DiMAGGIO J.A. et GOUGHNOUR R.D.

Federal Highway Administration, U.S.A.

Demonstration program on stone columns

Programme de démonstration sur les pieux ballastes

Le développement et l'amélioration du réseau des transports des Etats Unis sont sensiblement influencés par les nouvelles contraintes de l'environnement. L'utilisation des colonnes ballastées permet de résoudre quelques fois ces problèmes. Bien qu'elles soient utilisées depuis 25 ans en Europe, elles restent relativement peu connues aux Etats Unis.

Des sites expérimentaux concluants, une large application en Europe et la perspective d'économie appréciable, ont poussé l'Administration Fédérale des Autoroutes à lancer un programme de recherches de 4 ans sur ce sujet.

Le but et les grandes lignes de ce programme sont ainsi présentés avec plusieurs projets d'application.

INTRODUCTION

The soil reinforcement concept is becoming increasingly popular with geotechnical engineers involved with highway projects. In the United States this popularity is primarily a result of modifications which have occurred in the National highway program. The emphasis in transportation projects is changing from new location to upgrading of existing facilities. A large percentage of new roadways that are being constructed are in an urban environment and require some modification of an active roadway facility. On these type projects consideration of safety, maintenance of traffic, environment, time and economics are critically weighed during cost comparison and alternate selection phases of the project. From a geotechnical viewpoint, the resulting design criteria have severely limited the application of many tools traditionally employed as solutions to geotechnical problems. Treatments which require movement of large earth volumes, shifting of roadway alignment, right-of-way acquisition or extensive construction delays are being seriously questioned.

During the past two decades soil reinforcement methods such as Reinforced Earth, stone columns, arrays of small diameter cast in place piles and deep chemical stabilization, have provided positive and cost-effective solutions to many transportation problems. With the exception of Reinforced Earth, many American geotechnical engineers have very limited knowledge concerning design theory and potential applications of these methods. The Federal Highway Administration believes that expanded acceptance of soil reinforcement methods could be extremely beneficial in meeting future public transportation needs. The obvious advantage of employing these methods is elimination of many undesirable aspects associated with conventional treatments. New methods however, cannot be incorporated into public transportation projects until documented design techniques have been established and construction performance verified in the field. A prime function of the Federal Highway Administration is to provide transition of worthwhile methods from the conceptual phase to routine usage in construction. A demonstration program was developed to provide such a transition for the stone column method of soil reinforcement. The overall objectives of this program are:

(1) Impart a basic understanding of the stone column technique and its applications to interested transportation agencies.

(2) Promote implementation of this method at cost effective locations, and in areas where its application is in the general public interest.

(3) Expand existing knowledge on stone columns through encouragement and participation in research studies, field testing programs and project evaluations.

CONCEPT

The stone column process of strengthening cohesive soils in situ was developed in Germany about 25 years ago. Column construction is accomplished by penetrating the cohesive soil with a vibrating probe to a preestablished depth (Figure 1). Penetration occurs under its own weight, with vibration and the assistance of a jetting fluid. During the penetration process, the soil immediately surrounding the vibrator is disturbed or remolded to a nominal extent. The jetting process flushes a portion of the disturbed material from the hole. After penetration to full depth, the probe is withdrawn while the jetting fluid prevents the hole from collapsing. The penetration process may be repeated to ensure the hole remains open over its entire depth and that a majority of the disturbed material has been removed. After the desired depth has been developed, approximately one half to one cubic yard of coarse granular backfill is

