PHASE II

PROTOTYPE MANUAL

ON

CIVIL DEFENSE ASPECTS OF WATERWORKS OPERATIONS

CONSIDERING RADIOLOGICAL RECOVERY PROCEDURES, ALTERNATE DISTRIBUTION TECHNIQUES FOR SAVING WATER, AND ANALYSIS OF BLAST VULNERABILITY OF SELECTED DISTRIBUTION SYSTEMS

SEPTEMBER 1966

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SUBTASK 3237A

ENGINEERING-SCIENCE, INC.

HEAD OFFICE
150 East Foothill Boulevard Arcadia, Calif.

RESEARCH OFFICE
4144 Telegraph Avenue Oakland, Calif.

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PHASE II

OF

A PROTOTYPE MANUAL ON CIVIL DEFENSE ASPECTS OF WATERWORKS OPERATIONS

CONSIDERING RADIOLOGICAL RECOVERY PROCEDURES, ALTERNATE DISTRIBUTION TECHNIQUES FOR SAVING WATER, AND ANALYSIS OF BLAST VULNERABILITY OF SELECTED DISTRIBUTION SYSTEMS COMPONENTS

SEPTEMBER 1966

A report prepared for

OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
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Contract No. OCD-PS-65-15
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By

Engineering-Science, Inc.
150 East Foothill Blvd.
Arcadia, California

ABSTRACT

This study presents information on the blast vulnerability of community water distribution pipelines, alternate operating techniques for controlling the use of water in early postattack periods, and on radiological recovery procedures and shelters available to waterworks personnel.

The results of the analysis of the vulnerability of pipelines indicate that the primary mode of failure will be crushing of the pipe. The five principal alternate operating techniques considered are: (1) isolation of portions of the distribution system; (2) rationing consumer water use; (3) reducing hydrostatic operating pressures; (4) rerouting water; and (5), the utilization of auxiliary sources of water.

Planning is stressed for postattack radiological recovery procedures, such as, wet decontamination and the determination of the safe stay times for recovery personnel. It is essential to provide shelter in locations as close as possible to the designated tasks that waterworks personnel must perform in early postattack recovery situations.

SUMMARY

The objective of this study is to develop a prototype manual and guide for the postattack recovery and operation of a water supply system. Phase I (OCD-OS-62-106) developed a prototype manual on methods for survival and recovery including a procedural guide for restoration and for training personnel in postattack emergency repair procedures, recovery techniques, and safety measures. The present work, Phase II, places emphasis on: (1) feasible radiological recovery, including shelters for waterworks personnel; (2) blast vulnerability; and (3) techniques for saving water in the surviving system. The following chapters present information on these three basic subjects.

Chapter II emphasizes the importance of planning for the provision of shelter in locations close to the designated tasks that waterworks personnel must perform in early postattack situations. The two classes of decontamination procedures, wet and dry, are discussed in detail. Wet methods are only efficient on smooth, impervious surfaces, while the dry methods, which utilize mechanized equipment, are generally the most efficient for all tasks. Before waterworks personnel can engage in any radiological recovery tasks, such as decontamination, the safe stay times must be determined based on an assessment of the actual intensities of fallout gamma radiation.

Chapter III deals with the response of buried pipelines to overpressure induced shock loads. The mathematical analysis herein indicates that the primary mode of failure will be crushing of the pipe. Other failures may occur due to longitudinal bending, shear, and axial crushing.

The magnitudes of overpressures that fail a pipeline are a function of five primary variables: internal pressure, bedding condition; soil properties; pipe characteristics; and, the relationship of the pipe to other connected structures. The comparative crushing overpressures of three representative types of pipe are shown in Figure 1.

Chapter IV presents various postattack operating techniques that can be used to attain the goals of saving lives and protecting property. The five basic techniques are: (1) isolation of portions of the system; (2) rationing of water to consumers; (3) reducing pressures; (4) rerouting; and (5), the utilization of auxiliary supplies. Basically, all of these techniques have the mission of saving water so that the water available in the system postattack can be used to the best advantage. The water in the system postattack can be categorized as follows: (1) water in distribution reservoirs; (2) water in collection reservoirs; and (3) water in the pipe system itself.

The San Jose Water Works System, which serves the San Jose, California metropolitan area, has been used as an example to illustrate the use of the basic technique of rerouting water in a system which has lost all electrical power.

The system studied contains approximately 200 million gallons of distribution reservoir storage, with 13 major pressure zones, and approximately six million gallons in collection reservoir storage. The system daily produces approximately 60 million gallons of water.

The water stored in the distribution reservoirs can be rerouted by gravity to other zones of need by the manual operation of valves in the system. As the system runs dry, much of the water stored in the pipelines can be utilized, at decreasing pressure, by gravity flow. However, on this system, the supply in the ground water collection reservoirs can be transferred only by pumping into the system or by tank trucks hauling to locations of need.

RECOMMENDATIONS

It is recommended that additional study be given to the interrelationship of available shelter in waterworks facilities, the waterworks personnel, and the postattack operations of the waterworks system. More study should be given to the blast vulnerability of all of the various distribution system components and the factors that determine their strengths, in order to provide a broader basis for evaluating the relative vulnerability of the whole system. It is further recommended that study be given to the questions of relating essential postattack needs to water supplies, in other systems, during early postattack in order to test and expand the knowledge of the principal operating techniques discussed herein.

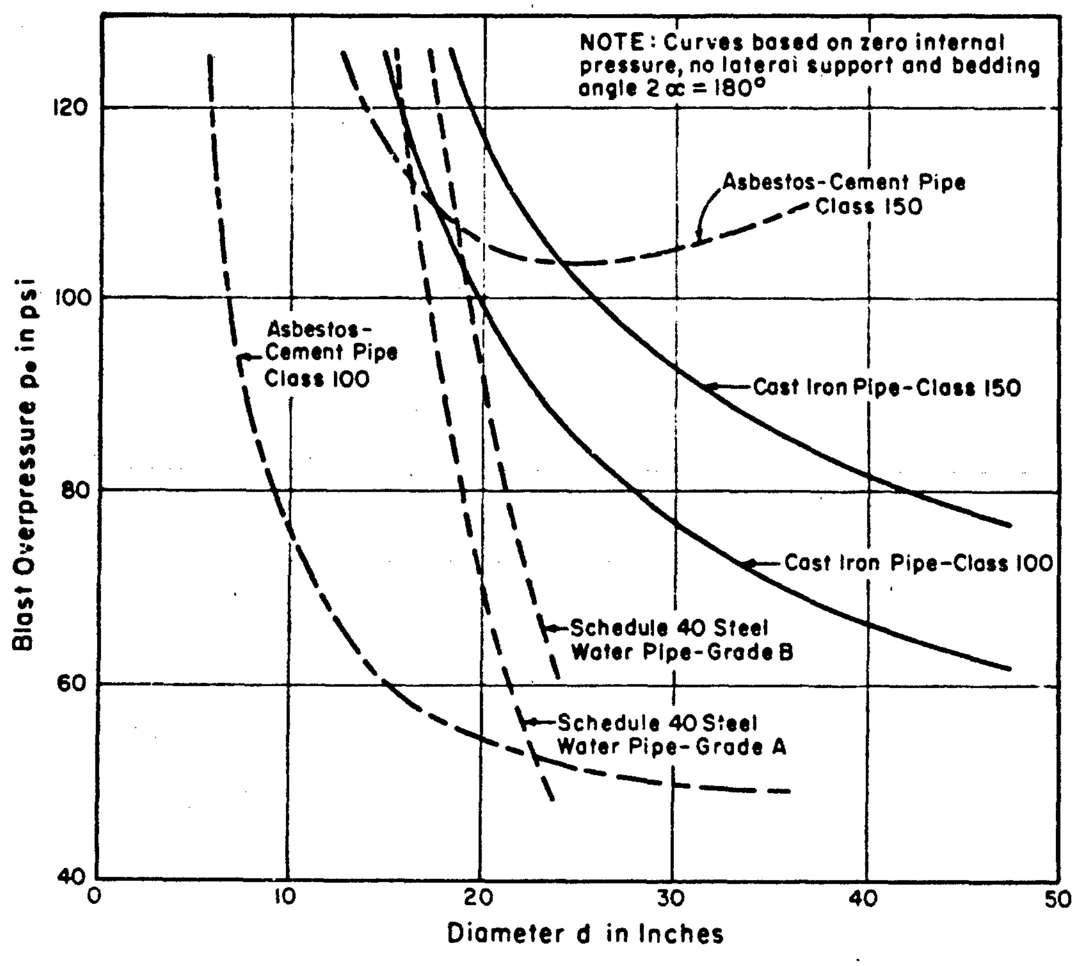

Figure 1.— COMPARATIVE CRUSHING OVERPRESSURES FOR VARIOUS PIPES

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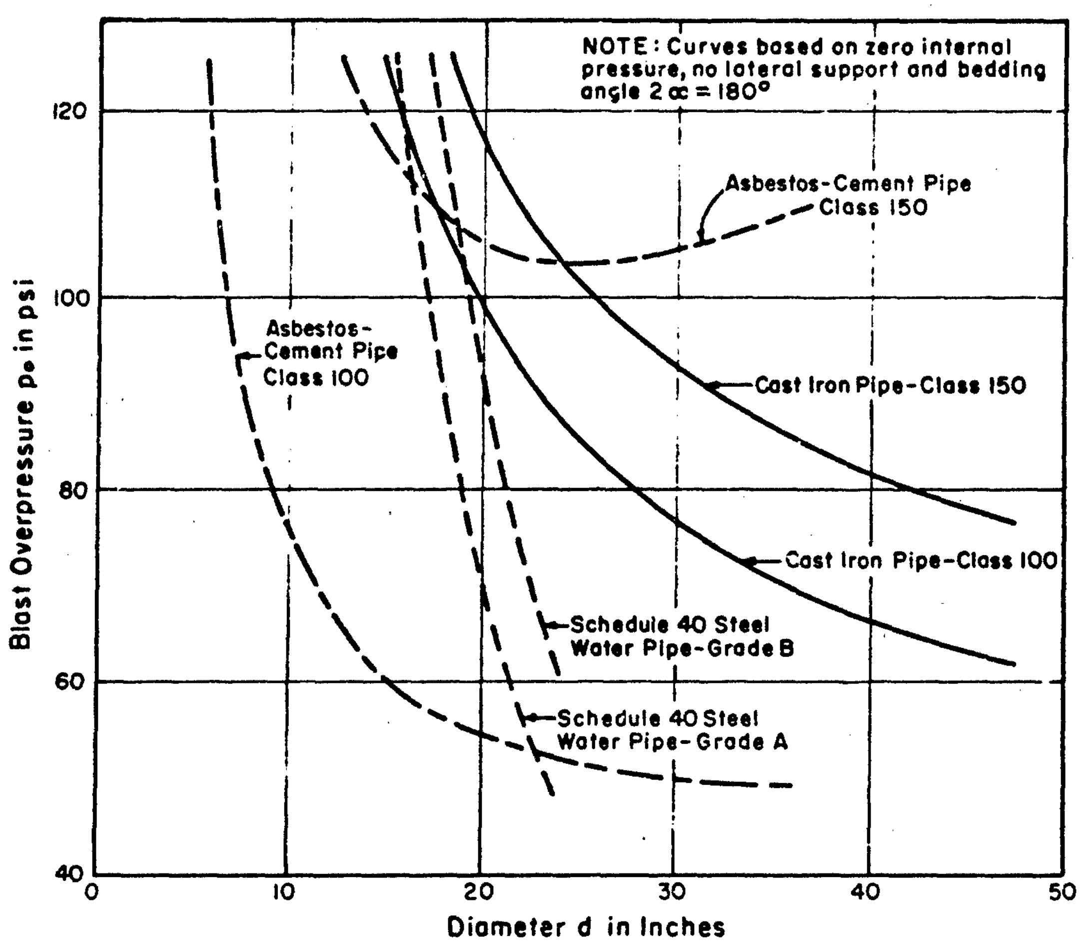

Figure 1.— COMPARATIVE CRUSHING OVERPRESSURES FOR VARIOUS PIPES

CHAPTER I

PURPOSE AND SCOPE OF STUDY

This study develops information on:

(1) radiological recovery procedures and shelters available to waterworks personnel,
(2) blast vulnerability of the community water distribution system, and
(3) alternate techniques for saving water.

Based on this information, feasible procedures are determined for (1) radiological recovery and (2) alternate distribution techniques (rerouting and damage isolation), now capable or with simple modifications, that can be used for the saving of water postattack.

OBJECTIVES

The objective of this study is to develop a prototype manual and guide for the postattack recovery and operation of a water supply system. Phase I (OCD-OS-62-106) developed a prototype manual on methods for survival and recovery including a procedural guide for restoration and for training personnel in postattack emergency repair procedures, recovery techniques, and safety measures. The present work, Phase II, places emphasis on: (1) feasible radiological recovery, including shelters for waterworks personnel; (2) blast vulnerability; and (3) techniques for saving water in the surviving system.

STATEMENT OF WORK

The Contract provides that specific work and services include, but not necessarily be limited to, the following:

(1) develop the information and prepare material for a prototype manual for planning and conducting a water system recovery operation in a postattack fallout situation:
(2) determine feasible radiological recovery procedures to be used and the shelters available to plant supervisors, operators, and maintenance personnel;
(3) analyze city water distribution systems with respect to blast vulnerability; and,
(4) determine techniques for saving water in the undamaged portion of systems and indicate alternate distribution techniques, rerouting and isolation procedures, now capable and with simple modifications.

EXTENT OF STUDY

The study considers (1) feasible radiological recovery procedures, (2) the effects of overpressure induced shock, of various assumed magnitudes, on water supply systems, and (3) techniques for saving water in the surviving portions of community water supply systems.

CHAPTER II

RADIATION VULNERABILITY AND RADIOLOGICAL RECOVERY PROCEDURES

The capacity of a waterworks structure to reduce the effects of fallout gamma radiation on personnel inside depends upon the barrier characteristics and geometric configuration of the structure. The total effect of the radiation can be made up from contributions from the roof, the ground surrounding the structure, the adjacent walls, and "skyshine" (the radiation scattered by air molecules).

The summation of these effects, expressed as decimals, from all contributing components of a structure, gives the reduction factor (R_f); and, the reciprocal of the reduction factor, the protection factor (P_f). These values can be calculated in the prefallout period for an assumed fallout distribution and from the shielding characteristics of the structure. Postattack the values can generally be determined with greater accuracy than with preattack calculation, because actual levels of radiation in the location of concern can be used. However, of greatest importance postattack is determination of accessible areas within the shelter wherein the fallout radiation dose is minimal under the then prevailing conditions.

In general, for above ground structures the protection factor tends to decrease as one moves from the central portion of the shelter toward a wall or corner, while in the case of underground structures the reverse is true.

ADVANCE PREPARATION

A utility functional radiological disaster recovery plan, activated immediately upon warning of impending attack, enhances recovery operations. This plan would name emergency operating centers and alternate control centers and would include measures for personnel protection. Regular personnel, essential for operation and maintenance, would be assigned to report to their work location (where shelters are available) or to an emergency shelter near their assigned work area. Emergency assignments would include (a) control center operation, (b) shelter monitors, (c) field monitors, (d) radiological evaluation officer, (e) radiological recovery task forces, (f) utility repair crews, and (g) field operating personnel. A preattack assessment of radiological vulnerability, evaluation of recovery operations, and inventory of available manpower, material and equipment will provide information indicating the postattack needs for the hypothetical attacks and guide the utility in advance preparation for auxiliary personnel and equipment in the event of an attack creating fallout affecting the utility system.

Prior training of personnel to acquaint them with radiological monitoring and decontamination techniques, as well as knowledge of essential emergency operating techniques in areas contaminated with radioactive fallout is a necessary prelude to a successful postattack recovery operation. In addition to the basic training, refresher training is needed to keep the organization in a state of readiness for an emergency situation.

POSTATTACK RECOVERY

In radioactive fallout areas where the outside infinity dose of 200 r (roentgens) is exceeded the radiological recovery operations may generally be divided into three priority time phases.

Initial Survival

The first is the emergency phase during which the object is survival of recovery personnel. The countermeasures that may be employed are:

(a) remain in sheltered location until the outside radiation intensity at each location has decreased by decay to a level at which short-term outside "priority" operations can be conducted;
(b) during the shelter period, obtain radiological assessment data, determine availability of personnel, review and revise recovery plans and schedules; and,
(c) plan for controlled decontamination and recovery operations.

Operational Recovery

Following the emergency phase, the operational recovery phase begins at the earliest time possible. The main objective of this phase is to sustain survival of the survivors by organizing and carrying out critical priority radiological decontamination procedures in areas where the most essential waterworks facilities must be repaired and/or operated.

The first step postattack in a recovery operation will be the assessment of the condition of personnel and facilities. This will include the following:

(a) determine the number and condition of surviving manpower at each designated utility shelter, both regular and auxiliary personnel;
(b) determine which operational centers are adequately staffed for recovery operations;
(c) determine radiation levels in each shelter and how this is expected to change with time;
(d) estimate total exposure within shelter and allowable exposure outside shelter for various projected recovery operations and time intervals;
(e) determine external fallout radiation levels and estimate the changes expected with time with and without decontamination;[1]
(f) estimate earliest entry time for missions to assess blast and fire damage and need for decontamination; assuming negligible exposure to radiation while in the shelter, the earliest entry time may be estimated from Figure 2;[2] more accurate estimates may be obtained from Reference 3;
(g) determine the influence of blast and fire damage on radiological recovery; decontamination operations may be seriously hampered by structural debris; contrariwise, this debris may provide additional shielding to attenuate the radiation in certain work areas; fire damage may also impede radiological recovery operations because fallout may be more difficult to remove from fire-gutted or charred structures; and,
(h) determine the availability of communications, other utilities, and mutual aid from other water utilities.

The "sheltering" of available manpower from radiation, fire, blast, and the natural elements, cold, rain, etc. becomes one of the most critical aspects of the recovery operation. Below ground level portions of waterworks structures, such as structures housing valves and/or pumps, reservoir outlets, and filter galleries will usually provide excellent shelter facilities for personnel whereas aboveground structures are likely to provide minimal protection. The range of protection factors for various structures is shown in Table I. Structures having a high shelter protection factor, see Figure II, may be expected to limit the accumulated dose to less than 50 r in spite of high initial radiation intensities immediately after a nuclear detonation. This would allow an acceptable exposure to 150 r of gamma radiation during the postattack recovery phases; whereas the man exposed to 200 r in the shelter would survive, but would not be useful for outside recovery operations during the early recovery period.

Based on damage assessment and postattack water needs priority of recovery operations should be established. Water, including surface waters stored in deep reservoirs, will be suitable without decontamination treatment for most uses during the immediate postattack period. Therefore, utility operators should endeavor to maintain controlled operation of the system, (at reduced pressure if necessary) in order to conserve water to supply the minimal needs.

Restoration

The final recovery phase begins when the decay of radioactive fallout and radiological countermeasures permit greater freedom of movement of personnel to complete the recovery operation and to restore the water system to normal operation.

SHELTERING OF PERSONNEL AND EQUIPMENT

To facilitate emergency operations and recovery, fallout shelters for waterworks personnel should be designated at locations near the more important water system facilities. Selection of the shelter area may be based on barrier and geometry shielding effects outlined in Fallout Shelter Surveys: Guide for Architects and Engineers.[4] The term "protection factor" (P_f) expresses the relative reduction in the amount of radiation that would be received in the protected location compared to the amount of radiation that would be received three feet above a smooth, infinite plane contaminated by the same amount of fallout per unit area.

Selecting a Shelter Area

The theoretical "protection factor" is a useful tool for planning shelter utilization that must be done preattack, but postattack use of the precalculated idealized protection factors may lead to error. Consequently, postattack recovery operations should be planned and performed using real radiological data that then would be available. Because of variations in the fallout pattern, it would be quite conceivable that the radiation level would be higher in another shelter location not too far away which has even a higher "protection factor". The problem facing the shelter manager, if the radiological situation became critical, is not to find a location with

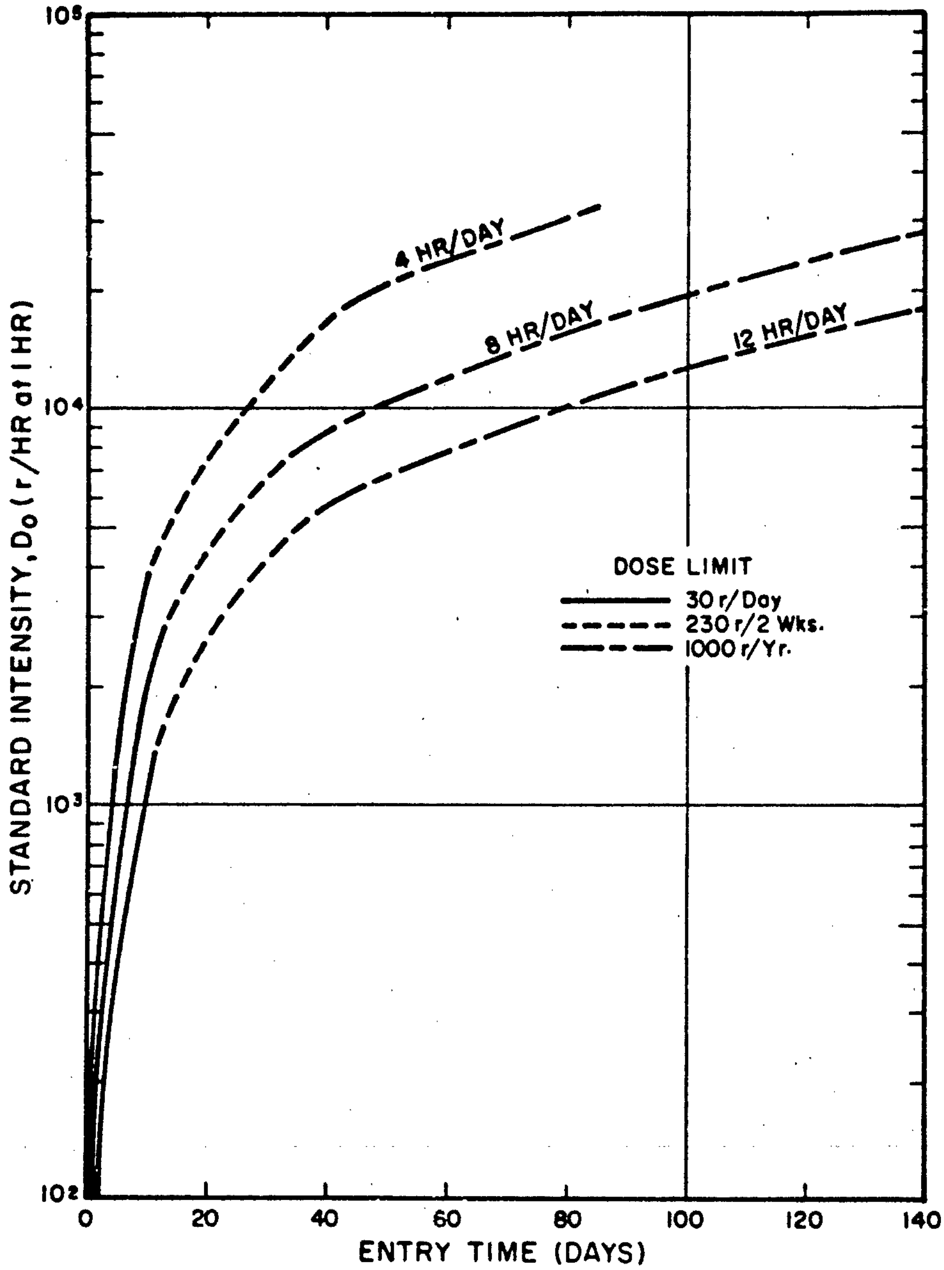

Figure 2.—— EARLIEST ENTRY TIME FOR COMBINED DOSE RESTRICTIONS vs. VARIOUS STANDARD INTENSITIES

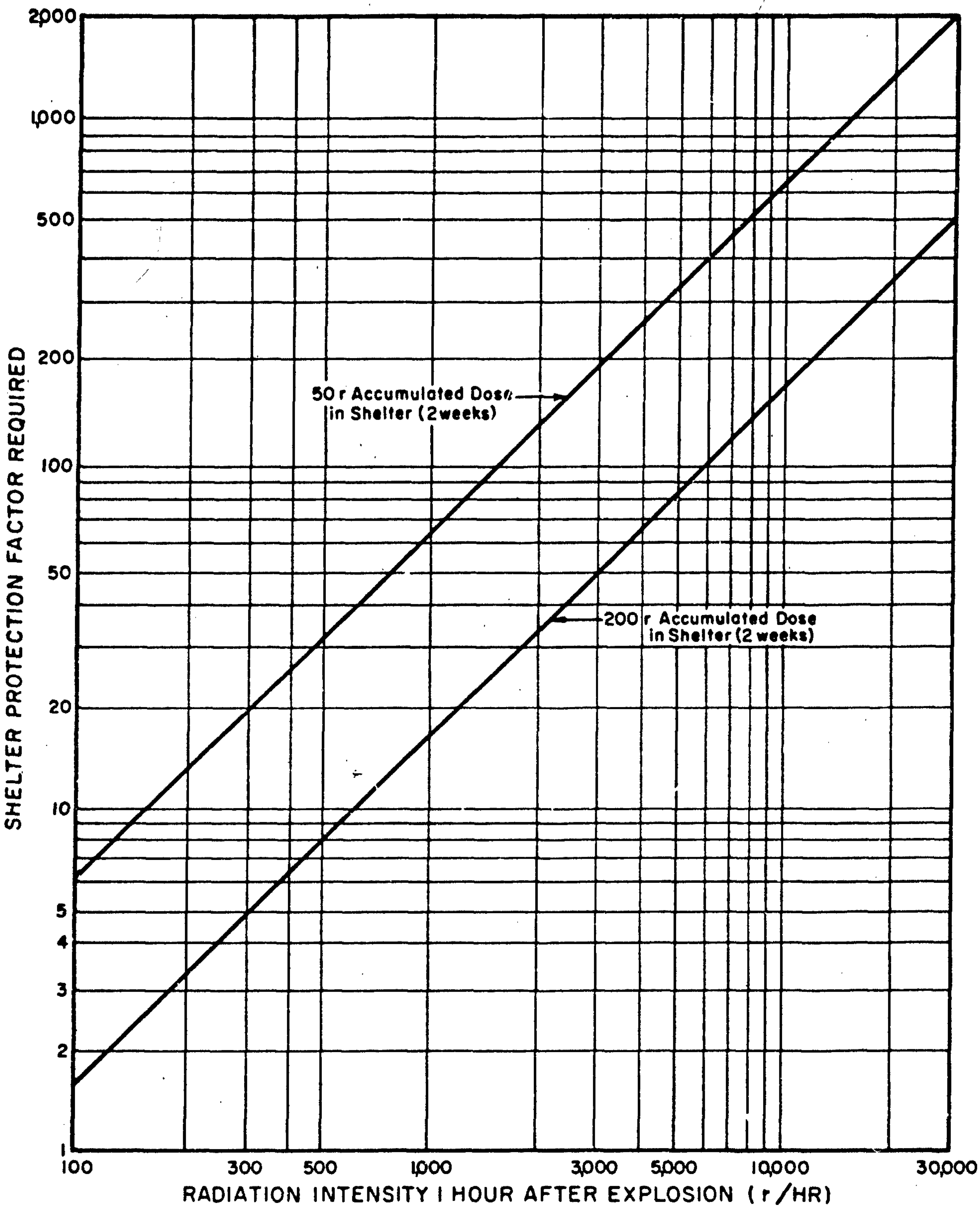

Figure 3. —— ESTIMATED RADIATION DOSE RECEIVED IN SHELTER

a higher "protection factor", but to find a place where the radiation hazard is less, or to determine if there is anything else, that is, the decontamination methods described below, that would reduce the expected radiation exposures of utility personnel.

TABLE I[1]

PROTECTION FACTOR RANGES FOR VARIOUS STRUCTURES

Type of Structure	Protection Factor Range
Underground shelters (3 ft earth cover or equivalent). Sub-basements of multistory buildings.[a]	1,000 or greater
Basement fallout shelters (heavy masonry residences) Basements without exposed walls of multistory masonry buildings. Central areas of upper floors (excluding top 3 floors) of highrise buildings[b] with heavy floors and exterior walls.	250 to 1,000
Basement fallout shelters (frame and brick veneer residences). Central areas of basements with partially exposed walls in multistory buildings. Central areas of upper floors (excluding top floor) of multistory buildings with heavy floors and exterior walls.	50 to 250
Basements without exposed walls of small 1- or 2-story buildings. Central areas of upper floors (excluding top floor) of multistory buildings with light floors and exterior walls.	10 to 50
Basements (partially exposed) of small 1- or 2-story buildings. Central areas on ground floor in 1- or 2-story buildings with heavy masonry walls.	2 to 10
Above ground areas of light residential structures.	2 or less

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(a) Multistory buildings are those having from 3 to about 10 stories.
(b) Highrise buildings have more than about 10 stories.

Protection of Equipment and Facilities

Insofar as economically feasible, waterworks facilities should be protected from radioactive fallout contamination. Material and equipment needed for radiological recovery operations should be available at locations near water system personnel shelters and essential operating facilities. It would be desirable to provide covered storage for all material and equipment essential for recovery, but if this is unattainable, the work areas, equipment, and materials needed for recovery and early operation, which are not easily decontaminated, should be protected from fallout contamination.

A permanent housing for water intake works, pumping works at wells, major control valves, booster pumping stations, and disinfection and filtration equipment will not only facilitate decontamination operations but may also provide some sheltering of recovery personnel from fallout radiation. In some cases, massive concrete structures and underground appurtenances at reservoirs, intakes, and treatment plants make shelters equal or superior to selected locations in multistory buildings.

Well water and water stored in undamaged covered reservoirs or tanks may be free of radioactive contamination. Surface waters are more exposed to fallout, but the CD-V 700 portable survey meters can be used to determine the levels of radiation in the water.

