PEAT - The Vancouver Experience

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ABSTRACT

This paper describes some of the City of Vancouver Engineering Department's experience dealing with infrastructure construction in peat deposits. General observations regarding watermain and sewermain installation, and performance of "standard" pavement structures are presented. These are followed by a more detailed discussion of four case histories where various techniques have been used for road construction on peat deposits.

INTRODUCTION

There are 18 identified areas of substantial peat deposits within the City of Vancouver boundaries. Figure 1 shows the location and approximate extent of these peat deposits. The settlements associated with these extremely sensitive and compressible deposits create significant problems for municipal infrastructure. These include:

- rupturing of pressurized watermains due to differential settlement at the pipe joints;
- sewermains may also rupture. However, the more significant problem is the compromised drainage of gravity sewers by localized settlement;
- drainage and ride quality of pavement surfaces are detrimentally affected; and
- trip hazards for pedestrians are created by differential settlement of sidewalks.

This paper reviews some of the City of Vancouver Engineering Department's experience with the impact of peat deposits on municipal infrastructure. Case histories illustrating the success of special construction techniques for streets are presented.

GENERAL OBSERVATIONS OF INFRASTRUCTURE CONSTRUCTED ON PEAT

UTILITY INSTALLATION

Underground utilities such as street lighting, gas, telephone, and hydro are generally quite tolerant of differential settlement. They are also usually installed less than one metre below grade, so the impact of the utility on the peat is not as significant as utilities installed much deeper.

Deeper utilities such as watermains, and particularly sewermains, are very intolerant of differential settlement. In dealing with sewermain installation in peat areas, the historical approach has been to support the utility on piles driven through the peat to an underlying stable material. Although expensive, this method is effective in minimizing the effect of differential settlement on the utility. Although the stronger pipe used for watermains makes them more tolerant of differential settlement than sewer lines, pile supported watermains are also being considered as a future solution to a history of more frequent watermain breaks in peat areas.

Although successful in supporting the utility lines, piles create problems with street and sidewalk construction. With time, the surface on either side of the pile supported utility trench settles considerably with negligible settlement of the utility trench itself (see Figure 2). The rigid pile supported utility will experience negligible settlement relative to a deep layer of peat, while the peat on both sides of the utility trench will consolidate as the pore water drains into the granular material used for backfill in the utility trench. In the case of a gravity sewer, the trench is constructed at the same grade as the sewermain and provides an effective drainage path which may drain the water out of the peat area entirely. Also as the depth of the utility trench increases, the depth of peat which is dewatered and consolidated also increases. A common manifestation of these settlements is high-centred streets with an associated rough ride.

PRIVATE PROPERTY

Construction on private property results in similar observations. New houses have efficient new perimeter drains which dewater the surrounding peat, resulting in a "wave" of settlement that radiates outward from the new house as the peat consolidates. This consolidation is also compounded by the weight of the new house, which is usually much larger and heavier than the previous structure.

TREES

Figure 3 shows similar observations with trees. As trees grow their root systems draw porewater out of a larger area of the peat, and the weight of the tree increases. These factors cause significant settlement around the tree which in turn causes differential settlement below the curb and gutter, sidewalk, and pavement. Figure 3 shows some examples on 19th and 20th Avenues near Fraser Street. The result on narrow residential streets is poor drainage of surface water, as well as uneven surfaces for pedestrians and vehicles.

FLEXIBLE PAVEMENTS

There are many examples of residential streets constructed over substantial peat layers with a standard flexible pavement structure consisting of between 200mm and 300mm of granular base and 50mm of asphalt. The long term performance is very poor with unacceptable settlement, very poor drainage, and high maintenance (Figure 3). It is, however, a relatively inexpensive pavement structure and is often a suitable short term solution for areas with on-going re-development. In comparison with the capital costs of other options, the flexible pavement is often a cost effective solution, recognizing that this pavement will have a shorter design life than flexible pavements constructed over competent soils.

RIGID PAVEMENTS

During the 1960's and early 1970's, several blocks of street were constructed over peat using a rigid pavement structure. This consisted of a granular base and a Portland cement concrete slab. Unfortunately, there is little information available regarding the specifications used to construct these pavements.

While they are much more expensive than flexible pavements, rigid pavements perform better and last longer before problems develop. Problems arise as the slabs start to settle differentially resulting in discontinuities in the surface, or the slab may "rock" back and forth under vehicle loading, leading to poor ride characteristics and the eventual breakdown of the pavement.

Utility cuts severely compromise the integrity of a rigid pavement because the utility cuts are usually repaired with asphalt patches.

UTILITY CUTS

Compounding the problems of installing public infrastructure in areas with peat deposits is the on-going renewal and upgrading of services required by adjacent private development. New buildings usually require service connections in trenches which cut through existing pavement, curb and gutter, and sidewalk. This makes it difficult to maintain the long-term integrity of special construction techniques that could be used to deal with the settlement of the peat deposit such as the use of rigid pavements or geosynthetic reinforcement.

ROAD CONSTRUCTION CASE HISTORIES

With the poor performance of flexible pavements and the expense and eventual deterioration of rigid pavements founded on peat, other construction methods have recently been tried by the City of Vancouver to mitigate the effects of settlement on curb and gutter, sidewalk, and pavements in peat areas. The following four case histories each describe a different method used and the performance results to date.

EXCAVATION AND REMOVAL (41st Avenue Reconstruction - Maple to East Boulevard)

Existing Conditions

In the summer of 1988, the City of Vancouver Engineering Department reconstructed and widened one block of 41st Avenue between Maple Street and East Boulevard. Figure 4 shows the location of this project. This project was initiated because of the large amount of maintenance required to keep the street in this block up to an acceptable standard. Due to a layer of peat underneath the pavement structure, ongoing settlement of the pavement surface, curbs, and sidewalks used up more maintenance funding than any other section of street in the city. Complaints from both vehicle drivers and adjacent property owners, who witnessed erratic driving due to the uneven pavement, were continually received by the Engineering Department.

The Engineering Department determined that a permanent solution to the ongoing settlement problem was required and a geotechnical consulting firm was hired to drill test holes and provide a breakdown of the soil stratigraphy for this block. The test holes indicated that the peat extended down to a depth of 2.5 metres at the west end of the block and to 2.0 metres at the east end. Below the peat were layers of clayey silt, sand, and then glacial till.

After considering various options for solving the settlement problem caused by the peat (preloading, removal of the peat, stabilization of the peat by injection of grout, etc.), plans were made to completely remove the peat along this one block of busy arterial street.

