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Why the Quality of Concrete Construction for Infrastructure Contracts Must Not be Undermined by Inappropriate Design Code Assumptions

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Abstract. *The concept of a draft international project specification (DIPS) has long been under consideration in relevant fib Task Groups, - even before the framework Standard, ISO 22966 (Execution of concrete structures) was published (2009). However, the quality requirements of ISO 22966 were developed from the product quality inspection principles of the Eurocodes and ISO 9001:2000; and the author has explained why these principles cannot be applied directly to contract works. Furthermore, these principles do not demand the necessary level of high-performance concreting and supervision to produce defect-free structures and the 100 plus year service life which Owners expect.*

The original ISO 9001:1987 was a simple, contractually effective model quality system specification which "aimed primarily at preventing nonconformity," (the fundamental purpose of quality assurance). *Its most powerful element was 'process control' (including 'special processes'), and it demanded that all processes which could adversely affect quality must be addressed by effective documented preventive procedures in the Contractor's Project Quality Plan (PQP). The Contractor had to document exactly how he would perform each (special) concreting process and then demonstrate that his proposed procedures worked.*

Since 2000, this powerful combination of mandatory quality planning requirements has been removed from most specifications for concrete works; but this is precisely what needs to be restored if Owners' and Designers' durability expectations are to be consistently achieved.

The author now proposes an amended draft version of the International Project Specification, - hoping that it will soon be used on a trial basis on selected construction contracts for reinforced and prestressed concrete bridgeworks in China, Australia, United States and Europe.

Keywords: *Concreting Processes Ignored by Structural Engineers, ISO Inspection Principles Apply to Finished Structures and Members, Quality Assurance Principles for Process Control, ISO 9001:2000 Invalid for Tenders and Contracts, Proposed Draft International Project Specification.*

1 Introduction

The concept of a draft international project specification (DIPS) has long been under consideration in relevant *fib* Task Groups, - even before the framework Standard, ISO 22966 (*Execution of concrete structures*) was published (2009). For example, the author, in his Yantai Paper (2008), proposed a '*Flowchart for Development of the Project Specification for Execution (Construction) of Concrete Structures*' as a basis for forming an *International Joint Task Force for Preventing Construction Disasters*. This Flowchart applied the principles of '*thinking construction*' and of developing specified process control requirements clauses as explained in *fib* Bulletin 44, Appendix G: '*Project specifications – An owner's tool*' (2008).

However, the quality requirements of ISO 22966 were developed from the product quality inspection principles of the Eurocodes and ISO 9001:2000; and the author has explained in Appendix G, (and below) why these principles cannot be applied directly to contract works.

Also, as explained in Appendix G, the quality inspection principles of ISO 22966 do not demand the necessary level of high-performance concreting and supervision to produce defect-free structures and the 100+ year service life which owners expect. The reasons for this, and the consequent limitations for reinforced concrete designers are discussed in the this Paper.

2 Relevant Historical Background for ISO 9001

It was in the late nineteen eighties that many public infrastructure owners, were exposed to the undeniable benefits of systemised quality control and quality assurance – not just for supply of concrete etc. but for all the products and processes in a construction project. The top bureaucrats in many public authorities were quickly convinced that ISO 9001 (1987 and 1994 versions were titled, "*Quality systems - Model for quality assurance in design/development, production, installation and servicing*") was the answer to all perceived quality problems.

However, what also attracted many of these bureaucrats was that, under the new so-called QA contracts, the Contractor was responsible for inspecting his own work – and thus the owner could dispense with his own inspection staff. They naively presumed that contractors would be able to quickly replace that inspection experience and expertise from within their own organisations. At the same time, owners continued to apply what some have called the 'low-bid syndrome', whereby 'good contractors' were penalised because they could not compete at tender stage with those who underestimated or under-quoted the cost of inspection QA.