RADIOLOGICAL MONITORING

Estimation of Intensities in Shelters and Stay Times

During the early postattack period, radiological information needed by shelter occupants will require monitoring of areas in the shelter to locate the useable shelter areas for which the dose rate is minimal. When dose rates have decreased to the extent that limited outside activities can be performed, monitors will support emergency recovery operations. Postattack operations will require measurement of dose rates in the shelter as well as estimation of permissible stay time outside the shelter. Radiation exposure records should be kept on all water system personnel.

During the final recovery period, the need for frequent reports of monitored data becomes less urgent, but the requirement for monitoring of specific areas and facilities, in support of large-scale decontamination operations increases. Monitoring is required until all radiation hazards are determined to be insignificant.

Monitoring Instruments

Instruments for radiological recovery operations can be divided into two classes: (1) survey meters for measuring gamma dose rates in roentgens per hour (r/hr) or milliroentgens per hour (mr/hr) and (2) dosimeters for measuring exposure doses in roentgens (r).

The CD V-700, 0-50 mr/hr survey meter, is a low range instrument that measures gamma dose rates and detects the presence of beta radiation. It can be used (1) in long term clean-up and decontamination operations, (2) for personnel monitoring, and (3) for indicating the degree of radioactive contamination in food and water.

The CD V-715, 0-500 r/hr survey meter will measure gamma doses only and is used for general postattack operations. It is designed (1) for monitoring shelter radiation levels, and (2) for ground survey of external radiation levels.

The CD V-742, 0-200 r dosimeter, is designed for measuring accumulated exposure doses of gamma radiation to shelter occupants and recovery operations personnel. It can be read by holding it toward any light source sufficient to see the scale and hairline.

Basic information on the use of these instruments and the reporting of radiation data is provided in Reference 3.

DECONTAMINATION METHODS

Principal Classifications

For the purpose of description in this report, decontamination methods are separated into two classes, wet methods and dry methods utilizing one or more of three basic principles: cleaning fallout from the surface; removing the surface layer with the fallout; and, covering the surface and thereby burying the fallout.

Cleaning pertains to structures and to hard, frozen, or paved areas. Methods of cleaning include washing, flushing and sweeping.

Removing the surface is applicable on soft, natural terrain, either with or without heavy vegetation, and to equipment, etc. that is provided with a removable cover. Surface removal includes methods for pushing away or loosening the surface material followed by picking-up methods.

Covering the contaminated surface will usually pertain to natural terrain in buffer strips which surround and protect decontaminated areas. Covering methods include turning under soft earth, covering contaminated areas with clean fill, and constructing shielding dikes between cleared sites and radioactive areas.

Decontamination With Water

Methods

If water is available, the wet methods are among the most effective means for decontaminating hard, coherent surfaces, such as roofs and pavement, provided there is adequate drainage to facilitate sluicing of material to a safe location. The methods include firehosing, firehose lobbing, and motorized pavement flushing. Firehosing and flushing rely on high velocity water streams which loosen the fallout particles and accelerate their natural drainage from high areas toward low areas away from the operational recovery area. Lobbing, recommended for steep roofs, relies less on impingement velocity than upon the washing action of the water as it runs rapidly down the steep surface. Lobbing has two distinct advantages: it permits the team to operate on the ground; and, the set-up, moving, and take-down time are greatly reduced. Although the rate of cleaning is somewhat slower than firehosing with impingement action, the total time, including preparation and dismantling of equipment, will be little longer. Lobbing should be used only on roofs with a surface covering and slope that will facilitate the washing down of the fallout (slopes greater than 3 horizontal on 12 vertical).

Motorized street flushing is the most efficient of the paved area decontamination methods. Like other wet methods, however, it is dependent upon slope, or crown, and adequate drainage for the removal of the fallout-water runoff. Its efficiency is impaired by the presence of large amounts of fallout, numerous obstructions, such as damage debris, and by irregularly shaped areas. Since street flushers wash fallout particles and debris to one side as they move along, the accumulation of earlier passes must be moved along with the newly loosened material. In general, multiple pass operations should be limited to two or three passes from the centerline of a roadway (to avoid mass buildup), or three spiral passes toward drains located in depressions in large paved areas.

Procedure Effectiveness

Table II shows the logistics and the effectiveness of the wet decontamination methods expressed as a residual number. The residual number is the decimal fraction of the potential dose which would be received if the countermeasure is used. The more effective the countermeasure, the smaller the residual number, and, therefore, the smaller the dose received by personnel.

Wet methods should be particularly effective at water intake facilities, water treatment plants with clarifier basins, or a finished water storage tank or reservoir, and near distribution system reservoirs if normal or auxiliary pumping equipment is available.

Dry Methods of Decontamination

Methods and Equipment

Among the dry surface cleaning methods utilizing brooms or brushes to loosen and sweep the fallout particles are manual sweeping, the mechanical sweeper, and vacuum sweeper. These methods are limited to hard surfaces, such as pavement and frozen ground.

Manual sweeping is so inefficient that it should be confined to such minor duties as "hot-spot" clean-up and cleaning around building entrances, steps, etc. A two man team is required, one man to sweep and one to handle the shovel and wheelbarrow.

The mechanical sweeper is a thoroughly efficient means of decontaminating large paved or frozen areas adjacent to waterworks facilities. Mechanized sweeping is a rapid one man operation. However, if the area has many "hot spots" left after decontaminating due to obstructions or rough and broken pavement, it may be necessary to clean these by manual sweeping or some other method. Because the fallout particles are collected in the machine's hopper and not pushed along toward a drain or collection point, this method can be used without regard to slope, crown, or pavement width. Water sprinkling for dust suppression should be used sparingly because water interferes with fallout pick-up. Two passes over the entire area are usually required for effective decontamination.

The fallout particles collected in the hopper constitute a radiation hazard to the operator. Effective personnel shielding can be provided by

TABLE II[3]

LOGISTICS, RATES, AND RESIDUAL NUMBERS FOR SEVERAL RECLAMATION METHODS

Method	Principle of Operation	Applicability	Men and Equipment Per Team	Observed Rate Per Team (ft^2/hr)	Planning Effort in Man-Hr (10^4 ft^2)	Residual Number
Firehosing	Water under pressure pushes contaminated dirt into drainage system	All roofs, walls, and paved areas.	3-men/1-1/2" firehose, using 100 gpm at 75 psig.	35,000	6	0.08 for I_o = 300 r/hr 0.05 for I_o = 1000 r/hr 0.02 for I_o = 3000 r/hr
Firehosing plus scrubbing	Firehosing alternated with mechanical loosening of contaminant.	Large paved areas.	4-men/1-1/2" firehose; 2 men with brushes	5,000	14	0.04 for I_o = 300 r/hr 0.02 for I_o = 1000 r/hr 0.01 for I_o = 3000 r/hr
Mechanical sweeping	Loosening of contaminant by a rotary broom and simultaneous collection.	Large, open paved and hard-packed areas	1 street sweeper with 80" broom and 2-4 yd. hopper 1 operator	100,000	2	0.01
Hand sweeping and shoveling	Accumulation of contaminant by push broom; collection by shovel and wheelbarrow.	Small paved or hard-packed areas.	2 men with broom 1 man w/shovel 1 man w/barrow	4,000-10,000	15	0.05
Mechanical surface removal	Remove 2-3" of surface material and carry to nearby disposal site.	Small areas of loose gravel, loose or packed dirt, or vegetation.	1 scraper and operator, 1 front-end loader, 1 man with shovel	3,000-6,000	15	0.01
Manual surface removal	Remove 1-2" of surface material and carry to disposal site.	Very small, cutup areas of loose gravel, etc.	3 men with shovel, 1 man with wheel-barrow	1,000-2,000	50	0.1

sand bags, filled with uncontaminated sand or earth, stacked between the operator's seat and the hopper. This type of protection should be provided for drivers of other vehicles, such as loaders, dump trucks, vacuum sweepers, etc. In addition, dry method decontamination team members should wear scarfs or face masks to avoid inhalation of airborne dust.

Motorized vacuum sweeping is also an efficient means of decontaminating large paved or frozen areas (without any damage debris). Because of the filter system, this method cannot be used in wet weather, nor can water dust suppression be applied. Dust masks and protection of the operator from radiation emanating from the dust hopper must be provided as in the case of the mechanical sweeper.

The surface removal and covering methods utilize earth moving equipment and are limited to areas which are unpaved and not frozen deeply. The top layer is removed, turned under, or covered to effect surface decontamination (shielding).

It is desirable to remove as little of the surface as possible to minimize the effort required. Removal of vegetation and two to four inches of soil is usually sufficient to effectively remove fallout. Fissures and cracks are sometimes deeper and fallout particles in them remain after the equipment has passed. These "hot spots" can be removed manually in a subsequent operation.

Turning under, to the depth obtainable by plowing, about six inches, is partially effective as a means of decontamination. Covering over with clean fill can be deeper and, therefore, still more effective.

The surface removal and covering methods utilize the following equipment: hand shovel, motor scraper, motor grader, bulldozer, plow and snow plow.

Hand shoveling, like other manual methods, is slow and inefficient. Its principal function is for cleaning up "hot spots" left by mechanical methods and areas not accessible to motorized equipment.

Motor scraping is one of the most rapid and effective methods of decontaminating large natural areas and areas covered by loose undisturbed snow. A surface layer including the fallout particles is cut and loaded into a hopper as the vehicle moves along. Besides being capable of operating independently to scrape up and haul away the contaminated layer of soil, motor scrapers may be used effectively with such other mechanized equipment as motor graders, bulldozers, and snow plows. Graders and snow plows leave the contaminated material in windows. Bulldozers push it into long mounds as they work across an area. The scraper may be used to pick up the windrows and mounds and transport the contaminant to the dump site.

The motor scraper is especially useful for covering and filling with clean, uncontaminated earth. Because it can procure, pick up, haul, deposit, and spread the cover soil, the motor scraper is the most efficient machine for this method of decontamination. Unfortunately, many water utilities may experience difficulties in trying to procure a motor scraper in an emergency, if not provided for in the advance preparation.

Motor graders, which are usually more readily available, provide a fast, effective means for decontaminating flat or gently sloped, natural and/or snow covered areas. They are designed to cut off thin surface layers and push the cut materials into windrows. Because they do not pick up and haul loose material, other means must be employed to move the contaminated soil to the dump site. A front end (skip) loader and truck which follow behind the grader provide an efficient means of picking up and hauling away the windrows.

Motor graders can also be used for covering surfaces with uncontaminated fill. The grader cannot procure and haul the fill material, but it is especially useful for spreading fill material over the surface, once trucks or other hauling equipment have delivered it to the area.

In general, the procedure to be followed in decontaminating with the motor grader is that recommended for peacetime, except that greater care must be taken to avoid spillage around the leading end of the blade and the pitch should be set to minimize spillage over the top of the blade.

A bulldozer should have the widest available blade for decontamination operations. Unless the passes are limited to less than 100 feet, side spillage of contaminated soil or snow becomes a problem. After the contaminated soil has been pushed into windrows, a front-end loader and truck will be needed to haul it to the dump site, as in the case of the motor grader operation. The relatively small size of bulldozers makes them suitable for use in confined spaces.

In addition, the bulldozer can be used to reduce the width of a buffer zone around a decontaminated area by the creation of a perimeter earth barrier. The top two or three inches of soil are first pushed beyond the edge of the desired zone. The bulldozer then takes a deep cut into the exposed clean earth and pushes it to the zone edge, creating an earth dike wide enough and high enough to act as an effective shield against the fallout radiation beyond. The dike dimensions should be great enough to shield personnel from line-of-sight exposure as illustrated in Figure 4. This technique could well be one of the more timesaving means of reducing the residual number in an area where a water system repair crew must perform high-priority work in the early operational recovery period.

All of the dry surface cleaning and removal methods discussed above require the selection of a dump site for contaminated material collected by the decontamination operation. The dump site should be located in an area which will not require subsequent decontamination. It should be downwind, if possible, and the shortest safe distance away from the area to be decontaminated, in order to minimize hauling time. After the decontamination operation is complete, the dump site should be backfilled with uncontaminated soil.

Plowing an unpaved fallout contaminated surface is a rapid process, and free of waste disposal problems. Plows can be expected to bury the fallout six to ten inches. Although a few inches of soil do not provide much shielding for persons standing directly above, they give several feet of oblique shielding to areas nearby. Plowing is acceptable for buffer zone preparation, around the edges of decontaminated areas. It is not satisfactory, however, for areas to be occupied by personnel.

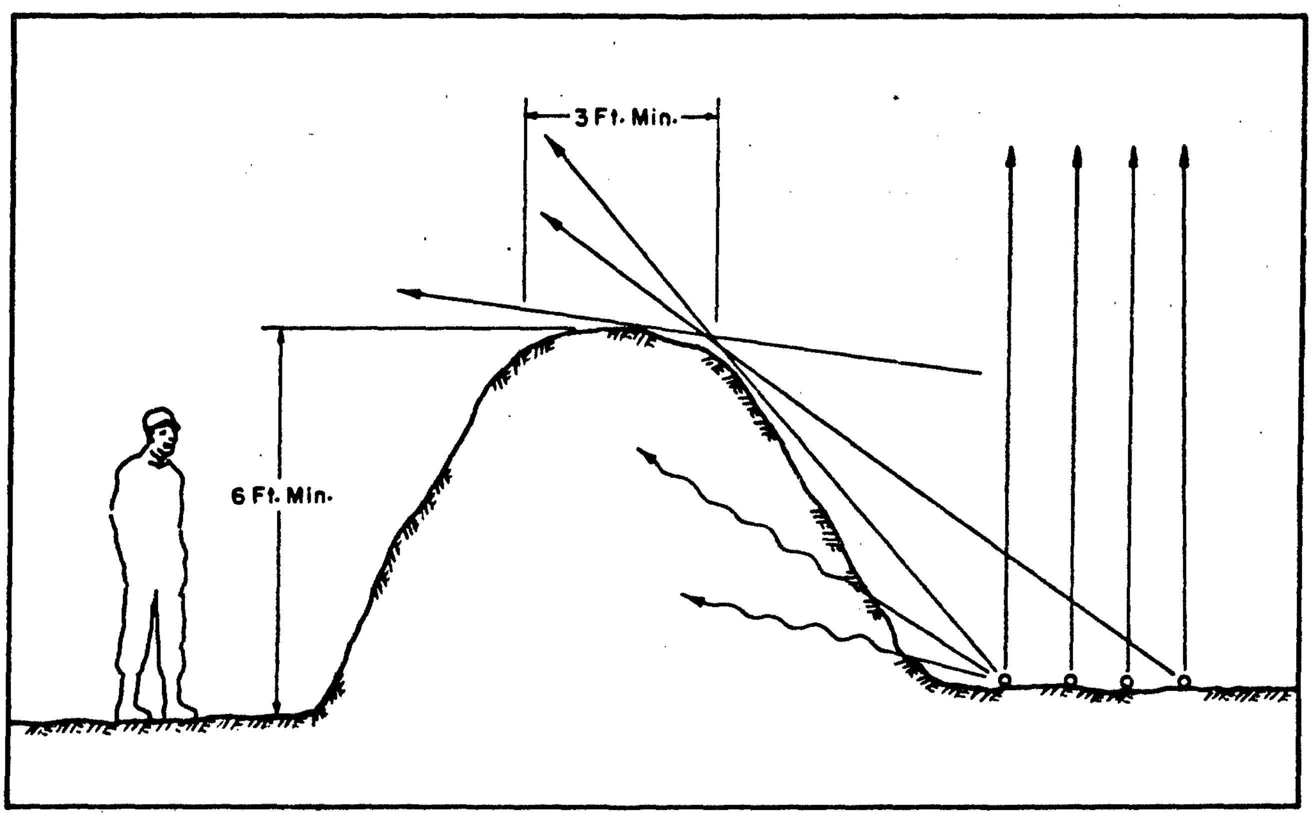


Figure 4.— EARTH DIKES SHIELD EDGES OF DECONTAMINATED AREAS FROM FALLOUT RADIATION (5)

Unlike surface removal methods such as scraping and grading, multiple passes with a plow do not increase the thoroughness of decontamination. On the contrary, a second pass will return a large proportion of the fallout particles to the surface. Plowing, after surface removal by sweeping or scraping, can decrease the remaining radiation by providing surface shielding.

Snow plows provide the fastest means of any of the decontamination methods for removing snow from flat or moderately sloped surfaces. The windrows of contaminated snow can be picked up and hauled away by a scraper or front end loader and truck.

Factors Affecting Selection of Methods

The use of a single or a combination of decontamination methods may be required as a countermeasure to reduce the gamma radiation at water utility structures, operational areas, and at points where emergency repairs are needed for restoration of operations. The emergency supervisory staff must be familiar with the applicability and limitations of the principal decontamination methods for each subarea surrounding the shelter or operation area.

Rainfall and wind will cause migration of fallout with the possible reduction or increase in a given location, either increasing or decreasing the radiation exposure of shelterees. After the admixing of fallout with eroded soil, the choice of decontamination methods to effectively decrease the exposure of personnel to radiation may be limited to surface removal or covering methods.

Winds may cause fallout to drift against the walls of a shelter and necessitate the removal of greater depths of soil where the more time-consuming manual decontamination methods must be employed.

The presence of debris from damaged structures may preclude the use of a mechanical sweeper, of a vacuum sweeper as well as firehoses in affected areas and force the use of the less efficient manual methods.

Large portions of the United States experience below freezing temperatures about ten percent of the time during December, January, and February. Because snow, ice, and below freezing temperatures seriously limit and affect the decontamination procedures which can be used effectively, the methods to use in five combinations of conditions are shown in Table III.

Because of the general availability of bulldozers to water system operators, the barrier shielding effect which can be procured by quickly pushing up an earth dike to shield out radiation from otherwise inadequate shelters and emergency work areas is strongly recommended as an efficient means of providing a sizable reduction in exposure of utility personnel to fallout radiation.

DECONTAMINATION MISSIONS

Decontamination is basically a recovery countermeasure, to get to areas of recovery and it should not be applied during the early period postattack,

TABLE III[5]

SUMMARY OF COLD WEATHER DECONTAMINATION METHODS

	Condition 1 Loose Fallout On Hard Frozen or Paved Surface	Condition 2 Fallout Encased In Layer of Ice	Condition 3 Loose Fallout on Hard Frozen or Paved Surface, Covered by Snow	Condition 4 Fallout Encased in Ice, Covered by Snow	Condition 5 Fallout Intermixed With Snow	Roofs of Structures
Mechanical Sweeper	Good	N/A	Good, after initial removal of deep snow cover or where snow layer is less than 2 inches thick.	N/A	Applicable, if depth of snow is less than 2 inches and snow is dry.	N/A
Vacuum Sweeper	Good	N/A	Fair, after initial removal of deep snow cover or where snow layer is less than 2"	N/A	Applicable, if depth of snow is less than 2 inches and snow is dry.	N/A
Motor Grader	N/A	N/A	Applicable only for removal of snow cover exposing fallout particles.	Applicable for removal of snow cover exposing ice layer.	Fair	N/A
Firehosing	Fair-Good	May be used if ice layer is thin. Salt may be used to assist melting.	Fair to good, after initial removal of deep snow cover or where snow layer is less than 2".	May be used where ice layer is thin after initial removal of snow cover. Salt may be used to assist melting.	Good, if snow depth is less than 2 or 3 inches.	Good, if roof is warmed by internal heating. Use lobbing technique if slope is steep.
Blade Snow Plow	N/A	N/A	Applicable only for removal of snow cover exposing fallout particles.	Applicable for removal of snow cover exposing ice layer.	Good	N/A
Motor Scraper	N/A	N/A	Applicable only for removal of snow cover exposing fallout particles.	Applicable for removal of snow cover exposing ice layer.	Good	N/A
Hand-broom Sweeping	Good	N/A	Good, after initial removal of deep snow cover or where snow layer is less than 2 inches.	N/A	Good, if snow depth is less than 2 or 3 inches.	Good, for dry, light snow on flat or low slopes. Use with hand shoveling where snow depth exceeds 3 inches.

unless shelter conditions are intolerable with respect to (1) radiation exposure or (2) overcrowding of shelter space, or other hazards, i.e., fire, flood, etc.

Decontamination missions should be undertaken when it has been determined that the mission is required to achieve a goal important to the overall recovery of waterworks operations, i.e., area of sheltering, area of work, movement of personnel and essential equipment, or the storage of supplies.

Determination of Stay Times

Once the decision to perform a mission is made, the overall time required outside the shelter including staging time to gather materials and equipment, travel time (to and from work area), and work time must be estimated conservatively in order to determine the earliest safe entry time to initiate the recovery task. In the final analysis, the entry time is restricted by the previous radiation dose received by the mission team, the intensity of radiation (dose rate) in the area, and the fallout decay rate at the start of the mission. Schedules should be prepared using accepted allowed dose criteria.

The three dose criteria most commonly used are the ERD (Equivalent Residual Dose), the Infinity Dose, and a selected "accumulated dose-time interval" concept. Figure 5 graphically illustrates the three criteria.

Both the ERD and the "accumulated dose-time interval" concept are based upon the premise that recovery from radiation exposure is a continuous process. Consequently, the effect of a moderate amount of radiation received over a period of weeks or several months will be quite different from the effect of the same exposure delivered in a few minutes or days. The ERD is computed on the assumption that 10 percent of any radiation damage is irreparable with the remaining repairable part repaired at the rate of 2.5 percent per day.

The Infinity Dose concept is much more conservative in that it specifies a maximum dose accumulation which may not be exceeded, regardless of the time interval. It is the preferred criterion for exposure of children and young adults to radiation.

The allowed dose to be received by emergency recovery personnel should be held within the ERD limits shown in Figure 5, or preferably within the "accumulated dose-time interval" criteria. In all cases, regardless of the allowed dose criterion, exposure to radiation should be minimized.

The earliest entry time for an eight hour mission outside the shelter under these allowed criteria is shown in Figure 2. The entry time may also be set by delaying the beginning of the mission until the entry dose rate (roentgens per hour, r/hr) outside the shelter has decreased to a value determined by

$$\frac{\text{Dose (roentgen) allowed for mission}}{\text{Estimated Stay-Time (hours) for mission}}.$$

When the decontamination or emergency recovery teams leave the shelter area, they must be provided with radiation dosimeters for measurement of the

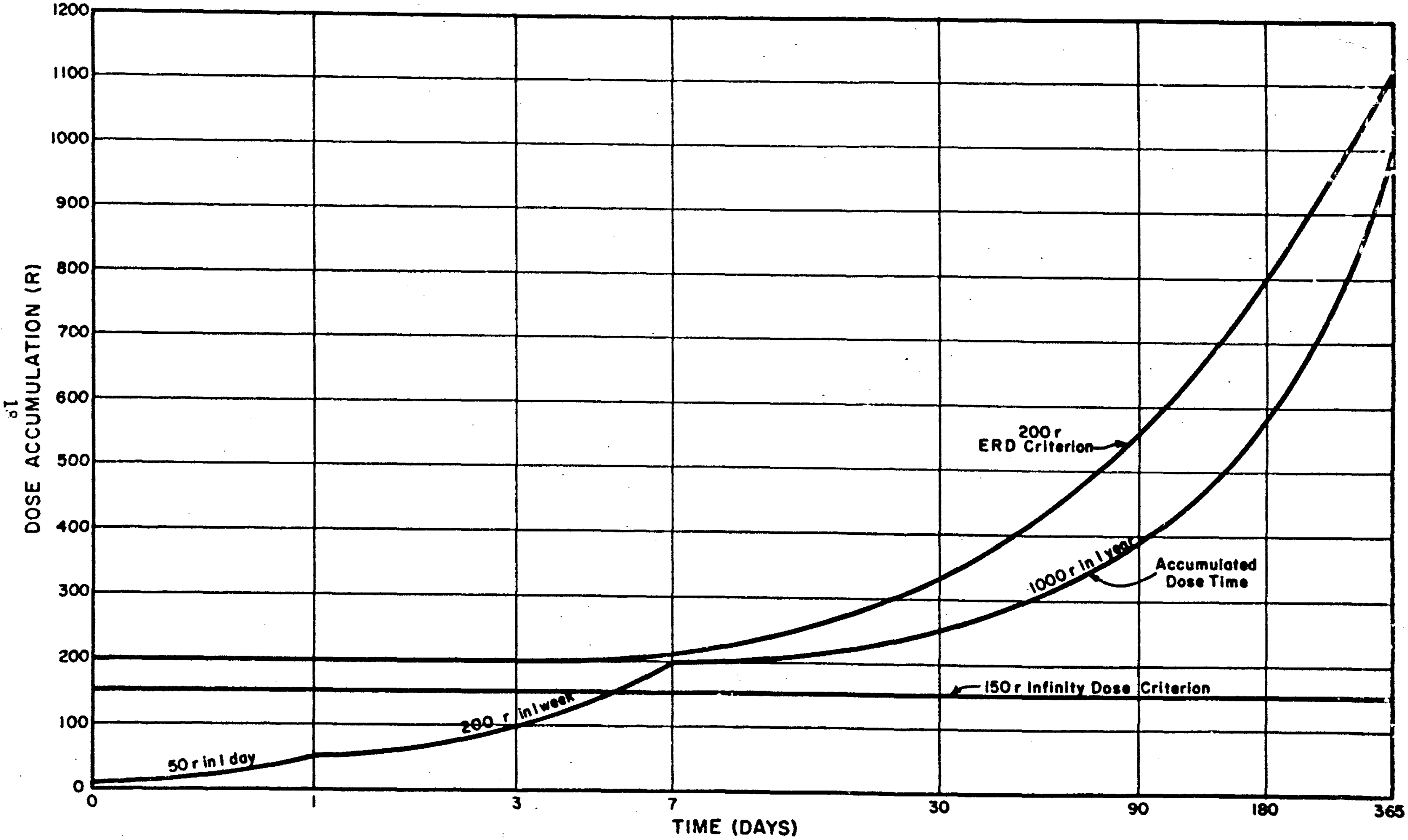


Figure 5. —— ALLOWED DOSE CRITERIA (5)

dose accumulated by mission personnel. In addition, decontamination teams should have rate meters for taking intensity measurements before and after the operation to assess the effectiveness of fallout removal and to mark the boundaries of safe and contaminated areas.

Operating locations that require an extended stay time, even under a planned minimum that may prevail with an emergency condition, should be housed in a shielded location. Such operations are:

(a) planning and directional control;
(b) communications center;
(c) microwave operational control center (read out of remote controls and operational facilities);
(d) quality control laboratory;
(e) essential sources, pumping stations, etc.; and,
(f) water treatment plants.

The shielding may be supplemented by decontamination to further reduce the in-shelter exposure; and in addition, this is especially important where the operation is one that requires personnel to leave the shelter for operation in a more exposed location. Decontamination is needed to facilitate movement to the secondary location to accomplish the minimum necessary operation with minimal exposure to fallout radiation.

Stay Time Calculations

Stay time for decontamination operations must be based on estimates of the total dose, D, received from exposure to gamma radiation:

(1) in shelter area, D_1;
(2) during movement of men and equipment from storage area to work area and return, D_2;
(3) in work area, D_3; and,
(4) the long term dose, D_4, sometimes called the infinity dose.

Mathematically, the total dose becomes the sum of all the exposures from the time of arrival of fallout until decay and decontamination operations reduce the gamma radiation to an insignificant level:

$$D = D_1 + D_2 + D_3 + D_4 + \ldots\ldots . D_n.$$

If D' represents the "open" field (outside) exposure dose that would be received by a person standing at the location, the actual dose for a person in the shelter would be $D_1 = R_f \times D'$.

In like manner, the exposure during travel to and from the work area would be modified from the "open field" exposure by a factor called the "Residual Number" which is the measure of effectiveness of any countermeasure used to reduce the radiation dose accumulated by people. It is defined as the decimal fraction of the potential dose that will be received after a countermeasure has been employed. The more effective the countermeasure, the smaller the residual number, and therefore the smaller the resultant dose.

The Residual Number (RN) during travel would depend on shielding characteristics of the vehicle and prior decontamination operations in the area. Thus, the dose while traveling would be

$$D_2 = \overline{RN}_2 \, D_2'.$$

And in the operational area this becomes

$$D_3 = \overline{RN}_3 \, D_3'.$$

After decontamination operations are completed, the residual number (RN_4) during the long term period of fallout decay should be quite small, and the dose accumulated in this latter period may be negligible.

The total gamma radiation dose may be expressed then as shown:

$$D = (R_f)D_1' + (\overline{RN}_2)D_2' + (\overline{RN}_3)D_3' + (\overline{RN}_4)D_4 + \ldots\ldots\ldots$$

In each case, the $\overline{RN}$ values represent the average or effective "Residual Number" for that exposure period. For example, the RN_3 values may decrease markedly during a work shift as the decontaminated area is enlarged. Firehosing, see Table II, may reduce the radiation intensity from 0.02 to 0.08 (RN) of the "outside" radiation level, if a large area can be cleaned by this method.

Several methods for estimation of the "open" field exposure dose have been proposed, and often there is confusion as to the applicability of these methods during an emergency situation. The water utility operator should understand that certain of the methods are developed for estimating exposure doses for advanced disaster planning and vulnerability assessment and others are more suitable for organizing postattack recovery operations or missions. The latter must be based upon actual radiation intensities measured in the field with monitoring instruments. For example, calculation of the "open" field dose, D', would be

$$D' = I' \times t$$

where I' is open field radiation intensity, r/hr
t is the time of exposure in hours.

Then the dose, D_3, in the recovery work area would be

$$D_3 = \overline{RN}_3 \times I_3' \times t$$

As previously noted, $\overline{RN}_3$ must represent the effective Residual Number as the decontamination operation proceeds. In like manner, I_3' should be computed for the duration of the mission. Except for the first two days following the nuclear disaster, an arithmetic averaging of three radiation intensities, at the beginning, middle, and end of the period, would be sufficient to estimate the stay time for a recovery operation.

