The observational method in geotechnics

La méthode observationnelle en géotechnique

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ABSTRACT

This paper presents the principle features of the Observational Method, lists the shortcomings of OM in EC7, and summarises how the OM should be applied across Europe within the design and contractual framework of an engineering project. This paper is based on a detailed study carried out under GeoTechNet, a European funded geotechnical forum site seeking to set the strategy for the geotechnical engineering sector on key issues that will affect European economies and businesses in the short, medium and long term. Details of the the work contained in this paper are presented with OM Case Studies of major projects in Europe, on the GeoTechNet web site (http://www.geotechnet.org) and in their publication "Innovative Design Tools in Geotechnics – Observational Method and Finite Element Method", published as Workpackage WP3.

RÉSUMÉ

Cette contribution présente les aspects principaux de la méthode observationnelle (OM); elle donne un aperçu des manquements de la méthode selon l'EC7, et résume la méthodologie pour son application en Europe, en considérant tant les aspects de dimensionnement que les aspects contractuels d'un projet. Cette contribution est basée sur une étude détaillée réalisée dans le cadre d'un projet européen de réseau thématique en géotechnique 'GeoTechnet'. L'objectif de ce projet, subsidié par la Commission Européenne, était de déterminer les priorités de recherches et développements technologiques en Europe et pour différents thèmes de la géotechnique, et ceci à court, moyen et plus long terme.

Le contenu de cette contribution est présenté plus en détails au travers de cas pratiques d'application de la méthode observationnelle dans des projets majeurs en Europe sur le site internet du réseau GeoTechNet (www.geotechnet.org), ainsi que dans le rapport «Innovative Design Tools in Geotechnics – Observational Method and Finite Element Methods» publié sous l'initiative du Workpackage WP3.

1 INTRODUCTION

In 2002, a European geotechnical forum was set up for the exchange of best practice ideas and innovations in geotechnical engineering called GeoTechNet (http://www.geotechnet.org). This forum was European funded and Workpackage WP3, concentrated on the use and harmonisation of Innovative Design Tools in Geotechnics across Europe, a document which has recently been published by GeoTechNet, 2006. This publication sets out how the application of the Finite Element Method and Observational Method (OM) can produce savings in cost and programme on engineering projects, without compromising safety, and how it can also benefit the geotechnical community by increasing scientific knowledge. Seven Case examples from major European projects where OM was implemented are presented on this website.

This study also highlighted the shortcomings in the implementation of OM in Eurocode EC7 (EN1997-2004). It also showed that there was a general lack of understanding on the principles of the use of OM, its use within the contractual framework of an engineering project and the important responsibilities incumbent on the client, designer and contracting teams when implementing the OM approach on a project.

This paper focuses on the key issues described above and the reader is also asked to look at the accompanying Case Studies of the OM applied to European projects, presented on the website (but not in this

Table 1. Comparison of the predefined design process and the Observational Method

Predefined Design Process	The OM Process
• Permanent works	• Temporary works
• One set of parameters	• Two sets of parameters
• One design/predictions	• Two designs and predictions
• Outline of construction method	• Integrated design and construction methods
• Contractors temporary works design/method statement	• Methods relate to triggers
• Monitoring checks predictions not exceeded	• Comprehensive and robust monitoring system
• If checks are exceeded, consider	• Review and modify process
(a) Best Way out approach to design; or	– Contingency plan
(b) redefine the predefined design approach reassessing the geotechnical uncertainties in the ground, see Table 4	– Improvement plan
• Emergency plan	• Emergency Plan

paper), which show the benefits in cost and programme afforded to Clients.

2 COMPARISON BETWEEN TRADITIONAL DESIGN VS OBSERVATIONAL METHOD DESIGN

Traditional ground engineering projects are usually based on a single, fully developed, robust design and there is no intention to vary the design during construction. Instrumentation and monitoring may also be carried out but it plays a very much **passive** role to check original predictions are still valid and provide confidence to third party checkers eg designers for adjacent building owners affected by a development. In recent work on OM, published by Construction Industry Research and Information Association's Report 185 (CIRIA, 1999), this traditional design approach is termed "predefined design".

In comparison, in OM the monitoring plays a very much **active** role in both the design and construction, allowing planned modifications to be carried out within an agreed contractual framework that involves all the main Parties (client, designer and contractor). The differences in the two design approaches are also illustrated in Table 1 below.

Peck set out the Observational Method in his 1969 Rankine lecture and defined two OM approaches:-

a) "*Ab Initio*" approach, adopted from inception of the project;
b) "*Best Way Out*" approach, adopted after the project has commenced and some unexpected event has occurred that is different to the predefined design or failure occurs, and where OM is required to establish a way of getting out of a difficulty.

Case examples presented on the GeoTechNet site give examples of both the "*Ab Initio*" and "*Best Way Out*" OM approaches. A paper by Nicholson et al. (2006) provides a structural framework on how the "Best Way Out" approach to OM can be used for recovery of deep, multistage excavation projects when problems occur during construction as that which occurred at Nicoll Highway, Singapore, 2004. The Best Way Out approach to OM is described in detail in Section 6 of this paper.

2.1 *Differences between Peck and CIRIA approach to OM*

The CIRIA approach to OM is different to Peck's method and this is explained below as it is an important factor when choosing the OM. Peck adopted the "most probable" design and then reduced the design to "moderately conservative" soil parameters, where triggers were exceeded. CIRIA on the other hand considers a "safer" approach to design by adopting a "**progressive modification**" of the design starting with the design based on moderately conservative parameters, and then reverting to most probable conditions through field observations (ref Powderham and Nicholson, DP (1996)).