Construction

Because 41st Avenue is a main arterial for traffic to the University of British Columbia and this block is busy with commercial/retail activity, the construction period had to be kept to a minimum and completed before the start of university in September. The project also involved agencies outside the city (BC Tel, BC Transit,etc.) along with many of the branches within the city such as Electrical, Sewers, Waterworks, and Streets. As a result, this job was scheduled using the critical path method with updates every week so that all the various branches, material suppliers, utility companies, and BC Transit were able to schedule their crews well in advance and perform immediately when required. In addition, at regular meetings with the local merchants and the Kerrisdale Commercial Association, the local businesses were kept informed of the construction schedule and their input was obtained on upcoming work. By being able to forewarn them of the various aspects of the job, the anxieties and frustrations of the local merchants were reduced and as a consequence, very few complaints were received.

Construction started in the middle of July 1988, with the replacement of the old watermain on the north side of the block which had been previously scheduled as part of the city wide life-cycle replacement program. After doing a cost analysis, the decision was made to install a second smaller main to service the properties on the south side of the block so that no services crossed the peat excavation site. By removing the only services in the peat area, a far more efficient method of backfilling and compacting of the granular material became feasible. The next step involved the removal of the street lights and traffic signals from the transit poles by the Electrical Branch, after which BC Transit removed their overhead trolley wires and poles and changed over to diesel buses for the duration of the project. Once this preliminary work had been completed, Streets Operations crews started the excavation of the underlying peat from the street. One third of the street width was removed in each pass so that one traffic lane in each direction was kept open at all times. Street parking was removed, but additional parking was made available by changing the parking regulations in an adjacent public parking lot for the local arena. Further efforts were made to alleviate the parking situation by way of signing the immediate area to direct shoppers to the alternate parking locations. Where possible, replacement work for the sidewalks was scheduled on Sundays to reduce conflicts with pedestrians and disruption to the adjoining businesses.

The excavation and the gravel replacement was generally a textbook example of this type of roadwork. As quickly as the peat was being excavated and trucked away, a bulldozer was spreading the replacement gravel in one foot lifts with vibratory rollers following behind to ensure that the fill was properly compacted. During a three and one half week period, 18,000 tonnes of pit run gravel was delivered and placed on this block of West 41st. However, several problems surfaced. These included the removal of the old trolley track and concrete base which ran down the middle of the road and excavating buried logs and stumps which had to be hauled out and trucked away. At times, the excavation looked more like a logging operation than a street reconstruction project.

Probably the most interesting problem was encountered when the peat was excavated out from alongside an old creosote wood BC Tel cable duct bank which had been installed when the telephone exchange at Maple and 41st was built back in the 1940's. It was determined that the duct bank had deteriorated so badly that it could not withstand the pressure of gravel being compacted alongside. Moving the existing

BC Tel cables to a new duct bank would have taken over a year. As a consequence, a lightweight cement grout fill was used to fill in a trench, approximately 2 metres wide and 2.5 metres deep, which ran parallel to the duct bank for the length of the block.

Summary of Long Term Performance

Although the project was very expensive and caused hardship to some of the businesses during the reconstruction period, the problems associated with on-going settlements of the peat deposit have been completely eliminated.

PRELOAD (CONSTRUCTION IN THE CHARLES/ADANAC SUBDIVISION)

Existing Conditions

This case study involved the construction of concrete curb and gutter, sidewalk and asphalt concrete pavement in the area bounded by Skeena, Boundary, Napier and Charles Streets on the very east edge of Vancouver. Figure 5 shows the location of this project. The City of Vancouver was the property owner of thirty-nine undeveloped single family lots within this area and a townhouse site at the southeast corner of William and Kootenay Streets. As such, the City wished to develop and market the properties in this area, in particular to make available local properties for those residents who were relocated due to the Cassiar Connector Project.

Throughout the 1980's, the City's Housing and Properties Department had investigated the marketing potential of this area and these investigations included geotechnical reports from an engineering consulting firm that culminated in detailed documentation of the underlying stratigraphy and specific recommendations for construction methods for the private sites and public streets.

The sections of streets that were unimproved and required street construction included:

- Kootenay Street - from the lane south of William Street to the lane north of Napier Street;
- William Street - from one half block west of Kootenay Street to Boundary Road; and
- Napier Street - from Skeena Street to Kootenay Street.

The peat layer underlying this area varied considerably in depth. On Kootenay Street, the peat layer was absent at the intersection of Napier Street, progressed to a maximum depth of 2.1 m at the intersection of William Street, and thinned to 1.2 m at the lane south of William Street. On William Street there was a definite peat basin. The thickness of the peat layer was 2.1 m at the intersection of Kootenay Street, and was absent at mid-block in both the east and west direction. There was essentially no peat encountered on Napier Street, and the soil stratigraphy at this location consisted of silt and silty sand fill with some topsoil and organics overlying sand or clayey silt. In conclusion, what had to be dealt with was a substantial localized peat layer with definite boundaries, centred at the intersection of William and Kootenay Streets.

Existing utilities on William and Kootenay Streets included both sanitary and storm sewers and watermains. Through the deep peat areas, the sewers were pile supported.

Design Options

The recommendation from the geotechnical consultant for this location was to preload the peat layer on Kootenay and William Streets over the area shown in Figure 5. Street design grades could then be raised approximately 400mm above the existing ground level. The proposed preload construction method consisted of removing the existing surface organic materials, placing 1.1 m of clean granular fill and installing settlement gauges. It was estimated that after 4 months, sufficient settlement would have occurred to permit removal of the preload. The settlement was expected to range from 150mm to 300mm. This method permitted a portion of the granular preload to remain as fill and future road settlements were estimated to be 25mm to 50mm.

The preload option was viable from the point of view of street access for residents because the residential lots adjacent the preload areas were all undeveloped and owned by the City of Vancouver. Residents to the west of this area could be notified and asked to use Skeena Street to Napier Street for access to either Boundary Road or Cassiar Street.

The major concern was the effect that the recommended street preloading would have on the existing sewers and watermain. For the sanitary and storm sewers, it was estimated that construction of the streets in accordance with the recommendations could result in settlements of up to 100mm. For piled sections, the preload would introduce an additional load on the pipes and concrete platforms, these loadings being identified for the various depths of sewers. An internal review confirmed that both the estimated settlements and additional loading should not sustain damage to the sewers. However, the sewers in this area were constructed in the 1960's and damage from construction equipment or preloading during the project was a possibility. Monitoring of the sewers was initiated to evaluate the condition of the sewers throughout the project.

