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ABSTRACT

A highway embankment and a sanitary sewer were constructed in the City of London, Ontario, Canada. During construction, a manhole settled approximately 1.5m. There were signs of rotational movement and slope instability in the interchange ramp embankment itself. These movements were attributed to insufficient removal of a deep deposit of peat beneath the ramp embankment identified in the original site investigation.

As part of remedial work, additional peat was removed and replaced with compacted sand. Despite these measures, the manhole continued to settle. Monitoring over a period of 30 months showed that the manhole settled by an additional 260mm.

Four alternatives were considered to correct the problem: 1. Repair the sanitary sewer at its present location using the same methods as previously employed (excavate and replace). 2. Relocate the sanitary sewer outside the area of influence of the ramp fill and support it on piles and restore the upper part of the embankment with lightweight fill. 3. Reinforce and support the sewer in its present location with pile foundations. 4. Re-route the sanitary sewer.

The final remedial strategy consisted of Alternative No 2 to reduce the amount of further settlements and instabilities. The case history of this project and application of lightweight fill under the conditions described above are discussed in this paper.

KEYWORDS

Peat, Settlement, Sewer, Excavation, Lightweight fill

INTRODUCTION

In the Province of Ontario, Canada, most of the highways leading to rural and suburban areas were constructed more than 50 years ago. Some of these roads were upgraded from a rural road to a highway by raising the profile grade as high as 10m or more. Bradley Avenue and Highbury Avenue interchange was located in an area in London, Ontario, where large wooded areas and several relatively extensive swamps were present. When the intersection was changed into an interchange, embankments were constructed over partially excavated soft organic material. That resulted in significant settlements and failure in the embankment and sanitary sewer.

This paper describes the restoration work undertaken for the embankment and sanitary sewer that settled and failed because of improper removal of soft and organic material. The paper describes the geological conditions of the site, construction history of the road and sanitary sewer and details of failure and restoration.

SITE DESCRIPTION AND GEOLOGY

The site where the embankment failure and settlement in the sanitary sewer took place is located at Bradley Avenue/Highbury Avenue interchange in the City of London, Ontario, Canada (Figure 1). Prior to the construction the site was generally a rolling grassland with ground surface elevation varying between elevation 269m and 275m. Several large wooded areas existed in the western portion of the site. In addition, several large swampy areas were present at the site.

Physiographically, the site is located in the "Ingersoll Till Moraine" region (Ref. Chapman and Putnam, 1984). During the retreat of the last glacial ice sheet, many large blocks of ice were deposited on the surface of the tills and overlying alluvial outwash to form the present moraine. Subsequently, these ice blocks melted to form isolated deep water-filled depressions. The lack of any continuous deep drainage of these depressions resulted in the deposition of considerable depths of peat and organic silt.

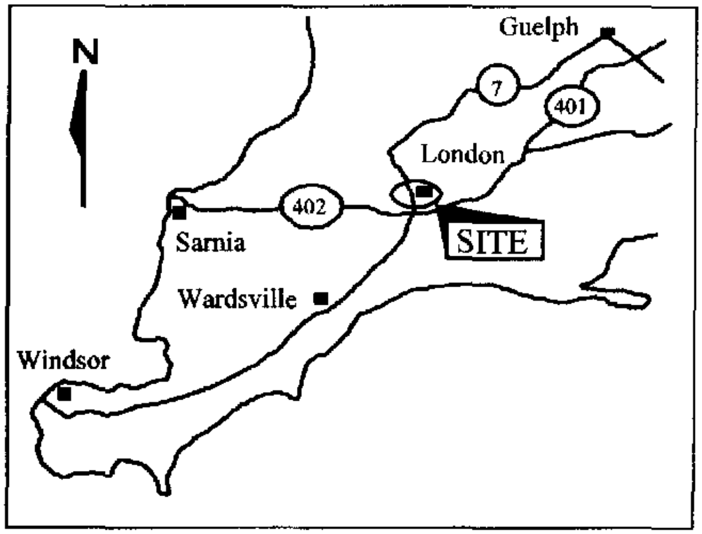

Figure 1: Site Location Map

BACKGROUND

The original Bradley Avenue embankment was constructed in 1967 by removing the organic materials and replacing them with compacted granular fill. In the area of Pond View Road, north of Bradley Avenue, the construction consisted of placing a layer of granular material over the organic to attempt to bridge the soft materials.

An independent geotechnical investigation for the design of a trunk sanitary sewer was carried out in 1973. Following the 1973 investigation, the proposed sanitary sewer was constructed at the site. During a site inspection of June 24, 1988 it was noted that the section of Pond View Road (that connected to the Bradley Avenue), about 200m north of Bradley Avenue intersection was severely distressed and was settling.

