Performance of Irrigation Pipelines Buried Within the Frost Zone

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The Carrington Irrigation Station (now Carrington Research Extension Center) was established in 1960 to provide research in advance of both private and public irrigation development in North Dakota. The basic function of the station at that time, in anticipation of irrigation development, was to discover the productive potential of various crops grown under irrigation. In addition to agronomic research, emphasis also has involved engineering phases of irrigation development, including the evaluation of shallow buried pipelines used for irrigation water distribution.

The station, when established in 1960, was partially developed for gravity surface irrigation with open irrigation ditches for water distribution. Prior to development of economical pipeline materials, open ditches were the traditional irrigation water delivery method. But seepage losses in unlined open irrigation ditches can be 25 percent or more of the total water delivered to a site. Buried irrigation pipelines offered many advantages to irrigators when compared to open ditches. Water delivery could follow the most direct route from source to point of delivery. In addition, buried pipelines would not interfere with field operations and both seepage and evaporative losses could be eliminated.

Although buried pipelines offered an obvious solution to increasing irrigation water delivery efficiency, it was not known whether an installation would perform satisfactory under North Dakota conditions. Traditional recommendations were that buried pipelines must be placed below the frost line, about 7 feet in North Dakota's climate. Shallow, graded pipeline placement with provisions for drainage would markedly reduce installation costs. In addition, buried pipeline distribution systems would greatly reduce labor requirements for uniform surface irrigation water distribution. Furthermore, choosing the best material to use for irrigation service was a challenge since little testing had been done for a northern climate.

Pipe materials and pipeline designs for irrigation water distribution systems vary widely depending upon application. Pipe materials used for open ditch replacement usually have only low head requirements, but pipe used for sprinkler systems are designed to withstand relatively high heads. Structurally, all buried pipe must be capable of withstanding external load forces imposed by the surrounding soil envelope and field equipment running at ground level, as well as internal pressure from the contained water. In addition, the pipe material must be resistant to corrosive effects of the soil and/or soil solutions as well as irrigation water.

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Furthermore, frost effects on water supply lines are well known to city water departments in northern areas. Frost heaving in frozen soil could cause extensive damage to buried pipe, necessitating costly repairs to an irrigation system. Consequently, prolonged freezing periods were of major concern when placing irrigation pipe within the frost penetration zone. Available information when the study began concluded that factors affecting frost heave were:

1) depth to free water table as related to depth of frost penetration
2) amount of capillary water movement through a soil profile
3) texture and permeability of the soil
4) duration of the annual freeze period

Cold temperatures during the winter months in the north central states require water line placement 6 to 7 feet below the surface for protection from winter freeze-up. However, an alternative for water lines used only during the summer months was shallow burial within the soil frost zone but laid to grade to allow water drainage before freeze-up. Cost differences between 3- and 7-foot burial suggested that, for irrigation pipelines, only the shallow placement was economically feasible.

Placement at shallow depths in more mild climates was commonplace, but in 1960 there was little evidence of similar application in the northern states where the pipeline would be frozen into the soil profile for several months of each year. Limited experience with shallow irrigation pipeline installations prompted the initiation of buried pipeline studies at the Carrington Irrigation Station.

The following will report on two characteristics concerning cement, PVC, and asbestos cement pipe material used for buried irrigation pipelines: 1) frost effects on external pipeline factors, and 2) internal pipe hydraulic characteristics.

The first pipeline installed at the station was 12-inch, low head, non-reinforced concrete with risers and alfalfa valves to replace an open ditch from which siphon tubes had been used for irrigation water distribution onto fields. Since then, pipelines of other materials and pressure ratings have replaced open ditches, with a total of more than 15,000 feet in use on the station for both low head surface irrigation and high head sprinkler system installations (Table 1). All pipelines have shallow placements with soil cover over the pipe ranging from 30 to 36 inches. The Portland Cement Association and U.S. Bureau of Reclamation have provided financial assistance together with a number of private companies which have made grants in the form of materials. These have helped support the field studies thus far.

Table 1. Pipeline materials installed at the Carrington Station.