The settlement of the watermain along William Street was a more significant concern. It was identified that a differential settlement of 210mm would occur at the boundaries of the peat layer. The horizontal distance over which this differential settlement would occur was relatively short and therefore the potential for rupture of the watermain was substantial. An internal review identified some solutions to the problem. Earthquake couplers, capable of absorbing 450mm of differential settlement, were to be installed at the boundary transitions. It was identified that all excavation of in-situ soils prior to preloading had to be undertaken with extreme caution to prevent damage to watermains and services that were located a depths of 450mm to 1200mm. As well, the watermain was to be throttled during construction of the preload and streets construction to minimize damage from potential pipe failure.

Construction

Construction began on this project on May 28th, 1990, with the installation of the earthquake coupler on the watermain by City of Vancouver crews at the west peat boundary on William Street. The second earthquake coupler was installed on June 1, 1990 at the east end of the peat boundary. Once excavated, the peat boundaries were very visually apparent and facilitated the placement of the watermain couplers.

The preload over the peat layer was placed during the period from June 20th to June 27th, 1990 by City of Vancouver crews in accordance with the recommendations from the geotechnical consultant. The preloaded area was closed to all traffic with concrete traffic barricades during the settlement period.

The settlement gauge readings were taken by the City of Vancouver from June 29th, 1990 to September 7, 1990. The settlement gauge readings showed movements that had stabilized at 50 to 75mm. These settlements were less than the minimum 150mm settlements predicted by the geotechnical consultant. In reviewing the settlement data, the consultant estimated that 75mm of settlement may have occurred during the week of construction prior to the initial settlement gauge reading. It was considered that total settlements of up to 150mm occurred in the peat layer due to the preload placement.

The preload was removed between October 15th and October 23rd, 1990, after being in place for approximately 4 months. The geotechnical consultant estimated that, due to the actual settlement achieved, future street settlement over the next twenty years would be approximately 35mm.

Concrete curb and gutter, sidewalks and asphaltic concrete pavement were constructed throughout the subdivision after removal of the preload. There was no damage to any existing services during the placement of the preload, the settlement period, or the subsequent preload removal and construction of the street infrastructure.

Summary of Long Term Performance

The performance of the pavement, curbs, and sidewalks constructed on the preloaded subgrade has been excellent. There are no signs of deterioration caused by settlement to the present date.

FUJIBETON GROUT (16TH AVENUE TEST SECTION)

Fujibeton is a product on the market which consists of lignin cellulose and small quantities of other chemicals. This material in combination with Portland cement and flyash is being marketed as a soil improvement agent.

A test section on 16th Avenue, from the west side of Prince Edward Street extending one third of a block towards Sophia Street, was selected to evaluate the use of Fujibeton grout to stabilize thick peat deposits. Figure 6 shows the location of the test section and the soil profile of the area. Differential settlement in this area had resulted in damage to the street infrastructure.

Fujibeton

Fujibeton is a chemical admixture which is added to pozollanic materials to form a grout or cement. The materials used in the grout for this project included:

- i) Portland cement - normal Type 10 Portland cement
- ii) Flyash - standard grade supplied by Ocean Construction Supplies Ltd.
- iii) Lomar D Plasticizer - a water reducing cementious additive
- iv) Fujibeton - a patented lignin cellulose
- v) Water

The actual proportions of dry materials blended by Ocean Construction Supplies Ltd. for this project were: flyash, 78.7%; Portland Cement, 21.1%; and Fujibeton mix, 0.2%.

At the time this test evaluation was being conducted, late in 1989, Fujibeton was being marketed as a soil improvement agent in the suppliers promotional literature. There had been one independent research study published which examined the soil stabilization properties of a Fujibeton cement (Ref.1). It was found that the laboratory results for the Fujibeton cement compared with typical results expected for cement treated soils provided by the Portland Cement Association (Ref.2) for the silty and sandy soils examined.

The objective of the 16th Avenue test project was to stabilize the peat layer. Fujibeton grout of this type had been used in Surrey, B.C. by a developer to stabilize a peat area and this application had been offered as an example. Unfortunately, the Surrey project proceeded in a manner whereby independent evaluation and documentation without vested interest was not available. The City of Vancouver decided to investigate this product in a small, controlled test to evaluate its potential for use in peat areas.

Test Section

The test section was located on 16th Avenue starting at the west side of Prince Edward Street and extending for approximately one third of a block west towards Sophia Street. Figure 6 shows the plan and soil profile of the test section. The full 11 m width of the street was grouted. This location was selected for the soil stabilization process because the underlying stratigraphy contains a substantial layer of peat. A more detailed description of 16th Avenue is contained in the subsequent description of the reconstruction of this street.

Conventional methods of minimizing future differential settlement of a location such as this would include preloading the site or excavating the peat layer prior to reconstruction. As the area surrounding 16th Avenue is a mature residential district, soil stabilization using Fujibeton grout or a similar product was considered a less disruptive option to pursue.

A number of quantitative measurements were taken on the 16th Avenue test section prior and subsequent to injecting the Fujibeton grout to evaluate the effectiveness of this process:

1) Survey Grid - Initial survey level measurements and subsequent measurements were taken on the test section and a control section to insure that heaving of the street surface due to injection would not exceed 75mm.

2) Strength Improvement - Benkelman Beam and Dynaflect testing was done to evaluate the strength improvement achieved by Fujibeton grout injection.

3) Sewer Video Inspection - The sewer main from Sophia Street to St. George Street was inspected and recorded by video camera. The sewer inspection was done to insure that no damage to the sewer was done as a result of the drilling on the street or that the Fujibeton grout did not ingress into the sewer line.

Construction

The Fujibeton grout was prepared on site and placed in a holding tank with a continuous agitator to prevent segregation of the grout. The injection operation consisted of the insertion of a wand into the peat soil mass through pre-drilled boreholes in November, 1989. The maximum depth of the injected grout on this project was 3.2 m below the asphalt surface. The Fujibeton grout was pumped into the peat layer under grouting pressures ranging from 40 to 80 psi with 1.5 cu.ft. of grout placed in each borehole. Half the grout was injected at the bottom of the borehole and the remaining grout was injected evenly along the borehole to the underside of the granular base during the withdrawal of the injection wand.

The pattern of injection that was specified by the supplier and their consulting engineer included borehole spacings in a 1 m grid, staggered within the test section. Injection was to begin at the west of the site and proceed east. As well, injection would start at the borders of the test section and proceed to the centreline of 16th Avenue.

The 1 m spacing for the grout injection was specified to mobilize the required strength characteristics. The additional specifications for the pattern of injection were related to the grade on this site. The street grade on this portion of 16th Avenue falls from west to east. The specifications were to insure that as the grouting proceeded, the water displaced by the grout would be "pushed" down the street. Due to site difficulties, the actual grout injection did not proceed as specified and most of the Fujibeton grout injection on 16th Avenue "pushed" displaced water against the street grade.

