IV.2.

PUBLIC UTILITIES PROBLEMS IN THE DISCONTINUOUS PERMAFROST AREAS[1]

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The townsites of Uranium City, Saskatchewan and Thompson, Manitoba are fully developed, modern towns which have grown up in the post-war period, due to mining operations. Both of these townsites are in the discontinuous permafrost zone. The developments have presented problems which differ substantially from those experienced in the continuous zone or areas only subject to seasonal frost penetration.

Uranium City, located on the north shore of Lake Athabasca was provided with water and sewerage utilities in 1957 and 1958. Sidewalks and streets are not fully developed to city standards but compare favourably with those in towns of comparable size in the prairie regions of North America. The Thompson, Manitoba development located north of Lake Winnipeg approximately 400 air miles north of Winnipeg and 300 air miles west of Churchill, began in 1959 and now has all the public utilities, such as water, sewerage, storm sewers, sidewalks, curbs and pavement comparable to other cities in Canada. Thompson is the site of the second largest nickel producing operation in the world and has been developed by the International Nickel Company of Canada Limited.

Climatic conditions in both of these areas are similar but more severe than those experienced on the Western Canadian prairies. The summers are short and warm whereas winters are long and cold. Approximately three to four weeks time lag is experienced in the spring and fall seasons.

This more extreme condition makes it necessary to change engineering designs to conform to these climatic differences and to carry out operational and maintenance procedures considerably different than in other regions.

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[1] See also - Klassen, H.P. "Solving Problems in the Discontinuous Permafrost Areas", Canadian Municipal Utilities, Vol. 103, No. 3, March 1965, p. 21-24.

Preliminary engineering investigations, must of necessity be much more thorough and extensive, to minimize expenditures for initial construction as well as operation and maintenance.

In this paper greater stress will be placed on the Thompson development because the soil conditions encountered presented more typical problems associated with permafrost. The geological features at Uranium City are such as to preclude most of the associated problems and limit the problem to one of protection against cold temperatures. In Thompson, on the other hand, the temperature problem is outweighed by structural complications and effects. For this reason the two locations will be considered separately.

URANIUM CITY

Surface Features

The local geology is typical of the Precambrian areas of Canada. The topography consists of glaciated bedrock, producing a rolling terrain with depressions or valleys between rock ridges. These contain gravels, sands, silt, rockflour and muskeg. The vegetation in these valleys consists of jackpine, aspen and white birch. The mature trees are 30 to 40 feet high and have butts measuring five to six inches.

Design and Construction

The water system is a one pipe recirculating system, i.e. each loop begins at the heating and recirculating station following one series of streets out and returning along one or more other streets. This allows for continuous controlled recirculation and heat addition at this station. The water pipe selected is spun-cast, cast iron pipe with mechanical joints. Where it was not economically possible to complete a loop, as in the case of the supply main, water is wasted at the end of the line. Since there is no shortage of raw water this practice can be effected.

In general, all pipe is buried to a minimum of 9 feet and is laid in common trench with the sewer mains. Wherever the sewer pipe is much deeper than 9 feet, the water pipe is placed on a ledge above the sewers. Heat losses at this depth are minimized and insulating valves were calculated from References 1 and 2.

The sewer system was designed to provide basement drainage over most of the townsite. No additional protection was provided against freezing. House service connections are all fully insulated. The water service pipe is normally 3/4 inch copper, wrapped with an electric wire for heat addition and then taped to a 4 inch sewer pipe. The whole service is then covered with 3 to 4 inches of insulation. In this case a product of vermiculite and asphalt was used. Further details are available in Reference 3. This type of hydrant was first used by Underwood, McLellan and Assocs. Ltd. at Flin Flon, Manitoba in 1949.

One of the more interesting features was the use of on-line hydrants. The use of this type of hydrant eliminates dead water in hydrant leads. Specially manufactured hydrants are placed directly into the distribution main which is offset to the side of the street.

In construction, conventional equipment was used exclusively. Due to the sandy nature of the soil, excavation in winter conditions did not present a particular problem. Cold temperatures did affect equipment operation and maintenance. Where pipes had to pass through outcrops or ledges of rock the trench was usually blasted out to its proper depth and back-filled with suitable materials.

