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Creation, Maintenance and Management of the World's Assets: Appropriate Quality and Technology for the Future

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Peter Head, born 1947, received first class honours degree in Civil Engineering from Imperial College London in 1969. Joined Maunsell in 1980. Design and management of many major bridges including the Second Severn Crossing. Awarded the Royal Academy of Engineering's Silver medal in 1995, received an OBE in 1998 and in 1998 received the IABSE International Award of Merit for innovative work in advanced composite materials.

Summary

The construction industry has lagged behind most other industries in the improvement of quality and reliability of its products. In many ways the search for ever lower capital costs and speed of construction has tended to drive reliability to the bottom of the agenda and clients are now often faced with deteriorating assets with no built in methods of monitoring or yardsticks for judging whether the situation is unsafe for the users or not.

The paper will examine these issues in an open honest way and conclude that designers are currently too willing to repeat the mistakes of the past because engineers are conditioned to follow proven and yet poor practice. There is an underlying dishonesty about what can actually be achieved in many real world situations, a detachment between design and the reality of construction quality and usage.

A new step by step approach will be set out which addresses the key problems, based on the total quality method for the complete system which is used in many other industries. For example vulnerable components should either be avoided or, if this is not possible, protected as much as possible, be able to be monitored and be accessible for maintenance or replacement without compromising the convenience and safety of the users. Accessibility should address not just the situation on opening, but the access available once the asset is overwhelmed by use.

Quality of construction needs to address the complete system and high quality factory produced components will not help unless they can be installed without damage and the joints can be formed in-situ without compromising the whole life integrity. Again if joints are vulnerable they should comply with the above.

Another vital area is flexibility for change of use which is so often ignored in a low material content approach to design and yet can be the key economic issue for the owner.

The paper will aim to set out an approach that can be followed to achieve many innovative approaches to construction which will provide clients with more appropriate lower whole life cost solutions tailored to their needs. Examples will be given of successful applications of these techniques.

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Aesthetics and Structural Design

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Armando Rito, born 1936, received his civil engineering degree from the Technical University of Lisbon. Has devoted is professional life essentially to bridge design. Received the AFPC medal (1997) and the FIP medal (1998) for his accomplishments in prestressed concrete design.

Summary

Where structure is dominant and where technical and structural matters used to control the design, esthetical considerations are now, among learned designers, considered to be an issue as important as the other two. Aesthetics in structural design is, at last, considered a fundamental issue.

As a contribution to this matter, in the following text a few considerations on the subject will be presented.

Keywords: Structure; aesthetics; beauty; design; environment; quality; roof; dome; tower; bridge.

Abstract

The fundamental goals of structural design should be to serve the public needs with economy, durability, scrupulous environmental respect, and good aesthetic quality.

Design must be governed by function. A functional design is simple and simple designs are beautiful. A gigantic design, record breaking for record sake, is neither responsible designing nor progress. No technological breakthrough can justify a design out of proportion with the intended objective.

Many old structures are superb because their designers, their builders and also their Owners considered esthetical quality a value as important as safety, functionality or economy. Besides the creativity, they possessed the necessary educational and cultural background to understand this simple truth and, thus, implement aesthetics in their works.

Unfortunately, in spite of the present concern with aesthetic quality in structures, many of the contemporary designers and public officials still lack the adequate cultural and educational preparation needed to carry out their jobs properly.

From the second half of this century to the end of the eighties, economics took precedence over creativity. In fact, design became governed by "economics", in the sense that building cheaply became the final goal for the majority of the Owners.

The consequences can be perceived everywhere. Hideous constructions invaded our environment.

We, designers and builders, should make every effort to see that this state of affairs is changed.

Every construction involves modifications on its surroundings. Therefore, if the structure is apparent, as its structural options will be reflected in the final aspect of the building, a bad option can disfigure the edifice and its environment.

As such, the structure must represent, with simplicity, economy of means and in harmony with its environment, the flow of forces it is called upon to master. Simplicity of design leads to simplicity of construction and simplicity of form. Furthermore, form must clearly represent the function for which the structure was conceived. A sound structural design is always a good foundation for an aesthetically pleasing structure.

Consequently, if those objectives are achieved, the structure will certainly have a beautiful visual aspect. It certainly does not need any additional, and usually superfluous, embellishment.

Design must address from the very beginning the key issues of functionality, safety, durability and cost. However the designer must be well aware that aesthetics, being also a key issue, is as important as the other ones.

In fact, if a good design is to be attained, one must start one's own work by addressing first of all both functional and esthetical issues. Still, esthetical considerations, having been present at the very beginning of the project, must continue to be addressed during every step of the subsequent phases of the design.

As an engineer, I have a strong feeling that the structural designer must handle himself the aesthetics of his own structures. In fact, no one knows better how to satisfactorily deal with this challenge. No adviser can aesthetically rescue a poorly designed structure, or conceal its inadequacy.

In the last twenty years we witnessed that, among several renowned structural engineers, a renaissance of esthetical concerns has been under way setting an example for their contemporary colleagues and for the new generations of designers.

Contrary to the earlier habits, in designs where structure is dominant, the absolute prevalence of the technical and structural aspects began to soften and aesthetic considerations commenced to change for better the appearance of many of our present works.

Without abandoning structural functionality and economy, sensible designers began to integrate in their projects cultural values, as well as social and environmental concerns.

Unfortunately, the present computing capacity and modern technological means allow us to materialise almost any absurdity we can conceive. We can thus witness that, by the sole desire of being different, many designers have departed from sensible design creating structural aberrations that serve no other purpose than promoting their egos and the ones of their clients.

