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The Observational Method – safety, serviceability and code provisions

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ABSTRACT Engineering Codes, until Eurocode 7, have not explicitly included provision for using the Observational Method, OM. Nevertheless, in the absence of specific Code requirements, the OM has been safely implemented for several decades across a wide range of different civil engineering works, through application of a set of key requirements. These key requirements include technical considerations, such as: reliably obtaining the critical observations in a timely way and preparing effective contingency measures, together with the vital importance of effective communication and collaboration between design and construction teams. In this context, Peck's eight steps for a complete application of the OM provides a very useful checklist. The requirement to assess 'the most probable' conditions and the most unfavourable conceivable deviation from these 'conditions' is particularly important. The term 'conditions' need to be broadly interpreted to include geology, hydrogeology, structural behaviour, etc, and not, merely, a consideration of a range of ground properties. Code provisions, Peck's steps and the key requirements are compared. The issue of most probable conditions is discussed, together with independent design checker requirements, and the role of advanced analysis.

KEYWORDS: Observational Method, Instrumentation & Monitoring, Case Histories, Codes, Potential Damage Assessments, Risk Management, Safety, Serviceability Limit State.

1 INTRODUCTION

The Observational Method, OM, is a natural and powerful technique for managing uncertainty and enhancing safety, yet when the OM is suggested, it often raises concerns about safety and sometimes rejected on this basis. Perhaps, it is because many engineers are often '*uncomfortable about properly addressing and managing risk*', (Mair, 2020). In general, clients and project managers have a desire for certainty, especially during construction, whereas during the implementation of the OM it must be possible to change the design during construction. Given that one of the most common causes of project delays, cost increases, and failures is due to 'unforeseen ground conditions' (Chapman and Walsh, 2024), it is questionable whether conventional geotechnical design actually provides the certainty which clients and project managers are looking for. Safety in conventional geotechnical design is usually achieved by following rules and guidance given in relevant Codes. Historically, the OM fell outside the scope of engineering Codes; until the first generation of Eurocodes (EN1997-1:2004). Regrettably, there have been flawed applications of the OM which have led to failures. Nevertheless, prior to Eurocode publication the OM was successfully and safely implemented on many highly complex projects (for example, Powderham and O'Brien, 2020). Comprehensive technical guidance is available (e.g. Nicholson et al, 1999), which builds on the eight key steps given in Peck's Rankine lecture (Peck, 1969). This paper summarises the key requirements which must be followed to ensure safe application of the OM and discusses the extent to which Codes can facilitate safe implementation. Some case history examples are given to highlight some of the key issues.

2 SAFETY, RISK AND KEY REQUIREMENTS

2.1 *Safety*

When discussing Codes and Standards in geotechnics, and specifically Eurocode 7, Orr (2024) states that 'Ensuring compliance with all of these assumptions is more important for ensuring the safety of geotechnical structures and reducing the risk of failure than is precision in the design calculations or the values adopted for partial factors.' These assumptions, listed in Eurocode 7, include: 'the experience of the personnel during investigations, design and site works'; 'continuity and communication between personnel involved in investigations, design and construction'; and the 'adequacy of site supervision and quality control during construction'. When the OM is effectively implemented 'continuity and communication' and 'site supervision and quality control' are far stronger than during conventional design/construction. In turn, this is a major factor in reducing risk and enhancing safety since the greater intensity of monitoring and site supervision typically deployed during the OM enables key design assumptions (such as the mass field behaviour of the ground) and construction quality issues to be directly and quickly addressed whereas this is not so readily achieved during conventional design and construction.

2.2 *Risk in Geotechnics*

Best practice in risk management in geotechnics requires practitioners to anticipate a range of possible conditions. Chapman and Walsh (2024) highlighted the importance of the following:

1. '*the possibility (even probability) of some uncertainty'* and the severe consequence of outlier (or Black Swan) events;
2. '*clarity of risk ownership with the best strategy being ownership of the risk by those best able to manage it – not just dumping of risks on those at the bottom of the supply chain'*
3. *'communication and information sharing will often result in earlier identification of problems enabling them to be solved earlier and more easily'*

Effective implementation of the OM, as discussed below, will naturally address these issues and, especially for more complex projects, it is likely to lead to more successful outcomes than a conventional design / construction approach.

