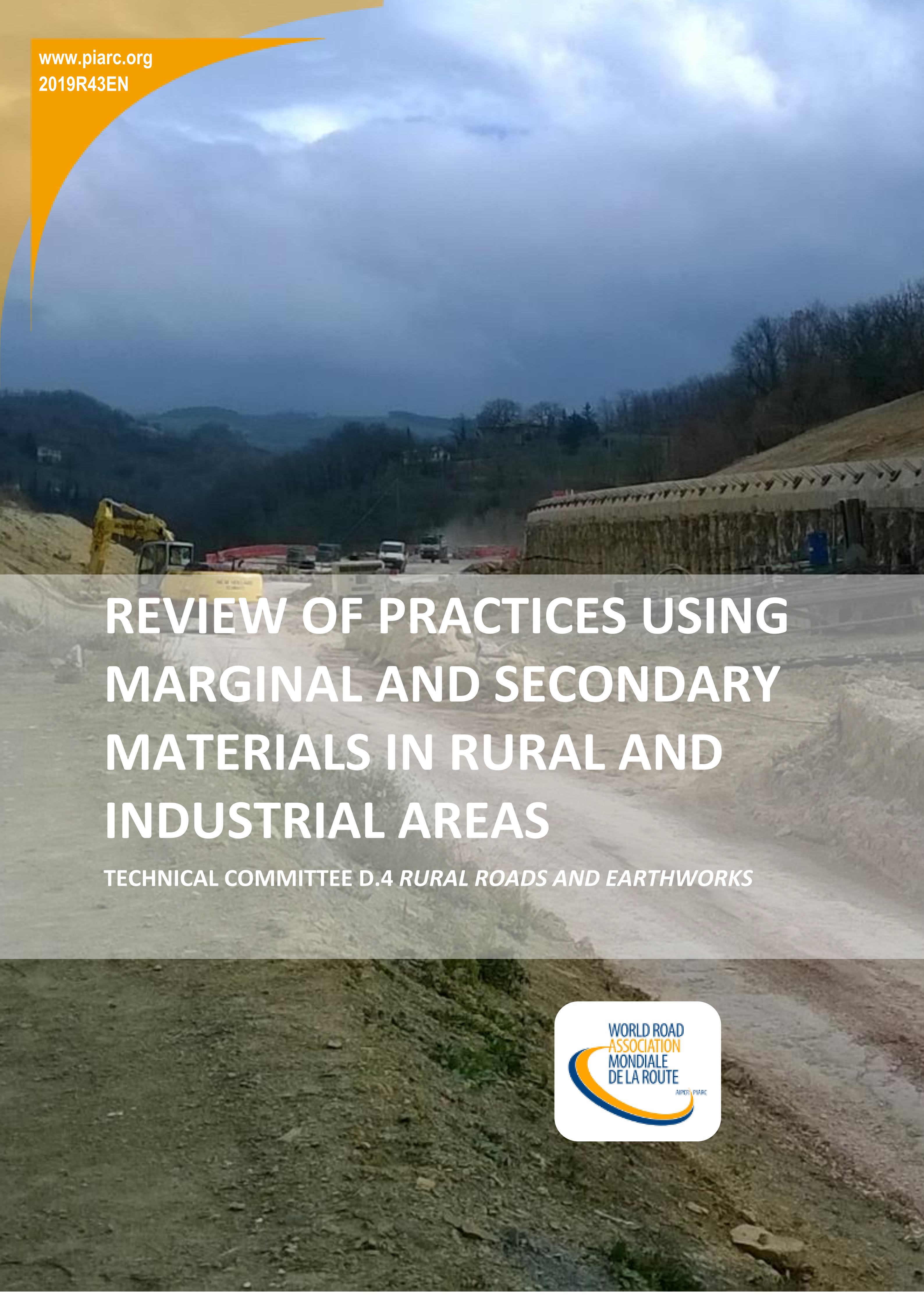

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REVIEW OF PRACTICES USING MARGINAL AND SECONDARY MATERIALS IN RURAL AND INDUSTRIAL AREAS

TECHNICAL COMMITTEE D.4 *RURAL ROADS AND EARTHWORKS*

WORLD ROAD ASSOCIATION
MONDIALE DE LA ROUTE

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2016– 2019 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

This report is available from the internet site of the World Road Association (PIARC): http://www.piarc.org

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This report has been prepared by the working group D.4.2 of the Technical Committee D.4 “Rural Roads and Earthworks”.

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EXECUTIVE SUMMARY

2019R43EN

REVIEW OF PRACTICES USING MARGINAL AND SECONDARY MATERIALS IN RURAL AND INDUSTRIAL AREAS

The use of existing materials along the alignment of a road is an essential issue within the Sustainable Development policies, which is being promoted worldwide from many years ago. In the World Road Association (PIARC) this subject has been investigated by different Technical Committees during the last 20 years.

The optimization of earthwork projects is an obvious issue related to this concern, with important benefits (no spoil disposal or supply of natural noble materials can lead to a strong pollution reduction). But this may imply the use of materials whose geotechnical characteristics may not be as good as desired or required by usual standards.

The term “marginal material” is defined as “material which is not wholly in accordance with the standard specifications in use in a country or region for highway materials but which can be used successfully, either under special climatic conditions or following progress in construction techniques or treatment to enhance its properties”.

This work carried out by PIARC Technical Committee D.4 – Working Group 2 has been focused in four tasks:

- The first task is related to the use of new natural marginal materials little or not at all considered in previous works. Identification of these materials have been carried out by using data collected from a dedicated enquiry.
- The second task is focused on identification of non-natural marginal materials, little or not considered previously, like industrial by-products, construction and demolition wastes, slags or recycled materials. Canada, Spain, France and Italy proposed most cases, in respect of using marginal materials, as appears from enquiry answers collected.
- The third task is focused on collecting new cases in which non-natural marginal materials, as identified in the second phase, have been used in road embankments: cases from Spain, France and Italy are comprehensively described.
- The fourth task is to get new data about the medium- and long-term behaviour of road embankments constructed with marginal materials, both natural and non-natural. Very likely, this task can only be outlined in the present cycle and its completion will be hopefully left to the following cycles, as medium- and long-term behaviour data are barely available at present.

This report first presents some generalities related to the design of earthworks for roads and reviews the most relevant aspects of previous PIARC reports, making a brief summary of the main issues addressed in them and summarizing the main conclusions reached on those previous works.

After that, the new data collection performed at this new stage is exposed. First, the following information is presented:

- information collected from 13 countries with respect the type of marginal materials they use in road embankments;
- information related to the standards used in 12 countries to specify the technical characteristics of road embankments and/or unpaved roads;
- information related to the standards and technical specifications for classification of materials for earthworks used in 6 countries plus the one defined by CEN (European Committee for Standardization).

Then, there is a summarized explanation of 26 cases histories of use of marginal materials in road embankments collected in 4 different countries (13 cases from Spain, 8 from Italy, 3 from France and 2 from Canada). The data collection has focused on specifying the main problems related to the use of certain materials, i. e. the cause for them being considered marginal, their main geotechnical characteristics and the most relevant data related to their placement in the embankment.

As tentative conclusions from the data collected we could highlight the following:

- The use of marginal materials in road embankments is wide spreading although it is not usual practice in many places in the world. There are not yet many documented cases or specific technical guidelines for their use. Nevertheless, their use in road earthwork is often highly recommended, mainly due to environmental regulations, as it allows reduction of earthmoving, with less spoil disposal and a reduction in the need to supply natural noble materials.
- In most cases, the use of marginal materials is limited to the core of the embankment, where they are less exposed to climate actions and water flows that may cause its degradation. These materials are often arranged in the core with encapsulation by impervious clay layers or geomembranes to isolate them from water flows entering and leaving the embankment.
- In most cases, use of marginal materials is performed through stabilization (lime, lime-cement). When used in the core, a minimum of 2% of lime is added while when used in shoulders or foundation the percentage is a little higher, around 2.4%.

CONTENTS

1. FOREWORD

The utilization of materials locally available on the site of a road project is a major concern in the context of sustainable development and perfectly meets the socioeconomic and environmental criteria involved in it.

The optimization of earthwork projects is an obvious issue related to this concern. It allows reduction of earthmoving and, consequently, of transport on and off work sites (no spoil disposal or supply of natural noble materials can lead to a strong pollution reduction). The potential for advance in knowledge on the reuse of marginal natural materials excavated on sites – which are the most difficult to use – remains considerable.

The term “marginal material” is defined as “material which is not wholly in accordance with the standard specifications in use in a country or region for highway materials but which can be used successfully, either under special climatic conditions or following progress in construction techniques or treatment to enhance its properties”.

Much good work has already been done in previous periods of PIARC related to the use of marginal materials, and the related issues will be considered in the following.

Since the first studies within PIARC related to marginal materials, it was stated that marginal materials are also called “non-traditional” materials, and they include either natural or waste products, indicating several aims on the study of their use (“Marginal materials. State of the Art”, PIARC, 1989):

- to make savings;
- to compensate for the shortage of natural high quality materials or ensure their continued availability;
- to protect the environment by eliminating dumps which cause often pollution and unsightly quarries.

Technical Committee D.4 – Working Group 2 has endeavoured to develop this subject by organizing exchanges between member countries through a survey launched for that purpose.

This initiative has been a continuation of, and a complement to, that taken by former technical committees who had been dealing with marginal material issues for some twenty years, with a view to developing innovative approaches to the use of such materials.

This work carried out by PIARC Technical Committee D.4 – Working Group 2 has been focused in four tasks:

- The first task is related to the use of new natural marginal materials little or not at all considered in previous works. Identification of these materials have been carried out by using data collected from a dedicated enquiry.
- The second task is focused on identification of non-natural marginal materials, little or not considered previously, like industrial by-products, construction and demolition wastes, slags or recycled materials. Canada, Spain, France and Italy proposed most cases, in respect of using marginal materials, as appears from enquiry answers collected.

- The third task is focused on collecting new cases in which non-natural marginal materials, as identified in the second phase, have been used in road embankments: cases from Spain, France and Italy are comprehensively described.
- The fourth task is to get new data about the medium- and long-term behaviour of road embankments constructed with marginal materials, both natural and non-natural. Very likely, this task can only be outlined in the present cycle and its completion will be hopefully left to the following cycles, as medium- and long-term behaviour data are barely available at present.

The success obtained in each of this task has been uneven. Collecting published data or published information may be an easy task, but collecting not published data or information of materials or Standards used in different countries is not an easy task at all, especially when there are not compulsory normative documents or guides of general used.

Nevertheless, all the data and information collected through the works performed in this period may be a small step forward in the knowledge of use of marginal materials.

This report first presents some generalities related to the design of earthworks for roads and reviews the most relevant aspects of previous PIARC reports, making a brief summary of the main issues addressed in them and summarizing the main conclusions reached on those previous works.

After that, the new data collection performed at this new stage is exposed. First, the following information is presented:

- information collected from 13 countries with respect the type of marginal materials they use in road embankments;
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Then, there is a summarized explanation of 26 cases histories of use of marginal materials in road embankments collected in 4 different countries (13 cases from Spain, 8 from Italy, 3 from France and 2 from Canada). The data collection has focused on specifying the main problems related to the use of certainmaterials, i. e. the cause for them being considered marginal, their main geotechnical characteristics and the most relevant data related to their placement in the embankment.

It was intended to collect data about the behaviour of the embankment over time but, in the end, it has not been possible due mainly to the two following reasons: the first one is related and monitoring and data collection and the second one is related to time. The monitoring has not always been implemented properly in order to allow for data collection that could be later on analyzed. Sometimes it is only possible to deduce that the embankment has properly behaved because there is no news about repairing works being needed for a long period of time. The reason related to time is related to the short period of time passed since the end of construction in most (but not all) cases.

The exchange of information performed between member countries have made it possible to identify at least six different families of (locally available) marginal natural materials:

- materials which are changeable or fragmentable (brittle);
- materials with particular constituents;
- very wet or very dry materials;
- very clayey materials;
- homometric or poorly structured materials;
- lateritic materials;

And also non-natural materials, industrial wastes, construction and demolition wastes.

A few conclusions have been reached for some of them from all the works performed, mainly the summarized in the table:

Material	Description	Recommended treatments
Changeable or fragmentable	Material may become brittle or deteriorate under loading: -in short term during laying (extraction, transport, compaction, etc.); -in the long term after laying among other things owing to mechanical stress (traffic, etc.) or to the action of water or frost. Materials which are changeable or fragmentable are illustrated by the argillites (Belgium), pelites, marls, micaschistes, metamorphic schistes, argillaceous rocks (France), flysch (Greece and Slovenia), tuffs (Mexico) and weathered rocks (Germany and United Kingdom).	-Encapsulation of materials in order to protect them from further break down due to climatic influences (water, frost, erosion, etc. – argillites of Belgium); -Intense [heavy] compaction to reduce the percentage of voids in the weathered rocks (Germany); -Screening of the coarse fraction (tuffs of Mexico); -Fragmentation, addition of water, placing in a temporary stock pile (in order to obtain a balance of water content and suction with the environment) of flysch which must be used as soil fill rather than rock fill (Slovenia and Greece). -United Kingdom uses "weathered rocks" as a capping layer: it has been possible to utilise this material by modifying the grading or by reducing the requirement for Los Angeles coefficient – backed up by site trials and /or local experience".
With particular constituents	Materials with specific compounds are illustrated by glauconitic sands (Belgium), gypsiferous clays and massive gypsum (Spain), coal shales, variegated clays, indurated marls (France), organic soils and mixed soils (Germany), karstic clay (Slovenia).	-Implemented with control of water content and light compaction for glauconitic sands (Belgium); -Encapsulation of gypsiferous materials – gypsum content between 5 and 35% - (placed in the core of embankments) to protect them from external agents (Spain); -Encapsulation of organic soils (core of noise bunds) and enhanced drainage to prevent percolation into the underlying ground (Germany); -Improvement by treatment with lime and/or fly ash to red karstic clays in Slovenia and by hydraulic road binders for coal shales and indurated marls in France (PST and capping layers); -Mixture of low consistency soils with recycled materials to improve mechanical properties (Germany).
Very wet or very dry	Materials which are too wet are illustrated by the very wet silts of Belgium, products derived from drilled tunnel excavations (Spain, Germany), Turonian spongolites, flooding areas products (sandy silts), silts, sands and clays (France).	-improvement with lime, in case of very wet -watering using sprinklers, in case of very dry
Very clayey	High plasticity	Lime stabilization

As tentative conclusions from the data collected we could highlight the following:

- The use of marginal materials in road embankments is wide spreading although it is not usual practice in many places in the world. There are not yet many documented cases or specific technical guidelines for their use. Nevertheless, their use in road earthwork is often highly recommended, mainly due to environmental regulations, as it allows reduction of earthmoving, with less spoil disposal and a reduction in the need to supply natural noble materials.

- In most cases, the use of marginal materials is limited to the core of the embankment, where they are less exposed to climate actions and water flows that may cause its degradation. These materials are often arranged in the core with encapsulation by impervious clay layers or geomembranes to isolate them from water flows entering and leaving the embankment.
- In most cases, use of marginal materials is performed through stabilization (lime, lime-cement). When used in the core, a minimum of 2% of lime is added while when used in shoulders or foundation the percentage is a little higher, around 2.4%.

Much good work has already been done in previous periods of PIARC related to the use of marginal materials, but still much work is still be done by performing new studies on material behaviour and by collecting more case histories with data about the medium- and long-term behaviour of road embankments built up with marginal materials.

As previously said, the potential for advance in knowledge on use of marginal materials is still important. For instance, use of certain marginal materials may give rise to risks, particularly when materials contain specific constituents.

Specific preliminary studies which are sufficiently detailed permit putting into place adapted conditions of use to generally control of the risks. This task, however, just outlined in this cycle, is not being carried out and, certainly, it will constitute the main further step forward in earthwork technologies.

Recomendations to road administrations and operators.

At present developing sustainable development policies is a real and urgent need. These must apply to a widespread range of areas, and road construction is an important one that may contribute notably to drive progresses in the field. But in order to be effective, administrations operators must be aware and help to facilitate things, as it is in their hands the possibility of creating new paths for sustainability.

Referring specifically to this report issue, it is very important to promote the use of marginal materials in order to reduce spoil disposal or the need to supply high amounts of natural noble materials, enhancing pollution reduction by optimizing earthworks and reducing transport of material over great distances.

More studies have to be carried out and, in order to speed up our common learning, we must encourage the proper data collection when road embankments with marginal materials are designed and built up. This may be effectively propelled if road administrations managers will take action on these topics.

2. INTRODUCTION: PIARC AND TECHNICAL COMMITTEE D4

PIARC World Road Association was founded in 1909 and has its headquarters in Paris, France.

PIARC is a forum for road administrations and private sector to exchange and discuss their policies, trends and ideas for roads and road networks. PIARC has 124 member countries in 2019. PIARC structures its technical work in Technical Committees (TC) (which have a 4 years mandate) and Task Forces (which have 2 years mandate). The TC are consisting of technical experts of the member countries. In the cycle 2016-2019, the TC and TF where organized in 5 Strategic Themes: Management and Finance (A), Access and Mobility (B), Safety (C), Infrastructure (D) and Climate Change, Environment and Disasters (E).

The outputs of Technical Committees are reports including best practices and recommendations for their field, as well as International Seminars, Workshops and Conference around the World, and asignifican contribution to the World Road Congress.