2.2 *OM Definition*

The best definition of the OM approach is described in CIRIA 185 (1999) in Table 2.

Table 2. OM Definition (CIRIA 185)

"*The Observational Method in ground engineering is a continuous, managed, integrated, process of design, construction control, monitoring and review that enables previously defined modifications to be incorporated during or after construction as appropriate. All these aspects have to be demonstrably robust. The objective is to achieve greater overall economy without compromising safety*." CIRIA 185 (1999).

3 FUNDAMENTALS OF OM IMPLEMENTATION AND BENEFITS

3.1 *General*

The implementation of OM in construction requires an integrated approach to the design and construction process as well as close management cooperation amongst the whole Project Team, including the client. This approach is fundamentally different to the traditional design approach where designs are based on "moderately conservative" parameters (CIRIA 185) or "characteristic values" of parameters (defined in Eurocode 7:2004) and where emergency plans are rarely activated, unless an impending failure is likely.

In OM, the modification of moderately conservative predefined design to the "most probable" (most likely situation) reduces the margin against structural failure and therefore greater site controls are necessary, balanced by rigorous monitoring and establishment of proper contingency plans before the OM is implemented. The construction works also has to be flexible and be able to easily accommodate any changes in design or programme, necessitated by any implementation of contingency plans.

Eurocode EC7 does not define the framework to be followed when adopting OM and there are other drawbacks which if strengthened may result in a wider use of OM in Europe. This is explored below.

3.2 *OM drawbacks in Eurocode EC7 (2004)*

The OM method described in Table 4 of EC7 has been reproduced in Table 3 below to illustrate the main drawbacks, which are as follows:

a) it is primarily aimed at the ab initio approach to OM, although it does not exclude the "best way" out application of OM;
b) whilst it refers to "acceptable limits of behaviour" it does not define how these may be derived, since EC7's premise for design is based on use of "characteristic values" or moderately conservative geotechnical parameters which present a lower cautious limit in design, but not the upper limit to represent the most likely behaviour ie most probable case needed to implement the OM approach;
c) no trigger limits are defined to establish planned contingency actions to check behaviour;
d) there is no operational framework described to manage OM within a contract, neither within national policy or project organisation.

Observational Method

(1) When prediction of geotechnical behaviour is difficult, it can be appropriate to apply the approach known as "the observational method", in which the design is reviewed during construction.

(2) The following requirements shall be met before construction is started:

— acceptable limits of behaviour shall be established;
— the range of possible behaviour shall be assessed and it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits;
— a plan of monitoring shall be devised, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully;
— the response time of the instruments and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system;
— a plan of contingency actions shall be devised, which may be adopted if the monitoring reveals behaviour outside acceptable limits.

(3)P During construction, the monitoring shall be carried out as planned.

(4)P The results of the monitoring shall be assessed at appropriate stages and the planned contingency actions shall be put into operation if the limits of behaviour are exceeded.

(5)P Monitoring equipment shall either be replaced or extended if it fails to supply reliable data of appropriate type or in sufficient quantity.

Table 3 Eurocode 7, Table 4 clause 2.7 (2004)

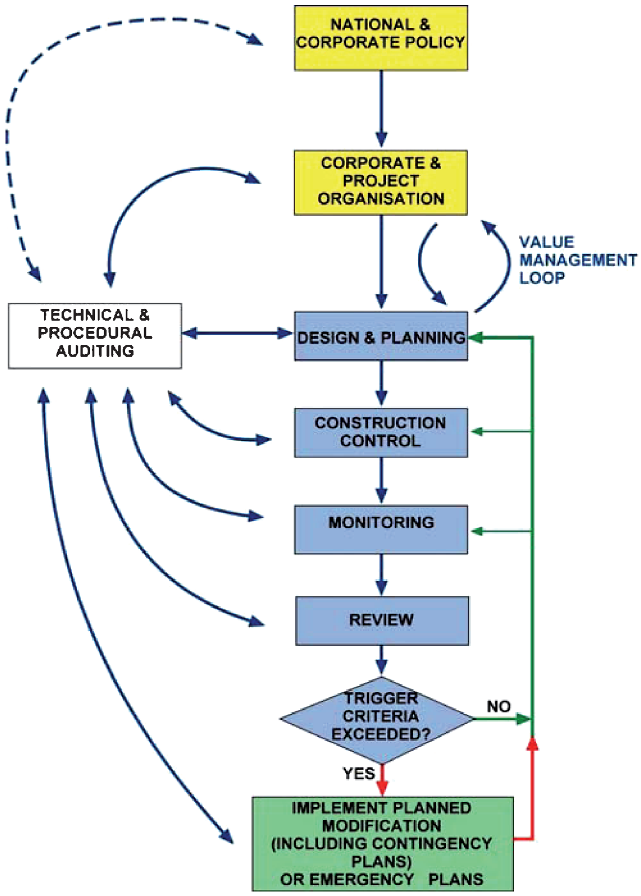

Figure 1. The Observational Method (CIRIA 185, 1999).

This paper provides details on how to strengthen the OM method described in EC7 by reference to published sources such as CIRIA 185.

3.3 *Operational Framework for following OM*

The operational framework for implementing the Observational Method (as described in CIRIA 185) is illustrated in Figure 1.

The OM has to be carried out within the framework of any national and corporate policies governing design codes, specifications, quality management sys-

Table 4. Examples of uncertainty in the ground

Geotechnical Uncertainty	Example
Geological	Complex geology & hydrogeology
Parameter and modelling	Undrained soil verses drained behaviour
Ground treatment	Grouting, dewatering
Construction	Complex temporary work

tems and health and safety (eg in the UK this is Health and Safety (HSE) regulations, and Construction Design & Management (CDM) Regulations, 1994). This is represented by the upper box in Figure 1.

