Utilisation du renforcement des sols en génie civil

Use of soil reinforcement in civil engineering

La session est ouverte sous la présidence de
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My name is David Gedney. I am Director in the Federal Highway Administration, as well as Director of Engineering in the Federal Railroad Administration for the High Speed Rail Program, U.S. Department of Transportation. It is my pleasure to serve as your chairman today for the session entitled, "The Use of Soil Reinforcement in Civil Engineering". According to the original program there were some 28 papers submitted for this session. However, we are not exactly sure how many of these papers are reproduced in the proceedings. There seems to be some confusion between the programs and the published proceedings. In any event we will proceed with a very interesting session. Not to take issue with Professor Kerisel who indicated that yesterday should be the most interesting session, but I believe that this is the most interesting session of the conference. First I would like to exercise the prerogative of a chairman and speak a few words on behalf of my own experience in reinforced earth and why perhaps I am here before you today.

In 1968 I was approached by Mr Gérard Godet for discussions on the subject of Reinforced Earth, which was new to American engineering. Mr Godet suggested that the Federal Highway Administration would be interested in considering the economies and possible engineering solutions by using a material called "Reinforced Earth". Again in 1969 Mr Godet, accompanied by Mr Henri Vidal, visited my office with much detailed information about the use of Reinforced Earth in civil engineering works. The Federal Highway Administration has a principal role in seeking economical engineering solutions to a very large and massive highway engineering program. We currently expand some $ 8 billion per year in construction and must seek new methods of doing engineering works which conserve dollars and construct high quality civil works. Thus, one of the goals of our program is to seek new ideas.

As a result of Mr Godet's visit, our staff began to examine the concept of a reinforced earth material as it related to the U.S. highway system. We researched all of the literature that Mr Vidal left with us and through our research offices evaluated 5 years of research Vidal had with the L.C.P.C. as well as with others. I Subsequently visited many of the works that were in effect in France in 1971, after which I made the recommendation to my superiors that the U.S. Federal Highway Administration sponsor an experimental project using Reinforced Earth materials.

In our country experimental projects are used for the purpose of demonstrating the utilization of a new method or new material of great promise into an actual construction project where intense observations are made of performance in place. As you know, in the United States of America we work with the 50 States, each State having its own separate Highway Depatment. The Federal Highway Administration serves as technical experts and advisors and also as the major funding agency for the works that are to be accomplished. A decision to proceed with an experimental / demonstration-type project was initiated with the idea of using a very simplistic problem as the first candidate for construction. Since engineering is in the practical world, the first problem encountered which offered a unique solution for the use of Reinforced Earth, was shown yesterday on Highway 39 in the Angeles National Forest (San Gabriel Mountains). This particular section of highway had been destroyed by a large avalanche. The first design proposal by the California Department of Transportation was to construct a very deep pile foundation with a rigid bridge structure. The cost for this construction was far more than the Federal Highway Administration was willing to support since the roadway served primarily for recreation and forest fire control. Thus, we were able to quite readily decide that, despite the magnitude of the problem, an experimental project using reinforced earth would be designed. In conjunction with the California Department of Transportation and with the assistance of Terre Armée here in Paris, a design was prepared.

In order to convince the California Department of Transportation, who in the end must maintain this particular section of road after construction, the Federal government agreed to finance the major portion of the investment as well as to guarantee its success. The order was placed with the metal and strips manufactured and imported from France by ship. A contract awarded for the project construction included the installation of an elaborate drainage system below the earth and rock fill material placed as a foundation to receive the Reinforced Earth wall. Because the construction site was in a remote mountainous area, and because good quality construction was necessary, much detail was given to control of the contractor's efforts. I think it goes without saying in the reinforced method that the quality of the back fill is directly related to the success of the wall construction. In the end, the wall was constructed to the designed specification and has been serving successfully now for almost 6 years.

With that one project in California we were able to go forward and develop more uses, not only for the metal faced walls but also for the newer concrete facing blocks. In fact, the concrete facing proved to be the more aesthetically pleasing choice on United States projects. Concrete walls are architecturally acceptable, easy to construct and have proven to be the most econo mical approach to many of our difficult engineering desing problems.

A reinforced Earth Company was established in America in the early 1970's with a competent high-level technical staff, presently headed by Mr David McKittrick who quickly became able to respond to the needs of the Federal Highway Administration and to the State Highway Departments throughout our country. When problems arose it was not difficult to receive the technical attention required. With the birth of Reinforced Earth in our country we immediately saw improved economies in many o: the previously considered design alternatives.

I have been away from the subject of Reinforced Earth and its application directly for some years now ; however, I was indeed pleased with the many papers that were presented yesterday. From those papers, I conclude that we have gone through many degrees of refinement in the design procedures, and to a better understanding of the interaction between soil and the reinforcement members and between the soil reinforcement members and the various facing elements. I was indeed also pleased to note that the finite element methods of analysis, the discrete and the composite analyses, all lend themselves to further understanding of the interaction of the various components of Reinforced Earth as a construction material. However, at the end of a day I was also able to discern that the original design approach suggested by Mr Vidal still held true. That approach may prove to be somewhat conservative, but as a practical engineer I am not fearful of being conservative with a truly economical design solution. I salute those who continue to effect design economies because as you know, construction costs have tripled in the last 5 to 8 years.

At the conlusion of yesterday's session, I felt very, very happy about the experience and gratified to Professor Kerisel, Dr Mitchell, Professor Schlosser, and to all of the other speakers who spoke so well and who have done such good work on the subject matter presented. It certainly gave us the challenge and the introduction to today's session on "Soil Reinforcement in Civil Engineering".