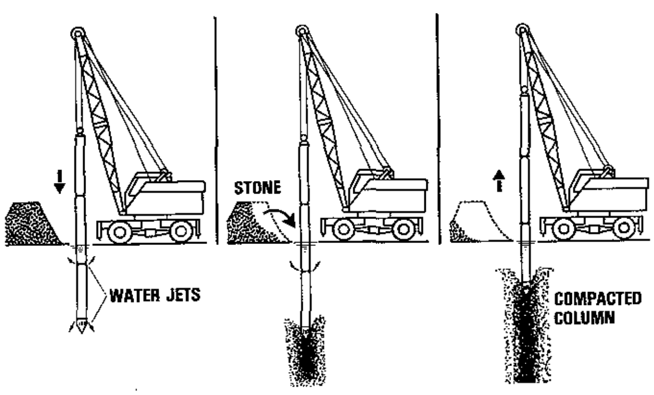

Figure 1. Stone Column Construction Procedure

dumped into the hole. This backfill material usually consists of coarse gravel, crushed stone or slag, sized 3/4 -3 inches. The probe is then lowered into the hole and under its own weight with the assistance of vibration it compacts the backfill material. Repetition of the process of incremental feeding and compacting produces a very dense granular column which is embedded with native cohesive soil. Depending on the consistency of the natural soil, columns 2 to 3½ feet in diameter are formed. The system is self-compensating, in that the softer the in situ material, the larger the column diameter.

By constructing stone columns in a square or triangular grid pattern, the originally soft ground is transformed into a composite mass of vertical, compacted granular cylinders and intervening native soil (Figure 2). This method provides the dual advantage of increasing the average shear strength and decreasing the overall compressibility within the composite soil mass.

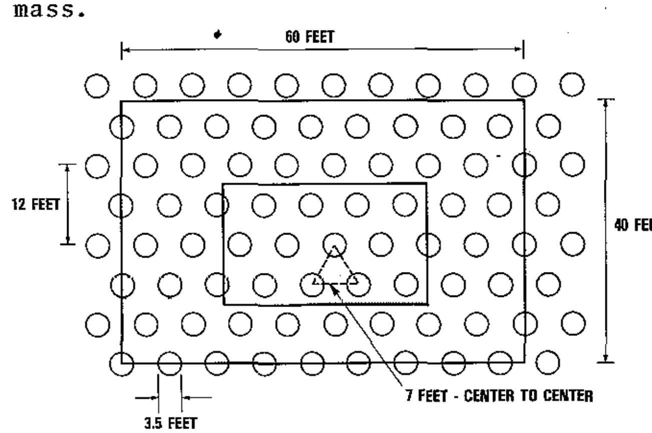

Figure 2. Plan View - Typical Stone Column Foundation Pattern

U.S. EXPERIENCE

Although this method has been successfully employed abroad for quite some time, it is relatively unknown within the United States. The first highway application within the U.S. was at Clark Fork, Idaho, in 1975. Details on this project will be presented in the case study section of this paper. The successful installation at Clark Fork, along with the widespread success in various countries abroad, indicated that numerous potential benefits might be achieved along United States roadways, and prompted the Federal Highway Administration to initiate a stone column demonstration program in the fall of 1976. Applications to transportation facilities include: Stabilization of cut slopes or embankments, reduction of post construction settlement, and support of structural foundations. The attractive benefits of using this method include:

Elimination of excavation and unsuitable material disposal, construction within narrow confines, minimal traffic disruption, no dewatering required and reduction of construction time.

After approximately 18 months of development, the demonstration program was officially introduced in March 1978 to Federal, State and local highway agencies. The program consists of the following: Introductory and design related slide presentations, a guidelines manual on the use of stone columns in highway construction, both technical and financial assistance during projects for field testing, instrumentation and evaluation. The first two items were combined to form a familiarization package on this subject which was presented in a 3½-hour seminar to transportation agencies across the country. Since March 1978, 49 seminar requests have been received and 35 presentations given. The guidelines manual, which is 70 pages in length, covers the presentation topics in detail. It is available to interested agencies thru the Federal Highway Administration.

Through our efforts with the stone colunm demonstration program, we have identified a number of areas where a research program would be extremely valuable. In addition to minimizing construction and evaluation problems, a comprehensive research program could also serve to advance the state of the art of stone column design. The design procedures outlined within our guidelines manual were developed based on European experience and limited field test results produced in the United States. These procedures are considered to be an interim methodology which will eventually be refined and improved.

The Federal Highway Administration presently plans to initiate a stone column research program during 1979 which will address the following:

(A) Define acceptable and unacceptable stone column construction procedures.

(B) Quantify engineering parameters which can be used to define the borderline between soil types that can and cannot be stabilized by this method.

(C) Determine optimum backfill requirements related to particle shape, gradation and durability.

(D) Develop a suitable procedure for quality assurance.