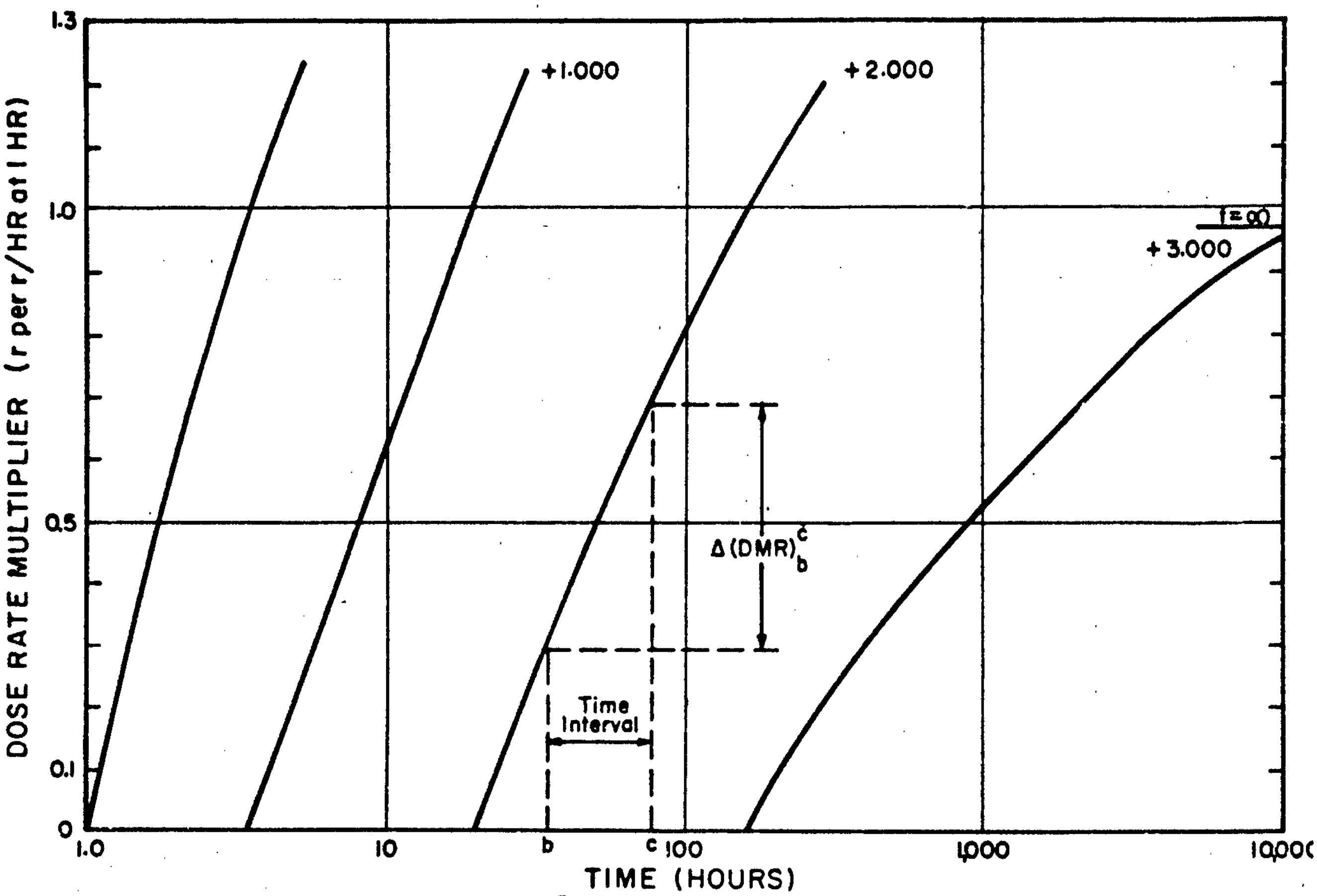


Figure 6.— DOSE RATE MULTIPLIER CURVE

The earliest entry time would be estimated from the actual decay characteristics of the fallout rather than an assumed decay rate based on theoretical decay curves. Substituting these values in the first equation, the total dose is:

$$D = (R_f)I_1' \times t_1 + (\overline{RN}_2)I_2' \times t_2 + (\overline{RN}_3)I_3' \times t_3 + (\overline{RN}_4)I_4' \times t_4 + \ldots\ldots$$

Stay Time, Advance Planning

During the early postattack period, when the data on open field radiation intensities and decay rates are sparse, the computation of expected doses must be related to the predetermined, theoretical decay characteristics of mixed fission products. For advanced planning under these conditions the allowed dose is estimated by the equation:

$$D = I_\circ \ (\overset{\infty}{RN})_a \ (DRM)_a$$

where $I_\circ$ is the Standard Dose Rate at H + 1 hour.

$(\overset{\infty}{RN})_a$ is the Residual Number in the area from effective fallout arrival time to infinity.

$(DRM)_a$ is the Dose Rate Multiplier from effective fallout arrival time to infinity.

When the persons move from an area of one Standard Dose Rate to another or when the Residual Number changes, the total dose must be broken down into its several components as in the previous analysis. The principal difference in treatment relates to the use of the Standard Dose Rate and Dose Rate Multiplier, Figure 6, for computing the dose for each period. If the Standard Dose Rate remains constant, the equation becomes

$$D = I_\circ \left[(\overset{\infty}{RN})_a^b \ \Delta(DRM)_a^b + (\overset{\infty}{RN})_b^c \ \Delta(DRM)_b^c + \ldots . \ (\overset{\infty}{RN})_n \ \Delta(DRM)_n \right]$$

where $(\overset{\infty}{RN})_a^b$ is the Residual Number in the area, from the time of fallout arrival to time b.

$\Delta(DRM)_a^b$ is Dose Rate Multiplier from fallout arrival time to time b.

$(\overset{\infty}{RN})_b^c$ is Residual Number from time b to c.

$\Delta(DRM)_b^c$ is Dose Rate Multiplier from b to c, etc.

If the Standard Dose Rate also changes then each factor becomes

$$D = (I_\circ)_a \cdot (\overset{\infty}{RN})_a^b \ \Delta(DRM)_a^b + (I_\circ)_b \ (\overset{\infty}{RN})_b^c \ \Delta(DRM)_b^c + \ldots\ldots + (I_\circ)_n \ (\overset{\infty}{RN})_n \ \Delta(DRM)_n.$$

Thus, the analysis for predicting probable gamma radiation doses for advance planning is considerably more complex than the computations needed after monitoring data is available which establish the outside field radiation intensities. However, this method of analysis is useful when monitoring data is inadequate or nonexistent.

CHAPTER III

BLAST VULNERABILITY OF COMMUNITY WATER DISTRUBUTION SYSTEM

GENERAL

The effects of nuclear explosions occurring at or near the surface of the ground and the response of structures resulting from the shock wave has been studied and is reported in considerable detail in the Effects of Nuclear Weapons.[1] It is the purpose of this study to relate the blast induced shockwave effects to the waterworks distribution system. This study briefly considers the response of essential waterworks facilities to blast damages and the ability of such facilities to continue operating. The functioning of some facilities will be little impaired by the complete sweeping away of the superstructure housing the facility. On the other hand some essential works, especially mechanical and chemical feed equipment, may be rendered inoperative through missile damage where only minor overall destruction is experienced.

Study shows distinct differences between the wind forces of a hurricane and the effect of blast wave from a nuclear weapon. Likewise the shock wave of the nuclear weapon does not have an effect similar to that of an earthquake; however, structures constructed to withstand such forces will generally better withstand the blast effects of nuclear weapons.

Blast Characteristics

At a fraction of a second after the burst of a nuclear weapon, a high-pressure shock wave develops and moves outward radially from the fireball. The shock front, behaving like a moving wall of highly compressed air, resembles, and is accompanied by a very strong wind. In the ground, however, the effect of the pressure wave is like that of a sudden impact and thus the term "shock" is used to denote the ground pressure wave. Initially the velocity of the blast wave is many times the speed of sound. However, at long ranges from the blast-center the velocity becomes essentially that of sound.[1]

After a short time, the pressure behind the front drops below that of the surrounding atmosphere and a so-called "negative phase" of the blast wave forms. The peak values of the underpressure are generally small compared with the peak overpressures and, generally, less damage occurs during the negative than in the positive phase of the blast wave.

Associated with the strong winds accompanying the passage of the blast wave is a "dynamic pressure" that may create a drag force on some structures that is more damaging than the peak overpressure. The period of time over which the positive dynamic pressure is effective may be taken as essentially the positive phase duration of the overpressure. The following tabulation from Reference 1 indicates corresponding values of peak overpressure, peak dynamic pressure, and maximum blast wind velocities for an ideal shock front in air at sea level.

TABLE IV(1)

OVERPRESSURE, DYNAMIC PRESSURE, AND WIND VELOCITY IN AIR AT SEA LEVEL FOR AN IDEAL SHOCK FRONT

Peak Overpressure (pounds per square inch)	Peak Dynamic Pressure (pounds per square inch)	Maximum Wind Velocity (miles per hour)
200	330.0	2,080
150	223.0	1,778
100	123.0	1,414
72	80.0	1,170
50	40.0	940
30	16.0	670
20	8.0	470
10	2.0	290
5	0.7	160
2	0.1	70

In a surface burst, there will be a merging of the incident blast wave and the wave reflected from the ground surface to form a single wave front called the "Mach" wave. The behavior of this fused wave is the same as that of a blast wave. For moderate heights of burst Mach fusion occurs at a distance from ground zero approximately equal to the burst height.

Some of the blast wave energy of the air wave will be transferred into the ground as the wave impinges on the ground producing a ground shock. The principal stress in the soil will be nearly vertical and about equal in magnitude to the air blast overpressure. Beyond the immediate crater region (ground zero), the direct ground shock, the shock transmitted entirely through the earth, is usually small in comparison with that induced by the air blast wave passing over the surface.

For a ground surface burst, the area affected by the air blast will greatly exceed that in which damage is caused by both direct and induced shock waves in the ground. For buried structures outside the plastic zone, the damage will be caused by induced rather than by direct, ground shock.

For purposes of blast vulnerability study, waterworks facilities can be divided into above ground structures and below ground structures, including pipe lines.

Below Ground Distribution System

Reference material on the nuclear weapons testing program affords little information on the response of below ground pressure water distribution systems. We can, however, draw some information from the peacetime operation of water systems.

Experiences in the operation of pressure water distribution systems illustrates the damaging effects of sharp changes in (1) external loadings (impact), (2) internal pressure surges (water hammer), and (3) the longitudinal stresses in the pipe lines. Such forces experienced through peacetime operations and natural storms, generally are of a much lesser intensity than that which may result from a nuclear explosion.

Arnold[15] reports on a pressure change in a water distribution system, which raised the pressure only about 10 psi, that resulted in eighteen main breaks in a single hour. He points out that changing pressures in water distribution systems can cause main breaks, particularly if pressure changes are sudden, such as those associated with water hammer or rapid changes in operating pressures.

Clark[15] reporting on breaks in water mains, finds that many of the breaks take place during the early morning hours when the water demands are low and there are slight increases in internal pressures.

Remus[15] lists among the related variables that he finds are a cause for breaks in cast iron water mains - water and ground temperature changes, water hammer, and excessive street loads causing street settlement which are amplified by shock.

Niemeyer[15] in a study of water main failures in his water distribution system extending over a period of 34 years, found that circumferential breaks appear to occur during periods of low water temperature, whereas joint failures occur during periods of rapid temperature change. Breaks have been stopped completely, on several occasions, by the addition of well water to the surface supply, thus raising the water temperature by 4° or 5°F; and from his study, concludes that longitudinal stress created by temperature change has been a primary cause of circumferential pipe breaks during the past 10 years.

Thomas[15] experienced a rash of breaks in a water distribution system within the first few hours of changeover from a warm ground water source to a surface supply in a temperate climate.

Hawkins[17] in a review of the sharp increase of main line breaks during extremely cold weather finds that stresses caused by lengthwise contraction cause tension breaks generally characterized by being circumferential. He found that the converse is true when there is an abrupt rise in temperature; the breaks then caused are the result of extreme compression.

Will the blast waves, beyond the crater, resulting from nuclear explosions do more than create damage of this same character? Will water hammer pressures be created in the distribution grid? Will the compression of the supporting soil collapse the piping? Will damage result which is of a character differing from that experienced in peace time? These and many other conditions, not now visualized, may need to be considered.

In an effort to answer some of these questions and to determine theoretically the response of a water distribution system to the effects of a ground surface nuclear weapon burst, we shall consider a system subjected to the following:

(1) external pressures induced by air blast wave;
(2) external pressures of direct ground shock; and,
(3) shock wave acting in longitudinal direction of water main.

In this analysis, the reaction of the water, the pipe, and the supporting soil will be considered. To simplify the problem, a theoretical analysis of hypothetical piping arrangements subjected to assumed pressure wave loadings will be done, and using the findings of the theoretical analysis, the response of actual operating water systems to a hypothetical nuclear attack will be described.

Above Ground Facilities

Available information in References 11, 12, and 15 provides guidance and technical assistance in evaluating the blast vulnerability of existing waterworks structures. Some information relative to correlation of structural damage and functional operation of water supply systems is presented in Reference 12.

PARAMETERS OF THE ANALYSIS OF OVERPRESSURE INDUCED SHOCK WAVE EFFECTS

General

The general nature of the problem is to determine the blast overpressure which underground piping can withstand when suffering damage which causes interruption in functional operation. Underground structures will be affected by the air induced ground shock and overpressure of the blast. All structures are assumed to be outside the region of regular reflection where the mach stem is high enough to cover the structure. The approach to the problem is outlined below, along with a general description of information about existing structures which will be required for analysis.

Definitions

Underground Structures. Loading for underground structures will be considered as caused by an air induced ground shock front only as defined in Reference 18, Paragraph 2-3.

Underground Piping. Effects of earth shock on piping will be studied in light of Chapter XI of Reference 18.

Damage. Slight damage will be sustained when structural elements are loaded to the dynamic yield point of materials, as given in Chapter VII of Reference 18. Moderate damage will be sustained after this yield point is exceeded, but short of ultimate failure of materials. Severe damage will occur when stresses exceed the ultimate. Failure of frangible and other overpressure sensitive materials will be assumed to occur, as given by Table 4.39 of Reference 1.

The analysis of existing structures will be subject to many uncertainties inherent in our incomplete knowledge of how complex systems will react to blast effects. The investigations should not indicate an accuracy greater than justified by the assumptions. Nevertheless, to know the physical nature of the materials and elements of which the structures are constructed and how they are connected together can make the results of the analysis subject to less error. To this end information is needed to determine the response of each structure to blast effect.

INFORMATION REQUIRED TO EVALUATE POSSIBLE BLAST DAMAGE

In order to evaluate the ability of structures and underground piping to withstand the effects of a nuclear blast, it is essential that certain essential data be collected. For example, it is important to know the pertinent details of construction, location, design loadings, foundation conditions, soil conditions, general state of repair and operating water pressures. Ideally, the engineer making the evaluation would inspect each facility. Lacking this inspection, next best would be that the person assigned to make the survey be knowledgeable as to structural design. Such a person would be better qualified to know what features of a structure or pipeline contribute to its strength.

Photographs could prove an efficient and economical means to procure information, when accompanied by appropriate explanatory comments. Although it is considered unnecessary to collect detail drawings of structures, their use by the surveyor of the facilities to enhance the completeness of his report would be desirable. Reduced drawings of floor plans and elevations may prove convenient.

The following features should be covered by the examination report on each structure.

Locality

A map location of each structure, its orientation, and its proximity to other structures should be given. Ground surface features and other objects which may shield it from blast effects should be reported.

General Description

Approximate plan dimensions, shape, height, number of stories, size of rooms, pipe diameters, kinds of materials, and other geometrical features should be described. A judgment as to age and general condition of the structure should be made.

Design Loadings

Available data on loads used in design, or an estimate of what was used, should be reported. Dead and live loads, storage loads, wind and earthquake loads, earth pressures, fluid pressures, would all be valuable information to have.

Soil Conditions

The classification of soil in which piping and facilities are founded should be described. Details of embankments and ground cover will be needed. Depths of ground water should be given. Available data on the geology of the region to disclose the underground rock structures would be helpful.

Construction Details

Perhaps most important of all are the details of construction. These should be as accurately described as possible. Materials used for the roof, floors, foundations, walls, pipes, etc., should be described. It should be determined whether masonry, concrete, or gunite is reinforced or not, what the thickness is, and what the size, spacing, and location of reinforcement are. It is important to know what the vertical load carrying structural elements are --- steel beams and purlins, concrete beams and slabs, flat slab, wood joists, to name a few. And what the lateral load carrying elements are; steel bracing, rigid frames, concrete shear walls, wood shear walls, etc. A description of connections between these elements and between these elements and the foundation should be described. Of particular importance would be the location and size of openings for doors, windows, vents, etc., in the walls and roofs of these facilities. In describing piping, state the type, size, and thickness of walls, and type of joint used in construction of each line. Also, determine the bedding angle and the crushing strength and/or the bursting strength of pipes. The wall thicknesses used in tanks is important to know.

Other Considerations

In addition to the above, the examiner should note any other features that he feels would be of value in assessing strength characteristics.

VULNERABILITY OF UNDERGROUND PIPING

General

Above ground facilities, being exposed directly to the blast wave, will be damaged at overpressures considerably below the loads that underground piping and facilities will be affected. When above ground buildings and structures are destroyed and/or moved laterally by the blast, piping will likewise be broken or distorted where connected to those above ground facilities. Likewise, piping exposed above ground and dependent for support on bridges, trestles, or other exposed structures, will be more vulnerable than piping below ground. Damage to piping above ground will be related to the vulnerability of the supporting structures. These situations must be individually investigated.

The following portion of this report will be confined to studying the vulnerability of lines embedded below the ground surface. How piping in its underground environment will react to the blast induced forces will be investigated.

Existing underground lines may be in such a condition that any slight stress increase could set off a series of failures. Such lines fail due to minor seismic disturbances, or even to small changes in temperature. Numerous failures of a maintenance nature can be expected to occur when a blast wave traverses an area. The investigation, however, will not attempt to anticipate these kinds of failures. They are not considered to be within the scope of this report. Examination will be made of those instances when the blast forces alone will be sufficient to rupture lines that are in good condition. Engineering judgment of the existing condition of pipes must be used to further assess additional damage which may result due to the substandard condition of existing lines.

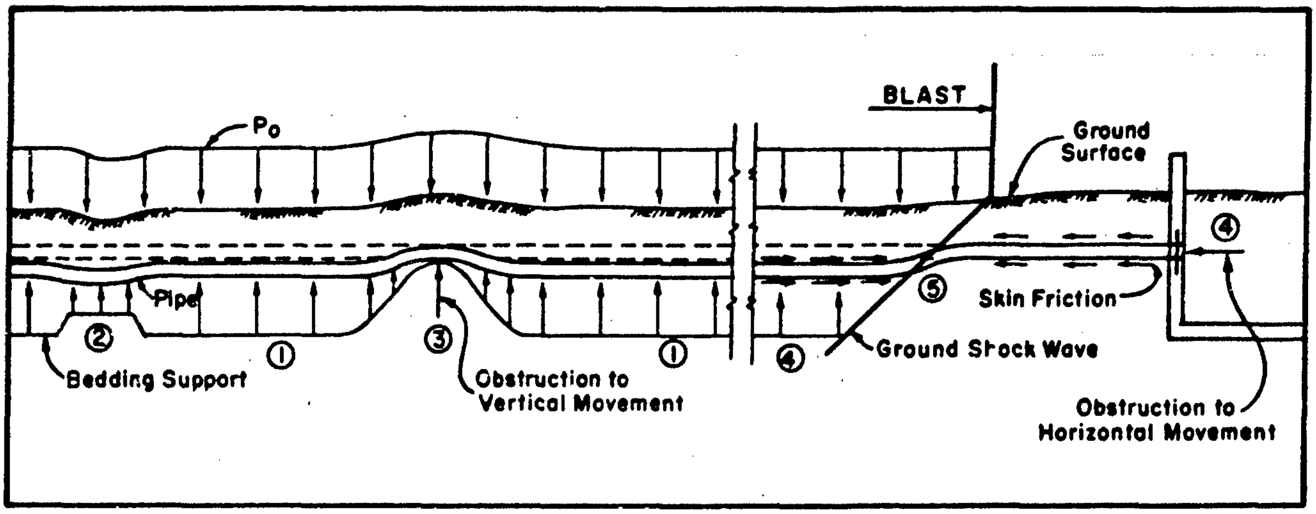


Figure 7. —— THE ENVIRONMENT OF UNDERGROUND PIPE, PRECEDING AND DURING A BLAST WAVE

① Fully bedded-vertical and lateral loading

② Weak bedding for short distance-longitudinal bending and shear

③ Vertical obstruction to movement-longitudinal bending and shear

④ Skin friction near shock wave front-longitudinal axial loading

Obstruction to longitudinal displacement-longitudinal axial loading

⑤ Bending at ground shock wave-longitudinal bending and shear

Crushing Effects on Piping Due to Overpressures

For a blast wave of long duration, the vertical air pressure over the ground can be taken to be uniform. Piping for water and sewer systems is usually located at shallow depths. Hence, the vertical earth pressure acting on pipe in an elastic, homogeneous soil will be equal to the overpressure, p_o, plus the weight of the earth overburden. In saturated soil, the lateral pressure will equal the vertical pressure. For unsaturated soil the lateral pressure will be somewhat less than the vertical pressure. Pipe will be more vulnerable to collapse when there is no lateral pressure to help support its walls against stresses due to bending. Since lines running underground for some distance may be expected to have conditions favorable to no lateral resistance, analysis of the general case must anticipate that such sections of underground lines will exist. Therefore, the analysis will assume no lateral support of the soil surrounding the pipe as the worst condition. Suitable corrections can be applied for less severe loading where lateral support can be expected.

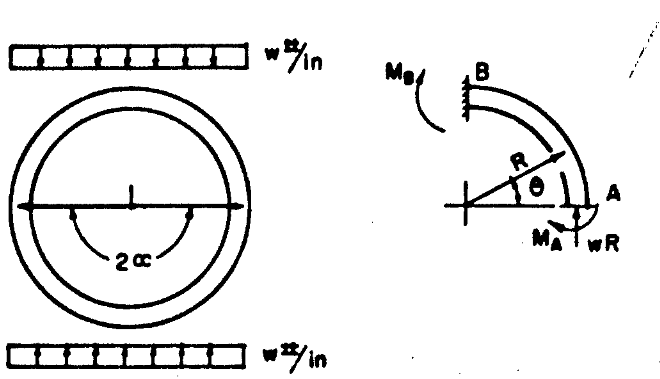
The first consideration will be the case where there is complete bedding of the pipe in the soil, giving ideal vertical support to blast pressures. The second consideration will be what happens when less than perfect bedding exists, giving a reduction in resistance to overpressure. By relating the pipe stresses when subjected to overpressure to its stresses under the crushing strength test, tensile strength test, or modulus of rupture test, as given by the ASTM specifications to which it was manufactured, the minimum blast pressures can be evaluated for various types of pipe with respect to what they can be expected to withstand without rupture. Brittle lines will be considered to have failed when the elastic limit of the material is reached. Ductile lines will be considered to have failed when plastic hinges are formed on the pipe's circumference, thus leading to collapse of the walls. Clay, asbestos-cement, unreinforced concrete, and cast iron pipe are considered brittle. Reinforced concrete, ductile iron, and steel pipe are considered ductile.

In addition to the effects of the blast forces tending to crush the pipe, another consideration would be what happens when vertical support conditions vary along the pipe's length, producing bending and shear stresses that are perpendicular to the stresses tending to crush the pipe's walls.

Also, as the air-induced shock wave in the ground propagates along a pipe, it will produce stresses in the pipe. Points along the pipe will move relative to one another to accommodate the ground motion. The varying nature of a pipe's ground environment will influence the loading conditions. It is necessary to consider what effect this type of loading will have on the pipe.

Case I - Vertical Pressure and Complete Bedding

Following is an analysis for the case where pipe is subject to vertical pressure only (Reference 20, Articles 56 and 57). Assume that the pipe is completely bedded ($2\alpha = 180^o$).



Through symetry of loading, no rotation takes place at Sections A and B, therefore:

$$\text{(I)} \quad \int_0^{\pi/2} \frac{MR}{EI}\, d\theta = 0 \quad \text{(Equation 208, Page 184, Reference 20)}$$

M is the moment, R is the mean pipe radius, E is the modulus of elasticity of the pipe material, and I is the moment of inertia of the section.

The particular function of M for Case I is expressed by the following equation:

$$\text{(II)} \quad M = M_A - wR^2 (1 - \cos\theta) + wR^2/2\, (1 - \cos\theta)^2$$ (Equation 207, Page 184, Reference 20)

By substituting (II) in (I) and noting that E, I and R are constants we obtain the following equation:

$$M_A \int_0^{\pi/2} d\theta - wR^2 \int_0^{\pi/2} (1 - \cos\theta)\, d\theta + \frac{wR^2}{2} \int_0^{\pi/2} (1 - \cos\theta)^2\, d\theta = 0$$

Integrating and evaluating the above equation yields:

$$M_A \frac{\pi}{2} - wR^2 \left(\frac{\pi}{2} - 1\right) + wR^2 \left(\frac{3\pi}{4} - 2\right) = 0$$

Solving the above for M_A yields:

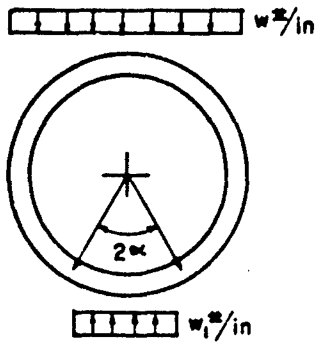
$$\text{(III)} \quad M_A = \frac{wR^2}{4} = M_B$$ (Equation 209 and Equation 210, Page 184, Reference 20)

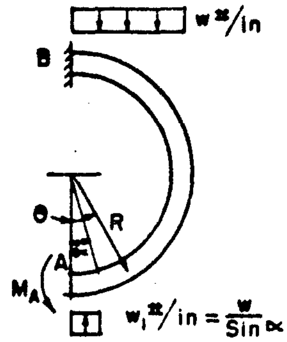
Because $M_A = M_B$, the plastic or ductile moments at failure will equal the elastic moments from theory of plastic design. Therefore Equation III is valid.

Case Ia - Vertical Pressure and Partial Bedding

Case I assumed uniform pressure evenly distributed over entire diameter top and bottom (Reference 20). Consider bottom pressure over a bedding angle, 2α, less than 180°.

Elastic Behavior





Through symetry of loading no rotation takes place at Sections A and B, and therefore

$$\text{(IV)} \quad \int_0^{\pi} \frac{MR}{EI}\, d\theta = 0$$

The particular functions of M for case Ia are expressed by the following:

$$\text{(V)} \quad \text{From } \theta = 0 \text{ to } \theta = \alpha, \quad M = M_A - \frac{w_1 R^2}{2} (\sin^2 \theta)$$

$$\text{(VI)} \quad \text{From } \theta = \alpha \text{ to } \theta = \frac{\pi}{2}, \quad M = M_A - \frac{w_1 R^2}{2} (\sin \alpha) \ (2 \sin \theta - \sin \alpha)$$

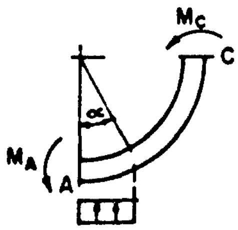
$$\text{(VII)} \quad \text{From } \theta = \frac{\pi}{2} \text{ to } \theta = \pi, \quad M = M_A - \frac{w_1 R^2}{2} (\sin \alpha) \ (2 \sin \theta - \sin \alpha) - wR^2 (1 - \sin \theta)^2$$

Inserting equations (V), (VI), and (VII) in equation (IV), and noting that E, I, and R are constant, integrating and evaluating the equations at the limits, and then solving for M_A yields the following equation:

$$\text{(VIII)} \quad M_A = \frac{wR^2}{2\pi} \left[\frac{3}{2} \cos \alpha + \alpha \left(\frac{1}{2 \sin \alpha} + \sin \alpha \right) - \pi \sin \alpha + \frac{3\pi}{4} \right]$$

Plastic Behavior

By the theory of plastic behavior $M_A = M_C$ at failure. Therefore the following equations are obtained by static analysis:



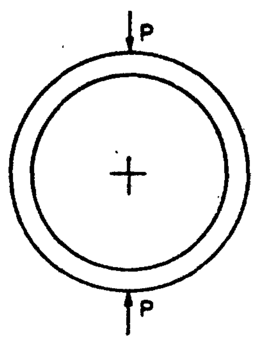
(IX) $M_A + M_C = wR^2\left(1 - \frac{\sin \alpha}{2}\right)$ or because

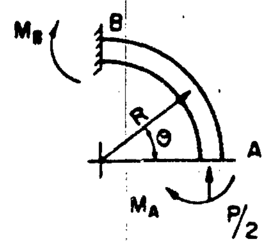
$M_A = +M_C$,

(X) $M_A = M_C = \frac{wR^2}{2}\left(1 - \frac{\sin \alpha}{2}\right)$

Case II - Concentrated Load

For the case where the pipe is subjected to a concentrated load, P, only (Reference 20), as in the "Crushing Test" the following applies:





Through symetry of loading no rotation takes place at Sections A and B, and therefore:

(XI) Again $\int_0^{\pi/2} \frac{MR}{EI}\, d\theta = 0$ (Equation 201, Page 180, Reference 20)

The particular function of M for Case II is expressed by the following equation:

(XII) $M = M_A - \frac{1}{2}PR\,(1 - \cos \theta)$ (Equation 199, Page 178, Reference 20)

Inserting equation (XII) in equation (I), noting that E, I and R are constants, and integrating and evaluating the equations at the limits, and then solving for M_A yields:

(XIII) $M_A = \frac{1}{2}PR\left(1 - \frac{2}{\pi}\right)$ (Equation 202, Page 180, Reference 20)

By static analysis:

(XIV) $M_B = \frac{PR}{\pi}$

By the theory of plastic behavior, $M_A = M_B$ at failure. Therefore the following equation is obtained by static analysis:

(XV) $M_A = M_B = \frac{PR}{4}$

Brittle Failure

Pipes made of brittle materials such as clay, cast iron, and asbestos-cement, will fail under the crushing test when the elastic limit is reached. If no lateral pressure is exerted on the pipe, a simple relationship will exist between the blast pressure p_o and the crushing strength, P per lin ft.