The second box defines the structure of the key players in the stakeholder's organisation (the client, designer, contractors, 3rd party checkers and other inspectors), their roles and responsibilities, and the relationship between organisations and the individuals.

This needs to address the culture of each organisation, the level of staff training, experience, openness to communication, and management commitment to implementing the OM approach. The stakeholders also need to "buy-into" the technical and commercial risks should any planned contingency or emergency measures need to be implemented. This would also include buy-into any overall impact on programme or cost, should the planned contingency measures need to be implemented.

Once the OM is agreed at "Project Organisation" level, the remaining boxes describe the management structure required to implement OM at both Design and Construction stage and to control the Monitoring and Reviewing aspects of the Observational Method. The works have to progress to an agreed plan, with risks being recognised.

Daily construction progress has to be under the control of a management structure that ensures any deviation from the method is fully thought through and covered by an amendment to the plan. A monitoring regime has to be set in place, with competent staff made available to check, review and respond to all monitoring results within a given timescale from when they become available. There then needs to be clear instructions to all involved for all foreseeable situations. Finally, contingency plans need to be in place that can be rapidly implemented should preset "trigger" limits be breached or any other unforeseen situation develop.

"Auditing", preferably by an independent geotechnical firm, is essential as it checks that the OM designer and Project Team are following established procedures and reaching the correct technical interpretations. Ideally this should be carried out by a designer that is unconnected with the OM process.

3.4 *OM management process on site*

At site level, there are usually many layers of contracting organisations involved in a project and all the main players need to (a) buy into the OM process and (b) have clearly defined responsibility level. An example of the interaction between these organisations and the **managed** reporting of the construction and monitoring process is illustrated in Figure 2.

Figure 2 also shows the traffic-light system of green, amber and red trigger levels, the interaction between the various parties within this traffic-light system, and those tasked with the responsibility for carrying out the planned modifications or contingency plans. This site management structure illustrates that successful OM relies on establishing a coordinated team implementing an integrated process.

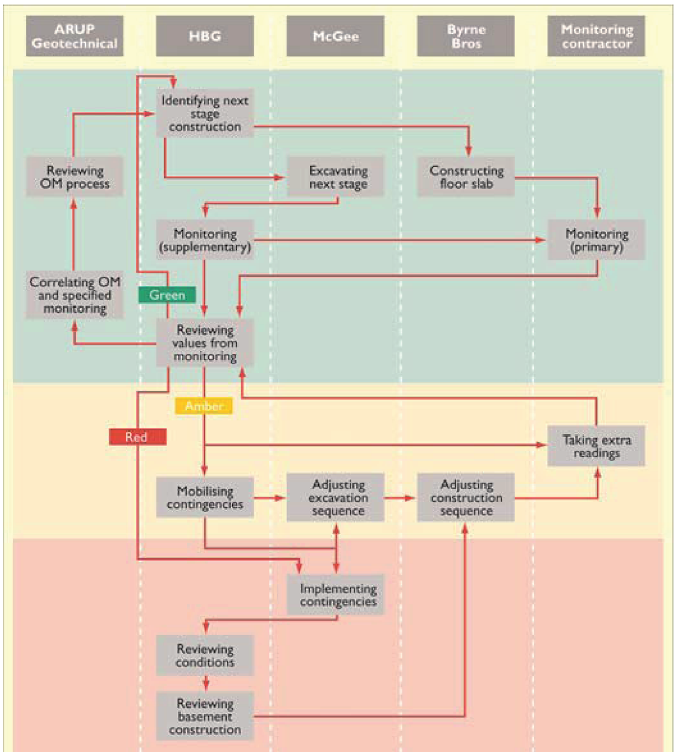

Figure 2. OM management process on site (ref Fenchurch St, http://www.geotechnet.org).

On this particular deep basement project the organisations concerned with implementing OM were as follows:

- OM designers and reviewers (Arup Geotechnics)
- Main or Principle Contractor (HBG Ltd)
- Substructure groundwork's contractor (McGee Ltd)
- Substructure concreting contractor (Byrne Bros)
- Instrumentation and monitoring contractor (SES Ltd)

It can be seen that the Principle contractor had a major role in managing the OM process with his trade subcontractors.

3.5 *Benefits of the Observational Method*

The OM offers potential savings of time and money and the monitoring provides the needed assurance concerning safety. Some potential benefits of OM are illustrated in Figure 3 and seven detailed case examples of the benefits provided to clients is described in WP3 http://www.geotechnet.org, and the accompanying publication of this work by GeoTechNet.

4 OM CONCEPTS AND DESIGN

A number of national documents referring to the use of OM were examined (including EC7) as part of this study:

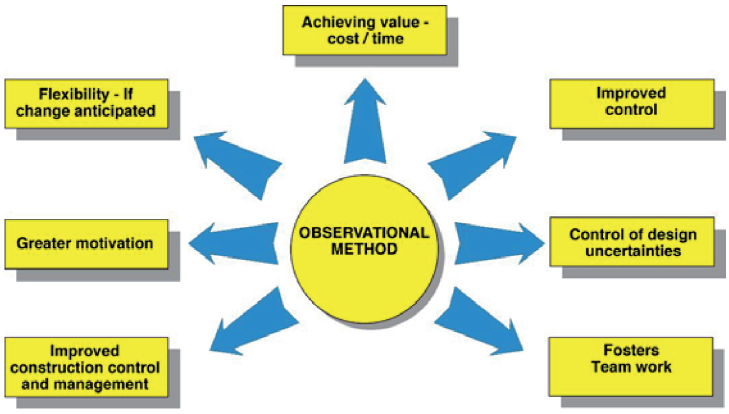

Figure 3. Some potential benefits of the OM (CIRIA 185).