Results

In March, 1990, a 2.0 m trench was cut into the test section on the south side near the intersection of 16th Avenue and Prince Edward Street to view the Fujibeton grout. The underlying peat had moisture contents in keeping with the material (534%) but was very compressed. A modified permeameter test on the peat indicated a permeability similar to clay (4.96 x 10 -5 cm/sec). This could be expected in a peat layer that has been loaded with a pavement structure for many years.

It was considered that the compressed nature and low permeability prevented the Fujibeton grout from permeating the peat layer. The grout was concentrated in small "piles" at the borehole locations, while some grout penetrated the more permeable granular base of the pavement structure.

The survey level run on the test section and control section showed that heaving due to the Fujibeton grout injection was minimal. This concurs with the fact that the

Fujibeton grout did not significantly penetrate the peat.

The Benkelman Beam and Dynaflect testing showed that some seasonal and individual variation in results occurred in both the test section and the control section. There was no significant increase in pavement strength in the test section.

The subsequent video inspection of the sewer main after the injection of the Fujibeton grout showed that there were no problems with the sewer main that could be attributed to the drilling and grouting.

Conclusions

The intent of the Fujibeton grout test section was to stabilize the underlying peat layer on 16th Avenue prior to reconstruction to eliminate the existing problem with differential settlement.

The main reason for the poor results on this test section can be attributed primarily to the impervious nature of the peat. The Fujibeton grout did not permeate the peat layer as expected but remained in "piles" in the boreholes. These piles did not stabilize the peat layer and therefore did not significantly alter the strength of the pavement.

The Fujibeton grout did not stabilize the peat layer on 16th Avenue. Therefore, other more conventional methods of minimizing the future differential settlements on this street had to be evaluated with respect to cost effectiveness.

GEOSYNTHETICS (16TH AVENUE RECONSTRUCTION)

Existing Conditions

This case study documents the reconstruction of the concrete curb and gutter, sidewalk and asphalt concrete pavement on 16th Avenue from Watson Street to St. George Street. The project limits are shown on Figure 6.

The underlying stratigraphy at this location contains a significant layer of peat. Borehole logs showed that the peat layer was absent at Sophia Street and increased to a maximum depth of 4.5 m at Prince Edward Street. Figure 6 shows the profile of 16th Avenue from Sophia Street to St. George Street.

The existing street surface on this section of 16th Avenue was badly deteriorated as a result of differential settlement of the peat layer. The differential settlement had also resulted in numerous separations of the existing sewer main and sewer connections on this street.

The sewer main running under the middle of this street was originally installed in 1908 on piles to bridge over the peat layer. The design records, although incomplete, indicated that the sewer support system consisted of timber piles with a reinforced concrete cap. The street had settled on either side of the piled sewer main, producing a very rough ride and a high-centred pavement.

Due to the need to replace the sanitary and storm sewers, watermains and to also repair the street surface, a decision was made to investigate a comprehensive infrastructure reconstruction program that would mitigate the negative effects of the peat layer in the future.

Design Options

An analysis of a number of design options was carried out, the results being summarized in Table 1. It was finally decided that the sanitary and storm sewers, watermains and street would be reconstructed without peat excavation or other special measures, as outlined in Option 6. This option was chosen recognizing that long term infrastructure maintenance would be higher and the design life reduced. However, the benefits included less interruption of service to adjacent properties and lower capital costs.

Construction of Selected Option

City of Vancouver Operations crews were responsible for the reconstruction of the sanitary and storm sewers and watermains through this area. The sewer installation involved the removal of the original timber piles and concrete pile cap as construction proceeded down the street along the original alignment. The sewers were installed in a 2400mm deep utility trench bedded on 900mm of crushed granular fill and sand. The trench was backfilled with granular fill. It was anticipated that differential settlement would inevitably occur and to mitigate some of the future maintenance all sewer joints were restrained. It was also recognized that this method introduced a discontinuity in the peat layer across the width of the street and could lead to differential settlement of the overlying street pavement.

The reconstruction of the curb and gutter, sidewalks and pavement was built by contractor. The 340 m long section, from Sophia Street to St. George Street, underlain with peat was reconstructed in the manner described below.

All the existing concrete curb and asphaltic concrete pavement was removed. The existing contaminated granular subgrade and peat was excavated to a depth of approximately 500mm below the surface design grade. Prior to backfilling the excavation, a geotextile mat was placed as a barrier between the peat and the granular base. The geotextile mat extended to 500mm behind the curb face for a total width of 12 m. A minimum overlap of 300mm was used to place the geotextile mat and the mat was pinned. A 100mm thick layer of 20mm minus granular base was placed over the geotextile mat and compacted. Care was taken to ensure that equipment did not operate directly on the subgrade when in the peat areas or on the geotextile mat.

In order to introduce some additional strength to the pavement structure over the peat, a geogrid was installed within the granular base. The geogrid was placed on the 100mm thick granular base and extend to 500mm behind the curb face for a total width of 12 m. Again a minimum overlap of 300mm was used when placing the geogrid. An additional 200mm thick layer of compacted 20mm minus granular base was placed over the geogrid. No equipment was permitted to operate directly on the geogrid. The new overlying asphaltic pavement consisted of a 150mm thick base pavement with a 50mm surface pavement.

The design grade along the centreline of the project met the existing grade at the west end of the project where underlying soils were competent and was progressively lowered in a relatively straight line until at the east end of the project the design grade of the centreline was approximately 200mm below the original grade. The lowering of the design grade was carried out to reduce the weight of the pavement structure on the peat layer. Due to the original high-centred pavement, and the need to meet existing properties, the design grades along the curb line on both sides maintained the original grades.

Summary of Long Term Performance

The performance so far has been disappointing. There is continued significant differential settlement of the asphalt surface on both sides of the pile supported sewer trench. This settlement is most obvious near the intersection of Prince Edward Street.

SUMMARY

Peat deposits present a re-occurring problem for municipal infrastructure in the City of Vancouver. The compressibility of the peat and the effects of drainage provided by granular backfill in utility trenches are generally found to be the two main factors which contribute to settlement problems.

A number of special construction methods for streets have been considered and used on a trial basis. The most effective methods are considered to be preloading and full excavation of the peat. Other construction methods using rigid pavements or geosynthetic reinforcement are not effective because of the detrimental effects of utility cuts in the street which effectively destroys the beneficial effect of these methods.

Due to the cost and interruption of service to adjacent private properties, preloading and full excavation of peat layers are not always practical. In these instances, flexible pavements are constructed over the peat layers as a cost effective solution, recognizing that this pavement will have a shorter design life than flexible pavement constructed over competent soils.

REFERENCES

1. Graham, M.D. and Dawley, C.B. "Transport Canada Report No. TP5287E,"Laboratory Evaluation of Flyash Cement and Lignin Cellulose Cement as Soil Stabilizers", March 1984.