2.3 *Key requirements for the OM*

The key requirements for the OM are:

1. The critical observations can be obtained reliably and within acceptable timescales
2. Timely contingency plans can be implemented.
3. The ground and structure(s) (and any associated interactions) are not prone to sudden or progressive collapse

4. There is stakeholder support

The rigour demanded by these requirements is onerous. These requirements must be met for all foreseeable conditions, i.e. varying from 'worst credible' through to 'most probable', and there is a planned course of action for every foreseeable eventuality. Superficially these factors may seem to be independent, however they are essentially a combination of the first two. Therefore, as noted by Powderham and O'Brien (2020) the essence of the OM can be expressed as: '*the key to success in applying the OM is in identifying the critical observations and having the means to obtain and act upon them in a safe and timely manner.*'

In the OM a fundamental criterion is the associated time factor. It must be possible to detect adverse trends in advance of an unacceptable event and be able to implement a planned contingency to safely deal with it. The recent development of Real-Time Back Analysis (RTBA) software aims to reduce this time factor by connecting the design model with the construction works. The construction performance can then be analysed and compared against assumed design behaviour, to enable modifications to the design and construction to be made based on actual performance to better manage risk and create opportunities for safe modifications – see section 4.2.

The third factor ('sudden or progressive collapse') also relates to the time factor, and requires a fundamental understanding of credible collapse mechanisms, potential load paths and likely associated timescales. Typically, deep and broad expertise in geotechnics and structural engineering is required, together with engineering judgement based on appropriate experience.

Finally, stakeholder support is vital because OM applications demand clear communications and close teamwork throughout the OM implementation. Lack of support or commitment from any member of the project team could undermine this essential communication and critically impair risk management. Any lack of trust or ownership of specific tasks would unacceptably compromise the ability to obtain reliable measurements or implement contingency measures in a timely manner. This trust and commitment are particularly important between designer and contractor.

It follows that any inability or shortfall in the above four requirements means that the OM cannot be safely implemented on a project. A cardinal limitation of the OM is if it is not possible to change the design (in a timely manner) during construction, then this renders the OM a non-starter. This also leads to two additional factors which must be supportive of the OM:

(a) The contractual conditions must be compatible
(b) The design approval regime, including any independent design checking/assurance process, must be compatible and allow design to be directly related to actual construction means, methods, sequence and/timing

The appropriate contractual and commercial environment for the OM has been discussed by O'Brien et al (2022) and will not be discussed further here. Design approvals are becoming more complex and time consuming, especially for large projects, which has led to changes in how OM has been implemented – see section 4.2 below.

3 CRITICAL OBSERVATIONS

3.1 *Instrumentation, Monitoring and Observations*

By definition, observations are essential in the application of the OM. Measurements from instruments are not sufficient on their own. It is vital to establish a comprehensive record of contemporary construction activities, and this can sometimes be more problematic than setting up a robust and reliable instrumentation system. The advice by Peck (1972) should be remembered: '*Even with the most sophisticated instrumentation system, other types of observation are essential.*'

The identification, timely collection, interpretation and communication of the critical observations are safety critical. When designing an instrumentation system, every instrument deployed should answer a specific question. The OM designer should take the lead in this, although the advice of an instrumentation specialist should be sought so that instrument selection is based on an understanding of the advantages and limitations of different instrument types for the site-specific function required. It is important to establish a primary system (ie the instrument data on which OM decisions are based) and a secondary system (which should facilitate behavioural understanding). It must be possible to identify trends and separate key construction induced events from background and secondary effects. This means that some of the instruments should be installed well before construction commences, so environmental background effects (eg daily and seasonal changes) can be understood.