(E) Analyze and refine existing load settlement and time rate of settlement relationships.

(F) Develop a comprehensive specification which addresses pertinent design and construction considerations.

Results of this effort, complimented by continued activity of the demonstration program, will provide a better understanding of where and how to most effectively apply stone columns on transportation facilities. The following case studies should provide some indication of typical highway problems being corrected by stone columns.

CASE STUDIES

Clark Fork, Idaho - Lake Pend Oreille, located in the northern panhandle of Idaho, is one of the most scenic areas in the United States. Due to this area's popularity, the decision was made to upgrade seven miles of the Clark Fork Highway to eliminate sharp, dangerous curves. The highway was shifted from a slide-hill cut to an alignment that would follow the lake's shoreline. Along the lake's shore, near the village of Hope, the position of the Northern Pacific Railroad forced the highway alignment out into the lake for approximately 2,000 feet. The original plan was to construct a 25-foot high embankment, but when construction began in 1965, an embankment failure occurred resulting in an estimated 30,000 cubic yards of material disappearing into the lake.

During 1973, a detailed geotechnical investigation revealed a very loose sandy silt deposit which had not appeared in the previous exploration program. A detailed stability analysis of the area indicated safety factors as low as .9 for a 1,300 foot section of the originally planned embankment. A typical section is shown in Figure 3.

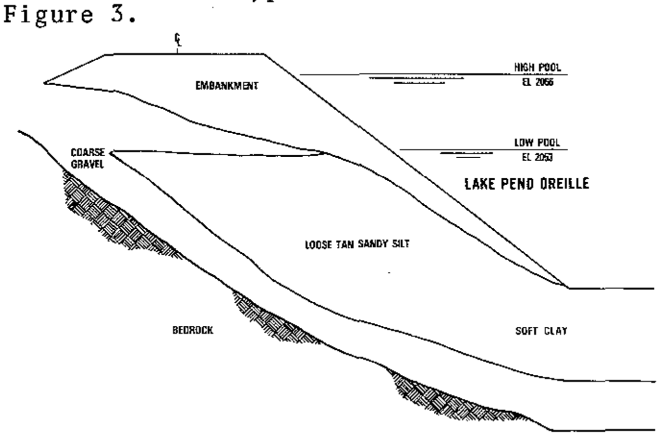

Figure 3. Original Design - Station 334+00 Clark Fork Highway, Idaho

Two possible solutions were examined, a structure and a combined Reinforced Earth-stone column treatment. The structural choice was eliminated due to the bedrock's steep dip angle and economics. Use of Reinforced Earth eliminated a substantial portion of the embankment weight and was adequate to produce suitable safety factors in all but 500 feet of the troubled section. Within this 500-foot section, stone columns were installed on 7-foot centers. A section view of the combined solution is shown in Figure 4.

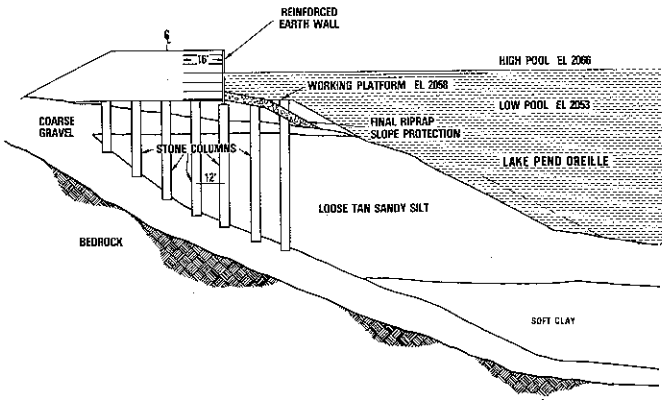

Figure 4. Stone Column - Reinforced Earth Solution - Station 334+00 Clark Fork Highway, Idaho

This project was completed in the spring of 1975 and monitored using slope indicators and surface settlement gages for two years. The combined treatment saved $1.5 million versus the structural alternate.

Newport News, Virginia - This project is located on Interstate 64, approximately five miles west of the Hampton Roads Tunnel in Newport News, Virginia. The proposed construction provides for additional traffic lanes along the Interstate and a new four-ramp interchange connecting Route I-664 (Figure 5).