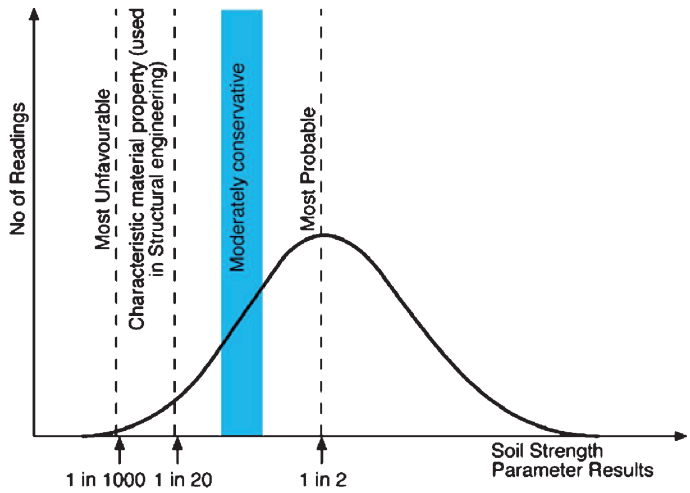

Figure 4. Types of soil strength parameters (CIRIA 185).

a) France - La Methode Observationnelle pour le dimensionnement interactif des ouvrages" (2005);
b) section 4.5 of the German Standard DIN 1054:2005-1 Verification of the safety of earthworks and foundations; and
c) Dutch CUR document 166: sheet pile construction.

These documents lack details on some of the main features of the OM process such as an understanding of contracts, when to use it or not, selection of design soil parameters, factors of safety, the concept of introducing traffic-light system to establish behaviour and planned modifications of the design. These issues are discussed below and comparisons are made against existing standards and EC7.

4.1 *Uncertainty and serviceability*

The OM is most effective where there is a wide range of uncertainty.

Table 4 summarises the types of uncertainty that are often encountered in geotechnical projects:-

The OM approach is not suitable where there is a possibility of a "brittle" behaviour in the structure or rapid deteriation in the materials which does not allow sufficient warning to implement any planned modifications (ie "discovery – recovery" contingency plans to be used). Examples of such are rapid deteriation of soils caused by groundwater or non-ductile failures of structural members (struts/waling connections) in multi-propped basements.

4.2 *Selection of design soil parameters*

Where there is a wide range of uncertainty in the soil parameters the OM process in CIRIA 185, uses the terms "most probable" and "most unfavourable" to describe the range of soil conditions as illustrated in Figure 4.

The "most probable" is a set of parameters that represent the probabilistic mean of all the data, although a degree of engineering judgment must be used in assessing this to take account of the quality of the data. The "most unfavourable" parameter represents the 0.1% fractile of the data as shown on Figure 4, and this represents the worst value that the designer believes might occur in practice.

The moderately conservative parameter (CIRIA 185) or "characteristic value" of geotechnical parameters (defined in cl 2.4.5.2 EC7) represents an "cautious estimate of the value affecting the occurrence of the limit state", and should ideally result in prediction of the upper 5% fractile of the **measured deflections** as shown in Figure 5.

The moderately conservative parameter is therefore not a precisely defined value. It is a **cautious estimate** of a parameter, worse than the probabilistic mean but not as severe as the most unfavourable as shown on Figure 4.

In assessing these parameters the designer should carefully consider the quality of the site investigation data and assess its appropriateness for use in the OM approach. Often the original data may be appropriate for a more robust "predefined design" approach but may not be of a higher quality for purposes of implementing OM.

4.3 *Serviceability and ultimate limit state prediction*

When designing to EC7, checks are required to ensure that the following ultimate limit states (ULS) are not

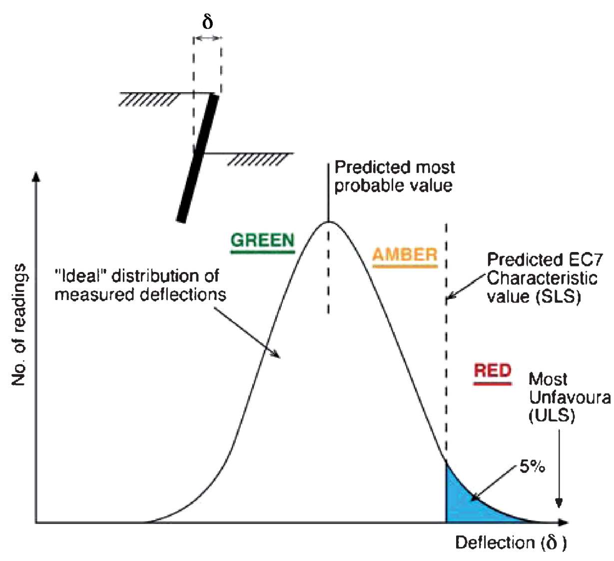

Figure 5. Ideal EC7 Predicted versus Measured Performance.

exceeded:

- Loss of equilibrium of the structure or the ground;
- Internal failure or excessive deformations of the structure or structural elements;
- Failure or excessive deformations of the ground due to loss of strength;
- Loss of equilibrium of the structure or ground from uplift water pressures;
- Hydraulic heave, internal erosion and piping of ground caused by hydraulic gradients.