3.2 *Setting Performance Limits*

An important practical development was the use of a simple traffic light system, (Powderham, 1998), to define performance limits for critical observations, Figure 1. Establishing these limits is a good example of where the OM is not well served by a prescriptive approach. Powderham and O'Brien (2020) outline ten different factors, summarised in Table 1, most of which will be site and structure specific, which should be considered when determining performance limits. Establishing a performance limit, or trigger level, may be relatively straightforward if the critical factor is solely associated with ground failure. However, failure mechanisms involving ground-structure interaction are more common and generally more complex, involving a wider range of factors. This is particularly important when the OM is used in urban areas, and the performance limits are required for protection of existing infrastructure. For these situations, the critical performance limit typically relates to allowable movement, ie SLS considerations. As noted by Burland (2024) the allowable movement of structures is very subjective and varies both with the function of the structure and the reactions of users (and their technical advisers). Any rational assessment of allowable movements should be based on its structural capacity, which in general requires an analysis of induced curvature and/or strain (tensile or compressive, as appropriate) within the structure, rather than some arbitrary total movement limit. Examples, for masonry structures, include the charts by Boscardin and Cording (1989) and Burland and Wroth (1974). Although, as noted by Powderham et al, (2004), structural details, such as wall to floor connection details can dramatically affect how a structure will respond to ground movements (for example, if lateral ground strains will be transferred into a building or not).

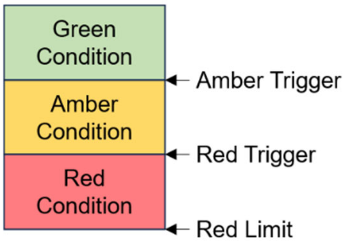


Figure 1. Performance Limits, traffic light system for OM

Table 1. Setting performance limits, key factors

Factor	Considerations
Nature of failure/deformation mechanisms	Does failure or critical deformation involve ground only or ground/structure interaction
Consequences of potential failure/deformation mechanisms	Is the limit set by SLS or ULS, how serious are consequences? Are permanent or temporary works affected or existing infrastructure.
Timescale for failure/deformation to reach critical level	This will typically define the margin between red limit + red trigger (based on practical logistics for implementing contingency)
Accuracy, precision + repeatability of instrumentation systems	Key factor in setting the green limit
Is monitoring data relative or absolute	For example, is differential settlement or angular distortion the critical observation
Nature of critical observation, ease of collation + interpretation	How much data manipulation is necessary, ideally critical observation is kept as simple as possible
Based on most probable conditions what is likely trend + will it remain in green zone	Ideally this should be based on reliable + relevant case history data, ie avoid solely relying on analysis.
If worst credible conditions- will trends develop towards red trigger levels	Would these trends allow enough time to implement planned contingencies
Is there enough margin in the green (+ amber, if used) zone	It is important to avoid false and/or frequent breaches of trigger levels
Can critical observations be captured within a single set of performance limits.	In general, OM should be managed through a single set of performance limits.

This highlights why performance limits need to be site and structure specific, and why geotechnical and structural engineers need to work closely together to set appropriate limits.

Often with existing infrastructure (eg buildings, tunnels, underground utilities, rail systems) their structural condition is poorly understood and may have undergone several modifications/repairs in the past. A classic example, of the challenges associated with this type of assessment is given by the Mansion House case history (Powderham and O'Brien, 2020), an 18th Century building of national importance. One of many issues, was the degree of building stiffness which could be relied upon, which would modify the greenfield settlement trough (induced by tunnel construction). In addition, an adjacent large building also interacted with the Mansion House, hence any settlement trough was a combined function of tunnelling works, plus interaction between the two existing buildings. Given the sensitivity and the nature of the different stakeholders involved achieving a consensus on the 'most probable' conditions for this type of ground-structure interaction was impractical (even unlimited analytical power would not resolve this type of issue).