Material	Length (feet)	Year Installed	Diameter (inches)	Rating psi	Coupler
Non-reinforced concrete	1775	1964	12	5	roll gasket in bell
Asbestos-cement class 5	4200	1966	12,10,8	22	gasket in sleeve
PVC plastic	1000	1968	12,10	22	solvent-weld
PVC plastic	600	1968	6	80	solvent-weld
PVC plastic	600	1968	6	125	gasket-bell
PVC plastic	360	1968	8	100	solvent-weld
PVC plastic	300	1969	6	160	solvent-weld
PVC plastic	300	1969	6	160	gasket-bell
Vinyl clad aluminum	600	1969	6	125	buckle-joint
Vinyl clad aluminum	600	1969	8	125	buckle-joint
PVC plastic	3000	1970	8	100	gasket-bell
PVC plastic	1900	1982	6	100	gasket-bell

FROST EFFECTS

Effects of frost action on buried irrigation pipe were examined at sites on the Carrington station. Vertical control was established and monitored periodically to identify any changes in pipeline elevation that may have resulted from the soil profile freezing and thawing. Elevation measurements were performed in 1969 (year 1), 1974 (year 5), and 1984 (year 15) using the same reference points. Changes in pipeline elevations after initial pipeline settling are assumed due to frost action.

An abbreviated pipe material data summary is given in Table 2. Data suggests little, if any, frost action has caused vertical displacement of the pipe lines studied. Elevation readings taken before, during, and after winter freeze-up have been essentially the same.

HYDRAULIC CHARACTERISTICS

Both the design and sizing of an irrigation water distribution system on a farm is dependent on several factors, including pipe size, length, and hydraulic characteristics of the pipe material used. Friction head losses in both new and used irrigation pipe have been investigated by both the irrigation industry and a number of scientists, mostly in controlled laboratory experiments. Information concerning total irrigation pipe head loss with field applications is somewhat lacking, however.

Total head loss is not only dependent upon the smoothness of the pipe's surface, but also the configuration of the pipe in a field and the type of coupling used between straight pipe sections. Further, after a period of time and repeated seasonal use, those characteristics may change. Corrosion, erosion, and sometimes tuberculation can affect the pipe's inside wall surface roughness (C factor). Furthermore, in the Carrington installations, it was thought that frost action might alter pipe alignment. Lastly, the possibility existed that surface loads imposed by farm equipment and settlement of backfill could alter the cross sectional area of the thin-walled, low-head, PVC pipe sufficiently to reduce its carrying capacity.

Measurements were taken to determine the overall effect of changes in the irrigation pipe system which may occur with use and time. Head loss measurements were initiated on the newly installed buried pipe at Carrington in 1969 (year 1) and repeated at the same locations in 1974 (year 5) and 1984 (year 15). Irrigation water flow rates were verified using a Hall Flowmeter. Flowrates of 1, 2, and 3 cubic feet per second (cfs) were studied. In addition, before measurements were taken, trapped air was removed from the pipeline being studied. Tests were performed under normal irrigation operation conditions. Head loss measurement was accomplished by installation of piezometric taps in the pipeline which allowed total head measurement at a given point. Measured head losses between successive points along a pipeline were averaged on the basis of loss per unit of length, inserted in the Hazen-Williams equation and the roughness coefficient calculated. Roughness coefficient (C) was calculated from the Hazen-Williams equation expressed as follows:

$$Q = 1.318\, C\, R^{.63} S^{.54} A$$

Q = Flow rate in cubic ft./sec
R = hydraulic radius (D/4 for round pipe)
S = slope of energy line (head loss/length)
C = roughness coefficient
A = cross section of pipe

Data were calculated over a range of flow rates and average to obtain a mean value. Mean values are summarized in Table 3 for low-head PVC, asbestos-cement, and non-reinforced concrete pipe across years.

There was little change over the 15-year period in the roughness coefficient (C) with three of the four pipeline

Table 2. Mean elevations from vertical control points on irrigation pipelines placed within the frost zone.

