

Quality In Construction – The Long-term Owner's Needs The Necessary Policy and Management Actions

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SYNOPSIS

This paper discusses the general principles that can assure road projects conform to specification. The principles are general, but it is a bridge engineers perspective on quality.

It assumes the road authority is capable of selecting a contractor who is technically competent to do the job, and the detailed specifications to guide the contractor are in the contract documents.

This paper focuses on the responsibilities and actions of the road authority to ensure they are delivered the quality they specified. The supply chain for a bridge can be through five or six organisations. Quality of intermediate products will not be assured by a contract between a road authority and a contractor. The road authority needs to monitor quality issues in casting yards, concrete suppliers, cement, aggregate and steel suppliers, and others. Unless care is taken, the certificate of compliance to a standard may be worthless.

It takes effort and expertise and a long term systematic approach. The wealth of a community can be very adversely effected by poor quality basic infrastructure.

• SIMPLE OR COMPLEX (REAL LIFE) QA MODELS

The quality assurance system described in ISO9001 – 2000 is a simple "three party" model describing the relationship:

Suppliers _____ Contractor _____ Customer

Real world contracts have a more complex supply chain, with six or more levels of interaction between many parties (see Figure 1)

Quality Assurance systems were developed to control mega-projects initially (North Sea Oil platforms, Concorde, Nuclear Power station construction) but the principles are general and apply to normal small construction projects such as bridges. Most of the principles are "common sense" or "good practice" and most competent organisations had many of the elements of a quality system in their normal operating systems. However, few organisations had a "comprehensive" system until they went through the rigour of assessing their procedures against a quality system code.

Unfortunately, ISO9001 does not clearly describe the economics of risk, testing, inspection and prevention, specific to any one industry, as it is an abstract model designed to cover any situation. Keeping the total costs of a construction project to an optimum level (maximum benefits for minimum costs) is always the primary driver in allocating the "prevention and checking" resources. The amount of effort invested in controlling a construction process should be proportional to the cost of "process failure", which leads to "product failure", and, if the product is critical, leads to "project failure".

• VARYING PERCEPTIONS OF QUALITY AND HOW TO IMPLEMENT IT

Unfortunately, many construction authorities saw the introduction of QA as an opportunity to wind back on their "prevention and checking" activities (cost saving) without ensuring that equivalent control was resourced and motivated elsewhere in the supply chain. Intense competition has reduced the investment in "prevention" at all stages of the supply chain. Some fundamental quality control activities require knowledge, experience and laboratory resources not available in the normal supply chain. If the construction authority does not monitor these fundamental issues, no one else does either. These include the quality of fundamental construction materials such as bitumen, cement, aggregates, reinforcing steel, prestressing strand, and concrete additives.

In the 1980's and 90's, Total Quality Management also developed as a major quality initiative in Australia, following Japanese and American experience. The concepts of continuous improvement and statistical process control were complementary to QA but for a period, many saw them as competing and incompatible philosophies. Fortunately both concepts have evolved to include each other, and only the relative emphasis on TQM or QA seems to separate the business models today.

The concept of "continuous improvement" is a double edged sword. It can lead to significant improvements in products or cost savings, but it can also lead to significant high-cost "disasters" when applied without profound knowledge of the system. Any change in materials, design details, or processes that can affect the quality of the product, must be done with great care, and preferably as a separate R& D project with additional monitoring, testing, time and control of resources, rather than at the hectic pace of a normal construction project.

This paper sets out how quality assurance in bridge construction should operate, combining

- The QA principles,
- Economics of risk and prevention,
- Technical knowledge and resources,
- Economics of critical mass,
- Costs of "at-source" testing v.s. project testing,

to achieve "conforming" projects (customer satisfaction), plus supplier and contractor satisfaction (profitable contracts).

Any engineer who has supervised construction contracts knows the difference between

- A contractor with clear and accurate documentation, minimum latent risks, and operating profitably, and
- A contractor with inadequate documentation, high latent risk, and operating at a loss.

If the Construction Authority's own quality system doesn't deliver the first option in virtually every contract, then no quality system will save them from the problems inherent in the second option.

- **CONCERN OVER CONSTRUCTION QUALITY**

Many construction authorities adopted Quality Assurance as a technique to ensure construction quality in the late 1980's and early 90's. A decade or so later, many are disillusioned with the results. Is QA a failure?

No! As a basic management theory, QA is still widely accepted as a valid approach.

