STONE COLUMN USE IN HIGHWAY CONSTRUCTION

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ABSTRACT

Stone columns are gaining widespread use in North American insitu ground improvement practice in the resolution of problems associated with settlement, bearing capacity and slope stability. Alberta Transportation and Utilities has virgorously explored this concept during the last 3 years. So far, 10 sites have been subjected to this form of remediation. This paper presents information on the construction and performance of "drilled stone columns" for eight of those sites. Since completion of construction, no further distress manifestations have been reported. This technique can be particularly useful in resolving slope stability and bearing capacity related problems within paved roadways where constraints of construction and traffic accommodation may obviate the use of more traditional methods of remediation.

INTRODUCTION:

The use of stone columns in geotechnical engineering practice dates back to around 1830 when the French Military Engineers dug holes and filled them with rock to improve the ground for accommodating heavy military equipment. Development of present day techniques for the installation of stone columns is credited to the Germans around 1950. In North America, this concept was not utilized until about 10 to 15 years ago. Since then, the popularity of this technique has been increasing rapidly such that the stone column technique is now one of the preferred methods of present day ground modification for problems associated with bearing capacity, stability and settlement.

The Geotechnical Section of Alberta Transportation and Utilities undertook its first trial of this concept in 1980. This trial was undertaken in an attempt to stabilize a section of Highway 43 near Valleyview, Alberta, which was undergoing yearly maintenance through settlement. This stabilization method did not prove to be successful in preventing further settlement and lime-flyash injection was eventually used to modify the ground . In retrospect, it was felt that semi rigid stone columns, created by incorporation of cement, referred to as "stone-cement columns" may have shown better performance.

Further use of stone columns by Alberta Transportation and Utilities did not occur until around 1987 when a section of roadway on Highway 27 near Torrington, Alberta, which was treated 5 years previously with lime flyash injection began to undergo cracking and lateral displacement. An investigation of the site was undertaken along with a review of the ground information prior to the lime flyash injection modification. Based on this study and consideration of constraints imposed by traffic accommodation, it was decided to utilize stone-lime columns in the treatment of this problem.

The apparent benefits of this procedure in replacing poor ground by the introduction of better material resulted in the consideration of this technique in ground stabilization of bearing capacity, settlement and stability problems. Another attractive feature that was evident was the elimination of stabilization methods resulting in roadway closure or inconvenience to motoring traffic especially on primary highway routes where detours can result in very long commuting distances.

Several other sites were treated with either straight stone columns, stone-cement columns, or stone-lime columns. A total of 10 projects have been undertaken since the Highway 43 project covering bearing capacity, settlement and stability problem areas. Eight of these projects will be discussed in this paper. The locations of the test sites are shown on Figure 1.

The objective of this paper is to describe the projects where the "stone column" technique was applied and the performance of these projects so far.

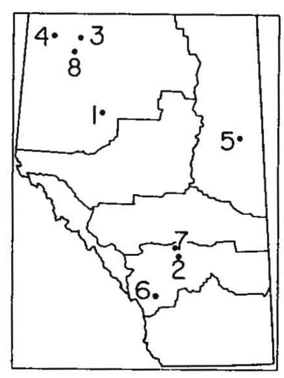

Figure 1 Location of Test Sites

METHOD OF CONSTRUCTING STONE COLUMNS

The known methods of stone column construction consist of vibroreplacement (wet method), vibrodisplacement (dry method), rammed method, and dynamic replacement method. The more popular of these methods in North American practice are the vibroreplacement and vibrodisplacement methods. Rammed stone columns are popular in Belgium while the dynamic replacement method was recently reported in France.

The construction approach used by Alberta Transportation and Utilities can be categorized as the rammed stone column method or as we have chosen to describe as the "Drilled Stone Column Method". The technique uses a Texoma Drill rig to drill the holes into which gravel (crushed or uncrushed) is introduced. Compaction of the aggregate is undertaken with the drill stem by mounting a heavy metal plate or shoe onto the kelly bar and exerting pressure on the aggregate through a pressing and torquing action and by raising the backend of the drill rig at quick intervals to apply static pressure. The use of the "drilled method" has been found attractive since the Texoma drill rig is readily available versus the non availability of the vibroreplacement or vibrodisplacement techniques locally.

