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Autor: Sriskandan, K.

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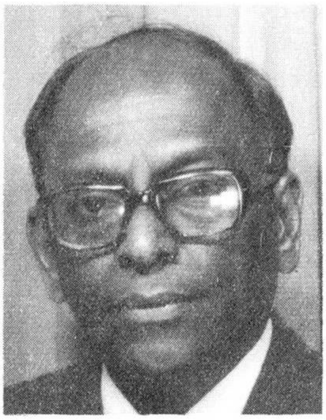
Quality Assurance under Different Forms of Contract

Assurance de la qualité selon le type de contrat

Qualitätssicherung in verschiedenen Vertragsformen

K. SRISKANDAN
Chief Highway Engineer
Department of Transport
London, UK



K. Sriskandan, born in 1930, got his Civil Engineering degree from the University of London in 1952. He has worked on highway bridges for most of his career and is now Head of all Engineering matters connected with the Design, Construction, Maintenance and Operation of the Major Highway network in England.

SUMMARY

It has been established that the majority of structural failures occur due to gross human error during the various stages of the construction process. Proposals which have been tried and found to be successful are put forward for minimising these failures. Finally, the way in which these can be carried out within various types of contract is discussed.

RÉSUMÉ

Il a été constaté que la majorité des dommages causés aux structures est due à des erreurs humaines grossières se produisant à divers stades du processus de construction. Des solutions qui ont fait leurs preuves, sont proposées pour réduire ces dommages au minimum. L'article présente enfin l'introduction de ces diverses solutions selon les types de contrats retenus.

ZUSAMMENFASSUNG

Es ist erwiesen, dass die Mehrheit aller Schadenfälle auf grobe menschliche Fehler in den verschiedenen Phasen des Bauprozesses zurückzuführen ist. Vorschläge für Massnahmen zur Verringerung dieser Schadenfälle, die versuchsweise eingeführt wurden und die sich als geeignet erwiesen haben, werden vorgestellt. Schliesslich wird diskutiert, wie sich solche Massnahmen innerhalb verschiedener Vertragsformen realisieren lassen.

1. INTRODUCTION

Any structure is expected to remain safe and fit for its purpose during its design life. To fulfil this expectation the structure should not fail - and failure is interpreted in its widest sense, ranging from collapse (of the whole or part of the structure) to inadequate durability or unsatisfactory behaviour during normal use, requiring excessive repair to restore the structure.

Assurance about the safety and quality of a real structure cannot be guaranteed by some form of test on the completed structure. Analysis by Melchers et al [1] of selected papers on structural failures has shown that the cause of failure is due in a large percentage of cases to gross human error in the concept, or design, or detailing or specification sense of materials or in the erection of the structure. Two of the tables from the above paper are reproduced here as Tables 1 and 2. Table 3 lists other failures with comments. If failure is to be minimised some form of control must be introduced at each stage and these are discussed in the first part of this paper.

The various forms of contract for the commissioning of structures and how these relate to quality control at the different stages are discussed in Part 2 of this paper.

2. PART I

2.1 The Design Stage

This is the first stage in the construction process. It starts with the concept and goes on to the design of the structure, which in most cases has to comply with building regulations, (where the building is subject to regulations) or some other requirements. The culmination of the design stage is the preparation of the drawings, the specifications and other documents necessary for the construction of the structure.

Gross errors are possible in

- i. The concept of the structure
- ii. Assumptions on structural behaviour
- iii. Calculations
- iv. Translating the design to the drawings
- v. Specifications.

There are two types of 'errors' which arise directly from the structural concept. The first is where the structure is unstable, ie. a mechanism, and this will be treated with ii-iv above. The other is the case where the structure as designed is stable, but has some inbuilt characteristics which makes it unstable in time when some key elements lose their strength due to corrosion and fatigue - and what is worse is that these elements are covered up so that inspection is either difficult or impossible.

In the main these are structures which depend on a tension member for structural integrity (tied arches are a typical example. In the author's opinion, if structures of this type are to be built, provision should be made for easy access to make regular inspection of the tension members, and the client or maintaining authority should be made well aware of the need for regular inspection of the key elements. A large section of the roof of the Berlin Congress Hall collapsed in 1980 and the main cause was the failure of some prestressing tendons due to corrosion and other reasons. Apparently the nature of the structure was such that the collapse could not have been foreseen even by regular inspection

Failures due to error in structural concept are very rare. The author is aware of one case where an error was made, but discovered in checking before the structure was actually built. Such errors are more likely to arise when novel type of structures are being thought of - and of course one cannot emphasise too strongly that one of the major ways of preventing failure is to employ people who have the necessary competence and relevant experience for the job.