There is little doubt however, that many organisations misunderstood the concepts of QA, failed to implement effective quality systems, and are suffering from alarming reductions in the quality of projects. For many, this was due to lack of effort in training, and a lack of understanding of what was involved. For most, one of the basic reasons for failure was the simplistic model being used. If a "customer" believes that quality is the sole responsibility of the manufacturer / contractor the system is destined to fail. To be effective, each organisation in a supply chain must have complementary quality systems, controlling all the critical risks.

- **THE ROLE OF THE "BUYER"**

This paper sets out to describe practical multi-layered quality systems with emphasis on the role of the Construction Authority. Responsibility for control of each risk should fall to those best able to do the job. The long term owner must deal with the long term risks!

One way of looking at the joint responsibilities of a buyer and supplier (and real systems have many buyer/supplier pairs in the supply chain) is to set out the two "basic axioms"

- o The supplier is responsible for achieving the specified quality and being able to demonstrate compliance.
- o The buyer is responsible for clearly specifying what is wanted, how it is to be measured and assessed, and to check carefully that they receive what is specified, and to do all this at minimum cost to both parties.

Expressed this way, the buyer carries a fair proportion of the quality responsibility. It is not all the suppliers responsibility.

Why is Quality an issue? Many Construction Authorities are concerned they are not getting the quality they have specified, and are blaming QA, when they should be considering how to make an effective multi-layered system that economically and effectively controls the risks.

- **THE SIMPLE CODE MODEL FOR QA**

The simple three-party supply chain (previously described) and details what the "manufacturer" should do. (In bridge construction, this would be the "contractor".)

For many situations, this is quite adequate, and most household goods are produced this way (ignoring wholesalers / retailers between manufacturer and customer.)

This model assumes all technical knowledge about "fitness for purpose lies with the manufacturer, and the customer has no unique or specific requirements.

It also assumes the customer has little technical knowledge, but can tell if the product (a refrigerator, computer or car) works satisfactorily, but cannot tell whether it complies to the detailed specifications (e.g. engine torque, or computer operating speed).

• NOTATION AND TERMINOLOGY

In adapting the terminology of the Code to civil construction the following terms will be used.

- Supplier and subcontractor are similar entities in this model
- Manufacturer and contractor are equivalent.
- The customer is the Road Authority
- Different names are used in different situations.
- This paper will use the terms common to civil construction or the code as relevant.

• THE REALITY OF A CONSTRUCTION CONTRACT

- The customer is the Road Authority. There are more "customers" in reality, (motorists, freight industry, maintenance contractors etc.) but for the purpose of this paper, the road authority acts as agent to ensure the product delivered (a road link, bridge etc.) is "fit for purpose" for the other customers.
- The road authority normally appoints a superintendent to fairly administer the contract. This person can be a staff member of the authority, or a consultant. It is assumed this person has the knowledge, skill and experience to accurately interpret and clarify all the plans and specifications and ensure the contractor understands what's required and delivers it.
- The main contractor is responsible in a legal and technical sense to deliver the works as specified for the agreed payment.
- The contractor will engage one or more subcontractors in a chain that may have several levels. A precaster may supply concrete bridge components or culverts, and in turn has subcontractors who supply formwork and premixed concrete (both critical to the final quality of the job).
- At the start of the supply chain are the material suppliers who may supply to a subcontractor, the main contractor, or even to the construction authority depending on circumstances. These suppliers (cement, aggregate, steel, prestressing strand etc.) may be manufacturers or importers from overseas suppliers. The quality of these materials is fundamental to the quality of the finished product. Few, if any contractors, have the ability to check the quality of these materials for conformance.