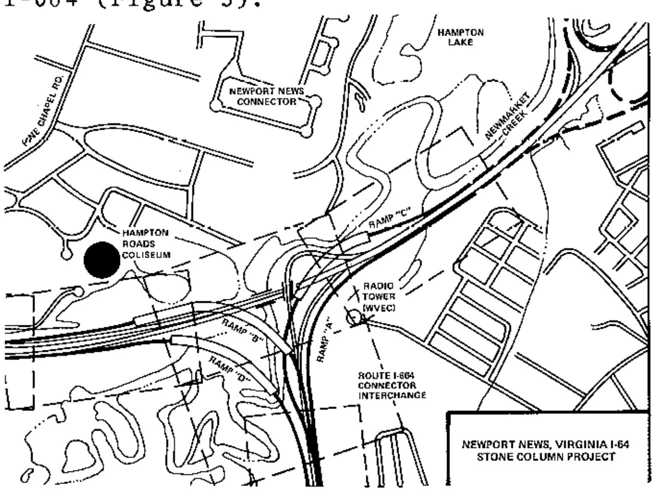

Figure 5. Plan View of I-64 - Newport News, Virginia

The stone column treated area involves stablization of approximately 500 linear feet of I-64 adjacent to New Market Creek, between stations 625+00 through 630+00 and embankment sections of Ramps B, C, and D.

Subsurface conditions at the site consist of approximately 10-13 feet of normally consolidated marine clay. This material is underlain by a loose, fine sand deposit which progressively becomes denser with depth. Laboratory and field tests indicated the clay material to have an undrained shear value of 200 psf and a compression index of 1.06.

The original roadway design specified a displacement treatment with a subsequent addition of surcharge loading. The surcharge height varied according to the embankment loading and the minimum time for surcharging was one year. This design was undesirable for two reasons: First, the one year surcharge delay would place an additional traffic strain on the already congested Interstate. Second, the westbound portion of the project is adjacent to New Market Creek and other environmentally protected marshlands. It was felt that a displacement treatment might cause excessive environmental disturbance within these areas. Excavation of the compressible material was also considered undesirable for environmental and economic reasons. The only acceptable alternate in addition to stone columns was a structure. Based on economics, the structural alternate was rejected except for Ramp A.

During the fall of 1977, a field testing program was conducted to validate the undrained strength of the columns and to secure field data concerning their longterm load-deflection behavior. Test section results indicated that total settlement and time rate of settlement conditions were improved significantly by the stone column installation. The results also showed that properly arranged column rows could provide a factor of safety exceeding the required 1.3 for all embankment sections. A typical embankment section is shown in Figure 6.

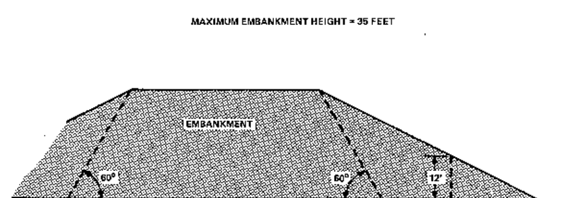

Figure 6. Typical Cross Section - Ramp Areas of Virginia Project

The maximum embankment height is 35 feet and center to center column spacing varies from 5.0 to 8.0 feet. The column spacing selected depends on the height of embankment and column location within the embankment prism. In zone A, the limiting design criteria was settlement while in zones B and C, stability was used to determine column spacing. A monitoring program will be implemented during construction to check design assumptions. Column construction should be complete by May 1979.

<u>Sioux City, Iowa</u> - This project is located at the I-29/US 20 Interchange in Sioux City, Iowa. A portion of the interchange configuration requires the construction of two Reinforced Earth walls approximately 35 feet in height. Stability analyses of the wall sections indicated minimum safety factors around 1.0. Subsurface conditions consist of approximately 25 feet of loess material, underlain by a shale bedrock. Laboratory shear tests indicated the loess to have a c = 400 psf and angle equal to 8 degrees. Stone columns were selected to increase the minimum factor of safety to 1.5 along the entire length of both walls. Figure 7 illustrates a plan and profile view of the stone column treatment. A typical cross section of the final design is shown in Figure 8.

