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Baracos, A.; Hurst, W. D.; Legget, R. F.

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Effects of Physical Environment on Cast-Iron Pipe

ANALYZED

By Andrew Baracos, W. D. Hurst, and R. F. Legget

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Effects of Physical Environment on Cast-Iron Pipe

—Andrew Baracos, W. D. Hurst, and R. F. Legget—

A paper presented on Jun. 15, 1955, at the Annual Conference, Chicago, by Andrew Baracos, Asst. Prof., Civ. Eng. Dept., University of Manitoba, Fort Garry, Man.; W. D. Hurst, Chairman of Comrs., Greater Winnipeg Water Dist., Winnipeg, Man.; and R. F. Legget, Director, Building Research Div., National Research Council of Canada, Ottawa, Ont.

UNUSUALLY severe soil conditions in the Greater Winnipeg area have resulted in numerous and expensive failures in the municipal water distribution system. The consequent economic loss to Winnipeg is estimated to have exceeded \$1,000,000 in the past 20 years. For a system consisting of approximately 395 miles of 4-in. to 36-in. diameter mains, having 55,000 services and 7,000 valves, and serving a population of 244,000, these maintenance costs assume major proportions (1, 2). During 1954 alone, about \$96,500 was spent on maintenance of mains, \$90,000 on maintenance of services, and \$55,000 on maintenance of valves. Earlier studies had determined that corrosion caused rapid deterioration of cast-iron pipe and valves in as short a time as 12 years. Lead service pipes, too, had failed in relatively short periods in the corrosive soil. It had been suspected that pipe thus weakened by corrosion often failed under the induced stress caused by the shrinking and swelling of supporting and covering soils.

Previous Research

Water main failures studied in the past chiefly as a problem in chemistry had brought significant results. As

early as 1921 it was established that electrolysis, such as that caused by stray currents from street railways, was not the only corrosive factor, and that extensive corrosion was observed in areas remote from possible stray currents (3, 4). It was also recognized that the soluble salts of sodium, magnesium, and calcium are among the chief causes of the corrosive action of Winnipeg soils. The corrosion results when underground water containing these dissolved salts produces graphitic softening of cast-iron pipe. The same salts were found to be detrimental to concrete pipe. In 1919 it was discovered that a recently completed 96-mile concrete aqueduct servicing the Greater Winnipeg Water Dist. was being attacked externally and was rapidly deteriorating. The investigation of this action was instrumental in the development of alkali-resistant Type 5 cement by T. Thorvaldson of the University of Saskatchewan and the late A. Fleming of the Canada Cement Co. The alkali resistance of steam-cured concrete was also verified.

The prevention of pipe corrosion by the use of protective coatings and wrappings proved to be impractical because of the high costs or the extreme care required in placing the pipe to

prevent damage to the coating. In recent years, corrosion-resistant steam-cured asbestos-cement pipe has been extensively used with partially satisfactory results (5). The lighter Class 150 asbestos-cement pipe, having 6-in. or smaller diameter, is no longer used by Winnipeg because it was found to be subject to transverse cracking near the mid-length of the pipe section. Similar failures had been observed in both corrosion-weakened and new cast-iron pipe. This seemed to indicate that mechanical action was an important factor in the failure of both the asbestos-cement and the cast-iron pipe. To overcome such breaks in asbestos-cement pipe, a sand bed and cover have been utilized and blocks are no longer used for supporting the pipe.

Present Investigation

In 1947, because of the economic losses to Winnipeg and to all of western Canada resulting from common failure problems, Winnipeg's city engineer discussed the water main failures with the director of the Building Research Div., National Research Council of Canada, and asked that the council assist in finding methods of overcoming some of the difficulties. (The National Research Council is not a department of government, but is a public agency supported by funds granted by federal parliament.) Cooperative research in Canada involving federal, provincial, municipal, and private organizations has had many successful precedents (6), and it was therefore not unusual that a joint research project to investigate the water main failures was initiated by the Building Research Div., Winnipeg's engineering dept., and the civil engineering dept. of the University of Manitoba.