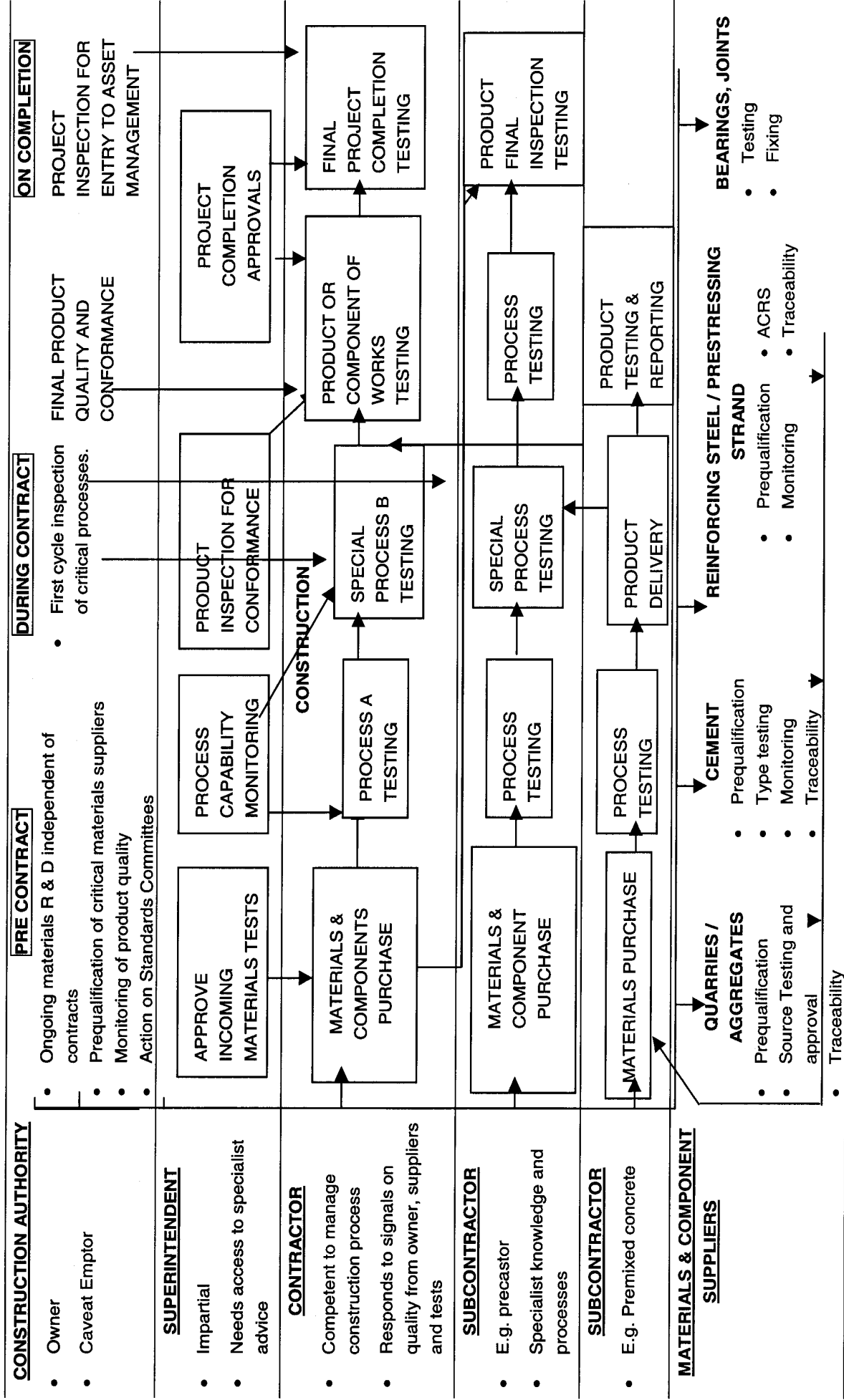
All these parties to a typical bridge construction contract need to interact in a fairly complex way as illustrated in Figure 1

There will usually be many other stakeholders involved in a bridge project, including

- Services authorities (water, telecom etc.),
- Adjacent landholders,
- Environmental consultants, authorities etc,
- Local government authorities.

Although these add to the complexities of managing the construction processes, they normally don't affect the quality of construction, and will not be considered further in this paper.

Figure 1 Quality in Civil Construction – map of "quality issue" interactions in a typical bridge contract



NOTE: This diagram is INDICATIVE, and not meant to show ALL interactions.
Some of the interactions fall under the Contract. Others occur independent of the Contract.

(a) NEED FOR VISION, ORGANISATION AND CO-ORDINATION

Complex real-life effective quality management systems as illustrated in (figure 1) do not happen by accident.

Most of the man-power requirements for a road authority are needed at the project level, superintending the works.

Most of the thinking, planning and co-ordination needs be done at a corporate/central level, outside any specific contract. Since the issues are mainly technical (specifications, testing, acceptance criteria, industry liaison etc) this is best done at a "technology head-of-discipline" level to ensure the appropriate quality is specified, that the appropriate regime of contractor (process-control) tests and owner-supervised (acceptance) testing is done, and only conforming product is accepted and paid for.

Many construction authorities have downsized the corporate technical specialist areas and many of these higher level quality management processes are not operating effectively. Relying only on project based management systems can never be effective as much of the material and product testing is long term (months to years) and cannot be done in a tender or rapid construction process time period.

