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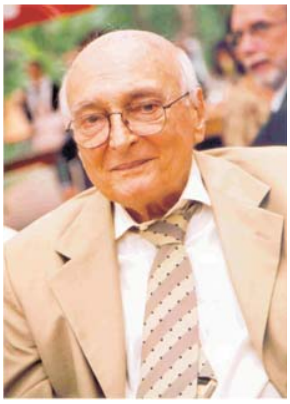
Victor de Mello Lecture



The Victor de Mello Lecture was established in 2008 by the Brazilian Association for Soil Mechanics and Geotechnical Engineering (ABMS), the Brazilian Association for Engineering Geology and the Environment (ABGE) and the Portuguese Geotechnical Society (SPG) to celebrate the life and professional contributions of Prof. Victor de Mello. Prof. de Mello has been a consultant and academic for over 5 decades and has made important contributions to the advance of geotechnical engineering. Each year a worldwide acknowledged geotechnical expert will be invited to deliver this special lecture. It is a privilege to have Prof. John Burland (Imperial College London) delivering the first edition of the Victor de Mello Lecture. Prof. Burland and Prof. de Mello have been close friends for three decades and in his lecture he highlights not only Prof. de Mello's professional contributions but also the man himself as well as their friendship and professional collaboration throughout the years.

Prof. John B. Burland, CBE, DSc(Eng), FREng, FRS is Professor of Civil Engineering at Imperial College London, UK. After having worked for 13 years at the Building Research Station, in 1980 Prof. Burland was appointed to the Chair of Soil Mechanics at Imperial College London. He is now Emeritus Professor and Senior Research Investigator at Imperial College. Prof. Burland has been responsible for the design of many large ground engineering projects such as the underground car park at the Palace of Westminster, the foundations of the Queen Elizabeth II Conference Centre, the stabilisation of the Metropolitan Cathedral of Mexico City and was a member of the Italian Prime Minister's Commission for stabilising the Leaning Tower of Pisa. He has received many awards and medals including the Kelvin Gold Medal, the Harry Seed Memorial Medal of the American Society of Civil Engineers and the Gold Medals of the Institution of Structural Engineers, the Institution of Civil Engineers and the World Federation of Engineering Organisations.

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Reflections on Victor de Mello, Friend, Engineer and Philosopher

John B. Burland

Abstract. The author first met Victor de Mello in 1975 at the 6th African Regional Soil Mechanics Conference in Durban, South Africa. For over 30 years he has retained a close personal friendship with this remarkable man and his family. The First Victor de Mello Lecture illuminates something of him as a person, an engineer and a philosopher. It describes his upbringing and schooling in India, his university education at MIT and some highlights of his professional career as an international civil engineer specialising in dams and geotechnics. The key messages from some of his major lectures are presented and discussed. Engineers of all disciplines have much to learn from this brilliant, inspiring and cultured man. Above all we can learn from his insistence that we are human beings first, engineers second and specialists third - the order being very important.
Keywords: Victor de Mello, geotechnics, engineer, philosopher.

1. Introduction

Words cannot adequately express how privileged I feel to have been invited to deliver this first lecture in honour of Victor de Mello. But a huge responsibility rests on my shoulders for I have no doubt at all that the Victor de Mello Lecture will become one of the major events of the geotechnical calendar.

The more I thought about possible topics the more strongly I felt that this first lecture should attempt to capture something of Victor the person and Victor the engineer. The responsibility suddenly becomes even greater, for how can one adequately portray someone with the vitality, the breadth of interests, the culture, the creativity, the intellect and, yes, the shear genius of Victor de Mello? My aim is to reflect on my friendship with Victor and share something of that. This is not the time or the occasion for a scholarly treatise on Victor's engineering contributions. The word 'reflection' means 'the throwing back of images' and that is what I hope to do - to share some images of this remarkable man.

2. First Encounter with the de Mellos

I first met Victor and Maria Luiza de Mello on Friday 5th September 1975. I had been invited to give a keynote lecture at the 6th African Regional Conference in Durban, South Africa. A small group of us had the privilege of participating in a pre-conference tour starting in Pretoria, driving eastwards to the Kruger National Park, south to Swaziland and then south west to Durban. The small party included Professor Kevin Nash (Secretary General of the ISSMGE) and his wife Mel, George and Daphne Donaldson, Andy Robertson (who acted as our leader) and his wife Renée. The de Mellos were due to join us in Swaziland.

We set out from Pretoria on Wednesday 3rd September reaching the eastern Transvaal town of Nelspruit (famous for growing delicious oranges) that evening. The next day we entered the Kruger National Game Park and were thrilled by the wide variety of birds and game that we saw including hippopotamus and elephant. The evening was warm and we had a braaivleis (barbecue) under a clear sky, heavy with the stars of the southern hemisphere and serenaded by the croaking of frogs and the chirping of crickets. We were a cheerful and friendly group. Kevin Nash teased us saying that tomorrow, when the de Mellos joined us, things would change. This sounded a little ominous so we pressed him further but he simply said, somewhat conspiratorially, *wait and see*.

I had been at the 1969 Mexico City International Conference when Victor de Mello had presented his weighty State of the Art Report on Foundations in Clay (de Mello, 1969). It was an impressive document presented with flair and panache. I was far too shy too introduce myself but was hugely delighted to see that he had referred to some of my work. I was keen to meet Victor because I had been invited to prepare a State of the Art Report on Foundations and Structures for the 1977 Tokyo International Conference with Victor, Bengt Broms and Jacque Florentin as co-authors. I had managed to get together with the latter two but so far had not had contact with Victor.

On the Friday at 6:00 a.m. in the morning, and in high spirits, we headed south to towards the exit of the Kruger Park at Crocodile River with the Bushveld looking lovely in the early morning sun. We saw many types of antelope and even a pack of wild dog. We then had a long, hard, hot drive to Mbabane in Swaziland where we stopped for lunch at the Holiday Inn. We were relaxing around the swimming bath when Victor and Maria Luiza arrived - both wearing large floppy sunhats. Immediately the whole atmosphere became vibrant, there was non-stop conversation and we laughed, joked and even sang. It wasn't that Victor and Maria took us over - they galvanised us and we were all drawn in to this new experience. Once or twice Maria Luiza scolded Victor

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for showing off and he took it like a lamb! In my vote of thanks to Victor's 1977 Rankine Lecture I referred to this meeting and the fact that for the rest of the trip, and for some weeks afterwards, we were all living at what can only be described as a state of 'heightened intensity' (Burland, 1977).

During the next two days we drove south west to Durban, visiting various civil engineering projects on the way. At each site Victor subjected the engineer in charge to intense interrogation, not just in relation to the technicalities of the scheme but the economic and social aspects as well. It was done with good humour but with an obvious breadth of experience and a remarkably quick and incisive mind. In between, during our bus journey and in the evenings, our conversations ranged widely over almost every conceivable subject.

During one conversation Victor expressed concern about the dangers of developing countries relying on the advice of experts imported from developed countries - a theme he returned to frequently in his lectures and writings. Referring to the classical story of the siege of Troy by the Greeks he would use the phrase *Beware the Greeks bearing gifts*. A modern adaptation of the phrase, when you are being offered computer soft-ware is: *Beware of geeks bearing gifts*! Learning from these conversations with Victor, I tell my students from developing countries not to believe that the sophisticated developed countries have all the answers: *Remember that your own special challenges are just as intellectually demanding as ours*.

As we approached Durban we passed through the seaside resort of Umhlati where I had holidayed in 1950 as a boy of 14. On mentioning this to Maria Luiza she insisted that we stopped. We went onto the golden sands and danced to celebrate my return after 25 years. Maria Luiza referred to this occasion in her farewell address at the 1985 San Francisco Conference (de Mello, 1985): *I recall a beautiful night dancing barefoot with John Burland on a beach in Durban. Brother John, that night was unforgettable*.

3. Sixth African Regional Conference

And so we arrived in Durban for the 6th African Regional Conference. Here for the first time I was able to watch Victor in action at a conference, both formally and informally. He participated as a Panel Member in a number of the technical sessions; two in particular made a profound impression on me. The author of one paper was attempting to correlate the coefficient of subgrade reaction K from plate loading tests with relative density as determined from the Standard Penetration Test. Victor completely demolished the paper using the arguments that he had developed in his classic 1971 State of the Art Report on the Standard Penetration Test (de Mello, 1971).

What interested me particularly was how upset Victor was that this well known author made no reference to this SOA Report (indeed Victor pointed out that there was no reference later than 1967 in the paper). I quote:

> *I excuse myself for repeating my own earlier work: I would have been quite satisfied if the authors had quoted it as a reference and had curtly stated their disagreement with such and such. I am sure that there is much room for disapproving and correcting some of my preliminary claims; but, since they were offered with the best of intentions and were aimed at avoiding unnecessary effort and pitfalls, the thing that I find quite disconcerting is that four years can pass without agreement or contestation but only a disparaging silence!*

This intervention taught me that Victor loves debate and goes out of his way to seek it. He is quite prepared to revise his views in the light of that debate. But he thoroughly disapproves of any work that does not take due regard for previously published results - particularly when they appear in a major international forum.

On another occasion he spoke of the dangers of over-reliance in indirect indicators of soil properties as deduced from the deepsounding static cone penetrometer with friction sleeve. At the 6th International Conference in Montreal he had warned strongly of the dangers of replacing careful inspection and description of representative soil samples with an indirect indicator in the form of the friction ratio (de Mello, 1965). He referred to this intervention as follows:

> *I took the liberty to submit a discussion decrying the introduction of mechanistic practices that would wipe out the painstaking gains of the fundamental principle of Soil Mechanics of requiring first the determination of the nature (classification) of the soil type by direct sampling, and not by indirect inference*.

Victor's contributions certainly livened up the sessions!

But it was Victor's keynote address that impressed me most. The title of his lecture was: Some Lessons From Unsuspected, Real and Fictitious Problems in Earth Dam Engineering in Brazil (de Mello, 1975). During his opening remarks he reminded the audience that we should never forget the primordial precedence of values: human being first - engineer second - specialist third:

> *But I am compelled to state, right from the start, that in my experience it is principally in the connection between Soil Mechanics and the overall field of Civil Engineering, and in our obligations as members of society, that the greatest challenge and chances of creative vision beckon us and lead us forward*.

During the lecture he described the evolution of his experiences of the design and construction of over 50 major earth dams in Brazil and elsewhere in Latin America using residual soils and saprolites in particular.

In true de Mello style he began his lecture with a Latin quotation. The whole statement is worth repeating:

> *If a geologist declares that at a given site the joints strike unfavourably in an upstream-downstream direction and tend to open to a significant depths, and therefore the site should be abandoned, as a Civil Engineer I would say:*
>
> (a) *accept the first part of the statement, as the information comes from the appropriate source,*
>
> (b) *challenge it ("so what") to the point of requiring and achieving some quantification, and*
>
> (c) *as regards the concluding affirmative, do not hesitate to say 'ne sutor ultra crepidam' - the consequence and decision are part of an overall Civil Engineering optimization, and should be so assessed.*

The Latin quotation is a rebuke said to have been addressed by the famous Greek artist Apelles to a shoemaker who pointed out some errors in the painting of a slipper in one of the artists works and then went on to criticise other parts of the picture. *The shoemaker should not go beyond his last* (*i.e.* mould) retorted Appelles or perhaps more bluntly, *stick to shoe making*.

Victor was warning of the grave dangers and distortions that can result if a specialisation is permitted to drive the project. The overall balance and coherence of the project needs to be maintained with each specialisation playing its part. Excessive domination of specialisations can also obscure the chain of responsibility, which is a very serious matter. He also warned of the grave dangers of importing technical *know-how* from western temperate zones to geological settings which are outside the expertise and experience of the experts. He called it the import of technical *don't know how*. The micro-structures of residual and saprolitic soils are very different from those of classic sedimentary soils, even when compacted. Also, climatic factors are usually very different. This means that transfer of experience using the empirical indicators of Atterberg Limits etc. is extremely simplistic and likely to lead to grossly misleading advice, particularly in relation to permeability and hence pore pressure responses.

Towards the end of his lecture Victor described the case of the Paraibuna Dam which had been designed on the basis of local experience and had been successfully completed - see the upper section in Fig. 1. Immediately prior to

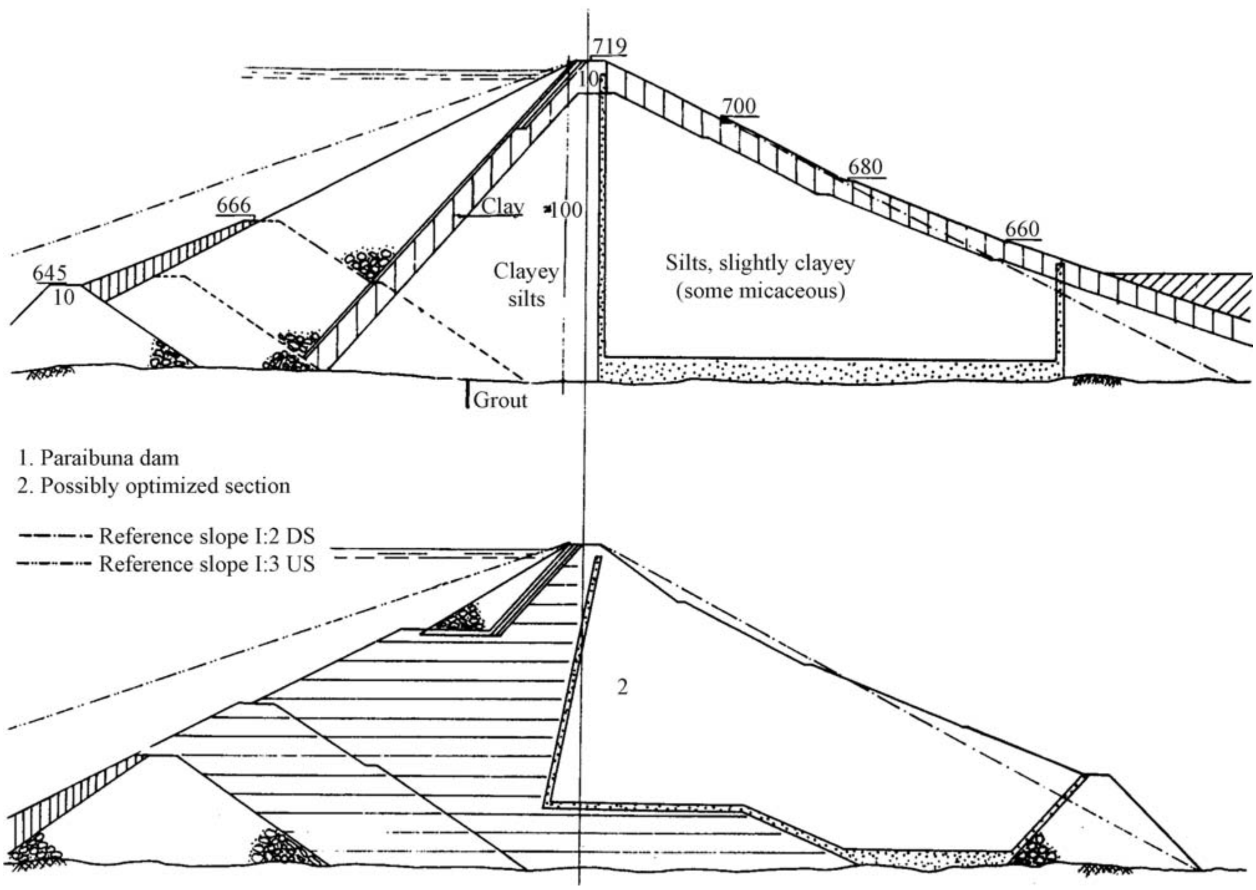

Figure 1 - Paraibuna Dam and suggested optimised section.

filling, it was considered prudent to appoint a special consultant to review the design. The expert had not worked with saprolites before and recommended the use of residual strengths and high pore pressures in the downstream shoulders. The downstream clayey face (which had been placed to limit rain erosion during construction) was to be ripped up with drainage trenches. The final conclusion and recommendation was that the downstream slope should be reinforced by compacted rock fill reducing the slope from 1:2 to 1:2.5.

When asked to intervene Victor recommended that filling should commence without these suggested measures and with careful monitoring of the extensive instrumentation in the dam. Its performance proved to be outstanding. In Victor's view the dam truly represented a considerable advance on the more traditional empirical designs that were being used at the time. The lower section in Fig. 1 shows Victor's schematic ideas for improving the dam design still further by means of an inclined upstream chimney filter and a central clay blanket. He enlarged on these ideas in the Seventeenth Rankine Lecture. It is worth noting that he always made a point of attempting to improve even a successful design in the light of the experience gained - a valuable pointer for a young aspiring civil engineer.

Victor's keynote lecture to the Sixth African Regional Conference was packed with engineering wisdom and philosophy, challenging conventions and expressed in complex, poetic and colourful English. It was truly inspiring. What is the genesis and the background of this remarkable person whom I had just encountered?

Figure 2 - The de Mello family. Victor is standing in front of his father.

4. Biographical Notes

In preparing these notes extensive use has been made of the contribution prepared by Moreira and Décourt (1989) for the *De Mello Volume*. Victor Froilano Bachmann de Mello was born in Pangim, Goa on 14th May, 1926 and is one of six children - see Fig. 2. His Father, Indalencio Froilano de Mello, was Indo-Portuguese and was a renowned bacteriologist specialising in tropical diseases. His mother, Hedwig Bachman was Swiss German and had been head of a secondary school in Switzerland. A chance meeting with her future husband on a Paris to Lisbon train brought her from Zurich to Pangim. The early education of the six de Mello children was undertaken at home by their parents. They each learned a musical instrument in addition to the piano and were taught painting, languages (French, German and Italian) and literature. They were also encouraged to take part in sports including swimming, tennis, horse-riding etc.

Victor's parents had planned for their children to be educated in Europe but the impending 2nd World War caused them to send their children to study at British boarding schools in India. At the age of eleven Victor went to Bishop Cotton Boys' School in Bangalore (photograph in Fig. 3). Here he excelled, winning many prizes both for academic and sporting achievements. At the final public examinations he was ranked first out of 2000 candidates for the Mysore State High School examinations and he won high distinctions among more than 40000 candidates for British Empire Senior School Certificate. The school awarded him the Kothavala Cup in recognition of Best All-rounder.