Successful structures are the final result of a complex and joint labour of skilful designers and discerning Owners. Therefore, both should be very demanding on their projects. It must be clear to us all that if the Owner demands cheap designs no designer, no matter how talented he is, can deliver an aesthetically satisfying structure.

One of the best ways to development is to educate people through the example of fully accomplished constructions. We should never forget how pervasive structures are on our day to day lives, how they contribute to ameliorate, or to ruin, the perception of beauty and, consequently, the quality of life.

Thus, although aesthetic quality is an elusive and hardly quantifiable value, we should spare no efforts to provide the public with structures of purer aesthetics and more human dimension. To accomplish that, aesthetics must become a full concern of our everyday life.

Future generations will not forgive us for ruining the environment and spreading hideous and obtrusive constructions, no matter how technologically exceptional they are.

Sustainability and Civil Engineering: From Concept to Action

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Abstract

Developed and developing nations have been facing problems such as widespread infrastructure deterioration, pollution, and urban sprawl; natural resource depletion and degradation, waste generation and accumulation, and environmental impact and degradation; and overpopulation, disease, and social, economic, and political conflicts. The complex interrelationship between the economic development needs and the environmental problems resulting from development efforts is compounding these problems, and also, is the source of increasing conflicts and growing concerns for many nations of the world today, affecting individuals, communities, businesses, industries, and private- and public-sector organisations. In response, scientists; engineers, architects, and urban planners; medical and other health professionals; members of the financial community; government, policy-making, and regulatory officials; members of non-governmental organisations and civic groups, are devoting significant efforts toward finding workable solutions to these problems. Sustainable development has emerged as a potential solution. In broad terms, sustainable development was defined by the Brundtland Commission as "...meeting the needs of the present without compromising the ability of future generations to meet their own needs."

For engineers, sustainable development and sustainable technology mean that sustainability goals, concepts, and principles must be integrated within all stages of the life cycle of the planning, design, production, delivery, and use of goods, products, and services. Specifically within the Architecture-Engineering-Construction (A/E/C) industry, to achieve sustainability either at a global Civil Infrastructure Systems (CIS) project or at a specific Structural Systems (SS) project levels, two fundamental changes are needed: (1) decision-makers must integrate sustainability goals, concepts, principles, and guidelines explicitly and systematically within their decision-making processes at all stages of the life cycle of a project, particularly the early funding allocation, planning and conceptual design phases; and (2) manufacturers, vendors, and suppliers must develop and offer a new generation of sustainable building technologies, systems, products and materials for CIS. These changes are not easy, and few of the discussions on sustainability have addressed directly or explicitly what it means at a global A/E/C industry, at a general CIS project, or at a specific SS perspectives. This paper is a direct response to this void. The paper discusses sustainable SS from the following points of view: (1) what is the intellectual foundation of sustainability, and what does it mean for engineers? and (2) what actions must civil engineers take to achieve sustainability at a global A/E/C industry level, at a CIS project level, and at the specific SS level?

The first part of the paper discusses sustainability from its multiple dimensions. These dimensions create a rich spectrum of complexity, and force any substantive discussion on sustainability necessarily to address issues as diverse and complex as environmental ethics, international justice and equity, bio-ethics, and conservation. In addition, meaningful discussions on some of these issues require that they be framed in either economic, ecological, or technological terms.

Furthermore, attempts to discuss sustainability from a social or political policy perspective require adding a temporal dimension and a spatial dimension to the discussions, which further complicates the discussions. Also, there is no consensus on a unified conception of sustainable development, nor on a unified framework for sustainability. Consequently, as a starting point for the creation of a common intellectual foundation of sustainability, this paper provides a discussion of several of the most prevalent conceptions and frameworks. In addition, to address what sustainability means for engineers, the paper presents two challenges: (1) specific requirements needed to achieve sustainability; and (2) a conceptual framework for the role of engineers within the context of sustainability. Finally, the paper concludes the first part with a description of specific possible responses that the next generation of engineers can provide as a response to these challenges.

The second part of the paper discusses a set of proposed specific actions that civil engineers must begin to take to achieve sustainability at a global A/E/C industry level, at a CIS project level, and at the specific SS level. These are:

- *significantly change the prevalent paradigm in the A/E/C industry towards the delivery and operation of CIS, to a paradigm of the A/E/C industry as a sustainable system.* The new paradigm strives to create a closed cyclical system for the industry, which is framed within a social/cultural, political, economic, technological, and ecological/environmental context, and gradually moves towards sustainability.
- *significantly change two additional prevalent paradigms in the A/E/C industry at a CIS project level: (1) the current relationship between the supply of building technologies, systems, products and materials for CIS, and the demand for them, which currently interact mainly at the commercialization and procurement phases respectively; and (2) the prevalent emphasis on cost, time, and quality as the principal parameters to evaluate CIS project performance.* A new framework is proposed, which views the life cycle processes for the development and supply of the technologies, systems, products, and materials used in CIS, and the life cycle processes for delivery, operation, and maintenance of CIS as an integrated system. In this system, these two life cycles come together more symbiotically, in a way that the problems, needs, and opportunities within each one, at each phase of their life cycle, provide both "push" and "pull" drivers towards finding tangible sustainable solutions to the problems, satisfaction of the needs, and realization of the opportunities. Also, both life cycles are framed within an expanded set of performance parameters that establish the constraints within which they are executed: physical and non-physical contextual compatibility and response; manufacturability, useability, and maintainability or constructability, procurability, operability, and maintainability performance; and short-term and long-term functional, formal/physical performance, risk, cost and schedule, safety and security, and quality, reliability, and sustainability performance.
- *significantly change the way that SS project definition packages are developed as the basis of planning and design, and the design process itself.* A new approach is proposed, which addressing sustainability is an explicit project attribute, an explicit project objective, and an explicit project scope parameter. In addition, the SS project must framed within an intra- and intergenerational, a complete resource supply chain, and a broader regional, national, and global contexts and perspectives. Furthermore, at every stage of the design process, there should be proactive input of constructability, procurability, operability, maintainability, and sustainability knowledge and experience. Also, as the design evolves through its different phases (i.e., conceptual, schematic, design development, and contract documents), there should be explicit and systematic short-term and long-term checks for functional, formal/physical, risk, cost and schedule, safety and security, and quality, reliability, and sustainability performance parameters. Finally, specific strategies, mechanisms, and tools to support sustainability need to applied throughout the planning, design, construction, and use of the SS.