For the years 2016-2019 the TC D.4 is responsible for rural roads and earthworks. The goal of the Strategic Theme D is “to improve the quality and efficiency of road infrastructure through the effective management of assets in accordance with user expectations and government requirements”. The goal of the TC D.4 is “investigate road administrations response to adverse conditions as a result of climate change activities while considering the use of local, marginal, and secondary materials in rural and unpaved roads.”

The current report is the final output of the work carried out by TC D.4 during 2016-2019 cycle.

3. GENERAL EXPLANATIONS

The use of existing materials along the alignment of a road is an essential issue within the Sustainable Development policies, which is being promoted worldwide from many years ago. In the World Road Association (PIARC) this subject has been investigated by different Technical Committees during the last 20 years.

“Until recent times, several materials extracted from right of way and showing unsatisfactory geotechnical characteristics (water content, mineral content, etc.) were dumped because their immediate use was not possible. These materials were substituted with other natural materials obtained from outside quarries. Nevertheless, several countries are now taking into account the objectives of sustainable development, especially in road earthworks. In these countries, it is required to save natural resources and to optimize the use of natural resources. In this context, soil treatment methods and the use of industrial by-products contribute to save natural resources and build stable works” (Promoting optimal use of local materials, PIARC, 2007)

In the PIARC dictionary the term “local material” is currently defined as “natural marginal material (soil, rock) locally available on site”. On the other hand, the term “marginal material” is defined as “material which is not wholly in accordance with the standard specifications in use in a country or region for highway materials but which can be used successfully, either under special climatic conditions or following progress in construction techniques or treatment to enhance its properties”.

It can also be said that “marginal” natural materials is “the field of materials which are little or rarely used because of limits or characteristics which do not fit within the generally required technical specifications” (“Innovative approaches towards the use of locally available natural marginal materials”, PIARC, 2012).

Since the first studies within PIARC related to marginal materials, it was stated that marginal materials are also called “non-traditional” materials, and they include either natural or waste products, indicating several aims on the study of their use (“Marginal materials. State of the Art”, PIARC, 1989):

- to make savings;
- to compensate for the shortage of natural high quality materials or ensure their continued availability;
- to protect the environment by eliminating dumps which cause often pollution and unsightly quarries.

In the same document it was also highlighted that the concept of “marginality” is “related to a particular time or place and even sometimes the course in which the material is used. As an example, unlike now, forty or fifty years ago, gravel could have been considered a non-traditional material as at that time macadam with crushed stone was normally used”.

The utilization of materials locally available on the site of a road project is therefore a major concern in the context of sustainable development and perfectly meets the socioeconomic and environmental criteria involved in it.

The optimization of earthwork projects is an obvious issue related to this concern. It allows reduction of earthmoving and of transport on and off work sites: consequently, it permits to achieve zero spoil disposal or supply of natural noble materials target, and a strong pollution reduction related to lorries travels.

The potential for advance in knowledge on the reuse of marginal natural materials excavated on sites – which are the most difficult to use – remains considerable.

That is why technical committee D.4 has endeavoured to develop this subject by organizing exchanges between member countries through a survey launched for that purpose.

This initiative has been a continuation of, and a complement to, that taken by former technical committees who had been dealing with marginal material issues for some twenty years, with a view to developing innovative approaches to the use of such materials.

It has been based on pooling knowledge gained among other things through feedback from earthwork projects.

The replies received have made it possible to identify at least six different families of (locally available) marginal natural materials:

- materials which are changeable or fragmentable (brittle);
- materials with particular constituents;
- very wet or very dry materials;
- very clayey materials;
- homometric or poorly structured materials;
- non-natural materials, industrial wastes, construction and demolition wastes.

They also highlighted that the utilization of lateritic materials is a vital economic issue for certain countries.

The placing and processing techniques have been identified within each of those five families, on a case-by-case basis.

The principal information included in this report as gathered from the survey is interesting and meets the expectations placed on the initiative undertaken by the committee:

- the development and implementation of innovative progress clearly appears from the replies. It should be emphasized, however, that innovation depends on the various national contexts (climate, soils, technical skills and available equipment, etc.);
- progress is based mainly on thorough design studies, on techniques and methods implemented with high-performance equipment, and on exhaustive analyses of the products and materials used;
- maximum reuse of excavated marginal materials involves scheme-specific risks that must be allowed for and well controlled.

With a view to clarifying the references of certain replies, a reminder of the main classifications and international specifications is presented, including an evolving European standardization of earthworks.

Emphasis is also placed on the different approaches adopted by the various countries to the use of materials discussed in this report, and on the appearance of specific classifications and specifications in a number of countries.

Depending on the replies received, a few significant examples of design studies, experimental projects and completed works illustrate success achieved in utilizing local marginal materials while also reporting difficulties encountered.

Research projects are also mentioned in this report.

4. USE OF LOCAL MATERIALS IN EARTHWORKS FOR ROADS: A CURRENT PIARC ISSUE

PIARC approved in 2015 the Terms of Reference for the Technical Committees and Task Forces for the 2016-2019 cycle, establishing the following five Strategic Themes:

- Management and Finance
- Access and Mobility
- Safety
- Infrastructure
- Climate Change and Environment

As indicated in the Terms of Reference (ToR) for this period, “these themes represent a continuation of work that remains at the core of road agencies’ interest as well as the emergence of concerns about how to address the need of road infrastructure to withstand conditions imposed by short-lived extreme weather events and changes in long-term weather patterns. Within these themes are a total of 18 Technical Committees and 4 Task Forces”.

It is also stated that the goal of Strategic Theme D “Infrastructure is to “improve the quality and efficiency of road infrastructure through the effective management of assets in accordance with user expectations and government requirements”. It is specifically written that “in the field of rural roads and earthworks, Technical Committee D.4 (Rural Roads and Earthworks) will investigate road administrations response to adverse conditions as a result of climate change activities while considering the use of local, marginal, and secondary materials in rural and unpaved roads”.

In order to structure the work program there are three issues defined in the ToR, which are included in Table 4.1. The strategies to apply and the expected outputs are the ones included in that table.

With the purpose of working on Issue D.4.2 a sub-committee within TC D.4 was established from the kick-off meeting of this period celebrated in Paris in March 2016. This paper is intended to be the final output of the works carried out by this group in relation to the work issue.

In this work we are considering local materials in a wide sense, including not only natural marginal materials but also industrial by-products and waste.

Issue D.4.1: Exposure of roads to climate change	
Strategies	Outputs
Investigate and document simulation and modelling tools and techniques to support road administrations in managing and responding to adverse conditions as a result of climate change (e.g., drainage and storm water management).	Report of best practices on before/after strategies, and guidance.
Investigate and document local practices and techniques for "all-weather" service (dry season, rainy season).	Report of best practices and recommendations.
Issue D.4.2: Local materials, practices and techniques	
Strategies	Outputs
Investigate and document construction and maintenance practices and techniques incorporating the use of marginal and secondary materials.	Review of practices using marginal and secondary materials in rural or in industrial areas.
Disseminate work on use of local materials produced in previous cycles.	Seminar/Workshop incorporating Technical Committees' past products
Issue D.4.3: Management of earthworks	
Strategies	Outputs
Collect information and conduct analysis of best practices in earthworks management with a focus on systematic approaches that could be incorporated into broader road networks asset management to support the decision making process.	Guidance report on how to develop and implement Earthwork Management Systems considering the tools for those systems: inventory, assessment and aids to decision making. To include updates to the Asset Management Manual in consultation with TC D1.1 charged with the development of the web-based Asset management manual to ensure consistency in content and format.

Table 4.1: Issues defined in the ToR (2016-2019) for the Technical Committee D.4 "Rural Roads and Earthworks".

5. DESIGN OF EARTHWORKS FOR ROADS: GENERALITIES

Earthworks and earth structures

Earthworks include to extract, load, transport, transform/improve, place, stabilize and compact natural materials (soils, rocks), by-products or recycled materials in order to obtain stable and durable cuttings, embankments or engineered fills, with prescribed properties, for road construction and maintenance. Earthworks require planning, design, construction and maintenance. They depend on the properties on the materials, the required properties of the structure and the environment.

The design of earthworks differs from the design of earth-structures.

For earthworks, “designing” means “defining the process” enabling to transform natural in situ ground (soil or rock) and/or by-products or recycled materials into a well compacted and durable embankment with the required properties or a stable cut. This decision process includes the characterization of natural ground, the choice of suitable equipment and rules to plan extraction, transport, compaction and control of the materials. The products of this design include risk assessment reports, execution plans, time-tables, work-flow schemes, etc. These conditions may be met by experience-based prescriptions or by performance-based design.

The standards on earthworks all assume that the earth-structure (i.e. the embankment or the cutting) to be built has been properly designed.

Information needed for earthworks design

The description, identification, classification and characterization of soils, rocks and other fill materials are an essential part of the design of earthworks. They yield the necessary information to determine the nature of each material, the best way to take that material from excavations or cuttings, the final state it may reach after compaction and the best way to achieve this final state.

Geotechnical investigations for earth-structure and earthworks

Geotechnical site investigations for an earth-structure project shall provide adequate and sufficient information for the design and construction of the new structure. This information should cover the design of the completed structure and of the temporary slopes and structures created during the construction works. The geotechnical model shall cover the zone of influence of the structure, both for mechanical analysis and for hydrological and hydrogeological analysis.

The stages of a geotechnical investigation should include a desk study (sometimes referred to as a preliminary sources study), a preliminary investigation, to characterize the site in general terms, and wherever required, subsequent phases of design investigation to provide detailed information for specific elements of the design.

Geotechnical investigations also include the detection and characterization of any infilling and old waste disposal sites, former mining areas or contaminated soils, depending on their nature and extent. If pollution is suspected during exploration as a result of anthropogenic changes or geogenic material accumulations, the environmentally relevant parameters shall be determined.

Site investigations for geotechnical design

Earthworks create two main types of earth structures: “excavations and slopes” and “embankments”. These structures shall be designed following the relevant rules, which generally consider at least stability, deformations and durability of each structure.

The geotechnical designer should be consulted and contribute to all stages of the investigation. When planning a phase of ground investigation, it is important to consider the needs of all those who will use the data obtained, at a later phase of the scheme.

Geotechnical measurements may be necessary for the purpose of monitoring stability, testing calculation assumptions concerning the ground stability, for the purpose of observing the behaviour of structures and for preserving evidence on adjacent structural works.

It should be appreciated that no ground investigation, however carefully done, ever examines more than a very small proportion of the ground. It is essential that the soil conditions revealed during progress of the excavations are checked to see that they correspond with the geotechnical model, which forms the basis for earth-structure design. It might be necessary to undertake further investigation to determine the extent of anomalous conditions.

Specific geotechnical investigations for earthworks

The design of earthworks needs information on the nature, state, geometry and volumes of soils, rocks and other materials, which will be excavated, dredged, transported, treated, stockpiled, put in layers and compacted. Part of this information is shared with the geotechnical design of the final structure and the main construction phases. Investigations shall cover all zones from which materials can be extracted and the location of final deposits.

The nature of the materials is determined by geological analysis and testing of samples taken from borings, pits or stockpiles. The state of the materials is assessed from density and water content measurements in situ or in the laboratory. Geometry and volumes of natural ground layers are based on geological analysis and borings and other in situ tests, including geophysical investigations.

For embankment construction, the compaction characteristics of soils are determined by means of laboratory densification and deformation tests. An adequate amount of soil should be recovered to enable testing at a set of water contents, allowing to assess the acceptable range of water content of the material for efficient compaction. Specific studies may then be made for the appropriate treatment of soil material falling outside of this acceptable water content range. When the material cannot be tested in laboratory because of the size of the individual particles or blocks, large test apparatus or in situ full scale compaction tests shall be used.

When appropriate, laboratory and/or in situ tests for determining lime and/or cement quantities for stabilisation shall be carried out.

Design of earthworks for embankments

The earthworks project specifies the execution procedures (strategy for excavation, transport and use of extracted ground or by products, equipment for extraction, transport, spreading in layers and compaction, process adapted to each fill material, quality control) in order to achieve results conform to the requirements (or assumptions) of the earth-structures project.

Since earthworks are frequently controlled using density of the compacted fill, there is a need to link density to the mechanical properties of the resulting embankment, in terms of stability (i.e. shear resistance), deformations (i.e. deformability) and water tightness (i.e. permeability). Durability and long-term stability of the completed body of fill material should be explicitly considered when defining the density requirements.

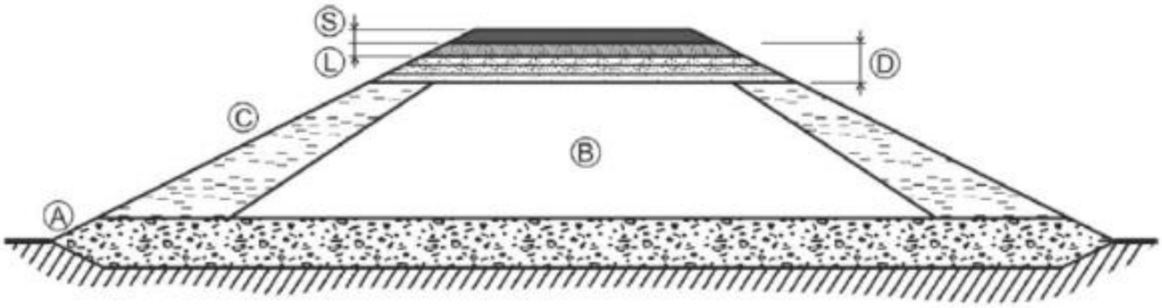
The design process will thus normally include:

- assessing the nature and material properties of available soils, rocks, by-products or recycled materials;
- assessing the required properties of the compacted fill materials and how these can be achieved;
- defining the construction process while considering the type of work (excavation, compaction, etc.), the available equipment, the nature and initial state of the soil/rock, the climate, and the desired final state;
- optimising the earthworks project in terms of equipment use, limitation of transport, protection of the environment, sustainable development, cost, duration of works, etc.;
- identifying the appropriate form of validation of the works (testing and monitoring method and frequency of testing during construction).

Infrastructure embankments

The cross-section of infrastructure embankments for roads and highways may be divided into the zones, as herebelow described (see Figure 5.1):

- **Base** (A): Embankment zone in direct contact with the existing ground. This zone may be divided into layers, e.g. for drainage, working platform, impervious protection layer. It may include replacement of existing foundation ground to some depth or improvement of existing ground by binders or installation of geosynthetics.
- **Core** (B): Embankment zone located between any base layers and upper zone. To make this zone exist, a minimum embankment height is needed. The core can be protected from water or isolated to limit pollution of the environment.
- **Shoulders** (C): lateral zones of embankments. These zones can have various functions, e.g.: enable steeper slopes, protect the core, serve as filters, protect from erosion.
- **Upper zone** (D): zone located between the core and the superstructure (pavement - S). This zone may comprise different layers such as the “upper part of fill”, the “capping layer” (L), a “transition layer” to separate rock fill from the upper granular layers, an impermeable layer, etc. It does not include the superstructure layers.



Key
A — base
B — core
C — shoulders
D — upper zone
L — capping layer (part of upper zone)
S — superstructure (pavement /rail track)

Figure 5.1: Typical cross-section of an embankment for roads and highways.

Criteria for assessing the compacted material

The requirements to be satisfied by the earth-structure are identified either by the client or as an output of the geotechnical or structural design. For example, this might result in a required end performance related to stiffness at finished ground level and limitations on permitted settlement beneath a defined loaded area.

The earthworks design should identify the earthworks criteria that are to be satisfied in order to deliver the earth-structure requirements (such as stiffness) and to avoid problems both during and after construction. These criteria will vary depending on the particular site conditions, materials available and end use of the embankment, and may include some or all of the following:

- criteria relative to the completed embankment;
- minimum value of the vertical deformation modulus;
- minimum value of the bearing resistance;
- maximum or minimum value of the permeability, when required;
- criteria relative to construction phases:
- trafficability (for ease of execution);
- no mattressing or separation of layers or cracking due to desiccation (for quality of compaction/method of working);
- criteria relative to durability:
- long-term stability of the compacted fill, especially resistance to water content changes (no collapse, no heave, no settlement);
- frost resistance;
- degradability.

Characterization of materials

The identification and characterization of materials available for use as fill is the first step of all procedures for earthworks design. Identification involves the characterization of the nature of soils and rocks. This will include some of the following intrinsic properties: grain size distribution, water content, carbonates, sulphates, organic matter contents, plasticity and liquidity limits, methylene blue value for soils, Los Angeles coefficient, dynamic fragmentation, friability, degradability, fragmentability, frost resistance for rocks, and specific tests for other materials.

The design of embankments built of some types of materials may require specific prescriptions, going beyond those which are common and considered valid in most general cases.

The first stage is the knowledge of relevant long-term properties of these materials, and their influence on the predictable behaviour of the earth-structure. These materials can be either natural soils, by-products or waste of industrial or mining processes, or even specific man made materials. Usually, specific rules concerning health, environmental and other sectorial aspects have to be taken into account.

The general framework for the specific materials used for building earth-structures shall be acceptable in terms of:

- health;
- environmental issues;
- bearing capacity and long term behaviour, according to the purposes of earth-structure;
- constructibility.

From this point of view, there can be materials which are not wholly in accordance with the standard specifications in use in a country or region for road and highway. These materials are commonly defined as marginal materials.

Marginal materials can be used successfully, either under special climatic conditions, following progress in construction techniques or suitable treatment to enhance their properties.

A pictorial representation of marginal materials using physical properties of soils (i.e. liquid limit LL and plasticity index PI) is presented in Figure 5.2.