The author is a firm believer in the need for structural Codes of Practice. Over the last 15-20 years there has been an overwhelming amount of research carried out on all aspects of structural behaviour that even the most competent of designers will have difficulty in choosing what is more appropriate for their structure. An intelligent use of codes of practice can prevent errors in assumptions about structural behaviour.

Finally, the calculations themselves have to be checked. Different forms of checking have been employed by various authorities. In some, the checker actually goes through the initial calculations and in others the checker carries out a completely independent set of calculations. In the former case the checker, being 'led' by the designer's calculations, may not spot an error. In the latter, any differences found may be difficult to resolve. In the author's opinion, some form of combination of the two is the best. The checker must, using some simple methods, independently work out the critical load effects to compare with the designer's results. Subsequently, it would be necessary to do a rigorous check to verify that the elements are strong enough to carry these load effects.

Computers are used these days not only to analyse a structure but also to calculate the reinforcement, prestressing, etc., necessary in the member. It is essential that intermediate results are printed out if proper checks are to be made. If the checker knows the computer program used by the designer and has sufficient confidence in it, he could accept the results, having verified that the data was correct in the first place.

The building is of course constructed in accordance with the drawings and it is essential therefore that they fully represent the design. In many instances, it is the actual detailing which is in error or gives rise to failure. The provision of reinforcement and laps, etc., can be in error and it is essential that these detailed drawings are kept as simple as possible

Causes of Failure	%
Inadequate or unsuitable temporary works or erection procedure	8
Inadequate design in permanent material	3
Unsuitable or defective permanent material or workmanship	15
Wind	3
Earthquake	8
Flood and foundation movement	49
Fatigue	3
Corrosion	1
Overload or accident	10

Reference: /9/

Table 1 Prime Causes (Bridges)

(especially in heavily reinforced structures) so that mistakes do not slip through the eyes of the checker and then later the builder. The weld details in the steel fabrication drawings may give rise to fatigue and other problems and should therefore be examined by someone with suitable experience.

The specifications describe the quality of material and workmanship required. The structure is designed on the basis that these will be met. It is usual in the UK to use standard specifications for most type of structures and the author is not aware of failures from errors in specification. Nevertheless it is necessary for the designer to ensure that the specification covers all the requirements for his design.

2.2 Construction Stage

During the construction stage errors can arise from

i. Quality of materials manufactured off the site, ie. cement, reinforcement, etc.

ii. Quality of materials produced on site, eg. concrete.

iii. Components prefabricated off the site

   a. Standard, eg. nuts, bolts, anchorages, lintels, etc.

   b. Special.

iv. Erection at site.

Materials and standard components prefabricated off site, ie i and iii (a), will probably have to meet national specifications (eg. BSI) and there will be some kind of quality assurance testing carried out by the manufacturers, in accordance with the national standards. In most cases it would therefore be sufficient to rely on the manufacturers test certificates. Spot checks may be made if necessary.

The other operations can be divided into those which if not properly executed will lead to problems of durability and to others which are likely to lead to failures.

Thus errors in production of concrete on site, placing of concrete, cover to reinforcement, addition of calcium chloride to accelerate curing, etc., are likely to lead to problems of durability. A large number of failures however occur in the final erection stage and this is where more resources should be used in checking.

Following a number of failure of falseworks in the early 70's, both in the UK and abroad, a committee of inquiry was set up. In their Final Report [2] they list a number of cases of failures, and following from their recommendations a British Standard Code of Practice has been published on Falseworks [3] Independent checking of falsework that was set up soon after has reduced falsework failures dramatically in the UK.

2.3 Conclusions on Part 1

The conclusions from Part 1 are that the whole of the process from concept through design to construction should be checked by some party who is independant of the party who did the original work.

PRIME CAUSES OF WHICH SAFETY AND SERVICEABILITY DESIGN FACTORS DO NOT RELATE (Gross errors which could be reduced by checking and supervision)	Weighted %
Grossly inadequate appreciation of loading conditions or real behaviour of structure	36
Grossly inadequate appreciation of loading conditions or real behaviour of connections	7
Grossly excessive reliance on construction accuracy	2
Seriously mistakes in calculations or drawings	7
Grossly inadequate information in contract documents and instruction	4
Grossly contravention of requirements of contract documents and instructions	9
Grossly inadequate execution of erection procedure	13
Gross, but unforeseeable, misuse, abuse and/or sabotage, natural catastrophe, deterioration	7
Others	5
Sub total	90
PRIME CAUSES TO WHICH SAFETY AND SERVICEABILITY DESIGN FACTORS DO RELATE (Stochastic variations which, singly, should not lead to failure but of which a combination of two or more may form an unfavourable situation leading to failure)	
Unfavourable load variation or combination (foreseeable, relating to γ_{S1} γ_{S2})	0
Inaccuracies in design assumptions of support conditions, hinges etc., neglect or environmental effects (relating to γ_{S3})	3
Deficiencies in materials (γ_{m1}-related)	1
Deficiencies in workmanship (γ_{m2}-related)	3
Unforeseen, but foreseeable deterioration	3
Others	0
Sub total	10