The session will go as follows : first, our general reporter, Dr Deinhard, will give his summary of the papers that were presented to the Conference on the subject of soil reinforcement. Then we will have additional speakers who will be presenting papers invited by the general reporter, Dr Deinhard. Now, I would like to introduce to you our general reporter for this morning's session, Dr Martin Deinhard, who is Director in the Highway Administration in Hessen in charge of engineering and construction. Dr Deinhard received his technical training at the University in Darmstadt and completed his doctoral thesis in 1962.

Rapport général - General report

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I. INTRODUCTION

The topic of session II is the "use of soil reinforcement", "reinforced earth" and other techniques, in civil engineering.
Before giving a review of selected papers I should like to make some general remarks.

For session II 28 papers have been submitted. About 85 % of these papers deal with the method of "reinforced earth", the rest with other techniques e. g. root piles, stone columns and other reinforcements.
Since the majority of these papers concern "reinforced earth" I would like to concentrate on this technique in my report.

There are some difficulties in the interpretation of the papers which contain no printed illustrations at all. In case this results in misleading conclusions, I wish to apologize in advance!

II. "REINFORCED EARTH" IN CIVIL ENGINEERING

"Reinforced earth" is a composite material formed of reinforcements and soil fill for the construction of different retaining structures. During construction of a "reinforced earth" retaining wall the reinforcing strips are successively placed in layers within the reinforced volume which transform the developed tension by friction into the fill. Such a reinforced "massiv" is thus similar to reinforced concrete which is capable of bearing tension forces in the direction in which they are subjected to tension. Thus the soil itself performs the function of a main construction element. A facing made either of concrete or steel only prevents the flowing away of the soil between the reinforcing strips.

The reinforcing strips, smooth or ribbed are made of galvanized or stainless steel for corrosion protection, or of plastic. For the fill, a soil with no more than 15 % passing through the 0,06 mm sieve will be used. This soil will be placed in layers of 30 to 40 cm and compacted like an earth embankment. For corrosion protection the soil has to fulfill certain physical and electro-chemical requirements. The facing can be made either of precast panels or of steel profiles.

Due to their great flexibility "reinforced earth" structures are not sensitive to differential foundation settlements. They are similar in settlement behaviour to conventional earth embankments. In the case of poor foundation soils, conventional rigid reinforced concrete structures have to be founded in deeper layers of soil because they are incapable of differential settlements when founded in the poor foundation soils mainly in longitudinal direction. Also, due to the vertical flexibility of the facing in longitudinal direction these differential settlements could easily be withstood by "reinforced earth" structures. Therefore, often costly foundations which have to be taken into account when designing conventional retaining structures could be avoided and instead "reinforced earth" retaining structures could be used.

The authors of "reinforced earth" papers describe mainly case histories of real structures, which could be divided into the following 4 main sections:

1. Highways in the mountains and urban areas, railroads, abutments

2. Housing and landscaping

3. Industrial projects and special uses

4. Buildings in contact with water (waterways, canals, hydraulic structures)

In his paper DARBIN (1) gives a report about 14 years of "reinforced earth" applications all over the world. In 1964 the first "reinforced earth" structure was erected in Pragnière/France.

Since then, up to the end of 1978, about 2.260 structures have been built in 28 countries of 5 continents. The total of these structures have a facing area of about 1,35 mill. m^2. Most of these are in France, Spain, in the United States and Japan. About 83,5 % of all erected structures belong to the main section "Highways, urban expressways and railroads". 12 % were structures for industrial projects and about 4,5 % belong to the section landscaping and housing. In most of the countries, "reinforced earth" is part of the standard engineering know how. Standards and specifications were worked out in France, Great Britain, in the United States and in Germany.

In the following I would like to give a review of different papers. Some authors have been advised by me to present their papers themselves, since their contributions are in my opinion interesting and representative enough to merit more than just a mention in an overall review.

II.1. "Reinforced earth" structures in the mountains and urban areas, railroads and abutments

II.1.1. HIGHWAYS

The flexibility of "reinforced earth" structures is well-known. As an alternative construction method to viaducts and founded conventional angular retaining walls this method could successfully be used for retaining structures on unstable slopes.

The significant reducing of the volume of embankments, particularly of fill slopes across deep narrow valleys. In case of widening of an existing highway the weight and the spread of the embankment are reduced by elimination of a slope. Instead of the slope a retaining wall will be arranged.

Spread should be eliminated, particularly if there are difficulties in land acquisition or if there is no right-of-way where a wall arrangement or access ramp for trucks can be constructed.

Consideration must be given to protection of the "reinforced earth" against future excavations. The possibility of unauthorized excavations and damage to the reinforcement by mechanical excavations should also be foreseen. Standard signs are placed on the walls as a warning against such abuse either by digging at the top of the wall or too close and too deep the bottom of the wall. If an excavation is required, it will be provided for.

An interesting case history on the above mentioned problem was announced by AMAR, KÖNIG, PERRIN and others (2) in their paper. For the approach to the Fréjus tunnel a road had to be constructed along the hillside. The slope of this hillside had an angle of inclination of about 42°. To build the road, a fill with a crest width of 13,5 m had to be placed. In order to construct this project, different retaining methods together with cut and fill had to be taken into account with the following functions:

1. Retaining structures below the road surfacing carrying the road
2. Retaining structures above the road surfacing carrying the slope

For the first category "reinforced earth" structures were chosen because of their great flexibility. The second category was constructed with so called "Peller-Zellen-walls" (like a crib wall) because of minimum cut requirements.
In regions with steep slopes where retaining walls have to be excessively high, combined construction methods, anchored walls together with "reinforced earth" structures carrying the approach to the tunnel, have to be taken into account.