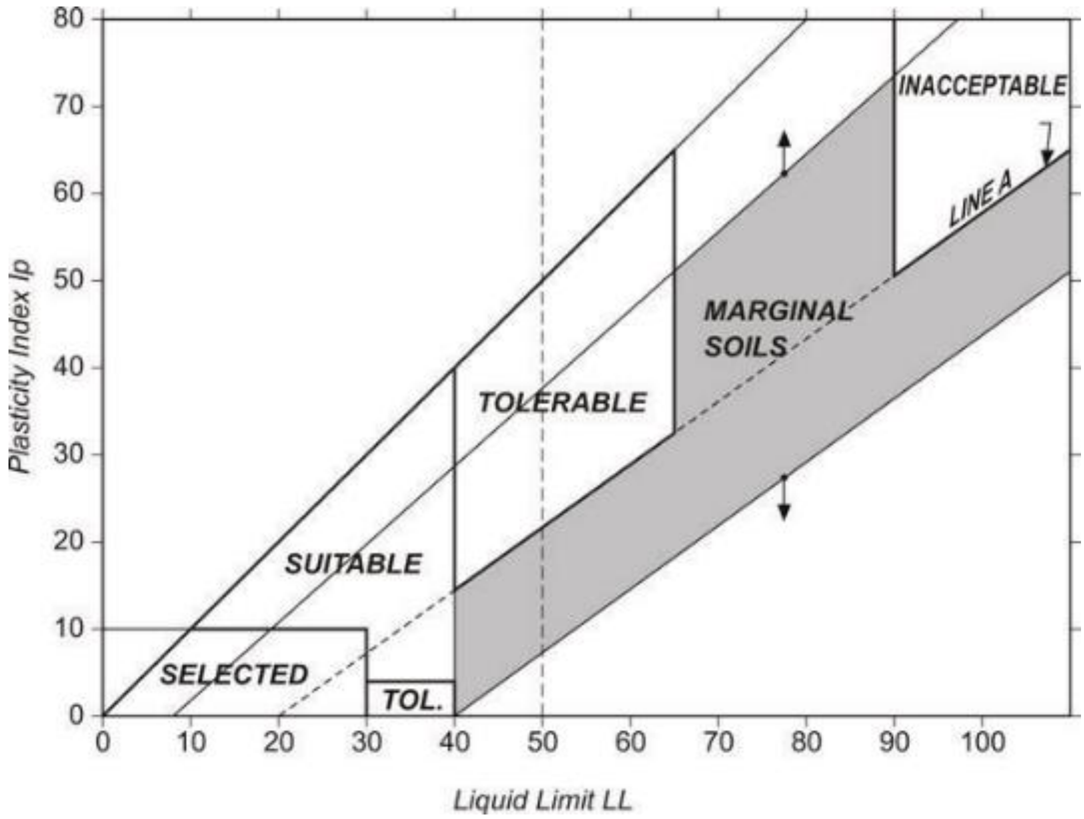


Figure 5.2: Classification of materials for road construction.

Marginal materials

The marginal materials are not of the same nature. The first major distinction that can be made is related to their origin:

- Natural marginal materials (compressible inorganic clays, organic clays, peat, gypsum),
- Non-natural marginal materials:
    - Wastes from industrial processing (blast furnace slags, etc.),
    - Iron and steel production industries, foundries,
    - Exhausted tyres,
    - Construction and demolition (C&D) waste,
    - Coal-fired thermoelectric power plants (fly and bottom ash),
    - Incineration of Municipal Solid Waste,
    - Other materials.

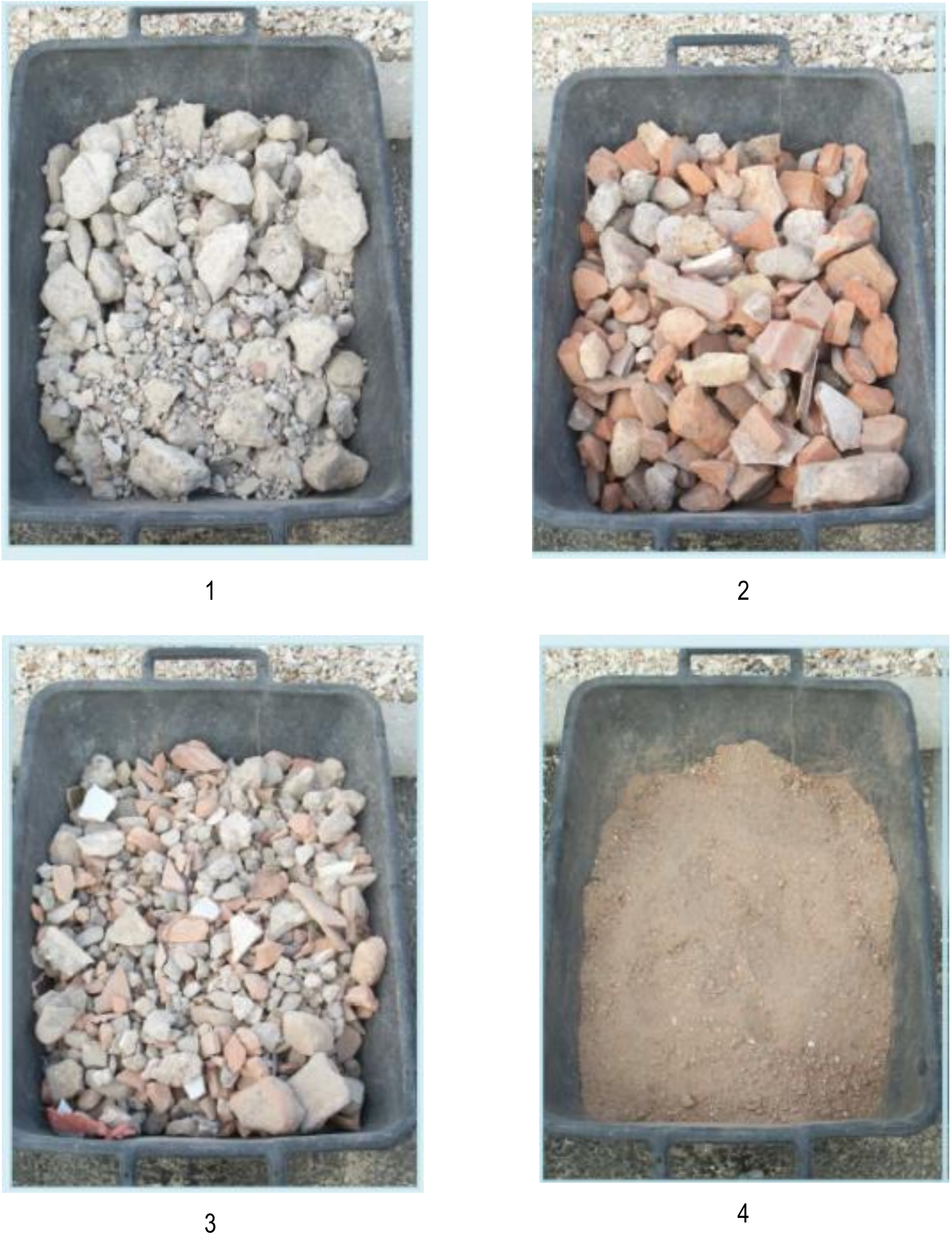


Figure 5.3: Materials coming from C&D waste; 1 – Coarse for structural use, 2 – Coarse for filling, 3 – Mix for structural use, 4 - Sand

It is interesting to put the emphasis over non-natural marginal materials that present, as said, the greatest variety of origin.

For instance, non-natural marginal material, in order to be considered suitable for use in earthworks, must be classified by using the results of proper geotechnical laboratory tests, aptly designed and correctly carried out.

In particular, requirements to comply with are divided into geometric, physical and chemical.

Geometric requirements:

- grain size;
- content of fine;
- quality of the fine (equivalent in sand);
- dimensional designation: the aggregate must be characterised in dimensional terms by the expression of the ratio d/D in which d represents the minimum size of the grains present, while D represents the maximum size;
- shape index: this value expresses the percentage of elongated aggregate particles, defined by the standard as "non-cubic", over the total mass of the test portion.

Physical requirements:

- density;
- water absorption;
- resistance to fragmentation: this resistance is evaluated by the "Los Angeles" test, which consists in evaluating how much fine fraction is produced by placing the aggregate in contact with a moving steel ball charge;
- resistance to abrasion and wear;
- resistance to frost and thaw cycles: the frost-thaw resistance test consists in subjecting the aggregate to ten frost-thaw cycles, after which the effects on the granules are analysed, especially in relation to the occurrence of cracks or possible mass losses;
- durability to alkali-silica reaction;
- volume stability.

Chemical requirements:

- content of chlorides, sulphates, sulphur and carbonate;
- solubility in water;
- loss of mass after ignition;
- free lime content.

6. PIARC REPORTS ON MARGINAL MATERIALS

6.1. PREVIOUS PIARC WORKS

Specifically related to the topic of marginal materials, the following PIARC documents have been delivered in different periods:

- 1989: Marginal materials. State of the Art.
- 1991: Testing of marginal materials.
- 2003: Limits of use of natural soils, specifications and controls in earthworks.
- 2007: Promoting optimal use of local materials.
- 2012: Innovative approaches towards the use of locally available natural marginal materials.

All these documents are available at PIARC website. All of them are very good documents and they represent considerable advances from earlier works.

6.2. TERMINOLOGY

Questions 2 and 5a of the enquiry (see annex 1) relate to the actual and desired use of the materials within the different levels of application within the highway embankment which it is important to define – mass fill – subgrade – capping – sub-base – road base. To this end, the nomenclature proposed within report PIARC 12-12-B (2003) [9] was used for reference (Figure 6.1**Erreur ! Source du renvoi introuvable.**).

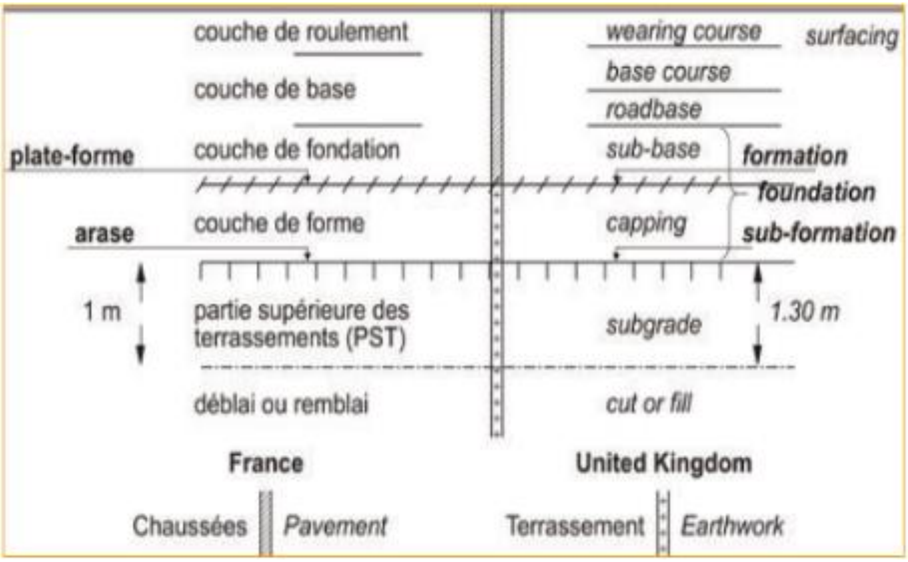


Figure 6.1: Nomenclature proposed for embankment layers within PIARC reports.

In addition, the specific areas of embankment construction should be defined as follows (Figure 6.2, following page):

- the lower layer in contact with the ground which acts as the foundation for the embankment;
- the central area/zone which acts as the core of the embankment;
- area/zones located on the sides of the slopes which are referred to as shoulders, haunches, etc.;
- finally, the upper part of the embankment (PST) which is identified as the transition layer beneath the capping layer (sub-formation).

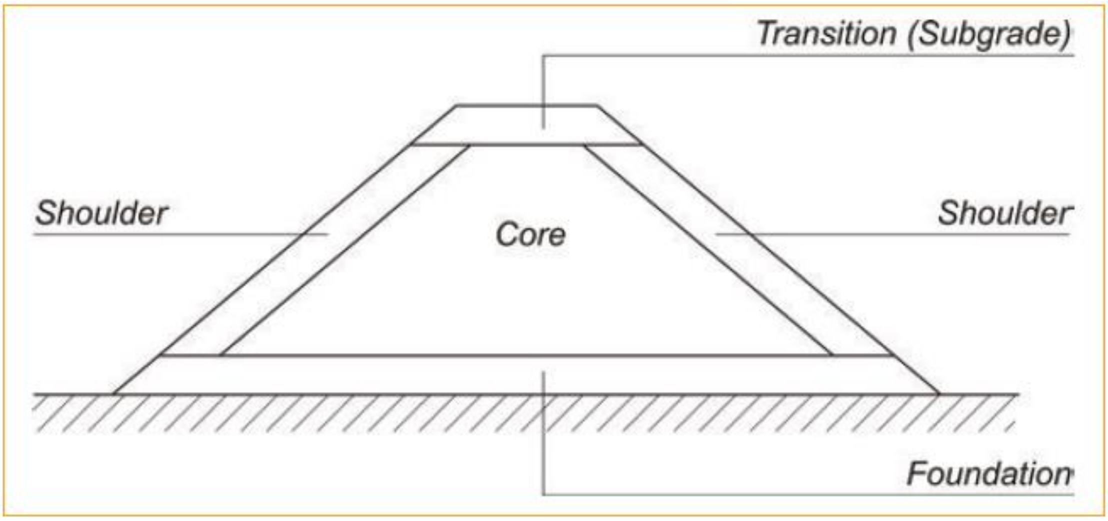


Figure 6.2: Part of a road embankment as defined for the purposes of the present report.

6.3. Brief description of previous PIARC reports

1989 – PIARC Technical Committees on Testing of Road Materials, Flexible Roads, Earthworks, Drainage, Subgrade – Marginal Materials. State of the Art

Link to the full report:

https://www.piarc.org/en/order-library/4064-en-Marginal%20Materials%20-%20State%20of%20the%20art

This document is the first one dedicated exclusively to marginal materials, including among them not only natural materials but also industrial by-products (from metallurgy, from thermoelectric power plants or from chemical industry) and wastes (from mining activities and quarries, municipal and industrial wastes, construction and demolitions and dredging muds). It includes descriptions of those materials, reporting briefly about their past use, their quality requirements and the main precautions to be follow with them.

The main conclusions reflected in this document are summarized as follows:

- "Highway engineers are making increasing use of non-traditional materials in pavement construction for reasons concerned with both economics and protection of the environment.
- "Potential materials of this type are numerous, and they often vary from one country to another".
- "Spread of the use of these materials is very uneven. For some of them operational use is already possible in a large number of countries. Enough is known about their behaviour and when necessary, special technical specifications have been drawn up. Because of this, it can be said of these materials that they have almost entirely lost their «marginal» quality. This is the case with blast furnace slags and steel wastes".
- "A similar situation exists for some other materials, but in only a few countries. An example of this are incinerator refuse wastes which are already used operationally in France and Switzerland, but are still undergoing investigations in many other countries. In other countries significant operational applications have not as yet been undertaken and investigations are still being conducted on experimental stretches or even in laboratories".

- "Beside these materials, there are many others which either have special properties or are present in very small areas which may be used when suitable techniques have been developed".
- "Allowance must be made for the fact that even in the case of widely-used non-traditional materials, it is never possible to rely solely on the experience of other countries. This is because their properties may vary from one country to another. It is therefore necessary to exert caution and undertake the required laboratory studies and field experiments".

1991 – PIARC Technical Committees on Testing of Road Materials – Testing of Marginal Materials (02.05.B)

Link to the full report:

https://www.piarc.org/en/order-library/4071-en-Testing%20of%20Marginal%20Materials

Testing and Evaluation of marginal materials (natural marginal materials, industrial by-products, waste) for the use in road construction is handled very differently in national regulations and road laboratories all over the world. There is a vast number of different conventional tests and special (or substantially modified) tests applied to these materials. This is expected to render the exchange of experiences between the various countries difficult, and may even be an obstacle for trade related to these materials. The PIARC therefore deems it desirable to advance harmonization and establish uniform criteria as soon as possible. In a first step, the PIARC published two studies, both based on questionnaires which were sent to experts from member and non-member countries. The first study was published in 1989 (PIARC reference No. 02.04.B, 1989) and is strongly referenced throughout the text of the second report. The document described in this executive summary (PIARC reference No. 02.05.B, 1991) is a direct extension of the publication from 1989 and is mostly concerned with the conventional tests applied to some industrial by-products and special (and substantially modified conventional) tests applied to marginal materials in general.

Conventional tests on marginal materials

There is a large diversity of natural and waste materials, of countries which use them, and of the tests adopted to characterize them (and of definitions of suitability). Because of the strong variability of the characteristics of these local materials, any attempt of standardization of tests is considered to be difficult. No data is given in the report about such materials.

Marginal materials in the form of industrial by-products, however, are not as diverse as natural marginal materials. Still, there are considerable differences in how different countries characterize them and define suitability for their use. This point is underscored in the report by three tables, each one showing the conventional tests typically conducted in different countries and on different materials. The materials described in these tables are blast furnace slag (granulated), steel slag aggregate (LD) and fly ash aggregate and binder. From these tables, the very different concepts of classification become obvious, with next to none of the tests being employed by all countries listed. For any one of these materials only few conventional tests appear to be required in more than one country. One exemption from this observation is, for example, the "size grading". It is stated in the report (p.11) that the "[…] diversity of tests related to teach material appears to be connected rather with different criteria for characterization than with differences concerning the material itself or the way in which it is used. An effort to bring the criteria of various countries closer together may be considered in these cases, once the technical or other bases of each criterion is known."