(b) QUALITY ISSUES ARE INDEPENDENT OF CONTRACT FORM

Much of the debate about quality in construction revolves about the various forms of contract.

- (c) Traditional – competitive tender to a detailed design
- (d) Design and construct (D&C)
- (e) Build, own, operate and transfer (BOOT)
- (f) Partnering
- (g) Alliances.

In principle, the contract form should not effect quality, IF the owner carries out his responsibilities to:

- (h) Specify clearly and precisely what is required, and
- (i) Check that what is delivered conforms to the specification.

If the owner prefers to distance himself from clear and comprehensive specifications, and rely on vague legal concepts such as "fitness for purpose", and assumes the Contractor's quality system will be so good that the owner does not need one, then quality is highly likely to become an issue. The reason is simple. The owner's needs (for a highly durable and fully functional product) and the contractor's needs (to save time and cost and maximise profit) are not automatically compatible. Of course they can be made compatible, but only by concerted effort by both parties.

(j) YOU GET THE QUALITY YOU PAY FOR

This often forgotten principle has two distinct meanings;

- (k) If you want a high quality, functional and durable (minimum whole-of-life maintenance costs) project, the owner must be willing to pay more than the cheapest

price offered in the market place. This is a process of setting adequate standards, and having a tender selection process that includes competence and quality as well as price.

- (l) If the owner pays (monthly progress pay) for any product or service that doesn't fully conform to specification, he has implicitly approved a new (less rigorous) specification. If this process continues over time, the quality will continuously degrade. This is not the contractors fault, as payment is a practical and legal indicator of satisfaction.

In the end, the quality decline may be halted by strong and resolute action by the owner – enforcing the removal and replacement of non-conforming work at the contractors cost. This will not happen by chance. The longer the quality decline continues the more difficult it is to fix the problem. Superintendents must be competent, have access to expert assistance, and demand conformance. Rejection must occur when the first nonconforming product is offered for payment, not when the job is near completion.

Unfortunately, many quality defects are hidden, and cannot be economically detected at the end of the process. This leads to earlier than normal failure and rapidly rising maintenance costs. If the time lapse is several years, the owner has little chance of recovering these costs from the contractor. This is why "special processes" are defined and closely monitored by a quality conscious purchaser. ISO 9001 has a number of requirements for the customer to monitor inspect and control product quality and acceptance. See Appendix A.

(m) CONTROL OF THE "DESIGN AND CONSTRUCT" PROCESS

At a superficial level, this is apparently quite a simple task. Specify the right design method (e.g. Austroads Bridge Design Code) and adequate construction specifications (e.g. authority's normal construction specifications) and the problem is solved. Unfortunately all design and construction specifications allow a wide range of choices, which dictate the final product quality.

In "traditional" contracts it is assumed the designer acts for the owner in selecting appropriate choices so the project is "fit for the owner's purpose". In a traditional contract, the prudent owner (who is interested in obtaining adequate quality) will carefully check that the design meets the owners requirements before going to tender.

In a "design and construct" contract, unless the owner is involved with expert staff who understand and vet every detailed design decision, it is highly likely the design will be "fit for the contractor's purpose". This detailed supervision is difficult and rarely done as it is seen to conflict with the "spirit" of a design and construct contract. But it can be done, and is very effective.

There are innumerable ways of degrading "quality" that occur every day, and only expertise and vigilance can prevent this. A single example will be used to illustrate how the quality (strength and durability) of a simple component such as a bolt can change through a series of steps that may not be at all obvious until a component fails in service:

- (n) High tensile, highly durable stainless steel
- (o) Normal tensile, durable SS
- (p) Lower grade SS

- (q) Galvanised high tensile
- (r) Galvanised normal grade
- (s) Electro-galvanised normal grade

The cost, time and effort in getting the high quality product may be considerable, while the cheaper product can be bought at most hardware stores. The savings are obvious. So are the costs if a major bridge expansion joint fails due to installing the wrong bolts, and has to be repaired under traffic. Sometimes, failure is very rapid, and the reason obvious. But often, failure is slower, and the reasons difficult to determine after a few years.

(t) CRITICAL MASS

Many quality-related tasks require specialist knowledge and equipment. In many cases, these are found only in university and road authority laboratories, or with major manufacturers such as cement works and steel mills.

It is economical to use existing facilities and expertise. If the testing authority is "independent", one set of tests can satisfy all parties. It is wasteful to test more often than necessary, and if the tester is not independent, then either:

- (u) Additional "audit" testing can be done by an independent body, or
- (v) The owners representative / superintendent can witness the contractors / suppliers testing.