Performance limits should be developed on a pragmatic basis, and for some OM applications the three zones, red/amber/green traffic lights, have been changed to two zones only. Powderham and O'Brien (2020) and Pye et al (2022) give examples of how OM has been safely implemented with two zones (red/green only). The original basis of having an 'amber' zone was to enable more focused interrogation and analysis of instruments which were showing a significant change. When the traffic light system was first developed, some three decades ago, there were greater data management challenges and instrumentation accuracy was more limited than is currently the case with modern systems. More recently, for applications of the OM on geographically constrained sites, the performance limits have been set on a simple red/green basis. The greater accuracy of modern instrumentation (when well installed), together with modern data management systems, means there is less risk of data overload. Back-analysis has then been used to assess the risk of the red trigger being breached in subsequent construction stages, Pye et al (2022). Nevertheless, for very large sites and where ground/groundwater conditions are highly variable the original three zone traffic light system remains a valuable and effective way to focus attention on more critical areas of a site.

4 CODE PROVISIONS, PECK'S STEPS AND 'MOST PROBABLE CONDITIONS'

4.1 *Code Provisions and Peck's Eight Steps*

The first generation of Eurocode 7 (EN1997-1:2004) was the first Code of Practice that explicitly permitted the use of the OM. The clauses are summarised in Table 2, and it is apparent that the OM clauses are brief and provide little guidance on implementation. The critical importance of effective communication and collaboration between design and construction teams is not mentioned, refer to section 2 above. Also, the critical need to observe and record actual construction activities and relate these to performance is unfortunately not emphasised. The second generation of Eurocodes maintains support for the use of OM as one of the permitted approaches for geotechnical design; some key text extracts are also given in Table 2. For conventional 'design by calculations' Eurocode 7 provides much guidance and rules on how ULS checks should be carried out, whereas it provides little guidance on SLS checks.

In general, as noted above, the key concern for most OM applications is the control of ground and structural deformations and often the ground will be remote from failure, ie SLS checks typically control OM implementation. Hence, because of the relative lack of guidance on SLS checks in Eurocode 7, it follows that SLS considerations during OM implementation will be reliant on the judgement and expertise of the OM designer.

When, as is common during the OM, the ground is remote from failure, monitoring is unlikely to provide reliable insights into mobilised ground strength, except if ground conditions are dominated by e.g. very soft clays. In the authors' experience, the focus during OM implementation is commonly structural and ground deformations and their trends with time. Time related movements, usually associated with the development and dissipation of groundwater pressures (and associated changes from undrained to drained conditions for fine-grained strata) remain a major uncertainty, as well understood by Terzaghi, who noted that this is often a function of 'minor geological details that are unknown' (Peck, 1969).

Table 2. Comparing EN1997: 2004 OM Clause with Peck's 8 steps

Eurocode 7 (EN1997-1: 2004), clause 2.7	Peck's 8 steps
(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 acceptable limits; 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. (4) 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.	(i) Exploration sufficient to establish at least the general nature, pattern and properties of the deposits, but not necessarily in detail. (ii) Assessment of the most probable conditions and the most unfavourable conceivable deviations from these conditions. In this assessment geology often plays a major role. (iii) Establishment of the design based on a working hypothesis of behaviour anticipated under the most probable conditions. (iv) Selection of quantities to be observed as construction proceeds and calculation of their anticipated values on the basis of the working hypothesis. (v) Calculation of values of the same quantities under the most unfavourable conditions compatible with the available data concerning the subsurface conditions. (vi) Selection in advance of a course of action or modification of design for every foreseeable significant deviation of the observational findings from those predicted on the basis of the working hypothesis. (vii) Measurement of quantities to be observed and evaluation of actual conditions. (viii) Modification of design to suit actual conditions. NB – the degree to which all these steps can be followed depends on the nature and complexity of the work.