2. Portland Cement Association (1971) "Soil-Cement Laboratory Handbook".

TABLE 1: SUMMARY OF DESIGN OPTIONS

OPTION	DESCRIPTION	CONCLUSION
1. Removal of Peat Layer	This option involved the excavation of the entire peat layer from the street and sewer alignment and backfilled with compacted granular fill. Construction by this method would result in negligible settlement.	Removal of this peat layer, with depths between 2 to 5 m, over a 340 m long section in a residential neighbourhood was considered too disruptive to service and too high a capital cost.
2. Preload	Long term settlement of the street and sewers could have been limited by preloading the site prior to construction. It was estimated that a preload of 1 to 1.5 m remaining on the street for 6 months would have been required to effectively consolidate the peat and soft surficial soils. The maximum height of preload would have had to be placed over the entire street width and tapered to the property lines to achieve uniform settlement.	Residential access, maintenance of 16th Avenue for traffic and maintenance of existing services to residences limited the effective use of this option.
3. Subgrade Stabilization by Grout Injection	This option involved stabilization of the peat layer by the injection of a grout into the peat layer through pre-drilled boreholes. A test section on 16th Avenue was performed to evaluate the effectiveness of this option.	The Fujibeton grout did not permeate the peat layer as expected, but remained in "piles" in the boreholes. These piles did not stabilize the peat layer and further soil stabilization methods were not pursued.
4. Removal of Peat Layer and Backfill with Lightweight Fill	This method involved the excavation of the existing pavement structure and a portion of the peat layer. A lightweight, air entrained concrete fill would be pumped into the excavation as backfill. This reduced both the thickness of the peat layer and the weight of the pavement structure. Thus the long term settlements in the peat would be reduced.	The capital costs of the lightweight fill were 2 to 3 times the cost of conventional backfills, thus making this option uneconomic. As well, there were concerns about the practicality of maintaining the sewer and water mains through the lightweight concrete.
5. Rigid Pavement	This option involved removing the existing asphaltic concrete pavement and constructing a rigid Portland concrete pavement to bridge the soft subgrade.	The long term performance of a rigid pavement over a soft, wet subgrade has proven to be not very successful in the past. As well, maintenance of utilities through Portland concrete pavements, and the subsequent cut repairs have been less successful than through asphaltic concrete pavements.
6. Build over Peat	This option involved removing existing surface infrastructure, replacing sewer and water mains and reconstructing over the peat layer. Some minor measures such as lowering the street elevation marginally to reduce the weight of the pavement structure, separating the peat from subgrade base materials with a geotextile, and providing some lateral support with a geogrid in the subgrade were part of the design.	This method had the lowest capital cost and least disruption to service for the adjacent property owners. It was anticipated that the long-term maintenance costs would be higher and the design life of the pavement would be shorter than the more capital-intensive options.