Life-Cycle Behaviour of Reinforced Concrete Structures
– What do we need to know ? –

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Abstract

This paper deals with what we know the deterioration process of concrete structures, and what we need to know for having concrete structures in sound condition during the design life time.

It has passed more than one hundred years since reinforced concrete structures were firstly constructed. At the first stage modern concrete was considered as stone and until the last three decades of this century concrete engineers must believe that concrete could be an eternal material without change. However, we have faced the deterioration problems of concrete in these days, such as alkali silica reaction of aggregates, carbonation of concrete, corrosion of steel reinforcing bars by salt attack, deterioration by cold weather and fatigue distress. The nature and the counter measures against these deterioration causes are briefly discussed in this paper, and some comments are extended to the reliability of counter measures.

What makes the deterioration problems difficult to solve is to take a long time for the examination of deterioration mechanism and for the verification of effectiveness of counter measures. In order to reduce the waiting time, various types of acceleration testing method have been developed, but it is not yet proved enough how the results by the acceleration test method coincides with the actual deterioration process.

In the first stage of taking counter measures against the deterioration, what we have done is to protect concrete from the bad influences of the deterioration causes, or to remove them. Usually with trial and error procedure we manage to find out some solutions. This approach may be all right at the time being, but can not give a long time assurance. In particular, the corrosion by salt attack and the deterioration due to cold weather can not be solved by this manner because these problems take some time to appear. There have reported many examples in which the effectiveness of repair ceased in 5 – 10 years. Then, the followings should be considered for what we need to know to obtain the proper solutions.

(1) Microscopic investigation of deterioration should be essential. In particular, the mechanism of deterioration and the deterioration rate are of most importance in study. In most cases the materials movement in pore of concrete, such as water intrusion, dispersion of chloride ion, oxygen and carbon dioxide, should be studied with respect to the time lapse. As for fatigue, the micro fracture mechanics must be a powerful technology.
(2) In order to determine the initial properties of concrete in structures, the influence of construction practice on them should be clarified although it is not easy to assess. Even if good materials are used for concrete, poor construction practice easily impairs the quality of concrete. In this point of view, self-compacting concrete can be one solution for this problem resulting in very little influence of construction practice.
(3) Except fatigue, it is not well understood how the deterioration of materials influence the structural behaviour. Taking the corrosion by salt attack as an example, the initiation of corrosion of steel bars does not affect the structural behaviour at all. When the amount of

corrosion exceeds a certain limit, cracking occur in cover concrete. The initiation of cracking is, of course, not necessarily the failure.

(4) Microscopic investigation again should be conducted to clear how the deterioration process goes after repair. The deterioration mechanism must be influenced by the repair method, and is not the same as that of original. The electro-chemical approach is necessary.
(5) Combined effects of different deterioration causes should be studied in the further step. For example, what is the fatigue strength of a corroded steel bar?
(6) In order to shorten the waiting time for deterioration study, it is necessary to develop proper acceleration testing methods.
(7) Finally, it is strongly expected to develop a model which can simulate the life cycle behaviour of concrete structures with consideration of material deterioration and effects of repair.

Everybody understands that the initial high quality of concrete with high cost can prove a longer life span of concrete structure. Nobody, however, knows how much of extra cost compensates the extra length of life span. This is because we do not know well how concrete structures deteriorate with the lapse of time. Then, it is difficult to pay an extra cost for high quality of concrete. Now is a time to consider the sustainable development with conservation of environmental resources. What we should do is to elongate the life time of concrete structures meeting with the mechanical and economical requirements. For this reason we need a new design code which enable the life cycle assessment of concrete structures. The code can be called "Performance based design code" in the world wide. The concept of the code is now being discussed in Europe, USA as well as Japan. The Japan Society of Civil Engineers has set up the time schedule to convert the current limit states design code to the performance based design code in 2006.

The performance based design code should involve the followings.

(1) The overall design flow consisting of the planning of structure, dimensioning, materials selection, consideration of construction practice, **verification of performance**, maintenance and repair, demolition.
(2) Trade off system among dimensioning, materials selection and method of construction practice.
(3) Easy acceptance of new technology for verification of performance.
(4) Life cycle assessment with consideration of maintenance and repair.

It is not to say that the verification technology for the life cycle behaviour of concrete structures is of most importance in this design code.

