EARTHWORKS, DRAINAGE AND SUBGRADE

Tuesday 21 October 2003 (8.30 – 12.00 a.m.)

SESSION AGENDA & INTRODUCTORY REPORT

SESSION AGENDA

1. **Session Introduction**

Mr. Giorgio PERONI (C12 Chairperson/ITALY)

2. **Natural materials not compliant with specifications and relevance of earthworks control**

   a) **Limitations of the use of natural soil, specifications and controls in the earthworks**

   Mr. Hervé HAVARD (C12 member/FRANCE)

   b) **Frost action considerations in roadway construction**

   Mr. Edward J. HOPPE (C12 English-speaking Secretary/ USA)

   c) **Control of the platform and the road economy by using of the new method for evaluating rigidity**

   Mr. Hervé HAVARD (C12 member/FRANCE)

   d) **Sand compaction control by shallow CPTs**

   Ir. W.O. MOLENDIJK (GeoDelft/THE NETHERLANDS)

   e) **Motorway A29 – Optimization of the earthworks in a sustainable development prospect**

   Mr. D. DEMEILLIERS (SANEF/FRANCE)

   f) **Description of compacted sand/clay mixtures: compaction process and classifications of soils**

   Mr. Hervé HAVARD (C12 member/FRANCE)

   g) **Reutilization of degradable materials more or less fragmentable**

   Mr. Y. GUERPILLON (SCETAUROUTE/FRANCE)

Discussion

3. **Column Supported Embankments**

   a) **Column Supported Embankments**

   Mr. Chris DUMAS (C12 member/USA)

b) Improved reliability of (rest) settlement predictions of embankments on soft soils

Ir. W.O. MOLENDIJK (GeoDelft/THE NETHERLANDS)

c) Lightweight filling in road construciton - Current situation in Italy

Dr. Giulio DONDI (University of Bologna/ITALY)

d) Trial embankment on soft ground using lightweight foam-mixed in situ surface soil

Mr. Hiroshi MIKI (C12 member/JAPAN)

e) A method for the evaluation of maximum embankment settlement due the widening of the road cross section

Dr. Ciro CALIENDO (University of Salerno/ITALY)

Discussion

4. Slope risk guidance for roads

a) Slope risk guidance for roads

Mr. David PATTERSON (C12 member/ UK)

b) Evaluation and management of the crumbling risks on the difficult relief roads – The case of the national roads of Reunion Island

Mr. Jean-Jacques GUEGUEN
(Ministry of Equipment, Transport, Housing, Tourism and the Sea/FRANCE)

Mr. Marc CRUCHET
(Ministry of Equipment, Transport, Housing, Tourism and the Sea/FRANCE)

Discussion

5. Approval of conclusions

Mr. Giorgio PERONI (C12 Chairperson/ITALY)

CONTENTS

EXECUTIVE SUMMARY

PIARC Committee on Earthworks, Drainage and Subgrade (C12) has pursued the following topics during the 2000-2003 work period:

1. Natural Materials Not Compliant With Specifications and Relevance of Earthworks Control
2. Column Supported Embankments
3. Slope Risk Guidance for Roads.

The committee's activities are in alignment with the PIARC Strategic Theme 1 – Road Technology. The goal is to improve the provision and maintenance of road infrastructure in accordance with the international best practice.

It has been established that the practice of re-use of natural soils in embankment construction is quite prevalent in many countries. There are, however, significant differences in approaches to utilizing natural marginal materials. Some countries have very demanding specifications concerning materials selection, while others are very flexible with their acceptance. Factors such as climate and topography often affect what some countries may accept, while others reject.

In evaluating the effectiveness of earthworks control, it is important to recognize the project-wide impact and not focus on a localized failure. Many design and construction problems affecting earthworks can be traced to the fairly common absence of a comprehensive preliminary site investigation. Often, the embankment substandard performance does not result from inadequate compaction, but from a poor drainage.

The use of column supported embankments is not a new technology. Embankments on relief piles have been used for more than 60 years, and "modern" stone column technology was first implemented in Europe in the 1960's. However, the economic, political, and the technological changes and improvements have dramatically increased their usage worldwide within the last five years.

The column support technique allows for the construction of roadway embankments on sites otherwise unsuitable—from a bearing capacity, stability, and/or time of construction perspective. The benefits include significant reduction in, or elimination of, settlement magnitude and time. Modern equipment and geosynthetic reinforcements have dramatically improved the economics of column supported embankments.