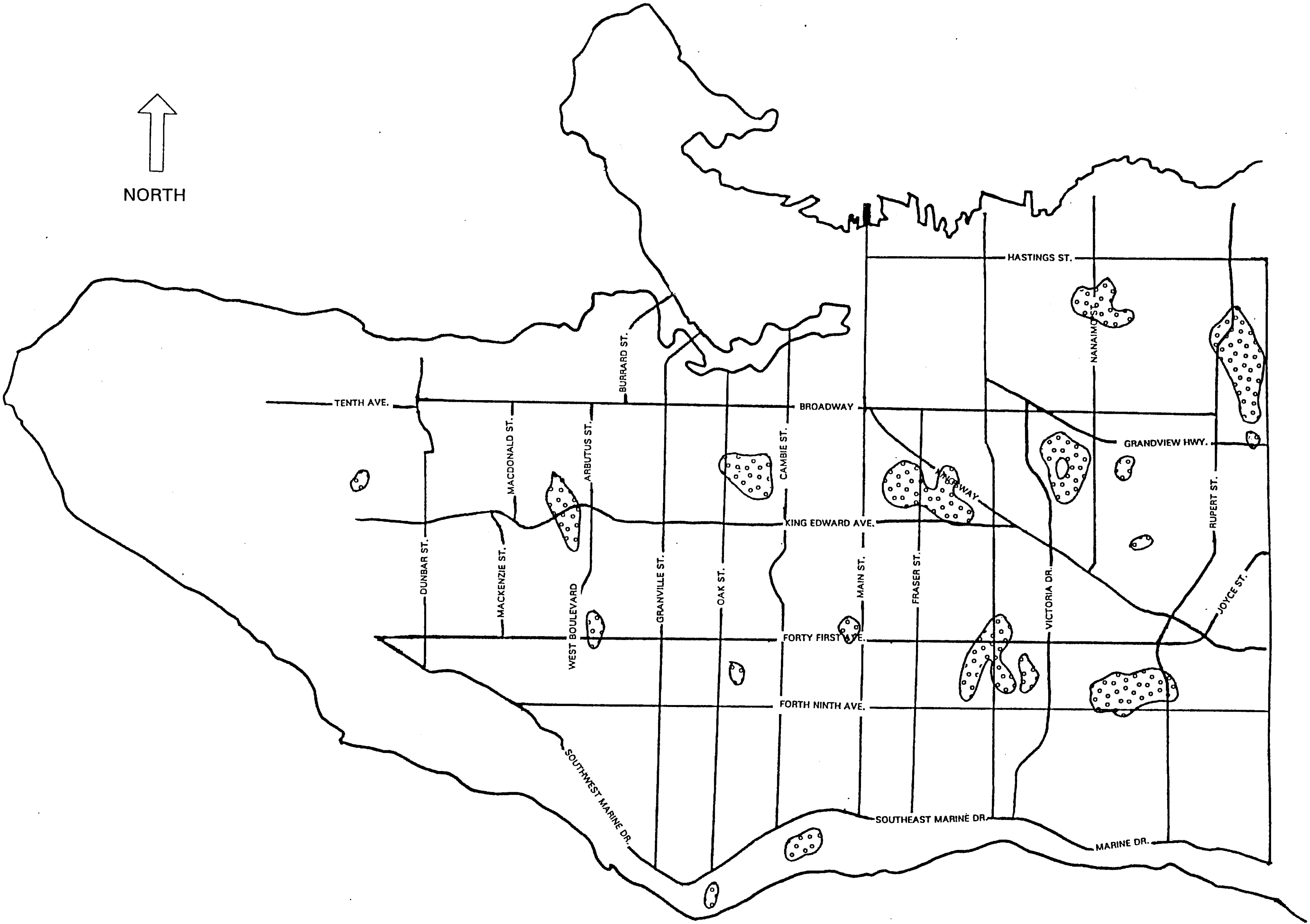


FIGURE 1. PEAT DEPOSITS IN THE CITY OF VANCOUVER

FIGURE 2: SETTLEMENT ADJACENT UTILITY TRENCHES

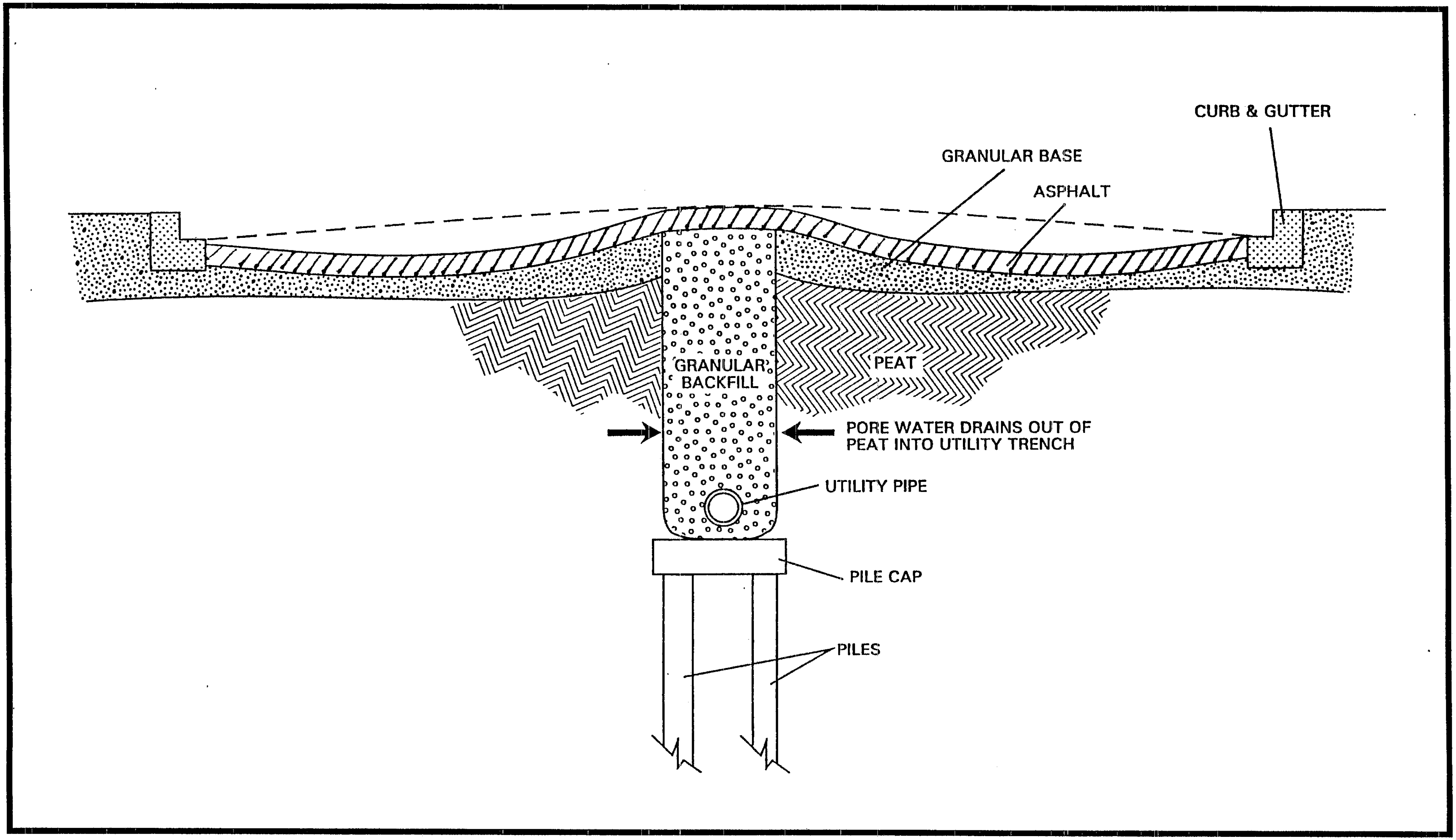
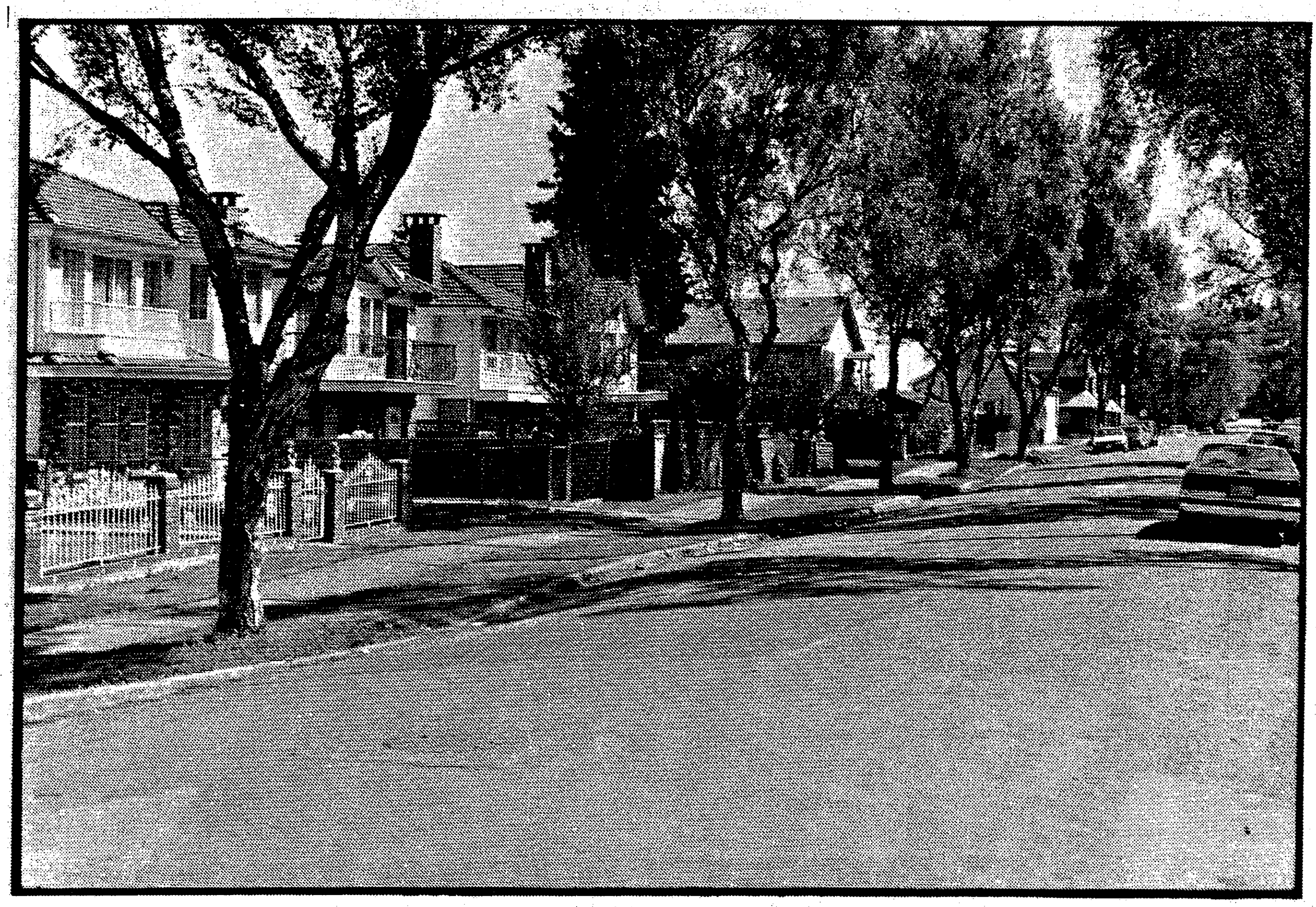