Special tests on marginal materials

There is a substantial amount of special tests employed on marginal materials. Depending on the type of materials, the number given in the report varies between 43 (natural materials), 42 (industrial by-products), and 11 (waste products). The nature of the tests employed can be categorized according to their nature:

- Mechanical/resistance/compression/impact/abrasion/wear/shear
- Chemical
- Petrographical
- Resistance to water/frost/weather
- Compound/mechanical and/or chemical test pieces/on roads

Based on the data given, the report states that the weight lies on mechanical testing for natural marginal materials, and on chemical tests for industrial by-products and wastes.

The report then summarizes the replies that were received from different countries to the second questionnaire regarding the special tests on marginal materials. This is done separately for natural marginal materials, and industrial by-products and waste. Once again, the report shows the very different materials and tests used in different countries.

In the report it is indicated that "according to the report of the Technical Committee on Testing of Road Materials at the XVIIIth World Congress", held in 1987, "43 types of marginal materials used in road construction were identified". That was possible due to the information provided by 22 countries through a questionnaire. "They referred to more than 300 conventional tests and more than 90 tests which were special or which substantially modified conventional tests". After collecting that information it seemed desirable to establish common criteria for those tests, in order to facilitate the exchange of experiences of use of those materials between different countries.

This document reflects the efforts done at that time within PIARC for harmonizing tests on marginal materials, distinguishing between conventional and more special tests, based on a questionnaire sent to experts from different member countries, with the "*its objective is to study thoroughly the information already published so as to assess the benefit of special tests and to attempt to obtain at recommendations in favour of the most valid tests, taking into account the number of special tests which is too high*".

In the conclusion section of the report the increasing relevance of marginal materials on our globe with respect to the lack of traditional road materials and to environmental protection issues is re-emphasised. It is further stated that "[…] one of the most important steps in this world programme is to be familiar with the properties of marginal materials. The means for this activity are the methods of testing. The purpose of the foregoing study is to assist in carrying out this programme." However, the report also concludes that "[…] it is still impossible to present recommendations, in the present state of knowledge of the special tests referred to."

From the analysis of the information collected through the questionnaire, these conclusions are stated as follows:

- "At the end of this research, it can be concluded that it is still impossible to present recommendations, in the present state of knowledge of the special tests referred to. The research was nevertheless considered to be necessary and to observe publication at international level on account of the increase in the number of types and of the tonnage of marginal materials on our globe.

- The lack of traditional road materials and the protection of the environment make it imperative to investigate marginal materials carefully. One of the most important steps in this world program is to be familiar with the properties of marginal materials. The means for this activity are the methods of testing. The purpose of the foregoing study is to assist in carrying out this program".

2003 – PIARC Technical Committee on Earthworks, Drainage and Subgrade (C12) – Limits of Use of natural Soils, Specifications and Controls in Earthworks

Link to the full report:

https://www.piarc.org/en/order-library/4212-en-Limits%20of%20use%20of%20natural%20soils,%20specifications%20and%20controls%20in%20earthworks

During 2000-2003 PIARC Technical Committee 12 activity, it was decided to be interested in the limits of use of the soils in the earthworks through the various Member States of the committee and simultaneously to analyze the control methods developed to guarantee the good completion of the work.

There was an increasing request in every country to enhance the protection of environment and of life setting to the detriment of our traditional, technical constraints (cf.: conclusions of PIARC Congress 1999 in Kuala-Lumpur and especially the C12 ones in magazine Roads N°305 - January 2000 – pp. 50 to 53). One among the consequences of this request leads to look for earthmovings very short and, when possible, in the right of way of the road. So it becomes unacceptable from an engineer to classify a doubtful soil of a cut as unsuitable to fill an embankment, sometimes a subgrade, while it could previously be laid in a definitive depository and possibly compensated by a borrow pit of attractive soils, sometimes far enough from the work place.

With some risks, some countries have attempted some progress methods to realize embankments or subgrades, using materials generally considered unsuitable because too plastic, too swelling (case of some clays), too soluble (some gypseous materials for example), too unstable after implementation (some clayey rocks like shale or marl) or more simply too wet, too dry or still too erosion sensitive. Solutions have been searched in various treatments applied to the cut materials (such as mediocre enough, bound soils for a use as subgrade fill), or in particular carrying out processes (for instance complementary crushing of blocks), or still particular designs of embankment or subgrade (such as structuring embankment with different natures of soils or subgrade layered with several types of soils).

C12 has considered interesting the mutual knowledge of gathered experiences, although difference of national contexts (by climate, soils, available techniques and mechanical equipment) does not permit easy, direct transposition of the progresses from one country to another. Nevertheless this exchange, as much as possible based on history cases, can provide many possibilities of engineering tools, in this way facing the challenge laid by the justified but demanding need of environmental protection since the design phases.

This survey does not include waste and by-products re-use techniques.

It appears possible to distinguish three types of soils classification:

- **1**: general classification of soils which is not connected directly to specifications of employment, but rather with privileged fields of application with concerning the classes of soil likely to generate difficulties, even whose employment is disadvised. They are generally the classifications of soils derived rather directly from classification USCS or HRB. In this case, one can quote the example of Germany and Switzerland. With these classifications, it returns to the engineering and design department charged to draw up the project to define the soils which will be employable for this project and which condition. So the specification is not generalizable with all the projects, but has to be thus adapted to each particular project under the responsibility of the geotechnical engineer.
- **2**: classification of all the soils suitable to be met and connected directly to a grid of the possible re-employment as fill or capping layer possibly supplied with particular methods of implementation to make the soils acceptable as fill or capping layer. It is in particular the case of the classifications of soils used by France and Portugal. These classifications are specialized for the field of the earthworks and it frequently happens that in the same country, one has a classification of different reference according to specific problems (for example in France for the soil mechanics or the management of resources materials).
- **3**: a third type of classification appears to be that developed by England which starts from categories of employment (for example soils usable as fill, soils usable as fill close to a bridge...) to define the characteristics that the soils must have. This type of classification opposites the reasoning which is not any more "what use can one makes with this soil?", but rather "for a determined need, what are the characteristics of the acceptable soils". So, this classification constitutes a specification for the contracts and is integrated besides in the Specification for Highway Works (SHW) in series 600 (earthwork). As in classifications of the type B, this classification is obviously dedicated to the projects of earthwork and there is another used in soil mechanics.

In this document the main interest is posed in the limits of use of soils in the earthworks and in the analysis of the control methods developed to guarantee the good completion of the work. It does not consider waste and by-products problematic re-use, but natural soils only.

It is explained in the introduction that “with some risks, some countries have attempted some progress methods to realize embankments or subgrades, using materials generally considered unsuitable because too plastic, too swelling (case of some clays), too soluble (some gypseous materials for example), too unstable after implementation (some clayey rocks like shale or marl) or more simply too wet, too dry or still too erosion sensitive”. So, it was considered “interesting the mutual knowledge of gathered experiences, although difference of national contexts (by climate, soils, available technicity and mechanic equipment…) does not permit easy, direct transposition of the progresses from one country to another. Nevertheless this exchange, as much as possible based on history cases, must open improvement possibilities of engineering in front of the challenge laid by the justified, but stronger and stronger constraints to protect environment of the projects”.

Based in the results of a survey launched to member countries, in this report there are proposed some “conclusions in the form of orientations likely to bring progress from the point of view of improvement of the practices with respect to the sustainable development”.

From this document it is very remarkable the clarification of the terminology related to the capping layer and the upper part of the embankment, as shown in the following figures 6.3, 6.4 and 6.5.

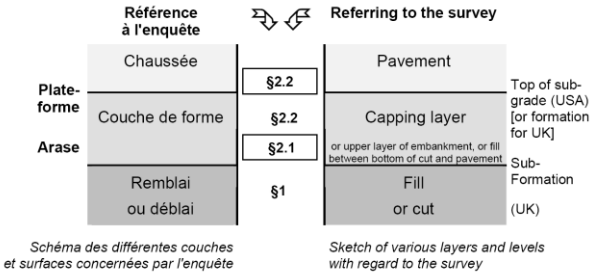


Figure 6.3: Diagram of layers in the road (PIARC, 2003).

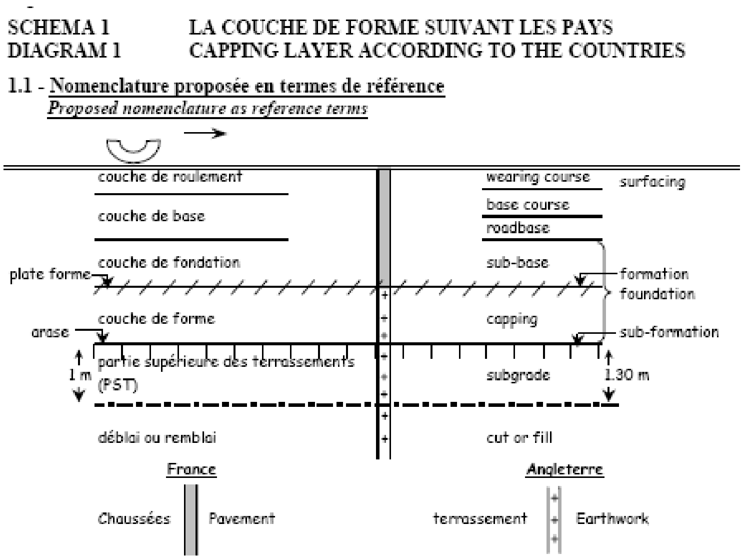


Figure 6.4: Detailed diagram of layers in earthwork and pavement in France and England (PIARC, 2003).

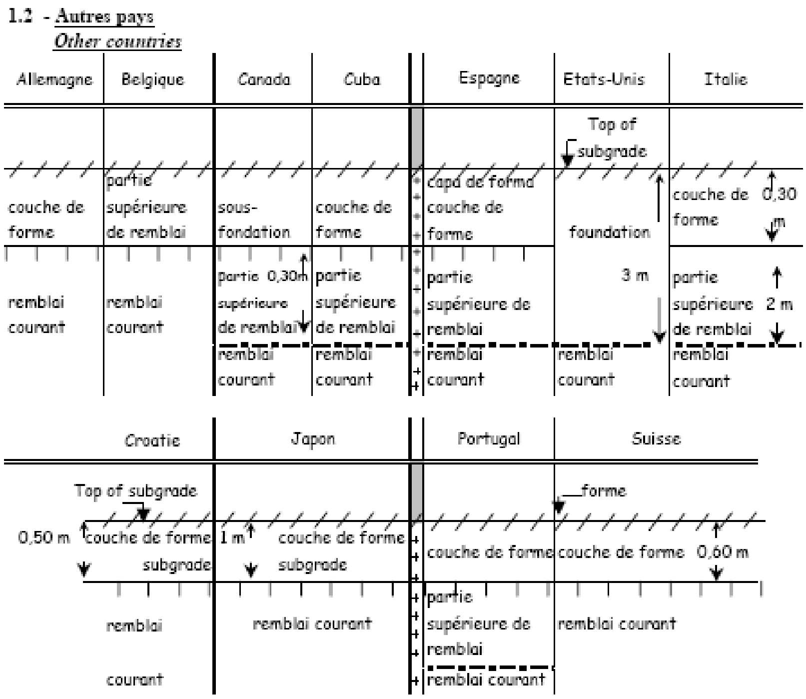


Figure 6.5: Detailed diagram of layers in earthwork and pavement in other countries (PIARC, 2003)

The main conclusions of this report are some recommendations distinguishing between the fill and the capping layer:

As fill

With respect to the drainage and the rainwater drainage: it states that the defects of drainage of the road are the most frequent causes of disorders in embankment, so it must be done an effort towards a more rigorous control of the drains.

*With respect to the allowed nature of soils as fill: i*t concludes that the nature of used soils is seldom a possible cause in the observed disorders, so specifications relating to admission of soils as should "*be widened when they are not justified in a precise way by risks specific to certain countries (for example embankments subjected to freezing or to an intense erosion)*".

Also states that:

"Pushed by need, certain countries extended soil employment as fill to increasingly unfavourable soils with new methods. One can thus quote:

- *the observed development of lime treatment for employment of wet and clayey soils in several countries,*
- *methods developed at the point by Germany, England, France and Japan to allow employment of expansive rocks,*
- *provisions used by Spain to employ very gypseous and thus soluble soils,*
- *processes developed at the point by Japan not to reject the soils named as "excess soils", which, if they are sometimes expensive, seem to answer the social and environmental claims,*
- *method of implementation of arid soils (compaction known as "dry compaction") tested by France for soils of arid areas,*

- *the embankments structuring according to the requested characteristics of each embankment zones, such as usually practiced by Portugal, the United States or France at the time of particular embankment and/or when unfavourable available resources.*

Some of these methods rather simply seem transposable with other countries".

In capping layer

With respect to the design of earthwork formations: the report refers that it should be sought a higher optimization of "upper part of earthwork/capping layer/pavement structure" in the sense of optimizing the investments in "upper part of earthwork/capping layer" and in "pavement structure". It also says that "large progress was performed in soil stabilization with lime and hydraulic binders. It seems interesting to diffuse this progress to limit recourse to borrowed materials out of projects right-of-way on the one hand, and to reduce the hauls on the other hand". It also remarks that there are other ways of improvement like mixtures of materials or homogenizations highlighting that "the so treated materials develop performances which it is advisable to take into account in the total design of the upper part of earthwork, the capping layer and the pavements to also limit recourse to manufactured noble materials which belong to the non-renewable resources".

The capping layer controls: the report refers that "it is necessary to seek the weakest zones of the capping layer to dimension consequently the overlying pavement" and that "in fact the weakest zones will constitute the "fuses" for the behaviour in the time of the operating pavement". So, it is important to have effective and quasi-continuous measures of the bearing pressures and to promote their use.

The drainage: it is remarked that quality of drainage is necessary to protect frost-susceptible soils and also for a satisfactory operation during rainy seasons. In this sense, more rigor in controls of these works is needed.

2007 – PIARC Technical Committee C4.5 Earthworks, Drainage and Subgrade – Promoting optimal Use of local Materials

Link to the full report:

https://www.piarc.org/en/order-library/5747-en-Promoting%20optimal%20use%20of%20local%20materials

Advances in soil treatment are studied, determining the factors that promote and those that hinder its development, advances in equipment and products to stabilize, advances in techniques and methods and a revision of the regulations and legislation is made in this respect.

New developments in the treatment of waste or industrial by-products are then identified through a survey sent to the different countries.

With regard to advances in soil treatment, the factors identified that encourage progress in the development of the use of non-conventional soils for road use are economic benefits, environmental incentives and regulations. The factors hindering them are lack of experience and technical abilities, lack of standards, guidelines or specifications, absence of locally produced binders, economic disadvantage in countries where replacement materials are very cheap, insufficient technical performance in light of climatic conditions and bad publicity from past failures.

In addition, in recent years, high-performance equipment, high power mixing machine and more and more precise spreaders have been developed resulting in savings. This progress is likely to continue.

With regard to products, cement and lime remain the most widely used stabilizing materials, but other stabilizing agents have been developed which are increasingly adapted to material specifications.

Soil characterization tests are the traditional ones such as: Proctor and CBR, Atterberg limits, granulometric analysis, etc. The most recognized mechanical performance test for treated materials is the unconfined compression test, sometimes complemented by triaxial tests, direct box shear tests, or diametric or tensile compression tests. In some cases, the resilience module is also measured. Recent literature also indicates an interest in technologies to stabilize organic soil.

It has been seen that legislation is a contributing factor to the development of the technique, there is a correlation between the development of soil treatment techniques and the preparation of the relevant legislative documentation, i.e. technical documents and standards, most of which have been drafted in recent years, come from European countries.

With regard to identifying new developments in the treatment of waste and industrial by-products, this was done by sending questionnaires to the different countries. Little or no information was received from Asian, African or North American countries. Most of the available data come from Europe and only a small amount from Central and South America.

With regard to definitions, in the European Union waste is defined and classified in Directive 75/442/EEC.

Almost all countries responding to the survey report that they are experiencing a significant increase in the use of waste material or industrial by-products for road construction. Most of the time, the reasons for this are the scarcity of natural and high quality materials, the need to conserve natural resources, the prohibition or limited number of landfills and waste dumps, the implementation of Sustainable Development policies, among others.

The type and amount of industrial waste and by-products are mainly related to the type of industry that exists in the country. By-products are regularly used near production sites and are rarely transported over long distances. The most commonly used heat treatment residues come from the steel, cement and lime processing industries, as well as materials resulting from coal combustion in thermal power plants or from the incineration of solid waste. Others are blast furnace slag, steel slag and fly ash. Another type of material used is demolition waste: by-products of building demolition projects and partial or total demolition of road pavements. The latter seems to be common practice in most countries.

Geotechnical and environmental characterization is performed using conventional test methods and is the most widely used in different countries: particle size analysis, moisture content analysis, Atterberg limit test, CBR and IPI indicators, Proctor density test, sand equivalent test, Los Angeles and micro-Deval tests and also frost resistance, swelling/shrinkage and ignition loss test.

Industrial waste or by-products are most often used for basic road embankment work.