In 1988 another geotechnical investigation was carried out at the site to determine the subsurface conditions for the construction of proposed Highway 126 and Bradley Avenue East Interchange in London, Ontario. The interchange work would involve raising of Bradley Avenue embankment by 3m and widening the embankment crest by 7 m. In addition, approach fills as high as 9m above the original ground level was to be constructed for the access ramps north of Bradley Avenue East.

The area of the proposed construction was crossed by storm and sanitary sewers. The storm sewer was to be relocated, however, the 750mm diameter trunk sanitary sewer was to be maintained on its original location. The sanitary sewer consisted of Class V reinforced concrete pipe with Class B-1 bedding placed on inorganic soil on the north side of Bradley Avenue East. On the south side, the sewer consisted of steel pipe and was supported on steel pipe piles through the organic deposits.

SITE INVESTIGATION & RECOMMENDATIONS

The fieldwork consisted of drilling 54 boreholes and four dynamic cone penetration tests. The report showed that the subsurface soil and groundwater conditions were extremely adverse. The soil conditions were highly variable but generally consisted of varying amounts of the fill, often overlying thick layers of highly compressible and soft organic soils underlain by thin layers of granular strata and extensive strata of glacial tills. The groundwater levels were often less than 2 metres below the existing ground surface.

Many boreholes encountered layers of surficial cohesive and non-cohesive fill ranging in thickness from 0.1m to 9.0m. The measured N-values in the cohesive fill, as determined in the Standard Penetration Tests, ranged from 2 to 39 blows per 0.3m with an average N-value of about 13 blows per 0.3m. The granular fill had N-values ranging from the weight of the sampling equipment to 86 blows per 0.3m with an average N-value of about 10 blows per 0.3m.

The undrained shear strength of the cohesive fill, as determined from the results of six insitu vane tests, ranged from 28 kPa to 115 kPa with an average undrained shear strength of 60 kPa. The sensitivity of the cohesive fill ranged from 2 to 5 with an average sensitivity of about 3.

Layers of peat ranging in thickness from 0.2m to 8.0m were encountered in most of the boreholes, generally either at the ground surface or beneath the surficial fill. The peat had in situ water contents ranging from 23 to about 770 per cent with an average in situ water content of about 310 per cent. The N-values of the peat ranged from the weight of the sampling equipment to 14 blows per 0.3m. The undrained shear strength of the peat, based on the results of 49 in situ vane tests, ranged from 9 to 96 kPa with an undrained average shear strength of about 32 kPa.

Based on site conditions it was recommended that to satisfactorily found the proposed embankments to reduce both short and long term deformations, the variable fill materials and the organic soils should be removed in the vicinity of the proposed embankments. This would require excavations as deep as 10 m below the existing ground surface. It was thought that dewatering and achieving practical temporary excavation side slopes in the organic soils will be very difficult.

DETAILS OF FAILURE

During the construction of the highway embankment for the N-E/W ramp at Bradley Avenue and Highbury Avenue (formerly Hwy 126) interchange, a large settlement of the sanitary sewer near manhole No. 33 and the failure of the ramp fills occurred. The manhole No. 33 settled 1.5m and experienced rotational movement. The cause of the movement was to be investigated.

Site investigation was carried out by the ministry staff to investigate the cause of the failure. Twenty-six boreholes were put down. The investigation revealed insufficient removal of a deep deposit of peat up to 3m under the embankment. Additional peat was removed and replaced with compacted sand. Upon completion of the Bradley Avenue/Highbury Avenue interchange construction, the road facility was transferred to the City of London.

The Ministry construction office monitored the settlement in that area over a period of 2.5 years. The monitoring results showed some 260mm of settlement of Manhole No 33 as shown on (Figure 2).