In order to show how the discussion in this paper is accomplished in the actual structures, the simulation is conducted on the life cycle behaviour of off-shore concrete structure under the salt attack condition. The simulation consists of three parts, such as intrusion of chloride ion in concrete, cracking and crack width of cover concrete with regard to the amount of corrosion of steel bars in concrete, and impairment of structural behaviour (reduction of flexural capacity). Although the analysis and the experimental results used in the simulation process are not necessarily sufficient enough, the example simulation indicates what is the direction we should go from now.

We are now in the century of conservation of environment and of sustainable development. What is required for structural engineers should make concrete structures durable and elongate the life time of structures. The knowledge on the structural behaviour of concrete structures becomes fairly high level although there are still some problems to solve. On the contrary, much more efforts should be done to extend our knowledge on the deterioration processes of concrete structures since the wide range of knowledge from a micro level to a macro level, and from chemical behaviours to mechanical behaviours, is necessary to reveal how concrete deteriorates under certain conditions. The development of effective acceleration testing methods is essential to proceed the study on deterioration mechanism and to establish the counter measures against deterioration. Finally, a performance based design should be introduced with the consideration of life cycle assessment for constructing durable concrete structures.

Quality Assessment and Damage Detection by Monitoring

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Helmut Wenzel is chairman of WC V of IABSE. He earned a Ph.D. in Bridge Construction from the University of Vienna in 1978 and is the Managing Director of VCE, with offices in Vienna, Taiwan and Korea. Dr. Wenzel also teaches Bridge Design and Construction at the University of Vienna.

Abstract

Owners of structures realize the need for quality control tools to be applied for maintenance and rehabilitation planing as well as lifetime assessment. Practicing engineers highly desire quality control of construction and a feedback from structures for more economic design and better understanding of the performance. Researchers were always fascinated by the potential of full scale dynamic tests of structures. These common aspects triggered the development of structural monitoring. Each structure has it's typical dynamic behavior which may be addressed as vibrational signature. Any changes in a structure, such as all kinds of damages leading to decrease of the load carrying capacity have an impact on the dynamic response. This suggests the use of the dynamic response characteristic for the evaluation of quality and structural integrity. Monitoring of the dynamic response of structures makes it possible to get very quick knowledge of the actual conditions and helps in planing of rehabilitation budgets.

General

Monitoring the quality of structures comprises a wide field of engineering tasks. The most promising recent development has been achieved with Ambient Vibration Testing and dynamic System Identification tools.

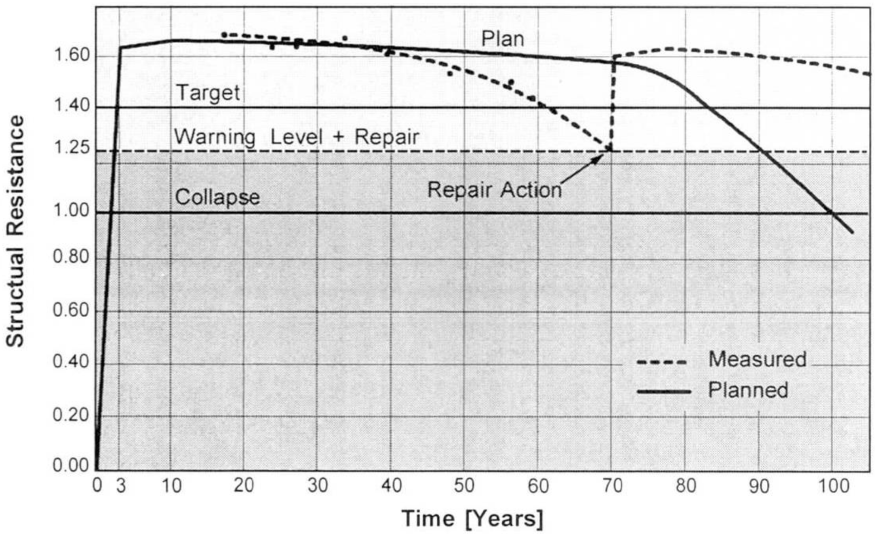

Fig. 1 Development of resistance over time

Therefore this contribution concentrates on this subject. Life time assessment is another high light. The full paper provides a brief history of monitoring, an introduction to the most important tools of system identification. 12 examples of application are provided out of which 2 are shown in the following page. There seems to be no limit in application.

Quality Control of Construction

The vibrational characteristic changes with each construction stage. Monitoring instruments are able to record these changes and therefore confirm the quality of construction steps carried out. Another benefit is that major impacts are recorded which might influence the quality of the structure. In case of cable stayed bridges the stresses in the cables can be monitored and compared to the desired values. Another application is the check of the removal of temporary fixations during construction. Complex systems can so be checked easily as demonstrated in Fig. 2.