There are geotechnical and environmental restrictions on the use of certain waste products. The use of waste material near or in contact with rivers or ground water areas or drinking water supplies is limited or prohibited and contact with any area involving water management activities should be avoided. The French Road Directorate is preparing a guide on acceptable waste for public works. This guide includes information on usable waste and industrial by-products for roads

Finally, the following two basic recommendations are made that should govern the process of using industrial waste and by-products in road works:

the valorization of these materials must be carried out on treatment platforms that have been adapted to properly detect the geotechnical and environmental characteristics of the product;

the obligation to develop a quality assessment policy (production, valorization, transport, implementation) and make the tracking of these materials possible.

From the perspective of the use of local materials from 1997 to 2007, the use of marginal materials has made great progress in developed countries, but it is relatively slow in developing countries due to various reasons.

The definition of waste and industrial by-products as marginal materials for road construction is both a category of sustainable development and a factor in the protection of natural resources and/or the optimization of their use. In this sense, they are closely intertwined.

Some countries have established legal and technical reference documents. Legislation seems to be an essential factor in the development of soil treatment R&D technology. This factor is a trigger and it encourages the use of specialized technologies. Without this legislation, these technologies cannot be implemented. Therefore, legislation is a contributing factor to technological development. Therefore, there is a correlation between the development of soil treatment technologies and relevant legislative documents.

Economic benefits, environmental considerations and the formulation of standards have resulted in a strong development of soil stability in several developed countries.

Overall, the development of these materials for road construction is very rapid. The main reasons are the lack of quality materials, the need to save natural resources, the restrictions on waste disposal, new policies for sustainable development, and the relatively low cost of these materials. The most used wastes and industrial by-products are the bottom ash of construction demolition materials, recycled concrete pavement (RCP), recycled asphalt pavement (RAP), blast furnace and steel slags, fly ashes, municipal solid waste incinerator (MSWI), but sometimes tires, plastic waste, dredged mud and cellulosic waste. The use of these materials depends on the country and its nature. Common uses are common roadbeds, coverings or alternative materials. They are often used alone, sometimes mixed, and less used after treatment.

However, the past two decades seem to have impeded soil treatment in developing countries due to a lack of technical capacity, lack of adaptation materials, lack of locally produced binders (handling materials), and poor attempts in the past to handle the soil improperly or under certain climatic conditions. Technological development.

Soil treatment must be integrated into the entire process of sustainable development, taking into account positive factors (for example, saving high-quality materials, increasing the amount of re-use of on-site materials, reducing the use of transport and landfills) and the production of adhesives. Adverse factors such as energy use and greenhouse gas emissions.

As a conclusion, we must continue our research in order to better understand the physical and chemical changes that occur during soil treatment in order to increase effectiveness and durability.

If the technological advances of the past few years have created the most advanced soil processing equipment, it is still necessary to develop more sophisticated processing tools and implementation techniques to better adapt to the needs of developing countries.

In general, there should be international support for the promotion of research on the value of these non-natural, marginal materials, and ensure that these results are widely publicized. A few years ago Europe introduced a number of programs such as ALMAT and SAMARIS, which is the initial effort to bring together these materials.

The practice of some countries has proved that it is necessary to consider both the geotechnical characteristics and the environment.

The uncertainty of environmental factors exists due to the risk of long-term stability of the salting out of pollutants. It is beneficial for all countries to coordinate and study the project. In addition, the existing knowledge should be used to assess the value of contaminated waste and industrial by-products based on the type of waste or by-product. In these circumstances, the reuse of certain types of waste requires a very large initial investment to manage the risks and exert constant pressure on the use of these materials.

The cost estimation of these materials must be performed on a processing platform suitable for testing the geotechnical and environmental characteristics of the product.

2012: – PIARC Technical Committee D.4 Geotechnics and Unpaved Roads – Innovative Approaches towards the Use of locally available natural marginal Materials

Link to the full report:

https://www.piarc.org/en/order-library/19067-en-Innovative%20approaches%20towards%20the%20use%20of%20locally%20available%20natural%20marginal%20materials

This document is a very good compendium of all previous works, and it includes many data and advances on the purpose of sharing knowledge and good practices performed around the world. It is centered in the natural marginal materials, so it does not consider materials like waste or industrial by-products.

The document analyzes and summarizes the results obtained in an enquiry done related to "local marginal natural materials"; a profound analysis of the data is done and presented both by country and by material type, structuring this last aspect according to nature of the material, its state, its behaviour and its application; data related to 22 countries are presented: Austria, Belgium, Benin, Bolivia, Brazil, Canada (Quebec), Ivory Coast, France, Germany, Greece, Iran, Italy, Mali, Mexico, Norway, Slovakia, Slovenia, Spain, Sweden, Czech Republic, Switzerland and UK.

Descriptions of some classifications and specifications and their applications are done, focusing on applications of specifications in the case of marginal materials; the classifications compared are the ones collected in Table 6.1 and specifications referred are the ones in Table .

Classification	Country	Organism	Comments
USCS	USA	ASTM D 2487	
AASHTO	USA	ASTM M 145	
Classification Canada-Quebec	Canada-Quebec		Norme 1101-Classification des sols-Tome VII, ch.1
STN 736244 and STN 736133	Slovakia		
Classificazione delle terre C.N.R.-UNI 10006/1963	Italy	CNR – Consiglio Nazionale delle Ricerche	Updated and widened in EN ISO 14688:2018 (part 1 & 2)
CSN 736133	Czech Republic		
GTR guide: NF-P-11-300	France	AFNOR	
SHW: 600 Earthworks	UK		Specification for Highway works

Table 6.1: Material classifications collected in 2012 PIARC document.

Country	Year(1)	Name	Comments
Belgium	2010	Code de bonne pratique (CRR R 81/10) pour le traitement des sols à la chaux et/ou aux liants hydrauliques	From the Centre de recherches routières
Czech		CNS 736133 Design and execution of earth structures in roads	Standard for earthworks
France	2000	GTR Guide technique Réalisation des remblais et des couches de forme	GTR, GTS (LCPC-SETRA)
	2003	GTR Technical guide on Embankment and capping layer construction (English version)	
	2000	GTS Guide technique Traitement des sols à la chaux et/ou aux liants hydrauliques	
	2004	GTS Technical guide Soil treatment with lime and/or hydraulic binders (English version)	

Country	Year(1)	Name	Comments
	2007	Conception et realization des terrassements (SETRA/CFTR) Design and execution of earthworks	
Germany	2009	ZTV E-StB09-2009 Zusäliche Technische Vertragsbedingungen und Richtlinien für Erdarbeiten in Strassenbau	
		TL BuB E-St B09 Technische Lieferbedingungen für Böden und Baustoffe für den Erdbau	
Slovenia	2009	New specifications for earthworks	New specifications in 2016: Slovenski Standard – (English version) oSIST prEN 16907-1:2016
Slovak		Technical Standard STN 736244	Transitions in road and highway bridges
		Technical Standard STN 736133	Road Construction Body of the roads
Spain	2002	PG3 General Specification for Road and Bridge works	Construction of earthworks, drainage and foundations
UK		Manual of contract documents for highway works Vol. 1 Specifications for highway works-Highway Agency Series 600 Earthworks	

(1) Last version

Table 6.2: Specifications referred in 2012 PIARC document.

The marginal materials, even if they do not completely conform to specifications in use for normal road materials, are allowed to use in fills by applying a treatment with binders (lime and cement) or spread fibres.

Several risks may be arise by using certain marginal materials. However, specific preliminary studies, which are detailed enough, permit to put in place proper procedures for effective control of the risks. Penalising elements, such as gypsum, organic sulfur or organic matter, may be contained in marginal material and may disturb or cancel the effects of the selected treatment.

Different research studies highlighted how the conventional classification tests (grain size, Atterberg limits, methylene blue value) are not adequate to assess particular constituents, so a complete physio-chemical analysis is needed to detect the presence of penalizing elements.

Treatments in road engineering received considerable interest for the following reasons:

- Possible use of silt-clay soils and suitable waste materials;
- Reduction of permeability and erosion;
- Reduction in swelling tendency;
- Increasing the strength of the treated volume;
- Reducing the soil thrust on the retaining structures.

In the Table 6.3 below are listed the recommended methods, grouped by family or materials, to allow the use of marginal materials.

Materials	Methods and techniques
Changeable or fragmentable soils/rocks	The correction of the block size distribution by mechanical treatment of the materials: sorting, caterpillar fragmentation, ripping, screening, crushing (in place or in plant). The correction of block size distribution by blending in a pulverizer. Increase in compaction energy (intense compaction). Decrease in layer thickness. Encapsulation after fragmentation in order to remove the materials (argillites, shales) from climatic influences. Fragmentation, addition of water, placed in a temporary stockpile to achieve equilibrium water content and suction with the environment (flyschs).
Materials with particular constituents	Construction applications (core, encapsulation). Encapsulation of materials to remove them from the risks of the penetration of water, frost action, (gypsum, etc.). Combination of weak soils with recycled materials to improve their mechanical properties ("soils with mineral impurities"). Treatment with lime or hydraulic binders after tests for applicability for treatment.
Clayey materials	"Sandwich technique" (intercalation of granular drainage layers). Intercalation with geotextiles. Treatment with lime (possibly in the core, smectites).

Materials	Methods and techniques
	Preliminary deposit to allow the material to freeze during the winter (Quebec clay).
Very wet materials	Aeration. Placing in storage for drying. Treatment with lime. The addition of a correcting grain size (flood plains sand deposits).
Very dry materials	Adjustment of the water content by adding water, irrigation and chipping of the upper part of the embankment (sands from the French Landes). Increase in compacting energy.

Table 6.3: Recommended methods to allow the use of marginal materials.

The treatment techniques have been changed over the years, both for availability of new equipment and in order to limit costs.

At present, the treatment in mixing plant are less used than in situ treatments, which have greatly improved in recent years. The difficulties to be solved for the latter type of treatment lie in the precision of the doses and the depth of mixing linked to the allowable size.

The equipment used for in situ treatments are:

- horizontal shaft soil pulverizers (for treating materials with large or heterogeneous elements);
- flusher ploughs (in situ moistening by injection);
- bulldozers and motor graders;
- stone crusher;
- crushing traction machine;
- mixing with a rotor.

As mentioned before, several research studies focused on the behaviour of treated marginal materials.

It is worth mentioning the project COGESTAC - COmportement GEomécanique des Sols Traités à la Chaux (Geomechanical behaviour of soils stabilised with lime - France), which allowed a number of advances in the study of the physio-chemical mechanisms for the treatment of soils with lime and provided new insights into the behaviour of these treated soils. According to this study, the effectiveness of lime treatment depends on the nature of the soils and its constituents. The characterisation of the mineral content of the soils (e.g. X-Ray Diffraction – DRX), especially clay minerals, is necessary to assess the effectiveness of the treatment. This study did indeed show that some clay minerals are more susceptible to lime attack and are rapidly degraded to form new pozzolanic products.

Regarding the change of mechanical strength, the temperature strongly influences the increase of resistance. An increase in temperature (up to 50°C in this example) leads to rapid changes from one stage to another by activating the development of pozzolanic reactions. ICU triaxial tests have shown the improvement of mechanical performance due to the increase in effective cohesion (the friction angle varies only slightly) that is found to be correlated to the formation of pozzolanic products like Calcium Silicate Hydrate (CSH).

This research concerns also the study of deformability in the field of very small deformations, showing how the stiffness modulus increases sharply with time and its value can reach and even exceed the one habitually used after for traditional materials a certain curing time (several months).

One of the most interesting results achieved regards the erodability of treated soils. Indeed, the treated material showed a significant behaviour against erosion, which becomes negligible after a few days. Hence, the treatment may be an interesting technique to ensure the integrity of slopes.

The research project TerDOUEST based on the construction of an experimental embankment in underway in France with the aim to use as fill highly plastic clay classed as A4 according to GTR. A4 soils are considered unusable due to:

- very poor strength characteristics in saturated conditions (friction angle and cohesion) that make the soil unsuitable to ensure the internal stability,
- shrinkage and swelling phenomena, which has the effect of making the structure unstable in the long term.

This project is based primarily on the need to increase fundamental knowledge on the mineralogical nature of the materials and the interaction with binders.

The research programme is made up of 4 modules:

- Demonstration of the relationship between physio-chemical processes and geotechnical behaviour of treated soils in order to optimise treatment and provide new tests.
- Study of long-term behaviour of treated soils from samples of earlier works (since 1978) to understand the aging in place of treated materials in different environments and complement the scientific approaches (microscopic) of module A.
- Construction and monitoring of a trial site to test the re-use of highly plastic clays.
- Environmental evaluation of earthmoving operations in the construction of a trial embankment.

The results on the trial site showed that the treatment has let to change the behaviour of the A3/A4 clays from a very plastic and wet state to a more powdery state easier to work and to put in place during the construction.

The mills obtained on the mixtures after the various treatment operations were good (0/31.5 mm for clay and 0/20 mm for silt) but may change during the recovery operations and transport.

An additional passage of the pulverizer before compaction may be recommended for the larger scale implementation in works.

It remains to be validated that all the practice of soil treatment allows an overall positive impact on the environmental impact of an earthmoving project.

Where the investment can be justified (for large infrastructure projects), preliminary tests will be conducted at the site or on trial sites to confirm the methods and techniques recommended for use of marginal materials (laboratory analyses).

6.4. Conclusions of previous PIARC reports

As said, much work has been already performed within PIARC committees since more than 20 years ago considering different aspects of the use in road embankments of marginal materials, either natural ones or industrial by-products and wastes.

From all those works we can highlight different aspects that can be grouped in general aspects and others, related mainly to types of materials, to treatments, to geotechnical risks or to future progress on the issue. The main conclusions extracted from the review of previous reports are shown in Table 6.4.

General aspects	There is a variety of marginal materials and they often vary from one country to another. The spread of use of these materials is very uneven. Some of them are used in many countries and their behaviour is quite known. The concept of marginality is related to a particular time or place. Some materials may lose their marginal quality as their behaviour is studied and they may be valorised. This seems to be the case of blast furnace and steel wastes. The use of non-traditional materials should not rely solely on the experience of other countries, as their properties may vary from one country to another. Current practices in a number of countries demonstrate the need to take both geotechnical and environmental issues into account".
With respect to materials	According to the last PIARC report on this issue (2012), the marginal materials most often used in Europe are mainly: o changeable materials, especially argillaceous rocks; o materials with particular constituents (sulphates, sulphides, organic matter); o homometric sands. Lateritic materials are a common problem for unpaved roads in South America and Africa. The use of industrial by-products in road embankments is directly related to local production industries. These materials are rarely or never imported or exported. Concrete demolition material, bituminous material from old roads, iron and steel material and steel slag, fly ash and MSWI (municipal solid waste incinerator) bottom ash, tires, plastic, and less frequently dredging mud or cellulosic waste, are being reused.

With respect to treatments of materials	The use in embankments of changeable materials and materials with particular constituents is possible, with specific conditions of treatment; improvements are needed to detect the presence of the constituents by surveys, specific tests, etc. Problems with lateritic materials are often solved by replacement with other materials or mixtures of treated materials; it is a critical economic subject that demands further thorough investigation. Treatments of materials which are too clayey, too wet or too dry require a better understanding of the reaction with binders; the use of very dry and very wet materials links to climate change adaptation and could be improved by new researches. Homometric sands may be used reliably by addition of a correcting grain size. Appropriate special design measures (core, encapsulation, etc.) are already applied; complete feedback from the behaviour along time is not available at present.
With respect to geotechnical risks	Changeable materials and materials with particular constituents are considered the ones with the greatest geotechnical risks. Emphasis must be placed on achieving technical advances which lead to improved use of potential resources consisting of marginal materials while controlling risks.
With respect to future progress on the issue	At least the following aspects can be indicated: • To continue updating the data with new cases can always be useful to increase the knowledge; these could either come from new cases performed or from old cases not previously referred; also, from the participation of new countries. • To collect feedback from the medium and long term behaviour of embankments constructed with marginal materials. These case histories should focused on: ▪ type of materials employed; ▪ parts of the embankment where they were used; ▪ how they were placed: treatments, compaction; ▪ machinery, alternative layers, use of impervious layers; ▪ use geotextiles to isolate layers; ▪ medium- and long-term behaviour.

Table 6.4: Main conclusions from previous PIARC works.

7. DATA COLLECTION METHODOLOGY

7.1. TC D.4.2 ENQUIRY

A first enquiry (2016-2017) was launched by TC D.4.2 subcommittee in order to collect data related to types of marginal materials used in various countries and relevant classifications and standards.

Enquiry has been organized as follows:

- Question 1: Are there any standards in your country to specify the technical characteristics of road embankments and/or unpaved roads?
- Question 2: How do you define marginal material in your country?
- Question 3: Are there any marginal materials used in road embankments and/or unpaved roads in your country?
    - If not, why?
    - If yes, please answer the following questions:
- Question 4: Which marginal materials are used?
- Question 5: Which benefits have been obtained from their use?

Some examples of studies, research projects and cases performed with marginal materials has been collected from Belgium, Canada (Québec), China, Spain, France, Germany, Italy, Slovenia, South Africa, Sweden and others.

Some recommended methods grouped by family of materials are exposed, some reflections on risk managements of projects are done and some conclusions are reached, from which we can highlight the following aspects:

With respect to materials, the ones considered are mainly:

- changeable materials, especially argillaceous rocks;
- materials with particular constituents (sulfates, sulfides, organic matter);
- lateritic materials, which are a problem for unpaved roads in South America and Africa;
- homometric sands.