In several locations, due to the topography, 9 foot bury was not obtainable. In such cases the water mains were insulated to make up for the lost cover of sand. Where pipes passed through roadways with insufficient cover, timber boxes were provided for protection.

Operation and Maintenance

The problems encountered in operation again are affected primarily by the extreme cold air temperatures in winter. The incidence of water main breaks has not been any greater than in comparable prairie towns. Steam thawing equipment is an essential item for the maintenance crew and special electric transformers are used to thaw house services. Here again, the incidence of frozen services is no greater than in any prairie town, since the householder has become familiar with the installation.

Street maintenance presents no unusual problems. The streets are all gravelled and drainage is provided by ditch and culvert. Some culverts freeze up in winter and have to be thawed out before spring break-up.

To summarize, the Uranium City utilities problems of design, construction and operation are related to cold air and ground temperatures rather than to associated factors such as are normally present in permafrost areas.

THOMPSON, MANITOBA

Topography

Thompson is situated in the Upper Nelson River plain, an area drained by the Burntwood River. The townsite is located in a bend of this river. The area is an undulating, ice-scoured lowland with localized clay deposits and rock outcrops. The bedrock is Precambrian granite and granite-gneiss found both in outcrop and below depths of 150 feet. The general elevation above sea level is 670 feet with the river at 600 feet.

Vegetation

The townsite area is well wooded with the majority of trees being spruce, but with jackpine, poplar and birch in the elevated areas. In such areas the trees measure up to 40 feet, decreasing in height toward low areas, where a predominance of short swamp spruce exist, with stands of tamarack. In low areas consisting of a broken network of ponds, trees are very small and non-existent in much of the area.

Higher areas produce healthy tree growth with 8 inch butts and 10 foot spacing while low areas or sloping ground to lower areas contain dense spruce growth of 4 inch butts and 4 foot spacing. The high areas have underbrush while low areas contain little since tree branches all but overlap, extending close to ground level.

Ground surface cover in elevated areas consists of feather moss 2 to 3 inch thick underlain by 3 inches of organic topsoil (peat). Downward along slopes the moss thickness increases to 6 inches, remaining fluffy, with 4 inches of peat. In low areas moss cover may be medium at the edges measuring 8 inches thick with a corresponding increase in thickness of peat. Towards the centre of low areas, heavy fibrous moss usually prevails, up to 2 feet thick beneath which is usually found a minimum of 18 inches of decomposed saturated peat. This area normally is very spongy to walk on with water present immediately beneath or on surface. Along the centres of the five main relief courses throughout the townsite, swampy conditions exist with elongated water ponds. There is no moss cover but rather sedge,grass and 2 to 3 feet of wet peat loosely held by plant fibre of moss and grass.

Soil

Beneath the organic layer in elevated areas, light brown clay of medium consolidation is found 2 to 3 feet in depth. Below this depth varves become evident in the clay to bedrock which lies approximately 125 feet below the surface. This varved clay has good bearing values to 14 and 16 feet; however it reduces in stability with increasing depth and moisture content. Off the higher ground in lower areas the soil to 6 or 7 feet is dark brown clay, granular and loose in appearance. Below this depth varves again become prominent in a light brown clay material to 12 feet with grey blue clay at greater depth. Soil bearing values of these soils decrease with depth beneath the 7 to 12 foot range with moisture contents increasing. In the swampy areas, beneath the saturated peat, little brown clay is visible. The soil is very dark, soft and contains varving from the 10 foot depth. Moisture contents are high and soil bearing is poor.

Rock outcrops are visible on the east side of the townsite on an elevated ridge and on the west side of the town near the river's edge. Another elevated bedrock point exists around the central area of the townsite where clay overburden is 28 feet thick. Only a few rocks of notable size have been encountered in the clays of the area all being less than 2 cubic yards in volume.