Derived from reference [10]

Table 2 Prime Causes

TABLE 3

No	Structure and Failure	Comment and Source	Stage in Construction
1.	Falsework collapse Chicago, USA (1982) (13 people killed)	Suspect foundation, and foundation pads; changes in bracing system; eccentric loading of main cross beams; cracks noticed in foundation pads before collapse but not followed up /1/	Design and Construction of falsework
2.	Walkway collapse, Kansas City, USA (113 Killed, 186 injured)	Walkway suspension system changed during construction but con-connections were also inadequate. /1/	Inadequate design of connections Effects of change during construction
3.	Collapse of apartment block Cocoa Beach, Florida killing 11 workers and injuring 23 others	Punching shear failure of 5th floor slab /1/. Two way top reinforcement was 25mm lower on average than shown in the drawings./1/	A combination of design and construction
4.	Partial collapse of Kongresshalle, Berlin (23 years after completion)	A combination of many faults - but finally due to failure of prestressing tendons. Nature of structure was such that this could not have been predicted by regular inspection /1/	Was it design, or inadequate maintenance - or should structure be constructed at all?
5.	Roof collapse: Camden School for Girls, UK (18 years after completion)	Insufficient bearings of roof beams off edge beams, aggravated by corrosion of steel and conversion of high alumina cement concrete. /7/	Design detail and wrong use of material in construction
6.	Collapse of one main beam of post tensioned steel in Warehouse with prestressed concrete main and secondary beams. UK	Corrosion of tendon due to 2%-4% calcium chloride in concrete by weight of cement /7/	Wrong use of materials in construction
7.	Corrosion of steel and cracking in concrete in prefabricated reinforced concrete houses designed before 1960 (UK).	R.C. components gradually deteriorating due to carbonation of concrete and in some cases presence of calcium chloride leading to corrosion of steel and cracking of con-concrete /8/.	Poor detailing and wrong use of materials in construction.

3. PART II

3.1 Types of Contracts

Structures can be commissioned in the following variety of ways:-

(a) i. By the traditional method, where the parties are a client, an Engineer who designs and supervises the construction, which is carried out by a contractor under a contract between the client and the contractor.

ii. By an alternative design submitted by the contractor under the same arrangements.

(b) A design and build contract where the client invites tenders for the design and construction, based maybe on an outline design.

(c) Target cost contract where a target cost is negotiated with a selected contractor, based on a design prepared for the client by his appointed Agent or Engineer.

(d) Structures designed and built by some organisation with the intention of letting the building (eg. large office buildings, blocks of flats or hotels) - here the owner is a construction company which finances the whole operation.

(e) Management contracts with or without the management contractor taking responsibility for the design team.

3.2 The Normal Contract-Alternative Designs-Design and Build and Target Cost

In the traditional type of contract, responsibilities need to be clearly defined in the conditions of contract. Under the ICE Conditions of Contract /4/ the Engineer takes responsibility for the design drawings, specifications, etc., and the Contractor for the construction of the structure. On the basis of the conclusions in Part I the design needs to be checked by an independent party. During construction the Contractor will carry out his quality control but the compliance with drawings and specifications should be checked by the Engineer carrying out such tests as necessary. The ICE Conditions are also very clear on the responsibility for temporary works. It states that if requested by the Engineer the Contractor should supply details of all temporary works and calculations of stresses, strains and deflections that will arise in the structure during construction so as to enable the Engineer to determine whether the works can be completed in accordance with the drawings and specifications without detriment to the structure.

The Engineer has to give his consent in writing to the Contractor's proposals but this consent does not relieve the Contractor of his responsibilities under the contract. In the Department of Transport, we consider this to be a sufficient check for the normal structure. However in the more complex cases, the Contractor is required to provide a certificate by an independent organisation about the adequacy of the falsework and/or method of erection.