Irrigation Pipe	---- Mean Elevations (feet) ---- year 1	year 5	year 15
12-inch PVC lowhead pipe	95.09	95.11	95.07
10-inch PVC lowhead pipe	92.25	92.27	92.22
12-inch concrete lowhead	92.06	91.92	91.91

Table 3. Roughness coefficients calculated from head loss measurements.

Pipe Material	Diameter (inches)	Roughness Coefficients		
		year 1	year 5	year 15
PVC plastic - low head	12	122	123	120
Asbestos - cement class 5	10	139	139	137
Asbestos - cement class 5	12	132	138	141
Non reinforced concrete	12	127	138	87

materials tested. The greatest change occurred with nonreinforced concrete pipe where the C factor decreased from 127 to 87, suggesting hydraulic friction losses have increased over the years. One suggested hypothesis is that increased friction losses over time are directly related to inorganic mineral constituents of the irrigation water being transported through a particular pipe material. High iron contents (6 to 10 ppm), calcium (96 ppm), and magnesium (29 ppm) values plus bacterial iron which can oxidize and deposit a film on the inside of the pipe may have contributed greatly to the lowered C values for this pipeline type. Other pipe materials did not, however, show the same reaction even though irrigation water characteristics were the same.

Another observation from Table 3 shows a lower C value from PVC compared to asbestos-cement, which is contrary to published literature. This suggests other subsurface conditions exist with the PVC pipeline (low head), such as a change in shape of the cross sectional area, coupling misalignment, or mineral adhesion to pipeline walls which also affects roughness coefficients. Further investigations revealed the low head PVC pipeline had become out of round with time.

Head loss versus flow rate curves were prepared for each pipe material tested for years 1, 5, and 15 and are shown in figures 1 through 4. Head loss data from the non-reinforced concrete pipeline paralleled the findings in Table 3 and indicates the head loss versus flow rate curve much higher in year 15 than in years 1 and 5. This curve concurs that some change has occurred to produce more friction inside the concrete irrigation pipe. One possible reason is that the irrigation water may have a corrosive or erosive effect on the inside walls of pipelines made from cement.

The 10-inch asbestos cement pipe may have had a similar reaction. As flow rates increased above 2 cubic feet per minute (cfs) in the 10-inch asbestos cement, head loss values increased more than in the tests run 10 years previous. Head loss characteristics from the 12-inch asbestos cement pipeline were not affected by time at flow rates of 1, 2 and 3 cfs. Should further deterioration in surface roughness occur within the 10-inch asbestos cement pipe, it is assumed the C factor will decrease accordingly as did C values from the nonreinforced concrete pipe.

SUMMARY

Approximately 15,000 feet total of concrete, asbestos-cement, steel, vinyl-clad aluminum, and PVC irrigation pipe have been buried within the soil frost zone (30 to 36 inches) at the Carrington Research Extension Center. Pipelines are laid to grade to permit water drainage before freeze-up and water is removed in early fall of each year.

Head loss measurements were made in several pipe sections first in 1969, shortly after installation. Measurements were continued in 1974 and again in 1984 to identify changes that may have taken place to alter the capacity of the irrigation pipelines studied. Data indicate little change over time occurred in hydraulic characteristics of the irrigation pipelines studied. The exception was irrigation pipe made from nonreinforced concrete, where a substantial decrease in the Hazen-Williams C value was noted.

Nonreinforced concrete was the most commonly used material for irrigation pipelines before thermoplastic compounds became popular. Concrete pipe joints can be designed for either rubber gaskets or mortar. Rubber gasket joints are slipped into place. However, mortared joints must be connected with specific bonding techniques to prevent leakage.