The original ISO 9001:1987, was a simple, contractually effective model quality system specification which "*aimed primarily at preventing nonconformity*" Its most powerful element was '*process control*' (including '*special processes*'), and it demanded that all processes which could adversely affect quality must be addressed by effective documented preventive procedures in the Contractor's Project Quality Plan (PQP). The Contractor had to document exactly how he would perform each (special) concreting process and then demonstrate that his proposed procedures worked. Under that specification, the Contractor had to pre-demonstrate that his concreting procedures were consistently achieving full and uniform compaction in the cover zone; and that he was using adequate resources of men and equipment to both do the work and continuously verify that it had been done . This all changed dramatically in 2000.

2.1 The Impact of ISO 9001:2000 on Contracts for Concrete Structures

During this same period structural designers and materials engineers/scientists were coming at the quality problem along a very different path to the one taken by the construction industry, which, (because of the differing interests of owners and contractors and suppliers), was hardly aware that the path to quality had become a battleground.(2008). (That comment is not true of the welding industry which was fully aware that welding is a '*special process*', and developed a set of codes accordingly. These codes (now called ISO 3834 series) specify the quality requirements not only for welding procedures but also for welders and for welding inspectors)

The steel construction industry is in safe hands because all steelworks contracts, whether for on-site jointing operations or for the shop fabrication of girders, beams and columns etc., have the ISO 3834 requirements embedded in the tender documents. All parties know the rules and the tendering process is relatively straightforward. They faced challenges when ISO 9001:2000 was thrust upon them, but they did what the new code required them to do. They upgraded their management organisations where necessary, but they didn't try to apply it to contract situations, for which it was specifically not intended – although some clients may have thought otherwise.

It took years for the concrete construction industry to realise there was a problem, let alone identify it and try to find a solution. Appendix G of *fib* Bulletin 44 (2008) was a serious attempt to present a solution, but it didn't adequately explain what the problem was. (It correctly defined the relevant limitations of ISO 22966, and its dependence on ISO 9001, but failed to understand and address the underlying dependence on ISO 2394 (1998/2015) and the fundamental assumptions contained in its risk and reliability principles.)

2.2 Why ISO 2394 Should Not Be Expected to Apply to Concreting Processes

Being neither a structural designer nor a mathematician, the author has struggled to come to grips with the principles and implications of ISO 2394, and why these principles should be expected to apply to field concreting processes, and especially those which determine durability of the cover concrete for structures in marine environments. A selection of documents has been collected together as a reference for readers, but the author highlights the following points:

1. The structural designers developing the Eurocodes and materials scientists driving EU-supported research programs like DuraCrete (2000) and Chlortest (2005), seem to have thought of conformity testing only in terms of laboratory samples or structures. It seems that the existence of 'special processes' was not appreciated outside of the welding industry. This thinking is also evident in the planning and publication of the special works specifications for the Storebaelt Bridge (1993), where conformity was to be assessed in terms of special tests (LOK-CAPO etc.) which involved pull-out tests on the structure. (This was despite the fact that Storebaelt was intended to set a new world standard for quality assurance contracts (and presumably ISO 9001:1987, in which 'special processes' are so clearly defined.))

2. ISO 2394 is written by designers for designers. The responsible committee is ISO/TC 98 '*Bases for design of structures,* SC 2*, Reliability of structures*'. The 2015 version "*is intended to reflect advances in the common basis for decision making related to load-bearing structures*. According to this latest version: *Compliance with* (ISO 2394:2015) *should therefore promote harmonisation of design practice internationally and unification between the respective codes and standards …*" This suggestion has obviously now become a guiding policy for *fib* and all international and most national organisations of structural engineers. Harmonisation obviously requires full acceptance of the probability principles espoused in ISO 2394:2015. However, the author can see no internal or external justification for assuming that this harmonisation goal is ready to be extended from design codes to construction (execution) codes – notably ISO 22966.

By linking ISO 22966:2009 (*Execution of concrete structures*) to ISO 2394 and therefore to ISO 9001:2000/2015, workmanship and supervision requirements for all concrete construction processes are reduced to the same level as designers call for in the inspection of products and structures. (The first sentence in ISO 22966 is: "*This International Standard applies to the execution of concrete structures to achieve the intended levels of reliability and serviceability that are given in ISO 2394 and in standards for the design of concrete structures*".)