Before starting the construction of the "reinforced earth" structures, a test reinforced earth wall was erected to study the deformations on a slope which was suspected to move about 10 cm per year.
Even if all of the retaining walls of the project are not yet finished the following conclusions can be drawn from the investigations:

1. Designing of structures on unstable slopes has to take account of practical construction sequences in advance
2. Application of "reinforced earth" is possible in spite of great deformations
3. A short time stability of excavation slopes during construction is necessary, if not, special measures e. g. anchored walls of the building pit have to be taken into account
4. Retaining structures of crib wall type are especially economical where minimum cut requirements are necessary

The paper by LUGIEZ and CAUSERO (3) reports on highway retaining structures which were excellently designed to fit in with the environment of the countryside.

During construction of a new highway route A 34 Paris - Strasbourg the road had to pass hillsides and cross valleys close to Saverne.

As an alternative to conventional hillside bridges, the opposite directions of the expressway have been divided and separated by a "reinforced earth" wall which is about 2 km long.

Furthermore, "reinforced earth" retaining walls were placed to secure the slope above the road. All the "reinforced earth" walls present about 19.000 m^2 of wall facing. The max. height of the walls is about 8 m.

The architectural facing of the walls was selected to avoid any impression of monotony.
The structures at Saverne seem to me to be an excellent example of good teamwork between civil engineers and landscaping staff.

The authores FERNANDEZ, VALCARCEL and RUIZ (4) describe in their paper the constructions of the new highway "Bilbao - Saragossa" which is situated in a mountainous area of Spain. Unstable slopes and poor foundation soils led to the construction of 68 interesting "reinforced earth" structures with an overall facing area of about 60.000 m^2 and a height up to 19,50 m.

The majority of the retaining structures were constructed as normal "reinforced earth" retaining walls. In special cases some retaining structures were erected in "reinforced earth" in the upper part, with reinforced concrete in the lower part, to prevent water erosion along river banks and to construct the walls with a minimum of excavation.

II. 1.2. <u>RAILROADS</u>

The contribution of VERRIER (5) shows the application of "reinforced earth" to railroads.

To connect the town of Cergy-Pontoise with the existing railroad system, a new railroad track had to be constructed along the river bank of the Oise. The river had to be crossed by the track. The ramps of the required bridge were within the influence zone of the highwater of the river. Therefore, certain special measures had to be taken to ensure the stability of the construction. The ramps were constructed in the lower part as sloped earth fill, and in the upper part as "reinforced earth" structure.
The railroad track takes two rails having a crest width of 11,4 m. The underlaying reinforced volume supports these rails directly and is able to resist vibration and heavy traffic loads. The structure is up to 6,60 m high and about 360 m long.

It is the first "reinforced earth" structure in France which is directly under railroad traffic. To guarantee a design life of about 100 years 5 mm thick reinforcing strips were used together with a galvanization of 95 µm. So called "dead" strips were placed within the reinforced volume to control a possible corrosion process.

To prevent the reinforcing strips from electro-chemical corrosion due to the electric trains, certain special measures had to be taken:

1. The fill must show a significantly high specific electrical resistance

2. A plastic foil had to be placed between the railroad track and the reinforced volume

3. The contact between reinforcing strips had to be avoided

4. The foundation of railroad pylons had to avoid contact with the reinforcing strips

Apart from these problems, the heavy dynamic traffic on the reinforced volume and its response is of interest.

The following questions, among others, may be put to the author:

Have in full scale tests any dynamic measurements been taken at site?

If so, is there a change in the angle of friction between fill and reinforcing strips due to dynamic surcharge?

Is it possible to quantify the influential zone of the dynamic surcharge loads?

II. 1.3. <u>ABUTMENTS</u>

During recent years there has been a trend towards the standardization of bridges in short and medium spans. The standard components of "reinforced earth" provide a useful method of introducing some standardization of the design of abutments. Darbin gives a number of 531 abutments constructed in recent years.

In the paper "Spanish experience in construction of numerous reinforced earth abutments" the authors DESCHAMPS and RUIZ (6) analysed the experience obtained in the construction of 332 Spanish "reinforced earth" abutments.

"Reinforced earth" has two essential functions:

1. Vertical limitation of the embankment (earth pressure)

2. Supporting of the bridge desk by using a concrete sill-beam which lies on the

top of the "reinforced earth" structure (loads of traffic and desk)

By single span bridges there are no problems with different settlements.
Most of the expected settlements occur during the construction of the embankment and prior to the casting of the sill-beam. In any event smooth transition from the bridge to the embankment is an advantage of "reinforced earth" and the "bump at the end of the bridge" is eliminated.

But in a statically undetermined bridge system special precautions against different settlements have to be taken, for instance, steel or concrete piles arranged inside or outside of the "reinforced earth" mass.

In some cases it is necessary that special measures have to be taken to stabilize a poor foundation soil with

- stone columns,
- vertical drainpipes
- or precompression etc.

to obviate the base failure and to obtain a quick settlement. With normal foundation soil and a span of more than 8 m the authors noticed that the "reinforced earth" abutments have an economic advantage of up to 25 % in comparison with conventional abutments. When the foundation soil has a low bearing capacity the solution of "reinforced earth" abutments should be more economical than 25 %.