Victor gained admission to the ETH in Zurich but he was unable to travel there because of the War. He sought admission to various top Indian Engineering schools such as Rorkee, Poona etc. But, despite his outstanding achievements at school, he was denied entrance because the system would not countenance a Portuguese Goan. Instead, through the family's contact with a famous American missionary surgeon, he joined the Interscience Course of Ewing Christian College at Allahabad in January 1942, a 36 hour train journey from his home. Once again he performed brilliantly in his examinations.

In order to complete his 3rd year he had to move once again, this time to Lahore in present day Pakistan, to the Forman Christian College. Because of his musical ability he used to play the organ in Chapel. One day, while he was practising the piano at the Principal's home, the Principal stopped him and asked him what profession he intended to follow. Victor explained that he wanted to study civil engi-

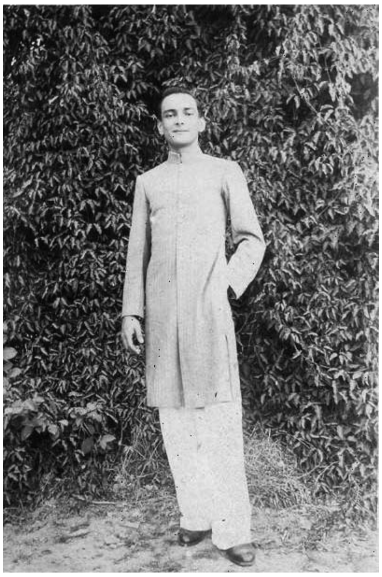

Figure 3 - At Bishop Cotton Boys' School, Bangalore.

Figure 4 - MIT Graduation with BSc degree.

neering but, as he was unable to travel to Zurich, he was filling in time by his studies. The Principal, Dr C.H.Rice, aware of his first term grades, responded: *Why don't you go to MIT? It is an engineering school of the highest ranking*. It turned out that Dr Rice was the brother-in-law of Karl T. Compton, President of MIT. Dr Rice wrote a letter to Karl T. Compton and some weeks later a telegram arrived, simply stating *Victor de Mello admitted July 1, 1944, Karl T. Compton*.

And so, with a quick trip to bid his home and family farewell, Victor travelled to Bombay and sailed out of Bombay in April 1944 on the S.S. Mariposa, a few hours before "The Great Bombay Explosion" razed the docks. Forty days later he arrived in Boston via the Pacific, Australia and the Panama Canal. Once again Victor's academic achievements were outstanding. By accelerating his studies, he obtained his BSc degree in June 1946 (Fig. 4) and completed his MSc in September 1946. He had planned to move to Brazil having been offered a contract by COBAST-LIGHT. However he was persuaded by D.W. Taylor to stay on as his Research Associate to conduct the new Soil Solidification Research Contract from the U.S. Corps of Engineers. The collage shown in Fig. 5 was taken at this time.

On completion of his Doctorate Victor began work on a new research contract on the shear strength of clays. But after seven months, and in spite of Donald Taylor's attempts at dissuading him, Victor ended his five-year association with MIT. He wanted the action and creativity of real civil engineering and its service to society. In particular the challenges of the brave new world of Brazil beckoned him. He arrived in Brazil under contract on 14 August 1949. From 1951 to 1967 Victor was successively, Chief Design Engineer, Technical Director and Superintending Director of Geotécnica, Inc., which at the time was by far the largest company for consulting and special services in geotechnical engineering in Latin America. Figure 6 shows a delightful picture with his father taken around this period.

From 1968 he has operated as a private consultant concerned with a significant proportion of the major civil engineering projects in Brazil, involving expenditure of billions of dollars per year on tunnels, railways, industrial and mining projects. In addition to his consulting work Victor took on the mantle of teacher and scholar as well. In 1957 he was appointed Professor of Soil Engineering at Mackenzie University in São Paulo and in 1967 he became Professor of Soil Engineering at São Paulo University. In addition he had been president of the Brazilian Society of Soil Mechanics (of which he is a founding member), the first recipient of its Terzaghi Prize, Vice President of the International Society of Rock Mechanics for Latin America and Vice President of the International Society of Soil Mechanics for Latin America. This was the man I had met in South Africa in 1975.

5. Tokyo International Conference State of the Art Report

As mentioned previously, I had been invited to prepare a State of the Art Report on Foundations and Struc-

Figure 5 - Selected photographs of Victor at MIT which include Casagrande and Terzaghi.

Figure 6 - Victor with his father, Indalencio Froilano.

tures for the 1977 Tokyo Conference with Victor, Bengt Broms and Jacque Florentin as co-authors. I must confess that I approached the task with some trepidation, not only because of its magnitude but also knowing that Victor's writing is colourful and requires a lot of concentration to unravel. Ideas and concepts come tumbling out and I found the task of capturing these and doing them adequate justice quite daunting. I invited him to draft the Preamble - Chapter I. At first my heart sank. His first draft contained sentences ten or more lines long, sometimes one full-stop per paragraph. But slowly I began to attune myself to his writing and to realise how to approach it.

Victor paints word pictures and he loves word play. Some years later I attended a conference in Brazil with him and he spoke in Portuguese. The translater broke down in the middle of his presentation and explained that she could not translate what he was saying *because he was playing with words*. The following are some examples of his play on words:

We need not look for new tasks, but merely look at the tasks newly

I may be described as specializing in being a practising generalist

Water has an unfortunate habit of seeping through every theory

Choose your love and love your choice

The way to understand an oil painting is not to examine each brush stroke in detail but to stand back and to take in the whole. This is particularly so of the flamboyant and zestful impressionists. I learned that the way to understand and read Victor's writings is to savour his figures of speech, his word play, his zest and to try to absorb a whole paragraph or even a whole section at a time.

That is the way Chapter 1 of our Tokyo State of the Art was written (Burland *et al.*, 1977). I will not quote from it but anyone who is acquainted with Victor's writing will immediately detect his hand in it. It may be easier to understand than the original but it lacks the bold colours and inspiring vistas which is vintage, uninhibited Victor.

6. The Seventeenth Rankine Lecture

Victor delivered the Seventeenth Rankine Lecture of the British Geotechnical Society on 10th March 1977 having the title Reflections on Design Decisions of Practical Significance to Embankment Dams - see Fig. 7. The first few pages of the paper form an illuminating and thought provoking treatise on the fundamental principles of engineering design and are well worthwhile close study and discussion (de Mello, 1977).

Characteristically Victor de Mello begins with a Roman Legend. During the long-running war between Rome and Alba Longa it was agreed that settlement of the war would depend on the outcome of a battle between the Horatii triplets from Rome and the Curiatii triplets from

Figure 7 - Delivering the 17^{th} Rankine Lecture.

Figure 8 - The oath of the Horatii.

Alba Longa, both sets of triplets being the same age (Fig. 8). In the battle, the three Curiatii were wounded, but two of the Horatii were killed. The last Horatii feigned flight and enticed the Curiatii to pursue him. Because they were wounded the Curiatti became spread out and this allowed Horatius to slay them one by one.

Victor argued that it is in Horatius that we find a real engineer. Rather than face, by full frontal assault, the uneven odds of direct attack he chose to feign running away from the problem, thereby sub-dividing it into components that were individually tackled with ease. He stated that good engineering design is founded on the ability to make creative and ingenious decisions which minimise or avoid the uncertainties at reasonable cost.

Then followed a fascinating discussion on the role of prediction in design. With the modern emphasis on developing sophisticated methods of testing and of numerical modelling there is an understandable tendency to believe that good design requires advanced analysis and prediction. Indeed many undergraduates leave our schools of engineering believing that you cannot design something until you can analyse it. Lambe (1973), in his Rankine Lecture emphasises that prediction is at the very heart of the practice of civil engineering. One must not only predict, but make decisions and take actions on the basis of the prediction.

Victor turned this approach on its head. While accepting that prediction is a necessary vehicle for adequate decision he pointed out that often: *Our ability to predict what will happen is poor compared to our ability to predict what will not happen*. This is a profound statement. What it means is that, wherever possible, good design should aim at avoiding reliance on precise predictions. It should aim at developing design solutions that cut across the uncertainties. Personally, I find all over the world that there is an increasing reliance on powerful computer packages and, worryingly, an increasing tendency to accept the output at face value. Beware of geeks bearing gifts indeed! Hugh Golder summed it up very nicely when he stated: *Any design that relies for its success on a precise calculation is a BAD design*.

It might be helpful to illustrate Victor's perceptive and important point with an example from soil-structure interaction which draws on an analogy with a three and a four legged stool. The analogy was first put forward by the late Edmund Hambly (1985), a colleague of mine at Cambridge, a brilliant creative civil engineer. It has come to be called Hambly's paradox (Heyman, 1996).

Figure 9 shows two stools, one with three legs and one with four legs. Imagine that each must support a milkmaid who weighs 60 kg, and who always sits with her centre of gravity directly over the middle of the stool. The problem is to determine how much load must be carried by each leg of the stools. The three-legged stool is straight for-

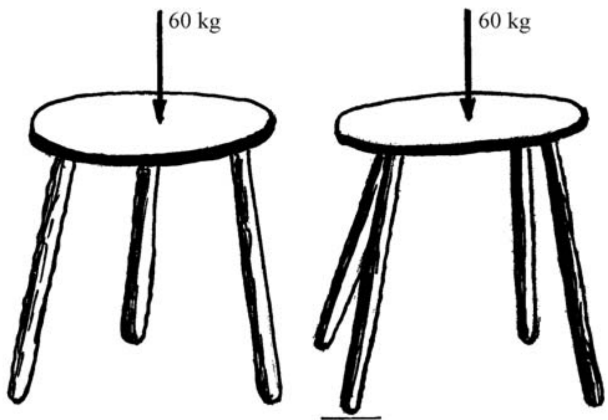

Figure 9 - Hambly's paradox.

ward in that one third of the milkmaid's weight must go down each leg *i.e.* 20 kg. For the four-legged stool the answer of 15 kg is wrong! Careful inspection of Fig. 9 shows that one of the four legs does not quite touch the ground, either because the leg is slightly short or because the ground is uneven, consequently the leg is not carrying any load. To satisfy equilibrium the opposite leg will not be carrying any load either. Thus we find that all of the weight is carried by two legs, *i.e.* 30 kg per leg, instead of being shared by the four legs. Hence the paradox - the addition of a fourth leg to a three-legged stool can increase, rather than decrease, the force for which each leg has to be designed. So what load should the legs be designed to carry?

It is here that concepts of ductility and robustness come in and the illustrative model can be extended to include material properties (Burland, 2006). If brittle material is used for the three-legged stool then accidental overload, due perhaps to a very heavy milkmaid or the cow kicking out at the stool, can easily result in total collapse. Clearly high factors of safety are required to deal with this design. It could be decided to opt for four legs but this may be of little help. The design load for each leg would have to be 1.5 times higher than for the three-legged design. Moreover accidental overload may cause loss of one member and there is then a risk of progressive collapse. In other words the structure is *fragile*.

If ductile properties are chosen there is little likelihood of catastrophic collapse if one of the three legs is damaged. Moreover, with four legs there is scope for redistribution of load once the carrying capacity of a leg is reached. Even accidental removal or serious damage to one member is unlikely to give rise to progressive collapse.

This simple example is very profound and can be extended to other aspects of structural behaviour and design including buckling and ground-structure interaction. Above all, it illustrates the importance of ductility, robustness and redundancy. It is useful to quote Heyman's conclusions to his study of Hambly's paradox (Heyman, 1996):

> *Hambly's four-legged stool stands, of course, for the general problem of design of any redundant structure. It has long been recognised that, in order to calculate the 'actual' state of a structure under specified loading, all three of the basic structural statements must be made - equilibrium, material properties and deformation (compatibility and boundary conditions). However, the calculations do not in fact lead to a description of the actual state. Boundary conditions are, in general, unknown and unknowable; an imperfection in assembly, or a small settlement of a footing, will lead to a state completely different from that calculated. This is not a fault of the calculations, whether elastic or not - it is a result of the behaviour of the real structure... There is no correct solution to the equations, but one solution that will lead to the greatest economy in material.*

The important message seems to be that, in the process of structural modelling, the inherent uncertainties are such that the precise state of the structure cannot usually be calculated. The art of structural engineering is to use the process of modelling to produce a design that is robust enough to safely cope with the uncertainties, at reasonable cost and which is fit for purpose.

In summary: The state of stress within most redundant structures is both unknown and unknowable - it is not the fault of the engineer and no calculation method will change it. It is because of the inevitable uncertainties of the real life situation. These uncertainties are dealt with in design by the incorporation into codes of practice appropriate ductility and robustness. Our structures stand up, not because the engineer has calculated the stress distributions precisely, but because the lower bound theorem of plasticity, or safe theorem, is harnessed - knowingly or unknowingly.

Victor set out a checklist of five design principles for embankment dams which aid decision taking in the face of uncertainty. In doing so he distinguished between mechanical behaviour which results from an integration of average properties (statistics of averages) and behaviour that is triggered by some type of local phenomenon (statistics of extreme values). He set out a check list of five design principles which I have generalised as follows:

DP1: Aim to 'design out' any risk from behaviour triggered by local phenomena *e.g.* piping; tension cracking; internal erosion. ROBUSTNESS

DP2: Use a dominant feature to cut across uncertainties *e.g.* a full-height chimney filter drain; downstream drainage blanket. CHANGE THE PROBLEM

DP3: Aim at homogenization *e.g.* long seepage paths; single, well-graded filter transitions. REDUNDANCY

DP4: Minimise rapid uncontrolled loading. Use pre-loading *e.g.* by permitting high construction pore pressures and observe the response. OBSERVATIONAL CONTROL

DP5: Question each design assumption and the consequences of departure from it. *e.g.* what happens if the permeability is ten times different?. ASK 'WHAT IF' QUESTIONS

These five design principles can surely be applied, not only to all aspects of ground engineering, but also to other fields of engineering endeavour.

Victor finished his *tour de force* with the following Arab proverb:

> *He who knows not, and knows not that he knows not - He is a fool, shun him.*
>
> *He who knows not, and knows that he knows not - He is simple, teach him.*

He who knows, and knows not that he knows - He is asleep, wake him.
He who knows, and knows that he knows - He is wise, follow him.

Recently he and I agreed that the last line should be re-written and a further line should be added as follows:

He who knows, and knows that he knows - He is insufferable, use him.
He who knows, and knows when he knows not - He is wise, follow him.

7. Visits to Brazil

Following the Rankine Lecture I worked with Victor on a number of projects and experienced the de Mello's way of life. As far as I could ascertain Victor would wake early and work. He would then arrive for breakfast as fresh as a daisy. We would then engage in the day's activities, be they work or relaxation. After an evening meal and a relaxed stroll we would all retire to bed and Victor would return to his study and work into the small hours. On one occasion I calculated that he must be averaging four hours sleep a day! Figure 10 is a photograph of Victor, Maria Luiza and their daughter Lucia taken during a visit to Rio de Janeiro in 1980.

One of the projects that we worked on together was the crossing beneath the River Tietê in São Paulo of a 4.5 m diameter interceptor sewer tunnel, for which we were both members of the Advisory Board. The ground consisted of hard closely fissured Tertiary clays. The crown of the tunnel was only 2.5 m beneath the river bed. Figure 11 is a photograph taken while I was inspecting a trial shaft with Victor's son, Luiz Guilherme, looking down the shaft anxiously. The tunnel was successfully driven under compressed air of about half an atmosphere. (Pan & Oliveira, 1983 and de Mello, 1983)

It was on Monday 27th April 1981, while we were working on the Tietê River project that I had a phone message telling me that Professor Kevin Nash, Secretary General of the ISSMGE, had died. The following morning I spoke to his wife Mel who had already spoken with the President, Masami Fukuoka. Would I take over as Secretary General at least until the end of the Stockholm International Conference which was due to take place in the middle of June? So it was that I came to be a very close witness of Victor's election as President of the International Society of Soil Mechanics and Geotechnical Engineering in Stockholm.

Figure 10 - Victor, Maria Luiza and Lucia in Rio de Janeiro.

Figure 11 - Trial shaft for the River Tietê tunnel.

8. President of the International Society

Prior to the 1981 Stockholm International Conference Victor had been on a consulting project in Mauritius. He had intended to attend the Executive meeting at which the election would take place. But he experienced a whole series of delays. We were kept posted on his progress towards Stockholm and the tension became almost unbearable. Maria Luiza was distraught and it is no secret that she carried out a fair amount of lobbying of delegates on Victor's behalf.

In dramatic fashion Victor arrived to cheers all round just in time to hear the results of the vote. There was no argument about it, Victor was elected President by a very clear margin. The result was announced on Saturday 13th June 1981 at 5 pm. Exactly 35 years to the very hour since President Compton of MIT gave Victor his BSc Diploma. Figure 12 is a photograph showing Victor with the President's gavel.

It is worth recalling Victor's acceptance speech in Stockholm for, once again, it reflects his primordial order of values: human being first; civil engineer second; specialist third (de Mello, 1981):

Indeed, we embrace a profession in order to better fulfil ourselves as human and social beings. Within our profession of civil engineering we delve into a specialisation in order to better fulfil ourselves as professionals: we may even need to restrict ourselves within geotechnique to a subspecialisation, but only in order to further fulfil ourselves within our calling as human beings. Let us never loose sight of the order of priorities in such allegiance, since specialisations are meant for the betterment of Society, through us and despite our deficiencies, and never to the detriment of our fulfilment as world citizens. Geotechnical Engineering is of service to all civil engineering.

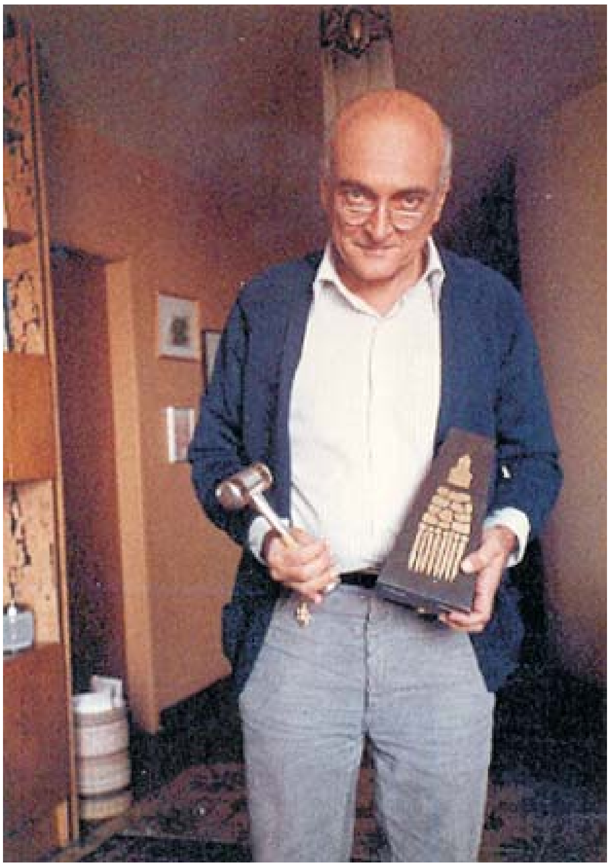

Figure 12 - With the President's gavel.