Underlying this claim is the assumption that quality can now be safely and reliably achieved on concrete construction works, provided the Contractor has in place a quality management system which complies with the requirements of ISO 9001:2000/2015. The author believes strongly that this is a false and dangerous assumption, and it is made even more dangerous by the risk framework approach introduced in the 2015 versions of ISO 2394 and ISO 9000. This approach may be logical and relevant for structural designers dealing with members and joints;

but is far too generic to be much help to either constructors or designers wrestling with the actual or potential problems of placing stiff, cohesive concrete into congested reinforcement so as to achieve full and uniform compaction in the cover zones of structures.

3. The special works specifications for Storebaelt (1993) provide an enlightening contrast between the tremendous research effort that was expended on designing the concrete mixes, and the apparently negligible effort that was put into identifying potential problems in placing and compacting that mix into the formwork-reinforcement assemblies for its major members. In fact, the guidance on "*placing and vibrating*' (pp 25-37 of '*Concreting*') consisted (in the author's opinion), of largely archaic, mostly irrelevant and often misleading diagrams supposed to show typical formwork and reinforcement situations the concretors would face.

Unfortunately, similar criticisms can be made of most other Guide Construction Specifications. For example, even the latest AASHTO Bridge Construction Specification, (2017), while it seems to have been satisfactorily updated with guidance clauses to cover recent developments in major bridge design and erection technology, its guidance clauses for concrete placement and reinforcement detailing are partly locked into the practices of fifty years ago.

4. A careful study of its Introduction, Scope, Terms and definitions, and Conceptual basis (2015) indicates strongly that the ISO 2394 Committee had in mind "*the design of complete structures (buildings, bridges, industrial structures etc.), the structural elements and joints making up the structures and the foundations*". ISO 2394 also claims to be "*applicable to the successive stages of construction, the handling of structural elements*, (which would include precast concrete as well as steel), *their erection, and all work on-site*". However, from the author's careful study, there is no indication that any thought was actually given to the casting of concrete members', either on-site or in casting yards. The Committee was no more concerned about the special process problems of placing and compacting concrete in congested formwork-reinforcement assemblies than it was about the problems of controlling heat inputs into the parent steel (and the associated problems of controlling deflections), when welding a web-to-flange joint in a big steel box girder. That was not their problem. Those concerns, both for design and construction, would be addressed by experts in those fields.

5. ISO 2394 incorporates the quality management principles and assumptions of ISO 9001:2000. It simply requires that "*In case of construction works at least a minimum basic level of quality management. assurance and control is required*". The author argued in Appendix G of *fib* Bulletin 44 that this level of control is quite inadequate. This was because ISO 22966 (the concrete execution code) incorporated those same quality levels of ISO 9001:2000, and these were obviously inferior to the quality control requirements required for special processes. These concerns were raised in *fib* Commission 8, but overall harmonisation requirements prevailed.

6. Delving deeper into the history of ISO 9001, we see that it was a reincarnation of earlier quality control standards used in factory production for armaments etc. (BS 5750:1979, the original version of ISO 9001, borrowed heavily from the US Defence Department's MIL-Q-9858 (1959), which set minimum requirements for potential contractors to supply to the DoD.)

ISO 9001:1987 was actually worded "*for use where a contract between two parties requires the demonstration of a supplier's capability to design and supply product*". It was not designed for inclusion in tender documents for on-site contracts. Nevertheless, by 1990 it was in use on major construction contracts in Europe and the UK. Contractors and clients were making it work on site, despite its factory, mass production orientation. However, the key element was 'process control', and it can't be denied that the wording of these specified requirements could be much better targeted if the document had been modified to suit field construction requirements – and particularly for one-off construction of reinforced concrete members.