The studies were not begun immediately. The first delay was caused by a serious problem which arose in connection with trolley bus operation on Winnipeg streets, causing vibrations which were transmitted through the soil to adjacent buildings. This problem was jointly studied (7). The 1950 flood of the Red River, in which a large part of the city was inundated, necessitated a study of damage to foundations. Although these studies were not part of the water main failure studies, they indirectly contributed to the investigation. Valuable information (8) was obtained regarding the mechanical action of Winnipeg clays, leading to the decision to study the effects of this action on buried pipe. The studies on water main failure were finally begun in the summer of 1953.

It was known that the cast-iron water main failures were primarily a problem in chemistry. After consultation with the Applied Chemistry Division of the National Research Council, however, it was established that the corrosion problem was similar to that encountered in many other places and that the principles elucidated elsewhere were probably applicable in the Winnipeg area. To investigate the corrosion further meant a duplication of research performed at other centers, such as the Chemical Research Laboratory of the Dept. of Scientific and Industrial Research in the United Kingdom, and the US National Bureau of Standards. The present investigation was therefore limited to those features which resulted from the physical action of highly plastic clays on water mains, and which intensified the failure action. It was felt that these features might explain certain irregularities observed in the earlier studies. Corrosion was not always accompanied by a high sul-

fate content in the soil and recent research elsewhere had indicated that physical factors such as temperature differentials between the pipe and the soil and stress differences in adjacent pipe sections, as well as the chemical action of sulphate-reducing bacteria (9), may also be causes favoring corrosion. A study of the physical environment of buried pipe seemed advisable.

Water Department Records

The water works branch of the city's engineering department has kept accurate records of all repairs to its system and has attempted to ascertain the cause of all pipe failures. From these records it was possible to determine the monthly rate of failures attributed to "cracked-pipe," a term used to describe pipe which has cracked transversely near the mid-length and where flexural failure is suspected.

Figure 1 shows the number of failures per month attributed to "cracked-pipe," for the years 1948-1953. Also shown are monthly mean air temperatures, precipitation, and approximate depth of snow cover. There is a definite cyclic pattern to failure occurrences, with September and January having the highest tolls, and it would seem that seasonal soil changes have a direct bearing on pipe failures. Seasonal volume changes in Winnipeg soils have been observed and measured (10, 11).

Soil Conditions

Swelling and shrinking of Winnipeg clays have been responsible for considerable damage to foundations. These volume changes occur seasonally and can be demonstrated in laboratory and field tests. Recent measurements taken by special equipment developed at the

University of Manitoba's civil engineering department show that the ground surface can rise and fall approximately 2 in. over a period of one year. In measurements taken 6-12 ft under the ground surface similar movements were observed, although the magnitude of rise or fall became less as the depth increased. During the 1950 flood, building foundations at shallow depths were observed to rise as much as 4 in. because of the swelling which accompanied increased moisture content in the supporting clays. At the University of Manitoba it was found that, during winter, soils at a depth of 4 to 8 ft can shrink. This action is believed to be caused by freezing of the soil nearer the surface, which draws water from the lower depths to form ice lenses. Percolation of surface water into the soil is negligible during these winter months, because the ground is frozen, and because precipitation is in the form of ice and snow. The reduced moisture content at the lower depth results in shrinkage, which is greater than the expansion caused by ice lensing. On the basis of soil mechanics the swelling and shrinkage of Winnipeg clays is readily explainable.

Briefly, the soils in the Greater Winnipeg area consist of highly plastic and stratified lacustrine clays and silts overlying consolidated and cemented subglacial till, found at a depth of 40 to 60 ft. The lacustrine clays are often overlain by a few feet of more recent fluvial silts of low plasticity (locally described as yellow clays) organic soils or clays which have been modified by weathering.

Shrinkage and swelling have been associated with the lacustrine clays which form two distinct layers. The upper layer (locally described as

Fig. 1. Monthly Mean Snow Cover, Mean Temperature, Precipitation, and Number of "Cracked-Pipe" Failures, July 1948 to August 1953

Because they affect soils and backfills, seasonal conditions are closely related to yearly "cracked-pipe" failures.

"chocolate clay"), having a brown to gray-brown color, has liquid limits ranging from 60 to more than 100. A limited number of analyses show that as much as 30 per cent of the solid content of this clay is montmorillonite, a very active clay mineral. Swelling pressures up to 20 tons per square foot have been developed in the laboratory on undisturbed samples which were first allowed to desiccate and were then rewetted. Swelling pressures of one ton per square foot are not uncommon

when water is added to undisturbed samples at natural moisture contents. In many areas of Greater Winnipeg, water mains have to be placed in this type of soil, which is found at depths of 5–20 ft.