SIMS and JONES (7) found the same result in their paper "Use of reinforced earth in highway schemes".

The authors FERNANDEZ, VALCARCEL and RUIZ (4) describe in their contribution "Bilbao - Saragossa" the construction of several "reinforced earth" bridge abutments.
The main advantage was that these abutments could be erected in connection with the on-going earth embankment placement.

The paper of BOGOSSIAN, RODRIGUES and LIMA (8) gives a quite recent example of a "reinforced earth" abutment near the City of Curtaba in the State of Paraná, South Brasil.

The abutment has a maximum height of 9,0 m. The subsoil consists of silty clay, and the water table was met at a depth of 2,5 m. The most economical solution was a "reinforced earth" abutment. The soft soil was particularly displaced by compacted fill in addition of "wood piles" and ditches refilled with crushed rock.

VERGE (9) reports on the increasing application of "reinforced earth" abutments in Australia. Since the first "reinforced earth" bridge abutment was completed at Swanport, South Australia, bridge designers there have gained confidence in this new technique.

The advantages are that unskilled labour can be used and this method is more economical in comparison with conventional techniques.

In general, the simplest arrangement is the open abutment with walls generally parallel to the lower way. "Reinforced earth" abutments support a 13,5 m single span concrete bridge at the Swanport deviation and a 32 m single span at Botany, Sidney.

Concrete facing panels are generally used for bridges in urban areas, steel facing panels have been used in remote areas such as industrial regions.

The bridge over Darlin Mill Creek on the North Parramatha By-Pass arterial road has a central span of 15,0 m and two side spans of 12,0 m. The vertical load is supported by steel piles within the "reinforced earth" mass. The "reinforced earth" wall withstands the embankment. The Francis Road overpass at Blacktown required a special solution: The superstructure was placed on columns in front of a "reinforced earth" wall to withstand the embankment. Horizontal forces from the superstructure are transmitted to the "reinforced earth" mass by a combined concrete thrust block and a relieving slab.

II. 2. "Reinforced earth" in housing and landscaping

"Reinforced earth" is applicable also in landscaping and housing. Well-known is the construction of terraces with "reinforced earth" retaining structures in some areas were the economical usage of costly ground is possible.

A new approach of connecting landscaping and housing is described by LEVISALLE (10). The new technique is called "Architerre-Habitat-Paysage". The main difference between the known applications and this new technique is the double function of "reinforced earth" as retaining wall on the one hand and as wall of a house on the other. Mr. Levisalle will give a short report of the application of the "Architerre-Habitat-Paysage" technique in Southern France and Spain.

II. 3. Industrial projects and special uses

"Reinforced earth" walls are being used for industrial applications, such as loading ramps at mines and for bulk facilities. The trucks and loaders at these sites impose large forces on the walls which are similar in principle to the bridge abutments.

The ability to erect a "reinforced earth" structure without any special skill has often been a consideration.

Since 1975, 12.000 m^2 "reinforced earth" retaining walls have been completed in the mining industry of Southern Africa. According to the paper of SMITH (11) the use of "reinforced earth" can be classified into three categories:

1. The "tip-walls" are required by all open cast mines to tip the ore load into receiving bins. The L-shaped tip wall at the Sampling plant of the Consolidated Diamond Mines is 21 m high and got a cathodic protection on 3 mm thick black steel reinforcing strips, because the only available backfill materials are clean marine sands with very high chlorid contents.

2. Another use of "reinforced earth" is to be found on "ore storage facilities". Stockpiles of coal mines often need a slot running beneath its entire length. If this slot is in soft material the sloping sides can be protected by "reinforced earth" facing panels. 1978 at Slifontein an ore storage facility for 10.000 tons has been executed in this manner.

3. Diamond mines require water and gravity to select diamonds from clay and sands. "Reinforced earth" is used to provide the vertical faced terraces, the so called "gravity feed plants". For example, the "Tweepad" structure is extremely high. One of the walls is 27 m high and is thought to be the highest continuous "reinforced earth" wall ever constructed.

In his paper Mr. McKITTRICK (12) outlined several of the most significant applications of the special use of "reinforced earth" structures in the United States.

These projects were secondary containment dikes for crude oil and liquified natural gas terminals, sedimentation basins for the retention and clarification of contaminated fluids, and foundation slabs designed to span potential sinkholes of 10 to 15 m diameter.

Special testing procedures have been developed to assess the performance of the structural components under unusual structural, thermal and hydraulic loading and special construction procedures have been developed for each of these applications. In the case of slabs, special design procedures have been developed to estimate deflection in the case of sinkhole collapse.

II.4. "Reinforced earth" in contact with water

In the paper "reinforced earth used as supporting structures in hydraulic engineering" Mr. MALUCHE (13) described some retaining walls, which were built on the banks of the river Saar.

During the high water period of the river Saar the "reinforced earth" structures are submerged, therefore they had to be designed and constructed in accordance with hydraulic requirements. In this case, the "reinforced earth" walls are hydraulic structures.

The largest "reinforced earth" wall, built in Germany, is on the highway route A 8 near Saarbrücken close to the river Saar. The wall is about 6,0 - 7,30 m high and 970 m long and separates, in the form of a quay wall, the highway from the river Saar.

The "reinforced earth" structure could be built in the dry due to waterway regulation works of the river Saar.
Since the wall is subject to the influence of annual highwater of the river Saar, during high water period 60 % of the "reinforced earth" structure is under water, certain special construction measures have been taken:

- A specified filter gravel behind the panels has to guarantee that in case of a sudden drop of the water level there will be no greater difference in front and behind the panels than 0,5 m.