From equation (XIV) $M_B = \frac{PR}{\pi}$

From (III) $M_B = \frac{wR^2}{4} = M_A$

$$\frac{wR^2}{4} = \frac{PR}{\pi}$$

Let $w = 12p_o$ lbs per lin ft of pipe per diameter inch, neglecting earth overburden:

$$\frac{12p_oR^2}{4} = \frac{PR}{\pi}$$

Let $d' = 2R$ and solving for p_o:

(XVI) $P_o = \frac{2P}{3\pi d'}$, psi, where d'= mean diameter of pipe in inches and P is the crushing strength in lbs per lin ft of pipe.

When the bedding angle is less than 180° use equation (VIII):

$$M_A = \frac{wR^2}{2\pi}\left[\frac{3}{2}\cos\alpha + \alpha\left(\frac{1}{2\sin\alpha} + \sin\alpha\right) - \pi\sin\alpha + \frac{3\pi}{4}\right]$$

(XVII) K_b brittle $= \frac{EQ(I)}{EQ(VIII)}$ (100)%

Evaluating equation (VIII) and (XVII) at various values of α yields:

α	M_A	K_b Elastic (%)
$\pi/2$	$0.25\ wR^2$	100
$\pi/3$	$0.30\ wR^2$	83
$\pi/4$	$0.37\ wR^2$	68
$\pi/6$	$0.46\ wR^2$	54
$\pi/12$	$0.50\ wR^2$	50
0	$0.61\ wR^2$	41

Where the tensile strength, or modulus of rupture, f_u, of the pipe is given, the ability of the pipe wall to withstand the bending stresses will be determined by the section modulus:

$$S = \frac{t^2}{6}.$$

Plastic Failure

Similarly, pipes made of ductile materials such as reinforced concrete and steel, will fail under the crushing test after the elastic limit is reached.

From equation (XV) $M_B = \frac{PR}{4}$ From equation (III) $M_B = \frac{-wR^2}{4} = -M_A$

Let $w = 12p_o$ lbs per lin ft of pipe per diameter inch, neglecting overburden:

$$\frac{12p_oR^2}{4} = \frac{PR}{4}$$

Let $d' = 2R$ and solving for p_o:

(XVIII) $p_o = \frac{P}{12R} = \frac{P}{6d'}$, psi where P = the crushing strength of the pipe and d' = the mean diameter of the pipe in inches.

When the bedding angle is less than 180° use equation (X):

(X) $$M_A = \frac{wR^2}{2}\left(1 - \frac{\sin\alpha}{2}\right)$$ (XIX) $$K_b \text{ Ductile} = \frac{\text{EQ (III)}}{\text{EQ (X)}}(100)\%$$

Evaluating equation (X) and (XIX) at various values of α yields:

α	M_A	K_b Ductile (%)
$\pi/2$	$0.25\ wR^2$	100
$\pi/3$	$0.28\ wR^2$	89
$\pi/4$	$0.32\ wR^2$	78
$\pi/6$	$0.38\ wR^2$	66
0	$0.50\ wR^2$	50

Where the tensile strength, f_u of the pipe is given, bending stresses will be computed using a section modulus for plastic behavior:

$$S = \frac{t^2}{4}$$

Effect of Internal Pressure

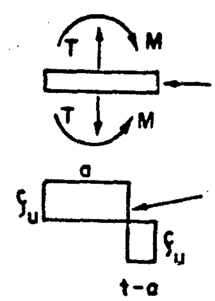
For a fully bedded pipe the ability of the pipe to withstand overpressure p_o related to the minimum crushing load P is;

(XVI) $p_o = \frac{2P}{3\pi d'}$ (Brittle), or (XVIII) $p_o = \frac{P}{6d'}$ (Ductile)

for a line not under internal pressure.

When internal pressure exists, the capacity of the pipe to withstand overpressure will be reduced. Let $T = Cf_u t$, where C is the ratio of internal pressure to bursting test pressure, f_u is the rupture stress, and t is the thickness of the pipe wall. For elastic behavior the capacity will be reduced directly with the factor C.

For ductile behavior, we will use the following relationships: (Reference 27 Article 4.2)



crossectional element of a pipe

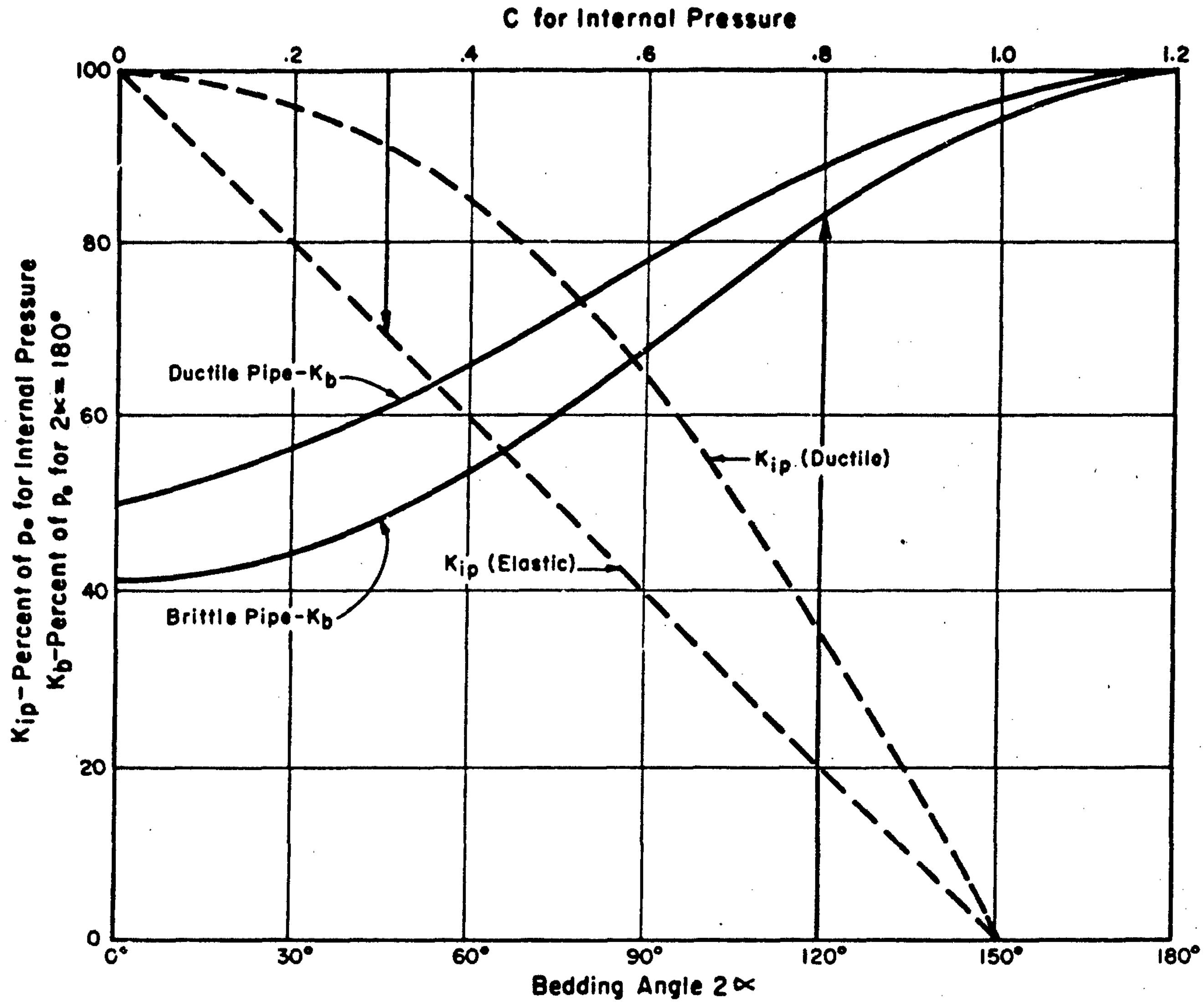
Plastic stress diagram based on the theory of plastic behavior

$$M = af_u(t-a)$$
$$T = f_u(2a-t)$$
$$Cf_u t = f_u(2a-t)$$
$$a = t\,\frac{(1+C)}{2}$$

Static relationships of the plastic stress diagram and letting $T = Cf_u t$

C	$a = t\frac{(1+C)}{2}$	a(t-a)	*K_{ip} = % of p_o Ductile	*K_{ip} = % of p_o Elastic
0.0	0.5t	$0.25t^2$	100	100
0.2	0.6t	$0.24t^2$	96	80
0.4	0.7t	$0.21t^2$	84	60
0.6	0.8t	$0.16t^2$	64	40
0.8	0.9t	$0.09t^2$	36	20
1.0	1.0t	$0.0t^2$	0	0

* For steel pipe, which distorts appreciably with considerable increase in the horizontal diameter, K_{ip} should not be applied because the effect of the internal pressure will reduce the pipe stresses[(21)].



NOTE:
K_b-Correction of p_o for Bedding Angle less than $2\alpha = 180°$
K_{ip}-Correction of p_o for Internal Pressure

Figure 8.—— CORRECTION FACTORS FOR BEDDING ANGLE AND INTERNAL PRESSURE

Numerical Evaluations

Following are tables and calculations which present the numerical data pertinent to pipes commonly used. Please refer to the various figures at the end of this section for further representation of this data.

TABLE V

CRUSHING OVERPRESSURE FOR ASBESTOS CEMENT PRESSURE PIPE (C296)

$$P_o = K_b \frac{2P}{3\pi d'}$$

Int. Diam. (inches)	Mean Diam. (inches)	Class 100			Class 150		
		P (lbs/ft)	Po (psi) $2\alpha=180^o$	Po (psi) $2\alpha=0^o$	P (lbs/ft)	Po (psi) $2\alpha=180^o$	Po (psi) $2\alpha=0^o$
4	4.5	4,100	193	79	5,400	254	704
6	6.5	3,900	127	52	5,400	176	172
8	8.5	3,700	92	38	5,500	136	56
10	10.5	3,700	75	31	7,000	142	58
12	13.0	4,000	65	27	7,600	124	51
14	15.0	4,400	62	25	8,600	121	50
16	17.0	4,800	60	25	9,200	125	51
18	19.0	5,200	58	24	10,100	113	46
20	22.0	5,600	54	22	10,900	105	43
24	26.0	6,300	51	21	12,700	103	42
30	32.0	7,500	50	21	15,900	106	43
36	38.0	8,800	49	20	19,600	109	45

TABLE VI

CRUSHING OVERPRESSURE FOR CONCRETE SEWER PIPE (C14) AND CLAY SEWER PIPE (C13 & C200)

$$P_o = K_b \, 2P/3\pi d'$$

Int. Diam. (inches)	Mean Diam. (inches)	Std. Strength			Ext. Strength		
		P (lbs/ft)	Po (psi) $2\alpha=180^o$	Po (psi) $2\alpha=0^o$	P (lbs/ft)	Po (psi) $2\alpha=180^o$	Po (psi) $2\alpha=0^o$
4	4.5	1,000	47	19	2,000	94	39
6	6.5	1,100	36	15	2,000	65	27
8	8.5	1,300	32	13	2,000	49	20
10	10.5	1,400	28	11	2,000	40	16
12	12.5	1,500	25	10	2,250	38	16
15	16.0	1,750	23	9	2,750	36	15
18	19.0	2,000	22	9	3,300	37	15
21	22.0	2,200	21	9	3,850	37	15

(TABLE VI, Continued)

Int. Diam. (inches)	Mean Diam. (inches)	Std. Strength P (lbs/ft)	Std. Strength P_o (psi) $2\alpha=180^o$	Std. Strength P_o (psi) $2\alpha=0^o$	Ext. Strength (lbs/ft)	Ext. Strength P_o (psi) $2\alpha=180^o$	Ext. Strength P_o (psi) $2\alpha=0^o$
24	25.0	2,400	20	8	4,400	37	15
* 27	28.5	2,750	20	8	4,700	34	14
* 30	31.5	3,200	21	9	5,000	33	14
* 33	34.5	3,500	21	9	5,500	33	14
* 36	37.5	3,900	22	9	6,000	34	14

* Clay pipe only

TABLE VII

CRUSHING OVERPRESSURE FOR REINFORCED CONCRETE SEWER PIPE (C76)

$$p_o = K_b\ P/6d'$$

Class	D-Load (lbs/ft/ft of diameter)	P(lbs/ft)	P_o (psi) $2\alpha=180^o$	P_o (psi) $2\alpha=0^o$
I	1,200	$P = \frac{1,200d'}{12} = 100d'$	17	9
II	1,500	$P = \frac{1,500d'}{12} = 125d'$	21	11
III	2,000	$P = \frac{2,000d'}{12} = 167d'$	28	14
IV	3,000	$P = \frac{3,000d'}{12} = 250d'$	42	21
V	3,750	$P = \frac{3,750d'}{12} = 312d'$	52	26

For cast iron water pipe (A44), ASTM, A44 gives a minimum modulus of rupture of 31,000 psi.

From Case I, $M_B = \frac{wR^2}{4} = \frac{p_o R^2}{4}$

where: p_o & f_u are in psi
R & t are in inches
M is in inch-lbs
S is in inches^3

$$f_u = 31,000 = \frac{M_B}{S} = \frac{6M_B}{t^2} = \frac{6p_oR^2}{4t^2}\ \text{(psi)}$$

$$p_o = \frac{31,000 \times 4}{6}\left(\frac{t}{R}\right)^2\ \text{(psi)}$$

$$P_o = 20,600 \left(\frac{t}{R}\right)^2 \text{(psi)}$$

Cast Iron Soil Pipe (A74)

$$f_u = 21,000$$

P_o for Cast Iron Soil Pipe will be proportional to the modulus of rupture of cast iron water pipe.

$$P_o = \frac{21,000}{31,000}\ 20,600 \left(\frac{t}{R}\right)^2 \text{(psi)}$$

$$P_o = 14,000 \left(\frac{t}{R}\right)^2 \text{(psi)}$$

Steel Pipe Grade A (A53)

$$M_A = \frac{wR^2}{4} = \frac{P_oR^2}{4} = f_uS = f_u\frac{t^2}{4}$$

$$f_u = 48,000 \qquad P_o = f_u\left(\frac{t}{R}\right)^2 = 48,000\left(\frac{t}{R}\right)^2 \text{(psi)}$$

Steel Pipe Grade B (A53)

$$f_u = 60,000 \qquad P_o = f_u\left(\frac{t}{R}\right)^2 = 60,000\left(\frac{t}{R}\right)^2 \text{(psi)}$$

TABLE VIII

CRUSHING OVERPRESSURES FOR CAST IRON WATER PIPE (A44)

$P_o = K_b\ 20,600\ (t/R)^2$

Class 50

Nom. Diam. (inches)	R (inches)	t (inches)	$t/R^2 10^4$	P_o (psi) $2\alpha = 180^\circ$	P_o (psi) $2\alpha = 0^\circ$
3	1.7	0.37	470	970	400
4	2.2	0.40	332	695	280
6	3.2	0.43	180	370	152
8	4.3	0.46	124	256	105
10	5.3	0.50	89	193	175
12	6.3	0.54	73	150	62
14	7.4	0.54	53	109	45
16	8.4	0.58	40	82	34
18	9.4	0.63	45	93	38
20	10.5	0.66	40	82	34

(TABLE VIII, Continued)

Class 50 (Continued)

Nom. Diam. (inches)	R (inches)	t (inches)	$t/R^2 10^4$	p_o (psi) $2\alpha = 180^o$	p_o (psi) $2\alpha = 0^o$
24	12.5	0.74	35	72	30
30	15.4	0.87	32	66	27
36	18.5	0.97	27	55	23
42	21.6	1.07	24	50	20
48	24.6	1.18	23	47	19
54	27.7	1.30	22	45	18
60	30.7	1.39	21	43	18

Class 100

Nom. Diam. (inches)	R (inches)	t (inches)	$t/R^2 10^4$	Po (psi) $2\alpha = 180^o$	Po (psi) $2\alpha = 0^o$
3	1.7	0.37	470	970	400
4	2.2	0.40	332	685	280
6	3.2	0.43	180	370	152
8	4.3	0.46	124	256	105
10	5.3	0.50	89	183	75
12	6.3	0.54	73	150	62
14	7.4	0.58	61	126	52
16	8.4	0.63	56	115	47
18	9.4	0.68	52	107	44
20	10.4	0.71	47	97	40
24	12.5	0.80	41	85	35
30	15.5	0.94	37	76	31
36	18.6	1.05	32	66	27
42	21.6	1.25	33	68	28
48	24.7	1.37	31	64	26
54	27.8	1.51	30	62	25
60	30.9	1.62	27	56	23

(TABLE VIII, Continued)

Class 150

Nom. Diam. (inches)	R (inches)	t (inches)	$t/R^2 10^4$	P_o (psi) $2\alpha = 180^o$	P_o (psi) $2\alpha = 0^o$
3	1.7	0.37	470	970	800
4	2.2	0.40	332	685	280
6	3.2	0.43	180	370	152
8	4.3	0.46	124	256	105
10	5.3	0.54	104	214	88
12	6.3	0.58	92	189	78
14	7.5	0.63	84	173	71
16	8.6	0.68	79	163	67
18	9.6	0.73	58	120	49
20	10.6	0.83	61	126	52
24	12.7	0.93	53	109	45
30	15.7	1.10	49	101	41
36	18.7	1.22	43	89	36
42	21.9	1.35	38	78	32
48	25.0	1.48	35	72	30
54	28.1	1.63	34	70	29
60	31.2	1.89	37	76	31

TABLE IX

CRUSHING OVERPRESSURE FOR SCHEDULE 40 STEEL WATER PIPE, GRADE A (A53) AND GRADE B (A53)

$$P_o = K_b\ 48{,}000\ (t/R)^2 \quad \& \quad P_o = K_b\ 60{,}000\ (t/R)^2$$

Nom. Diam. (inches)	R (inches)	t (inches)	$(t/R)^2 10^4$	P_o (Grade A) (psi) $2\alpha = 180^o$	P_o (Grade A) (psi) $2\alpha = 0^o$	P_o (Grade A) (psi) $2\alpha = 180^o$	P_o (Grade A) (psi) $2\alpha = 0^o$
8	4.2	0.32	58	277	138	350	175
10	5.2	0.36	48	230	115	290	145
12	6.2	0.38	37	177	88	222	111
14	6.8	0.38	31	14[illegible]	74	18[illegible]	9[illegible]
1[illegible]	[illegible].8	0.38	24	116	58	144	72
18	8.8	0.38	19	92	46	114	57
20	9.8	0.38	15	72	36	90	45
24	11.8	0.38	10	48	24	60	30

TABLE X

CRUSHING OVERPRESSURE FOR CAST IRON DRAIN LINES (CORROSION, PACIFIC FOUNDRY LTD.)

$$p_o = K_b \, 14{,}000 \, (t/R)^2$$

Nom. Diam. (inches)	R (inches)	t (inches)	$(t/R)^2 10^4$	p_o (psi) $2\alpha = 180^\circ$	$2\alpha = 0^\circ$
1-1/2	.94	0.38	1,620	2,270	930
2	1.19	0.38	1,020	1,430	590
3	1.69	0.38	520	730	300
4	2.19	0.38	300	420	172
5	2.67	0.41	240	340	140
6	3.16	0.50	250	350	144

TABLE XI

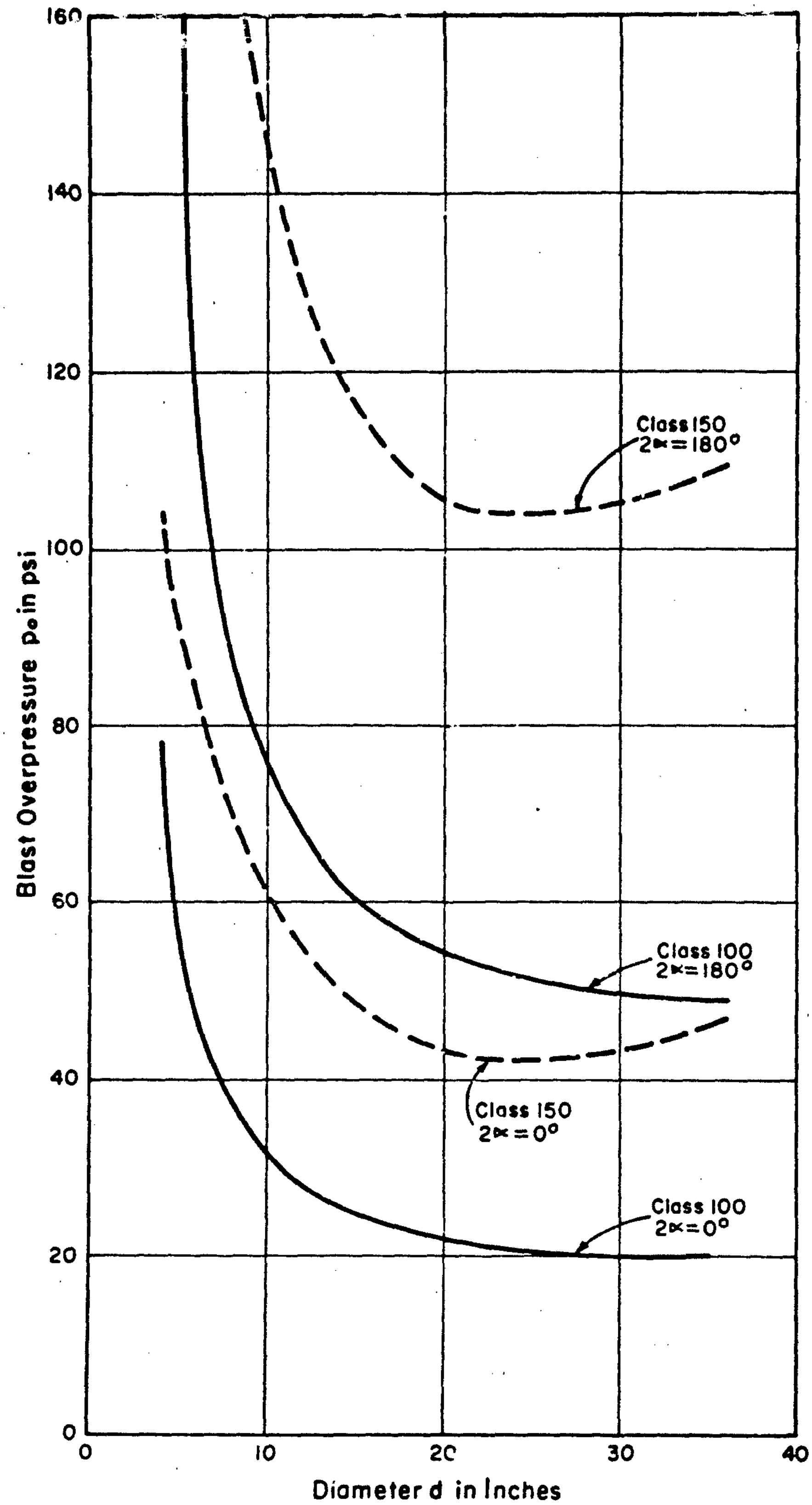
CRUSHING OVERPRESSURE FOR DUCTILE IRON PIPE - THICKNESS CLASS 2

$p_o = K_b \, 60{,}000 \, (t/R)^2$ $f_u = 60{,}000$ psi

(ASTM A339 Grade 60-45-10) (AWWA C151-65)

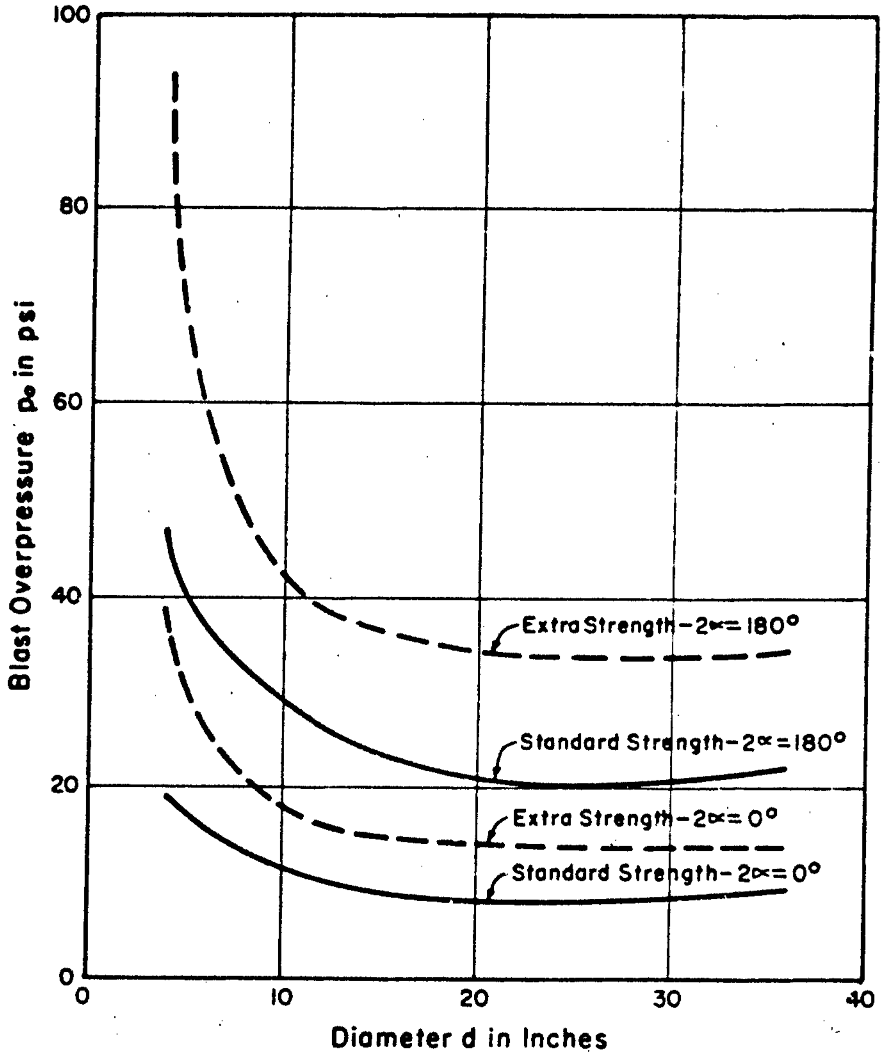
Nom. Diam. (inches)	t (inches)	R (inches)	$(t/R)^2 10^4$	p_o (psi) $2\alpha = 180^\circ$	$2\alpha = 0^\circ$
6	0.31	3.16	96.0	575	288
12	0.37	6.19	36.0	216	108
16	0.40	8.20	24.0	144	72
20	0.42	10.21	16.0	96	48
24	0.44	12.22	13.0	78	39
30	0.47	15.24	9.5	57	29
36	0.53	18.27	8.7	52	26
42	0.59	21.29	7.6	46	23

Following is a sample problem to illustrate the use of the numerical data just developed and presented in Figures 9 through 14.



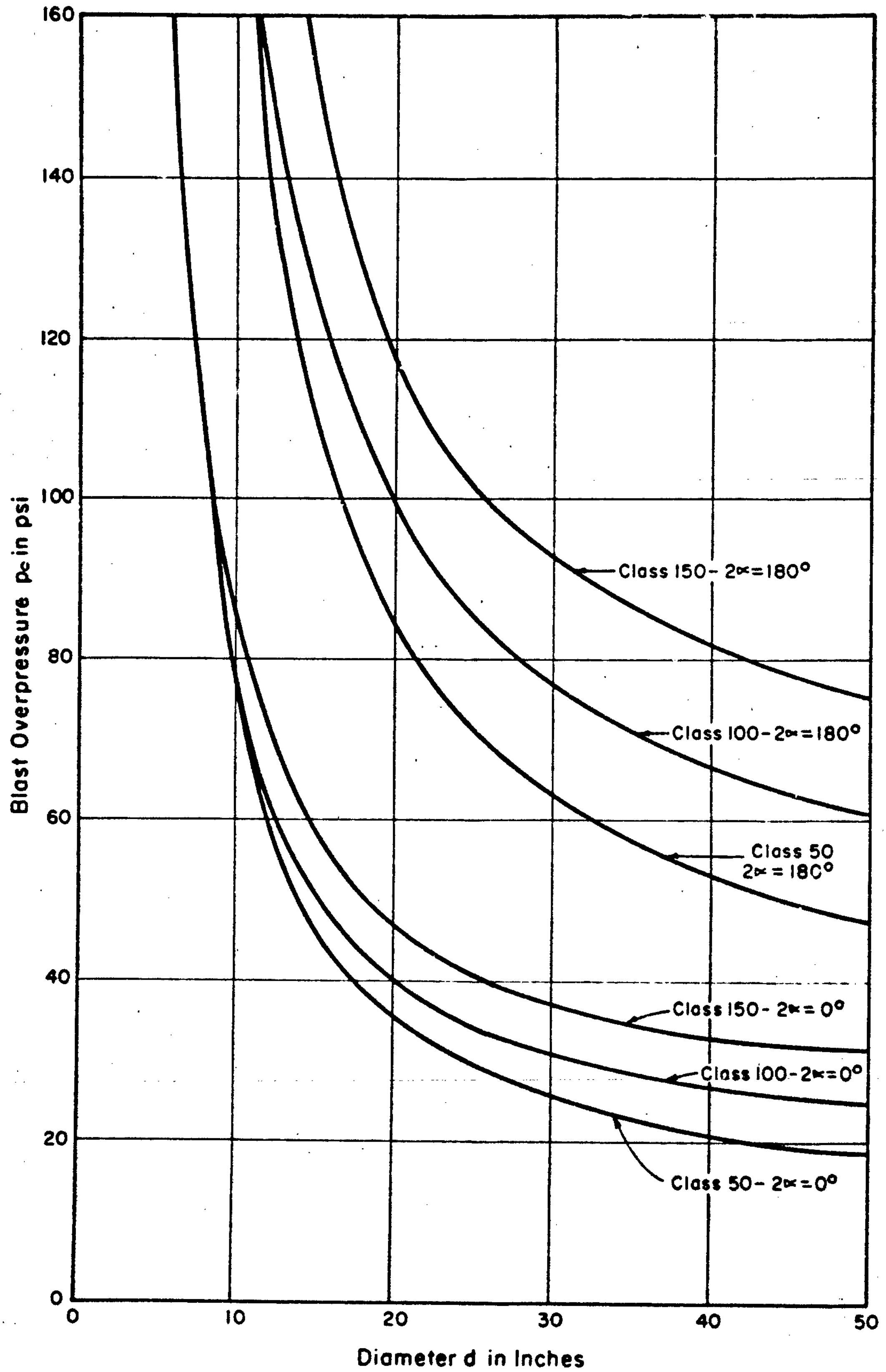
NOTE: Curves based on zero internal pressure and no lateral support.
See Figure 8 for internal pressure and bedding angle corrections.
See Pages 51 to 56 for lateral support corrections.