Following our actual trials with the Texoma rig, we found that the drilled method could be used quite cost effectively for most projects that required this type of remediation.

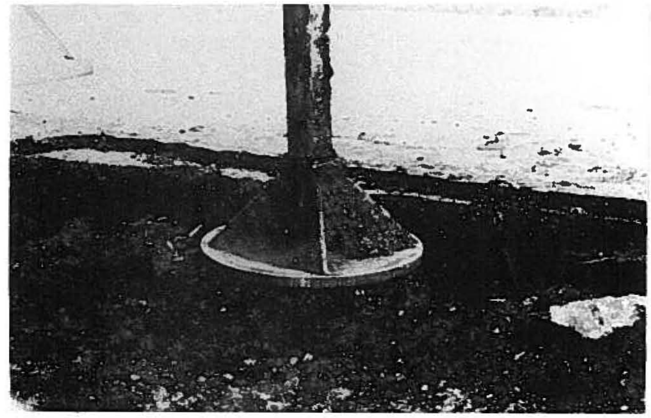

Photo 1: Plate Tamper For At Depth Compaction

Photo 2: Hand Tamper For Surface Compaction

HWY. 43 8 KM SOUTH OF VALLEYVIEW - SITE 1

The distress of a 100 m section of this roadway was diagnosed to be caused by settlement and has been categorized as a bearing capacity related problem. This roadway was constructed in 1959 as a one lane road to the east of the present roadway centreline. In 1979, the roadway was widened to accommodate two lane traffic. This widening was done to the west of centreline and construction consisted of excavating about 4 m of existing ground and backfilling with clay borrow over which the pavement structure was constructed. Performance records indicated that the one lane road had a history of settlements.

An inspection of the 2 lane roadway in 1980 resulted in the drilling of four testholes to determine the nature of the underlying soil. Testholes done to a depth of about 8 m revealed soft clay and muskeg. Muskeg probes and insitu shear tests revealed the depth of firm or hard ground to be about 6 m. Remediation to alleviate the settlement problem consisted of installation of a total of 90 columns as shown in Figure 2. These columns were placed to a depth of 8 m and constructed to a diameter of 0.6 m. The material used to fill the holes was well graded pitrun gravel. Compaction was undertaken by a plate tamper at depth and by a hand tamper near the ground surface (Photos 1 and 2). However, despite this treatment, settlement continued warranting the use of lime flyash injection.

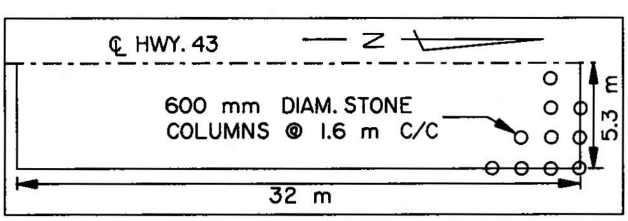

Figure 2: Location of Stone Columns

HWY. 27 EAST OF TORRINGTON - SITE 2

A section of this roadway, Photo 3, had been undergoing distress since its construction in 1960. Treatment up to 1980 consisted of overlaying the cracked pavement with hot asphaltic concrete. In 1980, a lime flyash treatment was undertaken to alleviate the problems at this site. Following this treatment, the roadway was reported to be stable until 1985 when cracking and lateral displacement were reported by district maintenance staff.

An investigation of ground conditions showed similar subsoil conditions prior to lime flyash injection except that the 12 m of soft clay was very waterlogged and possessed a moisture content of 104% compared with about 40% prior to lime injection. Underlying this soft clay was dense sand that was under artesian conditions. The previous investigation had punctured this artesian layer but this was reportedly plugged.

Photo 3: Cracking and Displacement of Roadway

Several approaches were considered to solve this problem. Finally, it was decided that in-place treatment using stone-lime columns would be utilized. The idea of using lime was to reduce the moisture content of the soft clay and improve the strength characteristics of the subsoils.

Two hundred and thirty three stone-lime columns were constructed using a Texoma 600 drill rig. About one half of these columns were constructed to a diameter of 750 mm outside of the shoulder while the remainder were constructed within the roadway to a diameter of 300 mm. The average depth of the columns was 6 m and spacing approximately 1 m on a staggered grid as shown on Figure 3.