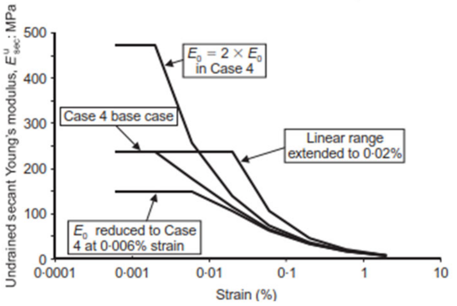
Note: for the second generation of Eurocode there are some changes to the OM clause, including: the range of different design variants 'shall cover all foreseeable relevant ground responses and ground-structure interactions'; contingency measures shall be prepared and applied when actual behaviour reaches 'acceptance criteria or threshold values'; 'ultimate and serviceability limit states shall be verified for each design variant.'

When structural checks are required a different approach is required depending on whether new structures, and if temporary or permanent works are affected, or existing structures are being checked. Typically, particularly for permanent works, SLS conditions will control. For reinforced concrete structures, such as embedded retaining walls, the wall curvature and crack width control will be the critical SLS consideration, which will be influenced by several factors including the mobilised ground stiffness. Wall curvature can be monitored during the OM, although in practice deriving bending moments from site monitoring is not straightforward.

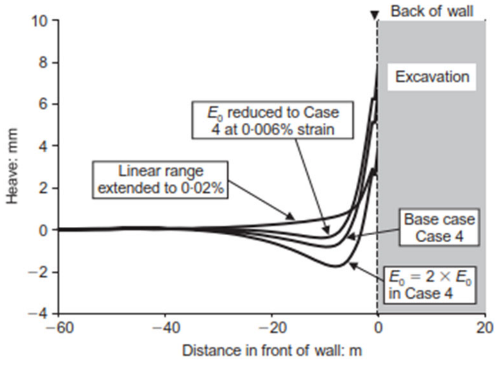
Some countries, such as Singapore, have developed regulatory frameworks to support OM implementation (Poh, 2019). The Singapore framework is ab initio in nature and specific to deep excavations, and prescriptive requirements are specified. The process requires the upfront design, independent checking, and authority approval of both characteristic and most probable OM scenarios. A clear decision framework is then developed for each decision point where the design will follow one of the two OM scenarios based upon an enhanced monitoring regime. Such a standardised framework is intended to address technical issues, however, commercial and contractual hurdles must still be overcome, particularly where most projects are lump sum Design & Build. The upfront cost to the Contractor of additional design, site investigation, and enhanced monitoring is often not palatable given the possibility of no benefit if the characteristic scenario is followed.

Back-analysis of monitoring data with advanced numerical modelling can provide helpful insights into induced structural demands and mobilised ground stiffness. Some care is required, because the pattern of ground movements and induced structural demands is dependent on the choice of constitutive model, the nature of ground stiffness non-linearity and changes of stiffness with depth, as shown in Figure 2 (Clayton, 2011). In this context, what constitutes worst credible or more optimistic, most probable, conditions would depend on the objective of the analysis – is it assessing the settlement trough behind the wall or the wall bending moment, see Figure 2. Again, this highlights the pitfalls of an overly prescriptive approach and the need for bespoke assessments for the most critical element of the OM works; is it a proposed new structure or protection of an existing structure?

Table 2 summarises Peck's original eight steps and these can be compared with the Code provisions. In general, the authors have found Peck's eight steps to be a very useful checklist. In particular, Peck emphasised that '*the essential ingredient, without which all the others may lead to nothing, is the visualisation of all possible eventualities and the preparation in advance of courses of action to meet whatever situation develops. Only if this is done can it be said that more than lip service has been paid to the use of the observational procedure'*. By comparison, the Code provisions are not an improvement on Peck's eight steps. In particular, the design modifications implemented during the OM do not have to be contingent measures of a corrective kind, as implied in clause 2.7 of EN1997. In fact, in the author's experience, it is far more common for OM to facilitate the introduction of beneficial changes in a safe and controlled environment (OM through Progressive Modification – see section 4.2).