FIGURE 3: PHOTOS OF SETTLEMENT CAUSED BY LARGE TREES



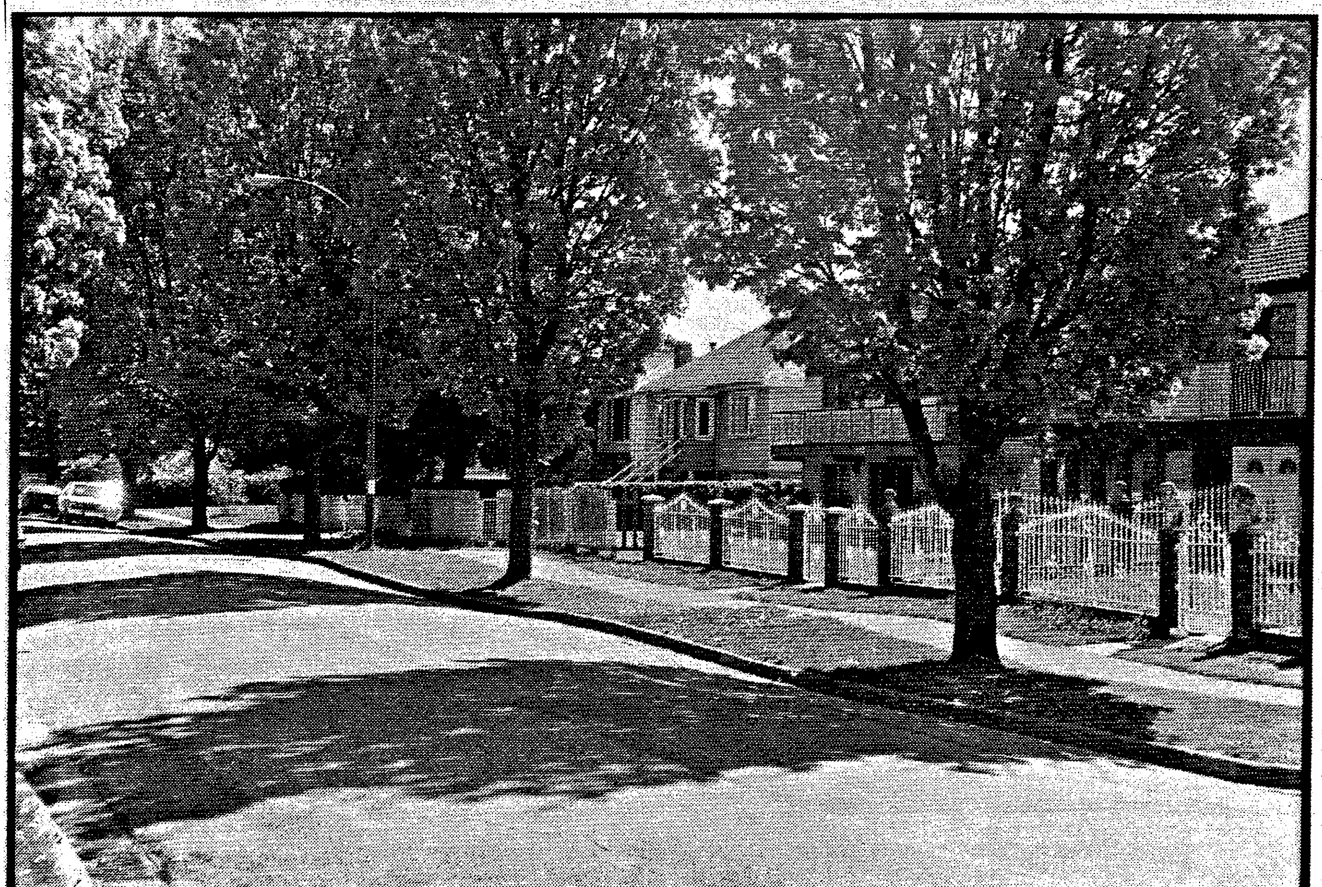


FIGURE 4: PLAN LOCATION OF PEAT REMOVAL ON 41ST AVENUE

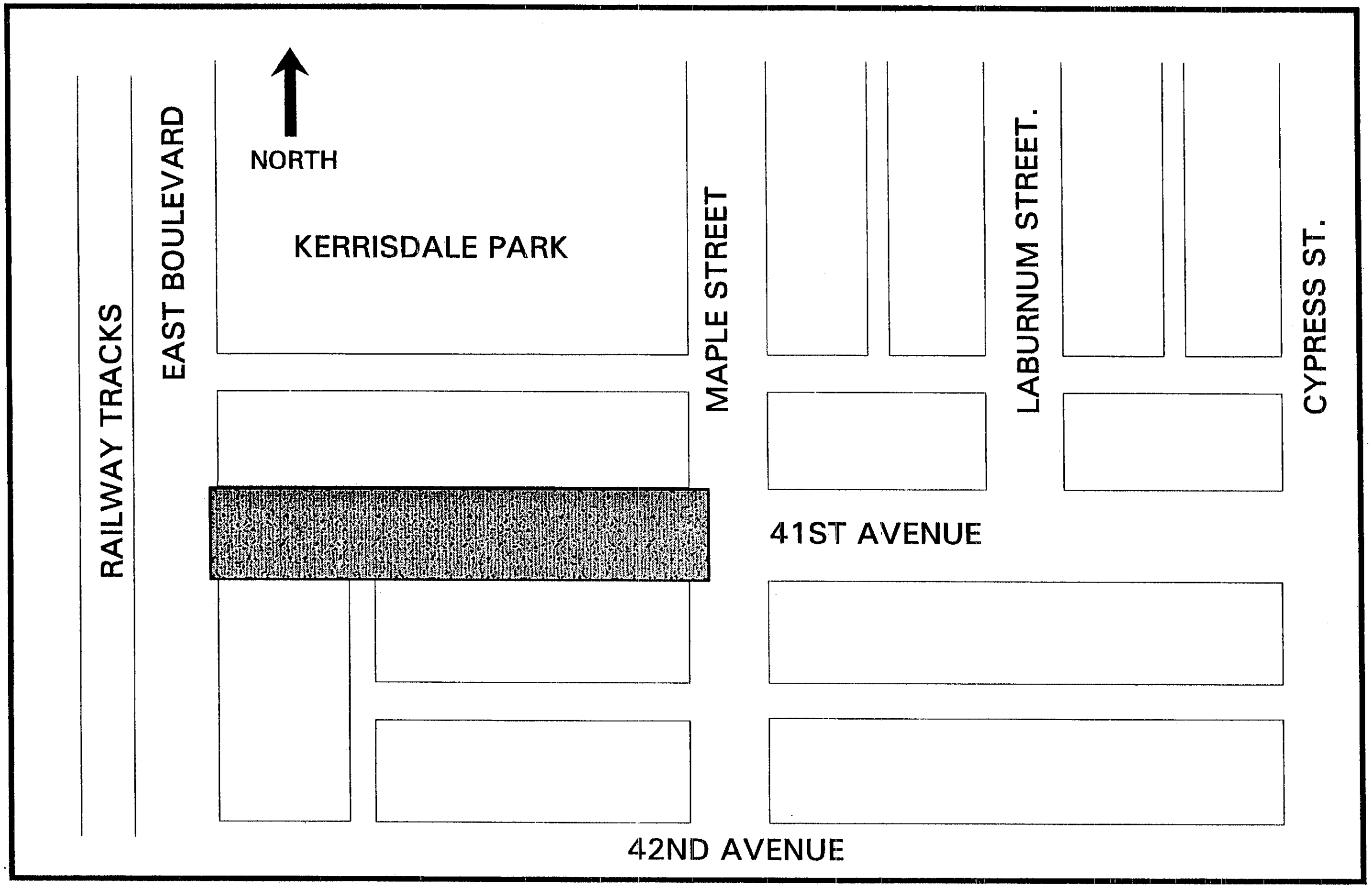