He then threw himself wholeheartedly into the service of the International Society. The first thing he did was to initiate a route and branch revision of the Statutes. He then expanded local and regional activity by encouraging an expansion in the number and diversity of the Technical Committees.

During his Presidency he travelled to over thirty countries to attend conferences and congresses. What is so remarkable about this is not simply the amount of travelling he undertook but the number of lectures and papers he gave. Working through his list of presentations reveals that he never repeated a title. And so often at his side was his inspiration and encourager - Maria Luiza. In parallel with this activity he was as active as ever in his consulting - mainly advising on the design and construction of earth dams but also slopes, tunnels and major foundations.

The International Conference is of course the climax of the President's term of office. The San Francisco Conference was no exception. But first there was a meeting of the Steering Committee (now called the Board) with the new Statutes to agree. Then there was the meeting of the Executive Committee which takes place over a two day period. The new Statutes were approved at this meeting. The photographs in Figs. 13 and 14 were taken during the days immediately before the San Francisco Conference.

During his Presidential Address to the Conference (de Mello, 1985) Victor referred, somewhat prophetically for me, to the Pisa Tower. He said that he found in the wide range of solutions offered for stabilising the Tower an object lesson in engineering. He then showed us 25 different solutions of which only four are shown in Fig. 15. He had concluded that:

When faced with a problem of high ratio of responsibility to feasibility, it is not in better analytical work that engineers seek solutions, but rather in different statistical universes in order to set aside, quite definitely, the possible histogram of degrees of undesirable behaviour.

This is an application of Design Principal 2 given in his Rankine Lecture and referred to previously. He then went on:

Have you not often woken up in the middle of the night with a flash of a brilliant solution to a problem that only becomes fuzzy during the day? If you are somewhat uncertain of being awake, I am with you: In the figure it does become certain that dreams and nightmares intermingle, requiring careful selection.

For me the nightmare commenced in 1990 when I was invited to work on the Commission for stabilising the Tower. But, of course, that was all in the future.

Towards the end of his Presidential address Victor made another prophetic statement which we should all aspire to:

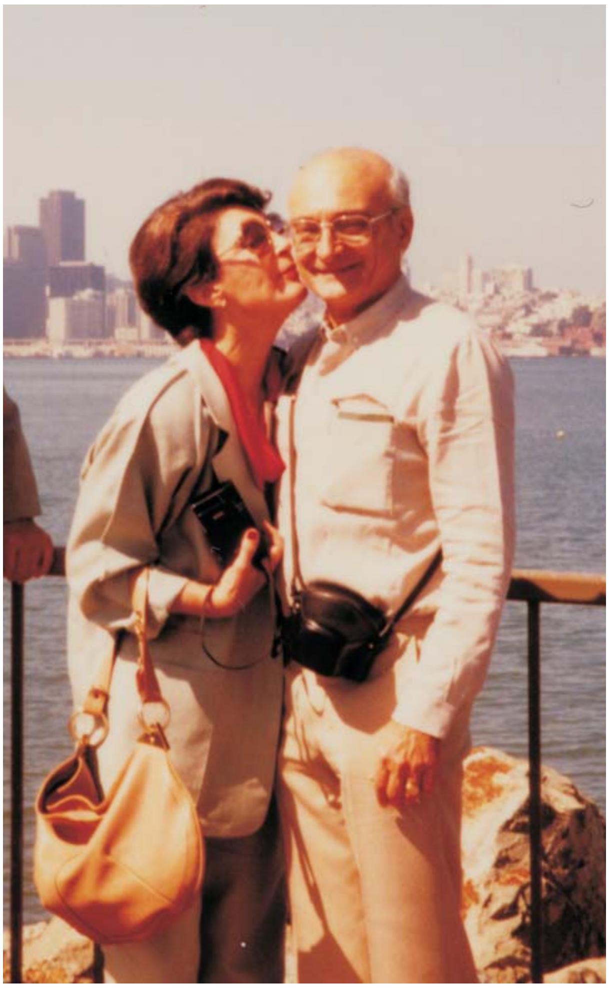

Figure 13 - Victor and Maria Luiza at the San Francisco International Conference.

Figure 14 - John Burland, Dick Parry and Victor reading the statutes before the San Francisco Board meeting.

I submit that the most important question facing the geotechnical engineer is for him to reassume a position as the foundation instrument of every civil engineering orchestra, and for the civil engineer himself to reassume his position as the most influential element of human society in affecting the environment.

9. Maria Luiza and Maria

The San Francisco Conference was over all too quickly and my close association with the ISSMGE, which had begun in Brazil in April 1981, came to an end. Victor launched into re-building his consultancy and his work, particularly with dams, continued. We continued to meet at Conferences and wonderful re-unions they were - see Figs. 16 and 17.

From the middle of 1988 Maria Luiza's health began to deteriorate and it was a terrible blow to us all when we heard of her death on 17th August 1990. Bravely Victor came to the European Conference in Firenze in May 1991. After the Conference he, my wife Gill and I had a most memorable two days as tourists. We exhausted ourselves visiting the major art galleries, museums and churches. Victor had the wonderful knack of discovering superb restaurants where we revived and talked endlessly late into the evenings.

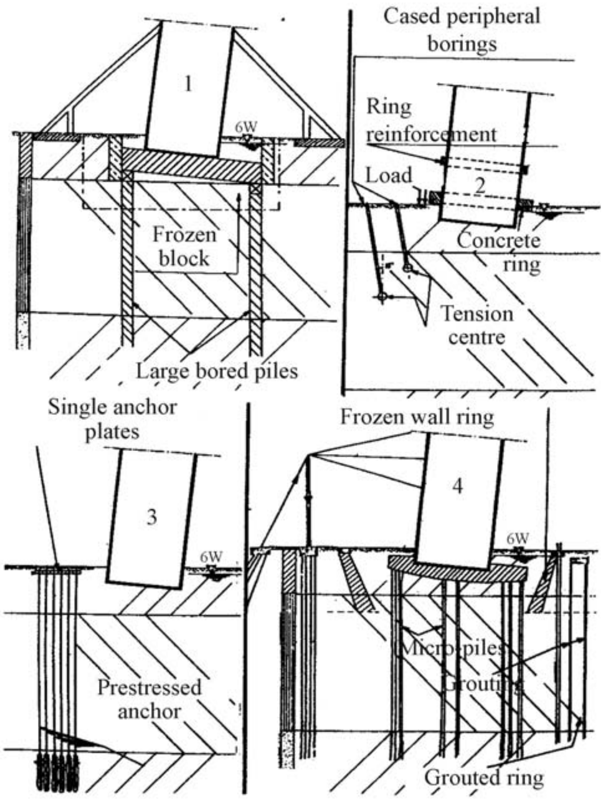

Figure 15 - Four examples of solutions for stabilising the Leaning Tower of Pisa.

Figure 16 - A reunion.

We were thrilled to receive the photograph in Fig. 18 with the news that Victor and Maria had married on 17 February 1995. In June 1995 Victor brought Maria to Pisa and they both sat in on one of the Commission meetings. We were all together again in Istanbul in 2001 and my last meeting with Victor and Maria was at the Skempton Memorial Conference in 2004. We have of course corresponded frequently.

10. Epilogue

Many of you will know that Victor is no longer in good health and finds it difficult to communicate. I want to share with you the most recent exchange of letters that I have had with him. On 28th September 2007 Victor sent me the following e-mail:

> *Maria wrote this note as you know I cannot move, eat or speak. The only movement left to my muscles is the closing and opening of my eyes by which I agree or disagree with what is posited to me. And it works! Silence is eloquent*!
>
> *What Maria wrote here is what I communicate to her that I wanted you to know*:
>
> *In my final times in this life I can assure you that one can reach other levels of reality and consciousness and open oneself to dimensions not accessed by our rationality, no matter how brilliant it might be; and the expression of Good, Beauty and Truth is in them.*
>
> *I read every word of what Maria wrote, and I blinked my eyes assuring her that what is written here is exactly what I wanted to tell you.*
>
> *Most affectionately and grateful for our so close, enriching and valuable friendship during these years.*
>
> *Victor de Mello*

Figure 17 - Maria Luiza with past Presidents Michele Jamiolkowski and William van Impe.

Figure 18 - Maria and Victor dancing at their wedding on 17 February, 1995.

In an e-mail dated 1st October 2007 I replied as follows:

> *In my vote of thanks to your Rankine Lecture (was it really thirty years ago? - it seems so recent) I said how much it would provoke thought and discussion and this has indeed been the case and will continue to be with your magnificent contributions. I have been honoured to give the first lecture in your name in Coimbra next year and I propose to devote it to promulgating your approach to engineering and to life.*
>
> *Also in the vote of thanks I referred to the 'heightened intensity' that you have brought to our lives. Your wonderful letter reminds me of the words of Elizabeth Barrett Browning:*
>
> *'Earth's crammed with heaven*
> *And every common bush is afire with God*
> *But only he who sees takes off his shoes*
> *The rest sit around and pick blackberries'*
>
> *So profound yet with a delightful touch of humour.*

Dear, dear brother, thank you for all that you have brought to our lives and to our profession. With our profound gratitude and love.

I feel sure that you will agree with these sentiments.

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Articles

A Procedure to Quantify the Variability of Geotechnical Properties

Daiane Folle, João Felipe C. Leite Costa, Jair Carlos Koppe, André Cesar Zingano

Abstract. The geotechnical properties of soil should be considered for several civil engineering purposes. Geotechnical information is used for urban planning, environmental management, slope stability analysis, and foundation design, among others. Given the importance that geotechnical information assumes in several engineering applications, geotechnical mapping is deemed relevant. Methods for integrating field tests and quantifying estimate uncertainty in the construction of these geotechnical maps is preferably used in the decision-making process. A methodology to build this kind of maps is proposed based on geostatistical stochastic simulation. Maps covering an area of 4 km^2 were built, based on the information derived from 141 boreholes, where standard penetration tests (SPT) were carried out. Sequential Gaussian simulation was used for building these maps, since it reproduces data statistics and spatial continuity. The soil resistance to penetration of panels of 100 x 100 m^2 was estimated and the estimation error was calculated. The results demonstrate the appropriateness and usefulness of the methodology for mapping geotechnical attributes.
Key words: geotechnical mapping, geostatistical simulation, SPT, uncertainty analysis.

1. Introduction

Highly heterogeneous soils impose difficulties in defining geotechnical properties correctly. This heterogeneity influences the choice of a safety factor to be used in engineering projects. In some situations, the geotechnical engineer adapts previous experiences to tackle the new conditions encountered (Elkateb *et al.*, 2003). Morgenstern (2000) reported 70% of failure in case studies where local experience was used to define geotechnical parameters. On the basis of these results, the authors of this study stressed the necessity for the use of novel methodologies that can assess uncertainty associated with the estimated geotechnical properties.

Generally, 0.5 to 1% of the total budget is allocated to civil engineering projects for application in soil investigation. For safety reasons, the project engineer tends to overestimate the safety factor used in relation to the soil strength when there is incomplete or inadequate geotechnical information. Geotechnicians are aware of the necessity of an adequate soil investigation, including field and lab tests. Some applications require maps of relevant parameters, showing their values at unsampled locations with the respective estimation error. These maps provide both the spatial distribution of geotechnical properties and their degree of uncertainty for risk assessment.

Many projects are not properly investigated in geotechnical terms, mainly due to budget restrictions. This incomplete geotechnical investigation leads to the use of interpolation techniques to infill values of relevant soil parameters at unsampled areas. The most used techniques include the polygon method, triangulation and weighting by inverse distance to a power. These methods do not provide the error associated to the estimate and are not proper methods to interpolate geological or geotechnical properties.

Over the past four decades, geostatistical methods have been used for estimating regionalized variables and the corresponding estimation error in mining and earth science (Matheron, 1963, Isaaks & Srivastava, 1989). Presently, these methods have been widely applied to other areas such as petroleum engineering, environmental and reclamation engineering, fishery, and, also, most recently in geotechnical engineering (Sturaro & Landim, 1996; Armstrong, 1998; Chilès & Delfiner, 1999; Phoon & Kulhawy, 1999; Folle, 2002; Folle, 2003).

This paper reports a practical geostatistical application in geotechnical engineering, where the variable mapped is derived from field tests used to characterize soil penetration resistance. The test used (SPT) is explained in the subsequent paragraphs and consists of a common index used for foundation design. The type of foundation for ordinary buildings (from 3 to up to 30 levels) and parameters such as type and length of the pile foundation are frequently based on these SPT results, geological information, and local experience (Pinto, 2000).

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This study aims at providing better tools for soil characterization used in foundation engineering. Also, areas of high uncertainty in soil properties should be identified and selected for additional sampling, in order to reduce engineering risk. These uncertainty maps are frequently used in mining (Pilger, 2000; Pilger *et al.*, 2001; Souza *et al.*, 2004), geology (Leuangthong *et al.*, 2004), petroleum engineering (Attanasi & Coburn, 2004), and environmental applications (Costa & Koppe, 1999) and can be promptly adapted for geotechnical engineering.

Considering the information provided by Standard Penetration Tests (SPT) and their spatial variability, this study investigates the appropriateness of a geostatistical methodology to map the spatial distribution of geotechnical properties derived from the SPT test. The map can be generated at a dense grid using geostatistical simulation.

The simulation framework provides access to the risk associated to an estimate quantifying its uncertainty. In this study, sequential Gaussian simulation (sGs) (Isaaks, 1990) is used to generate multiple scenarios of geotechnical properties of the soil. A case study illustrates this methodology generating maps at a 100 x 100 m^2 panels from a data set comprising standardized penetration tests.

2. SPT Test

Soil resistance is deemed relevant for foundation engineering and Brazilian technical standards (NBR-6484, 1999) define the procedure to collect soil penetration resistance, where the test known as Standard Penetration Test (SPT) consists basically of drilling and sampling soils along the hole. Also, a Brazilian standard such as NBR-7250 (1982) depicts two tables associating N_{SPT} with soil types; one table refers to sand-type soil and the other to clay-type soils.

The study area was irregularly sampled by 141 boreholes, where SPTs were carried out (Fig. 1). The maximum depth for those drill holes is 26 m, and most of them have not reached the so-called impenetrable level.

Four main soil types were observed along these drill holes with a gradational change from one type to the other. From top to bottom, the soil types are: red clay of medium consistency, silty red clay with yellow stains and medium consistency, silty-sandy red clay with yellow stains and rigid consistency, and silty-sandy gray clay with pieces of weathered rock very rigid to hard in terms of consistency. In order to explain the origin of these soil types, the local geological settings is presented hereinafter.

3. Geological Settings

Generally, the geology of the area comprises basalt rocks, belonging to Serra Geral Formation (JKsg), and sandstones and psamites, associated to the Tupanciretã Formation (Tt). Both formations are included in the Paraná Basin (RadamBrasil, 1986). Figure 2 shows a simplified geological map of the region. Note that the area object of

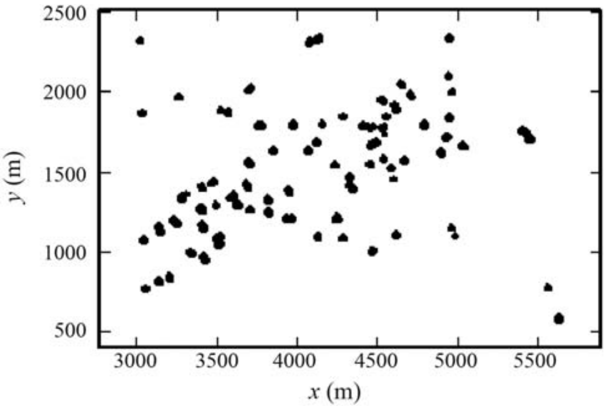

Figure 1 - SPT data set location.

this study is covered by the basalts from the Serra Geral Formation.

Serra Geral Formation (JKsg) is composed of continental toleitic volcanic rocks, usually basalts, dacites, and rhyolites, with dikes and tubular bodies of diabase. Occasionally, there are lens and layers of intertrapic sandstones of the Botucatu Formation.

Tupanciretã Formation (Tt) covers part of the volcanic basaltic rocks at the north of the area. It is composed mainly of sandstones, usually reddish, sometimes yellow-green, with variable texture, poorly classified, eventually conglomeratic and composed essentially of quartz and, subordinately, feldspar weathered to kaolinite.

The soil weathered profile descriptions are related to the elevation, bedrock, and surface morphology. The morphology of the horizons is presented by Naime (1999) as:

(i) Horizon A well defined and subdivided, brown to reddish, formed mostly by clay, with some granular material, porous, hard when dry, plastic, and sticky when wet. There is a gradational contact to the lower horizon;

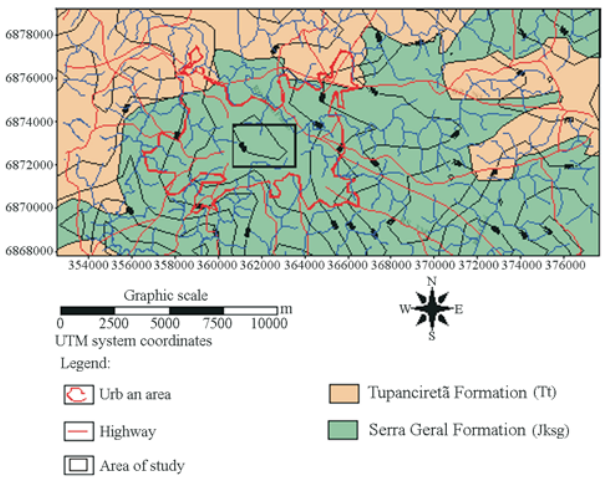

Figure 2 - Geological Map for Passo Fundo region, depicting the area studied.