The lower layer of lacustrine clay (locally described as "blue clay") is gray to blue-gray in color and has somewhat lower plasticity. Its liquid limits generally do not exceed 60, and it has a softer consistency. Swelling and shrinking do not normally occur

in this material as it is generally found below the zone of seasonal moisture variation.

Preliminary Considerations

The city records showed that, for the period 1940-49, there were 1,667 breaks in cast-iron pipe in the distribution system. Of these, 36 per cent were caused by "cracked pipe." For the period 1932-51, a total of 119 breaks occurred in asbestos-cement pipe, of which 21.8 per cent were classed as "cracked pipe." The smaller number of breaks in the asbestos-cement pipe reflects the limited quantity of this pipe in service at that time.

The percentages of "cracked-pipe" failures are significantly high. That such failures occurred in larger numbers during September and January suggested a correlation with the seasonal volume changes observed in Winnipeg soils. In particular, a correlation was suggested between times of peak failure occurrence and the dried-soil conditions existing after a hot summer or just prior to the spring thaw, as indicated by the university tests. Instrumentation was therefore devised to measure pipe displacements in the soil, soil temperatures, and pipe strains over a period of time, and to investigate the possibility of such a seasonal correlation.

"Cracked-pipe" failures, similar to those occurring in the smaller sizes of Winnipeg mains, have received consideration in the past. The ASA committee A-21.1, in preparing its cast-iron pipe manual (12), emphasized the effects of external loading on pipelines and stated that those effects must be considered if safe design is to be obtained. Backfill and surface loads cannot be ignored any more than the stresses caused by internal pressure

and water hammer effect. Nor are the stresses caused by the external loads independent of the strength and elastic properties of the pipe itself and the method of laying it.

Methods of Laying

Committee A21.1 investigated the following methods of laying pipe: *A*, pipe laid in a flat bottom trench with untamped backfill; *B*, pipe laid in a flat bottom trench with tamped backfill; *C*, pipe laid on blocks with untamped backfill; *D*, pipe laid on blocks with tamped backfill; *E*, pipe laid in a shaped bottom trench with untamped backfill; and *F*, pipe laid in a shaped bottom trench with tamped backfill.

It was demonstrated that laying conditions for pipe *C* caused the most severe stress in buried pipe, especially pipe of small diameters. To check on practices employed in laying pipe in Winnipeg, an examination of past specifications was made.

From about 1900 until about 1934, cast-iron bell-and-spigot pipe was used exclusively for the construction of city water mains. The pipe was supported on blocks 10-in. wide, at least 6-in. in depth, and extending the full width of the trench. The blocks were placed at the bell-and-spigot joints. Backfilling specifications called for the thorough ramming of 8-in. layers around and over the pipe until the trench was filled.

The first lengths of steam-cured asbestos-cement pipe were installed in 1932. In order to ensure that the manufacturer's guarantee would be honored, the pipe was laid according to the manufacturer's recommended procedure, which advocated wooden block supports placed at a distance of $0.208 L$ from the ends of the pipe, L being the length of the pipe. It can

be shown that, for a pipe acting as a simple beam, such support gives the least bending stress under conditions of uniform loading. Additional advantages derived from the use of the blocks were faster assembling and the ease with which the fill could be tamped on the underside to provide uniform support for the pipe. Moreover, the couplings would be kept off the ground during laying.

This method was followed from about 1934 to 1948. Field crews without proper authority applied the practice to the laying of cast-iron pipe, not realizing that the joint in this type of pipe imparted a certain continuity to the pipe sections, thus invalidating the block-spacing formula. From time to time, the inspection staff also found that the specified tamping was not always faithfully carried out, largely because of the character of the available labor.

It may be seen, then, that a very large percentage of Winnipeg's water mains had been placed using blocks, either in accordance with the manufacturer's recommendations, or because of the inadequate knowledge concerning the subject during the earlier years.

It is interesting to note that, in about 1950, the manufacturers of the asbestos-cement pipe altered their specifications and recommended the omission of the wooden blocks, except in unstable soils, for all pipe having diameters smaller than 12 in. This action apparently confirmed the city's observation that their recommended laying methods had not proven satisfactory.