The shoulder columns were constructed first. During this construction, trials were incorporated to assess the most effective method for construction of these columns. The approach used was to add about 4 bags of hydrated lime (Photo 4) at the 6 m depth followed by addition of gravel to a height of about 1 m above the excavated depth. The auger was then used to mix the gravel and lime (Photo 5) after which the auger was replaced with a tamping plate as shown in Photo 1 which was used to compact the stone-lime mixture by a pressing and torquing action to form a base plug.

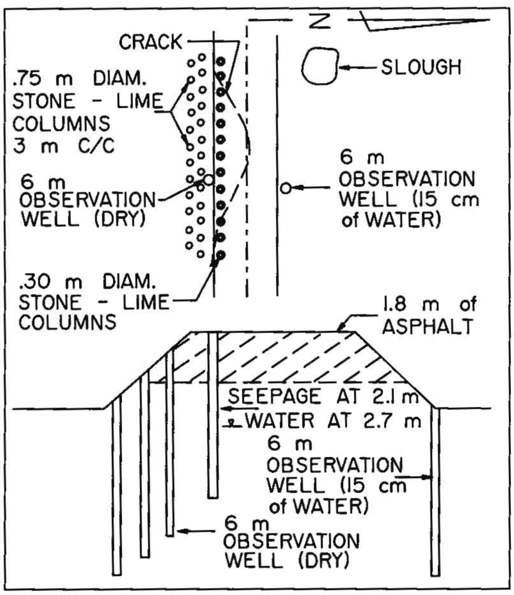

Figure 3: Layout of Stone-lime Columns.

Photo 4: Addition Of Lime To Form Base Plug

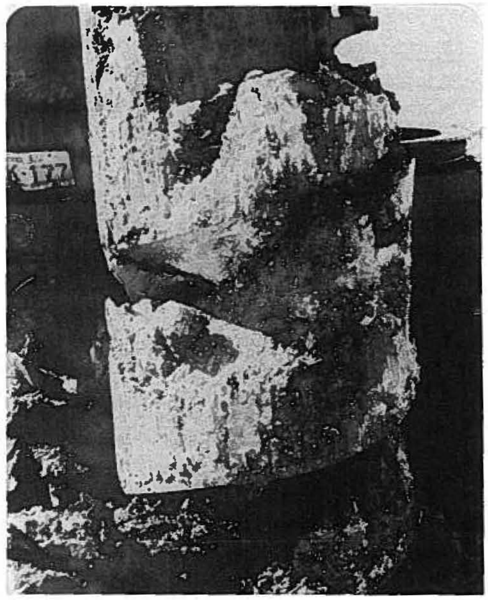

Photo 5: Stone-lime Mixture Using Auger

Following the base plug construction gravel and lime were added to a further 1 to 1.5 m thickness. Mixing of the aggregate and lime was then undertaken by the auger following which compaction of the mix was done using the tamper. This sequence of operation was followed until the columns reached about 300 mm below ground surface. The remainder of the column was then constructed with compacted clay to prevent surface run off infiltration.

The columns within the roadway were constructed using the auger only since it was determined from the trials that this approach would result in faster turn around time and that the quality of the column would not be different. Compaction was afforded through reversal of the auger along with the application of pressure.

During construction of the columns some safety related problems occurred due to the violent reaction of the lime with water where free water was found in drilled holes. To prevent this, cement was used instead of lime to construct the base plug. Stone cement holes were predominantly along row 3 in the roadway area.

Following completion of the columns a 90 mm asphaltic concrete overlay was placed over the roadway. This overlay was part of a scheduled overlay construction on Hwy 27.

Since completion of the overlay the site has been monitored on a frequent basis. To date, we have observed that the cracks prior to remediation have reflected through the overlay but that the roadway is intact without any signs of displacement as observed previously. Spikes have been set in the roadway to monitor lateral movement of the cracks. These were installed in October 1989. Based on our visual observation, this roadway is performing quite well so far. Photograph 6 shows the roadway condition approximately 2 years following remediation.