(ii) Horizon B thick with subdivisions, dark red, clayey texture;

(iii) Horizon C very deep, formed by weathered basalt.

All soil types described belong to the Passo Fundo unit (Fig. 3) and were developed over basaltic lithologies, forming brownish humic latosoils, intermediate brownish and purple latosoils, and latosoils with developed B horizons.

The top soils show an excess of 1% of organic matter at 1 m depth, defining its humic characteristics. These soils are derived mainly from basic volcanic rocks and intermediate or acidic volcanic rocks.

Soils presented in the study area are reasonably homogeneous, with few morphological variations and inclusions derived from basaltic rocks. The topography is smoothly hilly with slopes within 8 to 10 % gradient. Locally, horizons B and C prevail.

4. Data Set Description

The area sampled is formed by soils derived from the rock types mentioned before (mainly basalts). The sampling survey was carried out in the residual soils, consisting of 141 boreholes, and the samples were basically composed of clay material with few sand and gravel fragments. From the surface downwards to the bedrock, the residual soil is divided into three to four layers. The number of layers depends on the location. Each layer exhibits a specific range of N_{SPT} values.

Therefore, the data set was divided into subsets of similar soil typology and mean N_{SPT} values. The limits identifying each soil were proposed to be obtained by plotting the average of all N_{SPT} values at each depth (max 141) *vs.* the depth (Fig. 4). Note the sampling process, *i.e.*, SPT tests were conducted at every meter, starting immediately below the borehole collar. It is reasonable to assume a linear trend between N_{SPT} and depth. This linear trend is shown in the plot obtained (Fig. 4); however, four changes were observed in the slope of this trend. Each slope variation of the trend leads to a possible change in soil type, which in geostatistical terms would identify different stationary subsets.

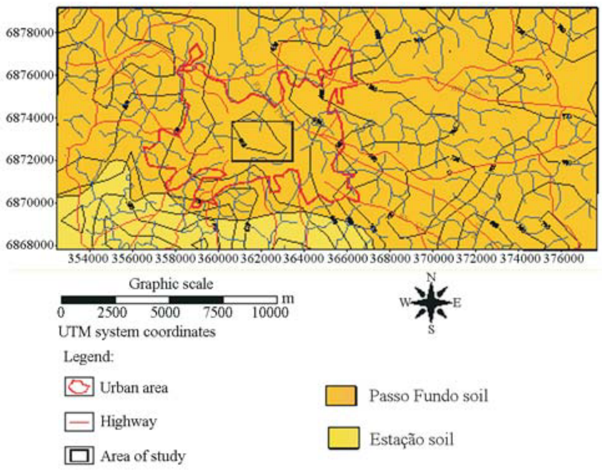

Figure 3 - Soil Map for Passo Fundo region, depicting the area studied (compiled by Lemos, 1973).

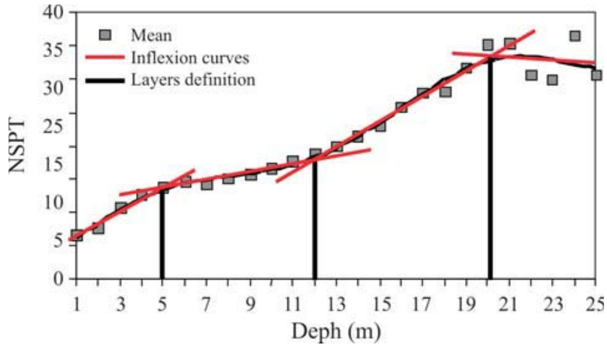

Figure 4 - Depth x N_{SPT}. Slope variation helps in identifying geostatistical domains.

Layers I and III are more erratic in terms of N_{SPT} values than layer II. The slope in the plot N_{SPT} *vs.* depth (Fig. 4) for layer II is distinct from the remaining layers. Layer II is also seen as a transitional zone from a low-resistance soil (layer I) and high-resistance soil (layer III).

Four groups (layers) were identified in Fig. 4 as follows: I (0 to 4.99 m), II (5 to 11.99 m), III (12 to 19.99 m), and IV (20 to 26 m). All these subsets were statistically analyzed and the results presented as follows (Fig. 5). Due to this criterion used to split the soil layers into geostatistical domains, the simulation will be run in 2D. The mean of N_{SPT} value for each soil interval intersected by each borehole is kept.

Figure 5 presents the histograms for the N_{SPT} values obtained for each soil layer. Histograms for layers I and II (Figs. 5a and 5b) show a positive asymmetry, layer III (Fig. 5c) is practically symmetric, and layer IV (Fig. 5d) presents a negative asymmetry caused by an excess of high values. These anomalous high values relate to the fact that various holes hit the bedrock. The last layer defines the contact with the bedrock. Many tests are known to be interrupted before reaching the bedrock (impenetrable by SPT). These asymmetric distributions (non-Gaussian) are typical of earth sciences datasets and are required to be normalized as it will be discussed hereinafter.

All layers have their N_{SPT} variograms modeled using a spherical variogram (Journel & Huijbregts, 1978). The main axes of anisotropy are, respectively, at N90E and N0. Equations (1) through (4) present the variogram models for layers I, II, III, and IV, respectively.

$$\gamma(h) = 3 + 22.70 \times Sph\left(\frac{N0°}{492} + \frac{N90°}{857}\right) \quad (1)$$

$$\gamma(h) = 6 + 70.40 \times Sph\left(\frac{N0°}{547} + \frac{N90°}{821}\right) \quad (2)$$

$$\gamma(h) = 10 + 75.90 \times Sph\left(\frac{N0°}{757} + \frac{N90°}{556}\right) \quad (3)$$

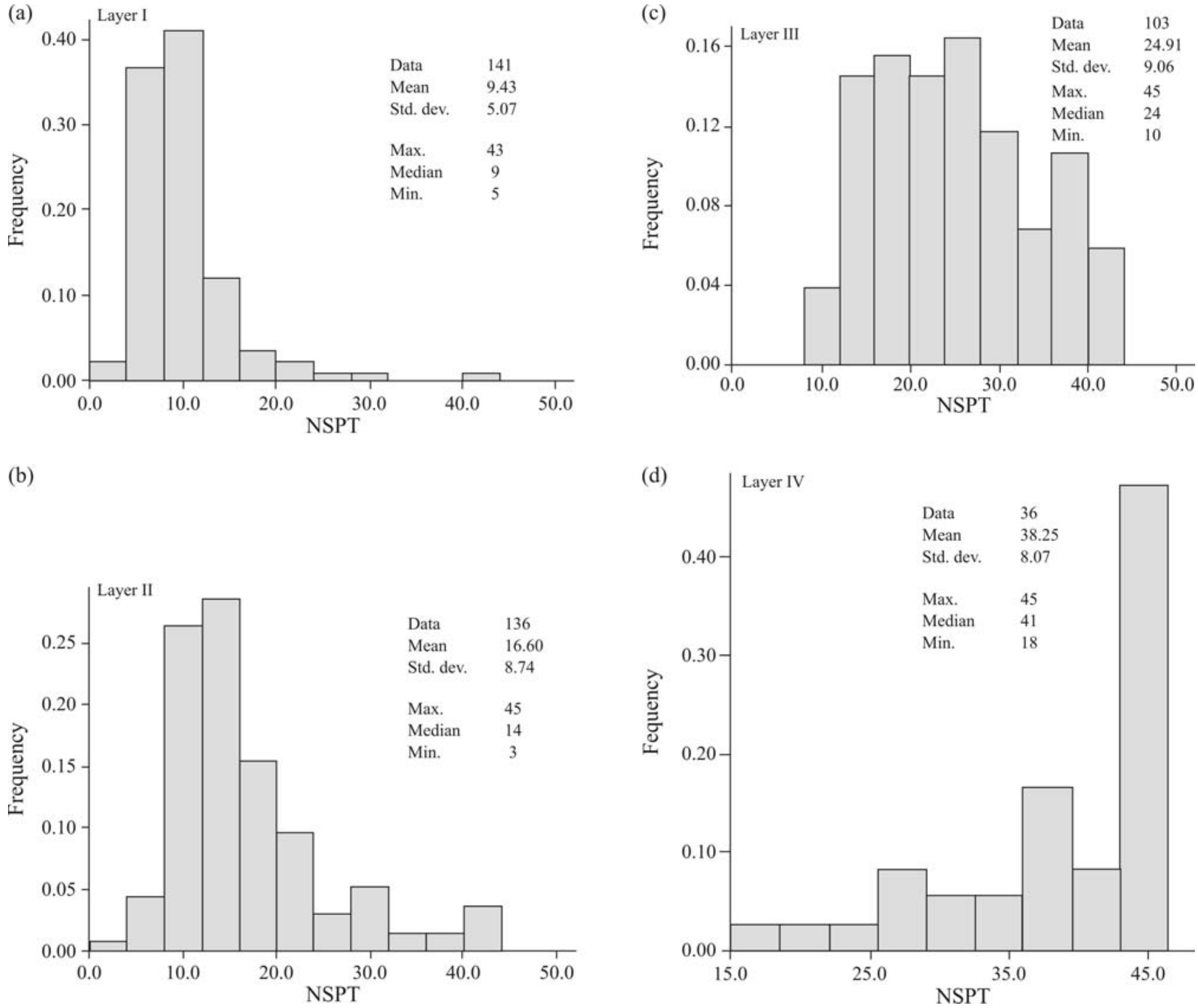

Figure 5 - Histogram of N_{SPT} values for layer I (a), layer II (b), layer III (c), and layer IV (d).

$$\gamma(h) = 10 + 55.10 \times Sph\left(\frac{N0°}{547} + \frac{N90°}{775}\right) \quad (4)$$

The terms in the above equations are:

$$\gamma(h) = C_0 + C_1 \times Sph\left(\frac{N0°}{a_1} + \frac{N90°}{a_2}\right) \quad (5)$$

where $\gamma(h)$ is the variogram, C_0 is the nugget effect, C_1 is the contribution to the sill from the 1st spherical model, *Sph* is the spherical model, a_1 and a_2 are, respectively, the length of the minor and major axis of anisotropy, and $N0°$ and $N90°$, are, respectively, the azimuths minor and major axis of anisotropy direction.

5. Geostatistical Simulation

Geostatistical simulation provides the framework to estimate an unknown value and its associated estimation error. A simulated model is said to be conditionally simulated if it returns data values at their location, reproducing data statistics and spatial continuity, *i.e.*, the histogram and variogram (Journel, 1974). Conditional simulation is constructed based on Monte Carlo methods (Chilès & Delfiner, 1999). Journel (1974), David (1977), Journel & Huijbregts (1978), and Deutsch & Journel (1998) present theoretical aspects related to the conditional stochastic simulations.

A variable $Z_s(x)$ is interpreted as a realization of a Random Function (RF) and it is characterized by a distribution function (histogram) and a covariance function or variographic model (variogram). The idea of simulation is to generate several realizations $z_s(x)$ from the same RF to provide the means to access local and global uncertainty (Journel & Huijbregts, 1978). Each simulated point is represented by a conditional cumulative distribution function (*ccdf*), derived from a model of multivariate distribution function $Z(x)$. In each location *x,* all distributions functions are specified through mean and variance values.

The principle is that, at each simulated point, L, equally probable results are generated. The simulation is considered conditional if it matches the data values at their locations. In addition to the distribution be conditioned to the data, each simulated point is randomly visited and its value is added to the dataset. Consequently, the local probability conditional distribution function is not the same for different realizations.

5.1 Sequential Gaussian Simulation

The most used stochastic conditional simulation algorithms are the sequential Gaussian (Isaaks, 1990), sequential indicator (Alabert, 1987), and the turning bands method (Matheron, 1973). These algorithms are available in most geostatistical softwares, such as GSLIB (Geostatistical Software's Library) (Deutsch & Journel, 1998) or Isatis®. Amongst the cited methods, the sequential ones, parametric or nonparametric, are preferentially used.

The main difference between these two groups is the procedure used for constructing the uncertainty models (conditional cumulative distribution function - ccdf): parametric vs. nonparametric. Sequential Gaussian simulation (sGs) is based on the multiGaussian formalism (parametric), whereas the sequential indicator simulation (sis) uses the homonym formalism (nonparametric).

The multiGaussian approach assumes that all multivariate distributions of the data follow a Gaussian distribution. Thus, the application of sGs algorithm demands that the experimental distribution of the random variable (RV) $Z(x)$ follows a Gaussian distribution. That is, the RV $Z(x)$ must be transformed into a RV $Y(x)$ standard normal. The multiGaussian hypothesis is very convenient, as it allows the uncertainty models (ccdf) to be obtained from a normal distribution, with mean and variance derived from kriging (Goovaerts, 1996). Thus, the mean and the variance of the ccdf in a given unsampled location, x, are equal to, respectively, estimate $y_{SK}^*(x)$ and variance $\sigma_{SK}^2(x)$ of simple kriging (SK). Then, the ccdf can be modeled as:

$$\left[G\left(x; y|(n)\right)\right]^*_{SK} = G\left(\frac{y - y^*_{SK}(x)}{\sigma_{SK}(x)}\right) \tag{6}$$

where y is a Gaussian value of the domain [-∞; +∞]. The estimated values $y_{SK}^*(x)$ and $\sigma_{SK}^2(x)$ are calculated from n information $y(x_\alpha)$ (α = 1, ..., n) in the neighborhood of x (Journel & Huijbregts, 1978, p. 566).

After constructing the ccdf, a simulated datum $y^{(l)}(x_j)$ is drawn from it via Monte-Carlo simulation. Generally, the following stages are common to all stochastic sequential simulation algorithms (parametric or nonparametric):

(i) definition of a random path, in which each unsampled location x_j (j = 1, ..., N) (point, cell or block of the grid) is visited only once;

(ii) construction of the uncertainty model (ccdf) at the location x_j - conditional to the n experimental information in the neighborhood of x_j;

(iii) simulation of a value $y^{(l)}(x_j)$ from the RV $Y(x_j)$, by drawing randomly from the ccdf (Monte-Carlo simulation);

(iv) inclusion of $y^{(l)}(x_j)$ into the data set, representing an addition to the conditional information to be used in the following N grid nodes to be visited $\{y^{(l)}(x_j), j = 1, ..., N\}$;

(v) repetition of the stages (ii) to (iv) until a simulated value is associated to each of the N locations;

(vi) repetition of the steps (i) to (v) to generate L equally probable realizations of the spatial distribution of the RV $Y(x)$.

Hence, the set $\{y^{(l)}(x_j), j = 1,..., N\}$ represents a realization of the random function (RF) $Y(x)$ in the physical domain defined by the information $y(x_\alpha)$ (α = 1, ..., n), in the normal space. Whereas the set $\{y^{(l)}(x_j), l = 1, ..., L\}$ represents L simulations of the RV Y at location x_j (j = 1, ..., N). Later, the simulated data set $\{y^{(l)}(x_j)$ (j = 1, ..., N and l = 1, ..., L)$\}$ is transformed to the original space of the RV $Z(x)$. Therefore, the value of the RV Z at each location x_j (j = 1, ..., N) is simulated within the domain of variation of the RV $Z(x)$, through a random procedure, from the ccdf. At each location, the simulation process generates a distribution, composed of L values. That distribution can be considered a numerical approach of the ccdf, *i.e.*:

$$F(x; z|(n)) \approx \frac{1}{L}\sum_{l=1}^{L} i^l(x; z) \tag{7}$$

where $F(x; z|(n))$ represents the probabilities assumed by the ccdf at each location x_j (j = 1, ..., N) and $i^{(l)}(x; z)$ is an indicator variable as follows:

$$i^l(x; z) = \begin{cases} 0 & \text{if} \quad Z^l(x) \le z \quad \text{with } l = 1, \dots, L \\ 0 & \text{if not} \end{cases} \tag{8}$$

Sequential Gaussian simulation is based on the multivariate normal random function model, which follows the Bayes theorem. It is demonstrated that there exists equivalence between an image generated from a multivariate distribution function and that generated from the sequence of univariate conditional distribution functions (Olea, 1999). The sequential Gaussian simulation (sGs) algorithm was applied to this dataset and results are hereinafter depicted.

5.2 Analysis of N_{SPT} variability

Every time one interpolates any geological or geotechnical attribute at a non-sampled location, given the information (boreholes) in the local vicinity of the grid node being interpolated, there is an error associated with this estimate. It would be reasonable to assume that the engineer responsible for the foundation design should have an estimate map with the geotechnical properties relevant for his/her project, combined with an error assessment (uncertainty associated with the estimates). These errors are associated with (Phoon & Kulhawy, 1999): (i) soil inherent spatial variability, due to variation in formation conditions and stress history from one point to another in space; (ii) measurement errors, due to insufficient control of testing procedure and equipment; (iii) deterministic trends in soil properties, such as the increase in soil strength with depth due to the confining increase in pressure; and (iv) the collection of field data over long time periods.

Following this rationale, the assessment of the error associated with the estimation of geotechnical properties (soil strength) using sGs is proposed here. In addition, this error should be incorporated in risk analysis along the decision-making process.

The foundation project requires soil-bearing capacity and the safety factor used in this project is associated with the degree of certainty one has on the soil properties selected. With the proposed procedure to quantify this uncertainty, the choice of safety factor can be conducted in a less arbitrary way. In addition, by mapping areas of high uncertainty in soil-bearing capacity, one can locate extra sampling points, in order to reduce locally the uncertainty, if necessary.

Fifty equally possible scenarios were generated at 100 x 100 m^2 grid. This grid is in accordance with the average panel size used for city planning at the location selected for this case study. To obtain a panel simulation, *a posteriori* change of support was used, averaging all point nodes simulated within the domain of a panel.

A perfect reproduction of histograms and variograms by the simulated models is unattainable due to uncertainities in the input statistics. The models should exhibit ergodic fluctuations, and there are some factors which control the magnitude of this fluctuation. Figure 6 shows ergodic fluctuations for the variogram using data on normal space. In order to illustrate the discussed methodology, only the results from soil layer III are depicted in this paper. The realizations generated by simulation were also checked for univariate statistics reproduction, and it was found that the ergodic RF model supports the statistics of the normalized input data (Figs. 7 a, b and c).

Figure 8 shows the distribution maps of the average (E-type) of N_{SPT} values simulated at each panel from layer III. These E-type models are similar to models generated by kriging (Zingano *et al.*, 1996; Costa, 1997; Goovaerts, 1997).