In 1951 the city engineering department, in concurrence with the asbestos-cement pipe manufacturer's representatives, decided that changes in laying specifications were necessary. Wooden block supports were considered detri-

mental and were not to be used at any time during construction. The cost of constructing in the clay an effectively formed bed conforming to the required grade was exorbitant. (In the manufacturer's earlier specifications, the formed bed was considered to be an ideal form of pipe support.) The use of sand offered the most practical and least expensive method of obtaining the required bedding for the pipe. In this method sand is introduced into the trench prior to laying the pipe and brought to the desired grade so that when the pipe is placed in position, it can be bedded directly into the sand. In 1953, instructions were issued to the effect that cast-iron water pipe was to be laid in exactly the same manner as the asbestos-cement pipe.

Beginning the Study

The writers suspected that the swelling and shrinking properties of the Winnipeg clays intensified the severity of the pipe stresses caused by block supports. It was possible for the blocks or the bed supporting the buried pipe to be lifted by the swelling which accompanied increased soil moisture content, since earth pressures causing the pipe to push against the backfill are theoretically greater than those caused by the backfill pushing downward on the pipe. The increased moisture content of the supporting clays could result from water percolating through the backfill, which would be more permeable because of its disturbed condition. Similar percolation of water through backfill around basement walls had caused damage to foundations, sometimes causing basement floors to rise as much as 4 in. Such vertical movements in soils could well cause the failure of corrosion-weakened pipe.

It was therefore decided to develop instrumentation to measure the differential vertical movement of water mains. Longitudinal strain measurements were proposed using electric strain gages. Since frost penetration is an important factor in the behavior of the backfill, thermocouples were installed to obtain ground temperature measurements. Three methods of supporting the pipe in the test sections were tried and more methods will be tried in the future. Pertinent tests were also performed on soils from the three sites now under operation.

Test Installations

Test Installation *A* was made at a site where previous performance of an existing cast-iron main indicated highly corrosive and mechanically active soils. During the period 1925-52, 13 breaks had occurred in an 800-ft length of this pipe. Five of these breaks had been attributed to corrosion, seven to "cracked pipe" in corrosion-weakened sections, and one to miscellaneous causes. Very high shrinkage and swelling properties were indicated for the supporting soils by a liquid limit of 96.8, and a plasticity index of 55.5. Increased demand had necessitated new pipe of larger diameter.

The test installation consisted of approximately 400 ft of 6-in. diameter Class 150 cast-iron pipe, and 400 ft of 6-in. Class 200 asbestos-cement pipe placed at a depth of 7 to 8 ft. Although, normally, asbestos-cement pipe would have been used for the replacement, the cast-iron pipe was installed because it permitted the use of electric strain gages which could not be attached to the asbestos-cement pipe and be satisfactorily waterproofed. Also, with the cast-iron pipe, a special plas-

tic tape wrapping could be tested for corrosion prevention.

The pipe was installed during December 1953 in extremely cold weather. Excavation was made using a series of shored open pits 6-ft long, connected by 4-ft long tunnels. The pipe was laid on wooden blocks placed 12-18 in. from the ends of each 6-ft length. Backfill was pushed into the trenches using a tractor and was manually spread into the tunnels. The frozen condition of the backfill precluded any compaction under or over the pipe. In the spring, considerable fill had to be placed in the trenches because the backfill had consolidated and left depressions. This installation was used as an experimental prototype in developing and checking all instrumentation.

Test Installation *B* was a 400-ft section located in a new residential development, where tests indicated high soil swelling and shrinking properties. The installation consisted of 4-in. cast-iron pipe installed in a residential bay (6 in. is the minimum size laid in ordinary streets), at a depth of 7-8 ft, supported by blocks on highly plastic clay. The trench was excavated by a trenching machine using conveyor buckets. The top 6 ft of excavation were predominantly in silt and silty clay. The wooden blocks were left in place and sand backfill was placed around the pipe to a depth of 6 in. Backfill material consisted of the excavated clay and silty clay in a well broken-up condition and was pushed into the trench using a tractor.

Test Installation *C* was similar to Installation *B* except that sand backfill was not used and the excavation was made with a backhoe. The use of this equipment resulted in the excavated soils being in large pieces. The weather permitted laying the pipe in

relatively dry trenches, and a tractor was used to push the backfill into the trench.