C12 has decided to examine various column technologies and synthesize the current state of the practice. Technologies encompassed in the study include Stone Columns, Concrete Vibro Columns, Combined Stabilization with Vertical Columns, and Geosynthetically Reinforced Bridging Mats.

Geotechnical assets, being largely natural materials, exhibit more inherent variability in performance and sensitivity to long-term degradation. The consequences of their response can significantly influence life cycle costs and impact on public safety. Predicting the geotechnical asset performance is fairly challenging and not yet fully understood. The aim, however, must be to develop a concept of the “residual life”, which will allow effective evaluation and formulation of appropriate maintenance strategies.

C12 has concentrated on embankment slopes because of their greater frequency and consequence of failure than of any other geotechnical asset. Case studies from various countries were analysed. The scale of the problem ranges from the most devastating geo-hazards with threats to life and economies to one of nuisance, requiring increased maintenance effort.

The assessment of slope hazards and their risk has progressed significantly. The terms and the methodology for risk assessment are now well developed. The value and contribution of the geotechnical asset as a whole is now being quantified.

LIST OF MEMBERS WHO CONTRIBUTED TO THE REPORT

1. Principal Author: H. HAVARD (France)
   Contributing Members: J. NOMERANGE (Belgium),
   E. HOPPE (United States), C. AIME (France),
   M. de VAULX de CHAMPION (Belgium),
   C. BARBOSA (Portugal), E. DAPENA (Spain),
   D. PATTERSON (United Kingdom),
   G. TOPHINKE (Germany)

2. Principal Author: C. DUMAS (United States)
   Contributing Members: J. NOMERANGE (Belgium),
   A. PHEAR (United Kingdom),
   E. HOPPE (United States)

3. Principal Author: D. PATTERSON (United Kingdom)
   Contributing Members: J. NOMERANGE (Belgium),
   E. HOPPE (United States),
   H. HAVARD (France), G. PERONI (Italy),
   M. MAHMUD (Malaysia), S. DOROBANTU (Romania),
   A. PARRIAUX (Switzerland)

NATURAL MATERIALS NOT COMPLIANT WITH SPECIFICATIONS AND RELEVANCE OF EARTHWORKS CONTROL

At the last PIARC World Congress in Kuala Lumpur the Committee C12 considered the impact of environmental protection on earthworks. Seventeen countries contributed to the study, largely confirming the rigorous requirements of environmental protection and the need to develop techniques consistent with the principles of sustainable development. One of the tentative conclusions was that “great progress can be achieved in earthworks engineering through the increased use of excavated soils in fill construction”.

This notion became a topic area for C12 during the 2000 – 2003 work period. The study pursued two principal objectives:

- Can we increase the proportion of natural excavated materials in fill construction (re-use of natural materials) while assuring the required performance?
- What effective construction practices need to be implemented in order to assure that the material specifications and the required performance of the finished product are met?

The study was launched in February 2000, involving a detailed survey distributed in 38 countries. The survey addressed the issues of material classification and material acceptance criteria as related to the embankment and subgrade construction. Methods of control pertaining to drainage works were also added, since the study followed up on the conclusions stemming from the article No. 306 in “Routes/Roads” (Survey on the pathologies of embankments in service), indicating that many in-service embankment problems can be traced to a defective drainage system.

It should be emphasized that this study was limited to the re-use of natural marginal materials. The subject of utilizing waste and by-product materials was not incorporated since the scope of the study was already quite broad.

Thirteen countries responded to the survey: Germany, United Kingdom, Belgium, Canada, Croatia, Cuba, Spain, United States, France, Italy, Japan, Portugal, and Switzerland.

The results revealed a lot of methods that are not always easily comparable from one country to another, because the practices are often complex and related to particular circumstances. It was possible, however, to arrive at some conclusions aimed at improving the performance of earthwork projects.

Soil classification systems currently used in earthworks fall into three types:

- General classifications, often derived from the American methods such as USCS and AASHTO, used to define classes of soils with the associated applicability, requiring the person in charge to determine the conditions of re-use by taking into account the particulars of a project (in Germany and Switzerland, for example)
- Specialized classifications with a matrix of re-use not necessarily imposed by a designer. These classifications can still be based on the USCS or AASHTO, but also on the original classifications designed specifically for the purposes of earthworks (in Spain and France, for example)
- Classifications of needs (performance) and not of materials, as in the United Kingdom where it is defined what specifications must be met in order to be compatible with certain works. The same material can satisfy the criteria set for several classes of works. Such performance based classifications are in fact specifications.