Figure 9.—— CRUSHING OVERPRESSURE FOR ASBESTOS-CEMENT PRESSURE PIPE



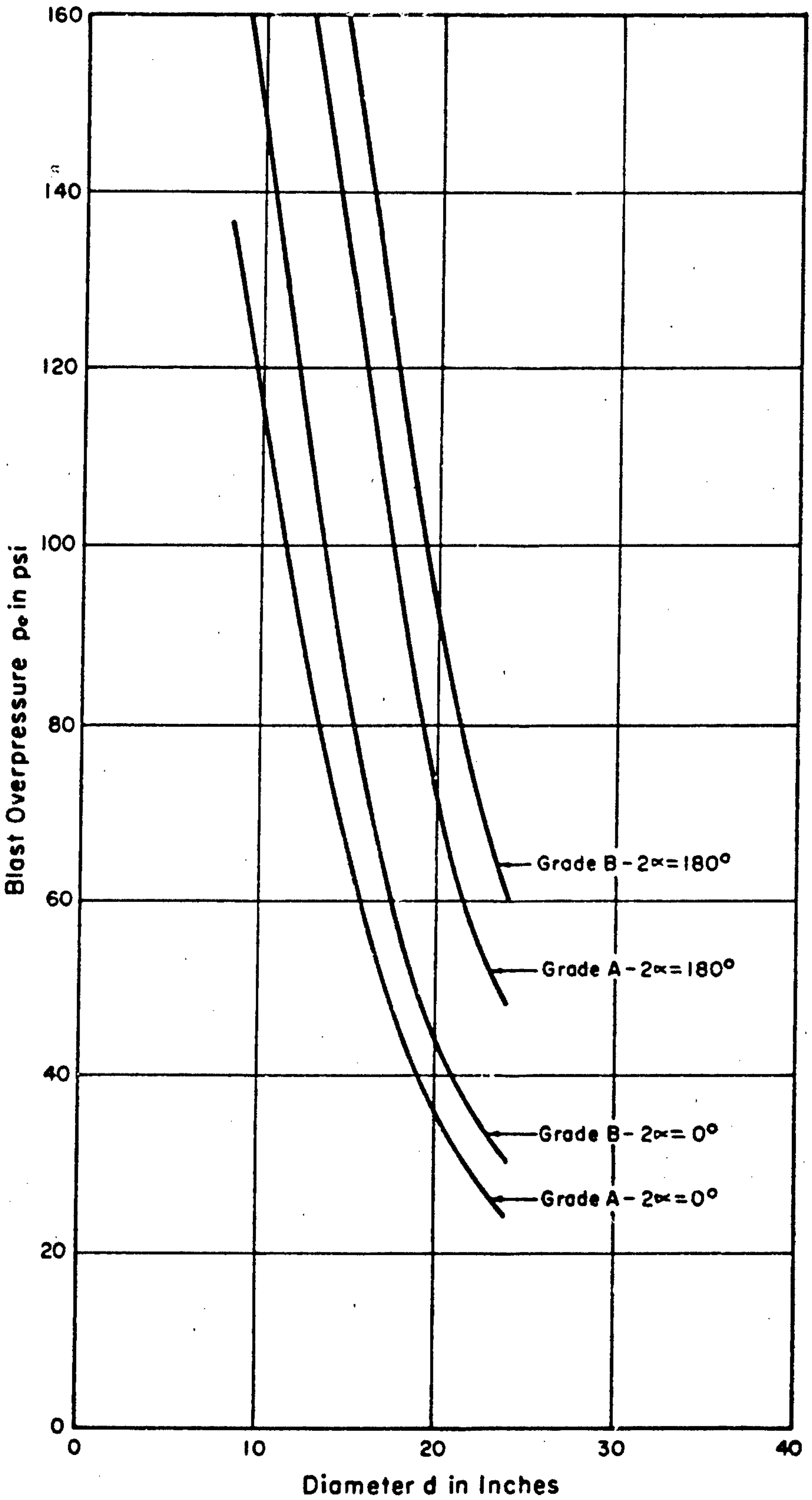
NOTE: Curves based on zero internal pressure and no lateral support.
See Figure 8 for internal pressure and bedding angle corrections.
See Pages 51 to 56 for lateral support corrections.

Figure 10.—— CRUSHING OVERPRESSURE FOR CONCRETE AND CLAY SEWER PIPE



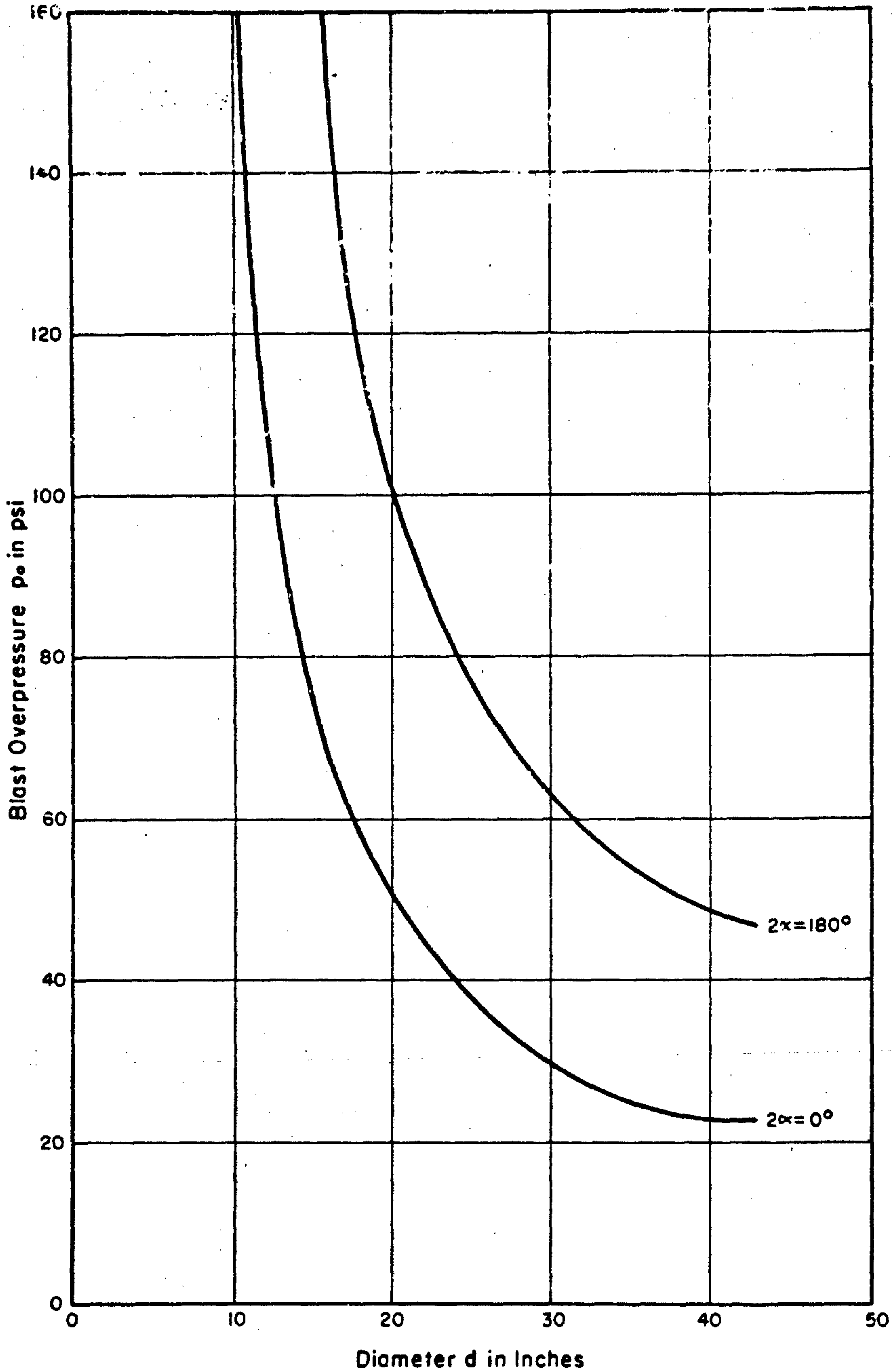
NOTE: Curves based on zero internal pressure and no lateral support.
See Figure 8 for internal pressure and bedding angle corrections.
See Pages 51 to 56 for lateral support corrections.

Figure 11.— CRUSHING OVERPRESSURE FOR CAST IRON WATER PIPE



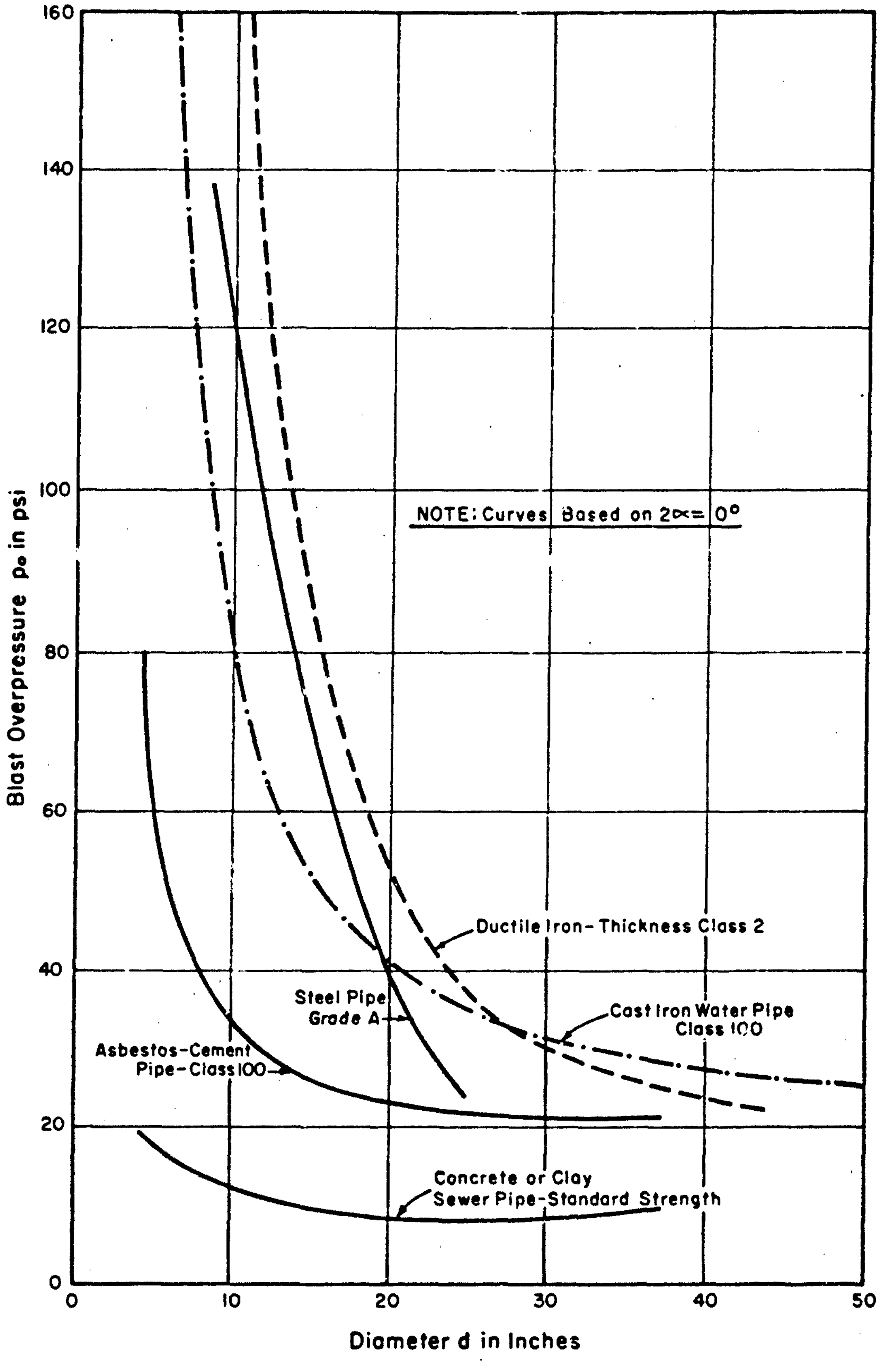
NOTE: Curves based on zero internal pressure and no lateral support.
See Figure 8 for internal pressure and bedding angle corrections.
See Pages 51 to 56 for lateral support corrections.

Figure 12. —— CRUSHING OVERPRESSURE FOR SCHEDULE 40 STEEL WATER PIPE



NOTE: Curves based on zero internal pressure and no lateral support.
See Figure 8 for internal pressure and bedding angle corrections.
See Pages 51 to 56 for lateral support corrections.

Figure 13.—— CRUSHING OVERPRESSURE FOR DUCTILE IRON PIPE-THICKNESS CLASS 2



NOTE: Curves based on zero internal pressure and no lateral support.
See Figure 8 for internal pressure and bedding angle corrections.
See Pages 51 to 56 for lateral support corrections.

Figure 14. — COMPARATIVE CRUSHING OVERPRESSURES FOR COMMONLY USED PIPES

Example: At what overpressure, p_o, should we expect failure of an asbestos-cement water line operating at 100 psi? d = 24 inches, Class = 100, bedding angle 120°, test pressure = 350 psi, and $C = \frac{100}{350} = 0.3$

From Figure 9, read $p_o = 52$ psi

From Figure 8, $K_b = .83$ and $K_{i_p} = .70$

Answer $p_o = 0.83 \times 0.70 \times 52 = 30$ (psi).

Corrections For Pipe With Lateral Support

Where the pipe is surrounded by well compacted soil it will gain lateral support from the soil. Rigid pipe will benefit from the active pressure, whereas flexible pipe will benefit from both the active and the passive pressure of the soil.

Active Pressure: The active pressure may be taken as a percent of the vertical pressure as given in the table below.

TABLE XII (18)

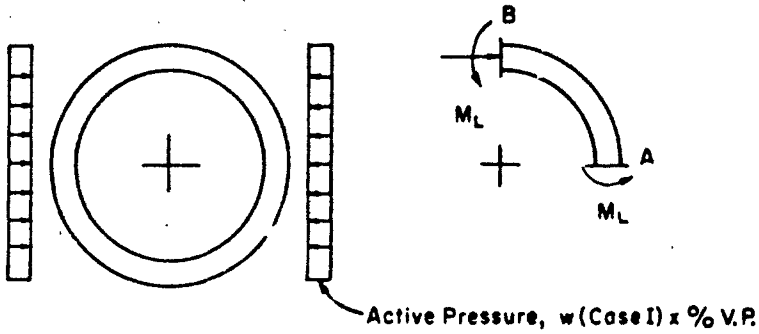
PERCENTAGE OF VERTICAL PRESSURE TO OBTAIN ACTIVE PRESSURE FOR VARIOUS SOIL TYPES

Type of Soil	Percent of Vertical Pressure
Dry loose	15
Dry or damp cohesionless	25
Unsaturated cohesive -	
Stiff	33
Medium	50
Soft	75
Saturated soil	100

Since analysis for this case is the same as Case I, except that the loading is applied to the sides of the pipe rather than the top and bottom, there will be a corresponding reduction to the moment applied to the walls of the pipe.

Case I applied laterally

$$M_L = \frac{wR^2}{4} \times \text{(percent of vertical pressure)}$$



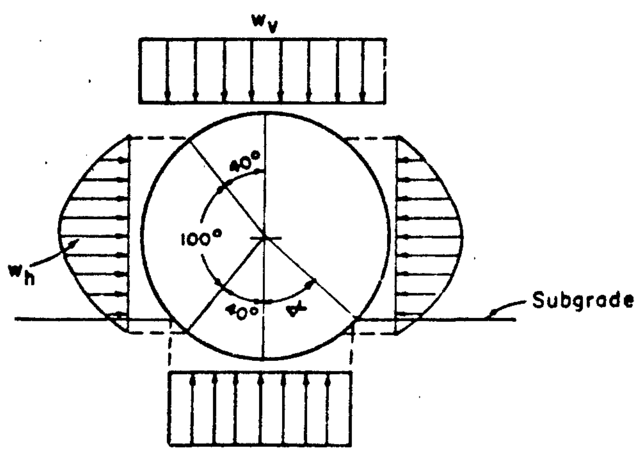
Therefore, the effect of active pressure will be to increase the ability of the pipe to withstand blast pressure. The increase can be taken as proportional to the corresponding moment reduction due to M_L.

$$p_o \text{ (corrected)} = p_o \text{ (no lateral support)} \times K_{ap}$$

$$\text{where} \quad K_{ap} = \frac{M_A \text{ (or } M_B)}{M_A \text{ (or } M_B) - M_L}$$

<u>Passive Pressure</u>: It is shown by Barnard's General Theory, Par. 8.10 of Reference 21, that under conditions of lateral support from the soil, ductile and flexible pipe will gain additional support due to the passive resistance of the soil. Failure values of p_o for steel, ductile iron, and reinforced concrete pipe should be increased accordingly.

Assume an earth cover of 3 feet and a vertical deflection of 20 percent d'. Then the lateral strain, ϵw_h, to the soil equals 10 percent of d'. From figures 8.18, 8.19, 8.20, and 8.21 of Reference 21 the data in Table XIII can be obtained.



DISTRIBUTION OF LOAD AND THRUST (PASSIVE PRESSURE)

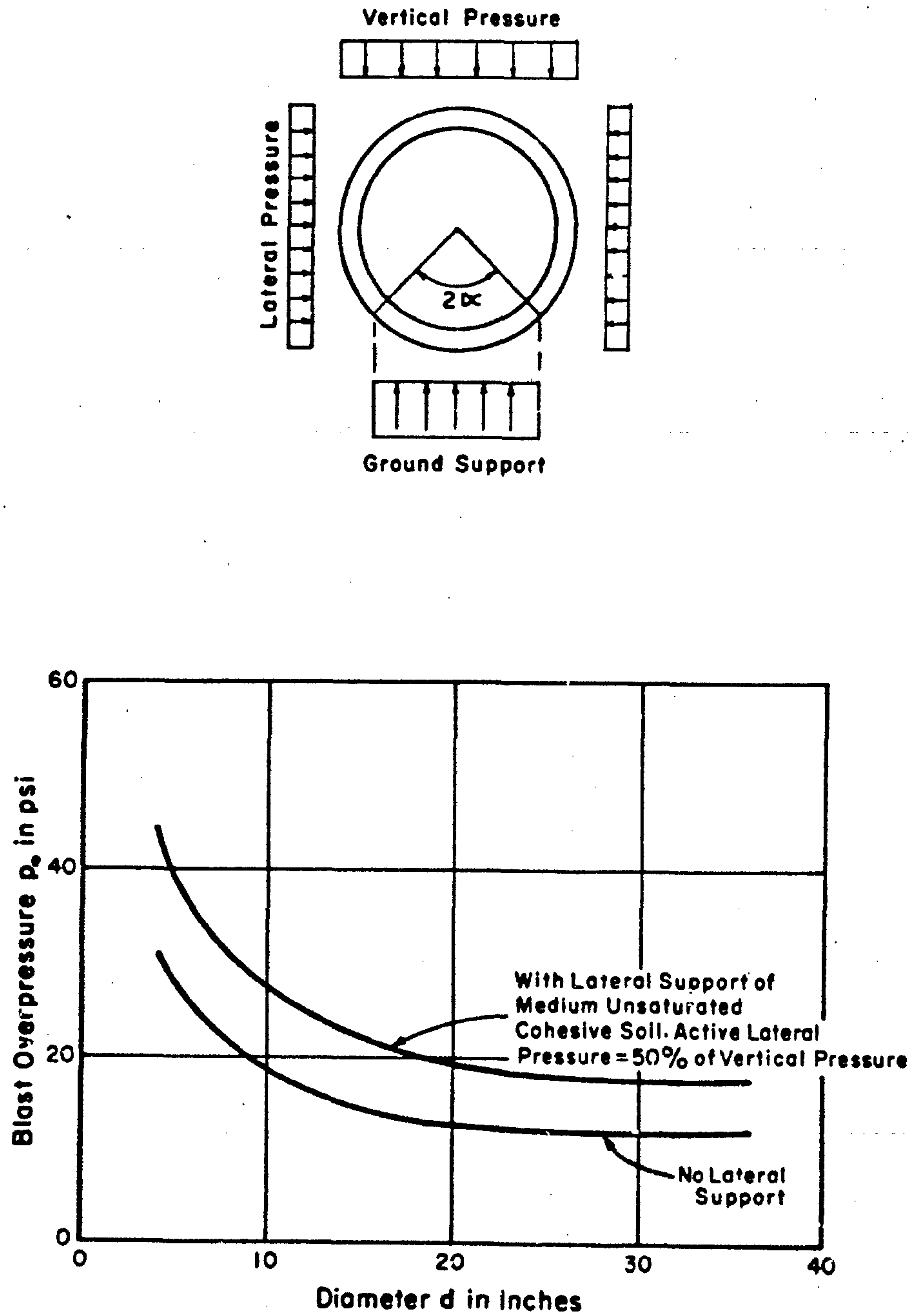
Where F is the shape factor from Table 8.3 of Reference 21 and $w_h = F \times (w_v - w_p)$ or $\frac{w_h}{F} = (w_v - w_p) = \Delta p_o$, the additional pressure the pipe will sustain due to the support gained from the passive resistance of the soil.

w_h = Intensity of lateral support at the center line of pipe in psi

w_v = Total vertical capacity of pipe in psi (p_o) with passive pressure support

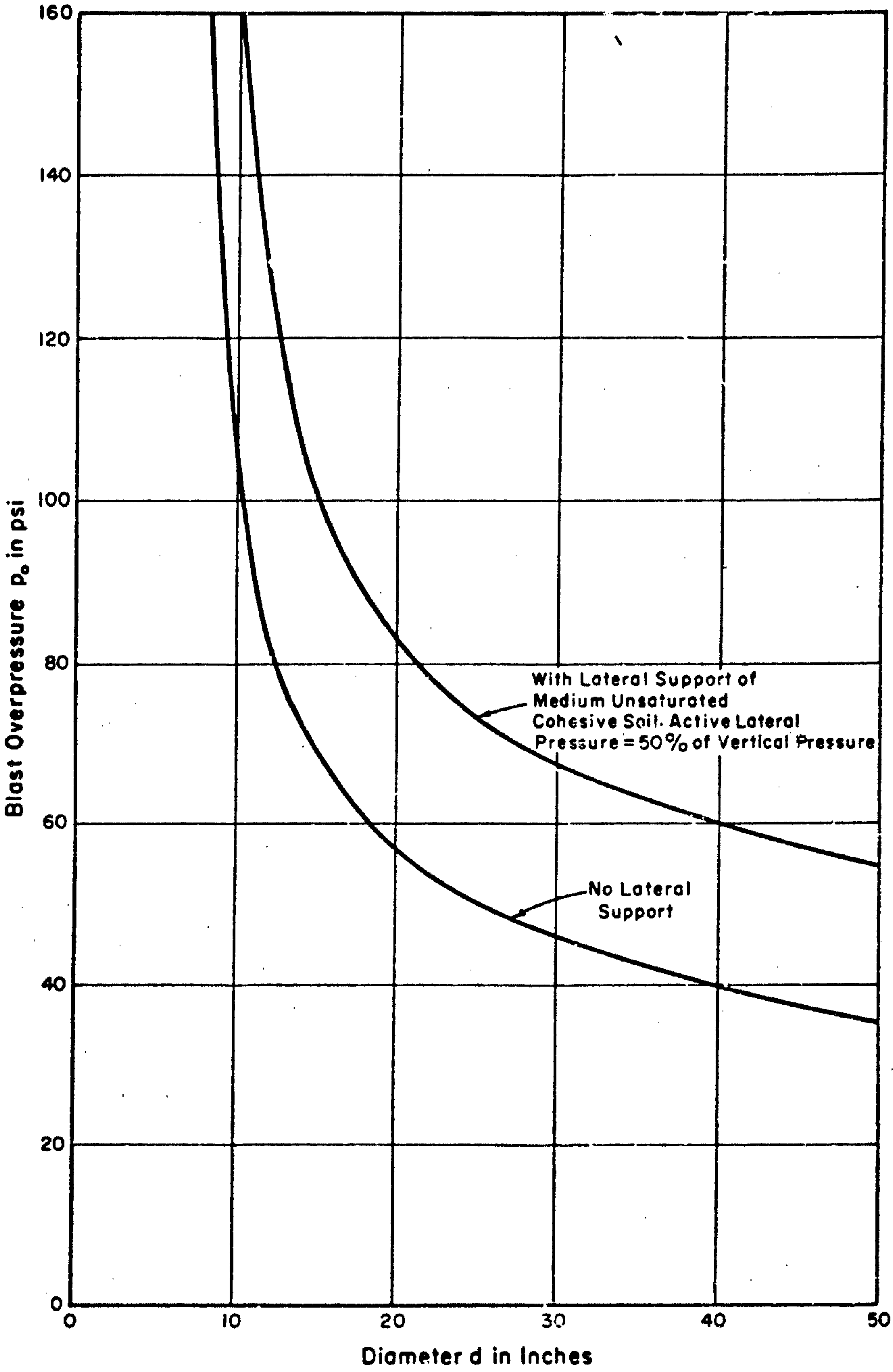
w_p = Total vertical capacity of pipe without passive pressure support in psi

Additionally, where lateral support of the soil is available, internal pressure will reduce or nullify the effects of blast loading on ductile pipe. Therefore the factor K_{i_p} is not applicable where ductile pipes have lateral support of the soil.



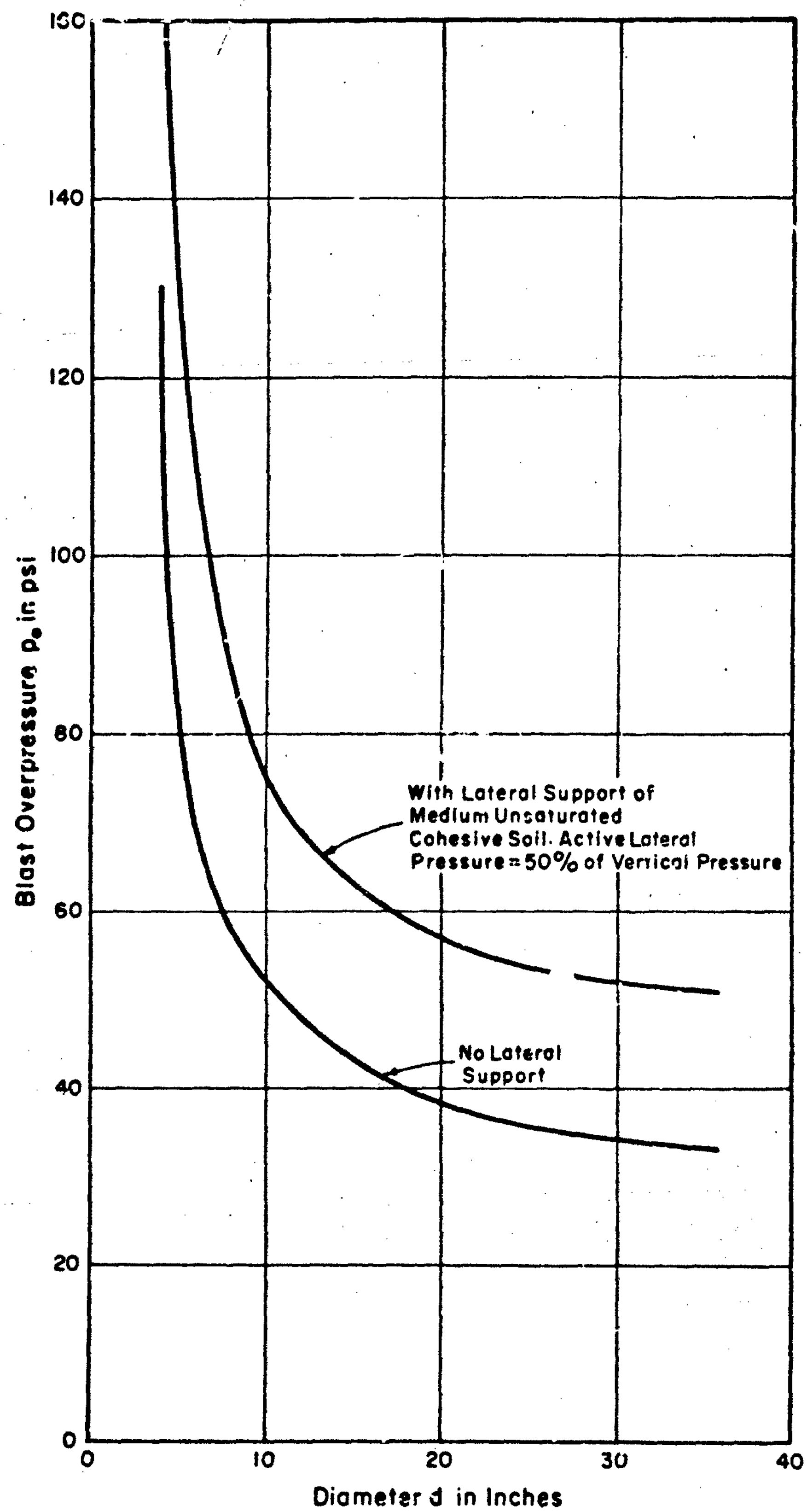
NOTE: Curves for Conditions $2\alpha = 90°$ and No Internal Pressure

Figure 15.—— COMPARATIVE CRUSHING OVERPRESSURE FOR LATERALLY SUPPORTED CONCRETE AND CLAY SEWER PIPE



NOTE: Curves for Conditions $2\alpha = 90°$ and No Internal Pressure

Figure 16.—— COMPARATIVE CRUSHING OVERPRESSURE FOR LATERALLY SUPPORTED CLASS 50 CAST IRON WATER PIPE



NOTE: Curves for Conditions $2\alpha = 90°$ and No Internal Pressure

Figure 17. —— COMPARATIVE CRUSHING OVERPRESSURE FOR LATERALLY SUPPORTED CLASS 100 ASBESTOS-CEMENT PRESSURE PIPE

TABLE XIII

INCREASE IN ALLOWABLE OVERPRESSURE GAINED FROM PASSIVE RESISTANCE OF SOIL

Type of Soil	w_h (psi)	$w_h/F = w_h/2.2 = \Delta p_o$ (psi)
Well Graded Sand	35	16
Sand Wity Clay	30	14
Lean Clay	20	9
Very Plastic Clay	30	14

Longitudinal Bending and Shear Forces

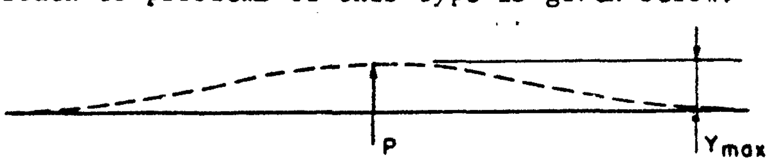
In the Final Report to U. S. Naval Civil Engineering Laboratory, Port Hueneme, Contract NBy - 32279, it is shown that all pipe lines, of the sizes described herein, will deform elastically to the configuration of the ground as the blast wave propagates across the surface. It is when the vertical motions of the pipe are interrupted by support conditions creating sudden relative displacements that rupturing may occur.