With respect to treatments of materials:

- the use in embankments of changeable materials and materials with particular constituents is possible, with specific conditions of treatment; improvements are needed to detect the presence of the constituents by surveys, specific tests, etc.
- problems with lateritic materials are often solved by replacement with other materials or mixtures of treated materials; it is a critical economic subject that demands further thorough investigation;
- treatments of materials which are too clayey, too wet or too dry require a better understanding of the reaction with binders; the use of very dry and very wet materials links to climate change adaptation and could be improved by new researches;
- homometric sands may be used reliably by addition of a correcting grain size;
- appropriate special design measures (core, encapsulation, etc.) are already applied; feedback from the behavior along time would be useful.

With respect to geotechnical risks:

- changeable materials and materials with particular constituents; these are considered the ones with the greatest geotechnical risks;
- emphasis must be placed on achieving technical advances which lead to improved use of potential resources consisting of marginal materials while controlling risks.

With regards to marginal materials used, answers from countries gave the following data (Table 7.1):

Counstry	Marginal materials used	Main benefits from its use	Comments
Belgium	Silty soils with high water content and low bearing capacity	Preservation of granular natural materials Reduction of costs and nuisances related to the transport of materials	Soil is treated with lime, cement and roads hydraulic binders
Benin	None		
Canada	Recycled concrete and recycled pavement (dmax: 300 mm) placed in embankment. Wood fibre Shredded tire Foam glass	Wood fibre: light material – isolation Shredded tire: light material and embankment were used as a "waste site" for tires. Foam glass: light material – isolation - embankment would be used as a "waste site" for glass Light concrete: light material – isolation Recycled concrete or recycled pavement: economical gain and environmental grain (less waste).	Wood fibre was used for many years but are no longer used in Ministry roads embankments because of poor long term behaviour Shredded tire was used for a few years but are no longer used because of lack of material availability Foam glass is under study to be used Light concrete is under study to be used
Chile	None in embankments		There are good quality materials in most parts of the country
China	Red clay High liquid limit soil Expansive soil Loess	Actually these materials are used when there is no choice; in Jiangxi Province, because of frequent rainfall, it will take a long time to deal with high liquid limit soil by lime.	Answered from Jiangxi Provincial Highway Research & Design Institute

Counstry	Marginal materials used	Main benefits from its use	Comments
	Saline soil Frozen soil		
	Expansive soil Collapsible soil Saline soil Frozen soil	Environmental and economical	Answered from Heilongjiang Institute of Highways and Transport Research
Czech Republic	Highly plastic clay soil usually treated with lime		Generally, not in road embankments and unpaved roads. However, if there is no other possibility, unsuitable materials are treated, e.g. by lime
France	Natural marginal materials as: high plasticity clay swelling clay very wet or dry soils (clays, limes, sand...) weak rocks dredging material (silt) homometrics material used under certain circumstances : depending on the height of the embankment and depending in which part of the embankment (core)	Optimal use of local soils in regards to environmental and economic benefits	It must be carried out a risk analysis to take into account the costs resulting from potential problems in the management phase

Counstry	Marginal materials used	Main benefits from its use	Comments
	Manufactured or by-products as: Construction and demolition recycling industries materials Foundry sand Fly ash Red and black Coal Shale Blast furnace slag, MIOM; garbage Stationery waste Dredging sediments	materials of the local industries, Use in areas with no possibility of contamination of the groundwater, specific environmental studies Case studies were already proposed in previous sessions	Shredded tire were just experimented
Germany	Soft, fine-grained soils (after improvement) Weak rocks (under certain circumstances) Soils with organic contents (under certain circumstances)	Optimum use of local soils Reduction of amount of deposited materials Reduction of consumption of primary raw materials	
Italy	In-situ alluvial soils Clays, soft clays, swelling clays Silty Clays Silts Gipsy marls Dolomia Chemical contaminated soils	Optimal use of local soils Reduction of amount of dumped materials Reduction of road transport of waste materials, with benefits in energy consumption and road safety Reduction of consumption of primary raw materials Environment protection-oriented design	Environmental benefits achieved but at cost of more expensive design

Counstry	Marginal materials used	Main benefits from its use	Comments
	(after specific treatment)		
Slovenia	Clay (embankments from poor soil, clay) combined with lime stabilization Recycled material (asphalt, concrete, pavement) mixed with good quality material	economic	
South Africa	Poor CBR soils for deep embankments Dusty clayey or coarse materials (crushed) for gravel roads Low durability or high potential for deterioration for breakdown	Varied. Good quality material sources are becoming scarce, so using marginal materials in non-critical areas of the pavement/ fill makes it more sustainable. With gravel roads it is mainly reduced costs due to savings in haulage distances but may increase frequency of regravelling or maintenance. So savings is not as significant	Embankments in particular may use very poor material if protected from moisture. Unpaved roads generally use material from the local area even if it is marginal to avoid additional haulage costs.
Spain	Swelling clays Gypsum Soluble salts High plasticity clays	The main benefits of using these materials are environmental and economic benefits. The Standard does not call for a pure and simple application of these marginal materials, which could degrade the quality of some infrastructure, but instead treats the topic with great detail, in projecting the need to conduct a custom study in order to justify potential uses and analyse application conditions on a case-by-case basis.	Most common marginal soils are swelling clays and gypsum, for which specific cartography is available at a basic level
Sweden	None in new constructed roads		Sweden has a very solid bed-rock consisting of granite and other hard

Counstry	Marginal materials used	Main benefits from its use	Comments
			rocks. Of course there are areas with clay and other materials. Lime pillars to stabilise foundation soils are used.

Table 7.1: Marginal materials used in some countries (from enquiry 2016-2017).

With regards to standards provided, answers from countries gave the following data (Table 2):

Country	Organization [1]	Standards	Year	Type of roads or part of road [2]	Comments
Belgium		SB2050 Qualiroutes CCT2017			They are regional standards
Benin		There is no Standard, but classifications contained in the Technical Specifications and Particular Clauses based on French standards (NFP, L.C.P.C) are used			
Canada		BNQ and Ministry Standards			
Chile	Dirección Nacional de Vialidad (National Roads Administration)	Manual de Carreteras (Roads Manual)			The Manual is updated every year
China		Technical Specification for Construction of Highway Subgrades (JTG F10-2006)	2006		It involves technical requirements for subgrade construction of different grades of highways

Country	Organization [1]	Standards	Year	Type of roads or part of road [2]	Comments
					including unpaved roads
Czech Republic		CSN 736133 Design and execution of earth fill on roads			
France	French Ministry for Equipment and Transport (DGITM-DIT) e) Private : Scetauroute	Technical specification : a) Guide of construction of embankments and capping layers (fascicles 1 and 2) b) Guide of soil treatment with lime and/or hydraulic binder c) Guide of earthworks conception and achievement : - fascicule 1: study and earthworks execution - fascicule 2: control organization - fascicule 3 : trials methods d) CCTG part 2: technical and administrative requirements in public procurement e) guide of earthworks platforms conception	1992 1995 2007 1998	a) Embankments and capping layer b) Application to the construction of Fills and capping layers c) Earthworks e) During earthworks execution	a)They define the description and classification of natural soils and rocks (A; B; C; D and R classes) and some organics and industrial by-products soils
	French Ministry for Equipment and Transport (DGITM-DIT) and publics establishment	f) OFRIR: French observatory of re-using by-products in infrastructures http://ofrir.lcpc.fr g) Guide of environmental acceptability of alternative materials in road technology h) Local/regional guides specially for industrial by-products used			More specific documents for the not natural materials

Country	Organization [(1)]	Standards	Year	Type of roads or part of road [(2)]	Comments
Germany	FGSV – German Federal Road and Transportation Research Association	Additional technical conditions of contract and directives for earthworks in road construction – ZTV E-StB 09		Road embankments	These documents specify the requirements for the technical and environmental suitability of soils, recycled materials and industrial by-products
		Additional technical conditions of contract and directives for the construction of rural roads – ZTV LW		Unpaved roads	
Italy	Ministry of Infrastructure	DM 6792/2001 (Road Geometry and Technical Specifications) DM 17/01/2018 (Technical Standards for Construction) DL 152/2006 (Environmental Code), now replaced by DPR 279/2016 DPR 120/2017 (Materials from Excavation Management)		Road embankment (mainly), non-structural fillings, exhausted quarries rehabilitation	Marginal natural materials are mainly used in the core and in foundations, rarely in shoulders and never on subgrade; A treatment is always mandatory for use of marginal materials in structural parts of earthworks
Slovenia	Slovenian Road Association	Special Technical Requirements (PTP): - Volume 3 is dedicated to earthworks and unbound layers Technical Specifications (TSC)	1989 2003	Paved and unpaved roads, Highways	These documents are national technical requirements for earthworks in road construction

Country	Organization [1]	Standards	Year	Type of roads or part of road [2]	Comments
		- TSC 06.100: Pavement embankment/subgrade - TSC 06.800: Use of Recycled materials in road construction			
South Africa		Technical Recommendation for Highways. Some chapters in the standard are: TRH 9-Construction of Road Embankments TRH 10-Design of Road Embankments TRH 14-Guidelines for Road Construction Materials TRH 20-The Structural Design, construction and Maintenance of Unpaved Roads			
		COLTO-Standard Specification for Roads and Highways			
Spain	Ministry of Public Works	PG-3 (Pliego de Prescripciones Técnicas Generales para Obras de Carreteras y Puentes) Chapter 3 is dedicated to embankments	2002	Road embankments	Though it is not prescribed for unpaved roads, it is usual practice to apply it to them as well
(1) It refers to the organization that published the standard					
(2) It refers to the type of roads the standard is designed for					

Table 2.2: Standards in some countries to specify the technical characteristics of road embankments and/or unpaved roads (from enquiry 2016-2017).

7.1.1. Classifications of materials

Standards and technical specifications for classification of materials for earthwork, up-to-date thanks to data collected by the enquiry, are presented in Table .

Country	Technical Regulation	Organization	Year	Notes
EUROPE	UNI EN 16907-2:2019	CEN - European Committee for Standardization	2019	Earthworks, Part 2: Classification of materials
ITALY	CNR-UNI 10006:1963, UNI-EN 13242:2008 and others (see notes)	UNI	2008÷2018	CNR-UNI 10006:1963 (Materials for Road Construction), now replaced by UNI-EN 13242:2008 (Aggregates For Unbound And Hydraulically Bound Materials For Use In Civil Engineering Work And Road Construction), UNI-EN 13285:2010 (Unbound Mixtures - Specification), UNI-EN-ISO 14688-1:2018 (Geotechnical investigation and testing - Identification and classification of soil - Part 1: Identification And Description), UNI 11531-1:2014 (Construction and manteinance of civil works for infrastructures – Materials Use Criteria – Unbound Aggregates Mixtures)
FRANCE	NF P 11-300	AFNOR	1992	NF P 11-300 : Exécution des terrassements. T2: Classification des matériaux utilisables dans la construction des remblais et des couches de forme d'infrastructures routières.
		SETRA	2011	Acceptabilité de matériaux alternatifs en technique routière – Évaluation environnementale – Guide méthodologique.
GERMANY	DIN 18196	Deutsches Institut fur Normung E.V. (DIN)		DIN 18196 Earthworks and foundations – Soil classification for civil engineering purposes
SPAIN			2002	Pliego de Prescripciones Técnicas Generales para Obras de Carreteras y Puentes (PG-3) regulation (see Clauses 322 and 330 to 333),

Country	Technical Regulation	Organization	Year	Notes
				from Dirección General de Carreteras (State Road Administration).
SWEDEN	EN ISO 14688-1:2018	ISO	2018	Geotechnical investigation and testing - Identification and classification of soil - Part 1: Identification and description (ISO 14688-1:2017)
	EN ISO 14688-2:2018	ISO	2018	Geotechnical investigation and testing - Identification and classification of soil - Part 1: Identification and description (ISO 14688-1:2017)
	EN ISO 14689:2018 (instead of quoted EN ISO 14689-1:2003)	ISO	2018	Geotechnical investigation and testing - Identification, description and classification of rock (ISO 14689:2017)
	EN ISO 14688-1:2018	ISO	2018	Geotechnical investigation and testing - Identification and classification of soil - Part 1: Identification and description (ISO 14688-1:2017)
UK	BS 6031:2009	BSI	2009	BS 6031:2009 Code of Practice for Earthworks.

Table 7.3: Specifications referred in present PIARC document.

7.2. Data related to cases of study

7.2.3. Required data

The most important data to summarize each case are: identification data, geometry of embankment, type of marginal materials used, execution techniques, machinery used, compaction, time behaviour (if available).

These data are presented in the following tables.

7.3. Cases collected

7.3.3. New and old collected data

Cases from Spain

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
Road A-23. Villanueva de Gállego-Zuera (Zaragoza). Opened in 1998. Source: Rivera Blasco (2005a).	Ground with gypsum in the whole route with high sulphate content and low density. Allowable pressures: 0.1-0.4 MPa	H_{max}= 14 m. Slopes 3/2. Shoulders 2.5 m thick.	White and grey gypsum	Sulphates > 20%. Allowable pressures: 0.2-0.4 MPa.	Core	> 1m under crown > 30cm over natural ground Impervious geomembrane under crown Layers of 25 cm (max. particle size=2/3). Compaction using tamping roller.	No data	The water must not get the core

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
			Gypsy silts from bottom of the valley	Sulphates > 20%. Allowable pressures: 0.1-0.5 MPa.	Foundation		No data	Necessary compaction of the silts in bottom of valley
Highway del Olivar: Conection West Baeza-North Puente del Obispo (Jaén). Starting Works date: 2009. Source: Ramírez Rodríguez y García Santiago (2013).	Grey marl of low bearing capacity, high swelling potential and low density after compaction.		Grey marls	HL=3.38% (free swelling) Unit weight=14.5 kN/m^3		Section 1: Treatment with: 1% lime+4% biomass slags	No data	The Project design was with layers heighs of 30 cm that after compaction should reach: CBR≥6 Dry density ≥95% PM IP<15
						Section 2: Treatment with: 1% lime+1% ash from thermoelectric power plant	No data	
						Section 3: Treatment with: 2% lime	No data	
						Section 4: Treatment with: 1%cal+2% ash from	No data	

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
						thermoelectric power plant		
Z-40. Tramo: Ronda Sur de Zaragoza (Zaragoza). Opened in 2003. Source: Rivera Blasco (2005b).	Gypsy ground with high sulphate content	H_{max}= 12 m. Taludes 3/2. Shoulders 4 m thick.	Alabastrine gypsum and gypsy marls	Sulphates > 20%. Good bearing capacity	Core; Shoulders	> 0.5m under crown Impervious geomembrane under crown (overlap 30 cm) Layers: 40cm (max particle size=2/3) Compaction using tamping roller.	No data	Gypsy silts from bottom of the valley in the route were substituted by granular ground. Deep settlement control (no data available)
Highway "ruta del Toro" (Cádiz). Opened between 2004 and 2006. Source: Atienza Díaz (2007).	Marls and marly clays of high plasticity and expansive properties.		Marls and marly clays	IP ≈ 22 HL ≈ 5% (free swelling)	Core	Stabilization with lime (2%) in layers of 30 cm (max. height)	IP is lowered from 20-23 to 5-10. CBR is increased from 1-3 to 18-55 at 7 days. Free swelling is lowered from a mean	

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
							value of 5% to 1%	
Section I of M-45 (Madrid). Opened in 2002. Source: Sahuquillo et al. (2002); Oteo Mazo (2007)	High plasticity clays with sepiolite and silts on the route	Core with high plasticity clay isolated; thickness: 3 m. Where higher thickness 3m capsules are separated by 1 m. Shoulders: 4 m. Foundation and crown: 1 m.	High plasticity clay with sepiolite	Mean values: Fines: 77.5% LL: 83.7 IP: 39.1 Dry unit /wet unit weight: 12.2 / 17.0 kN/m^3 Opt. moist. cont.: 38.4% CBR: 5.42%	Core	Compaction on wet side: moisture: +2% Opt. Proctor Dry density: 95 y 98 Opt. Proctor Min. wet unit weight: 16.7 kN/m^3 Compaction using tamping roller (7 double passes in layers of 30 cm height)	Wet density sometimes lower that required Compaction degree>95% Water content close to optimum Mean settlement: 3 mm Maximum settlement: 9 mm	
Section II of M-45 (Madrid). Opened in 2002. Source: Domingo et al. (2000); Castanedo	High plasticity clays with sepiolite		High plasticity clay with sepiolite	Fines: 23-99.5% LL: 49-162% IP: 13-83 Dry unit weight: 6.8-	Core; Shoulders; Foundation	Lime stabilization: 2.4% in shoulders and foundation, 1.8% in core	E_{v2}> 100 MPa Dry unit weight: 8.8 kN/m^3 Final height in layer= 26 cm	