- Woven filter material was glued behind the panel joints to prevent fine particles of the filling to be washed out during high water.

- As a specific German requirement it was necessary to arrange a PVC-foil on the top of the "reinforced earth" body to prevent the penetration of surface waters containing calcium chloride into the construction.

- So called "dead reinforcing strips" were placed all over the "reinforced earth" structure in order to investigate in certain time steps the corrosion progress of the reinforcing strips.

Recesses are built into the panels through with the dead strips can be pulled out with hydraulic jacks.

An interesting case history on the application of "reinforced earth" in coastal highway engineering is described by GAGNON (14) in his presentation.

At the bottom of a steep slope along the St. Lorenz-river close to Mont St. Pierre a "reinforced earth" retaining structure was built. The structure had to withstand tidal water table differences and heavy pressures due to floating ice on the St. Lorenz-river and had to be designed against this environmental occurrences.

Parts of the wall are submerged by sea-waters with high salt content. Therefore the reinforcing strips had to have a corrosion reserve of about 3 mm. The structure is designed for a design life of more than 50 years.
The concrete facing panels were especially designed for this application so that they can be erected without the conventional construction aids as e. g. strutting. Due to the placement of breakwaters on top of the wall the overall height of the structure could be reduced. The breakwaters were especially developed for this retaining structure.

In their paper "use of reinforced earth in dams" Mr. TAYLOR and Mr. DRIOUX (15) describe the necessity of the adaption of the reinforcing in the crest zone to take account of the upstream face and analyse the possible economies to be made by this type of dam.

The application of "reinforced earth" seems to be reasonable and economical. A 9 m high structure close to Vallon des Bimes is already in service and fulfills satisfactorily the technical requirements. It must still be investigated whether this method is applicable to higher dams.

II. 5. "Reinforced earth" - conclusion -

The presentation of the "reinforced earth" papers shows that "reinforced earth" is accepted on a world wide basis as retaining walls and bridge abutments for highways, expressways and for other structures serving various purposes in industrial, civil and waterwork projects.

Substantial cost savings can be made by the elimination of conventional foundations, short construction time and the use of unskilled labour.

III. OTHER TECHNIQUES OF SOIL REINFORCEMENT

A few papers describe other techniques of soil reinforcement. To improve the bearing capacity and to reduce settlements of soft soils under railways, dams, abutments, industrial structures the applications of soil reinforcement may be used.

III. 1. Stone colums

The stone column procedure of strengthening cohesive soils in situ was developed in Germany about 25 years ago. Column construction is accomplished by penetrating the soil by a vibrating probe.
The vibrator, that is a sort of vibro-pile, sinks under its own weight with the assistance of vibration and water into the ground until it reaches the predetermined depth. When the vibrator is withdrawn it leaves the borehole. The borehole is filled with gravel or crushed rock. The vibrator then repenetrates and displaces the fill material horizontally into the native soil. Alternating backfilling and compaction forms continuous stone columns.

The diameter of the stone column varies between 0,8 up to 1,0 m. Stone columns are generally installed in a square or triangular grid pattern.

The paper of DIMAGGIO and GOUGHNOUR (16) reports on a demonstration program developed by the US Federal Highway Administration to impart a basic understanding and to expand existing knowledge to the transportation agencies.
The method has been successfully employed in upgrading of existing facilities.

The Clark Fork Highway, Idaho, was aligned along the shoreline of Lake Pend Oreille. The position of a railroad forced the alignment out into the lake. An 8,0 m high embankment had to be constructed. The accepted solution was a flexible "reinforced earth" dam supported by stone columns on 2,0 m centers.

In some other case studies, stone columns were performed instead of structures.

III.2. Root-piles

When a slope is weathered and fractured, a solid retaining wall will be placed at the foot of the slope, but the upper zone must be protected from the landslide by special methods.

SUSUMU and IWABUCHI (17) describe in their paper examples of a method used in Japan with so called root piles.

The authors describe the application of root-piling in the highways of Kanagawa and Shiznoka. Near the town of Yamaguchi a landslip zone with an angle of internal friction of 8 degrees was consolidated by reinforced grillage girders and reinforced anchors.

As design system the following 2 types can be thought:

TYPE I:
The slope achieves its stabilization by forming the gravity structure using the matrix of the inside of the slope. This gravity structure is consolidated by concrete facing, which consists of reinforced shotcrete, grouting and steel members.

TYPE II:
The necessary zone of a loosened mass on the inferred sliding-plane is consolidated like type I, but, in addition to this method, the consolidated mass is firmly anchored not by steel members but by prestressed anchors.

The behaviour of stone column load settlement in soft clay has been studied by BROWN, JONES, MAYNE and DIMAGGIO (18).

A parameter finite element study utilizing hyperbolic stress-strain curves was conducted. In connection to a field load test it was found:

1. Stone column load settlement curves could be normalized by plotting vertical settlement/column diameter versus the ratic axial load/stone friction angle.

2. More than 50 per cent of axial load is transferred from the stone column to the clay within a depth of one column diameter.

III. 3. Inset elements

MAGYARNE, SCHARLE and SZALATKAY (19) report in their paper on investigations of inset elements made in order to increase the bedding resistance. These tests are started by the Hungarian Institute for Building Science.