When a pipe enters a structure that is so supported as to not move vertically with the pipe, it must be investigated for possible rupture. The most severe cases will occur when such a structure is supported on rock, or on piling, or has a vertical shaft extending far below the surface, such as may occur at pumping plants. In these instances, shallow piping supported on soil will move downward relative to the structures. The structure on rock will move vertically, but a negligible amount. Structures on piling or with a vertical shaft, if connected to the piping, will not move vertically at the same time as the piping, since they are supported far below the surface. The ensuing time lag will permit a relative displacement to occur between the pipe and the connection.

On the other hand, some structures may be displaced more than the pipe. Roofed structures supported on footings will displace downward relative to entering pipes. The overpressure on the building area will be concentrated on the footings, pushing them downward more than the surrounding ground surface. Also the pipe in the protected area under the roof will not move downward as much as will pipe exposed outside the buildings.

It is doubtful that damage will occur due to this cause where pipe enters underground tanks or reservoirs. The soil pressure under these structures will be evenly distributed, causing them to react about the same as the pipe to vertical motion.

An approach to problems of this type is given below.



A long length of pipe embedded in a homogeneous material, subjected to a pressure p_o, will displace downward with the soil. However, if at some point it meets with a vertical resistance to the downward movement, due to a rock formation or structure beneath the pipe at some location, bending and shear stresses will be introduced into the line. The problem becomes one of a beam on an elastic foundation as described in Reference 22.

$$\text{(XX)} \qquad V_{max.} = 1/2P$$

$$\text{(XXI)} \qquad M_{max.} = \frac{P}{4\beta}$$

$$\text{(XXII)} \qquad Y_{max.} = \frac{P\beta}{2k}$$

Where $\beta = \sqrt[4]{\frac{k}{4EI}}$ k = modulus of subgrade (k_o) times the beam width. The approach to the problem will be to find what values of Y_{max} that various pipes can sustain without rupture.

V is shear force in pounds
P is concentrated force in pounds
M is moment in inch-pounds
Y is displacement in inches

Since $Y_{max.} = \frac{P\beta}{2k}$ and (XXIII) $P = \frac{2Yk}{\beta}$

Inserting Equation (XXIII) in Equation (XXII) and letting $\beta = \sqrt[4]{\frac{k}{4EI}}$

yields: $M = \frac{2Yk}{4\beta^2} = Y\sqrt{EIk}$

I for a pipe $\frac{\pi d'^3 t}{8}$ and $k = k_o d'$

Therefore: $M = Yd'^2 \sqrt{\frac{\pi}{8} Ek_o t}$

The pipe stress $f_b = \frac{M}{S}$ where $S = \frac{\pi d'^3 t}{8} \frac{2}{d'}$,

or, $S = \frac{\pi d'^2 t}{4}$ and $f_b = \frac{Y}{2}\sqrt{\frac{k_o E}{\frac{\pi}{8} t}}$

$$f_b = Y\sqrt{\frac{2k_o E}{\pi t}}$$

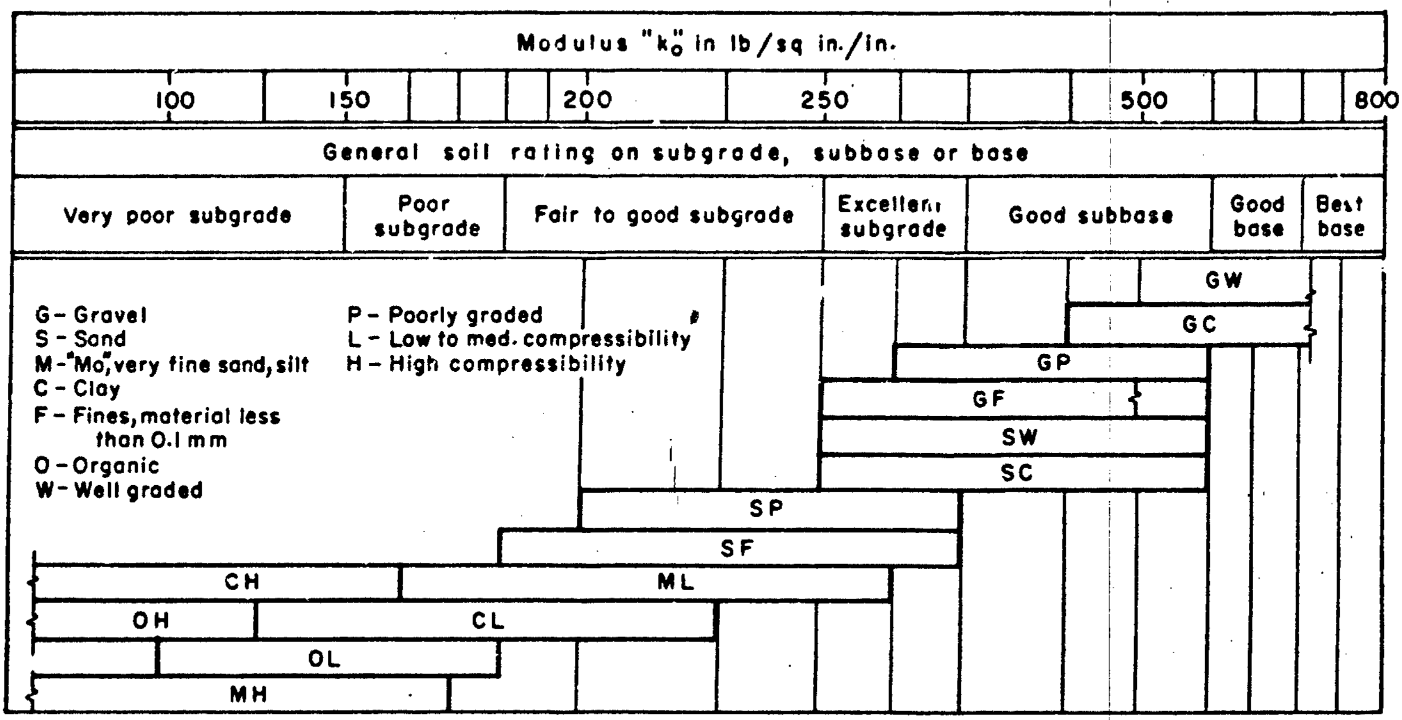
Taking k_o as 200 lbs/in^3 for average soil (see Table XIV for typical values of k_o) we have

$$f_b = 11.3\, Y\sqrt{\frac{E}{t}} \quad \text{and} \quad Y = \frac{f_b}{11.3}\sqrt{\frac{t}{E}}$$

Type of Pipe	f_b (psi)	E (psi)	Y (inches)
C.I. Water Pipe (A44)	31,000	15,000,000	0.55
Conc. Sewer Pipe (C14)	500	3,000,000	0.025
C.I. Soil Pipe	21,000	15,000,000	0.34

TABLE XIV[23]

VALUES OF THE MODULUS OF SUBGRADE



Therefore, for this problem it can be shown, within the accuracy of the available data, that the pipe is independent of the diameter d as to rupturing and is dependent only upon its modulus of elasticity E and thickness t. This is, of course, only approximately true for the bigger size pipes with d/t ratios that are large.

It can be assumed that ductile pipes of steel and iron will withstand all movements of this nature due to the plastic hinges that can be formed, since their plasticity will permit them to yield and distort to the new configuration of the earth's movement and crushing will take place before this condition occurs. Brittle pipes will be subject to rupture when f_b reaches the rupture point.

From page 140 of Reference 18, the maximum possible elastic strain between the surface and depth of 100 feet is equal to

$$Y_{max.} = 5 \text{ in.} \left(\frac{Po}{100 \text{ psi}}\right) \left(\frac{1000 \text{ fps}}{C_s}\right)^2$$

where C_s is the vertical seismic velocity of the soil. Taking C_s for average soil to be 3,000 fps, the worst condition that can be expected is $Y_{max.} = 0.0055\ p_o$.

To expect damage in bending from this source to underground piping, p_o must be high enough to give $Y_{max.}$ as computed above.

Type of Pipe	$Y_{max.}$ (inch)	p_o (psi)
C.I. Water Pipe (A44)	0.55	100
C.I. Soil Pipe	0.34	62
Conc. Sewer Pipe (C14)	0.025	5

Reference 18 further states that the actual displacement may be taken as half of this value, and may be interpolated as a straight line to a depth of 100 feet. Hence, p_o will normally be many times the values listed before damage to piping would occur, since many soils have C_s greater than 3,000 fps, and the depth for relative displacement will usually be less than 100 feet.

TABLE XV*

TYPICAL SEISMIC VELOCITIES FOR SOILS AND ROCKS

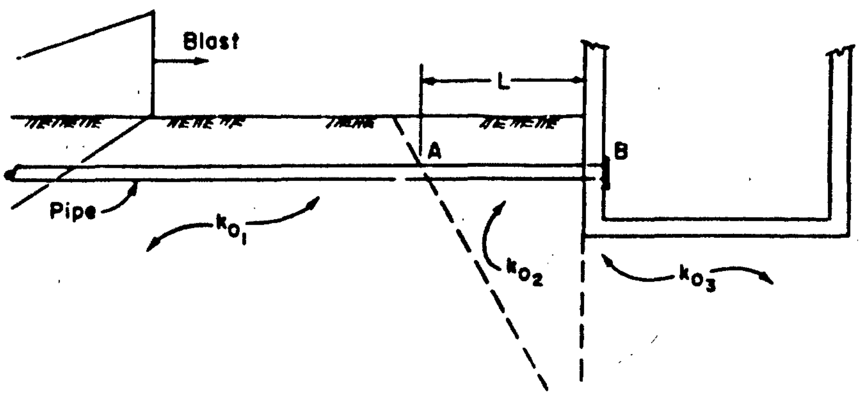
Materials	Seismic Velocity (fps)
Loose and Dry Soils	600 - 3,300
Clay and Wet Soils	2,500 - 6,300
Coarse and Compact Soils	3,000 - 8,500
Sandstone and Cemented Soils	3,000 - 14,000
Shale and Marl	6,000 - 17,500
Limestone - Chalk	7,000 - 21,000
Metamorphic Rocks	10,000 - 21,700
Volcanic Rocks	10,000 - 22,600
Sound Plutonic Rocks	13,000 - 25,000
Jointed Granite	8,000 - 15,000
Weathered Rocks	2,000 - 10,000

* Based on information taken from: "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes", by Juul Hvorslev, ASCE Research Report, printed by Waterways Experiment Station, Vicksburg, Mississippi, 1948, p.30. Fig. 4.

Where long lengths of piping will normally not be vulnerable to failure due to vertical displacements of the ground, relative to isolated supports, such is not the case for piping between adjacent support conditions of different relative displacements. Each individual situation must be evaluated.

For solving problems of many other conditions of loading which a pipe may be subjected to due to varying support conditions, see Reference 24. Pipe will be particularly vulnerable where bedding beneath the pipe is absent or nearly so and the pipe must span as a beam between supports, carrying the vertical loading of the overpressure by itself as a beam. Also when short lengths of pipe are required to sustain relatively large displacements with fixed end conditions such as may occur between closely spaced structures, pipe becomes more vulnerable.

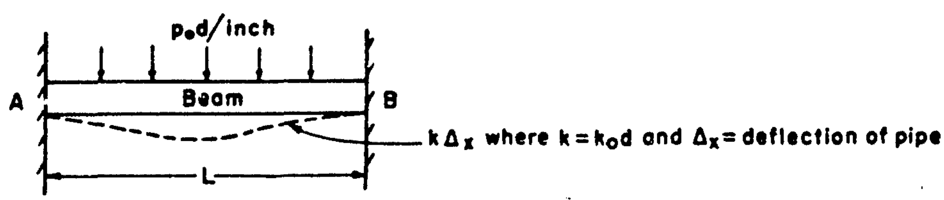
Problem of Pipe Spanning Across (Bridging) Area of Weak Support*



Pipe must span a distance L over the poor support condition k_{o_2}, as the blast engulfs this situation.

Because the pipe at A and the structure at B are both supported on strong soil k_{o_1}, points A and B can be assumed to displace downward equally.

If the pipe is "fixed" at A and B, the loading on length L will be



*See page 63 of Reference 24.

$$M_A = M_B = -\frac{p_o d'}{2\beta^2}\left[\frac{\text{Sinh}\,\beta L - \sin\beta L}{\text{Sinh}\,\beta L + \sin\beta L}\right] \quad \text{and} \quad \beta = \sqrt[4]{\frac{k}{4EI}}$$

$$V = \frac{p_o d'}{\beta}\left[\frac{\text{Cosh}\,\beta L - \cos\beta L}{\text{Sinh}\,\beta L + \sin\beta L}\right]$$

(Ref. 24, page 63)

<u>Example</u>:

12" diam. Class 50 C.I. Water Pipe, $I = 370\ in^4$, $E = 15{,}000{,}000$ psi

$L = 120$ inches, $k_o = 33.3\ lbs/in^2/in$, and $A = 19.8\ in^2$

$f_u = 31{,}000$ psi @ rupture

$$M_A \text{ (at rupture)} = \frac{2 f_u I}{d'} = 1{,}910{,}000 \text{ in - lbs}$$

$$k = 33.3 \times 12 = 400 \text{ psi}, \quad \beta = \sqrt[4]{\frac{400}{4 \times 15 \times 10^6 \times 370}} = 0.0117\ in^{-1}$$

$\beta L = 1.4$ Sinh $\beta L = 1.9043$ sin $\beta L = .9854$
Cosh $\beta L = 2.1509$ cos $\beta L = .1700$

M_A (inch-lb) = 1,910,000 = - 14,000 p_o p_c @ Rupture = 137 psi
V_A (lb) = Af_u = 19.8 (31,000) = 700 p_o p_o @ Rupture = 870 psi

<u>Approximate Analysis</u>:

Assume no support under pipe, ($M_{max.} = \frac{wL^2}{12}$ and $V = \frac{wL}{2}$, from basic statics and elastic design theory, for a beam fixed at both ends and loaded with a uniform load).

$$M_A = \frac{-wL^2}{12} = \frac{-12\ p_o \times 120^2}{12} = -14{,}400\ p_o$$

$$V = \frac{wL}{2} = 12\ p_o \times \frac{120}{2} = 720\ p_o$$

For this case, an extremely poor soil, the approximate analysis is quite accurate.

If the span were 240 inches, the rupturing p_o pressure would be

$$137 \times \frac{120^2}{240^2} = 34 \text{ psi}$$

If simply supported at B, the rupturing pressure would be, ($M_{max.} = \frac{wL^2}{8}$, from basic statics and elastic design theory, for a beam uniformly loaded, fixed at one support and simply supported at the other).

$$p_o = 137 \times \frac{8}{12} = 91 \text{ psi for 120 inch span}$$

$$p_o = 34 \times \frac{8}{12} = 23 \text{ psi for 240 inch span}$$

The $\frac{8}{12}$ factor results from comparing the constants in the two moment equations just noted.

For L = 20 ft $\beta L = 2.8$ Sinh $\beta L = 5.4662$ sin $\beta L = 0.6755$

$$M_A = -\frac{12\ p_o}{2 \times 0.0117^2} \times \frac{5.4662 - 0.6755}{5.4662 + 0.6755} = 35{,}400\ p_o$$

$$p_o = \frac{1{,}910{,}000}{35{,}400} = 54 \text{ psi}$$

Thus for elastic beam theory on 20 ft span the 12 inch diameter pipe can sustain considerably more load than by the approximate solution, 54/34 = 160%.

Longitudinal Displacement Forces

Where pipe is connected to structures or branch lines, the horizontal movement of the pipe may be of consequence. Paragraph 11-1-3 of Reference 18 gives the vertical displacement as:

$$\text{(XXIV)} \quad d_{eo} = 10 \text{ in} \left(\frac{p_o}{100 \text{ psi}}\right)^{0.4} \left(\frac{1000 \text{ fps}}{C_s}\right) \left(\frac{W}{1 \text{ MT}}\right)^{1/3} \text{(inches)}$$

Where W = yield of weapon, in Megatons

C_s = seismic velocity of soil in vertical direction in fps

p_o = overpressure in psi

The horizontal displacement is given as equal to 1/3 d_{eo}. Permissible displacement in pipe joints may be exceeded by this movement. If the displacement along the pipe is to elongate, joints may open. If the displacement is to shorten, the joints or the pipe may be crushed by this movement. With continuous unjointed pipes or jointed pipes, where movement is not permitted and the joints take tensile as well as compressive forces, these forces should not exceed the ultimate strength of the joints or pipes' walls if rupture is to be prevented.

Admittedly, the inaccuracy of predicting horizontal movements makes the problem one more of conjecture than otherwise. Nevertheless, sufficient motion between a pipe and a structure, or branch line, as the blast wave passes, would be sufficient to fail the line, assuming the analysis is only within 100 percent of being correct.

When an axial compression force is applied to an underground pipe, its movement will be resisted by the friction of the soil on the perimeter. Strains are present in the soil and in the pipe due to the stresses induced in both materials. How the soil reacts is a problem in soil mechanics to determine the properties of cohesion and shear resistance, usually referred to as "skin friction".

TABLE XVI [25]

ALLOWABLE SKIN FRICTION FOR FRICTION PILES TO A DEPTH OF TWENTY FEET

Material	Skin Friction (psf)
Soft silt and dense muck	50 - 100
Silt (wet but confined)	100 - 200
Soft clay	200 - 300
Stiff clay	300 - 500
Fine sand	300 - 400
Medium sand and small gravel	500 - 700

These "allowable values" have a factor of safety of 3 or more. Also, resistance to movement of pipe under blast loading will be greater due to the short time loading. Therefore, values at least five times those listed in the table should be used for the skin friction acting to resist pipe movement.

A cast iron pipe of 0.54 inches t, a friction of $5 \times 400 = 2{,}000$ lbs per square foot in sand, or $2{,}000/12 \doteq 170$ lbs per foot per inch of perimeter, and $f_u = 31{,}000$ psi, will take a length $L = \frac{31{,}000 \times .54}{170} = 98$ feet to reach the crushing load on the pipe. The pipe will shorten $\frac{f_u L}{2AE} = \frac{31{,}000 \times 98 \times 12}{2 \times 15{,}000{,}000 \times .54} = 2.25$ inches under its crushing load where A is an elemental area of the crossection = one square inch.

By the Equation (XXIV) for $W = 20$ MT, $C_s = 2{,}000$ and $p_o = 20$, $d_{e_o} = 7.06$ inches. The horizontal movement is $7.06/3 = 2.36$ inches.

Besides the movement the pipe may have, the strain of the structure applying force to the pipe must also be evaluated. The sum of the two strains, that of the pipe and that of the structure, must be used to judge whether a failure condition exists for any given situation. For this problem, the pipe will probably survive the blast loading.

Longitudinal Axial Loads

Due to cohesion to the soil, substructures attached to the pipe, or connections to branch lines, the pipe will be subjected to shock or impact loads.

As these impacts occur, compression and tension waves traveling respectively forwards and backwards along the pipe induce longitudinal stresses(22 & 26).

$$f_a = \frac{Ev}{c} \quad \text{where } c = \sqrt{\frac{E}{\rho}}$$

Or, $$f_a = v\sqrt{\rho E}$$

Where v is the velocity of the impact force, c is the wave velocity in the pipe, ρ is the mass per unit volume of the pipe, and f_a is either the tension or compression stress as the case may be.

Although the formula assumes the impact to occur uniformly over the cross section of the pipe, such will seldom actually be the case. Eccentric loading will produce higher stresses. On the other hand, damping of the impact due to imperfect connections, soil conditions, and other variables will tend to compensate by reducing the loading. It seems reasonable to assume the stress can be expected not to be more than given by the above formula.

From page 139 of Reference 18 the vertical velocity

$$v_o = \frac{C_s\, p_o}{\bar{E}}$$

from which

$$v_o = 50 \text{ in/sec} \left(\frac{p_o}{100}\right)\left(\frac{1000 \text{ fps}}{C_s}\right) \quad \text{(in/sec)}$$

Taking $C_s = 2000$ fps

$$v_o = 25 \text{ in/sec} \left(\frac{p_o}{100}\right) \quad \text{(in/sec)}$$

The horizontal velocity is to be taken as

$$v = 2/3\, v_o = 16.7 \text{ inches per second } \frac{p_o}{100} = 0.167\, p_o \text{ (in/sec)}$$

<u>For steel</u>

$$c = 16{,}850 \text{ fps} \qquad E = 30{,}000{,}000 \text{ psi}$$

$$f_a = \frac{30{,}000{,}000}{16{,}850 \times 12} \times v = 150\, v$$

$$f_a = 150 \times .167\, p_o = 25\, p_o \text{ (psi)}$$

Hence p_o must be of the order of 1000 psi to produce significant stress from this source in steel.

<u>For concrete</u>

$$E = 3{,}000{,}000 \text{ psi}$$

$$c = \frac{3,000,000}{2.25 \times 10^{-4}} = 115,000 \text{ inches per second}$$

$$f_a = \frac{3,000,000}{115,000} \times .167\ p_o = 4.4\ p_o \text{ (psi)}$$

Here again p_o must be of the order of 500 psi to produce significant stress from this source.

Similarly, other pipe will be little affected.

Therefore, it is concluded that underground piping will sustain little if any damage from stress waves caused by longitudinal impact on the pipe, although there may be local failure at the points of impact. Pipe materials may be stressed above the yield point in the fibers adjacent to the area of impact. Such failure can only be evaluated when specific details of the situations which produce the impact forces are known.

CHAPTER IV

ALTERNATE OPERATING TECHNIQUES FOR DAMAGED WATER SUPPLY SYSTEMS

INTRODUCTION

One of the goals of the postattack operation of a community water supply system is the saving of human life. A second goal is the protection of property through the control of fire and a third goal may be the removal of radioactive fallout by the use of wet decontamination methods that will minimize the shelter period. Other high priority water use considerations include the recovery of hospitals and food preparation and handling facilities. For purposes of this presentation these are included as a part of the first goal, namely that of saving life.

The damaged system model and parameters of the study problem are developed to relate (1) the undamaged water supply system to (2) the attack effects.

The attack effects are determined from the nature and extent of the weapons effects, and the response of the total environment to such effects. Early in this study the project was incorporated into the Five City Study for administrative procedure.

Operating on the principle of the "greatest good for the greatest number", surviving waterworks operators must in the early postattack period develop, based on reconnaissance and damage assessment information, a program for the maximum utilization of the surviving water supply. The ability to do this will in part be determined by (1) advance preparation, (2) the character and extent of damage, (3) the knowledgeable execution of applicable procedures.

Many of the waterworks procedures applicable under normal conditions will continue to be the most readily useable procedures postattack. These are the procedures for which the workmen are most experienced and for which they have operating equipment. Under postattack conditions, the usefulness of a procedure may not be the same as that preattack; and, furthermore, the execution of a particular procedure may (will most certainly under a condition of fallout) differ from preattack. Hopefully, revision in the application of procedures can be adopted where necessary for changed conditions. Through advance preparation, means to carry out desired procedures with variations are provided as well as guide-lines for judgment decisions postattack. This is accomplished by anticipating the situations, so far as practical, for which the procedure may be applicable (with alternates), the required logistics, and the effectiveness of the procedure under various inimical conditions.

This study considers waterworks operating procedures that may be effectively used postattack to save water, presents guide-line information to postattack judgment decisions, and thus enhances the ability to execute the selected water saving procedures. In this chapter the theoretical considerations for the saving of water will first be discussed. The water saving techniques listed below will be reviewed with regard to: their mission or objective; procedure for use; and, personnel, equipment and supply requirements. These techniques will then be applied, where appropriate, under assumed postattack conditions to the study system.

OBJECTIVE

To save water to supply essential postattack needs.

AVAILABLE TECHNIQUES

(1) Isolation to prevent wasting and/or contamination of water in the system and permit repair of damaged facilities so that they can be used without further wasting of the supply.
(2) Rationing to limit non-essential uses and give priority to the more critical needs.
(3) Reducing pressures to conserve water by minimizing excessive waste by consumers and excessive leakage from the damaged system.
(4) Rerouting water so as to make it more available for use in the system and to decrease excessive demands on particular sources.
(5) The use of auxiliary water supplies for such purposes as their quality and availability permit so as to save the utility supply.

MISSION OF TECHNIQUES

Isolation

Source Facilities - Isolate to:

(1) eliminate polluted or contaminated sources and thereby protect and save the water in the system.
(2) facilitate reconstruction and rehabilitation work so as to make the source capable of supplying the system again.
(3) exclude the source from service while water quality tests are being made to determine the acceptability of the supply for various purposes.
(4) exclude a ground water source from service while it is being disinfected prior to use in the system.
(5) minimize the possibility of polluted or contaminated surface supplies from being discharged into the system by the proper choosing of intake levels or of alternate intakes.
(6) facilitate direct service of water from the source, if water cannot be delivered satisfactorily to the distribution system.

Transmission Facilities - Isolate to:

(1) stop loss of water through damaged facilities.
(2) eliminate a polluted or contaminated supply, thereby protecting the water in rest of the system.
(3) permit reconstruction of the transmission channels so that they may be later used to supply the system.

(4) permit the disinfection of water in the transmission channels and its subsequent use.
(5) permit the service of water directly from the transmission channel, if this is feasible and water cannot be discharged to the distribution system.

Raw Water Storage - Isolate to:

(1) stop loss of water from the damaged facility.
(2) eliminate polluted or contaminated supply and protect water in the rest of the system.
(3) permit reconstruction of the facility so that it may then be used to serve water.
(4) permit disinfection of water in the facility to make it acceptable for subsequent use.
(5) provide time to determine the quality of water in the facility and the type of treatment needed.
(6) permit service of water directly from raw water storage if this is feasible and water cannot be delivered to the distribution system.

Treatment Facilities - Isolate to:

(1) reduce leakage from damaged lines and treatment facilities.
(2) permit bypassing of non-essential treatment processes and make more water available to the system.
(3) permit bypassing of all or part of plant.
(4) permit bypassing to dispense with pumping.

Distribution Facilities - Isolate to:

(1) prevent water loss in the damaged system.
(2) prevent loss of quality water by degradation.
(3) permit confinement of water in storage facilities, thereby:
    (a) preventing wasting of quality water;
    (b) preventing contamination of water in storage by water that could reach the facility;
    (c) permitting controlled release (intermittent supply); and,
    (d) permitting distribution directly from storage facility.
(4) permit formation of dual systems with the transmission of water of one quality through one system and of another quality through another system, thereby saving quality water.
(5) permit trapping of water in sections of system for controlled use.
(6) permit service of water in various parts of the system.
(7) save water for higher priority needs while lower priority needs would be shut off and not supplied.
(8) permit taking part of system out of service for repair and subsequent re-use.

Rationing

Source Facilities - Ration to:

(1) minimize demands on the source facilities, thereby saving water.
(2) facilitate taking damaged or less desirable sources out of service and enable them to be rehabilitated for further use.

(3) permit corrective work to be done on the source facility while it is not in use if intermittent service of water is initiated.
(4) permit direct service of the water from the source.
(5) permit the use of less sources, thereby making it easier to work on sources and develop higher quality supplies.