(a)



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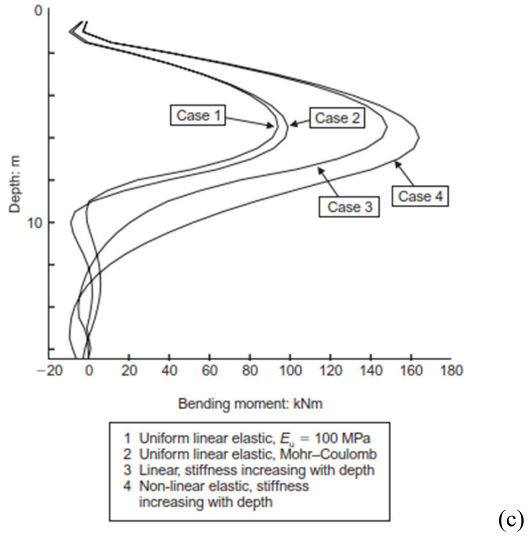

Figure 2. Influence of changes in small-strain stiffness non-linearity (after Clayton, 2011) (a) variations in small strain stiffness, (b) surface settlement troughs behind a wall, (c) wall bending moments for 4 different soil models

4.2 *Solving The Issue of the Most Probable Conditions*

One of the perennial debates regarding OM, and the one which raises most concerns, is that relating to Peck's 'most probable conditions', Table 1 – what they are, how they are used in design, and how to ensure an appropriate level of safety. Importantly, he caveated his eight steps by stating: '*the degree to which all of these steps can be followed depends on the nature and complexity of the work'*. There has been a tendency to ignore Peck's caveat and treat Peck's guidance too simplistically. The term 'most probable' also tends to be unduly focussed on ground parameters. It is less easy to establish and gain acceptance with structural engineers what 'most probable' conditions are for, say, a masonry building or a high-pressure gas main (although it is generally accepted that structural materials display different properties to those assumed in design). In addition to uncertainties associated with material properties and conditions of joints, etc, overall behaviour will depend on ground-structure interaction. In practice, there will be a wide range of views of what actually constitutes most probable conditions (except perhaps for the simplest of situations), both within specialisms and beyond. The views of a geotechnical specialist, a structural engineer, building owner and main contractor will also be influenced by more than just technical factors. A design based on most probable conditions still tends to be associated with low levels of safety. Significantly, Muir-Wood (2000) observed that commencing the OM on estimates of most probable conditions, even if possible to identify and get consensus upon, would usually lead to a more expensive outcome than commencing the OM on a more conservative basis. Hence, it is generally recommended that OM is commenced on a more cautious estimate of conditions than most probable.

Typically, the authors have commenced OM with assumed conditions close to 'characteristic' (using Eurocode terminology). As noted above, ULS checks are usually not significant and most effort and expertise is required in judging SLS behaviour. Whether conditions are assumed to be more optimistic or pessimistic than characteristic will largely depend on relevant case history experience for the type of works and geology. When this is lacking, or if there is particular uncertainty about time-related effects, then a preliminary site trial is invaluable for subsequent risk management. If OM is implemented through Progressive Modification (Powderham, 1998), then as outlined by O'Brien et al (2022) it is possible to commence construction with an acceptably low level of risk, yet also maximise potential savings.

Implementing OM through Progressive Modification also forms the basis for the 'verification process'. During OM implementation, the verification process has two objectives: firstly, maintain the approval/assurance of a design by independent checkers; and secondly ensure design changes can be made, and approved by independent checkers, within the timescales required for OM implementation. In practice this involves the selection of key construction stages which are defined as 'verification points' (VP). For each VP a workshop is attended by the OM team and independent checker. If detailed back-analysis of all monitoring data and site observations indicates that pre-defined performance limits will not be exceeded during subsequent construction stages, then pre-planned beneficial design changes (such as avoidance of the original design's temporary works, or combining construction stages) can be implemented and agreed with the independent checker. It is important that the independent checker has appropriately experienced senior staff actively involved in this process. Advanced analysis and use of RTBA is playing an increasingly important role in this type of process; however, its effective use requires a high level of expertise (e.g. O'Brien and Higgins, 2020). The rigorous calibration of analytical models against observations and clarity in the primary objective and use of any outputs are particularly important.