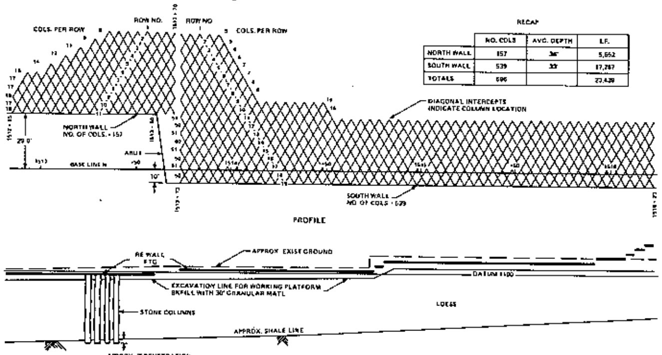

Figure 7. Plan and Profile Views - Sioux City, Iowa, Project

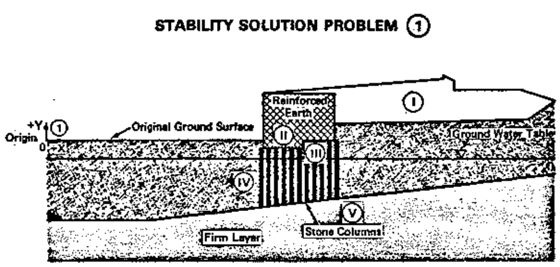

Figure 8. Proposed Stone Column Solution - Sioux City, Iowa

Although stability was the critical design consideration, column installation also reduced anticipated settlements by approximately 65 percent from the originally anticipated 2.3 feet. Column construction is scheduled to begin during the winter of 1979.

<u>Vicksburg, Mississippi</u> - The proposed project involves construction of a hospitality station on the east escarpment slope of the Mississippi River just north of the Interstate 20 bridge crossing over the river (Figures 9 - 10).

The construction area slopes downward toward the river from U.S. highway 61 on a slope of 1 vertical to 4 horizontal. The subsurface soils consist of a thick deposit of medium dense silt underlain by stiff to very stiff clays.

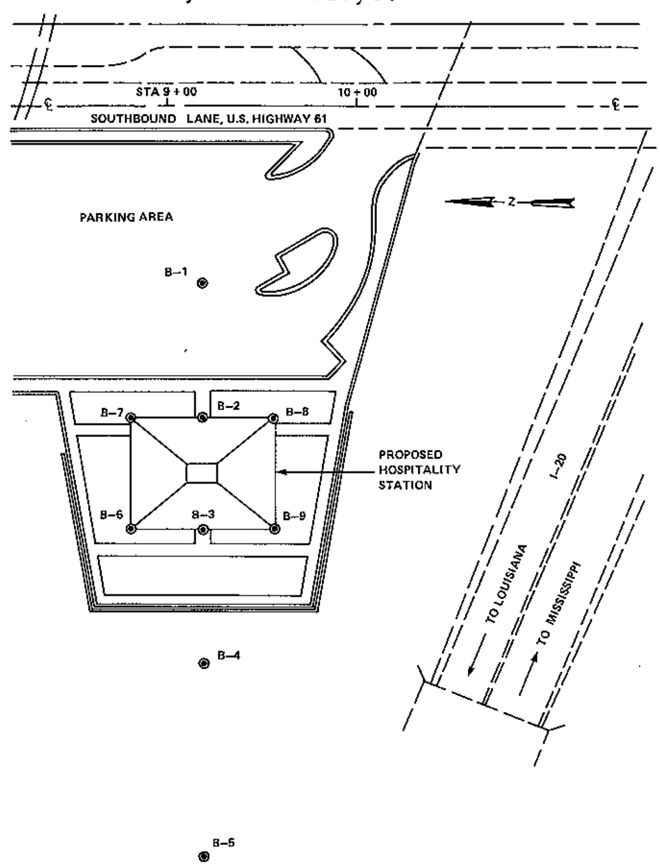

Figure 9. Plan and Boring Locations of the Stone Column at Vicksburg, Mississippi