Transmission Facilities - Ration to:

(1) permit, if feasible, direct service of water from the transmission facility.
(2) permit taking a damaged or questionable facility out of service and bringing it back to satisfactory operating condition.

Raw Water Storage - Ration to:

(1) provide for direct service of limited water from the raw water storage facility.
(2) permit taking a damaged or questionable facility out of service so that it may be repaired and subsequently used to supply water to the system.

Treatment Facilities - Ration to:

(1) permit direct service of water from the treatment facility.
(2) permit taking a damaged or suspected facility out of service so that an acceptable supply can be served after repairs are made.

Distribution Facilities - Ration to:

(1) limit the amount of water served.
(2) limit especially non-essential uses.
(3) save water for higher priority needs.

Reduction of Pressures

Source Facilities

The technique of reducing pressures is not applicable to source facilities.

Transmission Facilities - Reduce pressures to:

(1) decrease leakage from damaged transmission mains.
(2) minimize water loss through normal leakage.
(3) facilitate repair work for the elimination of leakage.

Raw Water Storage

This technique is not applicable to raw water storage.

Treatment Facilities

This technique is not applicable to treatment facilities.

Distribution Facilities - Reduce pressures to:

(1) minimize water loss through damaged facilities.

(2) minimize water loss through normal leakage.
(3) facilitate repair work for the elimination of leakage.
(4) minimize water consumption by consumers.
(5) reduce pumpage and power consumption.
(6) increase water flow in one portion of system by decreasing it in another section.

Rerouting

Source Facilities - Reroute to:

(1) permit sources to be used in areas where they are not normally used, thereby saving the supplies for more effective use in the system.
(2) permit some sources to be taken out of service or permit their use to be minimized so that the sources may be rehabilitated to save their supply.
(3) provide for greater flexibility of use.

Transmission Facilities - Reroute to:

(1) permit service of water through the transmission facility from sources not normally discharging to the facility.
(2) permit service of water from the transmission facility into areas not normally supplied.
(3) permit damaged transmission facilities to be taken out of service and worked on so that they can be subsequently used without wasting water.

Raw Water Storage - Reroute to:

(1) permit service of water through a facility from sources not normally discharging to the facility.
(2) permit service of water from a facility into areas not normally supplied.
(3) permit the facility to be taken out of service for repair and subsequent re-use.

Treatment Facilities - Reroute to:

(1) treat water sources that are not normally treated.
(2) deliver treated water to areas not normally served.
(3) provide for bypassing as described under isolation.

Distribution Facilities - Reroute to:

(1) save quality water for use in the system by rerouting it around damaged or contaminated facilities.
(2) provide for service of water in parts of the system that supplies normally do not reach.
(3) permit use of gravity supplies instead of pumped supplies and vice versa.
(4) permit dual systems, as previously mentioned.

Use of Auxiliary Water Supplies

Source Facilities - Use auxiliary water supplies to:

(1) permit use of the utility supplies for higher purposes.
(2) permit reconstruction or other work to be done on the utility sources.

Transmission Facilities - Use auxiliary water supplies to:

(1) permit reconstruction and other work on transmission facilities.
(2) provide for service of auxiliary supplies through alternate facilities so that limited utility supplies may be supplied for higher priority needs.

Raw Water Storage - Use auxiliary water supplies to:

(1) permit reconstruction or other work to be done on the raw water storage facility, so that it can be subsequently re-used.

Treatment Facilities - Use auxiliary water supplies:

(1) with treatment to help conserve utility supplies.

Distribution System - Use auxiliary water supplies to:

(1) permit saving the utility supplies for higher purposes.
(2) provide for service of water directly from the auxiliary source.
(3) permit taking parts of the utility system out of service for repair, etc. so they can be subsequently re-used.

APPLICATION OF TECHNIQUES

Isolation

Preattack

Provide effective preventive maintenance procedures to assure that facilities will be in good repair and operate with minimum manipulation and with minimum expected difficulties.

Provide clear, accessible maps showing the location of all facilities and referenced for quickly locating facilities and for determining alternate means of access under disaster conditions.

Plan and test isolation procedures.

Determine which areas or zones in the system can be most easily isolated and how this is best accomplished.

Provide means to determine quickly, at central locations, the areas where pressures are approaching critically low levels and provide means to control valves from these locations.

Have pressure telemetering at sufficient points in the system so that areas where isolation is needed will be quickly known.

At critical locations, provide for automatic operation by pressure, rate of flow, or telemetered command.

Plan for the formation of dual systems and for their operation.

Provide valves which automatically close when pressure goes below a designated level and stay closed until manually or semi-automatically opened.

Provide sufficient operable valves, at proper locations, so installed that a minimum amount of pipe need be isolated and taken out of service at any one time.

Follow the National Board of Fire Underwriters valve standards.

Make valves readily accessible.

Keep accurate valve records showing the location, type, size, make, time of installation, operation, maintenance and inspection date, direction of turning to close, and number of turns required.

Make records readily available.

Carry necessary valve information in all repair trucks. The service truck "gate books" should contain the necessary information needed to locate and operate the valves.

Either select definite standard locations for the installation of mains and valves, or use main and valve location sheets to expedite locating them under adverse conditions.

Place valves in some standard area, such as in a curb line, to facilitate the location of valves.

Number valves for easy location.

Mark curbs at points opposite valves so that the valves may be more quickly located.

For those valves temporarily turned off, leave a mark on the ground surface showing that this condition exists.

Procure and use quick acting valve operating equipment to expedite the isolation operation. Use power-driven valve operating equipment, preferably of a truck-mounted type, powered by a take-off from the truck engine, to facilitate and speed up the valve operation.

Investigate the vulnerability of valves.

Inspect each valve yearly and the larger ones more often. Inspect the condition of both the valve and valve box. Exercise the valve by turning the stem up or down several times and lubricate the stem.

Check valve boxes or vaults annually, which are located in streets subject to frequent maintenance, to see that they are not damaged, filled with earth, or covered with pavement.

Provide for easy, quick location of the service meters and shut-off valves.

Maintain adequate location records of all services.

Educate consumers on the need for turning off the shut-off valve on the service line during critical periods and on how it should be done.

Plan to locate knowledgeable personnel in shelters near critical operational points to expedite isolation operation.

Rotate storage facilities, keeping one or more tanks isolated.

Isolate critical storage or other facilities at the time of alert.

Maintain high water levels in the storage units.

Provide materials and equipment for quick repair jobs and for stopping leaks following isolation.

Plan to use several crews simultaneously on isolation procedures to minimize the time needed to do the job.

Make all available vehicles capable of travel through streets filled with debris, to facilitate the recovery operation.

Keep leakage and breakage records and make pressure-flow surveys to detect incipient failures or deficiencies in the system and allow them to be corrected in advance.

Postattack

During the period in the shelter, use automation and telemetering to determine the condition of the system and to isolate facilities or parts of the system so the water may be saved and protected.

Operate automatically, semi-automatically, or manually as available facilities permit.

When shelters can be left, locate and investigate leaks, breaks, and loss of water pressure in the damaged system.

By closing appropriate valves in the field, isolate undamaged facilities or areas so as to save and protect the water supply.

Make necessary repairs and/or replacements to make the system capable of carrying water without wasting it.

Have utility personnel shut off damaged services where there is excessive wasting of water.

Notify the public to close shut-off valves on services, if appropriate.

Keep records on all isolation work so that the changes made to the system are accurately known.

If available potable water is short in quantity, determine if a dual system operation could be effected.

Initiate isolation procedures to separate potable and non-potable supplies.

Notify the public of a dual system operation and warn them of non-potable water and the need for conserving potable water.

Discontinue the isolation operation when conditions permit and disinfect the system if necessary.

Rationing

Preattack

Determine emergency water quality and quantity needs for various categories of use such as potable, sanitary, decontamination, fire fighting, industrial, and agricultural water.

Determine secondary sources of supply and relate them to secondary uses.

Inventory critical water users and their quantity and quality requirements.

Prepare priority requirements.

Time-phase estimated water requirements.

Plan methods for conserving water for critical uses.

Plan methods for enforcing rationing and determine manpower needs to accomplish it.

Plan methods for the efficient delivery of rationed water.

Plan and test procedures for emergency service from the distribution system.

Plan to use water stations, near points of need, for the service of potable water, not only to the public, but to medical care facilities, mass feeding operations, and essential industrial and commercial operations.

Plan to serve water from fixed storage tanks, wells, fire hydrants, mains and other parts of the distribution system.

Plan to provide treatment and pumping at the stations if necessary.

Plan for supervision of the taking of water from the stations so that no waste results. If insufficient water is available, the points of delivery should not be left unattended. Facilities for taking water should be removed when no supervisory personnel are present.

Plan to serve water intermittently in the whole system, or in parts of the system, when only a limited amount of water is available or when continuous service would result in the wasting of large quantities of water.

Plan to use hydrants, or improvised connections to the water mains, to deliver water. These connections can be provided with taps.

Plan to increase the rate of delivery of water to consumers bringing their own containers by using manifolds with a number of taps.

Use a hydrant numbering system to make the hydrants easier to locate. Paint the number and size of the line on the hydrant.

Plan to use quick-closing valves on delivery outlets to help save water.

Develop measures to obtain water that may beheld in the distribution system piping or storage facilities. Plan to make water available by tapping at a low point, using a low lift portable pump, or dipping through openings.

Plan to haul water to deliver it directly to the distribution system by putting it into storage facilities or mains. Plan to expedite filling of the tank trucks by using a riser attachment with a manifold having a short fire hose. Plan for the proper cleaning and disinfection of the tanks to be used for hauling water.

Plan to use mobile treatment facilities to provide maximum flexibility in treating a contaminated supply at any point in the distribution system. (The type and degree of treatment that must be given must rely on the judgment and decision of the water utility and health department personnel.)

Investigate methods to minimize water use, such as limiting the amount of water in water-flush toilets, or by requesting the abandonment of water-flush toilets.

Test rationing procedures.

Postattack

Determine the availability of water, the areas of need, and the adequacy of the supplies to meet expected demands.

Institute rationing procedures to conserve the available water, if it is not sufficient.

Use preattack rationing determinations modified, if necessary, to meet postattack conditions.

Give priority to more critical needs.

Stop all non-essential uses.

Serve water intermittently in the distribution system, if feasible.

Determine the condition of the distribution system and its ability to supply water.

In those areas where an insufficient supply is available, but the distribution system is still capable of delivering an acceptable supply, provide for emergency controlled service from the distribution system.

Notify consumers of rationing, when and how they can expect to receive water, and the need for conserving water.

Keep records of the emergency operation.

Reduction of Pressures

Preattack

Plan and test pressure reduction procedures.

Provide sufficient valves at strategic locations for pressure-reducing, preferably capable of remote control operation.

Plan for manual reduction of pressure using pressure gages.

Consider the effect of reduction of pressures on various water uses, especially those which require high pressures, such as fire fighting and decontamination.

Investigate and inventory those users who need and use large volumes of water at high pressures.

Study the likelihood of backsiphonage from cross-connections resulting from lowered pressures.

Study if significant lowering of pressure in some areas will make pressures in other areas critically low.

Consider that the reduction of pressures may cause a change in the direction of flow in mains.

Plan, under certain circumstances, to only lower pressures in some areas, while pressures in other areas will remain high.

Reduce pressures during the alert period.

Valve considerations for pressure reduction are the same as those already given for isolation procedures.

<u>Postattack</u>

While in shelters, obtain information on pressures in the system and rates of flow, using automation and telemetering equipment.

Regulate pressures while in the shelters, if possible.

Place knowledgeable personnel in the shelters where critical valves are accessible so that pressures can be easily controlled by manipulation of these valves.

When shelters can be left, personnel should determine if conditions are such that a reduction of pressures should be initiated or continued.

Where there is excessive waste or leakage, pressures should be reduced or the valves closed entirely.

Keep records of the pressure reduction operation.

Check with fire-fighting personnel, and with others working in critical operations where high pressures are needed, to determine if pressures can be safely reduced.

Stop all non-essential activities which need and use large volumes of water at high pressures.

Increase pressures when conditions permit.

<u>Rerouting</u>

<u>Preattack</u>

Plan and test rerouting procedures.

Provide for equipment, material and manpower requirements.

Determine how water can be rerouted with minimum operation, equipment, and manpower.

Minimize dependence of rerouting operation on pumping facilities.

Provide emergency interconnections between high and low level zones which will permit water to be served between zones by either gravity or pumping.

Consider the possibility that the physical quality of the water may be affected by a change in the direction of flow or a change in velocity which may disturb material lying in the mains. (This in itself probably would not make the water unacceptable for emergency potable use.)

Plan to bypass those critical areas or facilities which may contaminate the supply, result in the loss of water, or impede the flow of emergency water.

For bypassing, plan to use smaller mains than those normally used.

Plan temporary bypassing arrangements using pipe lying on the ground surface. The pipe should be protected from damage by vehicles, collapsing structures, and other hazards.

Plan bypassing of transmission, storage, pumping, or treatment facilities.

Plan bypassing of all, or portions of, fixed treatment works to put sufficient water into the system or to eliminate treatment that is not believed absolutely necessary.

Plan emergency pumping procedures to reroute water to zones which are normally fed by gravity or to other areas which may be normally fed by pump facilities which have become inoperative. This may be done either through direct pumping from the utility distribution mains and storage facilities or by pumping from emergency auxiliary sources.

Plan to use portable pumps to reroute water.

Plan to use fire department pumpers to supply water for other than fire fighting, after the fire hazard has diminished.

Plan to reroute water by making use of stream beds, ditches, storm drains or other channels. Water could be delivered to those channels from one part of the distribution area and travel in them, by gravity, to other areas where it could then be put into the distribution system by pumping or gravity.

Postattack

In shelters use automation and telemetering to provide for bypassing of various units or for other rerouting procedures.

When outside conditions permit, investigate the condition of the system and provide for appropriate rerouting of water where needed.

Maintain complete and accurate records of rerouting operation.

Discontinue rerouting operation when conditions permit.

Use of Auxiliary Water Supplies

Preattack

Determine availability of auxiliary facilities in or near the service area.

Investigate the possibility of obtaining supplies from adjacent water utilities and adjacent industrial, irrigation, or other private supplies; surface waters that are not normally used for domestic purposes such as lakes, rivers, streams, ponds, and canals; salt water sources such as oceans, bays, and estuaries; and, water storage on private properties such as tanks, reservoirs, swimming pools, or cooling towers.

Inventory and arrange to use auxiliary supplies.

Determine and provide for the equipment, material, and manpower requirements to use these supplies.

Maintain complete records on auxiliary supplies.

Prepare and practice procedures for use of auxiliary supplies.

Determine what water quality to expect, what uses could be made of the supply, and whether treatment is necessary for potable water use.

Plan for pumping if necessary.

Provide a permanent connection between the distribution system and the auxiliary source or the means to make a quick temporary connection.

If a connection exists with an auxiliary system which may be supplied with water, provide methods to insure that water needed in utility system won't be discharged to the auxiliary system.

Keep interconnections valved until needed.

Provide for automated use of interconnections if possible.

Store equipment and materials needed to make the necessary connections to auxiliary sources close to the connection sites.

Maintain close contact with those responsible for the auxiliary water.

Consider that auxiliary supplies may be as badly damaged as utility facilities.

Postattack

Determine if utility supplies are operative, useable, and sufficient. If not, investigate the availability of auxiliary supplies.

In determining needs, review records and consider the auxiliary supplies' accessibility, location in relation to their ability to supply water at points of need, and possible pumping and treatment requirements.

First investigate those sources near the area of need and try to obtain a gravity transfer of water.

Having established the various needs, determine which auxiliary supplies could best serve.

If auxiliary water can be served directly into the utility distribution system this should be done. If this is not feasible and the auxiliary sources are located within or adjacent to the distribution area, then consider service of the water directly from the auxiliary sources, storage facilities, or pipelines.

Determine and provide the materials, equipment, and manpower necessary to use auxiliary sources.

Use auxiliary sources as water stations for delivery of water directly to the consumers, if necessary.

PERSONNEL

Preattack

Plan for the use of personnel to save water under postattack conditions.

Designate emergency utility personnel for the saving of water.

Provide for back-up utility personnel.

Use auxiliary personnel from outside utilities to supplement manpower.

Plan to use the most qualified personnel.

Plan for use of those most likely to be available in or near the utility area.

Train emergency personnel in the saving of water.

Train personnel to obtain an efficient postattack operation.

Provide repeat test exercises to perfect emergency procedures.

Provide test exercises with other cooperating agencies, groups, or personnel.

Plan and provide for adequate sheltering of personnel during the alert period and for a reasonable period after the attack.

Plan for mobilization of personnel needed for the saving of water.

Determine the required skills, number of personnel, and time for performing typical functions to save water.

Provide adequate records on skills, means of contacting, and transportation requirements of personnel.

Consider communication, transportation, and equipment requirements necessary for personnel to efficiently accomplish the job.

Provide for liaison inside and outside of the utility with personnel who may be of direct or indirect assistance.

Consider the physical capabilities necessary to perform the job of saving water.

Postattack

Using records, mobilize utility and auxiliary personnel needed to save water.

Provide for personnel to get into shelters as rapidly as possible.

Have personnel operate from shelters to save water if this can be done.

Determine in shelters, if facilities are available, the location and extent of the problems relating to the need for saving water and what can be done about them.

Determine where personnel needed for the saving of water are located, their condition, and their transportation requirements.

Provide for notifying personnel of the condition of the system and of the survivors as they relate to the need for saving water.

Contact auxiliary personnel if needed.

Contact mutual aid personnel if needed.

When shelters can be left, reconnaissance and assessment will determine in more detail the problems relating to the saving of water.

Determine which procedures for saving water can best be used by the available personnel for the existing system and survivors.

Initiate, continue, and/or expand on procedures for the saving of water from outside the shelters.

Use those personnel best qualified, most conveniently located, and in best physical condition.

Have personnel continue water saving procedures as long as needed.

EQUIPMENT AND SUPPLIES

Preattack

Determine the type of equipment and supplies needed to save water, including that needed:

to repair and replace mains, valves, and hydrants;
to repair source, transmission, treatment and storage facilities;
to ration water;
to use auxiliary supplies;
to treat water;
for installation of temporary water pipe;
for transportation of equipment and supplies;
for excavation work;
for pumping;
to provide power; and,
to locate pipes.

Determine reasonable quantities of such equipment and supplies that should be obtained and stockpiled.

Determine the availability, location of, and means for obtaining equipment and supplies from sources outside the utility.

Provide for obtaining equipment and supplies either from the permanent stock of the utility or on an emergency basis from outside sources.

Obtain and store utility equipment and supplies at reasonably dispersed, convenient, and protected locations.

Provide adequate records for proper classifying, describing, identifying, and locating the equipment and supplies.

Provide, if feasible, for special protection during the alert.

Postattack

Using records, information received in shelters from communication facilities, and information later received from reconnaissance and assessment, determine the condition of equipment and supplies needed for the saving of water and specifically the location and availability of the useable materials.

After learning of the condition of the system and postattack demands, determine the type and amount of equipment and supplies necessary for the saving of water.

If the available utility equipment and supplies are inadequate, determine the availability from nearby outside sources and obtain if possible.

If necessary, request needed equipment and supplies from distant sources through mutual aid agencies.

First, use the equipment and supplies which will complete the operation to save water as rapidly as possible, doing a reasonably good job, and which are located in storage areas near the points of required use.

Provide security measures to protect the remaining useable equipment and supplies.

Keep records of the use of equipment and supplies and of any change in their condition.

POSTATTACK PROCEDURES

General

The previous sections of this chapter have presented basic techniques that can be applied to a damaged water supply system, their mission or function, and their general application to a damaged system. However, it is important to illustrate the application of these techniques to an actual system, under an assumed damaged condition, in order to develop and test these ideas. The community of San Jose, California has been selected as an example of a metropolitan area where these operating techniques may be applied.

The following discussion will present the assumed damage condition of the San Jose Water Works, a description of the system, and a description of procedures that might be used in operating the system under the "damaged" condition.

Study Parameters

The following study assumes that the San Jose Water Works is without electrical power. However, it is further assumed that the system has not suffered any physical damage and that no fallout gamma radiation hazards exist.

The study is also based on the assumption that the water stored in each pressure zone of the system, at the time of the power outage, is needed by and can be completely utilized in that zone. Therefore, it is considered that this water will not be able to be consumed in another zone. However, it is assumed that water from surface water reservoirs or intakes would be available for input into the system at its normal points and this additiona water input would then be able to be utilized by the system by whatever means possible.

A major point in this study is the understanding that the discussion is concerned with operational techniques, such as manipulating valves, that will effect water distribution in the system when the power is off. Therefore, questions of water quantity and quality, needs, rates of consumption, and water treatment become extraneous and are not part of this presentation.

Description of the Existing System

The service area of the San Jose Water Works is located within Santa Clara County and includes the cities of San Jose, Los Gatos, Mone Sereno, Saratoga, and parts of Campbell, Cupertino, and Santa Clara. Water production during the calendar year 1965 was 25,431 million gallons. This required the purchase of 51.19 million kilowatt hours of electrical power.

The system derives water from two basic sources: (1) ground water, which contributes approximately 80 percent of the annual input; and (2) surface water which is impounded in five open reservoirs and input to the system through 12 major intakes. Table XVII relates these basic surface water sources to the major intake points and gives a designation to each group of related items. Further representation of the total system is made on Figure 19.

The water supply system contains 13 major pressure zones and 16 minor pressure zones. For the purposes of this study, only 14 zones (13 major and one minor) are considered. These 14 zones cover, essentially, the entire service area and provide the basis for a valid illustration of the use of the basic techniques involved with the operation of the system under the assumed "no-power" condition. The pressure zones under consideration are related to their basic surface water supply sources in Table XVIII. The relationship of the subject pressure zones to their sources of supply is also graphically represented on Figure 18.

Within each pressure zone are distribution reservoirs that are supplied by gravity or pumping from either a basic supply source and/or from another pressure zone. Table XIX relates the various distribution reservoirs to the pressure zones in which they are located. These distribution reservoirs are also shown on Figure 19.

The water supply system contains many wells, but because of the assumption that the power is off, the detailed description of the well system has been omitted from this study, as it would not add to the clarity of the presentation. Figure 18 and Figure 19 schematically show, in a general way, the water input from this system of wells.

The Alamitos Intake is not made a part of this study due to the fact that it serves a minor pressure zone which is excluded because it would not materially add any substance to the discussion.

Distribution Techniques Without Power

The hypothetical "no-power" situation creates the problem of not having energy, in the form of electrically powered pumps, with which to transfer water to higher elevations in the system. Therefore, the water supply system becomes completely dependent on gravity.

TABLE XVII

SURFACE WATER RESERVOIRS AND INTAKES

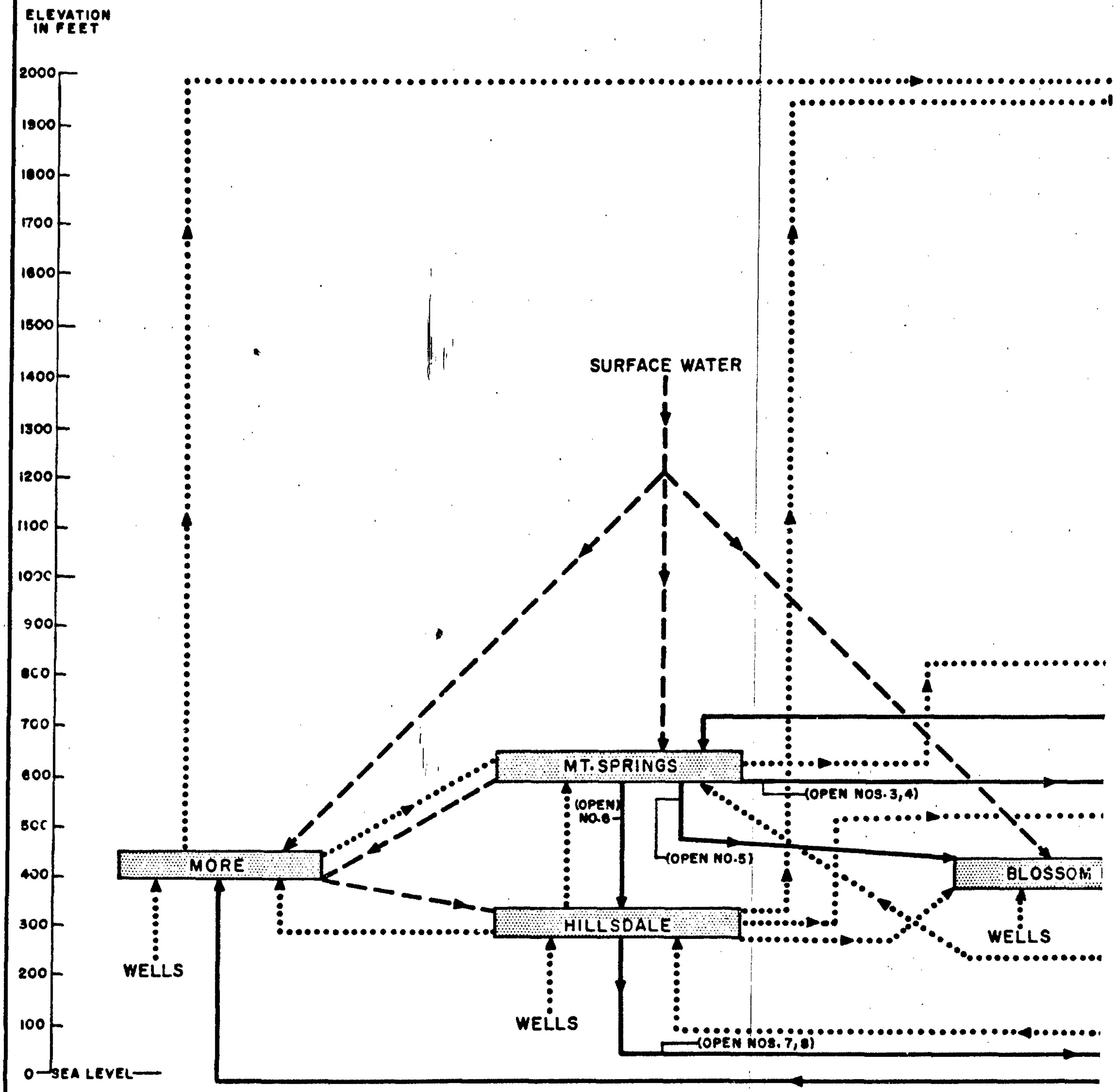
Group Designation	Surface Water Source	Intake
30 inch Transmission Main	Lakes Elsman and Williams	*Ostwald Intake *Hooker Gulch Intake *Moody Gulch Intake *Lower Cavanee Intake *Ryland Intake *Hendry Intake
Lake Couzzens Intake	Lakes Kittredge, Couzzens, and McKenzie	Beardsley Intake Upper Cavanee Intake
Beckwith Intake	Direct From the Stream	Beckwith Intake
Congress Springs Intakes	Direct From the Stream	Congress Springs Intakes
Trout Gulch Intake	Direct From the Stream	Trout Gulch Intake
Alamitos Intake	Direct From the Stream	Alamitos Intake

*Feed into a 30-inch transmission main.

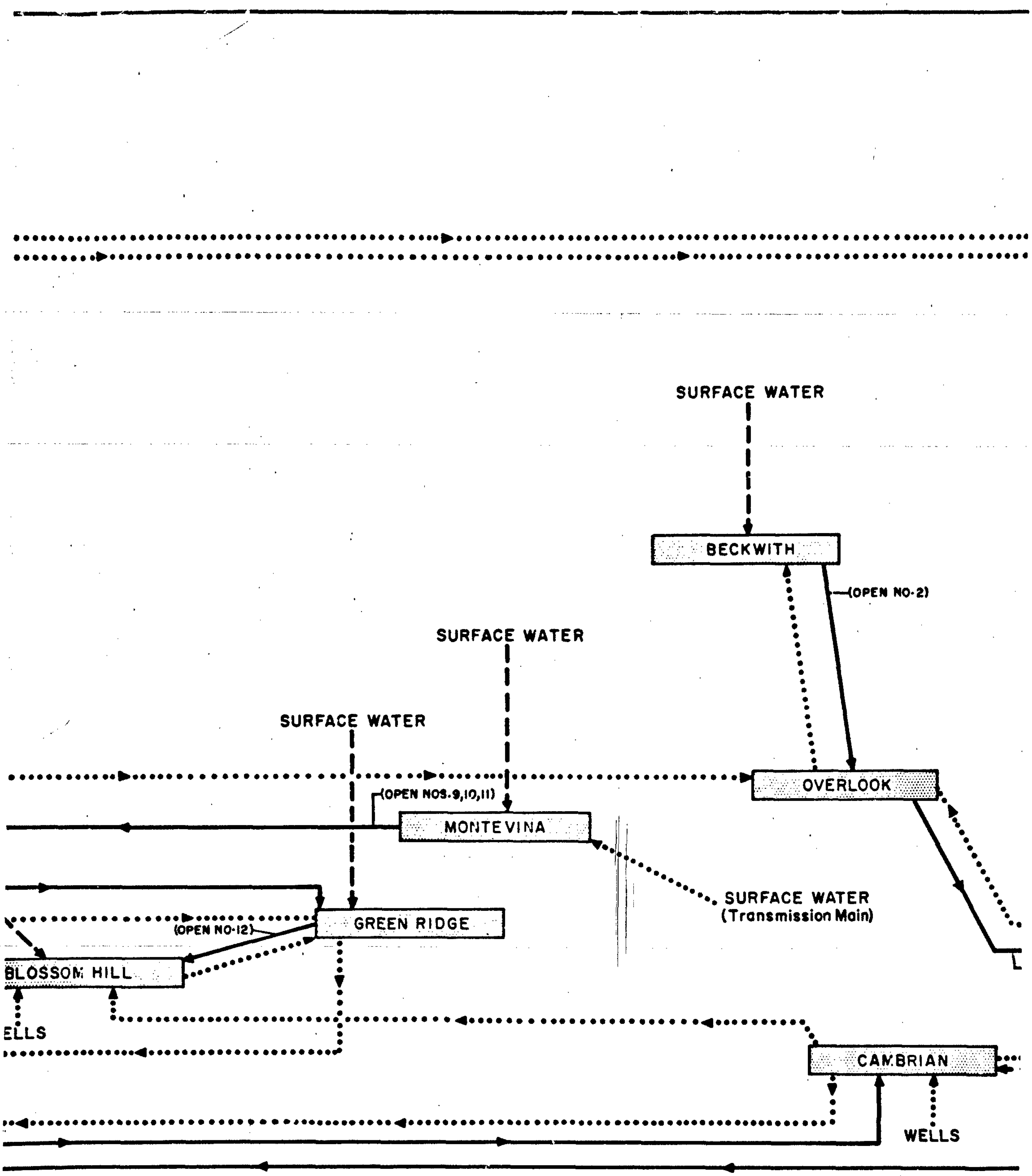
TABLE XVIII

PRESSURE ZONES AND THEIR BASIC SURFACE WATER SOURCES

Pressure Zone	Surface Water Source Group
Cambrian Pressure Zone	None
Hillsdale Pressure Zone	30 inch Transmission Main
More Pressure Zone	30 inch Transmission Main
Blossom Hill Pressure Zone	30 inch Transmission Main
Columbine Pressure Zone	None
Miguelito Pressure Zone	None
Vickery Pressure Zone	Congress Springs Intakes
Overlook Pressure Zone	None
Greenridge Pressure Zone	Trout Gulch Intake
Mt. Springs Pressure Zone	30 inch Transmission Main
Alum Rock Pressure Zone	None
Montevina Pressure Zone	Lake Couzzens Intake
Mt. Pleasant Pressure Zone	None
Beckwith Pressure Zone	Beckwith Intake



NOTE: Elevations refer to distribution reservoirs in indicated pressure zones.