7. It is only while preparing for this Paper, that the author fully recognised the reality that ISO 9001:2000, and therefore ISO 2394 – and other related design codes, can never be applied to special processes. Firstly, the process-focused, problem-solving, preventive-procedure approach that constitutes practical quality assurance has been removed (and replaced by some generic risk assessment principles, which most field engineers would find difficult to apply).

Secondly, ISO 2394 principles are based on product verification:– by definition, products which are manufactured (cast) using special processes cannot be verified for conformity.

Thirdly, ISO 2394 is applicable in a situation where the designer is in control – from concept to final detail design, (as is also the case for *fib* MC2020). While this applies for traditional contracts, it is not so easy to apply in design-and-construct contracts, which are today's norm.

Fourthly, ISO 2394 (with ISO 9001) is not intended for contractual use. Assignment of contractual responsibilities, including quality management has to be specified separately.

Finally, in the light of the above comments, it becomes obvious that ISO 22966,(because of its alignment with ISO 9001 and ISO 2394), cannot be included directly in tender and contract documents for reinforced and prestressed concrete structures. The author is now proposing for consideration by fib Commission 8, (2023) that the principles of *fib* Bulletin 44, Appendix G, be revised to remove all reference to a modified version of ISO 22966, so that the recommended Model Project Specification may be clearly and uncompromisingly based on the simple process control principles that were the centrepiece of ISO 9001:1987.

The author now proposes that a suitably amended version of the Draft International Project Specification (DIPS), be used on a trial basis in construction contracts for selected reinforced and prestressed concrete bridgeworks projects in China, Australia, United States and Europe.

NOTE 1: The '*Draft International Project Specification (DIPS)*' is basically the same that was proposed in the Yantai Paper and Flowchart. It has been slowly expanded in scope over the last twelve years through Papers and Presentations at *fib* and other conferences. For some time the author was referring to it as '*Draft International Construction Project Specification for High Performance Concrete Structures*', but more recently, in *fib* correspondence, it has been referred to simply as the '*Model Version of ISO 22966*'

NOTE 2: 'DIPS' is now suggested as the simplest reference name. However, all reference to ISO 22966 (and ISO 9001 and ISO 2394) will be removed, and it will be a contractually applicable document in the spirit of ISO 9001:1987 with respect to process control and quality assurance. However, it will be rewritten to ensure that its '*requirements clauses*' are suitable for verifying product conformity in terms of effectively documented process control procedures. It will be suitable for use in tender and contract documents for both major and minor projects. The requirements clauses will be separated into general and process-specific. A set of 'Requirements for Various Member Type' will be developed as indicated in the Yantai Flowchart. This work will be facilitated by the 'Centres of Concreting Excellence'. (Paper 200).

3 Understanding Concreting Processes to Identify Potential Problems

This Section contains clauses extracted from a Paper the author presented at the 3rd ICDC Congress, (Curtis et alia 2017), copy of which can be accessed through the references. The author hopes the reader will take the time to enter into the problems which are illustrated here.

The first Section was entitled "*What Happens When Concrete Doesn't Flow*", while the second was titled, "*How to Make the Concrete Flow – From Discharge to Final Placement*".

Figure 1. Close-up of Storebaelt Compaction Failure Showing Congested Reinforcement

The photo above is an enlarged close-up from the photo (Gimsing 1999) of a foundation plinth of the Storebaelt Bridge Recently, this photo has been examined in greater detail, to shed more light on the recent concreting failure on the new Panama Canal Expansion Project (Curtis, 2016). This, in turn, has led to an even deeper conviction that 'concrete which can reliably be made to flow when effectively vibrated' is the primary requirement for achieving full compaction in the cover zone; and this principle must be practised at all times. ....

When the concrete of the first pour is exposed, it can be seen how difficult it must have been for the concrete to force its way through the outer reinforcement and into the cover zone. Experience indicates that it would have "tumbled" rather than "flowed", and would have entrapped air in the process. ..... there tends to always be a temporary cavity at the top of the cover concrete, unless the vibration of the core concrete is maintained until the concrete in the cover zone is brought right up to the same level as the adjacent core. To do this requires skilled and conscientious vibrator operators able to clearly observe the flow of concrete from the core into the cover zone.