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
(2007); Oteo Mazo (2007).				10.8 kN/m^3		Put in place on the wet side, w: +2 y +8 Proctor Compaction using tamping roller	Footprint test (24 hours) < 5 mm	
Highway M-50 y R-4 (Madrid). Opened in 2007. Source: Simic (2007).	Soils in the route: 85% marginal soil and 5% inadequate soil	Foundation 1 m height Shoulders 2.5 m height with slope 2H:1V Last layer of core 0.6 m height. Vegetable covered in shoulders 0.25 m height	Gypsum clays and high plasticity clays	LL= 30-110% Water content= 10-60% Dry unit weight= 9.8-19.6kN/m^3	Core	Layers of 30 cm height Compaction with rammer rollers of high speed (6 double passes). Core: added 1% lime, Compaction using tamping roller to 98% PN Last core layer: added 2% lime, Compaction using tamping roller to 98% PN Crown: added 4,5% lime, compacted with smooth roller to 98% PN	Settlements between 1.15 and 1.2 mm.	Use of slaked lime. Wet -1 - +3 % w nat. Foundation: 30 cm with 4.8% lime in M-50 and 3.5% lime in R-4 . Rest: 25 cm with 4.5% cement. Uniaxial compression strength at 7 days over 1.5 MPa

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
Highway Bilbao-Behobia (Vizcaya/Guipúzcoa)) Opened in 1974. Source: Rodríguez Miranda et al. (1986).	Water sensitive materials	Place: Vaguada del Caño C-348: Length: 200 m Max. height: 35 m.	Clayey material	LL= 35 IP= 17.5 D_{max}= 18.8 kN/m^3 W_{opt}= 12% W_{nat}= 22%	Core	2 m clayey layers between 1 m layers of granular soil. Wherever embankment height is over 15 m width a shoulder of riprap is added. Clay compaction with specific equipment and riprap compaction with vibrating rollers.	Settlements of 15 cm in 3 months. No problems on posterior behavior.	Granular layers between clayey layers are essential to allow drainage.
		Place: Errotazar: Length: 300 m Max. height: 17 m.	Clayey material	LL= 70 IP= 36 D_{max}= 13.9 kN/m^3 W_{opt}= 27% W_{nat}= 30-45%		3 m clayey layers between 1 m layers of granular soil (limestone and sound clayey sandstones). Slopes 2H/1V. Wherever embankment height is over 10 m width riprap is added. When height is over 10 m: riprap protection at		

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
						foot. Granular soil on crown, 1.5m height.		
Detour from Alcalá de los Gazules (Cádiz). Opened between 2004 and 2006. Source: Rodríguez Ballesteros (sin fecha).	Expansive clays		Clay	LL= 30-95 % LP= 15-45 % IP= 10-50 %	Core	Removal of particles bigger than 80 mm. Clay layers of 40 cm. Lime added (2-3%) every 15 cm. Compaction to a minimum of 95% of PM.	No data	
CN-340 in Xátiva (Valencia). Source: Morilla (1994); Castanedo (2007).	Gypsum and medium plasticity clays with high content of illite		Gypsum and clay	Clay: LL= 40 IP= 13	Core	Layers of 30 cm compacted with vibrating roller or layers of 20 cm compacted using tamping roller.	No data	Compact on the dry side
Detour from road M-307 en San Martín de la Vega (Madrid) Source: Castanedo (2007).	Different gypsy grounds		Gypsy ground		Core	Gypsum is placed in layers of 90 cm isolated by an impervious geotextile	No data	

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
Highway Burgos-Málzaga (Burgos). Opened in 1977. Source: Soriano (2002); Castanedo (2007).	Clays and gypsum.	Height between 3 and 30 m.	Clay matrix with gypsum	Clay matrix with 30-40% of gypsum	Core	Layers of 30-40 cm height. Compaction on dry side with vibration roller	Good posterior behavior	
Highway in Venta de Baños área (Palencia). Source: Oteo (1994).	Expansive tertiary clays with some carbonates		Expansive clay		Core	Clay is completely surrounded by granular soils with some fine content (25-35 %)	No data	

Table 7.4: Cases from Spain.

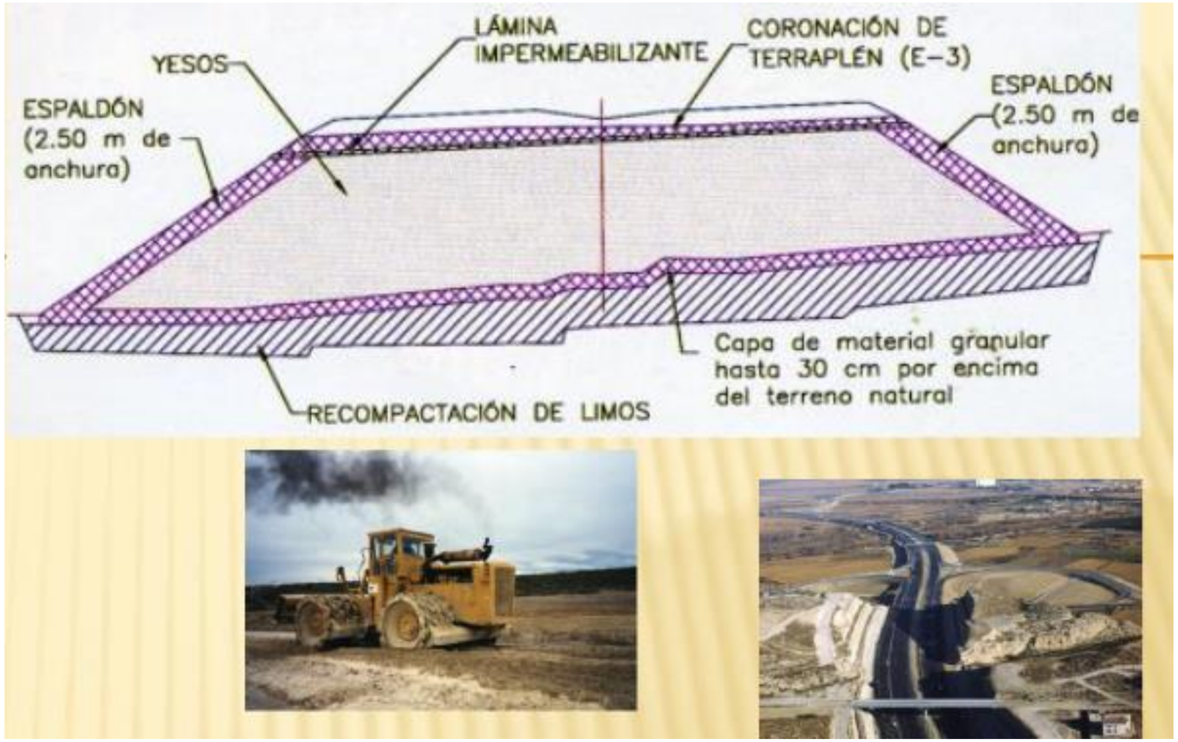


Figure 7.1: Highway A23 Villanueva de Gallego-Zuera (Spain) – Embankments geometry and materials.

Cases from Italy

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
Vicenza by-pass (Veneto, Northern Italy) - Work in progress (2017) - Source: Anas Spa	No quarry available for suitable materials within distances from the site up to 40 km. Strict environmental legislation in Regione Veneto	Hmax=5 m Slopes 3/2	In-situ alluvial soils - Clays, Silty Clays, Silts, very fine Sands.	Soft soils, compaction difficulties with usual techniques, strong dependence of mechanical properties to water content	Foundation, core	Foundation: stabilization with lime (2.5% to 4.5%) in layers 30 cm max. Core: stabilization with lime (2.5% to 4.5%). Geosynthetic for drainage coupled with geogrid at bottom.	No data	
Tenda Tunnel - France-Italy international link (Piemonte-Provence Alpes Cote d'Azur regions - Northern Italy-South-eastern France)- Works completed (2017), road	Filling materials from tunnel excavation	H>10 m Slopes 3/2	Gipsy marls, dolomia	Both materials prone to dissolution in water	Core	Deep mechanical fragmentation, compaction in layers max 30 cm, drainage at bottom, impervious layer (non-sensitive clay, geomembrane) at top	No settlements, no cavities recorded	A very environmental-friendly solution for mountainous areas

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
partially opened - Source: Anas Spa								
National Road No. 398 - Piombino harbour link (Toscana, Central Italy)- Project phase (2017) - Source: Anas Spa	Alignment through ex steel factory area	Hmax=6 m Slopes 3/2	Contaminated soils	Contaminated water should not be in contact with embankment core (made up of suitable materials)	Foundation	Impervious geomembrane coupled with geogrid at bottom; geocomposite for drainage underneath, contaminated water drainage	No data	
Roma-Fiumicino Airport Highway (Lazio, Central Italy)- Widening of carriageways (2000) - Works completed - Source: Anas Spa	Very soft soils (organic clays)	H=5m Slopes 3/2	Not marginal materials but very low unit weight materials to be used	Time-dependent settlements	Core	Expanded Polystyrene (EPS) used for core	Very low settlements recorded	Data on behaviour of EPS on the long run not yet available (in Italy), at present (~16 years from completion of works) no problems/failure detected.

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
Roma-Latina Highway - A12-Tor de' Cenci by-pass (Lazio, Central Italy) - Bidding phase (2017) - Source: Anas Spa	Very soft soils (organic clays), Highway and Railway parallel to new axis	H=5 m Slopes 3/2	Not marginal materials but very low unit weight materials to be used	Time-dependent settlements, induced settlements on parallel Highway and Railway	Foundation, core	Expanded Polystyrene (EPS), Light Clay Aggregates and pyroclastic soils (locally known as 'pozzolana' unit weight ~10 kN/m^3) used for core, 1.5 m of soil substitution in foundation (light expanded clay aggregates)	No data	
Terni-Rieti no. 79 National Road (Central Italy) – New road, works underway (2019) – Source: Anas SpA	Very soft soils (clays, organic clays); high seismic peak acceleration due to local amplification phenomena.	H=10 m Slopes 3/2	Proposed use of C&D waste materials coming from 2016 earthquake-hit areas in Central Italy for embankments	Time-dependent settlements	Core	Stone columns in embankments foundation	No data available yet	

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
Forlì Tangential Road (Emilia Romagna, Northern Italy) – New road, works completed (2007) – Source: Anas SpA	Soft soils (clays, organic clays)	H=10 m Slopes 65° (Reinforced Earth Walls)	Lime-treated soil	Time-dependent settlements	Core	Lime-treated materials put in place in layers of 30 cm max. No tamping roller use possible due to presence of geosynthetic reinforcements. Piles in embankments foundation	Settlements recorded within estimated values	No problems/failure detected

Table 7.5: Cases from Italy.

Figure 7.2: . Tangential Road of Forlì (Italy) – Embankments with lime-treated materials and Reinforced Earth Walls.

Cases from France

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
Highway A89 – Section Terrasson-Brive Nord	Presence of argillaceous rocks (pelites)	n.d.	Argillaceous rocks R31 to R34 (GTR classification)	n.d.	Fill at base as such or after lime stabilization, core after lime stabilization	Materials in thin layers (max 30 cm) with previous fragmentation. High compaction energy (98,5% of the reference PROCTOR). Wetting of materials to bring them to a state close to the reference PROCTOR. Protection of the base of the fill against the risk of water penetration.	n.d.	
RD 1089 – Detour North of Brive	Presence of argillaceous rocks	n.d.	Argillaceous rocks (pelites)	n.d.		Base of large embankments built up with good quality rock. Granular capping layer using rocky material from the site (micaschistes) placed	n.d.	

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
						directly on the PST without particular treatment. Locally, the recommendations were to stiffen the slopes of the fill with geosynthetic reinforcement as requested to reduce land occupation.		
Multimodal platform "DELTA3" at Dourges	Changeable materials and materials with particular constituents	n.d.	Black shales from the spoil heaps are changeable materials which are both highly degradable (pelites) and slightly fragmentable	n.d.	Fills: shales should not be used in embankments in presence of water (wet zones, soft soils substitution, etc.). Their use in embankments is	Preliminary fragmentation of the shales by appropriate mechanical treatment. The fragmentation must be sufficient to reduce the Dmax and ensure that the resulting matrix provides a proper coating for the remaining granular	n.d.	

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
					advisable in favourable weather conditions only. Capping layer: shales from spoil heaps treated with cement (tests previously conducted by CETE in Lille on the fraction 0/20, over a period of one year). Tests with cement treatment over one year have highlighted the absence of swelling.	particles (so that they no longer change as a result of compaction). This operation during processing (particularly for capping layers) enables an effective inter-action between the binder matrix and granular components to ensure the hydraulic action. Typically, a passage of a stone crusher monted on a tractor 250 CV is requested to break the largest blocks of shale down to 60 mm (Figure 7.3). Adjustment of water content through sprinklers (Figure 7.4).		

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
					Mechanical properties of the mixture of shale/ binder are very satisfactory and compatible for use in capping layers under heavy to very heavy loads.			

Table 7.6: Cases from France.

Figure 7.3: Stone crusher.

Figure 7.4: Sprinkler.

Cases from Canada

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
Nouvelle autoroute 30 (Quebec)	Presence of sensitive clay (Champlain clay)	n.d.	The surface of the Champlain clay has been subjected to desiccation, frost action, and weathering. This has resulted in the reduction of the water content and sensitivity of the crust layer of this very wet clay deposit, enough to be used as an earthworks material. However, the material is still	n.d.	n.d.	Moisture content and degree of compaction derogations achieved	n.d.	

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
			much wetter than its optimum moisture content					
Highway 402 overpass at Front Street in Sarnia, Ontario (1)	Soft soils, prone to settlements; lightweight materials needed	embankment 8 m high	Bottom and fly ash from generating station	The ash used in the embankment was produced by burning a bituminous coal. Laboratory tests performed on the samples yielded a standard Proctor density equal to 12 kN/m^3 at an optimum moisture content of 30.5%	Base layer, core	Base layer of bottom ash, a fly ash core and a bottom ash cap. The base layer consisted of a 1 m thick bottom ash drainage blanket to prevent the upward movement of ground water into the fly ash core. The fly ash was capped with approximately 1.2 m of bottom ash to minimize the effects of frost action on the fine-grained fly ash. A 5 cm layer of top	The consolidation of the natural soil due to the weight of the embankment averaged 30 cm after 10 months. Approximately two-thirds of this consolidation occurred within 1 month after placement of the fill was completed.	

Work	Main problems	Geometry of embankment	Marginal material	Main characteristics	Zone	Execution techniques	Time behaviour	Remarks
						soil was placed on the embankment slopes to control erosion and to support vegetation.	Consolidation of the embankment was monitored by 4 settlement rods installed in the fill. Results showed a maximum consolidation of 0.25 cm only within the embankment.	

(1) Data from document [20]

Table 7.7: Cases from Canada.

7.3.4. Analyses on data

As a summary, the following general outlines derived from the cases described are:

Spain

From cases analyzed it can be stated that:

- the most common marginal materials are gypsum materials and swelling clays;
- Marginal natural materials are mainly used in the core; few times in foundations and shoulders and never on subgrade;
- A treatment is given to them for their use;
- Expansive materials are treated with lime in percentages around 2% (a bit higher if used in foundations or shoulders);
- Gypsum materials are separated by impervious membranes;
- As it is known, the best way of compaction clay and gypsum clayey materials is by using tamping roller;
- The average layer height is around 30 cm.

Italy

From cases analyzed it can be stated that:

- In Italy the most common natural marginal materials are soft clays and swelling clays; these materials are usually used after lime or cement-lime treatment (Figure 7.5 and 7.6);

Figure 7.5: Pulvimixer for lime treatment

Figure 7.6: Pulvimixer for lime treatment and feeder

- Natural (and non-natural, when any) marginal materials are mainly used in the core and in foundations, rarely in shoulders and never on subgrade;
- A treatment is mandatory for their use in structural parts of earthworks;
- Natural marginal materials are mainly treated with lime in percentages around 3-5%;
- The average layer height is around 30 cm;
- Compaction is carefully carried out in order to assure stiffness within technical specifications limits; frequent use of dynamic roller (Figure 7.7) with automatic control of compaction results through dynamic analysis;

Figure 7.7: Dynamic roller.

- Large use of geosynthetics is very common and effective in order to assure strength and stiffness (Figure 7.8).

Figure 7.8: Geosynthetics for embankments.

France

From cases analyzed (2012 PIARC report) it can be stated that the most common marginal materials are:

- Argillaceous rocks;
- Changeable, often fragmentable and degradable materials;
- Highly plastic clays;
- Materials which are very wet or very dry;
- Poorly structured materials;
- Materials with specific constituents (shale from coal heaps, gypsum, marl).

Germany

From cases analyzed (2012 PIARC report) it can be stated that the most common marginal materials are:

- Soft to firm clays and silt with low plasticity for which conventional treatment with lime is applied;
- Soils mixed with recycled materials (soils with mineral impurities); the mixture allows improvement of soils like this (clays and silts of low consistency);
- Degradable rocks (non durable rocks) for which heavy compaction is required (reduction in percentage of voids) with addition of water;
- Organic soils which were the subject of a test embankment at Munich airport for the construction of noise embankments in which organic soils are encapsulated;
- Cohesive soils from the excavation of tunnels (cohesive soils as tunnel excavation materials) whose use depends on the mode of hydraulic transport from the face of the tunnel (influencing the water content);
- Uniform sands for which trafficability during embankment construction is undertaken by treatment with cement.

Canada

From cases analyzed it can be stated that common marginal materials are:

- Fly and bottom ashes from power plants;
- Soft and sensitive clays;
- Materials prone to frost attach and deterioration.

7.4. FAMILIES OF MARGINAL MATERIALS

After having analysed data collected (both from 2012 and 2016-2017 enquiries), at least in a qualitative form, the following families of marginal materials appear to be the most common.

- Changeable or fragmentable soils/rocks,
- Materials with particular constituents,
- Clayey materials,
- Very wet materials,
- Very dry materials,
- Homometric or poorly structured materials,
- Lateritic materials.