The deformations of thin-walled tubes and sewers depend on several factors, particulary on the bedding conditions. In loose soils the rigidity of the bedding can be improved by using inset elements enclosed in proper distance around the pipe. These inset elements may be used in many ways, for instance by reinforced prestressed arches.

III. 4. Barrage

CASSARD, KERN and MATHIEU (20) suggest the application of reinforced technique in earth dams. We can either improve the resistance of the down-stream embankment or permit the realisation of a vertical retaining wall in the down-stream portion. In the first case, the embankment gets an edge reinforcement, consisting of riprap and fabric stripes.

In the second case, for instance, in the Vallon des Bimes, (Bimes-valley), a vertical "reinforced earth" structure combines the advantages of an earthern dam and a spillway sill.

III. 5. Embankments

As suggested in the paper of SIMS and JONES (7) , the bearing capacity of embankments can be increased by reinforcement. An uniform compaction throughout the embankment and an equal settlement are encouraged, the spread of the embankment can be reduced.

This reinforcement consists of:

- sub-soil reinforcement
- internal reinforcement and
- an edge reinforcement.

There is a need to provide a self supporting edge around which reinforcement can be wraped. The use of lorry tyres can provide this function.

Practical design methods of an analysis are given.

III. 6. Conclusion

In review papers it becomes clear that soil reinforcements, for instance, stone columns, are a new building method for civil engineering.

Most of these methods are well-known and we have enough experience to check their success in the wide spectrum of civil engineering programs.

Ladies and gentlemen, I hope I have given you an adequate information about the "reinforced earth" method in my report and I am sure that possible misleading conclusions will be cleared in the following report of the authors and in the discussion.

Thank you very much for your attention!

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(8) BOGOSSIAN, F., RODRIGUES, L.F.V. and LIMA, S.A.
A Brazilian example of the application of reinforced earth founded on low strength compressible soils

(9) VERGE, G.C.
Reinforced earth applications for bridge abutments in Australia

(10) LEVISALLES, J.-F.
Use of the reinforced earth technique in the construction of housing

(11) SMITH, A.C.S.
Reinforced earth in the mining industry in Southern Africa

(12) McKITTRICK, D.P.
Special uses of reinforced earth in the United States

(13) MALUCHE, E.
Reinforced earth used as supporting structures in hydraulic engineering

(14) GAGNON, G.
Sea-wall constructed in reinforced earth

(15) TAYLOR, J.-P. and DRIOUX, J.-C.
Use of reinforced earth in dams

(16) DIMAGGIO, J.A. and GOUGHNOUR, R.D.
Application of reinforced earth in highways throughout the United States

(17) SUSUMU and IWABUCHI, S.
Root-piles for slope stabilization

(18) BROWN, R.E., JONES, J.S., MAYNE and DIMAGGIO, J.D.
A parameter study of stone column behavior

(19) MAGYARNE,J.M., SCHARLE, P. and SZALATKY, I.
Improvement of bedding conditions by inset elements

(20) CASSARD, A., KERN, F. and MATHIEU,G.
Use of reinforcement techniques in earth dams

Discussion

Question de M. MURRAY à M. VERRIER

Were there any restrictions imposed on the grading of the fill from the point of view of vibrations and is Mr Verrier aware of any possible adverse effects which might be produced if uniformly graded soil is used ?

M. VERRIER

Nous avons mesuré des vibrations dans un remblai normal, dans la région d'Arles, mais nous n'avons pas fait de mesures de vibrations sur un remblai calibré et en particulier de mur en terre armée. Je pense qu'on essaiera effectivement de le faire après mise en service.

Question de M. LEGEAY à M. VERRIER

Pouvez-vous préciser le genre d'expérimentation en cours, pour ce qui est de l'influence des courants électriques de fuite sur la terre armée (au laboratoire, in situ, ...) ?

M. VERRIER

L'influence est effectivement très importante en courant continu et actuellement nous avons exclu toute tutilisation en courant continu. En ce qui concerne le courant alternatif, l'influence est beaucoup plus faible, en particulier la génération de courants induits, par la longueur des armatures, c'est-à-dire par induction électromagnétique ; mais étant donné que les armatures sont perpendiculaires aux caténaires, cette influence est pratiquement nulle, surtout si on isole chaque armature. Si on crée une liaison électrique entre toutes les armatures, à ce moment-là on risquerait effectivement certains phénomènes. A titre expérimental, on a noyé les armatures dans un remblai qui se situe sur la ligne nouvelle qui se situe du côté de Carrières-sur-Seine, et qui peut être également influencé par des retours de courant continu puisque nous avons la ligne en courant continu du R.E.R. qui se situe à 1 kilomètre de là environ. Pour le moment il n'y a pas encore eu d'étude en laboratoire ; c'est d'ailleurs assez difficile.

Question de M. HOSHIYA à M. McKITTRICK

It is interesting that you made a comparative discussion on "two totally different, but resembling walls".

I like to know whether or not these two structures mutually violate each patents ? Did you talk with the International Enginerring Co. or Meheen International Consult Co., Colorado ? (I hear that Mr Meheen was the inventor of the tieback wall).

M. McKITTRICK

Now we have a question which is not philosophic, not technical, but legal...