Table 3. Limitations of the OM, example projects where OM could not be safely implemented

Project	**Structure**	**Key Issue**	**OM Challenge**	**Comments**
Heathrow T5 tunnels	Tunnel with pre-cast expanded lining, unbolted	Decompression + sudden collapse of lining	Obtain critical observation (total hoop stress)	Local works to eliminate decompression risk, OM used for bulk of basement works.
Limehouse Basin temporary cofferdam	Multi-propped sheet pile wall (design based on most probable parameters)	Bending failure of sheet piles	Insufficient time to implement contingency	A mid-height soft prop trial indicated wall failure may occur within 7 days
HEX CTA bored tunnels	Multi-storey car parks (MSCP) 1, 1A, 3	Shear + Flexural cracking of reinforced concrete columns. Foundations did not have ground beams, so horizontal restraints lacking.	Excessive cracks induced rapidly + at unusually small movements (5-10mm) at MSCP 1A only	MSCP 1+3 undamaged, MSCP1A had unique sensitivity to small horizontal ground movements due to combination of stiff columns built monolithically into isolated foundations + first floor slab.

4.3 *Some examples where OM could not be safely implemented*

Table 3 summarises a few examples of where the OM could not be safely implemented. The critical constraints, either being structural details or groundwater conditions, meant failure / excessive damage could occur before an effective contingency measure could be implemented. At Limehouse Basin a preliminary trial highlighted the key risk, and for the T5 tunnels the risk was anticipated from the known structural details for the tunnel. In the case of the multi-storey car park, MSCP1A, its sensitivity to small lateral ground movements was not anticipated. In fact, two apparently similar reinforced concrete structures, MCSP1 and 3, did not suffer any significant damage (even though they were subject to larger ground movements). The high sensitivity of MSCP1A is a reminder that differences in structural detailing can significantly change a structure's sensitivity to ground movements. Nevertheless, as noted by Powderham et al (2004), it remains a far outlier in terms of building sensitivity to ground movement.

5 CONCLUSIONS

The OM was successfully and safely implemented on complex projects well before the introduction of Eurocode 7. Whilst the Eurocode clauses supporting the use of the OM are welcome, they do not mark an advance on previous good practice, see 'key requirements' in section 2.3.

Safe and effective implementation of the OM requires close teamwork and effective communications, both across disciplines (eg between structural and geotechnical engineers) and between designer and contractor.

An essential ingredient is the assessment of all foreseeable conditions, from most probable to worst credible. Often this requires careful review of geological and hydrogeological conditions.

Often the OM has been most effective for complex projects in urban areas, where the control of ground movements and movements of existing buildings and infrastructure is of paramount importance. In this context, ULS checks are seldom critical. Whereas, assessing the risk of potential damage to existing buildings/infrastructure is usually the controlling factor for OM implementation. Hence, identifying the critical observations and setting appropriate performance limits for the OM needs to be site and structure specific, and take account of specific construction means/methods and local structural details of affected structures.

One of the main uncertainties which need to be managed through the OM are time-related effects, since this will influence the viability of the OM. When relevant case history data is lacking, preliminary trials can provide significant benefit.

Peck's eight steps provide a useful checklist for the OM. However, it is usually inappropriate to commence the OM on the basis of most probable conditions. A more cautious starting point for OM is likely to be safer and more cost-effective; especially if implemented through Progressive Modification, which facilitates a step by step evaluation of actual conditions and the introduction of beneficial design changes in a safe and controlled manner. This incremental approach also allows unfavourable conditions to be dealt with.

A development of progressive modification, known as the verification process, is facilitating independent design checker approvals within the timescales required by the OM (provided appropriate expertise is actively employed). Advanced analysis methods play an increasingly important role in this aspect of the OM. However, experienced engineering judgement, based on lessons learnt from relevant case histories, will continue to be central to the safe and effective use of the OM.

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