Permafrost

Thompson is located in the southern fringe of the discontinuous permafrost zone. Permafrost occurs along the transition point from low areas to rising ground and throughout the lower levels in no set pattern following the general water courses. It is found usually under elevated mounds or islands along these drainage courses. Heavily wooded areas along slopes usually have permafrost when accompanied by moss cover exceeding 6 inches in thickness. High ground with large tree growth is mostly free of permafrost; however three occurrences of permafrost in fairly large patches have been located in well elevated areas. Along the edges of the water courses in gullies permafrost is a certainty extending back into the slope. Permafrost does not exist immediately beneath water courses or areas where water has ponded to any depth; however, it is usually found at the edge of such water sources.

In the unusual cases where permafrost was encountered in the highest elevations of the area, horizontal ice lenses were evident from the 9 to 13 foot depth varying in thickness from 1/8 inch to 1 1/2 inches. These lenses were in light brown varved clay and the lens spacing was 6 to 8 inches. Most ice lensing is horizontal extending in rarely broken lines across the permafrost mass. Some vertical ice lenses do exist but they are rare and are less than 1/2 inch in thickness. At these locations some shearing of the main horizontal lenses may be observed.

Along higher slopes where tree growth is dense and the moss cover is thick, permafrost exists usually at a depth of 9 to 15 feet in the brown varved clay. Lens thickness increases from 1/8 to 2 inches with depth and spacing of lenses approaches 8 inches. The frozen zone usually wedges out away from the forest area. In relatively low areas where tree growth becomes stunted and moss cover thicker, permafrost begins near the 7 foot depth and extends to approximately 18 feet. Here lenses are thin in the brown clay and increase considerably in the grey clays to a maximum of 3 inches. Lenses are thin at the permafrost table and sometimes appear only as particles or crystals of ice. Here the permafrost also wedges out at its edges. Permafrost encountered under thick fibrous moss cover, with sparsely scattered small spruce and tamarack, is usually very thick. Here frozen ground may be encountered within 2 feet of the surface with ice lensing extending to an average maximum depth of 38 feet. Thin lenses begin at about the 7 foot depth and continue to increase in size to a maximum measured thickness of 9 inches spaced at intervals approaching 12 inches. The boundaries of these thick permafrost bodies are usually almost vertical but slope slightly inward with depth. Soil immediately adjacent to these areas is usually supersaturated.

The permafrost is in a delicate thermal state, its temperature being close to 32°F. In fact, a rise in temperature of 1°F will produce thaw settlement equal to the total thickness of the ice lenses. A temperature of 31.5°F has been recorded in the permafrost immediately below the depth of the influence of seasonal variations. Seasonal frost decreases the temperature of the permafrost down to the depth of its penetration. This depth is usually less than normal seasonal frost penetration because of the presence of the perennially frozen ground.

Design Considerations

Preliminary investigations were centered around the use of heated recirculation in pipe loops for the water distribution system. There are two major loops from the water treatment plant and several minor loops. The design required one supplementary heating and recirculating station which was constructed as a part of the building in which the municipal offices, fire hall and police station are located.

In studying the soil characteristics, it was found that the clays at Thompson offered a relatively high insulation value and that heat losses from deep buried pipes would be small. It was decided,therefore, to provide for the main heating at the water treatment plant and additional heating at the heating and recirculating station. It was also found feasible to distribute the water in uninsulated pipes. Investigations indicated that the sanitary sewer mains could likewise be uninsulated, relying on the overlying soil and the warm sewage to prevent freezing. In practice it has been found that the requirement for heating has decreased year by year and it is expected that maintaining recirculation in the water distribution systems, without the addition of heat, will be sufficient to avoid freezing in the future.

Storm sewers were provided according to conventional design, making no allowance for heating or avoiding frost or permafrost. The use of mobile steaming facilities to thaw out frozen mains, catch basins, leads, etc., has been necessary, since infiltration water has frozen and blocked mains where they passed through thick permafrost. These difficulties have not been insurmountable and are decreasing.