Codes such as EC7 also require checks on "serviceability" limit states (SLS); states which are less serious than ULS but which are nevertheless undesirable and would need intervention or repair. In predefined designs, calculations used to check these states use "characteristic values".

In OM, the acceptable limits of behaviour, is a "serviceability" calculation, made using both the "most probable" and "characteristic" parameters and conditions. These provide the predictions against which the field performance can be monitored and reviewed. Trigger values can be established and contingency plans introduced as shown in Figure 5 and Table 5.

The OM approach illustrated in Figure 5 is for a cantilever wall design. The green, amber and red zones represent the trigger limits or traffic light control system used in OM. The precise deflections set for the trigger values will depend on the "discovery – recovery" contingency plans being used and not simply from the calculated values of predictions made.

In respect to ULS predictions, EC7 identifies three sets of partial factors to apply when assessing the ultimate limit case. These partial factors are applied to "characteristic values" of the ground but in essence the ULS design values are then similar to the most unfavourable conditions. Although for example in retaining walls, the ULS predictions are used for assessing structural forces, moments and shear, the ULS deformations of the wall can also be a useful guide to determining the maximum predicted movements in the red zone. This "upper limit" of wall deformation (or curvature) can provide a useful input when developing emergency plans of unexpected behaviour in OM and also with the "best way out" approach in OM, provided the problem has been identified in time to implement a disaster and recovery plan well before a ULS condition occurs, and with due regard to safety.

Table 5. Definitions of most probable, characteristic values and most unfavourable.

Most Probable	50% likelihood of movement predictions being exceeded
Characteristic Values (EC7) or moderately conservative (CIRIA185)	5% likelihood of movement predictions being exceeded
Most unfavourable (CIRIA 185)	0.1% likelihood of movement predictions being exceeded

After CIRIA 185.

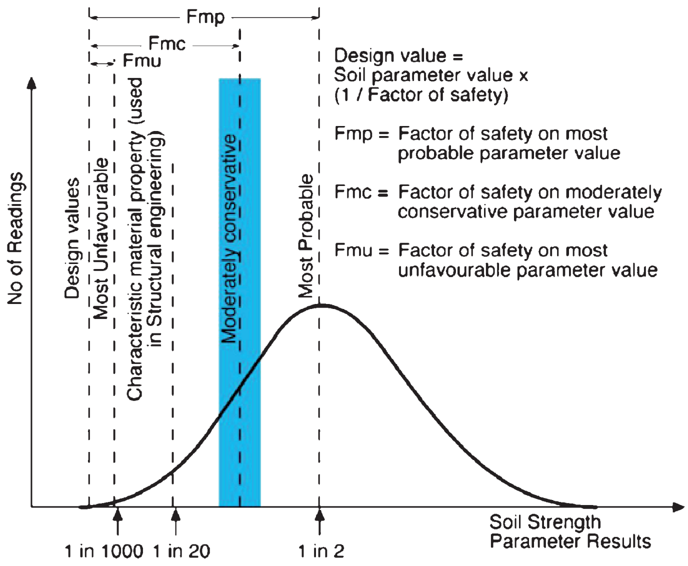

Figure 6. Application of factors of safety to different types of design soil parameters (CIRIA 185).

4.4 *Factors of safety*

The design values for ULS (stability) calculations are chosen so that the probability of failure will be acceptably small. It should be noted that the intent of OM is to take out uncertainties in the ground (see Table 4), **not reduce factors of safety**, when assessing the ultimate limit state condition in design.

UK standards including some European countries, have traditionally applied "factors of safety" on the design soil parameter, which can vary depending on the type of foundation and type of redistribution of load in the ground (eg for piled rafts). EC7 on the other hand, applies partial factors on the characteristic value of the ground parameters. Figure 6 illustrates how the two approaches can produce different factors of safety and how it can vary for different assumed design soil parameters.

4.5 *UK contractual model and safe Design*

In the UK, there are essentially two forms of main design contracts:

a) The Client appoints a consulting practice to carry out the permanent design ("**Engineer design**") and the contractor is responsible for carrying out the specified works. In this form of contract the contractor is only responsible for any temporary works design required to complete the permanent works; or
b) The Client appoints a "**Design and Build**" contractor to complete the design based generally on an outline or scheme design performed by a consulting engineering firm.

Other variations to this also occur where a Construction Manager or Project Manager is appointed by the Client to provide programme/cost input.

The OM process can be applied too both forms of contract. In both cases the Design Product comprises:

1. Drawings;
2. Work specifications and Bills of Quantities; and
3. Calculations;

In addition to this, the UK Construction (Design and Management) **(CDM)** Regulations (1994) places new duties on the client, designers and contractors to take health and safety into account in both the design and construction of the Project. For the designer this means that the design is no longer a set of calculations but must also:

- address Buildability issues
- identify hazards and risks in respect to safety
- eliminate hazards through good design or, where it is not possible, to reduce the risk to a low level
- show how this process has evolved in the design by producing a "Risk Register"

The new regulations are intended to produce stronger links between the design and construction via:

- production of "Heath and Safety Plans" by both the engineer and contractor; and
- appointment of a Planning Supervisor by the client, who vets these plans before and during construction

Therefore, the CDM Regulations are in line with the OM objective of integrating the design and construction process. From work carried under Work package WP3 of GeoTechNet, the UK contractual model with appropriate CDM Regulations and risk assessments do not exist in Europe. It is concluded that the CDM model adopted in the UK creates a stronger link between designers and contractors and reassures the Client of the importance of safe working design and might benefit European countries.