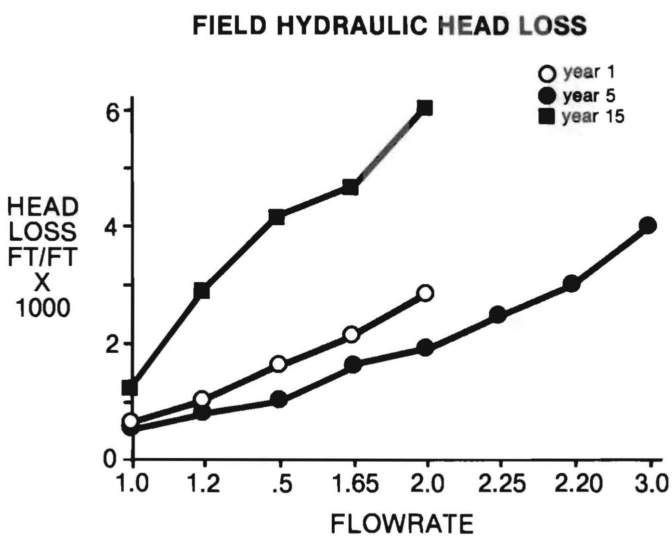

Figure 1. 12" Non-reinforced Concrete Pipe.

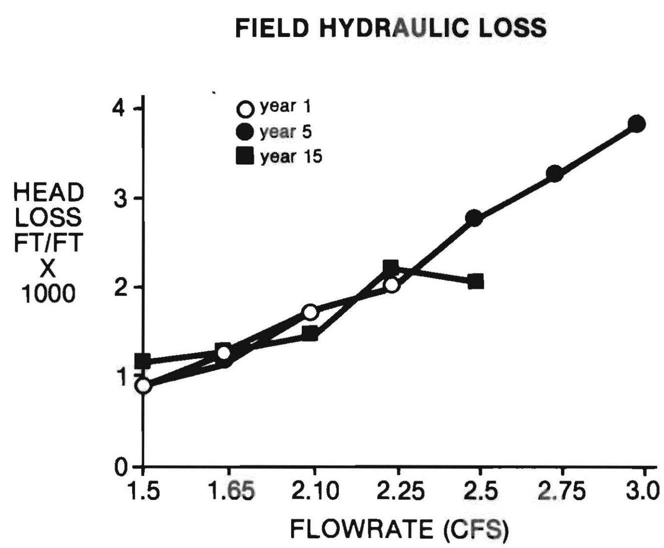

Figure 2. 12" Asbestos Cement Pipe.

Nitrogen fertilizers should not be used in concrete pipelines. Calcium carbonate in hard water may precipitate and adhere to pipe walls, increasing resistance to conduct water (decreasing C values). In addition, ammonium sulfate concentrations added to irrigation water should not exceed 0.1 percent. Any fertilizer application through irrigation pipelines should be followed by an adequate flushing.

Precast concrete is generally not cost competitive with plastic pipe. However, the U.S. Bureau of Reclamation does include reinforced concrete pressure pipe as an option along with various other pipe types in irrigation pipeline construction specifications.

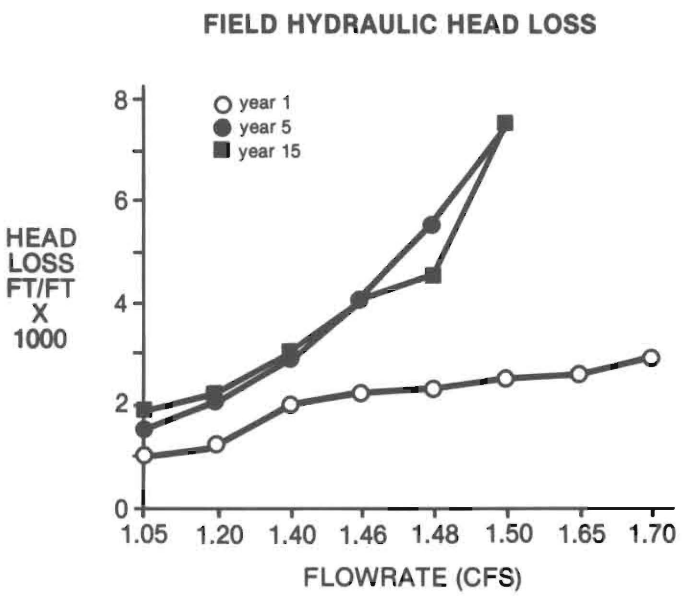

Figure 3. 10" Asbestos Cement Pipe.