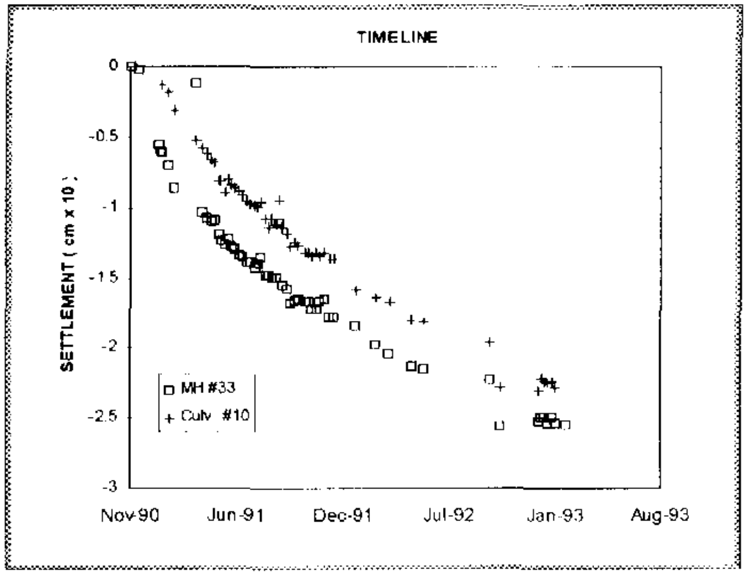

Figure 2: Settlement Plot of MH 33

The City of London conducted a video examination of the sanitary sewer between Manhole No. 32 and Manhole No. 38. The video showed high water level in 750mm sanitary sewer between Manhole No. 32 and Manhole No. 34, and between Manhole No 36 and Manhole 37. The City expressed their concern regarding the ongoing settlement of the ramp and potential failure of the sanitary sewer.

The Ministry of Transportation carried out additional investigations to resolve the problem. The subsoil conditions encountered in the boreholes drilled at the site were complex and highly variable. The road embankment fill of the existing Bradley Avenue and their ramp consisted of cohesive and granular fill. The embankment was generally underlain by peat and organic silt overlying layers of granular material and clayey silt till. Most of the boreholes drilled at the site encountered the fill of varying thickness, often overlying thick layers of peat and organic silt underlain by silty sand, silt and clayey silt tills. Groundwater conditions were observed by measurement of water level in the open boreholes. The groundwater level was at an approximate elevation of 268.0m that corresponded to depths of 2.4m to 1.5m below the ground surface.

RECOMMENDATIONS FOR RESTORATION

Recommendations indicated that the revised alignment of the sanitary sewer be located no closer than 5m away from the toe of the nearest embankment. It was also recommended that the restoration of the embankment be achieved before the construction of the sewer system by using lightweight material. The lightweight fill was used to reduce the amount of further settlements and embankment instabilities.

In consideration of the competent nature of the subsoils in one area, it was recommended to found the sanitary sewer on spread footing on native silty sand.

In view of the low shear strength and compressibility of the peat, organic silt and loose sand fill in other areas, conventional spread footing shallow foundations were not feasible at that site. In addition, to avoid the problems associated with deep excavation through weak overburden soils, it was recommended that structural loading for the sewers be transferred to the underlying very stiff to hard clayey silt till or dense to very dense silty sand by means of Steel 'H' piles installed through the overburden (Figure 3). It was assumed that the pile lengths would be in the order of 15 to 20m. The pile resistance for different areas and varying pile lengths ranged from 280kN to 850kN at SLS and 420kN to 1280kN at ULS.

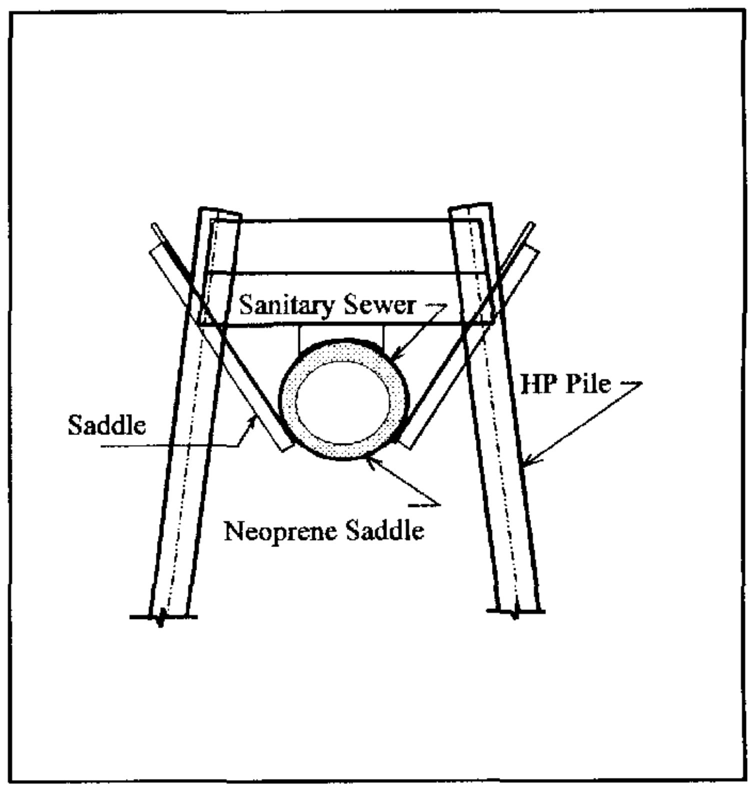

Figure 3 - Sanitary Sewer Pipe Support Frame

For the stabilization of the embankment it was recommended to use lightweight material in the upper 4m portion of the fill. It was recommended to first restore the embankment before constructing the sewer line. A subdrain was constructed at the base of the lightweight fill material to prevent a bathtub effect.