It was observed that many countries use classification systems specific to earthworks and notably different from the ones used in other fields, such as in soil mechanics.

The rules of acceptance of soils for fill construction vary from country to country. Moisture content is generally characterized with a reference to the optimum value, as determined by the Proctor test (generally the Standard Proctor, but sometimes the Modified Proctor test is specified). Thresholds for acceptance vary widely for very wet soils. Many countries use lime treatment on wet soils in order to reduce the moisture content. Very little information was provided for soils that are very dry of optimum (difficult to compact for a stable fill).

Soils that are too plastic to be placed in a fill can be evaluated using only one threshold, for example in the UK (liquid limit greater than 90 or plasticity index greater than 65), in Croatia (liquid limit greater than 65 or plasticity index greater than 30), in Canada, Italy and Switzerland (more than 50% of fines), or by using several thresholds simultaneously, for example in Germany and Portugal (more than 40% of fines, liquid limit greater than 50 and the position on the Casagrande diagram), in Belgium (more than 50% of fines and plasticity index greater than 12), in Spain (liquid limit greater than 90 and plasticity index higher than 0.73xLL-14.6), in France (more than 35% of fines and plasticity index greater than 40).

The maximum permissible particle size allowed in fills varies from 200 mm in Italy (100 mm for certain soils in the UK) to 1200 mm in the United States (bottom of embankment only), generally specified as between 50% and 100% of the compacted lift thickness.

The maximum permissible organic content allowed in the embankment soils generally varies from 1 to 10%. Several countries developed technical guidelines for the re-use of rocks subject to disintegration or dissolution, specific to local conditions. These guidelines generally match characteristics of in-situ materials based on experimental data.

Specifications concerning acceptable soils in the lower part of embankment and in the road subgrade vary widely. Many countries specify a subgrade on top of embankment. Some, like Canada and the UK, integrate the subgrade in the road sub-base, with the lower portion being a part of the embankment and the higher one classified as a part of the roadway section. Some countries do not have separate specifications for the fill adjoining the subgrade (Germany, Croatia, Japan, and Switzerland). Others have distinct specifications on the subgrade and the upper portion of embankment (UK, Canada, Cuba, Spain, France, Italy, and Portugal). Also, some countries do not specify a subgrade in embankment construction, but issue separate specifications for the upper parts of embankments (Belgium and the US).

The thickness of the upper part of embankment, to which particular specifications apply, varies from 30 cm in Canada, 40 to 85 cm in Portugal, 100 cm in Spain, France, Japan, and Switzerland, 130 cm in the UK, 200 cm in Italy, and 300 cm in the USA. Generally, specifications relevant to this layer refer only to the grain size, fines content and the degree of compaction. Some countries also specify bearing capacity and/or sensitivity to water, usually much more restrictive than for the lower embankment soils.

The subgrade thickness, where specified, varies depending on the needs of a particular project. Some countries stipulate a fixed thickness, for example Italy (30 cm), Japan (100 cm), and Switzerland (60 cm). Permissible materials generally include soils not very sensitive to moisture, with a grain size distribution adapted for easy levelling (generally ±2 to ±3 cm tolerance). Except in the case of materials treated with binders, the UK specifications call for less than 15% of particles smaller than 63 µm. France requires less than 12% smaller than 80 µm, Portugal less than 20% smaller than 75 µm, Spain and Italy less than 35% smaller than 80 µm and 75 µm, respectively. Those percentages of fines are associated with more or less restrictive thresholds of plasticity of fines. By contrast, Germany specifies the same material as in the embankment, but requires a minimum value for bearing capacity of the subgrade. Unfortunately, this criterion cannot be exploited to compare practices among countries, because the control standards and the frequency of testing for bearing capacity vary greatly.

The requirements for the compaction of fill vary from 90% to 100% of the Standard Proctor, depending upon the elevation within embankment. Sometimes the degree of compaction is referenced to the Modified Proctor test. Few countries have controls designed to verify specifications directly (France) or by some correlations established on site (Germany). Sometimes the response time from testing takes too long to rectify an ongoing unsatisfactory operation. In the case of coarse materials that are not compatible with the traditional Proctor tests, the field control methods are not very effective. To address this problem, some countries (Germany and Japan) developed control methods based on the percentage of voids.