The building services for water are of copper tubing, insulated with preformed styrofoam and laid with the sanitary and storm sewers in the same trench. The sewers are not insulated. Minimum burial was specified at 9 feet. In addition, the water service pipes have been coiled with a copper heating cable. This cable, when connected to a special household transformer, enables thawing out of frozen pipes or if desired, heat can be maintained when a dwelling is vacant and thereby avoid any freezing. Sewers, in the smaller sizes, are of vitrified clay tile pipe with a "slip-seal" joint. Neither the mains nor the services are insulated. The systems are constructed to serve basements of all dwellings.

Because of the nature of the perennially frozen soils, it was anticipated that melting of ice lenses would result in settlements equal to the thickness of these lenses. To minimize settlement of the water and sewer mains through the permafrost areas, it was decided to undercut the trenches and backfill them both below and above the pipes with granular material. It was considered to be more economical to take reasonable precautions to avoid failure, but to allow for some inevitable maintenance. Operations have substantiated the feasibility of this procedure.

In the design of roads substantially conventional standards were followed. The roads consist of normal granular base and sub-base related to the loads to be transported. Pavement consists of normal asphaltic concrete. The cross-sections vary in width with intended usage and are of the curb and gutter design. Sidewalks were designed for concrete construction underlain by a granular base.

Construction

The necessity for sound engineering and good construction practice cannot be over emphasized when development is carried out in a permafrost area. The reliability of the contractor is of utmost importance and engineering supervision must be extensive and practical.

The first step in construction at Thompson was the clearing, grubbing and stripping of moss in the areas to be developed. This work was necessary to enable movement of equipment because the area is generally heavily forested.

The removal of vegetation naturally enhanced thawing in these areas. It is evident that permafrost has receded in these areas whereas permafrost still exists in adjacent forested areas. It now is indicated that dissipation of the permafrost will occur in a period of 5 to 10 years. The lower time estimate would apply to those areas where frost penetration measures a maximum depth of 16 feet and where ice lensing is limited such as on high well drained ground. The lower areas with high ice content will take up to 10 years or perhaps longer. Continuous observations are being made and records of the retrogression will eventually be available.

Trenches for the installation of water and sewer pipes need special attention. The field engineers must determine the suitability of the trench material while work is in progress. Basically all permafrost must be excavated when encountered below the pipe inverts. This will be uneconomical in some areas where frost penetration is excessive. The practice followed at Thompson was to remove the frozen ground, that is, undercut below the invert of the pipe as much as 6 feet on water mains and backfill to ground level with granular materials. The remaining permafrost was left and inevitably further maintenance will be required as the permafrost dissipates and subsidence occurs. Care must be taken not to leave soil with high ice content under trench line construction. Only the experience of operators and inspectors can assure that such omissions are minimized. In many instances retracing and excavation of unsuitable material was necessary. A minimum soil cover of 10 feet on the pipe was found most suitable because this provided an increased protection from seasonal frost. This depth of trenching also reduced the possibility of passing over an area of permafrost which was not evident at its usual depth of about 8 feet.

Construction was carried out in all types of weather. The winter had some advantage in the control of surface water, but on the other hand involved unusually high stresses on the excavation equipment. The trenching machines were heavy duty nominal 1 cubic yard and 1 1/2 cubic yard backhoes equipped with special narrow buckets. Frozen material was handled quite readily. Summer construction was extremely difficult in those areas which were poorly drained. Although minimum width trenches were in order, wet soil conditions and wide trenches with multiple pipe installations, resulted in unexpectedly high trench loading on the pipes. Some very good construction progress was registered in the late fall and late winter periods.

In road construction particular attention was paid to the removal of all organic material, which varied greatly in depth. Sub-cutting was considered unnecessary since topping up after subsidence was used extensively. Road building aggregate was readily available so that both rock and sand mats were utilized to overcome poor subgrade zones. Paving was normally delayed for at least one year, and circumstances permitting, two years to allow for further melting of ice lenses and subsequent subsidence.

Operation and Maintenance

Heating of the water distribution system is required from January to the middle of May at Thompson. Recirculation is normally started several weeks earlier and continued for some weeks after the heat is turned off to ensure that all danger of freezing has passed.