Photo 6: Post Construction Roadway Condition

HEADSLOPE TREATMENTS - PEACE RIVER BRIDGE, DIASHOWA PULP MILL SH 686 - SITE 3

The construction of the Diashowa Pulp Mill Plant at Peace River necessitated the construction of a bridge structure across the Peace River approximately 22 km north of the Town of Peace River. The approach fills for this bridge were to be founded on the alluvial flats that form the present banks of the river (Photo 7). These fills were to be 18 to 19 m above ground level to accommodate alignment and river hydraulics considerations.

Testhole drilling at the headslope locations showed the ground on the east side to be composed of predominantly a low plasticity silt in a moist to dry condition with standard penetration resistance averaging 10 to 12 throughout its thickness. Underlying this silt is dense gravel followed by hard shale and sandstone. On the west side, similar conditions existed except that a 2 m thick layer of soft silt was found just above the gravel layer. This silt was wet and weak and was considered a poor layer that could result in foundation instability.

Slope stability analyses were conducted using both long term and short term strength parameters. These analyses provided factors of safety ranging from about 1.2 to 1.5. Along with judgement, these factors of safety were considered acceptable. However, it was considered that any improvement to the silt characteristics would be beneficial. Stone columns were considered to provide this increased improvement since they could be constructed to bear onto the gravel layer and hence penetrate the weak layer on the east side. For the west side, the effect would be also an improvement of shearing resistance to the potential slide plane as well as to transfer the embankment load directly to firmer ground below the silt.

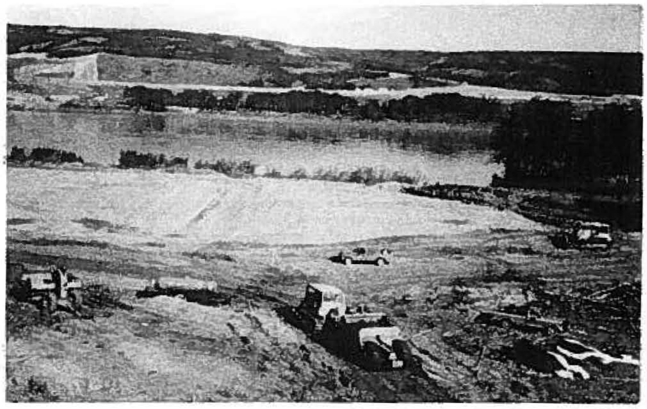

Photo 7: Overview Of Headslopes

Other techniques were utilized in the overall effort of stability improvement. These are shown on Figures 4 and 5.

A total of 110 stone columns, 750 mm in diameter were constructed on the west approach and 130 of similar diameter on the east approach, Figures 4 and 5. The columns on the west side were constructed with a Texoma 700 drill rig and a Texoma 330 rig. The Texoma 330 rig was used to provide compaction to the stone columns using a pneumatic tamper as shown on Photo 8. For the east approach, the Texoma 700 rig was used to construct the columns with compaction being afforded by a tamper plate attached to the kelly bar. Compaction was applied at 0.6 m intervals as the columns were constructed to grade.

Both approach fills were constructed to grade without any stability problems. The east side was constructed at a much slower pace than the west side due to the constraints of the softer ground and considerations of porewater pressure dissipation to guard against a failure during construction.