SURFACE WATER
BECKWITH
(OPEN NO-2)
SURFACE WATER
SURFACE WATER
OVERLOOK
(OPEN NOS. 9,10,11)
MONTEVINA
SURFACE WATER
(Transmission Main)
GREEN RIDGE
(OPEN NO-12)
BLOSSOM HILL
ELLS
CAMBRIAN
WELLS

2

— LEGEND —

Gravity water transfer effected after power off by opening gate valves which are normally closed.

Gravity water transfer with power on or off.

Water transfer accomplished by pumping.

MORE — Pressure Zone capable of being served by gravity from a surface water source.

ALUM ROCK — Pressure Zone served only by pumping water from other sources.

(OPEN NO.2) — Refers to opening a gate valve (see Figure 19 for location) to effect gravity transfer of water in a power off condition.

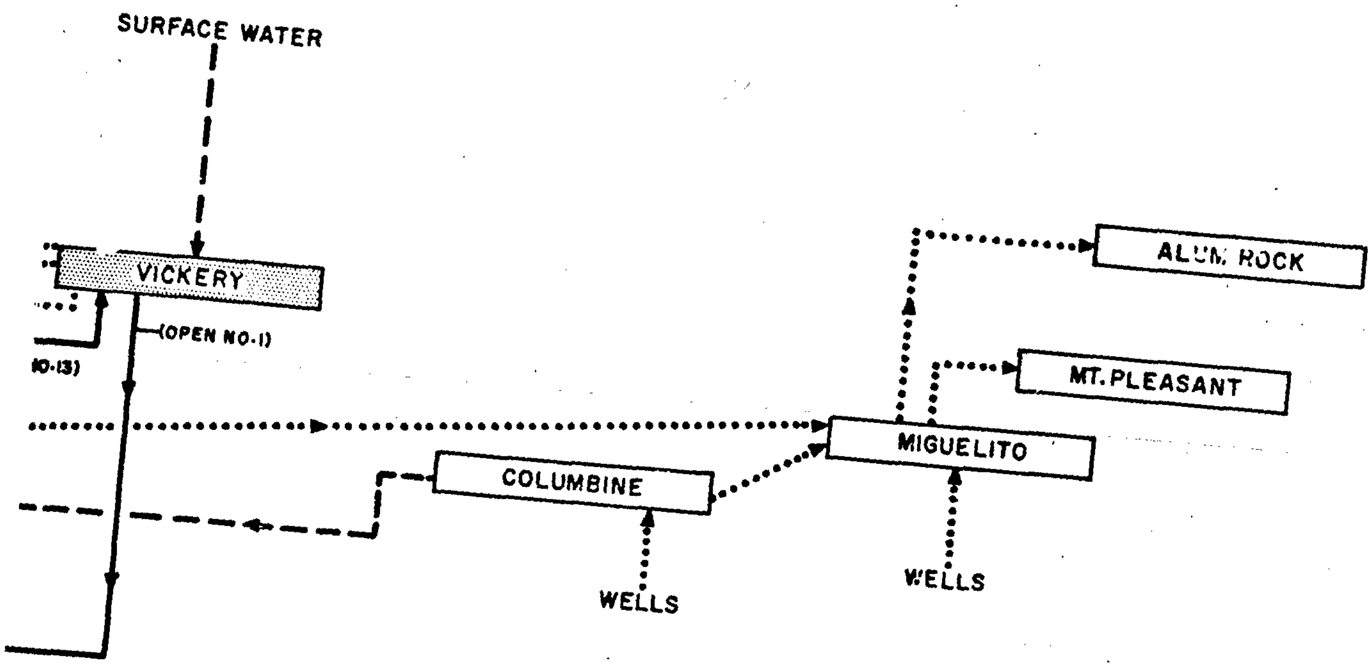
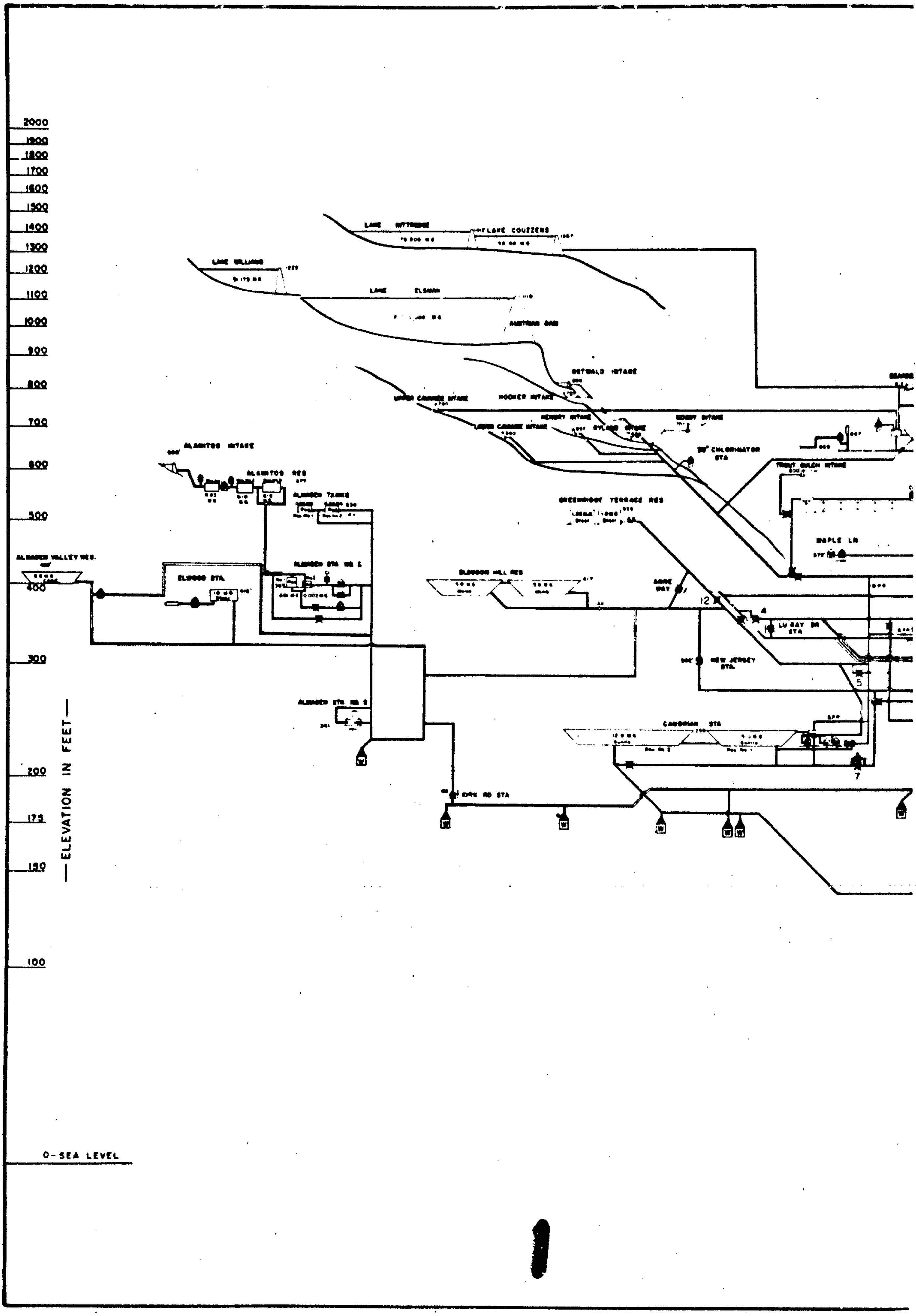


Figure 18.— VERTICAL SCHEMATIC DIAGRAM REPRESENTING DISTRIBUTION OF WATER BETWEEN PRESSURE ZONES, SAN JOSE WATER WORKS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O-SEA LEVEL
ELEVATION IN FEET
LAKE WILLIAMS
LAKE ELSMAN
AUSTRIAN DAM
HOOKER INTAKE
ALAMITOS INTAKE
ALAMITOS RES
ALMADEN TANKS
ALMADEN VALLEY RES.
ALMADEN STA NO 1
ALMADEN STA NO 2
GREENRIDGE TERRACE RES
BLOSSOM HILL RES
MAPLE LN
LU RAY DR STA
NEW JERSEY STA
CAMBRIAN STA
KIRK RD STA
ANNE WAY
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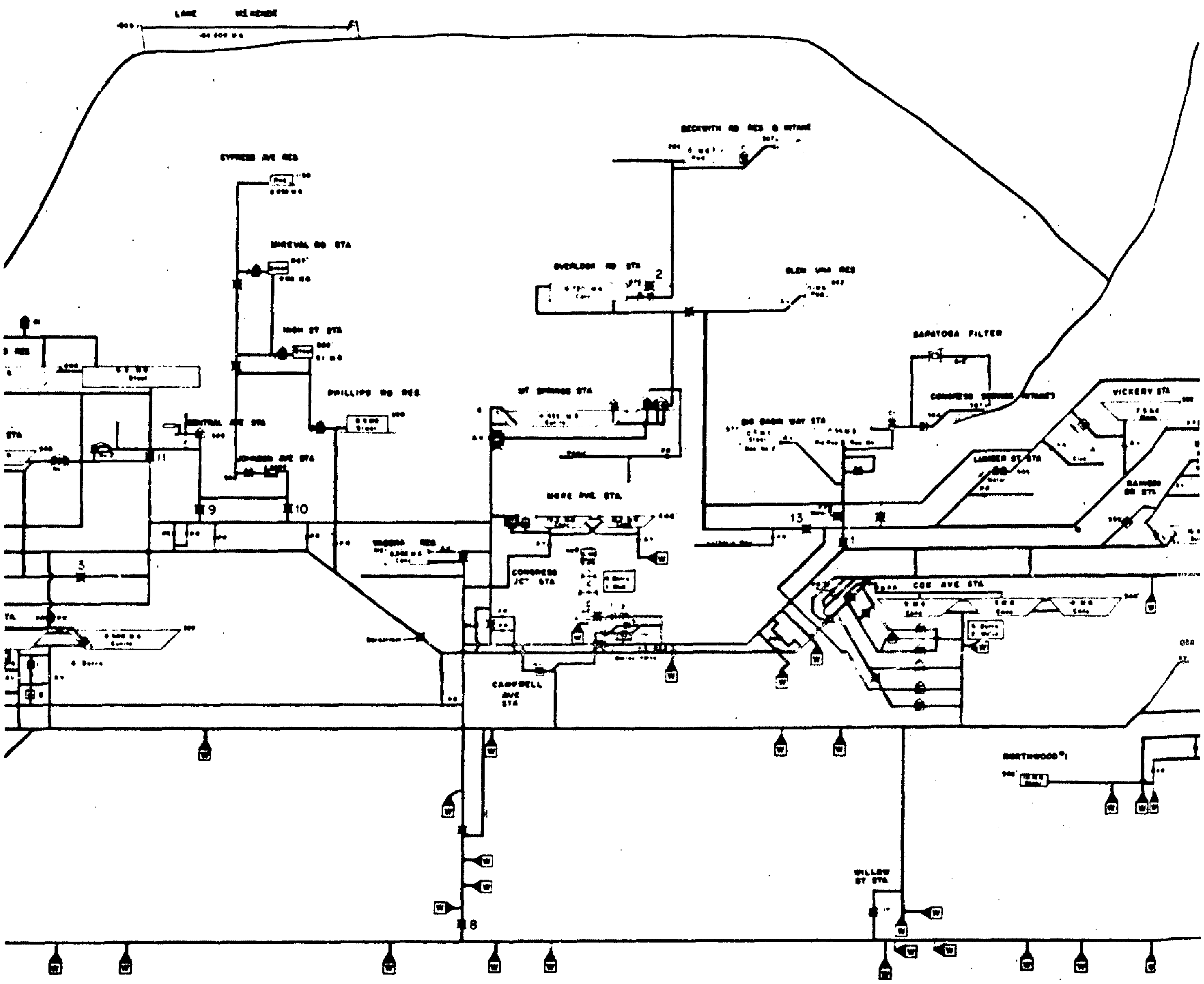
4
5
7


PHILLIPS RD RES
SARATOGA FILTER
VICKERY STA
COE AVE STA
CAMPBELL AVE STA
WILLOW ST STA

2

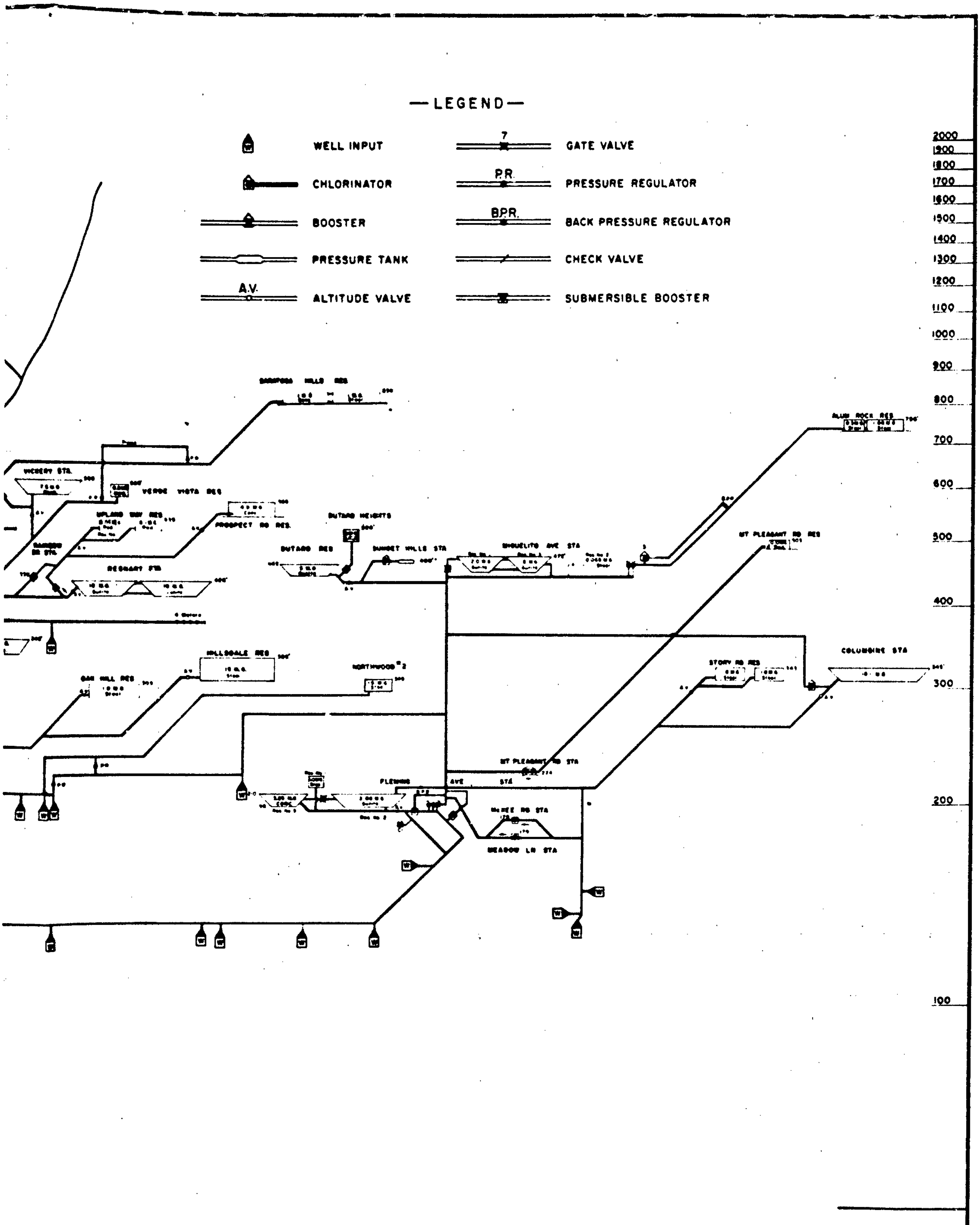


Figure 19.—VERTICAL SCHEMATIC DIAGRAM OF SAN JOSE WATER WORKS

3

This study shall consider the application of the basic technique of rerouting to the San Jose Water Works in order to illustrate what can be done to a water system, when a complete power loss occurs, in order to distribute water to as much of the service area as possible.

At the moment a power loss occurs, the only input to the water system is from the surface water sources described in Table XVII. The pressure zones which can be fed from these sources, without manually changing the system, are shown in Table XVIII and on Figure 18. When the power loss occurs the total water system effectively consists of five autonomous groups of pressure zones which are normally gravity fed and have an individual need for all of the water they each have stored. Each of these groups becomes isolated from the rest of the system. The five groups consist of: (1) Blossom Hill, Mt. Springs, More and Hillsdale Pressure Zones; (2) Montevina Pressure Zone; (3) Beckwith Pressure Zone; (4) Vickery Pressure Zone; and (5) Greenridge Pressure Zone.

The remaining six zones (Overlook, Columbine, Cambrian, Miguelito, Mt. Pleasant, and Alum Rock) are not only isolated, but they cannot receive an input of water because their basic sources rely on pumping to effect a transfer of water to the zones.

It has been assumed for this study that there will not be a reverse flow of water through pumps and pressure regulators when the system is affected by a complete lack of power. This study will not consider interzonal water transfer by gravity unless the entire lower zone can be served.

Because the assumption has been made that each pressure zone has a need for all of its stored water at the moment of power loss, it becomes apparent that the only zones to be considered as possible sources of supply, by gravity, for other zones are those which can receive an input from a surface water source.

An examination of the subject water system reveals that certain gate valves, normally left closed, can be manually opened to allow a gravity transfer of water from a pressure zone supplied by a surface water source to another pressure zone. Figure 18 illustrates this technique of rerouting. As an example, Figure 18 shows effecting this by manually opening a gate valve which allows the Beckwith Pressure Zone (fed from the Beckwith Intake) to put water by gravity into the Overlook Pressure Zone, which is normally fed by pumping from two other pressure zones.

It must be emphasized that proper control measures on the valve opening operation are necessary to prevent water being transferred to a lower pressure zone from overflowing the distribution reservoirs in that zone. This could happen if personnel were not trained to coordinate the valve opening operations with the water levels in distribution reservoirs which are being filled. Also, serious problems could be created if the distribution reservoirs, in the lower pressure zone receiving the supply, are bypassed or valved out of the system. If this is done very high pressures could be created in the lower lines which might cause damage, resulting in water loss from the distribution system.

TABLE XIX

PRESSURE ZONES AND THEIR DISTRIBUTION RESERVOIRS

Pressure Zone	Distribution Reservoirs
Cambrian	Cambrian Rd. Res. Fleming Ave. Res.
Hillsdale	Oakhill Res. Hillsdale Res. Cox Ave. Res. 7-Mile Res.
More	Congress Junction Res. More Ave. Res. Regnart Res. Vasona Res.
Blossom Hill	Almaden Valley Res. Elwood Res. Blossom Hill Res.
Columbine	Story Rd. Res. Columbine Res.
Miguelito	Dutard Res. Miguelito Res.
Vickery	Upland Way Res. Prospect Rd. Res. Verde Vista Res. Big Basin Res. #1 Big Basin Res. #2 Vickery Res.
Overlook	Overlook Res. #1 Overlook Res. #2 Glen Una Res. Saratoga Hills Res.
Greenridge	Greenridge Terrace Res. Los Gatos Res.
Mt. Springs	Mt. Springs Res. Phillips Rd. Res.
Alum Rock	Alum Rock Res.
Montevina	Montevina Rd. Res.
Mt. Pleasant	Mt. Pleasant Res.
Beckwith	Beckwith Res.

The Congress Springs Intakes normally feed raw water to the Saratoga Filtration Plant (Figure 19). However, in the no-power situation, unfiltered water can be diverted, by proper valve manipulation, directly into the distribution system which feeds the Vickery Pressure Zone.

Critical Service Areas

The critical service areas are those pressure zones which cannot be fed by gravity in a no-power situation. They become critical in the sense that they must depend entirely on the water stored in the pressure zone to supply the needs of that area. Figure 18 indicates four pressure zones (Alum Rock, Mt. Pleasant, Miguelito, and Columbine) which face this problem. There is no way that impounded surface water can be input to these zones by gravity.

Personnel Management

The San Jose Water Works employs approximately 100 competent maintenance personnel (not counting supervisory personnel). During an ordinary workday there are usually 20 men in trucks to answer emergency calls and nine three-man crews which handle routine, pre-scheduled maintenance and lake repair. On Saturdays and Sundays one three-man crew plus one service man are on duty, and at night one service man is on duty at all times. There is no set deployment of the maintenance forces during the day. The 20 men in trucks are directed to various locations by radio communications and the three-man crews might be working in any part of the entire service area.

At the time gate valves are being manually controlled, the individuals operating a valve will generally not be able to determine the effect of the operation on the lower distribution reservoirs. Because it is vital to conserve water and prevent overflowing the reservoirs, additional personnel should be dispatched to the reservoirs where they can communicate to the individual operating the gate valves. This communication and coordination can be accomplished through the use of mobile radio units.

APPENDIX I

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APPENDIX II

GLOSSARY

ACTIVE PRESSURE: The minimum horizontal earth pressure, for cohesionless soils, that occurs when the soil mass yields and is in a state of shear failure due to a support condition being reduced.

ASTM: The American Society for Testing and Materials. This organization creates standard material specifications.

BEDDING ANGLE: The angle formed by the lines from the center of a conduit to the points on the outer circumference of the pipe where the supporting foundation material ceases to contact the pipe.

CLASS 100, 150, etc.: Pressure class designations which refer to the hydrostatic operating pressure under which a given pipe is intended to be used.

CRUSHING STRENGTH TEST: A standard American Water Works Assn. test to determine the total load per linear foot of pipe which can be applied before the pipe will fail by crushing.

(C 296): An ASTM specification designation for the materials and performance required of a particular water pipe.

DISTRIBUTION SYSTEM: A system of conduits (laterals, pipes, tanks, and appurtenances) by which a community water supply is distributed to consumers. The term applies particularly to the network of pipelines in the streets in a domestic water system.

DUAL SYSTEM: A water distribution system in which potable and non-potable water are separately furnished to consumers.

ELASTIC LIMIT: The highest stress that can be applied to a metal without producing a measurable amount of plastic (i.e., permanent) deformation.

FIVE CITY STUDY: A series of point-by-point analyses of the effects of assumed nuclear weapon attack situations on five selected cities in the United States and the response of the cities to the attacks.

GATE BOOK: A map or tabulation on which the locations of gate valves are recorded. This is usually carried by waterworks maintenance personnel in their vehicles.

GRADE A, B, etc.: Is the grade of steel, as specified by ASTM, that is used in the manufacture of steel water pipe.

GROUND WATER: Subsurface water occupying the zone of saturation. This term applies only to water below the water table.

GUNITE: A mixture of sand and cement mixed so that it may be placed in a fluid state under pressure by a "cement gun".

INTERCONNECTION: A physical connection between the pipelines in two pressure zones.

MODULUS OF ELASTICITY: A numerical constant indicative of the tendency of a material to return to its original size or shape after having been deformed.

MODULUS OF RUPTURE: The maximum stress at rupture in the outer or extreme fiber of a member subjected to bending.

MODULUS OF SUBGRADE REACTION: The ratio of the load required to force a given or specified settlement of a 30-inch diameter plate into earth.

PASSIVE PRESSURE: The minimum horizontal earth pressure, for cohensionless soils, that occurs when the soil mass yields and is in a state of shear failure due to a supporting or containing force being increased.

POTABLE WATER: Water which does not contain objectionable pollution, contamination, or infection, and is considered satisfactory for domestic consumption.

PRESSURE-FLOW SURVEY: A survey undertaken to measure the water pressure and quantities of flow at various points in the water distribution system.

PRESSURE REGULATOR: An apparatus inserted in a water main to regulate the hydrostatic pressure.

PRESSURE ZONE: An area embraced within the distribution system of a domestic or municipal water supply, in which the pressure in the mains is maintained within certain specified limits.

RAW WATER: Water that has not been filtered or conditioned to render it acceptable for a specific use.

SECTION MODULUS: A mathematical ratio which is a constant geometric property of the cross section of a structural member. When the bending moment to be withstood by a structural member is divided by the section modulus, the quotient is the maximum bending stress which could exist in that member.

SEISMIC VELOCITY: The velocity of a shock wave through an earth mass.

SHEAR STRESS: The intensity of shear force per unit area of cross section, varying in some definite way across the section, e.g., as the radius in a twisted shaft, and parabolically across a beam.

SKIN FRICTION: The action between a pipeline and the surrounding earth, at their surfaces of contact, which opposes their relative movement.

SOIL PIPE: A standard type of bell-and-spigot cast iron pipe of limited strength.

SOURCE FACILITY: The works, structures, and equipment utilized to capture and deliver surface or ground water to transmission facilities.

STRAIN: Elongation per unit of length, i.e. inches per inch.

STRESS: Force per unit area of cross section, i.e. pounds per square inch.

SURFACE WATER: Water that flows over or rests upon the surface of the lithosphere.

TENSILE STRENGTH TEST: A test to determine the maximum stress developed in a material when a force is applied which tends to pull it apart.

TRANSMISSION FACILITY: The pipelines, structures, and equipment used to transmit water to the distribution system.

TREATMENT FACILITY: The works, structures, and equipment used to treat water for domestic, industrial, and fire use.

YIELD POINT: The stress at which a substantial amount of plastic deformation takes place under constant or reduced load.

WATER HAMMER: Pressure pulsations above and below normal operating pressure caused by suddenly changing the velocity of water in a pipe.

APPENDIX III

LIST OF SYMBOLS

a	length
A	cross sectional area
c	pressure wave velocity
C	ratio of internal pressure to bursting test pressure
C_s	vertical seismic velocity
d	nominal pipe diameter
d'	mean diameter of cylindrical pipe measured to mid-point of pipe wall
d_{e_o}	vertical displacement due to overpressure
E	modulus of elasticity
$\bar{E}$	modulus of elasticity of a soil mass (vertical pressure divided by vertical strain)
f_a	axial stress in pipe
f_b	stress in pipe - either tension or compression
f_u	modulus of rupture or tensile strength
F	shape factor
I	moment of inertia of a section about the neutral axis for bending
k	modulus of foundation which equals k_o times the beam width
k_{a_p}	correction factor for active pressure lateral support
k_b	correction factor for bedding angle less than 180°
k_{i_p}	correction factor for internal pressure
k_o	modulus of subgrade reaction
L	span of member subjected to bending
M	bending moment

List of Symbols (continued)

M_A	bending moment at A
MT	megatons - equivalent to explosive energy of one million tons of TNT
P	concentrated load
p_o	overpressure in psi
R	mean radius of cylindrical pipe measured to mid-point of pipe wall
S	section modulus
t	pipe wall thickness
v	velocity of pressure wave or impact force
v_o	vertical velocity of pressure wave or impact force induced by overpressure
V	shear
w	uniformly distributed load or pressure
w_h	intensity of lateral support at the centerline of the pipe in psi
w_p	total vertical capacity of pipe, in psi, without passive pressure support
w_v	total vertical capacity of the pipe, in psi, assuming passive pressure support
W	yield of nuclear weapon in megatons
Y	deflection or displacement
ρ	mass per unit volume
ϵ	lateral strain in soil
α	half of the bedding angle
θ	angle to point under consideration
β	reciprocal of the characteristic length of a system

APPENDIX IV

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13. ABSTRACT

This study presents information on the blast vulnerability of community water distribution pipelines, alternate operating techniques for controlling the use of water in early postattack periods, and on radiological recovery procedures and shelters available to waterworks personnel. (U)

The results of the analysis of the vulnerability of pipelines indicate that the primary mode of failure will be crushing of the pipe. The five principal alternate operating techniques considered are: (1) isolation of portions of the distribution system; (2) rationing consumer water use; (3) reducing hydrostatic operating pressures; (4) rerouting water; and (5) the utilization of auxiliary sources of water. (U)

Planning is stressed for postattack radiological recovery procedures, such as, wet decontamination and the determination of the safe stay times for recovery personnel. It is essential to provide shelter in locations as close as possible to the designated tasks that waterworks personnel must perform in early postattack recovery situations. (U)

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