Several lightweight materials were considered for this project. Their advantage, disadvantage and cost effectiveness were studied and are discussed in Table 1

MATERIAL	UNIT WEIGHT (kN/m3)	COST/m3 (Cdn $) *
CONVENTIONAL FILL MATERIAL		
Earth Borrow	20.0	6
Rock Borrow	18.0	20
Granular "A"	22.8	9
Granular "B"	21.2	6
LIGHTWEIGHT FILL MATERIAL		
Sawdust/Wood Chips	4.0-6.0	4
Fly Ash/Bottom Ash	12.2-15.6	3
Blast Furnace Slag	10.2-13.0	19 - 33
Polystyrene		
Extruded	0.3-0.5	250-400
Expanded	0.3-0.5	65
Elastizell	2.8-12.5	80-125
Rubber Tire Chip	6.4	80-125

Table 1: Lightweight Fill Material Comparison by Weight and Cost

** Note: Cost of installation, forming and mobilization is not included.*

After all the studies, it was decided to use lightweight blast furnace slag for this project. The supplier was National Slag Limited in Hamilton, Ontario, Canada. The supplier had two types of slag. They were called Unprocessed Litex and 9.5mm Structural Coarse. Unprocessed Litex has range of grain size through the sand range. The 9.5mm Structural Coarse has a relatively uniform grain size. Properties of these materials are presented in Table 2:

The concern in using slag was that if it was over compacted then it would be crushed and its unit weight would increase. The Ministry carried out several large scale field tests to establish the most suitable method of compaction for this material. In the tests, different techniques of compaction, different layer thicknesses, different moisture content and different type of compaction equipment were used. A non standard special provision was developed for the contract for properly placing and compacting this material (See Appendix)

	Unprocessed Litex	9.5mm Structural Coarse
In-Situ Unit Weight	14.0 kN/m3	11.5 kN/m3
Loose Unit Weight	12.5 kN/m3	10.0 kN/m3
Sieve Size	% Passing	% Passing
13.20 mm	95 -100	100
9.50 mm	95-100	95-100
6.70 mm	85 - 95	70-90
4.75 mm	75 - 85	30-60
2.36 mm	40 - 60	10-30
1.18 mm	20 - 30	5-15
600 um	10 - 15	0-15
300 um	5-10	0 - 10
150 um	0 - 5	0-10
75 um	0-5	0-5

Table 2: Properties of different types of Slag

The embankment was reconstructed using the lightweight fill according to the recommendation (Figure 4). The sanitary sewer was reconstructed at a new location, away from the zone of influence of the embankment and supported on steel piles. Since then, the sewer and the embankment have performed well.

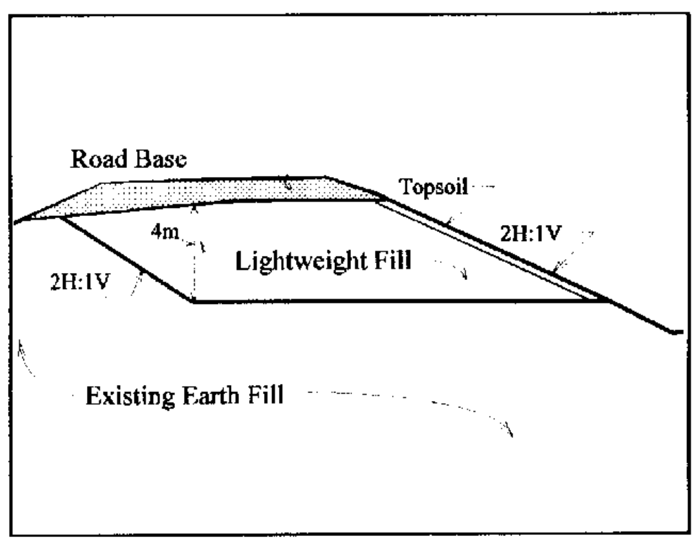

Figure 4: Typical Section Shows use of Lightweight Fill

CONCLUSIONS

Excavation of peat more than 7m is problematic and difficult to fully carry out.

In a situation where a thick deposit of organic or soft material is present, consideration should be given to constructing embankments using lightweight fill material

Structures that are sensitive to settlement should not be constructed in the vicinity and within the influence zone of an embankment.

Use of the lightweight fill and preloading can avoid need for deep subexcavation of soft compressible material.

Closer supervision of construction is very important. Knowledgeable supervision of the subexcavation/replacement operation during construction is critical to the success and long term performance of the embankment.

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