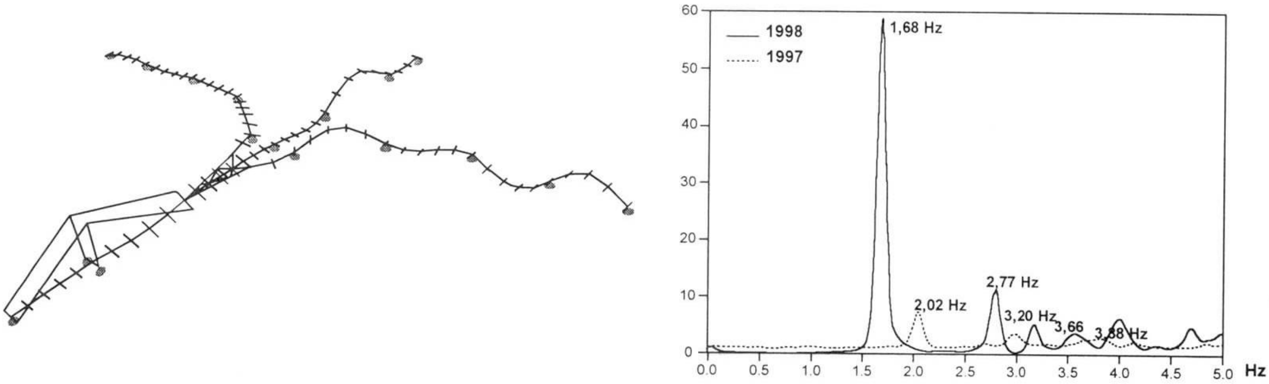

Fig. 2 Hall West Bridge, effect of the release of a horizontal restraint

Structures of the Cultural Heritage

The described method is not limited to bridges and towers, but can also be applied at monuments of the cultural heritage. The exceptional statue of Erzherzog Karl at the Heldenplatz in Vienna represents one of the two largest statues with a horse-rider situated on the two back shoes only. This 12 m high Bronze-statue is surrounded by thousand of tourists daily. The material properties of the structure formed 160 year ago can be assessed by the application of the vibrational characteristic method (Fig. 3). Consecutive measurement over a period of time provides information on the development of the structural integrity. Further application in this respect are the assessment of cantilever staircases built from natural stone, the assessment of the tiny structural members of Gothic churches and the integrity of Frescos and Mosaics.

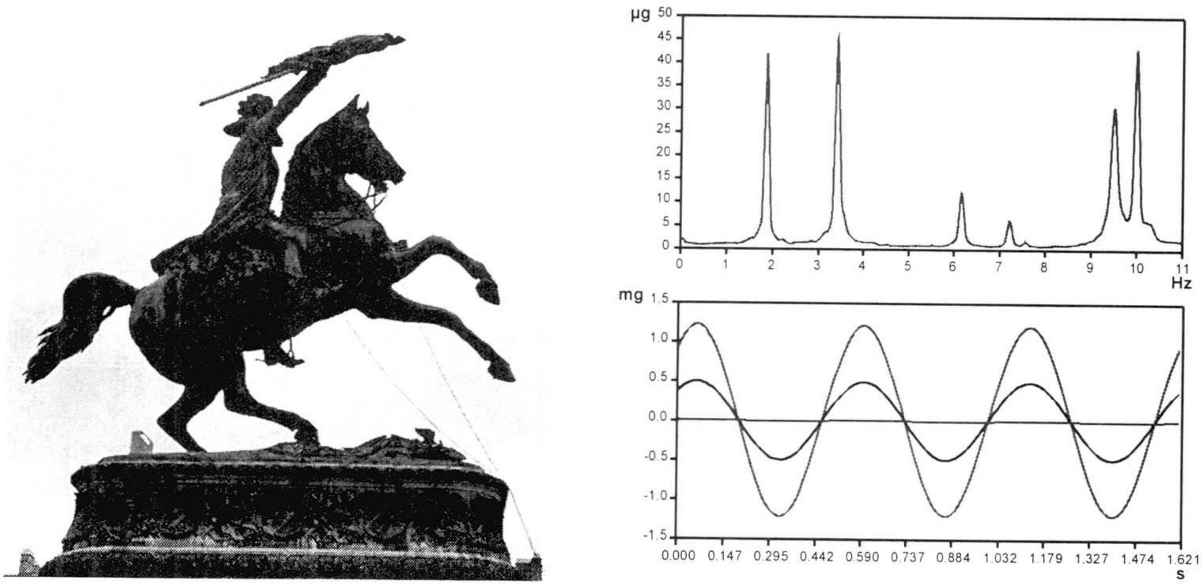

Fig. 3 Erzherzog Karl Statue with ambient spectrum and damping window

Performance-Based Design of Structures for the Future

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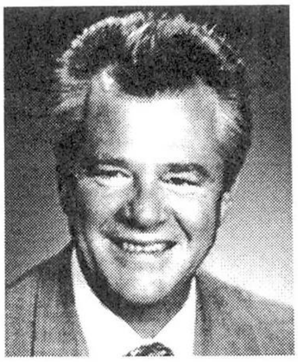


Steen Rostam, born 1943, received his MSc from TU-Denmark 1969 and his PhD 1977. His main tasks have been durability technology and service life design of concrete structures. Rostam chairs the new ***fib*** Commission 5 "Structural Service Life Aspects".

Integration of Durability and Structural Design in Performance-Based Design

The generally accepted aim of a design is "to achieve an acceptable probability that the structure being designed will perform satisfactorily during its intended life". In structural design the inherent uncertainties are taken into account by the semi-probabilistic approach using partial safety factors.

Within durability design it seems to be acceptable to use grossly over-simplified methods of verification, such as deemed-to-satisfy rules, particularly for concrete structures. The codes provide only qualitative definitions of exposure and they fail to define the design life in relation to durability. Previous approaches fail to recognise that it is the condition of the structure in its environment as a whole, that define durability and performance.

Challenge to the Designer of Concrete Structures

Concrete is the only important building material where the material properties in the finished structure are not known at the design stage and when writing the specifications. A valuable means to increase the knowledge of the expected performance and service life is to establish a base-line-study of the finally achieved properties. This could conveniently be done as a ***Birth Certificate*** and reported as part of the handing-over of the structure from the contractor to the owner. At later inspections this data can be updated as can the expected residual service life, resulting in an ever-increasing reliability of the residual service life forecast. The means are available today, and this has proven particularly valuable as a new and maybe revolutionary approach to the durability design of concrete structures.