The simulation of N_{SPT} distribution for all soil layers ultimately aims at estimating the soil properties and its uncertainty, incorporating it into the foundation design. For instance, layer I comprises values of N_{SPT} capable of supporting shallow foundations, whereas layers II, III, and IV are capable of bearing deep foundation.

Maps of local variability for N_{SPT} values are selected as an important tool for uncertainty assessment in foundation projects. There are several methods to evaluate and visualize these local uncertainties from the conditional simulation realizations (Srivastava, 1994; Goovaerts, 1997). An uncertainty measure was adopted for the present study, which is the coefficient of variation (CV) for N_{SPT} value at each panel.

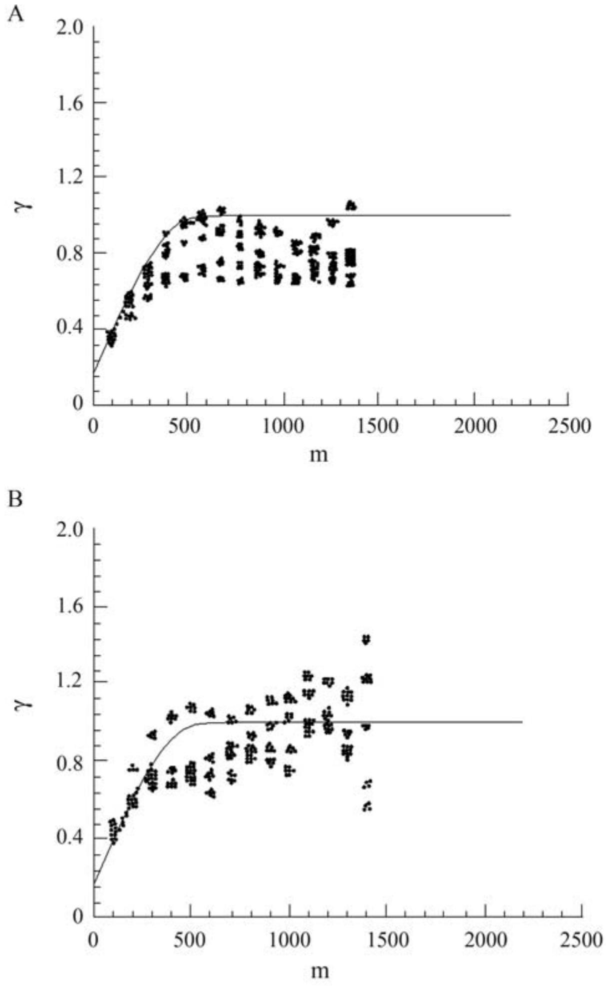

Figure 6 - Variograms of normalized data (layer III - solid line) showing ergodic fluctuation (dots) at the principal directions of spatial continuity (a) 0° and (b) 90°.

The maps for CV in each soil layer are presented in Fig. 9. The values of CV are obtained according to Eq. (9):

$$CV_{bl} = \frac{\sigma_s}{\overline{X}_s} \quad (9)$$

where CV_{bl} is the panel-by-panel coefficient of variation; σ_s is the standard deviation of the fifty simulated values at each panel; and $\overline{X}_s$ is the mean of these fifty values (E-type).

Maps for the CV show that central region of layers I and III (Figs. 9a and 9c) present low CV values, approximately 20%. This area is densely sampled, consequently showing a lower level of uncertainty compared with the remaining sectors. Layer IV (Fig. 9d) has CV values of

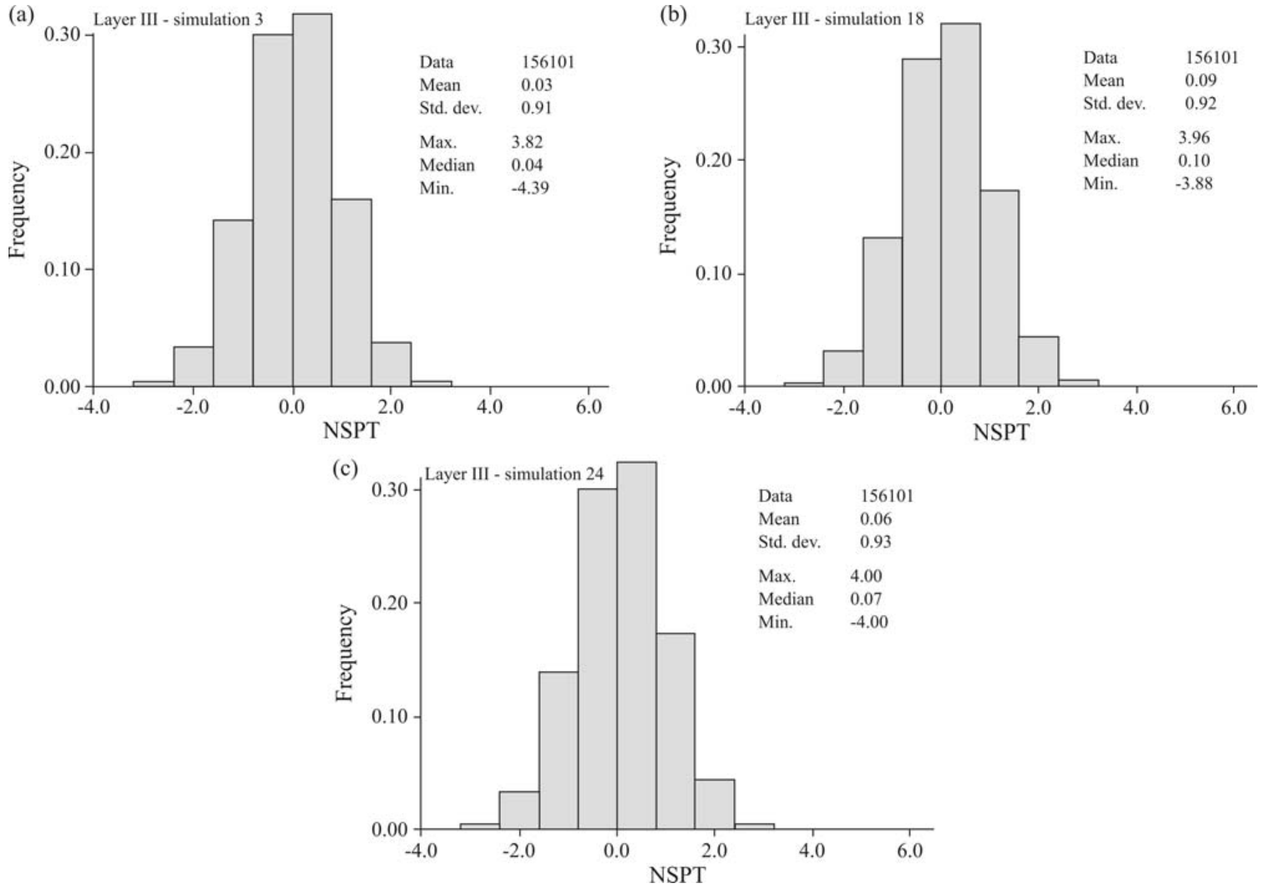

Figure 7 - Histograms of simulated models (normal space) selected randomly among 50 realizations. Layer III - simulation 3 (a), 18 (b) and 24 (c).

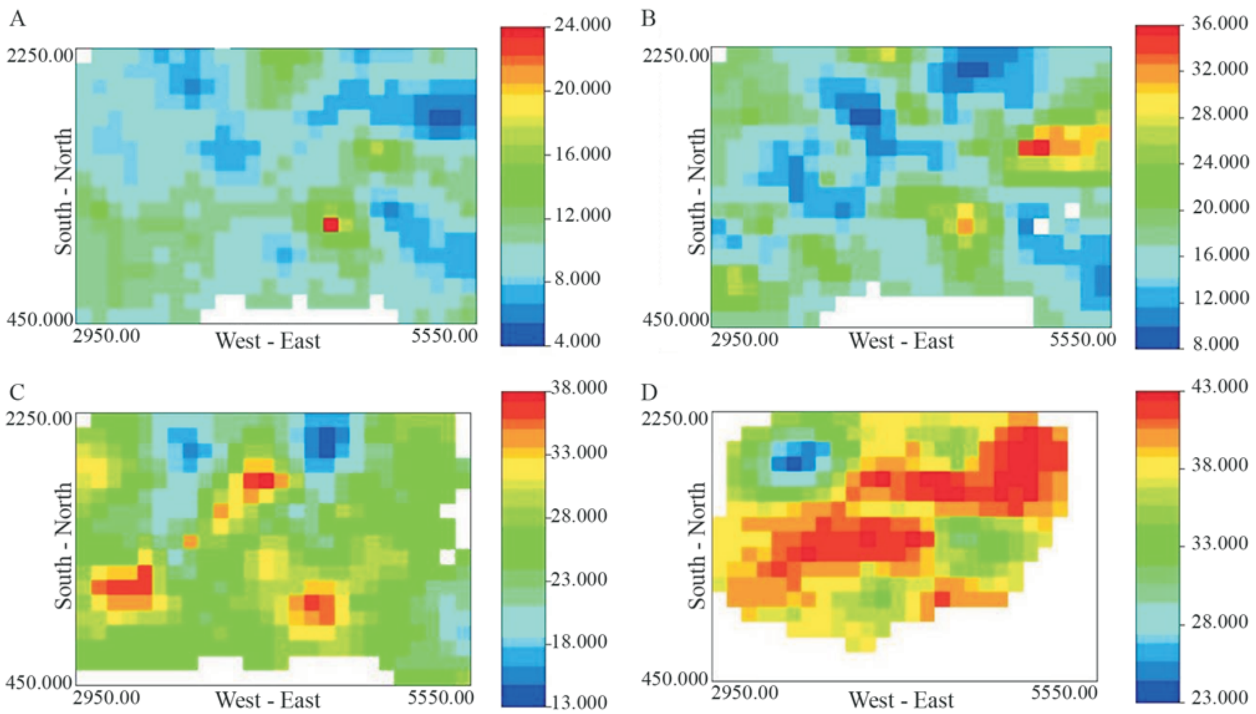

Figure 8 - Images showing the mean N_{SPT} value (E-type) at each panel (a) layer I, (b) layer II, (c) layer III, and (d) layer IV.

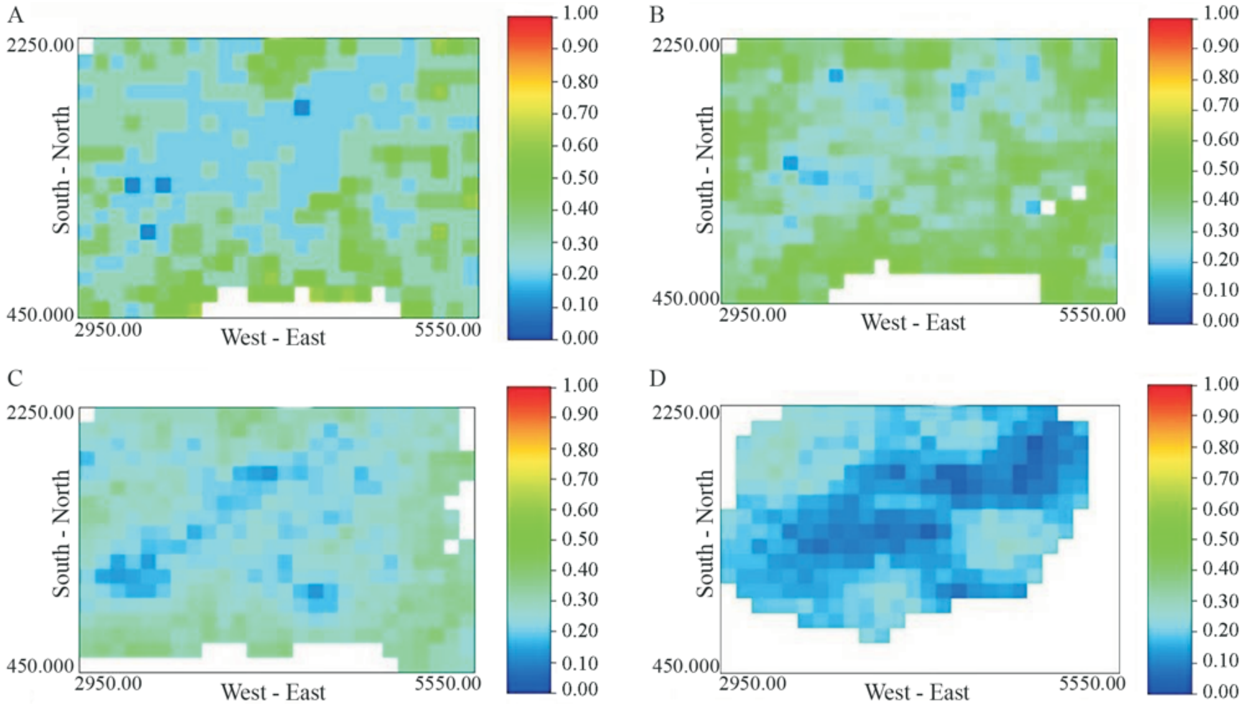

Figure 9 - Variability map measured by the coefficient of variation (CV) at each panel for N_{SPT} values (a) layer I, (b) layer II, (c) layer III, and (d) layer IV.

approximately 10% at the same central area and in the remaining regions the values are approximately 20%. Layer II (Fig. 9b) has higher variability than the other three layers, reaching 50% in the most extreme zones. On average, the variability ranges from 20% to 40% in the central area of layer II.

Layer II has higher variability than the others, possibly due to its transitional characteristics described previously. This layer is also the region where water level was detected frequently, which reduces soil strength followed by an increase in the next dried zone. The relevance in identifying variability in soil properties is presented in various papers (Soulié *et al.*, 1990; Folle, 2002 e Elkateb *et al.*, 2003). Geotechnical engineers are willing to improve the geotechnical investigation optimizing the whole process including: development of better survey methods, reduction of the period taken for the survey, better definition of the number of sampling points, and consequently reduction of the costs involved. Following this interest, this paper introduced a methodology that can quantify the spatial variability of soil geotechnical properties to corroborate with these needs.

6. Conclusions

Several stochastic simulations were generated and were used to evaluate uncertainty due to variability related to N_{SPT} values at different soil layers. Sequential Gaussian simulations proved to be an adequate tool to assess uncertainty associated to N_{SPT} estimate. sGs was used to generate equally likely scenarios which after combination could facilitate global and local error measurements. In this study, only N_{SPT} values were mapped; however, other correlated soil resistance measures or even other geotechnical properties could also be used.

Fluctuations around the mean estimated values (E-type) provide the means to evaluate the confidence intervals on interpolated results. In addition, the methodology can be used for planning infill drilling at zones of higher uncertainty in case risk reduction is desirable.

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Loss and Soil Deposition Estimate by Means of the Cesium 137 Concentration in the Rio das Ondas Basin, BA

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Abstract. Erosion is the most harmful form of soil degradation, it affects plants' productivity and causes severe environmental damage, such as sediment accumulation and pollution of water sources. With the purpose of obtaining significant information about losses and soil deposition on the *Rio das Ondas* basin, a study of the losses caused by erosion by means of cesium 137 (^{137}Cs) concentration in the soil was conducted. Soil samples were collected for reference in four places, in vertexes and in the center of a triangle with five meters edges in a soil under native vegetation. Thus, samples in two perpendicular transects to the pendant were collected, one (transect A) under soy crops and another (transect B) under corn crops. The samples of the triangle's vertexes and of the transects were collected at a depth varying from 0.00 m to 0.60 m, with intermission of 0.10 m between them and the samples collected in the triangle's center varied between 0.00 m to a 1.00 m depth, distributed between layers from 0.05 m to 0.50 m and, from this value on, a sample at a 1.00 m depth was collected. After being air-dried, these samples were reduced to bran and passed through a 2 mm sieve, they were bagged and sent to Nuclear Physics Applied Laboratory (LFNA) of the State University of Londrina (UEL)" so as to analyze the ^{137}Cs concentration in soil. The results obtained from the activity of ^{137}Cs in the three places of the transects A and B varied between 0.14 e 0.42 Bq.kg^{-1} (soy crop) and between 0.12 and 0.24 Bq.kg^{-1} (corn crop), showing a variation of ^{137}Cs according to the position of the place on the downgrade. It was observed in the results 22.52 t.ha^{-1}.year^{-1} soil losses on the transect located in the soy crop (A) and 38.13 and 21.18 t.ha^{-1}.year^{-1} in the transect B located in the corn crop. These results indicate great deposition of sediments in the valley, mainly in the soil under soy crop.

Key words: ^{137}Cs, erosion, soil deposition.

1. Introduction

The prediction of soil loss models through erosion were greatly used for the erosive process evaluation in soil under crops. Among these models the USLE (Universal Soil Loss Equation) is the most used. However this model requires information about rain, spacial distribution of areas under crops, ground declivity, downriver length, soil "erodibility", conservationist treatments and management. It is therefore often hard to apply this model (De Jong *et al.*, 1983).

Measurements of soil losses by erosion can be also obtained by portions maintained on fields for many years. It is possible too make use of rain simulators to study the factors that affect the erosion process, however the data extrapolation in these conditions is very difficult (Mech, 1965).

With the thermonuclear tests made from the beginning of 1950 to the end of 1970, ^{137}Cs was introduced into the environment. When this element is in the soil it is strongly absorbed by clay, so its side distribution is associated to physic process (Levens & Loveland, 1988), and its transport and deposition is linked to soil particle displacement. Therefore the variation of ^{137}Cs concentration can be used to determine the movement of soil by erosion (Rirchie & MacHenry, 1978).

Knowledge about the amount of ^{137}Cs in undisturbed soils compared to other soils that have suffered human action indicate a loss or gain of this element. In addition, the study of distribution and behavior of the radioactive elements inside the soil profile is important to the evaluation of its impact in the environment and its availability to plants.

The ^{137}Cs is a radioactive kernel, produced by nuclear fission of the ^{238}Uranium with ^{239}Plutonium. It is an unstable atom with 30.2 half-life years that decay by beta emission (β^-) to 137-Barium half-stable, with 2.55 half-life minutes, and became stable after emission of gamma ray (Y) with 661.6 keV, that, although it is emitted by ^{137}Barium, characterizes the ^{137}Cs.

Guimarães & Andrello (2001) describe that the armament race that started in 1945, provided the environment contamination caused by the *fallout* of the radioactive precipitation. In the more powerful atomic explosions (higher than 1 megaton) a great deal of the clouds produced enter the stratosphere, lengthening the dwelling time of the frag-

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ments from nuclear fission. The fragments' crossing through the troposphere were responsible for the global *fallout.* The time that elapses between the injections of products from nuclear fission into the stratosphere and the subsequent *fallout* vary from five months to five years, mainly depending on latitude, altitude and seasonal period of injection.