4.6 *Rapid deteriation*

In certain engineering situations, rapid deteriation can be controlled by modifying the construction sequence as follows:

1. **Using the multi-stage construction process** – for instance, an example may be embankment construction over soft clays. In this situation a rapid deteriation in the factor of safety can be controlled by "staged" filling, between rest periods, using monitoring to control when the next lift is done (an example of this is given in Figure 7).
2. **Using the incremental construction process** – for instance, an example may be in NATM tunnelling work, where the rate of advancing the tunnel face and controlling face loss is a critical component in determining how the ground movements are controlled in the discovery- recovery programme, see Figure 8 using the traffic light system described above. This figure shows that the later the problem is discovered, the higher the risk and the longer the structure remains in a state of reduced stability (in red zone). Late instigation of decision making and recovery would also have the same effect.

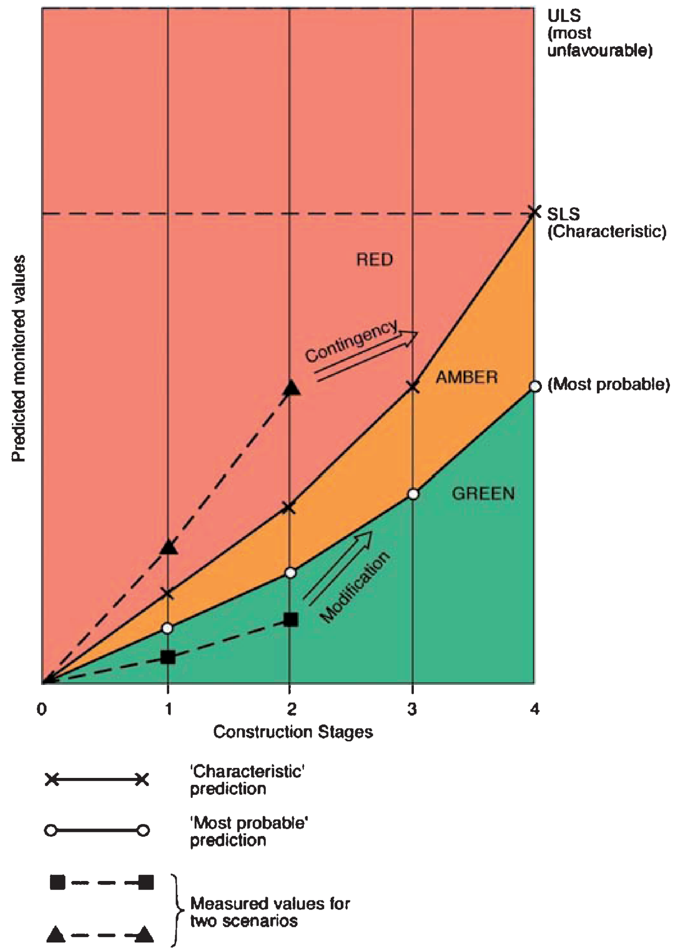

Figure 7. Multi-Stage construction trigger values.

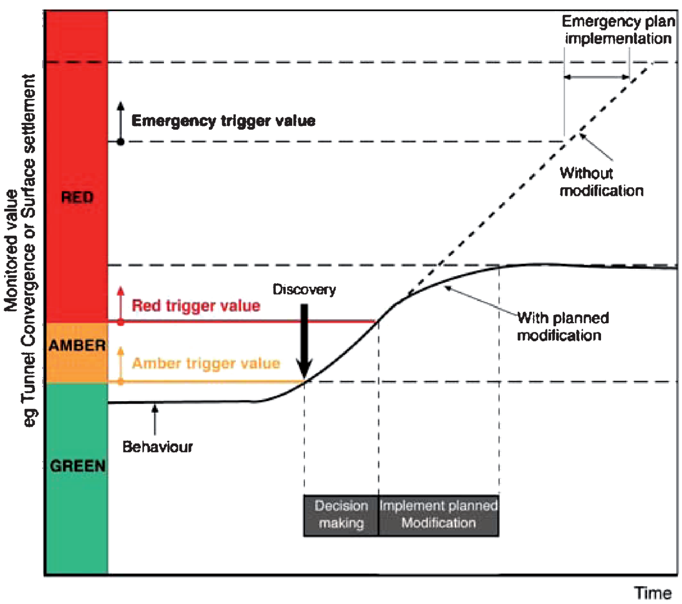

Figure 8. Traffic light system for an incremental excavation process (CIRIA 185, 1999).

The importance of early decision making to instigate actions for recovery is an important feature of the UK Health and Safety Executive (HSE, 1996- Fig 16) Discovery-Recovery model, and is a legal requirement for use on all UK construction sites. The use of

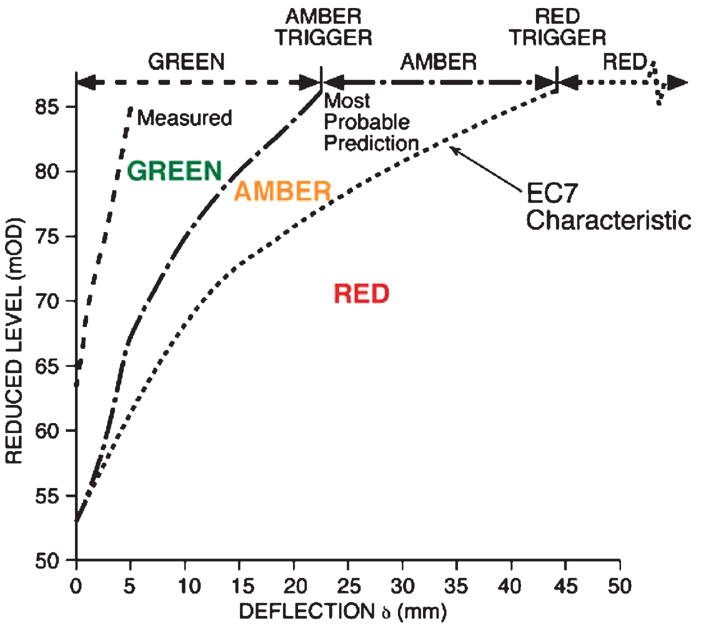

Figure 9. Example of trigger limits in retaining walls.