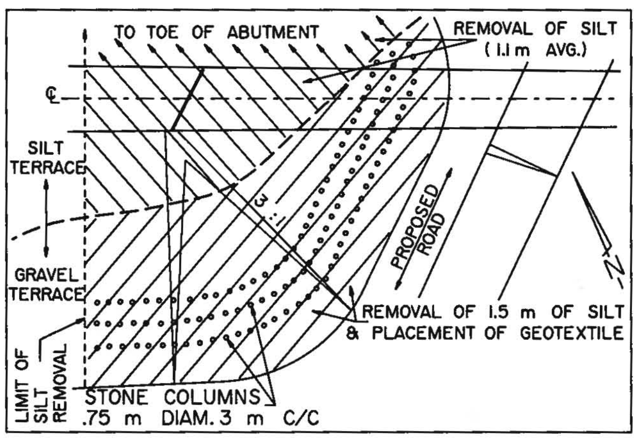

Figure 4: Stone Column Layout On West Headslope

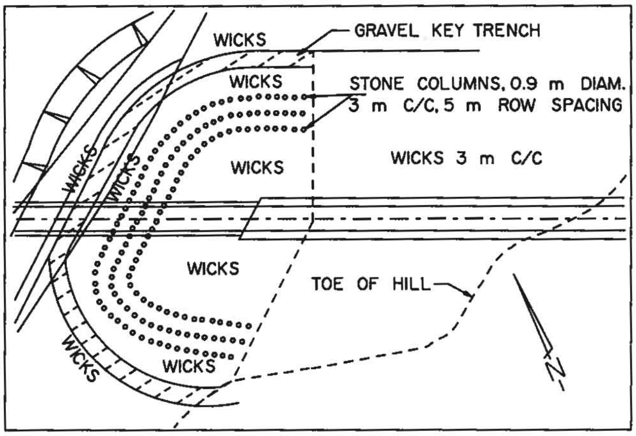

Figure 5: Stone Column Layout On East Headslope

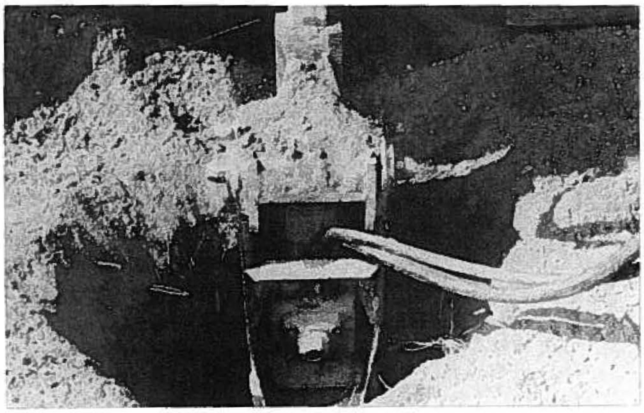

Photo 8: Tamper Attached to Texoma 300 Used To Compact Stone-Columns

SH 762 EUREKA RIVER, SOUTH OF WORSLEY - SITE 4

The use of the stone column technique at this site resulted from a slope stability problem that occurred following completion of the roadway grade construction. The instability extended over a length of 300 m and a width of 100 m in a section of roadway that was in a moderate sidehill fill situation (Photo 9).

Following an evaluation of this slide remediation using french drains perpendicular to the roadway and a toe berm over a gravel key at the toe of the fill slope was recommended and implemented. However, further sliding occurred beyond the key trench and extended to the creek banks following completion of the toe berm and roadway grade. An in depth investigation was undertaken and it was determined that weaker layers extended below the level of the constructed gravel key. From this investigation it was determined that the site had undergone previous deep seated movements. This observation was also borne out through discussions with local residents.

Photo 9: Headscarp of Slide In Main Slide Area

Several approaches to problem resolution were considered. Lightweight fill appeared attractive but was eliminated on account of material costs. Realignment further uphill was also considered but this would have entailed lengthening of the box structure and other undesirable alignment and cost associated problems. Finally, it was decided to utilize a combination of stone columns and stone-lime columns with lime being used where the shear zone was considered to be occurring and where the soils were found to be in excess of optimum moisture content.

In the main slide area which extended a longitudinal distance of 50 m, treatment was done as shown in Figure 6. A total of 210 columns of 750 mm diameter were drilled to a depth of about 12 m on a 2 m centre to centre staggered spacing.

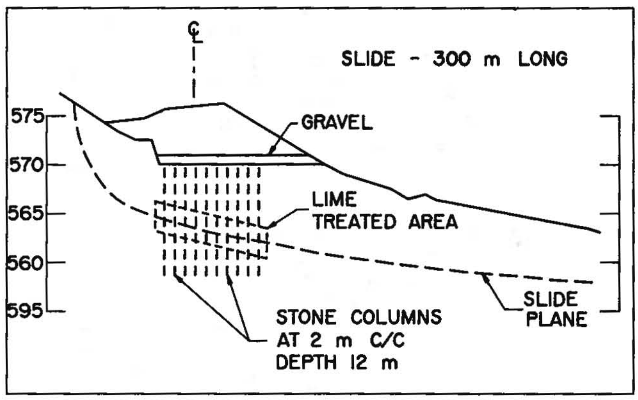

Figure 6: Stone-lime Columns in Main Slide Area

Beyond the main slide area further stone columns were constructed at varying spacings from the roadway centreline to the roadway shoulder in areas where cracks were observed to be occurring. This work was subject to field adjustment depending on what subsurface conditions were encountered as columns were drilled.