In areas where permafrost was not completely removed subsidence causes the pipes to settle and sometimes break. It is the policy to allow the pipes to settle until they break or until subsidence is complete. After settlement ceases the pipelines are repaired and regraded. Water mains may be raised above grade appreciably, in these areas, to allow for some additional settling. Main breaks are common at the boundaries between permafrost and non-permafrost areas. The use of ductile materials, such as steel, aluminum or ductile iron would probably have reduced the number of such breaks. Due to line settlement, drainouts placed for emptying water mains are not completely effective. It is considered necessary to have all lines blown out with air pressure in the case of a required shutdown.

It has been found that soil consolidation is greater in the low lying areas. In these areas trench excavation across road grades should not be backfilled with granular material because after drainage is effected and soil subsidence results, these trench lines form humps across the roadway. The settlement of the ground surface has left curbstops, manholes, catch basins and valve boxes, etc., above the grades of paved areas, lawns and boulevards. In elevated areas, trenches must be backfilled with granular material at all roadway crossings because consolidation is complete.

The maintenance of roads involves raising and reconstruction of subsided curbs, sidewalks and paved surfaces. The raising of curbs without damage to curb sections is most difficult. Various methods of curb capping and pressure grouting have been tried to date without much success. The filling of low areas in the pavement surfaces with fresh asphaltic concrete may prove to be the solution to this problem.

In review, the main problem on roads is caused by differential settlement brought on by consolidation of the upper layer of brown clay. This constitutes approximately 5 per cent of the roadway surfaces. These areas will require fill-in of granular material of asphaltic concrete, depending on the stage of construction of any roadway. Very little trouble has been experienced with frost heaving on any of the road beds. Shrinkage cracking of asphalt surfaces in the winter is quite commonplace; however, most of these cracks close by expansion by the middle of summer.

SUMMARY

The decision to remove vegetation and organic soil would seem to be contrary to accepted procedure for permafrost areas. It must be realized however, that this site is in the southern fringe of the discontinuous permafrost zone and that only 5 to 10 per cent of the area is affected. It is only in this relatively small area that extra maintenance costs will be incurred. It would be impractical to change methods of construction in such a case, especially when speed is a prime factor in servicing a development of city proportions and when retrogression of the permafrost is inevitable regardless of precautionary measures.

The assumption regarding dissipation of the permafrost has been substantiated in the few years since construction began. The differential settlements caused by this phenomena have reached a maximum of almost 4 feet. Some problems being experienced with asphalt road surfaces, curbs and walks could have been decreased greatly if this phase of construction had been delayed five years. Under the circumstances, however, the owners decided that the advantages of immediate paving and servicing of much of the area outweighed the disadvantages.

The need for preliminary engineering, site investigations and study is held in high regard by those familiar with the problems and recommended strongly to those who will be faced with development in our northern regions in the years ahead.

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Discussion

In reply to an enquiry by J.R. Rettie on the extent of water re-circulation at Thompson, the author replied that it is continuous within the distribution system. A supply line was installed by the International Nickel Company before the town was built. The line consisted of one major and numerous minor loops with no dead lines. Twelve million gallons of water were in continuous circulation and there was no possibility of freezing because of a heating plant at the intake and another in the town. The entire network was analyzed by a computer.

J.R. Rettie also asked whether precast concrete slabs had been considered for sidewalk construction. Klassen replied that this was a possibility but perhaps the poured concrete sidewalks were less expensive. Precast curbs were used in a few sections but they proved uneconomical. G.H. Johnston remarked that sidewalks were jacked up in some areas where settlement had occurred. Settlements take place so slowly that sidewalks can be jacked very gradually.

G.H. Johnston commented on the distribution of permafrost at Thompson. It occurs in small islands varying from about 15 feet to 700 feet diameter. The average depth of the permafrost table is about 7 feet and the average thickness of permafrost islands is about 8 feet. In a few areas, permafrost extends to a depth of nearly 40 feet and it was encountered to a depth of 50 feet in one borehole. The author noted that the town was built on the only area available at the time. New subdivisions have been located in areas where existing permafrost islands can be avoided. Areas underlain by permafrost are stripped and built on after the permafrost has thawed.

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