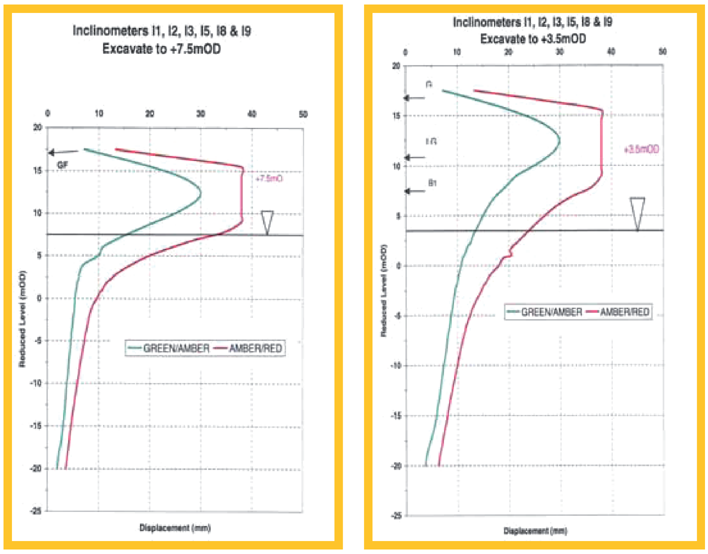

Figure 10. Example of predicted basement construction movements at various excavation stages for Quality Plan.

trigger values described below, an essential feature of OM, can also be used in the "predefined designs", to allow sufficient time for implementation of emergency measures when monitoring is being used.

5 IMPLEMENTATION OF PLANNED MODIFICATIONS

5.1 *Trigger values*

The Observational Method uses a "traffic light" system with green, amber and red response zones:

- *green*—continue construction
- *amber*—continue with caution and prepare to implement contingency, increase rate of monitoring
- *red*—stop progress, do everything possible to slow movements, implement contingency

These are linked to the "most probable" (green–amber limit) and the "characteristic values" (amber–red limit) for implementation of the planned modifications in OM, as illustrated in Figure 5, 7 and 8.

A further example, for use with cantilever retaining wall movements is illustrated in Figure 9 below. It can be seen that in this example the measured movements were also well below the most probable conditions.

5.2 *Monitoring systems*

Monitoring systems will vary depending on the type of construction project in which the OM is implemented. It is also very important to define both "Primary" and "Secondary" monitoring systems in OM. For example in multiprop deep basements, the primary system (eg inclinometers/electrolevels) may be the main instruments relied upon to allow implementation of any contingency measures in OM, whilst the secondary system (eg 3D targets or leveling at top of walls and surrounding ground) might be a more frequent and fast monitoring system to quickly assess the progress of the excavation works and aid a broader understanding of the pattern of ground movements on a site. An essential part of OM, is that the primary system needs to be immediately repaired if damaged on site, to ensure that OM can be continued.

5.3 *OM Quality Plans*

It is essential to have a Quality Plan before implementing OM on a site. This plan would show the designers movement predictions based on the defined construction sequence. Each stage of construction sequence should also show the acceptable limits of predicted behaviour using the traffic-light system described above. Simple graphical outputs, that the whole Project Team can understand, are essential and an example of this is illustrated on Figure 10 for a deep basement excavation in London.

This plan informs the Project Organisation and more importantly the project site team of what is likely to happen during each excavation stage and aids when implementation of the contingency measures is required, if any.

5.4 *Constructional Control*

Successful construction control is a vital part of the Observational Method; the main process is as follows.

- A construction control proforma is used to record all details of construction operations, strengths of materials exposed during staged excavations, the fabric and structure of exposed materials and the deterioration of surfaces exposed to water, see example of cutting Figure 11;
- This control has to be fully integrated within the project team and simple easy to read graphical outputs are essential for informed decisions to be made;
- Each process has to have a process owner, with certain levels of responsibilities and implementing of actions.

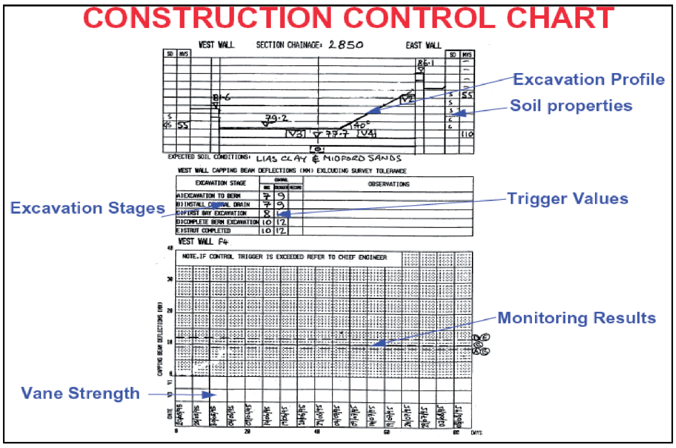

Figure 11. Example of construction control proforma sheets on site prepared by a contractor.