M. GEDNEY

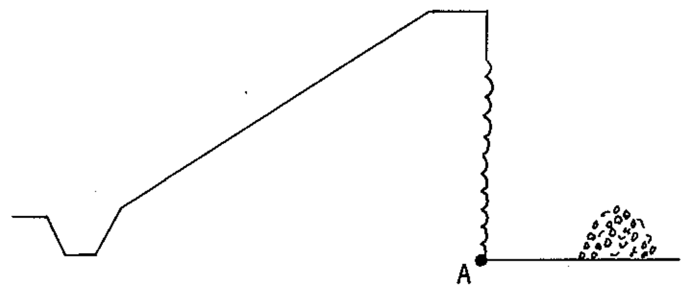
That may be why Mr Hoshiya is not here...

M. McKITTRICK

Let me attempt to describe the situation in Colorado. First of all the Reinforced Earth designs were developed in cooperation with International Engineering Company who was the consulting engineer for the Colorado Department of Highways for this particular project. The architectural design for the retaining walls through vail pass was developed by the Colorado Department of Highways in conjunction with the Frank Lloyd Wright Foundation in Arizona. Because the development of the architectural facing was done under a government funding situation, it is my understanding that no copy-right existed with respect to the visual appearence of the walls ; with respect to the structures themselves, they are completely different in concept and performance and therefore there is no interdependance of one design on the other and therefore it is my understanding there is no effect on the legal situation with respect to the proprietary rights in each system. The tie-back system designed by the engineering company who worked with International is a more or less classical rigid tie-back system, in which the facing panels act as compression members spanning between the counterforts or the ties. The Reinforced Earth system used is a classical Reinforced Earth system, that is the facing is simply an architectural facing, it is flexible as in all reinforced earth designs, and the structure itself is a combination of the reinforcements and soil. Therefore, I am confident that there is no violation of any proprietary rights and that, in summary, copyrights did not exist because of the Federal funding on the project.

Question de M. RADUKIC à M. CASSARD

The question is related to use of Reinforced Earth in embankment engineering. It actually shouldn't be restricted to Mr Cassard but I quoted it because it is the only paper mainly dealing with the subject. This kind of technique offers considerable savings in embankment engineering provided long-term safety is ensured. I illustrate it by the development of cofferdam design. When dealing with big rivers, the classical design with the cofferdam diversion tunnel is not anymore accepted. Cofferdam and tunnels become to big and the probability of over-topping an unacceptable risk. Solutions developed later which are really rainfall downstream slopes, have been used a couple of times. Some failures have been experienced and the problem is that it is rather costly, requiring flood slope, rock fill and a lot of reinforcement. Dramatic improvement in cost can be achieved if we use Reinforced Earth. The problem is that we are depending on the height of the structure, we will actually produce regressive erosion attacking the structure at point A.



Trying to solve this we come to the next sketch which shows that providing a sort of a water cushion will diminish the risk of regressive erosion but then we have pulsating loading on the wall itself. Yet, this problem can be solved by the last sketch showing a sort of a filling basin but then we are back to the cost question where this combination can be more expensive than the simple concrete dam. Now the question first, how has this problem been solved by the structure mentioned in this paper, that is the design by Coyne et Bellier which is a dam of about 24 meters, if I remember correctly ; and second, is anyone aware of any research work going in this way ? We heard something about vibrations today, something about dynamic loads, but of course here the difference is that if the wall yields and fails, it is quite a different sort of a failure - a disaster into itself. I think that the cofferdam has a good possibility for having a full-scale structure instrumented for that sort of loading to see what happens under these particular conditions.

M. MATHIEU

Je ne peux répondre qu'aux problèmes posés par les deux barrages déversants qui ont fait l'objet de la publication de Messieurs Kern, Cassard et Mathieu, et en particulier aux problèmes du barrage à "boudins" qui a été envisagé dans cet article.

Cette digue déversante a été réalisée dans le Var, dans le cadre de l'aménagement forestier du bassin de Maraval.

Cet ouvrage a été construit sur un site géologique constitué de schistes altérés en rive droite et d'éboulis schisteux en rive gauche. Les fondations de l'ouvrage reposent sur des schistes plus ou moins altérés qui confèrent au thalweg une résistance moyenne à l'érosion.

Le profil type du barrage à "boudins" qui est reproduit dans la publication est incomplet. En effet, au-dessous du plan zéro indiqué sur le profil, nous avons été amenés, au niveau du projet, à établir un boudin de pied, qu'on pourrait assimiler éventuellement à un parafouille, mais qui constitue plutôt une assise de fondations descendant à environ 80 cm au-dessous du plan de référence. (Voir rectificatif du profil type).

Ce boudin, constitué de tissu, qui est en l'occurence du CXXX de Rhône Poulenc, a été rempli exclusivement de galets roulés.

Cette fondation ou "parafouille" aval est réduite à la hauteur d'un seul boudin, car les érosions sont limitées par la nature gélogique et la présence d'un bassin de dissipation à l'aval.