According to Rogowski & Tamura (1970), particles derived from the *fallout* are, in part, intercepted by plants, which retain them in their leaves. The radiokernells that reach the soil's surface are perhaps under movement by lixiviation or by superficial flow off and erosion. A large quantity of soils are able to absorb ^{137}Cs in small amounts, just as what happens during *fallout*. So, ^{137}Cs is strongly absorbed and attached to the soil, which limits its movement to lixiviation process or other natural chemical natural processess. The cation Cs^+ strongly act in soil due to its hydratation level and its high polarization. Cations with low hydratation energy cause dehydration of the clay particles interlayers causing these layers to collapse, so they became attached in interplanar positions.

The soil losses (or gains) are measured appraising ^{137}Cs activity in soil samples. If this activity is smaller (or larger) than the reference ^{137}Cs activity, soil loss or gain will occur in its place. The reference ^{137}Cs activity is equal to the total of ^{137}Cs deposited by radioactive precipitation (*fallout*), determined by evaluation of a soil sample collected on an undisturbed area, that is, without evidence of soil loss or gain (deposition). In such cases, the ^{137}Cs movement also means soil movement, ^{137}Cs accumulation brings into relation with soil deposition, and ^{137}Cs depleting indicates soil erosion.

The objective of this study is to evaluate soil loss or gain (deposition) under climate and edaphic conditions of the hydrographic Rio das Ondas basin, Bahia, Brazil, using the ^{137}Cs concentration appraisal method.

2. Material and Methods

2.1. Location and climate and edaphic characterization of the studied area

The area of the hydrographic basin of Rio das Ondas belongs to the basin of the Rio Grande river, and surrounds the cities of Barreiras and Luiz Eduardo Magalhães. It is located in the southwest region of the State of Bahia, between the parallels 11°59'11.95" and 12°32'9.16" of south latitude and the meridians 45°00'54.68" and 46°20'3.52" of west longitude. The altitude varies from 400 to 900 m and the total area contains a surface of 5,141.94 km2. This Basin includes the affluent rivers: Rio das Pedras, Rio Borá and Rio Vereda das Lages. On Fig. 1 there are the points where the samples were taken and the location of the studied area.

According to the Köppen's classification, the climate of this area is of the Aw kind, a tropical savanna with dry winters and rainy summers. The annual average temperature is 24 °C, varying between 18 °C (minimum average temperature) to 32 °C (maximum average temperature). The annual pluvial precipitation varies from 1,121.9 mm on the seat of the Barreira, to 1,624.6 mm on the Goiás and Tocantins state boaders, around 150 km west of Barreiras. It is estimated that approximately 95% of pluvial precipitation occurs during October and April.

The predominant soil types of the hydrographic basin of Rio das Ondas are: Red-Yelow Latosoils and Quartz Newsoils, which occur on 63 and 25 percent of the area, respectively (Soares Neto 2005). Table 1 illustrates the values of the physic-chemical attributes of the sampled points, in the reference area as in the two evaluated transects. These soils in their native states offer erosion resistance, however the continuum use of agricultural implements, specially the heavy grade, can compact the superficial layers, favoring erosion.

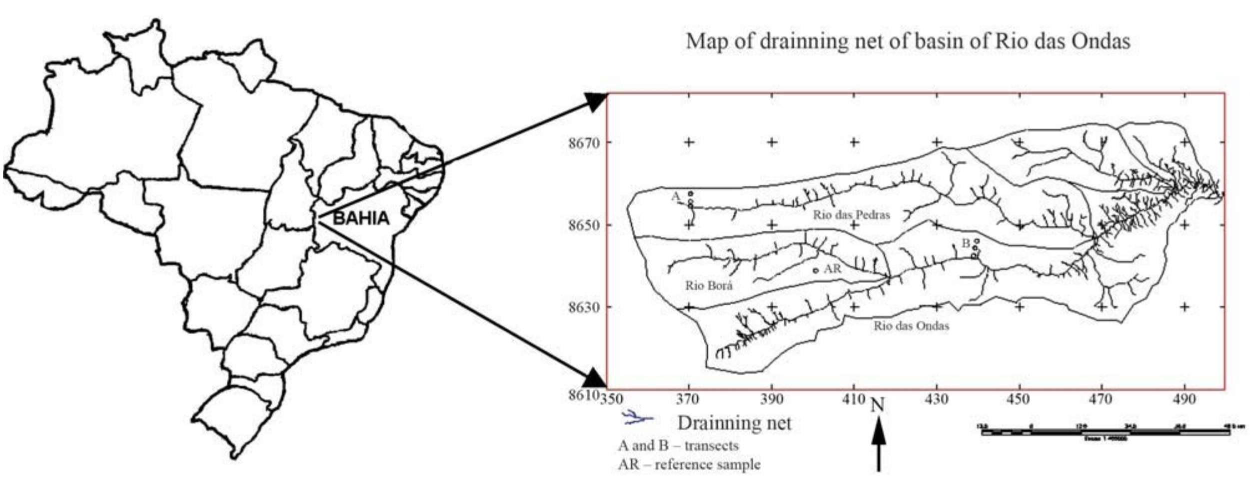

Figure 1 - Location of sampling points and studied area in the hydrographic basin of Rio das Ondas.

Table 1 - Results of grain size distribution, organic contents (OC), specific mass of the grains (ρ_s) and dry unit mass (ρ_d).

Sample	Depth (m)	Clay (%)	Silt (%)	Slim sand (%)	S. thick (%)	OC (%)	ρ_s (Mg.m^{-3})	ρ_d (Mg.m^{-3})
AR	0.00-0.10	8.0	0.7	31.0	59.0	1.48	2.50	1.48
AR	0.10-0.20	10.0	0.3	30.0	59.0	0.93	2.56	1.55
AR	0.20-0.30	11.0	1.0	30.0	58.0	0.81	2.60	1.62
AR	0.30-0.40	12.0	0.8	31.0	55.0	0.67	2.53	1.51
AR	0.40-0.60	11.0	0.8	28.0	59.0	0.50	2.56	1.58
A	0.00-0.10	5.0	2.3	40.0	51.0	1.04	2.60	1.62
A	0.10-0.20	7.0	1.5	43.0	46.0	0.72	1.63	1.66
A	0.20-0.30	9.0	1.0	43.0	45.0	0.72	2.53	1.56
A	0.30-0.40	9.0	3.5	40.0	44.0	0.60	2.47	1.50
A	0.40-0.60	13.0	2.5	41.0	41.0	0.74	2.47	1.49
B	0.00-0.10	9.4	2.4	51.8	35.1	0.93	2.53	1.55
B	0.10-0.20	9.0	2.9	49.7	37.0	0.84	2.67	1.69
B	0.20-0.30	12.8	2.7	50.7	32.7	0.64	2.60	1.60
B	0.30-0.40	13.0	1.2	51.8	33.0	0.45	2.47	1.50
B	0.40-0.60	13.1	2.6	51.7	31.6	0.38	2.56	1.55

AR = reference samples; A = samples of transect A on the mean position; B = samples of transect B on the mean position.

2.2. Procedure

The radioisotope activity average per sampled kilogram is determined by the following equation:

$$C_n = N_n(\varepsilon.m_a.P_\gamma)^{-1}, \quad (1)$$

where C_n = average of the activity of the radioisotope n (Bq.kg^{-1}); Nn = net tax of counting to gamma ray energy (γ) of the radioisotope n (counting per second - cps); m_a = mass of the sample (kg); ε = counting efficiency to gamma ray energy (γ) of the radioisotope n and P_γ = absolute probability of transition by gamma decay to gamma ray energy (γ).

The variables N_n and ε are determined by using standard sample with known activity (570 kBq ± 2.5%). The samples used in this study were prepared with a ^{137}Cs chloride solution to determine the calibration equation related to the activity of this radiokernell, according to what was described by Andrello (2004).

To determine soil losses by erosion, as recommended by Andrello (2004), the proportional model was used, which, according to the author, apart from being easier to apply, in relation to simplified models of mass balance, refined mass balance and mass balance incorporating the soil movement by crop, its results fall within acceptable deviation ranges (arising discrepancy from 70% of ^{137}Cs loss) in comparison with the most refined models. This model is represented by the following equation:

$$Y = 10.\rho_d.d.X(100.T.p)^{-1} \quad (2)$$

where Y = annual soil loss average (t.ha^{-1}.year^{-1}); ρ_d = dry unit mass (layer's average)(kg.m^{-3}); X = percentage reduction in the total inventory of ^{137}Cs; d = depth of cropped layer (m); T = time elapsed from the last deposition of ^{137}Cs, (year when the great fallout occurred,1964) and p = the correction factor for the particle size with respect to the position where the soil loss takes place.

The variable X (percentage reduction in the total inventory of ^{137}Cs) is calculated by the equation:

$$X = \left(\frac{A - A_{ref}}{A_{ref}} \right) \times 100 \quad (3)$$

where A_{ref} = inventory of ^{137}Cs in the reference sample (Bq.m^{-2}) until the depth of 0.30 m and A = inventory of ^{137}Cs in the evaluated sample of the area under antropic influence (Bq.m^{-2}) until 0.30 m in depth.

In addition, variable A, of Eq. (3), is calculated by the equation:

$$A = \Sigma 100.Ci.\rho_d.Li \quad (4)$$

where Ci = activity of level i (Bq.m^{-2}); ρ_d = soil density of level i (g.cm^{-3}); Li = soil layer thickness corresponding to the considered level (cm) and i = 1, 2 and 3 soil layers.

When the inventory of ^{137}Cs to a sampled point was larger than the local reference inventory (A_{ref}), then sediment deposition has occurred, if not, erosion has occurred.

The value of "p" expresses the size composition of the sediment grain that was mobilized in the original soil. As the mobilized sediment is usually increased with slim particles compared to the original soil, the "p" factor assumes values larger than 1.0 due to the intense affinity of ^{137}Cs with slim particles of soil.

For the estimate of the "p" value, information about grain size distribution of the original soil, of the mobilized sediment and of the deposited sediment are needed. According to He & Walling (1996) mentioned by Andrello (2004), the "p" value can be determined by the knowledge of the superficial specific area of the grains, by the following equation:

$$p = (S_{sm}/S_{so})^{\nu} \quad (5)$$

where S_{sm} ($m^2.g^{-1}$) is the superficial specific area of the mobilized sediment; S_{so} ($m^2.g^{-1}$) is the original soil area; and ν is a constant with value approximately equal to 0.65.

2.3. Sampling

The determination of ^{137}Cs was executed by samples collected from soil with native plants coverage (reference value), plotted on top of a slope and in two transects with three points located in the top third, in the middle and on the base of the slope, one of these under soy crop (transect A) and the other under corn crop (transect B). The samples used to determine the reference value (AR) were collected in the center and in the vertexes of a triangle, whose sides are equal (5 m of edges), as is shown in Fig. 2. In each sampling point three soil specimens were collected, for each depth in an area of 1.0 m^2, as illustrated in the detail of Fig. 2. These samples contents were mixed in pails, and then a new sample was formed composed by 1.5 L of soil, which was sent to the Nuclear Physics Applied Laboratory of the University (LFNA) of the State University of Londrina (UEL)", in order to obtain data of ^{137}Cs activity. These samples were collected at the following depths: 0.00 to 0.10; 0.10 to 0.20; 0.20 to 0.30; 0.30 to 0.40; 0.40 to 0.50 and 0.50 to 0.60 m. The samples located in the center of the triangle were collected from the layers ranging from 0 to 0.05; 0.05 to 0.10; 0.10 to 0.15; 0.15 to 0.20; 0.20 to 0.25; 0.25 to 0.30; 0.30 to 0.35; 0.35 to 0.40; 0.40 to 0.45; 0.45 to 0.50; 0.50 to 0.55; 0.55 to 0.60 on 1.00 m depth.

The ^{137}Cs activity readings were made by using a specific detector (GEM-M-7080-P-S model) to comply with the geometry of Marinelli bequer, with 69.9 mm germanium crystal diameter and 84.2 mm length.

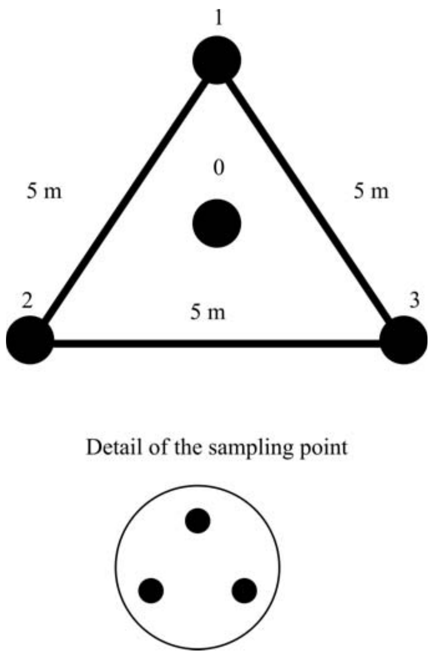

Figure 2 - Soil sampling points array for the evaluation of ^{137}Cs activity in an area under native vegetation (reference samples).

3. Results and Discussion

The results obtained from the activity of ^{137}Cs on two transects (A and B) and the reference activities (AR) are shown in Table 2. By viewing this data, it is verified that the ^{137}Cs concentration measured on the three points of the transects A and B varied between 0.14 and 0.42 $Bq.kg^{-1}$ (A) and between 0.12 and 0.26 $Bq.kg^{-1}$ (B). This variation indicates that the distribution of ^{137}Cs in the soil depends of the sampling point position on the slope (Fig. 3). These results show the loss and gain points of this element in relation to the value found in the reference sample, which represents the ^{137}Cs concentration deposited by *fallout*, on this hydrographic basin.

As is shown in Table 2, on transect A ^{137}Cs loss has only occurred in higher positions, while on the central and on the lower positions gain has occurred in relation to the reference value. In conformity, it was verified after the samples were collect that this occurred because the sampling point on the mean position was located close to the terrace basis, which is the soil deposition point. On the other hand, the lower point naturally occurs in a deposition zone. Guimarães (1988) also found similar results for points located next to terrace waterways. On transect B ^{137}Cs losses were found on the higher and central positions of the slope.

Analyzing the results of soil losses and gains, Fig. 4 shows that sampled points on the transect A (soy under con-

Table 2 - Values of ^{137}Cs activity on soil in the samples of transects A and B, according to the position in the slope and the reference sample, Barreiras, BA.

Transect	Position on the slope	Activity ($Bq.kg^{-1}$)
A 1	Top	0.14 ± 0.03
A 2	Mean	0.42 ± 0.04
A 3	Lower	0.39 ± 0.03
B 1	Top	0.12 ± 0.06
B 2	Mean	0.13 ± 0.04
B 3	Lower	0.26 ± 0.03
Reference (AR)	Top of an area under native vegetation	0.24 ± 0.03

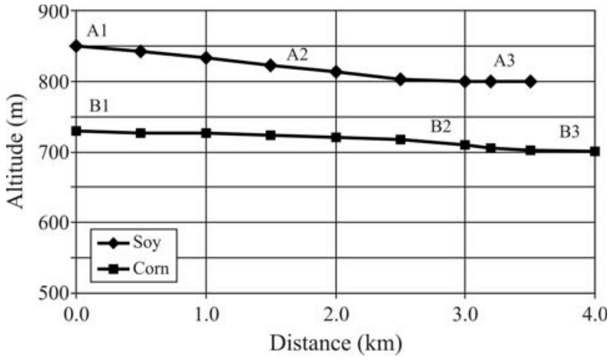

Figure 3 - Profile of sampled transects in soils under soy and corn crops in the hydrographic basin of Rio das Ondas.

ventional planting) presented soil loss by erosion only on the higher point (A1) of the slope (22.52 t.ha^{-1}.year^{-1}). The others sampled points of this transect showed behavior of deposition points, with gains of 86.10 t.ha^{-1}.year^{-1} (A2) and 75.50 t.ha^{-1}.year^{-1} (A3). For points B1, B2 and B3, sampled on the corn crop, also under conventional planting, large soil loss has occurred, except on B3 point, which presented gain of 4.24 t.ha^{-1}.year^{-1}, due to the fact that it is located in a sediment accumulation zone. These results indicate large soil movement in the Rio das Ondas basin, where there are areas under erosion and areas receiving sediments.

From this soil loss result one can deduce the need for using and developing conservational practice in order to guarantee the adequate control of erosion and, also, to discipline water movement by superficial flow off or torrent, as the maximum tax of erosion that can occur on Red-Yelow Latosoils and Quartz Newsoils (≈90% of the area), maintaining its sustainability is 12 t.ha^{-1}.year^{-1} and 15 t.ha^{-1}.year^{-1}, respectively (Soares Neto, 2005).

Besides soil loss in the erosive process, the losses of nutrients also are evident. Resk (1981), studying a Red-Dark Latosoil, with 5% declivity, applying rain with a simulator, verified that in an area under soy crop, the losses of calcium, magnesium and potassium were at least two times greater than the amount originally found in the soil.

In these draining basin conditions, it was verified that the soil loss average, on two transects, was 26 t.ha^{-1}.year^{-1},

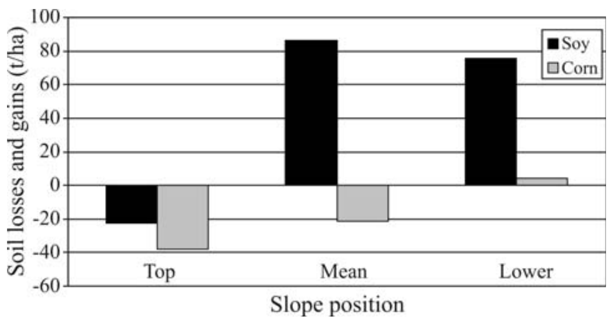

Figure 4 - Tax values of soil loss and gain (t/ha) on evaluated transects in the basin of Rio das Ondas, Barreiras, BA.

which corresponds to a layer of 1,67 mm.year^{-1}. On a similar study, using the same methodology, Andrello *et al.* (2003) evaluated the soil losses on a hydrographic basin on Paraná and found soil losses averaging 13.90 t.ha^{-1}.year^{-1} on areas under pasture and 15.80 t.ha^{-1}.year^{-1} on areas under annual crops, values that are lower than the ones found in this study. The soil losses on areas under pasture are always lower than those on areas under annual crops because pastures provide larger soil coverage. On the other hand, Kachanoski (1987), in Canada, and Andrello (1997) on the microbasin of Unda stream, in Paraná, Brazil, found soil loss values of 63 t.ha^{-1}.year^{-1} and 111 t.ha^{-1}.year^{-1}, respectively. These studies were carried out with soils with clay textures, which could favor the increase of losses by erosion. This variation of results is related to regional dissimilarities of the following factors: rain, soil, topography, coverage, management and conservational practices among the areas where these studies were conducted.