The requirements relating to subgrade compaction generally stipulate 100% of the Standard Proctor or 95% of the Modified Proctor test, representing roughly the same outcome. Testing for bearing capacity varies widely and the multitude of control methods does not allow for a meaningful comparison.

Finally, the survey results indicate that a significant progress can be achieved through more effective controls relating to the acceptance of drainage works. Drainage works frequently involve a rather significant investment and have a substantial impact on the project performance. This finding is reinforced in the previously mentioned article on the pathologies of embankments in service.

COLUMN SUPPORTED EMBANKMENTS

An efficient highway system is an economic necessity for most countries. In recent years, however, the public has been subjected to the effects of ageing and deteriorating highways, combined with dramatic increases in traffic volumes. Expanding existing roadways and introducing additional roadway capacity through new construction frequently pose a unique set of problems. In many places the only remaining available land is one that is not economically viable for most commercial purposes. Typically, the soils are very soft and/or contaminated, requiring a substantial amount of ground improvement in order to make them suitable for supporting roadway embankments.

The use of column supported embankments as a construction alternative has greatly increased in popularity in recent years, mainly due to economic considerations. The column support technique allows for the construction of embankments on sites otherwise unsuitable to support large embankment loads. The benefits include reduction in settlements and earth pressures, and ability to construct embankments in a single stage.

Column supported embankments have been used occasionally for more than 60 years. Recent technological advances and improvements have dramatically increased their application worldwide. Consequently, C12 has decided to examine various column technologies and synthesize the current state of the practice.

The report compiled by C12 addresses the following issues:

- Design and construction methodologies,
- Case studies,
- Decision protocol for selecting a column support system,
- General conclusions and recommendations,
- Future directions and research needs.

Technologies encompassed in the report include Stone Columns, Concrete Vibro Columns (VCC), Combined Stabilization with Vertical Columns (CSV), and Geosynthetically Reinforced Bridging Mats.

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SLOPE RISK GUIDANCE FOR ROADS

The scope for this work topic was to develop guidelines for the evaluation of risks associated with soil slopes in highway construction. This evaluation would be facilitated through the development of a framework for risk assessment and this would, in turn, be used to review and present case examples drawing on poor and best practices.

Previous PIARC Reports, which have led to this work topic, include:

- Soil erosion during and after construction (Marrakech, 1991)
- Landslides: Techniques for evaluating hazard (1997)
- Contribution to risk management of existing slopes (Mr Shimazu, 2000)

Also a survey was undertaken on the pathology of in-service embankments (published in Route Roads No. 306 11-2000) to understand embankment performance and to begin assess the quantitative scale of instability. At the first committee meeting in Paris (March 2000), slope risk guidance was identified as a major need for all countries within the design and construction work theme and a programme for the work topic developed.

The highway geotechnical asset principally comprises: embankments and cuttings; reinforced and stabilised slopes; subgrade and capping beneath carriageway; structural foundations; environmental/landscape earthworks; ground drainage and landscaping. Being largely natural materials, there is more inherent variability to geotechnical asset engineering performance and sensitivity to long-term degradation or changes, than is exhibited by other materials (largely manufactured) used to construct other elements of the highway network. However, the consequences of their response can significantly influence construction costs and programme and the safety, environment, performance and whole life cost of the highway. Also owners of assets have a duty of care to adjacent landowners and public at large in respect of retention of support to land, control of run-off and groundwater. Predicting performance is also difficult and not yet understood, but the aim must be to develop a concept of the “residual life” for the geotechnical asset, which will enable effective evaluation and allow worthwhile maintenance strategies to be formulated.

C12 has concentrated on embankment slopes because of their greater frequency of failure than any other geotechnical asset and the threat they pose economically and socially. It was determined that there is increasing rigour in the assessment of slope hazards and their risk. This rigour is described based on evidence from many countries involved in C12. The final report contains slope risk guidance, supplemented by case studies.

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DRAFT CONCLUSIONS

Topic 1

- **Monitoring the laying and functioning of drains** should be a major progress target for road owners; PIARC could bring its contribution by developing exchanges and recommendations on that matter as it is the cause of a large part of earthworks defects;

- **The varying levels of consideration of pavement subgrade** (upper portion of embankments) in the pavement design phase leads to very different practices throughout the world. This deserves further attention as it is a significant issue with regard to practices in favour of sustainable development (preserving non renewable natural resources and reducing haulage distances);

- **Reconciling earthworks and pavement techniques to optimise investments in low-cost roads** (low investment roads, low traffic roads, short life cycle roads, roads requiring a high level of maintenance in exposed areas, high-quality materials). This was revealed to be an urgent matter at the joint seminar held by C12 in Ulan Bator (Mongolia) to meet the needs of developing and transition countries and/or with extreme climate conditions, for earthworks techniques mainly (selected and improved soils) and a consistent pavement type design.

