooperating in a number of active programs in the American Right-of-Way Association and the American Public Works Association so that this scarce public right-of-way can be used to the fullest.

A conspicuous exception to the policy of sharing right-of-way has been practiced in the construction of the high-capacity, long-haul buried coaxial cable transmission systems. With but few exceptions these are on private right-of-way obtained by easement. One reason for the use of private right-of-way has to do with national security. Most of the coaxial systems are hardened and have redundant routing to avoid target centers. Another reason has to do with the need for frequent amplifier stations (every mile or so) and requirements for maintenance access. In all, the Bell System has only several hundred miles of coaxial cable installed on the right-of-way of limited-access highways. This has been the exception rather than the rule.

In the future, we expect many of the constraints to change. For one thing, because of the extensive network of hardened cable facilities already installed, the need to continue the rigid policy of avoidance routing is no longer so compelling. Perhaps more significant than this though is the planned availability of the new millimeter waveguide system. This system is substantially more trouble-free than coaxial cable, has a reduced need for maintenance access, and has increased immunity from interference due to nearby power lines or construction activity. For these reasons, our feeling is that joint occupancy of limited-access highway rights-of-way may be more feasible in the future than in the past. Waveguide will be used to link distant population centers, as does the Interstate Highway System. It should not be surprising that a substantial coincidence of routing is projected.

PROPOSED JOINT-USE FEASIBILITY STUDY

Existing governmental policies recognize in principle the merits of accommodating the highest type of utility facilities (trunkline and transmission facilities) along and within freeway rights-of-way (1, 2). These policies indicate that such joint use would be in the public interest in those situations where the routing is reasonably coincidental and where the particular right-of-way is of adequate width and otherwise suitable to permit the construction, maintenance, and operation of one facility without adversely affecting the other. These policies have been stated in principle, but many questions remain to be answered before either highway or telephone engineers can say with assurance that joint-use is indeed feasible from all standpoints.

We feel these questions must be answered, and we are prepared to support the study work and experiments necessary to get the answers. The Bell System has suggested a joint feasibility study on a particular freeway section, perhaps several hundred miles long, in cooperation with federal and state highway officials. Objectives are to develop a better feeling for the merits and constraints involved from the standpoint of both highway and utility interests. We visualize a small interagency task force that could begin this study in the near future. Only through such an effort can broad policies be properly defined and translated into action in keeping with the public interest.

CONCLUSION

The utility industries are under tremendous pressure to meet ever increasing demands for service and at the same time to become less and less conspicuous in the environment. The Bell System has implemented vigorous policies for construction of out-of-signt plant and other similar programs during the past 15 or 20 years, but more remains to be done. We need to strengthen liaison and joint planning with the other public and private utility groups. The broad question of right-of-way sharing seems particularly pertinent now as we plan for a major new system in the decade ahead.

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