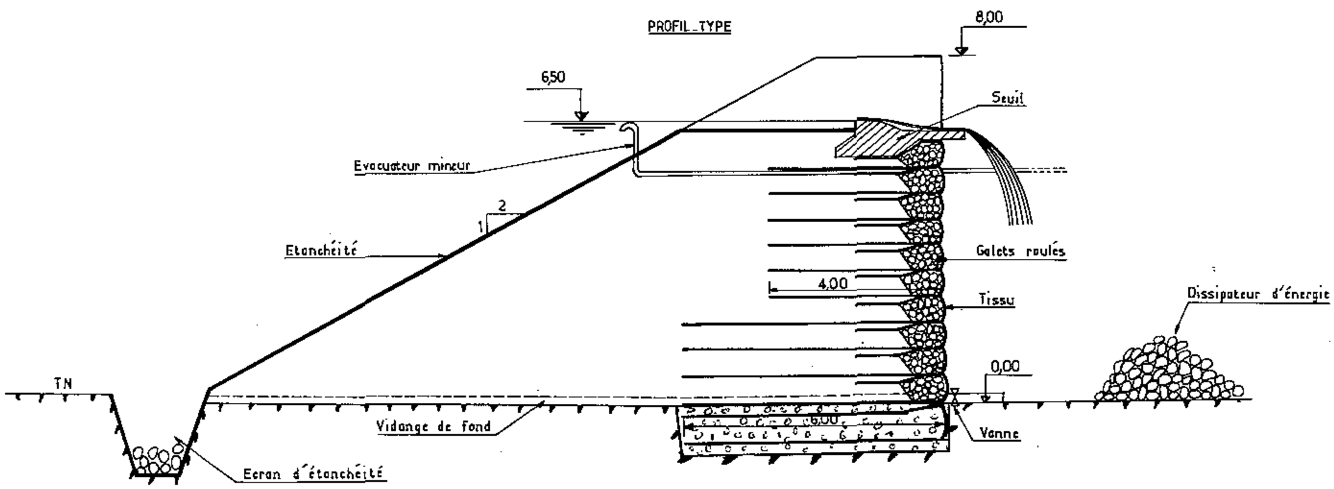
Il faut aussi remarquer que les crues observées dans cette région sont de faible durée, ce qui réduit dans de larges proportions l'approfondissement de la fosse de réception. Dans ce cas le Comité Français des Grands Barrages a admis une réduction notable de la hauteur des parafouilles avals.

Afin d'éliminer l'érosion résultant des petits débits, un petit évacuateur constitué d'un simple tuyau acier véhicule l'eau à l'aval.

Cet ouvrage à boudin n'a jusqu'à présent donné lieu à aucune manifestation anormale. De plus, il est important de noter qu'en cours de chantier, et alors que la partie déversante n'était pas encore construite, le barrage a été submergé par trois crues, et celles-ci n'ont causé aucun dégât.

La photo ci-dessous donne une idée de l'importance de la submersion.

Il est bien évident que dans le cas d'un ouvrage déversant sur fondation meuble ou rocher pouvant facilement se déliter, il serait obligatoire de prévoir un véritable parafouille et un bassin de dissipation d'énergie en béton armé ayant par exemple une forme en auge.

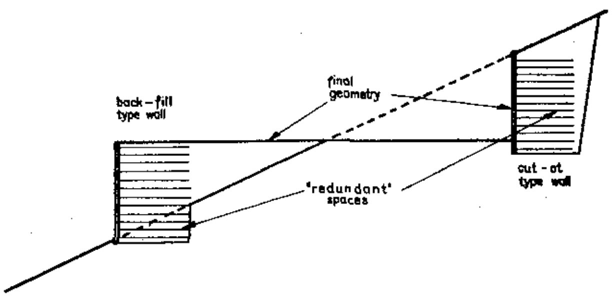


Echelle : environ 1/200e

Commentaire de M. SCHARLE

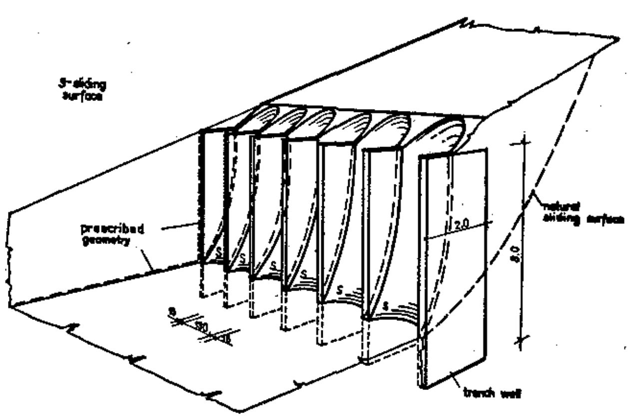
Professor Mitchell in his general report sketched out the bumpy road of developing a new structural concept. The background story of the reinforced earth, in a way, illustrates the eight periods mentioned by him, though - and thanks to God - the praise and honour is given to the worthies at this Conference. Considering the title with the reference "other techniques", I should like to present now a new structural concept, being in its first period of enthusiasm.

Maybe, for this reason, this presentation is somewhat early, but I can not resist the temptation to take the unique advantage of this conference, where the founders and experts of the soil reinforcement are among themselves and few words can be enough to outline an idea.



When a backfill-type construction is required, the reinforced earth wall seems to be optimum. But when you have to design a cut-out type retaining wall, there is some redundancy in the reinforced earth type construction, because the technology does not fit to the final geometry (Fig. 1).

Well, consider the idea. Let be given some prescribed geometry (Fig. 2). Narrow trench walls are built into the soil before any other site work - their dimensions are shown on the Fig. 2 as an example.



What happens when the soil is removed ? One can imagine with ease the double curved S surfaces as a result of the internal and soil-wall surface frictional resistance and the lateral arching effect. This latter one is well known and called as silo effect in vertical planes. In the given case the lateral earth pressure induces arching effect in the horizontal plane.

Naturally, a lot of questions - among others the type of soils coming up, facing, more elaborated statics, dimensioning - arise. To our up to date experience, most of these questions have been answered.

In the Hungarian Building Research Institute a model experiment of scale 1 : 4 is going on. It proved that the arching effect works, the sliding surface has much higher slope than the natural one. The details will be reported in a subsequent paper, but anybody interested in the results will be kindly informed directly, at request.