Comparing the result of soil loss average in the basin of Rio das Ondas with the results obtained by Maack (1981), in Paraná (28 to 34 t.ha^{-1}.year^{-1}) and Cogo *et al.* (2003), in Rio Grande do Sul, to a Red Latosoil under conventional planting system (30.94 t.ha^{-1}.year^{-1}), it was verified that these values are close to the ones found in this study.

4. Conclusions

The application of this methodology to calculate soil losses by erosion and the deposition by the measurement of ^{137}Cs activity seem to be quick and easy to be conducted. However, as far as the authors are aware, only the Nuclear Physics Applied Lab of the University “Universidade Estadual de Londrina (UEL)” has done this kind of analysis through scientific collaboration.

The results indicate large deposition of sediments in the valley, mainly on soils under soy crop.

This methodology can provide a better knowledge of soil movements in a hydrographic basin, and it can also allow the monitoring of soil movements in areas under different uses and management.

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Technical Notes

Comprehensive Methodology for the Evaluation of Clay Expansiveness. A Case Study

Domingo E. Delgado Martínez, Gilberto Quevedo Sotolongo

Abstract. Although expansive soils have been widely studied by different authors, just a few have made methodological proposals to comprehensively evaluate this phenomenon. The aim of this paper is to suggest a methodology which will serve as guideline to evaluate soil expansiveness in a comprehensive way. This methodology comprises a series of tasks: identification and classification of potentially expansive soils, estimation of the active zone depth, quantification of the expansion, calculation of heave and choice of a solution.

Key words: clay expansiveness, expansive soil, geotechnical investigation.

1. Introduction

Problems related to soils expansiveness are common worldwide (Jiménez Salas *et al.*, 1981 and Das, 2000), and Cuba is no exception (Monzón, 1976 and Delgado & Quevedo, 2002). The results of soil expansiveness (uplifting, cracking and failure in roads, light buildings, canals and dams) cause extensive damage and economic losses.

In Cuba, the volume of research and publications on the topic is disproportionately small, if compared to the number of problems caused by the phenomena associated to this type of soils. The importance of phenomena typical of expansive clays motivated this research, whose main objective is to apply a methodology to evaluate clay expansiveness in a comprehensive way so as to identify and quantify the problem and find a solution to it.

This methodology comprises the following tasks:

I) Identification and classification of the problem in order to determine whether potentially expansive clays exist, and if they do what degree of attention needs to be paid to them.

II) Estimation of the active zone depth to analyze the dynamic suction profile and predictable moisture changes in the expansive soil.

III) Quantification of the expansion to assess numerical values of deformational properties when the soils are sufficiently prone to volume change.

IV) Heave prediction to determine the potential vertical movement.

V) Choice of a solution to compare and assess alternative design solutions.

It is important to point out that this methodology is based on the premise that volume changes are the result of the soil's effective stress, as a consequence of either internal or external causes. From this point of view, the expansive nature of soils, mainly determined by the content of expansive laminar structure clay mineral, is a necessary condition, but not sufficient, for the phenomenon to occur.

2. Assessment of the Results Obtained with the Application of the Methodology. Case Study: Town of Crecencio Valdés

The main objective of this investigation was to evaluate the potential soil expansiveness in an area of the town of Crecencio Valdés, Cuba, where a day care center and a school were to be built (Delgado & Quevedo, 2002). This investigation was carried out in two stages: one, of preliminary investigation and the second, of detailed investigation. During the first stage, tasks I and II listed above were accomplished, while tasks III and IV were accomplished during the second stage. Task V was implemented during the project stage.

The experimental area is located in the northern coastal plains of the central region of Cuba, only 8 kilometers away from the coast, and less than a kilometer away from the right bank of the Sagua la Chica River.

2.1. Geotechnical investigations. Preliminary investigation stage

General geological and geotechnical data, necessary for the designer to preliminarily assess the construction economic and technical convenience, is collected in this stage. This data is based on previously obtained data and on the topographical data. Also, minimum field investigation was carried out in order to determine the soil physical properties and classification, among other characteristics.

Knowledge of the geotechnical soil profile is vital, and it was found to be:

0.0-0.30 m: Topsoil. Dark clayey material with a high content of organic matter;

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0.25-1.0 m: Highly plastic clay with little sand and no gravel, dark brown colour, eluvial-deluvial origin. Classification using the U.S.C.S.: CH (Layer 1);

1.0-5.5 m: Plastic sandy clay, brown to yellowish brown, with fine gravel and carbonate. Classification using the U.S.C.S.: CH-MH (Layer 2) Camacho Formation;

> 5.5 m: Limestones and dolomites of the Remedios Group. Water table position: 8.25 m.

2.1.1. Task I. Identification and classification of the expansiveness problem

The first step, and the most important, is observation. Through observation it was possible to detect clays of medium to high plasticity, a relatively high water table and the occurrence of a dry and a wet season. The existence of these characteristics suggests the presence of expansive soils, but so far it is not possible to determine whether they are active.

Also, superficial cracking was detected at the end of the dry season. The cracks were 60 cm deep and with a 4-5 cm maximum width, which is a clear evidence of the soil expansiveness when rehydrated.

Finally, the visual survey of the town (where approximately 75% of the houses were moderately or slightly damaged) and the inhabitants' comments sufficed to conclude that expansiveness problems indeed existed.

The second step is to consider the physical tests results as indicators of expansiveness. The physical test showed the existence of two fine soils with clay contents that ranged from 40.5% to 22%, low to medium natural water content mainly near the surface, low to high plasticity, and classified as CH and CH-MH according to the U.S.C.S. All these characteristics were a clear indication of expansiveness. Data obtained in previous investigations showed that the clays were esmectites with cation exchange capacity higher than 53 m.e./100 g, which warrants potential expansion.

Once the potential expansiveness is confirmed, the soil is identified and classified using a specific method for this. In this case a method was designed, which takes into account the characteristics of the Cuban soils. With this method, the natural water content (w_n, %), the liquid limit (w_{LL}, %), the clay content (C, %), the consistency index (I_c) and the dry density (γ_d, kN/m^3) are used to obtain the swelling indices, the final water content (w_f, %), the free swelling index (s_f, %), and the controlled swelling index (s_c, kPa). Table 1 shows the regression equations obtained to predict the soil swelling indices.

Although these equations allow a quantitative assessment of the swelling indices, they are only used in the investigation preliminary stages to classify the relative magnitude of the volumetric change. The following classification is recommended for this purpose (Table 2).

According to this method, layers 1 and 2 have a medium degree of expansion (see Table 3).

Table 1 - Regression equations.

N.	Regresion equation	Unit
1	$w_f = 0.92\ w_n + 16.29$	%
2	$w_f = 0.51\ w_{LL} + 8.85$	%
3	$\log s_f = 0.54 \log C + 0.67\ Ic - 0.39$	%
4	$s_f = 25\ \gamma_d + 14.3\ Ic - 38$	%
5	$\log s_c = 1.21 \log s_f + 0.66$	kPa

Table 2 - Classification of the degree of expansion.

s_f (%)	s_c (kPa)	Degree of expansion
< 4	< 25	
4-10	25-80	Low
10-22	80-200	Medium
> 22	> 200	High

Table 3 - Soil classification according to degree of expansion.

Soil	w_f (%)	s_f (%)	s_c (kPa)	Degree of expansion
Layer 1	41.0	15-17	130	Medium
Layer 2	36.6	10-11	85	Medium

So, by means of the observation, the physical tests and this method it was possible to make an accurate diagnosis of the problem and to determine the level of attention needed.

2.1.2. Task II. Estimation of the active zone depth

The active zone depth was obtained from the relation between natural water content and plastic limit (w_{LP}) versus depth (Z), and consistency index (I_c) and liquidity index (I_L) versus depth. The sampling was carried out at the end of the dry season and results are shown in Table 4.

These results prove that layer 1 is comprised within the active zone and in layer 2 the active zone (Ha) approaches 2.5 m. The indices show a water content deficit ($w_n/w_{LP} < 1.0$; $I_L < 0$ and $I_c > 1$), that is, the soil water content is well below the final water content up to a 2.5 m depth, where the suction profile begins to stabilize.

2.2. Geotechnical investigation. Detailed investigation stage

The results obtained in this stage allow the execution of the construction; therefore, the final data is to be very accurate and precise.

A number of investigation methods were used, the sampling was also carried out at the end of the dry season, and a series of tests were conducted to characterize the soil mechanically and physically.

Table 4 - Relation between depth and w_{ithin} / w_{LP}, I_L and I_c.

Depth (m)	Indices			
	w_n (%)	w_{ithin} / w_{LP}	$I_L \; \frac{w_n \quad w_{LP}}{IP}$	$I_c \; \frac{w_{LL} \quad w_n}{IP}$
Layer 1				
0.2-0.3	24.28	0.74	-0.25	1.25
0.4-0.6	25.63	0.78	-0.21	1.21
0.6-0.8	25.21	0.77	-0.22	1.22
0.8-1.0	24.97	0.76	-0.23	1.23
1.0-1.2	24.22	0.74	-0.26	1.26
Layer 2				
1.2-1.4	25.28	0.92	-0.08	1.08
1.6-1.8	25.47	0.93	-0.07	1.07
2.0-2.2	27.22	0.99	-0.01	1.01
2.4-2.6	27.61	1.01	0.01	1.01
3.0-3.2	29.59	1.08	0.08	0.92
3.4-3.5	30.63	1.12	0.12	0.88
3.6-3.7	30.99	1.13	0.13	0.87
3.8-3.9	33.19	1.21	0.21	0.79
4.0-4.1	34.59	1.26	0.26	0.74
4.2-4.3	33.43	1.22	0.22	0.78

2.2.1. Task III. Quantification of the expansion

Four tests were carried out in order to determine the swelling indices. These tests were the simple oedometer test modified by Ralph & Magor (1972) and the constant volume swell test (Sullivan & McClelland, 1969). Also, the data obtained from these tests was analyzed as if it was a two-embedded-samples oedometer test (Holtz, 1970).

The data obtained from the modified simple oedometer test are shown in Table 5, whereas the data obtained from the constant volume swell test appears in Table 6. The free swelling values shown in the tables correspond to the overburden pressure, while the probable swelling (s_{prob}) values were obtained under a 35 kPa pressure.

The two-embedded-samples oedometer test was not conducted, however, the data obtained from the modified simple oedometer test and the constant volume swell test were analyzed together as if it was the data obtained from the test proposed by Holtz (1970). The only condition for doing this was to use the same sample in both tests. The values in Table 7 are the ones obtained for the *C* curve[1], which is an approximation to volumetric change values for loaded embedded samples under an intermediate pressure, as required by the two-embedded-samples oedometer test.

Table 5 - Results of modified simple oedometer tests.

Layer	Indices			
	s_f (%)	s_{prob} (%)	w_f (%)	s_c (kPa)
1	14.0	4.8	39.21	142
2	11.9	3.1	36.89	84

Table 6 - Results of constant volume swell tests.

Layer	Indices			
	s_f (%)	s_{prob} (%)	w_f (%)	s_c (kPa)
1	12.4	3.5	37.69	150
2	10.2	2.1	34.90	90

Table 7 - Results of two-embedded-samples oedometer test.

Layer	Indices			
	s_f (%)	s_{prob} (%)	w_f (%)	s_c (kPa)
1	14.0	4.1	39.09	150
2	11.9	2.6	36.03	90

The free swelling values (12-14%) and the controlled swelling values (90-150%) correspond to those predicted in Table 3.

2.2.2. Task IV. Heave prediction

Once the soil expansiveness is quantified, it is necessary to calculate the active zone heave.

The proposed prediction method used the data obtained from the oedometric tests, specially the results of the two-embedded-samples oedometer test. The active zone was discretized using the sublayer method. The calculation was made taking into account a 0.8 m foundation depth, a 4 x 0.4 m superficial foundation beam, a 35 kPa pressure and a 1.7 m active zone depth. The results are shown in Table 8. The values of s_{prob} and Δe (change in void ratio) shown in the table correspond to the pressure acting on the foundation level.

The use of the two-embedded-samples oedometer test results and the method for the prediction of the active zone heave produced a more realistic evaluation of the phenomenon (S_{cal} = 2.19 cm). It is important to point out that it is possible to use the values obtained in the constant volume swell test when it is not possible to interpret the data as if it were a two two-embedded-samples oedometer test.

2.2.3. Task V. Choice of a solution

At this moment the designer is ready to analyze and compare different design alternatives and choose an adequate foundation solution.

1 The *C* curve is the fitting curve related to swelling pressure values obtained from the constant volume swell test and the free swelling values obtained from the modified simple oedometer test.

Table 8 - Active zone heave.

Test	Parameters and calculation of heave		
	s_{prob} (%)	Δe	Calculation method $h \frac{e}{1 \quad e_0}$ (cm)
Modified simple oedometer	4.8 3.1	0.091 0.064	2.61
Constant volume oedometer	3.5 2.1	0.066 0.044	1.79
Two-embedded-samples oedometer test	4.1 2.6	0.078 0.055	2.19

The analysis of design alternatives should begin with a comparison of the calculated heave (S_{cal}) and the angular distortion (tg p) with the limit values. Allowable limit (S_{allow}) values were obtained by Quevedo *et al.* (2001), and were reduced as suggested by the SNIP (1986). In order to adjust heave values to permissible values, the foundation depth was increased. Also, because of the soil profile homogeneity, similar acting loads, short spans, and safety measures to prevent the active zone wetting, together with the estimated foundation depth, angular distortion values were kept low, as required by the SNIP. Table 9 shows the results.

It is confirmed that the construction values adjust to allowable deformations, but lighter elements directly placed on the soil may be affected by heaving. Therefore, the solution was to act on the soil to avoid angular distortion and, consequently, damage to these elements.

The most important change made to the original project was to use a superficial foundation collar beam. Its depth was increased in 0.2 m (reaching 0.8 m), its width was reduced from 0,6 m to 0.45 m and compacted coarse aggregate with a 0.5 m width was used. Also, the excavation was carried out very fast and protecting the soil from desiccation and a 0.2 m sand and gravel layer was placed in all the construction area. Reinforced concrete beams were placed on block walls to stiffen them and the walls were reinforced in maximum stress points. Other measures were placing an asphaltic concrete perimeter, having the same width of the active zone (2.5 m), substituting the patio with a garden with a patio with lining, and using additional drainage solutions like placing the construction at a different height, using buried flexible connexions and piping (at 0.8 m) to keep them away from areas prone to volumetric changes.

Additional measures were also taken, which implied keeping the construction away from trees, forbidding the planting of trees at a distance shorter than 1.5 times the height of an adult tree, eliminating gardens to avoid water content variations, and keeping drainage systems at least 20 m away from the building.

Table 9 - Comparison of allowable deformations.

Calculated values		Limit values	
S_{cal} (cm)	tg p	S_{allow} (cm)	tg p
2.19	< 0.0001	10(0.25) = 2.50	0.002(0.5) = 0.001

3. Conclusions

• Soil expansiveness evaluation implies the implementation of tasks, which should be carried out in different stages, but should not be overlooked. The methodology applied in this case study proved to be effective.

• A comprehensive analysis of different physical properties of the soil is a reasonable indication of expansion, so the proposed identification and classification method provides realistic results.

• The modified simple oedometer test, the constant volume swell test, as well as the two-embedded-samples oedometer test can help to solve the problem of evaluating soil expansiveness.

• The active zone heave prediction using the results of oedometer tests and the discretization of the active layer using the sublayer method provide realistic evaluation of the phenomenon.

• The results obtained in this investigation showed that the proposed methodology can be used for the study of Cuban expansive soils, and it is flexible and precise enough to be generalized to other regions of the country.

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List of Symbols

w_n: natural water content (%)
w_{LL}: liquid limit (%)
w_{LP}: plastic limit (%)
IP: plastic index
I_L: liquidity index
I_c: consistency index
C: clay content (%)
γ_d: dry density (kN/m^3)
w_f: final water content (%)
s_f: free swelling index (%)
s_c: controlled swelling index (kPa)
Z: depth (m)
s_{prob}: probable swelling (%)
Δe: change in void ratio
Ha: active zone (cm)
h: heave (cm)
S_{cal}: calculated heave (cm)
tg p: angular distortion
S_{allow}: allowable limit (cm)

Classification of Municipal Solid Waste in the City of Rio de Janeiro Using the German Regulation E1-7 GDA

Cláudio Mahler, Ronaldo Luis dos Santos Izzo, André Vinicius Azevedo Borgatto

Abstract. The subject of this paper is the application of a morphological classification of MSW in the city of Rio de Janeiro based on the German recommendation DGGT (1994) – E 1-7 GDA. This recommendation deals with the identification and description of waste according to aspects of waste mechanics. This will give the environmental control agency and companies responsible for final waste disposal more comprehensive information about the geotechnical characteristics of the materials. First, the waste is described in relation to type, identification and its condition. After determining the type of waste, indications for analysis in groups of substances are obtained in a second step. The results have shown that in the Brazilian sample the percentage of waste with dimension 1 and dimension 2 is higher than 30% in weight, which is a favourable indicator in the MSW landfill analyses in view of stability. The results found using this classification furnish information for a better analysis of slope stability of MSW landfill by including the fibre reinforcement effects. It is also important for projects concerning waste recycling.
Key words: MSW, morphological classification, sanitary landfill, German regulation.

1. Introduction

In the past few years the world is becoming increasingly concerned with the Municipal Solid Waste (MSW) issue. In large metropolitan centers where there is a shortage of available space, the situation is even more of a problem. Accordingly, many attempts have been made to extend the lifespan of existing waste disposal areas. Common to these attempts is that due to the lack of knowledge of MSW characteristics and behaviour, harmful and unexpected consequences often arise. Slope stability problems in MSW landfills have occurred throughout world, including Brazil, such as, for example, a landslide in the Bandeirantes sanitary landfill in São Paulo city (Borgatto, 2006), in 1991. The purpose of this paper therefore is to adopt a morphologic classification of Brazilian MSW based on the German technical recommendation DGGT (1994) – E 1-7 GDA. The results found using this classification provide information for a better analysis of slope stability of MSW landfill by including the fibre reinforcement effects (Mahler & Neto, 2006). It is also important for projects for waste recycling.