(w) HOW MUCH INDEPENDENCE AND CARE IS NEEDED?

Few people are trusting enough to take a bag of money to the bank for deposit without counting it first. If you happen to be the treasurer of the school fete committee, it would be prudent to count the money in the presence of witnesses (preferably two) and get them to sign the cash book recording the takings before you go to the bank. Of course, you will expect the teller to count the money in your presence and issue you with a receipt that agrees with your previous witnessed count. All this care for a few hundred dollars.

How much care is needed on a bridge construction job? If you are exchanging millions of taxpayers dollars for an asset, the contractor will carefully check the quantity of dollars, and the authority should just as carefully check the quality and quantity of the "product". This means watching every critical operation, testing every critical component, and observing or conducting every critical test.

If you haven't got the expertise to check everything, the superintendent must seek specialist advice and assistance, not for every operation or test, but for all initial tests, and until it is clear to all parties that the construction processes are "under control" and producing conforming product. The basic concept is to find problems quickly, and fix them at minimum cost to all parties.

An Authority who leaves the task of "measuring the quality" of a multi-million dollar project entirely to contractors and suppliers, and relies on pieces of paper attesting to conformance is

failing its responsibilities of care. Why did the Romans declare "caveat emptor" two thousand years ago?

(x) TESTING AT SOURCE OR ON SITE

Major manufactured materials in road and bridge construction (bitumen, cement, steel etc.) can be quality assured in two ways

- (y) Testing at source, with identification and traceability down to the individual batches, products and components used in construction.
- (z) Testing on site, with site traceability into products and components.

In general, it is much more economical to test at source and have adequate traceability. The cost of sampling and testing on site is so high that it is rarely done.

Most large manufacturers have a critical interest in their reputation and the quality of their product, but others whose products are traded internationally as unbranded commodities may not supply reliable certification.

Where possible, industry wide product certification schemes can create a "level playing field" of independent testing and quality control. The Australian Certification Authority for Reinforcing Steels (ACRS) has been established to ensure both local and imported steel and stressing strand meet the relevant Australian Standards at a testing cost of approximately 20 cents per tonne.

If a 2 tonne coil of strand of unknown source has to be tested on a project (yield, ultimate strength and relaxation losses) the cost is over \$1000. This illustrates the efficiency of "at source" testing and traceability.

Who should control and monitor this process? Only the Road Authority can do it, and, as they are the major beneficiary of assured quality, it is logical the Authority does it.

Any attempt to pass this task on to a contractor will either:

- (aa) Be very expensive if effective, or
- (bb) Be not done effectively, be cheap, and provide no long term protection to the owner authority.

(cc) THE NECESSARY CAPABILITY OF SUPERINTENDENTS

Whether the superintendent is a member of the authority staff, or a consultant should be largely immaterial. It is a basic requirement that the superintendent has the knowledge and experience to do the job. If not, he must be trained and supervised by someone who does. If an authority buys in a consultant at the cheapest price, it should not be surprising that young graduates without knowledge or experience will be doing the job, and the product quality will be uncontrolled. If the contractor is competent, has a reasonable contract price, and has a reputation for quality to uphold, all may be well. But if the contractor has also bid the cheapest price, has inexperienced staff, and sees survival as more important than reputation, one can virtually guarantee increasing quality problems, and higher than necessary maintenance costs.

In general, there is sufficient expertise in Industry (if the authority can run an effective tender selection process) and in the Authority to get adequate (specified) quality.

The task, however, is to get the expertise to the job so that:

- (dd) Problems are foreseen and prevented,
- (ee) Problems are discovered in the first construction cycle when they can be fixed quickly at minimum cost, and
- (ff) Non conforming product / materials are identified and disposed of before they are incorporated in the works.

Finding problems early and fixing them quickly and cheaply is a necessary precondition for a successful contract – for both the owner and the contractor.

How many superintendents are properly briefed on the authority expertise available, how to contact them, and the imperative to seek help if in any doubt?

Many authorities have made this process more difficult with "commercial" arrangements where advice and help is seen as a significant extra cost.