Minimal Structures

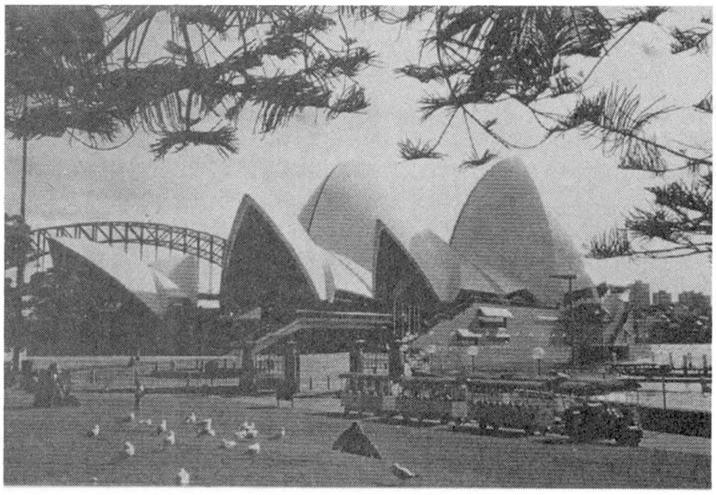
The full utilisation of the material strength throughout the structure assumes á priori that no deterioration takes place while the structure performs its long term load carrying duty under the influence of the prevailing environment. The more we engineers learn to optimise the material and structural exploitation of the strengths the greater becomes the demand also to master the ageing effects and control the deterioration mechanisms threatening the long term performance of our structures. During the 80´ies and 90´ies service life design of concrete structures has developed into a rational scientific discipline now becoming an integral part of the design of concrete structures.

Aesthetics

Concrete is a unique building material. It is used for all parts of structures. Such use requires front line technical knowledge and experience. The need to consider aesthetics in design is necessary if concrete shall not loose out to steel and other materials eager to take over the dominating role of concrete within the construction industry. In addition, it must be ensured that concrete structures grow old gracefully, thus enhancing its performance - and its reputation.

Durability Performance

Managing the durability of concrete structures will be a fundamental challenge for the engineer in the next millennium. Similar to the design concept used in structural codes, the design for durability must be developed on the basis of probabilistic analyses taking into account the variability of the environment and the structural performance. In particular, environmental factors, which affect the degradation processes, the materials and the geometrical properties, etc. may vary substantially.



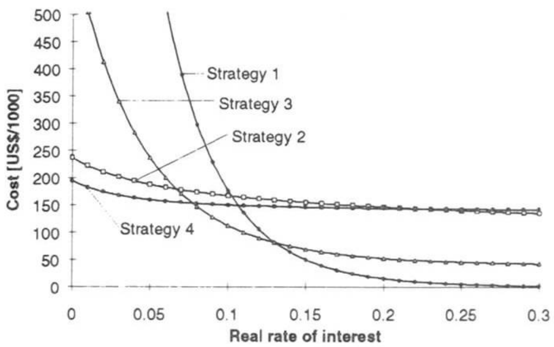
Sydney Opera House is a stimulating documentation that correct use of form and material can produce the most fascinating long lasting structure being a pleasure for the eye and for the user.

Economic Optimisation of Service Life Design

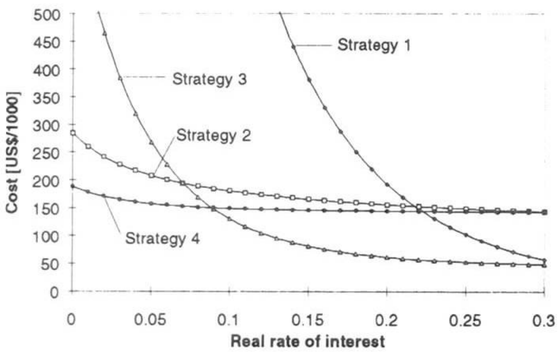
Already at the design stage the designer should consider different strategies for maintenance and repair. A fair comparison of the different strategies can be made on the basis of costs.

As an example a concrete pier exposed to chloride ingress has been analysed. The required lifetime of the structure is 50 years. A temperate climate, 10 °C, and a hot humid climate, 30 °C are checked. Four different strategies are considered. 1) A traditional structure needing extensive repair once in its lifetime. 2) A durability designed structure using high performance concrete and large covers. 3) A traditional structure prepared for cathodic protection being energised when found necessary. 4) A traditional structure but using stainless steel reinforcement in the most exposed zones, which in this case covers about half the reinforcement.

The total costs related to the four strategies are shown as functions of the real rate of interest for the temperate climate and hot humid climate, respectively.



Temperate climate.



Hot humid climate.

A rapidly growing demand for such reliability based service life designs is foreseen. This will challenge the engineering profession, and will in particular require a multi-disciplinary engineering education.

This renewal of engineering competence is needed to ensure that the future generations of engineers will be able to accommodate the rapidly growing requirements of society to provide reliable and cost optimal performance-based service life designs of structures for the future.