- **A review by member countries of the criteria used for refusing embankment soils would be very interesting.** Many differences have been identified among countries, which are not always justified by local characteristics (climate, relief, etc.)

- **monitoring of acceptance and laying of coarse materials (non compliant with the Proctor test)** very often lacks sound technical references and control method.

- **The issue of earthworks control and possible related conflicts highlights the need for adequate preliminary geotechnical studies** to enable contractors to assess the works to be carried out and warn of difficulties in contract management.

- **The goals of compaction, both in terms of density percentage of the Proctor reference, and range of acceptable water content** vary considerably from one country to the other. The reasons for this are not clear in many cases. A scientific foundation of these goals would represent a real progress.

- **Control methods and frequency :** this topic would no doubt lead to interesting and fruitful discussions. Indeed practices should be based on an objective risk analysis, which is not always the case.

Topic 2

The current state of the practice with respect to various column support technologies can be summarized as follows:

Stone and Sand Columns

a) The technology is mature, with detailed design and construction protocols having been established and applied consistently for many years.
b) Major improvements in the construction equipment have occurred. Modern equipment is simpler to operate, faster, and more efficient in column placement on land and over water.
c) The limits of usage (very soft soils) have to be taken in consideration. It can be helpful to wrap the stone column with geotextile.
d) Sand columns can be used with a geotextile coat. For this system a special design with the calculation of the consolidations effects an the required strength of the geotextile coat is important.

Concrete Vibro Columns (VCC)

a) Concrete Vibro Columns are installed using basically the same equipment as that for stone columns. They are used more frequently than stone columns in many parts of the world.
b) Major advantages include applicability to very soft soils, low cost per vertical capacity, and the ability to form a cap via mushrooming of the column at the ground surface.

Conventional Driven Pile Column and Continuous Flight Auger (CFA)

a) The usage of geosynthetic bridging mats has significantly improved the cost effectiveness of these “high” capacity piles (relative to the other systems).
b) The quality and economics of CFA system have improved dramatically in recent years.
c) A special design of the binder has to be carried out for every soil

Jet Grouting

a) The environmental influence of the superfluous slurry has to be solved

Geosynthetic Bridging Mats

a) The use of geosynthetic reinforcement has dramatically improved the economics of column supported embankments. Geosynthetics allow increased column/cap spacing without the use of expensive concrete slabs, and eliminate the need for battered piles at the side slopes and end slopes.
b) The design protocol is not yet mature and there is no generally agreed upon standard. Numerous methodologies exist, and several countries (Britain, Germany, and Sweden) have developed Guidelines and Standards. However, the methods employed vary with project designers.
c) Construction Control and Quality are extremely important to the success of a project. High quality materials, and due care taken to avoid damaging the columns and/or caps are imperative.

Topic 3

- The following slope risk issues, as related to roadways, have been identified from the PIARC report and their development in the Nepal Seminar 'Sustainable Slope Risk Management for Roads', Spring 2003:

- The scale of the problem ranges from one of the most devastating geo-hazards with threats to life and economies, to one of nuisance requiring increased maintenance costs only

- The development of the understanding of slope behaviour has tended to concentrate on the current or past mechanical aspects and not on the prediction of future instability

- Analytical techniques for predicting instability require assessment and development

- More study is required on the effect of global climate change and the frequency and size of areas of slope instability

- The terms and methodology for determining risk (the product of impact and likelihood) are now well developed. The understanding of risk must cover the life of a slope from conception, through construction to operation

- It is important to select appropriate 'standards' when assessing the acceptability of risks. These 'standards' may typically relate to safety, whole life cost, environmental impact, journey reliability and ride quality

- Developing Countries seek guidance on the selection and application of Technologies for remediation and improvement, as well as hazard and risk assessment

- The management of slopes on a whole transport route is relatively new, not from a technical aspect, but from an operations, planning and business perspective. Geotechnical Asset management should form part of a more holistic approach to Road Infrastructure Management

- To manage a highway network as a business and to provide data for predicting performance 'best practice' needs to be identified and guidance provided to the Developing Countries