In the normal case the Engineer would be able to discuss maintenance methods with his client and arrange for this in his design. However if a Contrctor submitted an alternative design, he would not necessarily know all the maintenance requirements. It is therefore useful if contractors who proposed to submit alternative designs did inform the client about it in good time. There is also the question of checking the alternative design. The Department of Transport normally permits submission of alternative design - but these are checked by the Engineer for safety and durability in accordance with prescribed rules before they are accepted. Once the Engineer accepts the design (which will also depend on the financial savings offered) it is adopted as his own within the conditions of contract.

Alternative designs and designs for a design and build competition are likely to be the minimum required in the tender. It is therefore absolutely essential that requirements for safety, durability (and maintenance, etc.) are clearly spelt out. It is fairly easy if the requirements for safety and durability both in design and construction, can be given in terms of national standards. Specifying one set of standards will also ensure parity of tendering. It will be much more difficult if as is reported in international tendering that tenderers are asked to submit designs in accordance with the standards of their own countries.

A client who wishes to adopt a design and build competition will want to be assured about the safety and durability of the design and also that the accepted design is constructed in accordance with the drawings and specifications. If someone checks the calculations and the drawings, there can be a blurring of responsibilities. The problem can be more aggravated in respect of foundations if the only ground investigations were done was on behalf of the employer. In two design and build contracts for the Kessock Bridge /5/ and the Foyle Bridge /6/, submissions were invited on the basis of fixed criteria and the clients appointed Engineers to check the designs and when satisfied, adopted them as their own and then administered the construction under the ICE Conditions of contract with minor amendments. This also overcomes the problems of the foundation. If the Engineer is content with the safety of design under the known ground conditions, there is scope for re-imbursing the Contractor for extra work necessary if unforeseen conditions are met during construction. The author understands that the clients did not attempt to specify the requirements for maintenance because they did not know what type of bridge or what material would win the day. Instead, during the design checking period, they negotiated with the successful tenderer and introduced such modifications as were necessary to facilitate access for inspection amd maintenance.

In some countries the checking of the design and supervision of construction is entrusted in some cases to insurance companies who employ competent engineers to carry out this work. The insurance companies then give a guarantee of 10 years. The position is not much different to the use of private consulting engineers who would carry a professional indemnity insurance, but the period of cover would vary according to the law in different countries.

As far as quality assurance is concerned, a target form of contract is no different from the normal type of contract. The design needs to be checked and the Contractor's work should be supervised, and compliance testing carried out.

3.3 No Contracts

Some structures are built by private developers for their own use and therefore a formal contract may not exist. Nevertheless safety and durabilty have to be assured and of course Building Regulations have to be satisfied. In UK this has meant that the structure has to be safe and designed in accordance with deemed to satisfy codes. This, nevertheless, meant that the design has to be checked by Local Authority Officials and the construction also supervised to ensure adequacy.

There is a new proposal now to pass the job of checking designs and supervision to the private sector. The proposals include setting up of a panel of Certifiers and another panel of Inspectors, with Professional Institutions accrediting these people. Parallel with that there is also a proposal to introduce approved documents (such as design codes and specification). These measures if accepted and properly carried out will improve the quality assurance of structures.

This proposed procedure is in a way analagous to that followed by the Department of Energy in the UK for the Certification of Offshore Installations. In their documents [9], they state that all offshore installations established or maintained in waters around the UK to be certified as fit for the purposes specified - and they have authorised 6 organisations to issue such certificates. The first certificate is expected to cover both design and construction followed by re-certification after major surveys.

3.4 Management Contracts

As far as quality assurance is concerned, these are not much different from those mentioned in 3.1. The designer may or may not be a part of the Management Contract team. If he is outside he will be independent as far as safety, etc., is concerned although he may be controlled by the Management Contractor on his programme of work and also the design as far as it affects the method of construction. Nevertheless, an independent check of the design is necessary. Usually the management contractor does not carry out any part of the construction. He will of course supervise the construction and this should be adequate.

4. CONCLUSION

a. All design and construction should be independently checked to ensure safety and durability of the structure.

b. From the point of view of quality assurance, most of the contract systems can be grouped into those where the designer is independent of the builder or those where the designer and builder are the same party.

c. In the traditional contract system the responsibilities of the parties are clearly defined and checking can be carried out without blurring responsibilities.

d. One way of treating design and build is for an independent checker, after satisfying himself on the adequacy of the design, to adopt it as his own and supervise the construction as in a traditional contract [other contract systems may exist for this in other parts of the world].

e. Provision has to be made by Governments for certification in the rare case where the owner is also the designer and builder.

5. ACKNOWLEDGEMENT

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