6 "BEST WAY OUT" APPROACH IN OM

The "best way out" is used when monitoring checks in a predefined design exceeds predicted values but before an emergency condition is reached, see Table 1. This would then trigger an "**Initial Recovery Decision Making**" stage as described in Figure 12.

In all cases this will result in stopping work and/or implementing emergency planned measures to secure the safety of site staff and the general public while the unexpected event is fully investigated. This assessment will inevitably be somewhat qualitive rather than quantitative as decisions would need to be made rapidly at this initial stage.

Once the safety of the site has been secured, the project team can then turn their attention to recovery of the project back to a fully stable condition which means first carrying out a "Design Review Process" of the unexpected event, by backanalysis of the actual conditions and comparison with the original design. This process can be broken down into four processes (RADO) shown in Figure 12 and summarised in section 6.1 below.

Following this design review, the project team can then consider the following two stages:

- Whether to initiate OM "Best Way Out", in which case this approach would follow the OM framework illustrated in Figure 1 and described in this paper, or
- Consider a complete redesign based on a traditional, but revised, pre-defined design.

6.1 *Four processes of design review(RADO)*

6.1.1 *Process R- data collection and review*

This process involves collecting all available data to define the behaviour of the structure for use in the backanalysis. Particular emphasis should be placed on understanding the actual conditions and behaviour operating in the field, rather than justifying the original design assumptions. Sources of data should include: soils data and stratigraphy; construction records; actual sequence of events to inform back

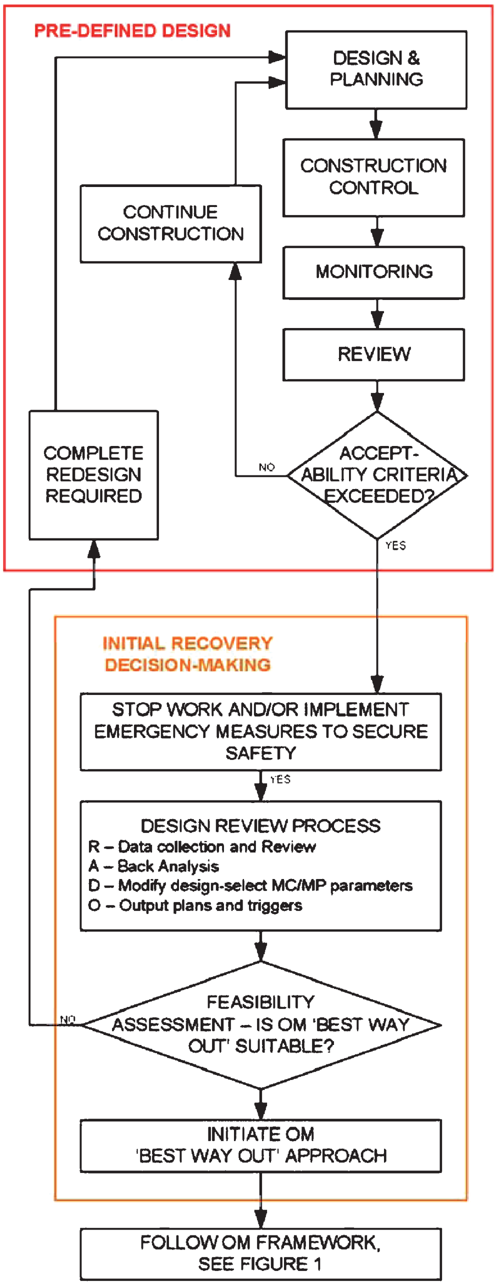

Figure 12. "Best Way Out" Operational Framework.

analysis process; and observations and physical measurements leading up to the unexpected event.

6.1.2 *Process A: Backanalysis*

The purpose of this process is to refine the designers understanding of the actual behaviour of the structure and reduce uncertainty in the design. The process involves: establishing most probable parameters; developing a satisfactory model using MP parameters; comparing results with monitoring data and field observations; reviewing/revising parameters if good agreement is not achieved; and once a reliable model has been produced, proceeding to design.

6.1.3 *Process D – Verify/modified design*

This process involves predicting the future behaviour using the realistic model and set of parameters developed from backanalysis, for the remaining construction stages, but adopting a level of conservatism in to the model. The structure behaviour should adopt moderately conservative (characteristic) parameters for the serviceability design and “Worst Credible” or factored parameters for stability checks.

6.1.4 *Process O: Output plans and triggers*

If the OM “best way out” is to be used then the process of OM as described in this paper has to be agreed with all stakeholders in the project, with appropriate contingency and monitoring plans and setting up of trigger values and management teams.

7 SUMMARY AND CONCLUSIONS

This paper provides an overview of the use of the Observational Method in Europe using both the “Ab Initio” and “Best Way Out” approaches. The reader is also asked to consult the GeoTechNet web link for the location of seven case examples of the use of OM on major European projects. These show how OM should be properly implemented on projects

Studies carried out under the European funded GeoTechNet project showed that current codes, including EC7, do not describe in detail how the OM approach should be implemented within the contractual framework of a project. The purpose of this paper is to inform the reader of this and the fundamental principles of OM, so that it can be more widely used on Europe projects. The most complete guide on OM is the UK CIRIA guide 185 (1999), and this was consulted widely in preparing this paper.

The paper also highlights improvements to EC7 to strengthen the OM approach and to define more precisely the “acceptable limits” of behaviour which is used in the OM design, see section 4.3.

It is also concluded that European countries could benefit from the UK CDM regulations which form a legal requirement for designers to implement safe designs on all construction projects in the UK. Such a framework is not apparent across Europe.

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