However, most authorities can provide a long list of jobs where the problems were found too late, and the cost of rectification was painfully high (irrespective of who pays for it on an individual job, the owner pays for it all in the end). Examples of "too little too late" include

- (gg) 220 prestressed concrete deck units found to be defective near the end of a construction job.
- (hh) Several thousand stainless steel sockets cast into concrete decks for bridge expansion joints, failing when joints were tensioned up, requiring complete replacement.
- (ii) 59 long-span PSC super T girders having defective concrete cover.
- (jj) Culvert pipes found defective after 13m of embankment and pavement constructed above them.
- (kk) Hundreds of rubber pot bridge bearings with faulty manufacturing tolerances (so the rubber gradually extrudes) found after installation in many bridges on major roads.
- (ll) Welded steel barrier posts with fillet welds instead of butt welds. These suffer crevice corrosion after acid dipping and galvanising and have little strength after 10-20 years.

(mm) **WHAT SHOULD BE DONE?**

As the problem of poor quality construction lies with the owner, the Road Authorities should do a number of basic things.

- (a) Train and retain sufficient competent and experienced staff to set standards (Australian Standards and construction specifications), supervise construction, and perform the specialist testing required during contracts and outside of contracts – source approvals, prequalification of products etc.
- (b) Train superintendents to do the daily monitoring and surveillance during construction. Ensure they have instant free access to specialist expertise, and insist they seek advice whenever necessary. Do not expect consultants to provide competent experienced staff at the lowest competitive price.

- (c) Review testing authorities and preferably prequalify them. If the testing company is employed and paid by the contractor and reports directly to the contractor, why should they be motivated to look after the road authorities interests? How should testing be structured so the testing company is "loyal" to the buyer rather than the supplier? Prequalification of testing companies, and regular audit and review would be a start.
- (d) Where the road authority has capable staff and a well equipped laboratory, the most economical outcome is likely to be that testing is done by the authority. QA codes don't dictate who tests, just that testing must be done effectively (not efficiently).
- (e) Clearly distinguish between process control tests and product acceptance tests. Process control is the Contractors responsibility, acceptance is the road authority's responsibility. The same tests can be used for both purposes, but care is necessary.
- (a) Study the supply chain and the risks of non-conforming product proceeding to the next stage of construction. At some point, the cost of rectification may dramatically increase. Quality must be assured before this point. Testing is determined by the risks and costs, not by abstract principles.
- (b) What was considered "good practice" before QA was adopted? It is highly likely that it is still good practice. QA and good practice are always compatible. I would be interested in any examples where this is not so.
- (c) Does the construction authority have effective feedback loops that enable field staff superintending contracts to feed problems and suggestions for improvement back to those who wrote the construction specifications. Does each specification have a contact name and phone / fax number to facilitate seeking advice and offering feedback?

Australian contractors and suppliers, on average, are competent and able to supply adequate quality in road construction.

A road Authority will get

- (a) The quality it is willing to pay for
- (b) The quality it insists on getting
- (c) The quality it deserves.

Quality requires competence, expertise, planning, a long term view, effort, persistence and vision by the buyer as well as the contractor.

Quality cannot be consistently purchased easily and cheaply. There is much work to do!

Appendix A

Clauses in ISO9001 which indicate a Customer should monitor supplier's processes. These are the responsibilities of a Road Authority in its role as "customer".

Introduction General	Adoption of a QM system should be a strategic decision of an organisation. The design and implementation of a QM system is influenced by varying needs, objective, products and processes.
4.1 General requirements (of QM System)	Where an organisation chooses to outsource any process that affects product conformity, the organisation shall ensure control over such processes. Control over outsourced processes shall be identified in the organisations QM system.
5.2 Customer focus	Top management shall ensure customer requirements are determined and are met.
6.1 Provision of Resources	The organisation shall determine and provide resources needed (a) to implement QM system (b) to meet customer requirements
7.4.2 Purchasing information	Purchasing information shall describe the product to be purchased, including (a) requirements for approval of product, procedures, processes and equipment. (b) Requirements for qualification of personnel (c) QM system requirements
7.4.3 Verification of purchased product	The organisation shall establish and implement the inspection or other activities necessary for ensuring that purchased product meets specifications. Where the organisation or its customer intends to perform verification at the suppliers premises, the organisation shall state the intended verification arrangements... in the purchasing info.
8.2.4 Monitoring and measurement of product	(a) The organisation shall monitor and measure the characteristics of the product. (b) This shall be carried out at appropriate stages of the process (c) Product release... shall not proceed until the planned arrangements have been satisfactorily completed, unless otherwise approved... by the customer.
8.3 Control of non-conforming product	The organisation shall deal with non-conforming product (a) to eliminate detected non-conformity (b) by authorising its use... by concession...by the customer