7.4.3. Changeable or fragmentable soils/rocks

Material may become brittle or deteriorate under loading:

- in short term during laying (extraction, transport, compaction, etc.);
- in the long term after laying among other things owing to mechanical stress (traffic, etc.) or to the action of water or frost.

“Changeable rocks are defined as those whose grains size can change after construction of an embankment due to the presence of minerals that swell or degrade under unfavourable water conditions. This term does not include soft rocks whose particle size changes owing to the stress exerted by mechanical plant during the earthworks" according to the report AIPCR 12.12.B [36].

"It is essential to determine how the material will behave during compaction; this can be done by using trial embankments. Field testing should be calibrated in advance using laboratory tests and, if the material is accepted, it is necessary to strictly control compaction during both the trial and the actual works" according to the report AIPCR 02.04.B [34].

Materials which are changeable or fragmentable are illustrated by the argillites (Belgium), pelites, marls, micaschistes, metamorphic schistes, argillaceous rocks (France), flysch (Greece and Slovenia), tuffs (Mexico) and weathered rocks (Germany and United Kingdom).

Some materials are deteriorated by and therefore must be protected from frost.

Recommended treatments are:

- Encapsulation of materials in order to protect them from further break down due to climatic influences (water, frost, erosion, etc. – argillites of Belgium);
- Intense [heavy] compaction to reduce the percentage of voids in the weathered rocks (Germany);
- Screening of the coarse fraction (tuffs of Mexico);
- Fragmentation, addition of water, placing in a temporary stock pile (in order to obtain a balance of water content and suction with the environment) of flysch which must be used as soil fill rather than rock fill (Slovenia and Greece).
- Slovenia also advocates a degree of saturation greater than 85% and a suction of less than 800 kPa.
- United Kingdom uses "weathered rocks" as a capping layer: "where local supplies of highly weathered rock are available on the route of the Highway it has been possible to utilise this material by modifying the grading or by reducing the requirement for Los Angeles coefficient – backed up by site trials and /or local experience".

The formations which are most commonly encountered in the recent road projects cited by France are argillaceous rocks with a changeable character more or less brittle and degradable:

- Argillaceous rocks, pelites, sandstones, marly limestones, especially in the region of the Massif Central.
- Materials which are more or less fragmentable and degradable, generally classes R31 to R34 according to GTR. These types of materials are mainly used as general embankment fill and PST. The methodology is based on manual mechanical treatment (fragmentation) to obtain a satisfactory size distribution for the materials in the embankment.
- Metamorphic schists which are very sensitive to water with phenomena of mattress effect, sliding, micaschistes where the particle size changes under compaction and releases micas (many plate-like elements).
- High embankments (up to 40 m) constructed with a core which is encapsulated.
- Chantier RN 106 (Ardèche).
- Coal shale (Dourges multimodal platform).
- Material which is changeable and also contains particular constituents. Utilised in embankments, PST and capping layer.

Techniques used: fragmentation of the schistes in place to correct the size and allow treatment with a hydraulic binder.

7.4.4. Materials with particular constituents

Materials with specific compounds are illustrated by glauconitic sands (Belgium), gypsiferous clays and massive gypsum (Spain), coal shales, variegated clays, indurated marls (France), organic soils and mixed soils (Germany), karstic clay (Slovenia).

Treatments recommended according to the type of constituent are:

- Implemented with control of water content and light compaction for glauconitic sands (Belgium);
- Encapsulation of gypsiferous materials – gypsum content between 5 and 35% - (placed in the core of embankments) to protect them from external agents (Spain);
- Encapsulation of organic soils (core of noise bunds) and enhanced drainage to prevent percolation into the underlying ground (Germany);
- Improvement by treatment with lime and/or fly ash to red karstic clays in Slovenia and by hydraulic road binders for coal shales and indurated marls in France (PST and capping layers);
- Mixture of low consistency soils with recycled materials to improve mechanical properties (Germany).

7.4.5. Materials too wet or too dry

Materials which are too wet are illustrated by the very wet silts (th) of Belgium, products derived from drilled tunnel excavations (Spain, Germany), Turonian spongolites, flooding areas products (sandy silts), silts, sands and clays (France).

Among the very wet materials cited were very wet silts A2 of Belgium in the state “th” defined for each class by GTR (France) with a water content exceeding the standard optimum water content (wOPM) by 25 to 40% and corresponding to “*soils which are non-trafficable by construction equipment (including treatment by binders)*”; they were nevertheless widely used as fill subject to improvement with lime (the latter subjected to strict quality prescriptions).

The use of products excavated during construction of underground tunnels is presented by Germany and Spain.

Germany cited the case of cohesive soils, whose nature and state after excavation depends upon the tunnelling techniques used and the initial consistency of the clay, as well as the mode of transportation between the face of the tunnel and the disposal site.

France cited, as very dry homometric sands, sands of the Landes found on the autoroute A 65 Pau-Langon, which are very dry in their natural state.

Their use in mass earthworks requires treatment to obtain the optimum natural content by means of permanent watering using sprinklers.

France cited an extreme case of very specific materials extracted with very high water contents, the Turonien spongolites, as well.

The Turonien spongolites are formed of spicules of sponges associated with glauconite and terrigenous detrital components. They are very porous with a large quantity of water giving elevated values and geotechnical tests are not suitable for this type of formation as they indicate consistency indices of zero when the soil shows visual consistency.

7.4.6. Very clayey materials

Examples of use of materials with high clay content are many. In most cases, lime treatment is applied to them. Some cases are:

- The smectites of Belgium are used in the core and improved with lime;
- Clays of Champlain in Québec whose water content must be reduced below the plastic limit for use in general fill by being placed on temporary spoil heap;
- Plastic clays sensitive to water ("peñuelas") in the region of Madrid stabilised with lime for use in subgrade;
- Clays A3/A4 form the basin of Puy-en-Velay (France), etc.;
- Clays and silts which are lightly plastic, presented by Germany, treated with lime.
- Several research studies have been conducted to determine the reduction in frost susceptibility of soils with the addition of lime;
- Mali, Italy, Mexico, Czech Republic, Slovakia, Slovenia and the United Kingdom use lime to improve very clayey materials.

A site in Puy-en-Velay in France required the use of sedimentary clays and clayey breccias A3/A4 (as GTR) as embankment fill. Systematic treatment with lime (dosage 2%) was achieved in excavation and backfill. The mixing was carried out using a pulvimixer. The fill was placed in thin layers with a tamping roller. Despite the strong mixing constraints, the technique used achieved the required objectives.

7.4.7. Homometric or poorly structured materials

These materials are mainly represented by sands: coastal sands of Italy, sands ("uniform sands") of Germany for which cement stabilization achieves adequate trafficability during construction.

Mexico and Italy also cited the products from degradable volcanic rocks:

- "light volcanic stone" of Mexico improved by screening and mixing the fraction passing sieve No 40 (0.475 mm) with crushed basalt;
- weathered volcanic rocks of volcanic districts of central and south Italy stabilized with cement of lime.

The silty sands of the Madrid region ("arena tosquiza") are stabilised with cement for application as capping (Spain).

In France, an important geological formation featuring homometric sands is the well-known sands of Fontainebleau. This type of formation was of particular interest for highway projects in the years from 1960 -1980 and showed the difficulties in using a large mass of homometric sands for filling.

The lack of cohesion of the sands creates very important issues for trafficability and erosion especially for cuttings and high embankments.

In windy regions, these materials could be prone to wind erosion.

7.4.8. Lateritic materials

This family of materials (Figure 7.8) is reflected in the survey responses received from countries in Africa and South America. They are widely encountered in these continents.

Brazil uses lateritic soils as a surface layer of gravel roads which may be topped with a medium to coarse sand layer to address the lack of grip.

Lateritic gravels were cited by the Ivory Coast. Depending upon their quality they are applied in different levels of the road structure: from mass fill to base-course.

This type of material does not generally meet the definition of marginal local materials. However, considering that these materials are of critical importance for the countries concerned, in the areas of unpaved and paved roads [less frequently], the information provided on these materials is included in the report.

The objective of optimum use of these materials with varying amounts of clay and gravel for the high quality layers within road foundations by treatment is to achieve the CBR values required by the technical specifications of the LBTP (or similar for Africa) leading to the design of the pavement structure.

Especially as deposit of quality materials are decreasing in different countries.

The limited data provided for South America and the lack of data from Asia suggests that this topic should be repeated and expanded in the next session of PIARC.

Figure 7.8: Lateritic soil.

7.5. QUANTITATIVE CLASSIFICATION OF MARGINAL MATERIALS

Marginal materials presented in this report have been described mainly in a qualitative form, through their overall behaviour in specific cases.

It is useful to perform quantitative analysis of marginal materials, in order to generalize their characterization. For materials cited in this report a very first temptative of quantitative analysis is presented on the Casagrande chart in Figure 7.9.

A deeper discussion about this point should be part of next cycles PIARC work.

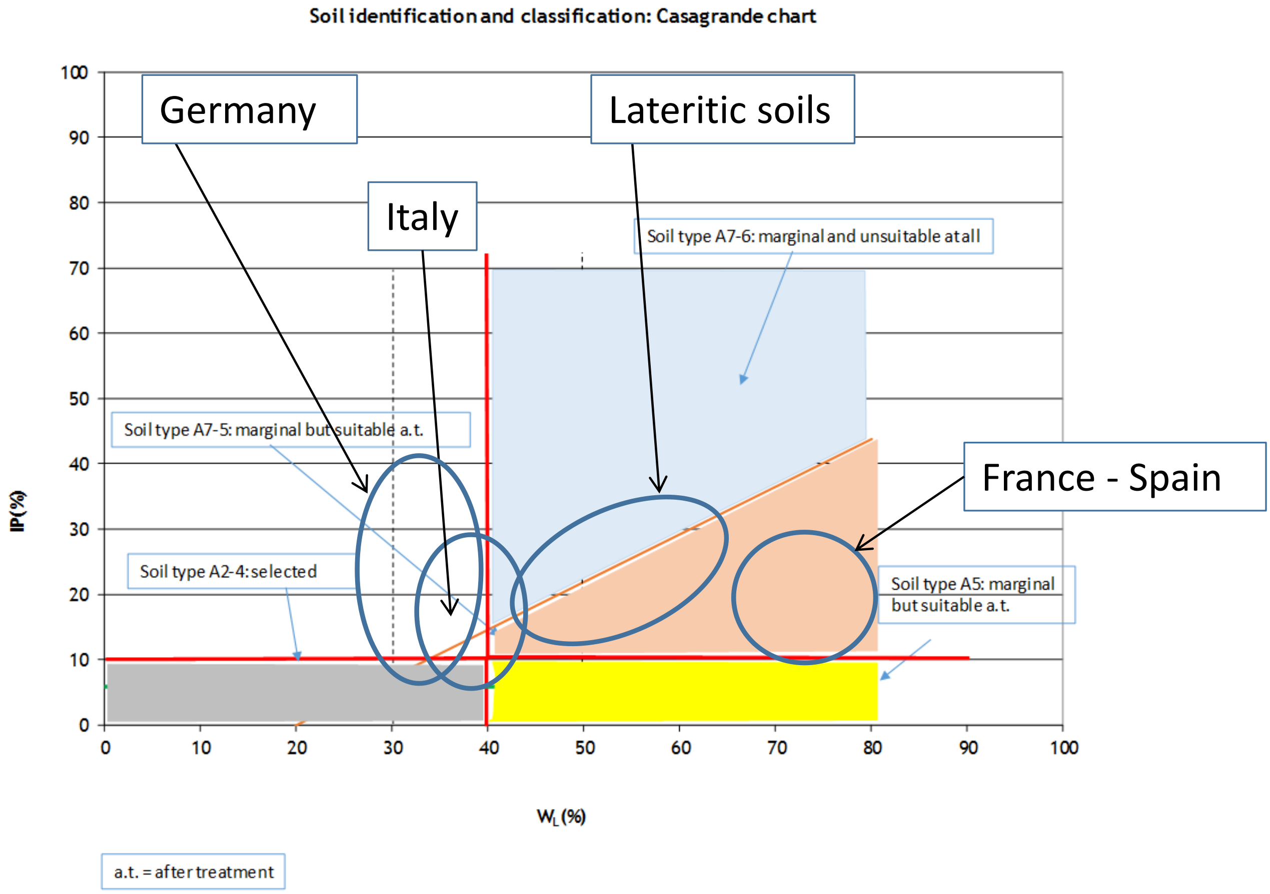


Figure 7.9: Casagrande chart with typical marginal materials cited in the report (part of data only).

8. CONCLUSIONS AND RECOMMENDATIONS

The exchange of information performed between member countries have made it possible to identify at least six different families of (locally available) marginal natural materials:

- materials which are changeable or fragmentable (brittle);
- materials with particular constituents;
- very wet or very dry materials;
- very clayey materials;
- homometric or poorly structured materials;
- lateritic materials;
- And also non-natural materials, industrial wastes, construction and demolition wastes.

A few conclusions have been reached for some of them from all the works performed, mainly the summarized in table 8.1:

Material	Description	Recommended treatments
Changeable or fragmentable	Material may become brittle or deteriorate under loading: -in short term during laying (extraction, transport, compaction, etc.); -in the long term after laying among other things owing to mechanical stress (traffic, etc.) or to the action of water or frost. Materials which are changeable or fragmentable are illustrated by the argillites (Belgium), pelites, marls, micaschistes, metamorphic schistes, argillaceous rocks (France), flysch (Greece and Slovenia), tuffs (Mexico) and weathered rocks (Germany and United Kingdom).	-Encapsulation of materials in order to protect them from further break down due to climatic influences (water, frost, erosion, etc. – argillites of Belgium); -Intense [heavy] compaction to reduce the percentage of voids in the weathered rocks (Germany); -Screening of the coarse fraction (tuffs of Mexico); -Fragmentation, addition of water, placing in a temporary stock pile (in order to obtain a balance of water content and suction with the environment) of flysch which must be used as soil fill rather than rock fill (Slovenia and Greece). -United Kingdom uses “weathered rocks” as a capping layer: it has been possible to utilise this material by modifying the grading or by reducing the requirement for Los Angeles coefficient – backed up by site trials and /or local experience”.
With particular constituents	Materials with specific compounds are illustrated by glauconitic sands (Belgium), gypsiferous clays and massive gypsum (Spain), coal shales, variegated clays, indurated marls (France), organic soils and mixed soils (Germany), karstic clay (Slovenia).	-Implemented with control of water content and light compaction for glauconitic sands (Belgium); -Encapsulation of gypsiferous materials – gypsum content between 5 and 35% - (placed in the core of embankments) to protect them from external agents (Spain); -Encapsulation of organic soils (core of noise bunds) and enhanced drainage to prevent percolation into the underlying ground (Germany); -Improvement by treatment with lime and/or fly ash to red karstic clays in Slovenia and by hydraulic road binders for coal shales and indurated marls in France (PST and capping layers); -Mixture of low consistency soils with recycled materials to improve mechanical properties (Germany).

Very wet or very dry	Materials which are too wet are illustrated by the very wet silts of Belgium, products derived from drilled tunnel excavations (Spain, Germany), Turonian spongolites, flooding areas products (sandy silts), silts, sands and clays (France).	-improvement with lime, in case of very wet -watering using sprinklers, in case of very dry
Very clayey	High plasticity	Lime stabilization

Table 8.1: Conclusions and recommendations.

As tentative conclusions from the data collected we could highlight the following:

- The use of marginal materials in road embankments is wide spreading although it is not usual practice in many places in the world. There are not yet many documented cases or specific technical guidelines for their use. Nevertheless, their use in road earthwork is often highly recommended, mainly due to environmental regulations, as it allows reduction of earthmoving, with less spoil disposal and a reduction in the need to supply natural noble materials.
- In most cases, the use of marginal materials is limited to the core of the embankment, where they are less exposed to climate actions and water flows that may cause its degradation. These materials are often arranged in the core with encapsulation by impervious clay layers or geomembranes to isolate them from water flows entering and leaving the embankment.
- In most cases, use of marginal materials is performed through stabilization (lime, lime-cement). When used in the core, a minimum of 2% of lime is added while when used in shoulders or foundation the percentage is a little higher, around 2.4%.

Much good work has already been done in previous periods of PIARC related to the use of marginal materials, but still much work is still be done by performing new studies on material behaviour and by collecting more case histories with data about the medium- and long-term behaviour of road embankments built up with marginal materials.

Recomendations to road administrations and operators.

At present developing sustainable development policies is a real and urgent need. These must apply to a widespread range of areas, and road construction is an important one that may contribute notably to drive progresses in the field. But in order to be effective, administrations operators must be aware and help to facilitate things, as it is in their hands the possibility of creating new paths for sustainability.

Referring specifically to this report issue, it is very important to promote the use of marginal materials in order to reduce spoil disposal or the need to supply high amounts of natural noble materials, enhancing pollution reduction by optimizing earthworks and reducing transport of material over great distances.

More studies have to be carried out and, in order to speed up our common learning, we must encourage the proper data collection when road embankments with marginal materials are designed and built up. This may be effectively propelled if road administrations managers will take action on these topics.

9. GLOSSARY

Term	Definition
CBR	California Bearing Ratio test
d	Minimum size of particle(s)
D	Maximum size of particle(s)
LL	Liquid Limit (Atterberg limit)
LP	Plastic Limit (Atterberg limit)
PI	Plasticity Index
W_L	Liquid Limit (Atterberg limit)
W_P	Plastic Limit (Atterberg limit)

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