The approach used for constructing the stone columns was similar to that used at the Hwy 27 site where the auger was finally utilized to excavate as well as to compact the stone columns.

In addition to the stone column treatment a 5 m subsurface drain was constructed in the uphill ditch throughout the slide area and exiting in the river downstream of the culvert. This subdrain measure was considered necessary to divert any water that was observed to be seeping through fissures in the clay subsoil and therefore assisting in the propagation of the instability problem.

Following construction of the stone columns the roadway surface was regraded and gravelled. Since completion of remediation in 1988 no further problems have been reported in the area and the roadway is holding quite well.

HWY 28 KEHIWIN LAKE - SITE 5

The problem associated with this site can be categorized as a slope stability/bearing capacity problem. This problem dates back to 1976 as shown in Photo 10. At that time the observation was that the fill, which was about 10 m in sidehill construction, was being eroded by the wave action of the lake. Remediation consisted of placement of riprap at lake shore and filling the cracks of slope. In 1980, this problem resurfaced and instrumentation monitoring was implemented.

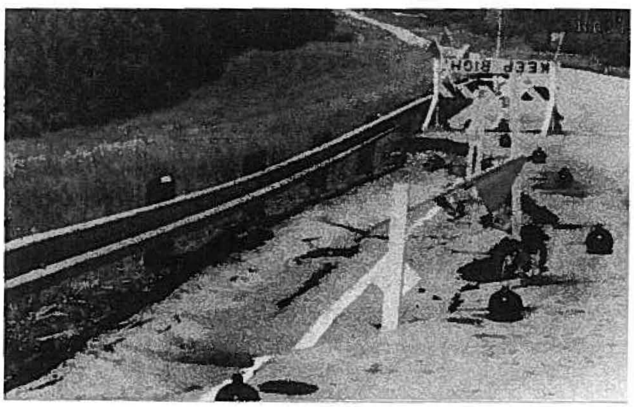

Photo 10: Roadway Failure

Roadway depression again became a problem in 1988. Following this a subsurface investigation was undertaken from which it was determined that the fill, which averaged about 6 m within the failed roadway was wetter than optimum. Below this fill fractured shale was encountered. Water was also observed to be seeping at the interface of fill and shale. One of the considerations was excavation of the cracked pavement and replacement with granular material along with french drains to bleed any moisture that may be travelling across the roadway. However, since the road was highly trafficked the technique of stone-lime columns was adopted within the cracked roadway along with construction of an uphill subdrain to divert any water away from the roadway.

The treatment consisted of constructing 40 stone-lime columns in 4 rows as illustrated on Figure 7. There was minimal disruption to traffic flow while this operation was undertaken.

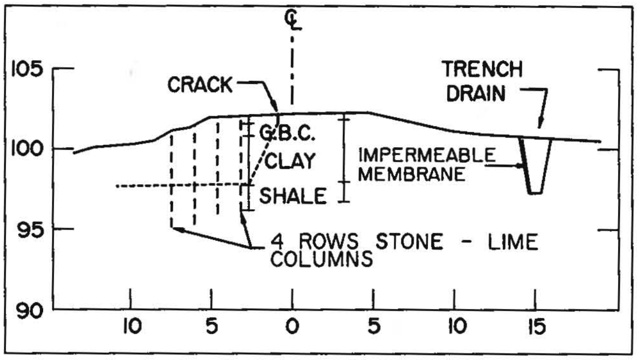

Figure 7: Stone-lime Column Treatment

SH 762 NORTHWEST OF MILLARVILLE - SITE 6

In 1987, a 10 mm wide crack running diagonally through a 50 m long section of roadway on sidehill construction was observed by the local road authority. This crack was associated with minor settlements. In 1988, the distress progressed to a width of 50 mm with roadway settlement of 100 mm and noticeable displacement of the sideslope and fence (Photo 11).