2. Test Procedures

The first activity carried out was to identify the waste from the location where samples have been collected. In this identification, a characteristic of the waste is defined, which is not possible during collection. At this stage the following criteria have been considered:

- Amount of waste received (t/day);
- Class of waste;
- Origin of waste;
- Supply type;
- Estimate of waste homogeneity.

2.1. Sampling

For this research a fresh waste was chosen, before being sent to the landfill. The samples were collected in the MSW storage and redistribution shed of Comlurb (Rio de Janeiro City Urban Waste Collection Company) at Jacarepaguá, Rio de Janeiro, Brazil.

Once the samples were collected, they were taken to an external area where they were displayed on a plastic blanket inside a square formed by wooden rulers 2.00 x 2.00 m in dimension, in order to undertake the homogenisation and quartering process.

The sampling procedure was repeated until a sample was obtained with approximately the volume of a Comlurb standard container, namely, approximately 50 kg of MSW.

2.2. Physical characterisation

At the Comlurb field laboratory the following physical analyses were done:

- Determination of water content;
- Distribution of the substance groups according to the regulation established by the German DGGT (1994);
- Analysis of the piece sizes that comprise the groups of substances established by the German regulation DGGT (1994);
- Morphological classification by groups of substances established by the German regulation DGGT (1994).

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2.2.1. Water content

Upon collection, the buckets were weighed and then taken to the selection table for separation. After that the waste was placed in trays that were taken to the oven, staying there at a temperature of 70 °C for a period of time varying between 48 h and 72 h.

The water content of the samples was determined using this procedure. The water content was determined for each group of substance.

2.2.2. Segregation into substance groups

Segregation into groups of substances consists of separating the MSW samples as defined in German recommendation DGGT (1994). These are separated so that each group of substances has characteristics of similar materials with regard to mechanical behaviour and biochemistry stability. The groups of substances are:

• Large pieces: large waste substances, consisting of miscellaneous components, such as mobiles, mattress, etc;

• Paper/cardboard: waste substances basically consisting of paper or paper-like fibres, such as cardboard, paper packing, carpets, diapers, etc;

• Soft plastics: waste consisting basically of soft synthetic substances or with similar characteristics, such as soft plastic packing, plastic film, textiles, soft rubber, soft leather, etc.;

• Hard plastics: waste comprising basically hard synthetic substances, such as rigid plastic packing, PET bottles, rigid plastics, rigid leather, hard rubber, etc;

• Metals: ferrous metal and non-ferrous metal;

• Minerals: waste basically consisting of mineral substances or that has similar mechanical or biological behaviour (inert), such as glass, ceramic, soil, etc;

• Wood;

• Organic: waste that has natural origin, organic, *e.g.* vegetables, grass cuttings, plants, dry leaves, etc.

2.2.3. Morphological classification of the MSW

The morphological classification of MSW was based on the German recommendation DGGT (1994), intending to classify the waste with regard to its shape and size, according to relevant mechanical characteristics. Each group of substances was submitted to this geometric description considering the parameters observed in Fig. 1.

The MSW was also classified according to piece size. The fraction over 120 mm was visually separated and again visually separated into 500 mm and 1000 mm sizes. The remaining fraction was sieved according to the proceeding adopted for soils in accordance with the Brazilian technical regulation NBR-7181. Two sieves - 40 and 8 mm mesh - for large dimensions were used first. The fraction that passed was sieved into seven different diameter sizes in mm (38.1, 25.4, 19.05, 9.52, 4.75, 2.36 and 2).

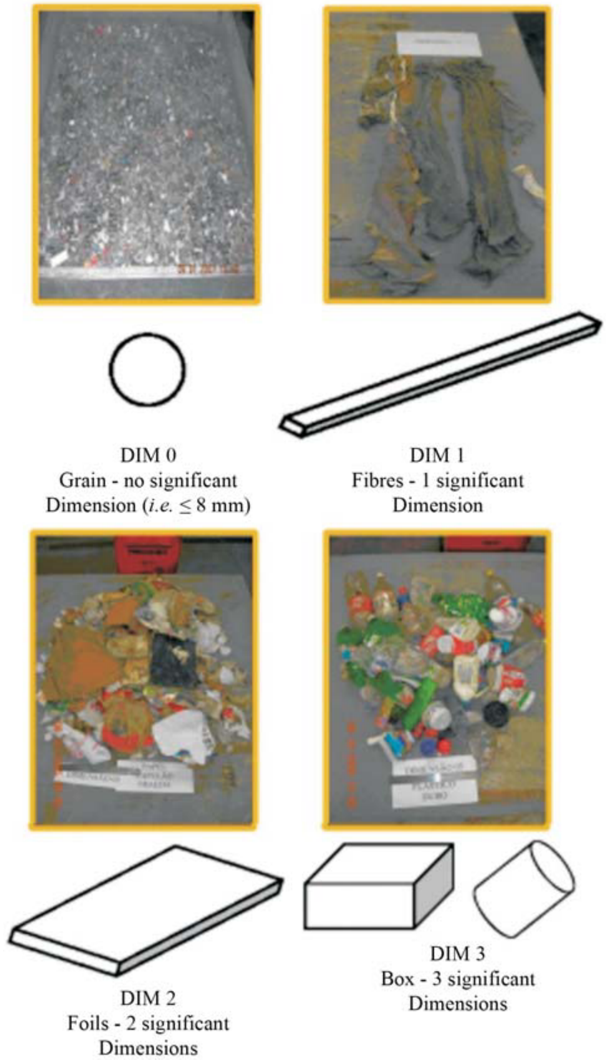

Figure 1 - Parameters considered in the morphological classification of the MSW.

3. Results

3.1. Classification into groups of substances

The values of the Classification into groups of substances are given in percentages of the total mass related to dry weight. The results are presented in Fig. 2.

3.2. Classification according to morphology

As described earlier, the classification according to the morphology is a combination of sieving and description of geometrical dimensions. The morphological classification of the substance groups is shown in Fig. 3. The results are also given in relation to the total dry mass of the sample.

For waste mechanics, in relation to the increases of shear strength, the percentage of fibre materials with dimension 1 and 2 (see Fig. 1) are more interesting because of the generated reinforcement. In analogy with reinforced

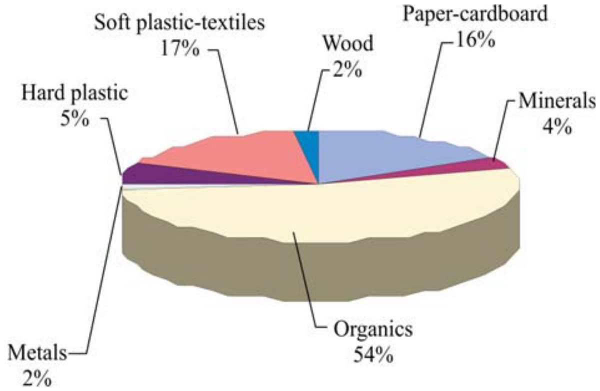

Figure 2 - Groups of MSW substances analysed.

soils, fibre concentration in the mass influences the gain in reinforcement.

In the soft plastics group it was found that the material with dimension 2 consists mostly (~76%) of plastic bags, plastic packing, textiles, and so on.

In the paper and cardboard group, dimension 2 comprises sheets of paper, cardboard, newspaper, crushed Tetra Pak type cartons, etc. (~65%). Dimension 3 consists of cardboard boxes, packing and other materials. One important point to be noted is that materials comprising the "dimension 3" group can, inside the landfill body, become dimension 2 materials because of crushing due to loading.

In the hard plastics group, the high percentage of dimension 3 is explained by materials such as PET bottles, different types of plastic packings, etc.

Again, as in the hard plastics group, the metal group shows a high percentage of dimension 3 materials, which is explained by the presence of food cans, vegetal oil cans, drink cans, etc.

The mineral group presented materials with dimension 0, such as small pieces of pottery and glass. The percentage of dimension 3 is represented in its majority by glass recipients.

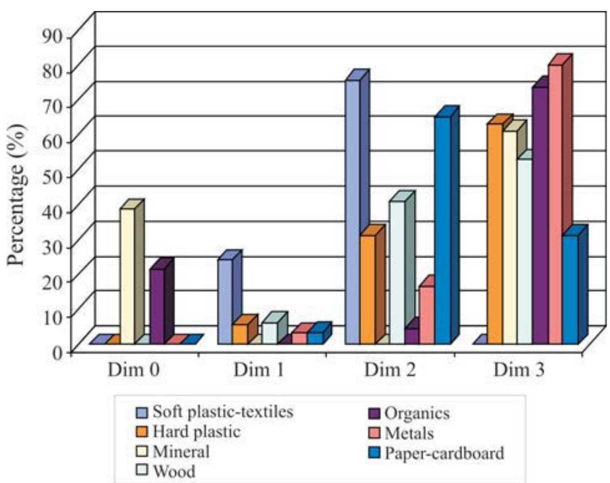

Figure 3 - Morphological classification of the MSW substances groups under study.

The wood group included materials such as wood veneers (dimension 2), boxes and crates (dimension 3).

The organic group includes remains of food and organics in general that, depending on their shape and size, were placed in group 0 and 3. The high percentage of dimension 3 is explained by the presence of bulky materials such as coconuts, oranges, and so on. Fig. 4 shows the sum of the obtained results for all the groups of substances.

By visually analysing the sample, the fraction of more than 120 mm was separated into 120, 550 and 1000 mm sizes. The waste was then passed through the 40 and 8 mm sieves. The passing fraction was sieved using small diameter mesh sieves to complete the process. The fraction of each sieving process of the substance groups is indicated in Table 1.

The total percentage of each group of substances was calculated as a percentage of each size divided by the percentage of each group of substance present in the MSW sample.

4. Conclusions

Important information was obtained through the MSW morphological classification. This information is very valuable for waste mechanics as it depends on the dimension and size of the waste particles. These MSW characteristics can be incorporated in slope stability analyses in order to take into account the effect of fibre reinforcement. The concentration and sizes of the fibres are compatible with those in fibre-reinforced soil, in spite of the different mechanical behaviour between soil and MSW.

The fibre materials responsible for the reinforcement effect on the MSW shear strength (materials with dimensions 1 and 2) presented a value (33.84%) at the concentration level for fresh waste (>30%), inducing the viability of potential fibre reinforcement effects.

Practice shows that a landfill can collapse because of many reasons such as, for example, high pore pressures inside the mass, poor compaction, fire, or a new building operation in the landfill. This is why fibre reinforcement should be considered only for back calculations of existing slopes and rupture back analyses. The fibre effect, such as

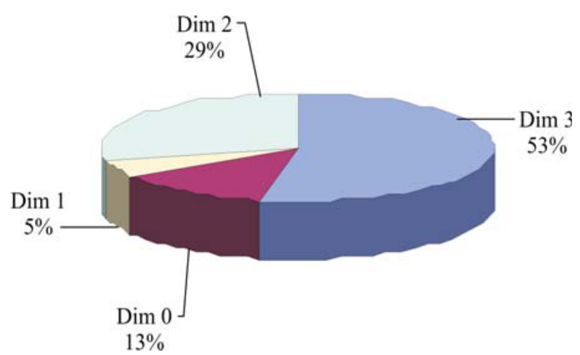

Figure 4 - Sum of results obtained from morphological classification of the studied MSW substance groups.

Table 1 - Results from the sieving process.

Group of subst.	Visual analysis			Sieves (% in retained weigh)							
	1000-500 mm	500-120 mm	120-40 mm	40 mm	8 mm	25.4 mm	19.05 mm	9.52 mm	4.75 mm	2.36 mm	2 mm
Paper cardboard	-	26.47	68.3	5.2	-	-	-	-	-	-	-
Soft plastic	23.57	41.43	34.13	0.9	-	-	-	-	-	-	-
Hard plastic	-	12.43	84.62	3	-	-	-	-	-	-	-
Metal	-	-	97.82	2.2	-	-	-	-	-	-	-
Mineral	-	24.56	31.78	10	6.9	4.8	3.6	5.7	3	5.8	3.5
Wood	-	10.12	76.34	14	-	-	-	-	-	-	-
Organic mater	0	0	21.45	17	12	6.9	9.4	7.7	8.3	8.5	8
Total (%)	4.12	13.09	36.66	11	7	4	5.3	4.4	4.7	4.9	4.5

suction in unsaturated soils, is an important characteristic of the waste. To plan new landfill areas and to use the maximum possible final slope this information should be used very carefully. For instance, in the event of internal combustion the fibre effect could be eliminated and the slope safety factor could decrease very quickly. Also, materials such as plastic, packing and textiles lose their tensile strength as time goes by at different velocities. At the same time they settle and have a higher specific weight leading to greater stability. This must be considered in the stability analysis. Therefore, the study of these phenomena can help in the near future towards a better understanding of the behaviour of the waste and to designing landfills with steeper slopes

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Instructions to Authors

Category of the Papers

Soils and Rocks is the scientific journal edited by the Brazilian Society of Soil Mechanics and Geotechnical Engineering (ABMS) and by the Brazilian Society of Engineering and Environmental Geology (ABGE). The journal is intended to the divulgation of original research works from all geotechnical branches.

The accepted papers are classified either as an Article paper, a Technical Note, a Case Study, or a Discussion according to its content. An article paper is an extensive and conclusive dissertation about a geotechnical topic. A paper is considered as a technical note if it gives a short description of ongoing studies, comprising partial results and/or particular aspects of the investigation. A case study is a report of unusual problems found during the design, construction or the performance of geotechnical projects. A case study is also considered as the report of an unusual solution given to an ordinary problem. The discussions about published papers, case studies and technical notes are made in the Discussions Section.

When submitting a manuscript for review, the authors should indicate the category of the manuscript, and is also understood that they:

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Manuscripts must be written in English. The text is to be typed in a word processor (MS Word or equivalent), using ISO A4 page size, left, right, top, and bottom margins of 25 mm, Times New Roman 12 font, and line spacing of 1.5. All lines and pages should be numbered. The text should be written in the third person.

The fist page of the manuscript is to include the title of the paper in English, followed by the names of the authors with the abbreviation of the most relevant academic title. The affiliation, address and e-mail is to be indicated below each author's name. An abstract of 200 words is to be written in English after the author's names. A list with up to six keywords at the end of the abstract is required.

Although alteration of the sequence and the title of each section may be required, it is suggested that the text contains the following sections: Introduction, Material and Methods, Results, Discussions, Conclusion, Acknowledgements, References and List of Symbols. A brief description of each section is given next.

Introduction: This section should indicate the state of the art of the problem under evaluation, a description of the problem and the methods undertaken. The objective of the work is to be clearly presented at the end of the section.

Materials and Methods: This section should include all information needed to the reproduction of the presented work by other researchers.

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Acknowledgenments: If necessary, concise acknowledgements should be written in this section.

References: References to other published sources are to be made in the text by the last name(s) of the author(s), followed by the year of publication, similarly to one of the two possibilities below:

"*while Silva & Pereira (1987) observed that resistance depended on soil density*" or "*It was observed that resistance depended on soil density (Silva & Pereira, 1987).*"

In the case of three or more authors, the reduced format must be used, *e.g.*: Silva *et al.* (1982) or (Silva *et al.*, 1982). Two or more citations belonging to the same author(s) and published in the same year are to be distinguished with small letters, *e.g.*: (Silva, 1975a, b, c.). Standards must be cited in the text by the initials of the entity and the year of publication, *e.g.*: ABNT (1996), ASTM (2003).

Full references shall be listed alphabetically at the end of the text by the first author's last name. Several references belonging to the same author shall be cited chronologically. Some examples are listed next:

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Proceedings (printed matter or CD-ROM): Jamiolkowski, M.; Ladd, C.C.; Germaine, J.T & Lancellotta, R. (1985) New developments in field and laboratory testing of soils. Proc. 11th Int. Conf. on Soil Mech. and Found. Engn., ISSMFE, San Francisco, v. 1, pp. 57-153.(specify if CD – ROM)

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Standards: ASTM (2003) Standard Test Method for Particle Size Analysis of Soils - D 422-63. ASTM International, West Conshohocken, Pennsylvania, USA, 8 p.

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Figures shall be either computer generated or drawn with India ink on tracing paper. Computer generated figures must be accompanied by the corresponding digital file (.tif, .jpg, .pcx, etc.). All figures (graphs, line drawings, photographs, etc.) shall be numbered consecutively and have a caption consisting of the figure number and a brief title or description of the figure. This number should be used when referring to the figure in text. Photographs should be black and white, sharp, high contrasted and printed on glossy paper.

Tables shall be numbered consecutively in Arabic and have a caption consisting of the table number and a brief title. This number should be used when referring to the table in text. Units should be indicated in the first line of the table, below the title of each column. Abbreviations should be avoided. Column headings should not be abbreviated. When applicable, the units should come right below the corresponding column heading. Any necessary explanation can be placed as footnotes.

Equations shall appear isolated in a single line of the text. Numbers identifying equations must be flush with the right margin. International System (SI) units are to be used. The symbols used in the equations shall be listed in the List of Symbols. It is recommended that the used symbols be in accordance with Lexicon in 8 Languages, ISSMFE (1981) and the ISRM List of Symbols.

The text of the submitted manuscript (including figures, tables and references) intended to be published as an article paper or a case history should not contain more than 30 pages formatted according to the instructions mentioned above. Technical notes and discussions should have no more than 15 and 8 pages, respectively. Longer manuscripts may be exceptionally accepted if the authors provide proper explanation for the need of the required extra space in the cover letter.

Discussion

Discussions must be written in English. The first page of a discussion paper should contain:

• The title of the paper under discussion in the language chosen for publication;

• Name of the author(s) of the discussion, followed by the position, affiliation, address and e-mail. The discusser(s) should refer himself (herself, themselves) as "the discusser(s)" and to the author(s) of the paper as "the author(s)".

Figures, tables and equations should be numbered following the same sequence of the original paper. All instructions previously mentioned for the preparation of article papers, case studies and technical notes also apply to the preparation of discussions.

Editorial Review

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