Adequate Design Criteria: the Key Issue to Attain Project Quality

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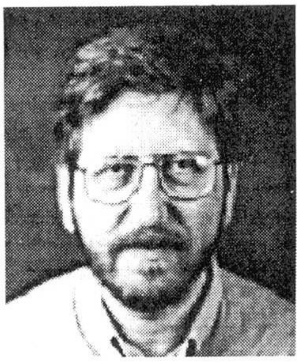

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Abstract

When one speaks about a design criteria to be used to design a structure the first thought to come to one's mind is usually a specific applicable code. In design practice one of the first documents to be prepared in any structural design is usually that called "Design Premises". In it the designer tries to consolidate all the design data and establishes the analyses and verifications that will be performed within the scope of the job. If the object of the project is a common structure, conceived according to well-known existing solutions, this document is really just an expanded description of specific code requirements for that type of structure. When, however, the structure to be designed is based on some new structural concept or has record breaking dimensions, or still when local conditions call for unusual loads, the engineer must stop to ask himself if there is any kind of verification, that must be added. He must consider effects, which sometimes lie beyond the state-of-the-art and that could cause his structure to fail or to fail to meet workability requirements. Some examples of structures listed under these conditions and which have encountered problems are presented below:

- A Shallow Water Fixed Offshore Platform Island

This example deals with the installation of oil production facilities in very shallow waters (approximately 12m), where an artificial island replaced the conventional fixed platform. The chosen concept was to use a crane barge to install a pre-assembled cylinder made of sheet piles, which were already interconnected and held together by a purpose built frame. After being set on bottom the construction sequence was to drive the individual sheet piles, fill the volume inside the cylinder with sand and then secure the whole assembly with a top concrete slab. The actual offshore facilities would then be floated out and installed on "solid ground".

On paper everything seemed perfect, but as soon as the first assembly was lowered into the water a small swell, no more than 1m high, hit its side and gently bent the first sheet pile inwards. This motion was then repeated by the two adjacent piles and again subsequently by the others forming a type of bending wave around the assembly on both sides. When these two waves met at the diagonally opposite side of the sheet pile cylinder they clashed and sent back two reflective waves in the opposite direction. Again it could be seen as they moved around the cylinder and, once again, they clashed when they met. This time, however, the impact was sufficiently strong to crack the weld that was connecting the first pile to the supporting frame. The sheet piles began to drop, one by one, from the supporting frame bending and twisting in such a way that the crane could no longer proceed to lower the structure onto the seabed nor lift it, bringing it back to the barge deck.

Can any one be blamed for the lack of quality of this project?

- Total Collapse of an Export Terminal on the Amazon River

A second interesting sample accident is one that occurred in 1994 to an ore ship-loading export terminal built in the 50s on the Amazon River. It was destroyed by great wave created by a landslide, which took place on an island in the river over 500m away. This wave threw a ship, which was being loaded, against the terminal. Also in this case one should ask if this accident could have been avoided by a more adequate design criteria.

- Main Span Problems of the Rio - Niteroi Bridge

The Rio - Niteroi Bridge has presented two chronic problems during the last 25 years, since it was built. The first is related to mid span wind vibrations, which in general occur for wind speeds around 65km/h. These cause discomfort to the users, but don't endanger the structure because the corresponding stresses are low. There were, however, two occasions in which it vibrated in a different manner, causing the users to panic. In both cases wind speeds were found to average 120km/h over a longer period. Wind tunnel tests have shown that this vibration took place in a second structural mode. Although these vibrations had been a major concern during the design phase the state of the art calculations had shown they wouldn't be a problem.

The second problem is related to the excessive flexibility of the steel deck cover plating. It was designed adequately for structural purposes, but unfortunately it undergoes deformations due to service loads, which are higher than those that the pavement can withstand. The result of this is that the pavement cracks and is easily destroyed due to water infiltration, which occurs during subsequent rains. This is a typical example in which there was a discipline interface problem, that wasn't adequately addressed by project quality assurance. It therefore, doesn't serve the purpose of this paper.

- The Ipanema Sewage Pipeline

The last example to be addressed here is that of a 2.8m diameter concrete pipeline, built to throw $6m^3/sec$ of sewage from the southern part of Rio de Janeiro 4.5km away from the Ipanema beach. Unlike many other similar type constructions, which are laid directly on the seabed, it was built approximately 2m above the bottom, supported by discrete steel open-ended pipe piles spaced every 50m. After twenty years in use, one of these piles broke dropping the pipeline onto the seabed. A new V shaped equilibrium position occurred at the missing support, but fortunately without disconnecting the adjacent pipes, thanks to the flexible design of the concrete head connection at the top of the pile, which absorbed the rotation at that point. Investigations carried out attributed the failure to fatigue of the welds performed on the steel piles caused by cyclic loads on the pipeline. In the mean time several other supports have failed and the entire pipeline with 70 of such supports, must now be strengthened. Although fatigue design wasn't a state of the art requirement when the aforementioned sewage pipeline was designed, it is still worth asking if a more adequate design criteria could have avoided this.

The paper goes on to conclude that uncommon structures or those subject to uncommon loads are not automatically covered by design criteria presented in specific design codes and can only attain project quality if the corresponding design criteria are adequately established. In order to do so both caution and solid engineering judgement exercised by highly experienced engineers are required during the preparation of the "design premises".

Rehabilitation: The Chance for Extending the Life of Structures

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Summary

Independently of its imposing achievements, structural engineering has to accomplish a less attractive task of solving the existing structures future. The essential factor of structural durability is searching and insisting upon the quality of design and construction which should be kept by regular and preventive maintenance. Rehabilitation is the chance for life extending of deteriorated, defected and damaged structures, and strengthening for structures with the increased requirements. Although rehabilitation and strengthening of structures have different purposes, the same methods are used for their implementation. Possible methods of rehabilitation and strengthening of structures are reduced to: changing the structural system, decreasing the span, changing the actions, increasing the cross section and replacing the structural members.