Photo 11: Roadway Prior To Treatment

Investigation of the area revealed that a slide was occurring at contact of the original ground and superimposed fill. One of the options of remediation was a complete replacement of failed material to a depth of 3 m with free draining pitrun gravel. The other option was the utilization of stone-lime columns. This option was finally chosen since it would allow minimal disruption to traffic. The scheme used is shown on Figure 8. These columns were constructed using a Texoma 700 rig.

A total of about 71 columns were installed to an average depth of 5 m. Since construction completion in November 1988, this site has been monitored by visual observation and is so far performing well.

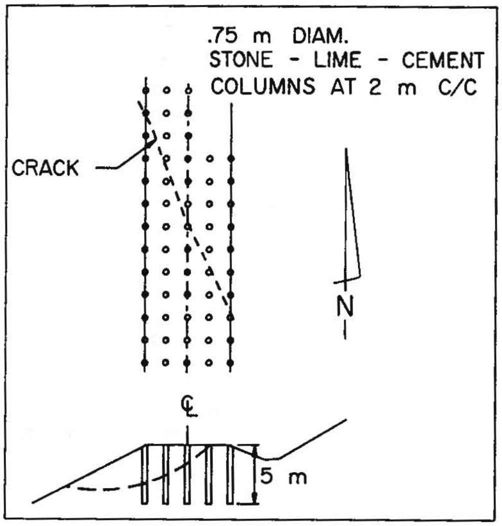

Figure 8: Stone-lime Cement Treatment

THREE HILLS CREEK BRIDGE - SITE 7

At this site, a single span bridge structure was to be constructed across the Three Hills Creek. This site was one that had a history of problems associated with soft ground conditions and underground springs. A 6 m high approach fill was to be constructed before bridge construction. Shortly after fill construction, cracks were reported in the embankment fill. These cracks were observed to progress diagonally through the approach fill on the side and towards the creek, Photo 12.

The stone column treatment was applied to this site as shown in Figure 9 using 750 mm diameter columns. The technique used in adding the lime and the compaction of the columns was identical to those used for other stone-lime column projects. Since installation of these columns no further problems have been observed. The bridge was completed and site inspected and no cracks have reappeared.

Photo 12: Cracks In Headslope

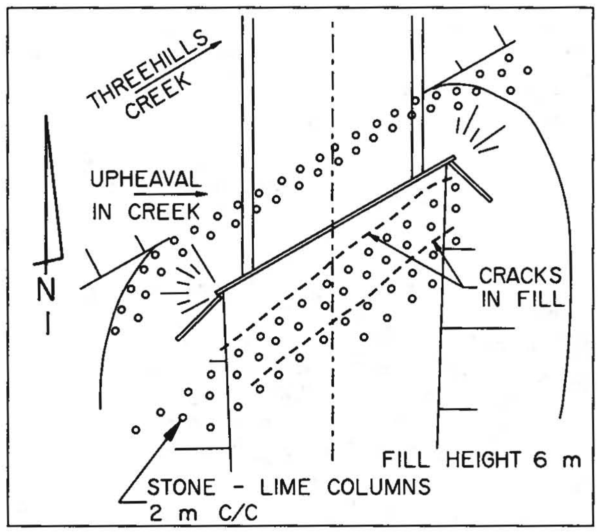

Figure 9: Showing Layout of Stone-Lime Columns in Headslope

SH 744 JUDAH HILL - SITE 8

The Judah Hill roadway in Peace River is a direct link to the Town of Peace River. Without this roadway there would be a 30 kilometre longer route for commuters living in the Judah Hill and surrounding areas. Present distress in the form of cracks within the pavement surface was observed following asphalt pavement construction in 1985. As the years progressed, these cracks became progressively wider and depressions occurred in the wheel paths. The topography of the roadway is a sidehill cut section with steep backslopes and sideslopes of 1 to 1.5 extending to about 40 to 60 m to a rail track below.

An investigation of the roadway through drilling showed the soils to be fairly dry though wetter than optimum at some locations. At first it was felt that there was seepage from the uphill ground but this was ruled out from a study of the topography. The problem was diagnosed to be a loss of bearing capacity through degradation of the sideslope due to runoff from the pavement structure. Some areas where this problem did not occur were associated with areas where pavement runoff was towards the backslope ditch.