Also, obviously, the more congested the outer rebars are, the more difficult and tiring the work of the vibrator operators will be; and the more difficult to observe what is happening. Even the provision of adequate lighting becomes more difficult.[End of first extract]

The second extract is from the more comprehensive "*From Concrete Pours to Concrete Placement*" (Curtis unpublished 2013).

The clean discharge, combined with effective lighting, facilitates observation of the flow of the concrete as the mound formed at the discharge point is constantly flattened by the combined effects of gravitation and vibration. The flow can thus be continuously monitored to ensure that all rebars are fully encased and the cover zone is progressively filled from the bottom up. ..... At the point of impact and penetration, much of the air which accompanied the falling concrete is eliminated. Then as vibration is applied adjacent to the mound, it progressively spreads out and flattens under the combined effect of vibration and gravity……

......At all times, it must be possible for appropriately positioned monitoring personnel to continuously observe the advancing toe and to verify that it flows under and around the lowest rebar layer without undue difficulty; thereby verifying the filling and compaction of the all-important cover zone. Because it is crucial to continuously monitor the advancing toes from each discharge point, it is therefore also crucial that no concrete is dropped directly on top of the advancing toe. If this is done, observation is obscured and effective monitoring is prevented.

4 Get the Tender Documents Right to Avoid Contractual Disputes

The title of this Section is taken from the title of a Section in a draft submission made by the author (Curtis 2021), as part of an unsuccessful attempt to resist the move to bring the construction related chapters of draft *fib* MC2020 (*fib* 2023), under the 'harmonisation umbrella of the design codes'. A major feature of this submission is that it focuses in great detail on the quality assurance failures on the Storebaelt Bridge, drawing deeply from very valuable self-criticism in the Storebaelt Publications' own fine report on the project. This draft submission is included also as a major practical research reference for guiding trial concreting operations for each "centre of Concreting Excellence" as it is established.

5 Concluding Remarks – A New Approach to an Old Controversy

The author is well aware that many of the statements of this Paper will be challenged. Its application (as presented in *fib* Bulletin 44, Appendix G (2008)), although initially welcomed within *fib*, has now been excluded from the soon-to-be-published *fib* Model Code MC2020. The problem was not that its application is wrong (at least no one has said this), but because it opposed fundamental assumptions of all the relevant ISO design codes and the Eurocodes. Its message (particularly as expounded in Section 2.2 (2) above), could not be accepted without flouting almost universally accepted '*code harmonisation requirements*'. (Not only RILEM, IABSE, *fib and FIDIC* etc. are committed, but also AASHTO and most national organisations of structural engineers. Even JCSS (Joint Committee for Structural Safety – of which Professor Li is a Board Member) appears to be accepting and advocating the same assumptions.)

These assumptions which the author disputes, relate to the level of inspection which will be applied to finished structures. They have been deliberately or unintentionally accepted by virtually all structural design organisations for the last twenty years or more. At the heart of these assumptions are the underlying probability based concepts of risk and reliability, where the latest (2015) version of ISO 2394 has virtually eliminated traditional concepts of quality assurance and process control from consideration. Thus the simple, effective pre-2000 ISO 9001 principles for identifying and resolving potential problems and risks, have been replaced by probabilistic principles which offer no guidance to a non-mathematician. In addition, the change in focus of post-2000 ISO 9001 towards quality management systems and continual improvement makes its requirements virtually useless for contract management purposes.

Most importantly, the referenced ISO Codes ignore the reality that most concreting processes (including prestressing) are *special processes*; and the properties of the cover concrete cannot be fully verified by inspecting finished product. Conformity can only be verified by effective process control and process verification according to pre-approved procedures

It is hoped that these matters can be debated exhaustively within a new construction-focused Task Group to be formed by *fib* Commission 8 (and in time to contribute at DBMC Tsinghua)

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