FIGURE 5: PLAN LOCATION OF PRELOAD IN CHARLES/ADANAC SUBDIVISION

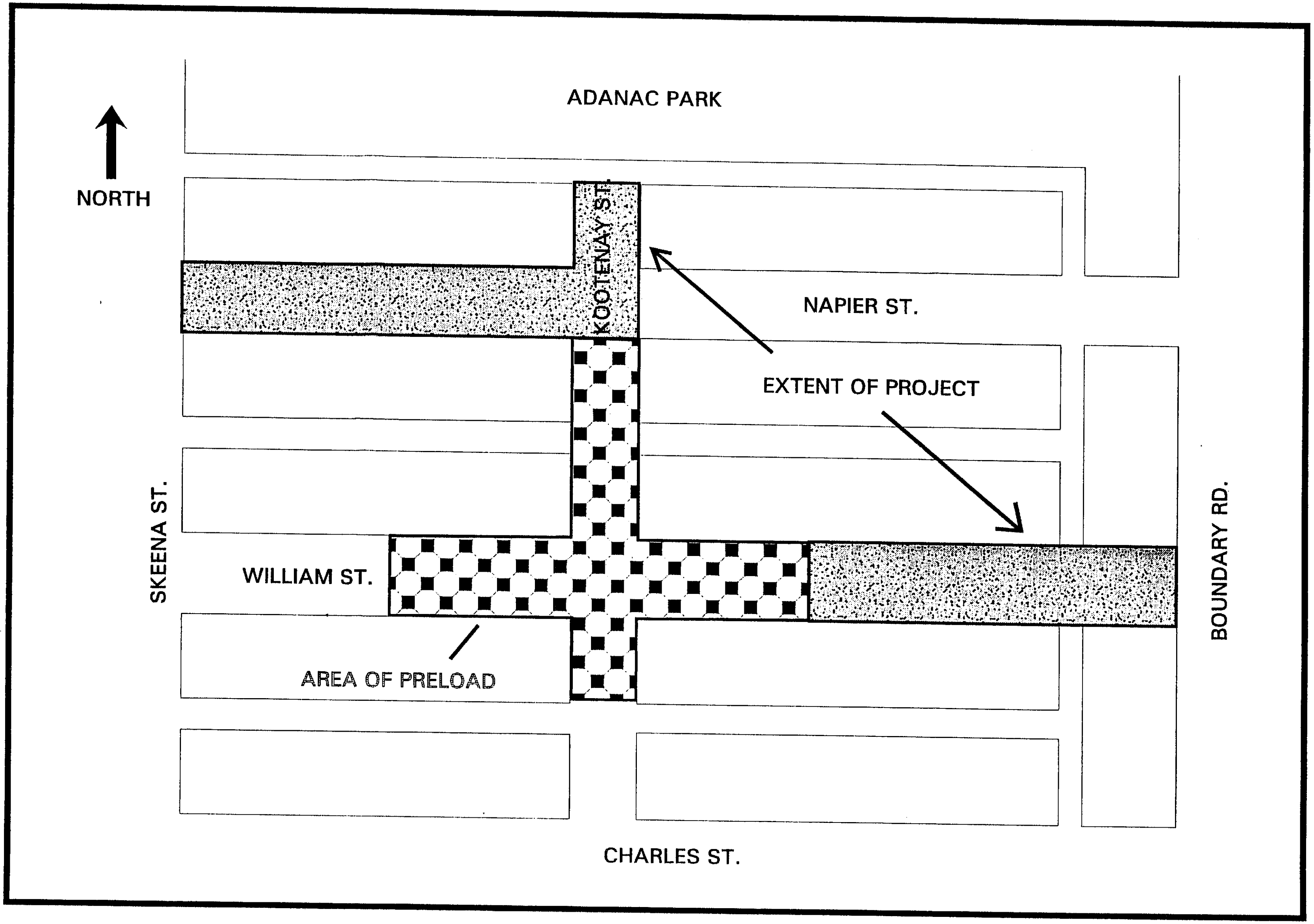


FIGURE 6: LOCATION OF RECONSTRUCTION AND PROFILE OF 16TH AVENUE