Vertical Movement Gages

Rods were supported on the pipe and extended to the ground surface through sleeves, with clearance to permit free movement. A removable cover at the top of the sleeves and

showed that, locally, this depth was relatively free of seasonal soil movements. Details of these pipe movement gages are shown in Fig. 2.

In Installation *A*, the gages were placed on four consecutive lengths of pipe. In Installations *B* and *C*, the gages were placed on 5 consecutive lengths. A further improvement in these two installations was a deep

Fig. 2. Schematic Representation of Typical Test Installation

Layouts similar to this were used in each of the three installations. Letters A-E indicate parts of the vertical movement gage: A—removable cap; B—grease packings; C—centering screws; D—rod; and E—sleeve. Other material is shown as follows: F—electric strain gages (water-proofed); G—compensating electric strain gage in water-proofed container; H—electrical leads; I—terminal box and selector switch; J—thermocouples; K—thermocouple temperature well; and L—deep benchmark in undisturbed soil.

grease packings at the top and bottom prevented water from entering. A similar rod was supported on undisturbed soil at a depth of 12 ft, and this was used as a reference datum for checking elevations at the top of the rods. The 12-ft depth was selected on the basis of the university tests which

bench mark supported at a depth of about 30 ft, although a much shallower depth would have been satisfactory. This bench mark was placed to determine whether such a 30-ft deep rod could be used to establish a satisfactory bench mark in Winnipeg soils. It had been specially developed by the

Building Research Div. for determining an elevation datum not subject to vertical soil movement, an essential factor in the division's soil and foundation studies. Readings on the benchmark and the vertical movement gages were carefully taken with an engineer's level.

Electric Strain Gages

The use of electric strain gages for measuring strains in buried pipe presents many difficulties. Considerable time was spent in devising methods of waterproofing the gages, which are extremely sensitive to moisture. For Installation *A*, the gages were waterproofed after being attached to the pipe, by using a plastic tape covering sealed with a self-vulcanizing synthetic rubber compound. The electrical leads were placed in a plastic hose. After the pipe was installed, gradual deterioration in the gages was indicated by the decrease in electrical resistance between the gage and pipe, showing that moisture had entered there. In Installations *B* and *C*, the gages on the pipe were covered by a thin copper sleeve which was packed with grease. This proved a very effective means of moisture-proofing. Compensating gages on nonstressed specimens of pipe, which are a necessary part of the instrumentation, were placed in separate water-tight containers and buried adjacent to the pipe. Bakelite-type electric strain gages were used in preference to paper-backed gages because of their superior long-period performance. For measuring longitudinal strains, the gages were placed all around the pipe, parallel to the longitudinal axis, at mid-length of a pipe section. A thermosetting cement was used to attach the gages to the pipe, which had been lightly ma-

chined to expose a clean metal surface. On Installation *A*, the gages were used on one length of pipe only. In Installations *B* and *C*, the gages were placed on two adjacent lengths of pipe. Initial strain readings were taken after the pipe was placed, but before back-filling. The readings were taken by connecting the necessary instruments to the terminal box, which was equipped with a double-contact rotary selective switch.

Thermocouples

Copper-constantan thermocouples, for measuring soil and water temperatures, were installed at various depths adjacent to the buried pipe. In the pipe in Installation *C*, they were placed in a temperature well. The electrical leads were taken to the terminal box and connected to a double-contact rotary selector switch. A potentiometer was used for taking the readings.

Soil Tests

Moisture content samples and bulk samples of soils underlying the pipe and of backfill were obtained. Plastic and liquid limit tests were performed, and they confirmed the high mechanical activity of the soils and their susceptibility to shrinking and swelling with moisture variations. These values were particularly high for the soils supporting the pipe at the bottom of the trench. Records were taken during the laying of the pipe and at frequent intervals thereafter.

An overall picture of a typical installation is shown in Fig. 2.

Test Results

The vertical movement gages proved extremely informative. Some typical ranges of movement are shown in Fig. 3. Test Installation *A* showed that the

pipe can move upward as much as 2 in. when "trench and tunnel" methods of excavation are used. The large upward movement here can be attributed to poor backfilling. This results in improper compaction, allowing surface waters to percolate into the trench and causing the supporting clays to swell. The backfill, because of its loose condition, does not effectively oppose the

the tightened joints. Such movement in corrosion-weakened pipe could well cause flexural or joint failure. The magnitude of the movement is particularly significant when it is realized that for the entire time that the test pipes were installed, generally wet climatic conditions prevailed. There were no dry soil conditions which would have permitted soil shrinking.