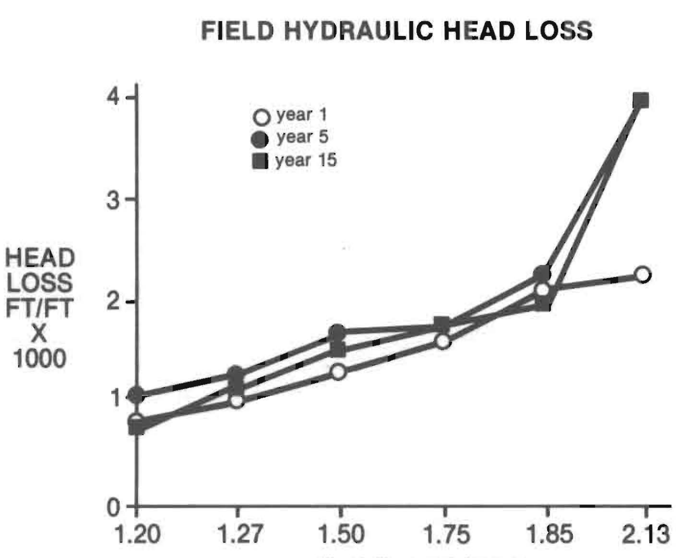

Figure 4. 12" PVC Pipe.

Concrete pipe's main advantage is its high strength which, in areas of heavy farm equipment traffic, would serve to protect the pipeline from breakage. Pre-cast concrete pipe sections are extremely heavy as compared to PVC however, resulting in increased installation costs.

Asbestos cement is available for both high and low pressure water lines. The material is manufactured from a mixture of Portland cement, Portland blast furnace slag, and asbestos fiber. This mixture provides a dense pipe with a smooth interior surface. Irrigation applications require specific grades.

Asbestos cement ends are machined for insertion into separate rubber gasketed couplers. Pipe assembly with asbestos cement must be done in the field trench because pipe rigidity and the gasketed joints do not allow for much pipeline deflection.

Other materials have been installed on an experimental basis at the Carrington Station, including steel pipe and vinyl coated aluminum. Thermoplastic piping (PVC), however, has been the least costly to both purchase and install in the diameters used at the Carrington Station. New materials, such as epoxy bonded aggregate, fiberglass, fiberglass encased PVC, and foamcast plastic pipe may hold promise for future use as buried irrigation pipeline materials, but they are not yet competitive with thermoplastic.

Availability and light-weight construction of semi-rigid plastic pipe has made PVC buried pipe an attractive alternative to open ditches for irrigation water distribution. Plastic pipe materials are available in a wide range of sizes and pressure ratings. Both solvent weld and gasketed pipe line joints are available. Both work satisfactory, however, inexperienced pipe installers can assemble leak free pipe lines more easily with gasketed than with solvent weld joints. Water leak detections should be accomplished before backfilling by filling the pipeline with water at line operating pressure and inspecting. Pipelines should remain full of water during backfilling to prevent collapse.

Underground irrigation pipe requires graded installations to allow a minimum drainage of one-half the pipe diameter at the pipeline's lowest point. Chain type trenchers work satisfactorily for preparing a proper bed, but pipeline trench beds should be free of rocks. Locations where rough rock beds cannot be avoided require overexcavating, and backfilling to the bedding depth with sand or finely graded soils.

At present, the irrigation water distribution systems at the Carrington Station have been in use for periods ranging from six to 24 years. Performance evaluations from the various irrigation pipeline materials under normal field conditions are being continued. Currently at the Carrington station, 320 acres are irrigated by center pivot sprinkler method and 120 acres by gravity surface methods using gated pipe, with the water being supplied to both methods by buried distribution pipelines. All installations have performed satisfactorily with the exception of nonreinforced concrete. Increased operating head losses have been noted over the years while irrigating with this pipe system. Pipeline maintenance required thus far has been restricted to occasional repairs. Gravity irrigation hydrant covers attached to pipelines have received damage caused mostly by farm implements.

LITERATURE CITED

Jensen, M.E. 1980. **Design and operation of Farm Irrigation Systems.** ASAE. St. Joseph, Mi.