To prevent deterioration of the roadway stone columns were utilized at all distressed locations. The need to undertake some repair was generated by the fact that this roadway was too important to the travelling public and the constraints for repair, should slipouts occur, would be great. Also, the repair techniques resulting for a slipout would not be easily undertaken.

The scheme used is shown in Figure 10. As shown, the columns were cemented only in the top 3 m following which plain stone columns were used below to the depth of treatment. The idea was to improve the overall resistance of the subsoils in the top 3 m where the traffic stresses were greatest. In addition, a series of curbs and catchbasins were designed to prevent the water running off the pavement onto the shoulder, weakening same thereby leading to overall pavement deterioration.

The stone-cement mix was initially mixed insitu but was later done in the Maintenance Operations Yards using the mixing arrangement used for mixing gravel and salt for winter maintenance of roadways. A cement content of about 5% by weight was used along with fairly clean gravel aggregate. To this mix a small amount of water was added so that the mix formed a cohesive mass when squeezed with the hands. Where the mix appeared dry some water was added into the holes as the columns were constructed.

Compaction of the columns was done using a plate tamper. Since construction of these columns there has been no visible signs of any further increase in pavement distress and the remedy is considered to be performing well.

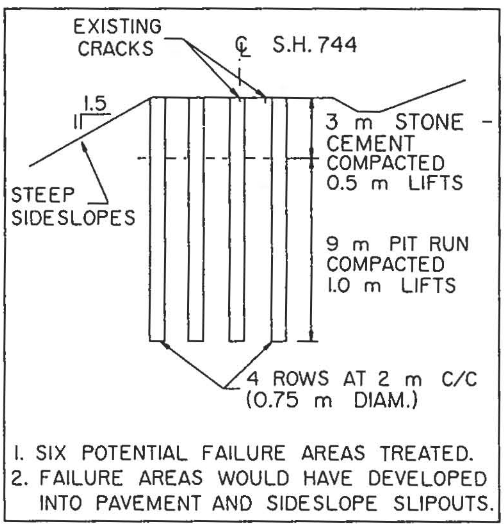

Figure 10: Layout of Stone Cement Columns

PROJECT EXPENDITURES

Table 1 provides summary statistics on the treated sites showing the total lengths drilled and the costs expended at each site as well as the cost per metre. The total expenditure for the eight sites amounts to $467,060 with an average cost of $42.09 per metre.

Table 1

SITE	DESIGN	M	COST	COST /M	AVE DEPTH/ COL.	DATE
1	Stone	685	33,346	48.80	8	Sept. '80
2	Stone-Lime	1258	48,900	38.85	6	May '88
3	Stone	869	33,389	38.42	8	April '88
4	Stone-Lime	2714	149,644	55.14	13	Sept. '88
5	Stone-Lime	275	9837	35.77	6	Oct. '88
6	Stone-Lime	367	20,524	55.92	5	Nov. '88
7	Stone-Lime	732	11,335	15.50	6	Nov. '88
8	Stone-Lime	3313	160,085	48.32	6	Dec. '88
Totals		10,213	467,060	42.09	7	

Note: Data has been rounded off.

SUMMARY

Alberta Transportation and Utilities has experimented with the use of "drilled stone columns" as a remedial measure for problems of slope stability, bearing capacity, and settlement along highways within the Province of Alberta. So far, none of the sites treated have given any problems requiring further treatment. Alberta Transportation and Utilities will continue to utilize this method of remediation where it is deemed to be appropriate and cost effective compared to other possible methods. The Geotechnical Section will continue to monitor the performance of these sites and report at a later date on future performance. Interested readers requiring further details on the approach can contact the authors.

ACKNOWLEDGEMENTS

The execution of the remedial measures at the various sites was undertaken by the Geotechnical Field Services Section under the general direction of geotechnical staff engineers assigned to these projects. Many of the variations to the installation approach regarding mixing and compacting were provided by field staff and their keen interest in this technique was very beneficial. The authors also like to thank Les Appleby and Gisele Chartrand for their patience and cooperation in drafting the diagrams and typing the manuscript, respectively.