Fig. 3. Typical Vertical Movements in Test Installation Mains

Installation A, installed Dec. 19, 1953, was of 6-in. cast-iron pipe. Installation B, installed Aug. 24, 1954, and Installation C, installed Nov. 18, 1954, were of 4-in. cast-iron pipe. Dates of the tests for which data are shown were as follows: a—Mar. 31, 1954; b—Oct. 20, 1954; c—Mar. 12, 1955; d—Sep. 1, 1954; e—Oct. 20, 1954; f—Mar. 12, 1955; g—Jan. 2, 1955; h—Feb. 14, 1955; i—Apr. 30, 1955. Datum is the elevation of pipe on date of installation.

upward movement. Winnipeg uses this "trench and tunnel" method for laying pipe under paved streets or for winter work when excavation in frozen ground is extremely expensive.

More important, however, is the differential movement of the buried pipe exhibited by all three test installations. This amounted to as much as $\frac{3}{4}$ in. and sometimes caused $\frac{1}{2}$ deg. of rotation at

It was found that the electric strain gages could be successfully waterproofed. The readings showed that the pipe was subject to axial as well as flexural stresses, and that bending could take place both in a vertical and horizontal direction. Because considerable study is still required in successfully developing the electric strain gages for underground work, only

qualitative results can be given at this time. It is interesting to note that high strains developed in the pipe on backfilling and that these strains have remained high.

For Installation *A*, the thermocouple showed a maximum frost penetration of 8 ft during the winter of 1953-54. This unusually deep penetration was caused by the frozen condition of the backfill when it was placed in the trenches. During the winter of 1954-55, frost penetration reached a depth of 5 ft in mid-March. The coldest ground temperature reached, other than at the surface, was 20°F at a 1-ft depth. At 8 ft, the temperature varied between 35° and 45°F. For Installation *C*, it was found that, from the end of October to the beginning of March, the ground at pipe depth was approximately 1-3°F warmer than the pipe. The coldest water temperature reached was 34°F and the coldest ground temperature at this depth was 35°F. The test pipes have not been installed for a sufficient length of time to permit a comparison of summer ground and pipe temperatures. Based on readings made to date, however, it is possible that the water is at least 9°F warmer than the ground.

This report represents only a condensation of the results obtained.

Conclusions

It will be clear that this paper is essentially a report of progress made on a long-term, extensive research project, which is still under way. Detailed findings and conclusive results will be reported in due course in appropriate research papers. The results obtained to date, however, show that the investigation has implications that go far beyond the purely local problem. On the basis of what the project

has already revealed, both from a study of the cumulative experience of the water works branch of Winnipeg's Eng. Dept. and from the initial information gained in the test installations, the following conclusions can be made:

1. Water main breaks occurring in the Winnipeg system have constituted a problem throughout the years that is of such magnitude that it has necessitated detailed analysis and regular review.

2. The corrosive character of the local soils in the presence of moisture is undoubtedly a principal factor in the failure of cast-iron mains. But other considerations, such as the breaks occurring in steam-cured asbestos-cement pipe, which has high corrosion resistance, and the seasonal recurrence of a peak in the number of failures, indicate that the physical environment of the pipe is also partly responsible for the failures. Cumulative experience with Winnipeg soils indicates that the associated factor is differential soil movement.

3. Such differential soil movements can result when pipe trenches are excavated in clay soils which are susceptible to swelling or shrinking with changes in the moisture content, a difficulty which is inevitably traced back to the backfilling operation.

4. The initial readings show that, because of differential soil movements, the pipes move to such an extent after installation that appreciable bending stresses may be induced. These stresses are believed to be of such magnitude that they could cause the failure of corrosion-weakened pipe.

5. The previously observed interaction of soil and pipes confirms most emphatically the long recognized importance of properly backfilling pipe trenches and of laying pipe on well

prepared soil beds without the use of solid blocking.

6. Even when excellent workmen are involved, field observations confirm the difficulty of achieving good laying practice without almost continual inspection of every pipe-laying operation.

7. Although the Winnipeg soil conditions are unusual, they are by no means unique. The experience recorded in this paper, then, is probably applicable to many other areas.

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