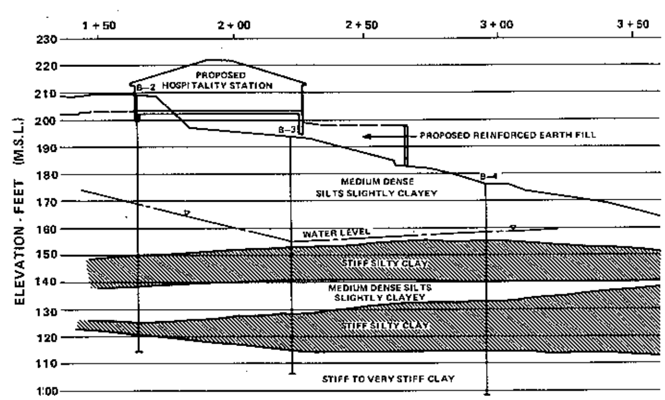

Figure 10. Soils Profile - Vicksburg, Mississippi, Hospitality Station

The areas north and south of the project have been repeatedly troubled in the past by landslides. The hospitality station is 60 by 80 feet in plan area and requires fill heights up to ten feet beneath the building and up to 16 feet in a scenic overlook area. Stability analyses indicate the safety factor of the slope as it presently exists is 1.04. The additional weight of the completed hospitality station and fill material would further reduce the factor of safety. A safety factor of 1.5 is desired for the completed facility The stabilization method selected involves 23 rows of 4-foot diameter stone columns (Figure 11). Column construction is scheduled to begin during the winter of 1979.

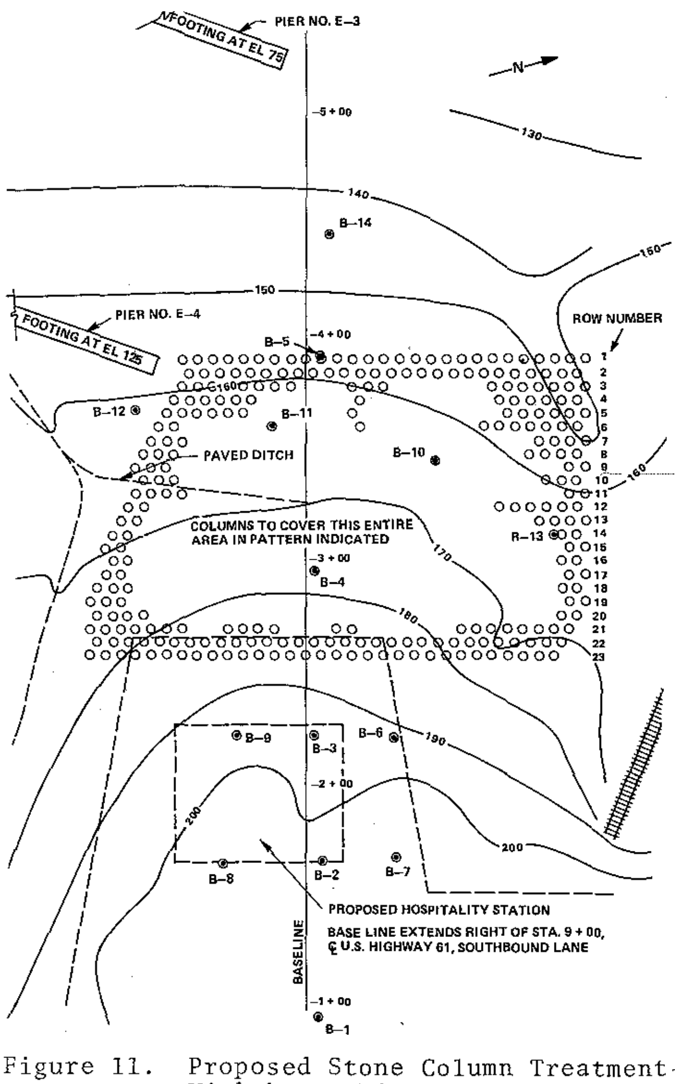

Figure 11. Proposed Stone Column Treatment-Vicksburg, Mississippi

CONCLUSION:

The application of stone columns can provide positive and cost effective solutions to many transportation design and construction problems. The Federal Highway Administration has developed a demonstration program directed at further implementation and development of this system on transportation facilities. Several example projects which have utilized soil columns were described.

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