Keywords: Structure; service life; deterioration; damage; maintenance; rehabilitation; strengthening.

1. Introduction

Structural engineering is very proudly entering the third millenium. Numerous great and important structures have been built, impressive for their size and beauty. Searching for and insisting upon quality in all stages from research and design to construction and maintenance significantly contributed to excellent structural achievements. However, independently of the imposing success, structural engineering has to cope with a very serious, but maybe less attractive task. It is inevitable to successfully solve the problem of the existing structures future. As many of them are quite old or approaching the end of their service life,it is urgent to decide on their destiny. Rehabilitation is a chance to extend the service life of structures.

2. Rehabilitation Purposes

The purpose of rehabilitation of the existing structures, deteriorated, defected or damaged is to re-establish their capability to accept all the effects of actions and to respond to all functional requirements of the original design. With the appropriate reliability level, a sufficient safety, the required serviceability and the necessary durability should be secured again. Thereat, it should be kept in sight that rehabilitation is not only an engineering problem of its implementation but also the economic problem of profitability.

The service life of structures is a period of time during which they have the sufficient safety and the required serviceability. It is absolutely clear that reaching the service life of structures does not mean it becomes indispensable to replace them. However, that is the ultimate time to decide on their future destiny. It should be estimated if the rehabilitation inevitable to extend the service life, including the future maintenance, is technically justified and economically more favourable then the replacement of the existing structure by the construction of the new one.

The specific measures required to provide the durability of structures are reached studying the basic forms and relevant factors of their time-dependent deterioration and gradual ageing. To take those specific measures mean to prevent, decrease or slow down the deterioration processes. The study of deteriorations is particularly important for concrete structures due to reinforcement and especially prestressing wires corrosion danger which can cause really serious problems.

Regarding the requirements defined during the planning of the structures, they can be subject to various defects. Defects are the consequences of very different failures, omissions, and mistakes, which can arise during the design and construction of structures.

During their service life, the structures can be more or less damaged due to unexpected events. Structural damages can come as a result of overloadings or because of other kinds of inadequate use during the service life. Damages of structures might also arise due to accidental actions which appear only rarely. As accidental actions up to the specific magnitude are provided for in the design they are only exceptionally of such an intensity to cause structural damages.

Special care should be taken of preservation and protection of the structures having historical and architectural heritage and the monuments of culture. However, the requirements to extend the service life of such existing structures by their rehabilitation are dominant and frequently they are claimed compulsory independently of their costs.

During the service life of structures, necessity may arise to change their purpose. When the requirements are increased the matter of their strengthening is considered. The purpose of strengthening of the existing structures which need not necessarily be deteriorated, defected, or damaged at all, is to make them capable to accept the increased effects of actions and to respond to the higher functional requirements compared to those anticipated by the original design. Although strengthening and rehabilitation of structures or structural members have different purposes, basically the same methods are used for their implementation.

3. Importance of Maintenance

The adequate maintenance during the service life is an essential factor to keep the level of quality of structures which significantly influences their durability. Advantage given to regular and preventive maintenance is the most convenient way from both engineering and economic points of view.

Optimization of engineering and organizational solutions in bridge management, the choice of an objective system of classifying and estimating the conditions of bridges and evaluating their remaining service life, and optimization in long-term planning the required engineering capacities and financial resources of the corresponding funds according to the priorities of the anticipated works in order to secure undisturbed and safe traffic on roads and railways require a scientific approach in solving those very complex problems. Bridge Management System is developed in many countries and its practical application greatly secures the achievement of the set purposes.

4. Rehabilitation Methods

Methods of rehabilitation of deteriorated, defected and damaged existing structures or strengthening of structures which need not necessarily be damaged at all, are very different. The ideas of possible methods of rehabilitation and strengthening of structures are most easily attained if the basic principles of dimensioning are reached. Possible methods of rehabilitation and strengthening can be achieved by changing the structural systems, decreasing the spans, changing the actions, increasing the cross sections, or replacing the structural members. The best illustration of rehabilitation and strengthening methods is with concrete structures.

Information Technology in Practice– Exploiting Potentials

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Summary

It is widely regarded that the potential of information technology in structural engineering is far from fully exploited. Current research and development are mostly concerned with challenging and sophisticated issues, which may result in major advances in structural engineering practices in medium to long term. The urgent needs of practising engineers are often left aside. The paper presents easily achievable goals that would significantly enhance efficiencies for all participants in building process. These can be attained by using the ability of computers to store, share and process huge amounts of data. This data document human design decisions and processing results. The necessity to agree on widely accepted storage formats for this data is emphasised. Finally the paper discusses the usefulness of component-based software in structural engineering.

Keywords: Information Technology, Structural Engineering, Product Model, CAD, Component-based Software

1 Introduction

In recent years a significant effort has been made to rationalise working processes in structural engineering, which has led to deployment of software in various activities. The emerging new applications in structural engineering like management systems, knowledge-based systems, monitoring systems, etc. are examples of this type of software. In the traditional FEM software as well one can observe an effort to create highly intuitive applications that can be readily integrated with Office and CAD applications.

These developments are useful and enhance our capability to cope with the growing complexity of the civil infrastructure in modern society. Nevertheless, it is widely felt that dramatic benefits from IT are yet to come. Some engineers even regard the deployment of IT in structural engineering practice as cost-irrelevant. In contrast to some other industries, one can argue that the use of IT in structural engineering is not the decisive prerequisite to survival in the marketplace.

IT research in structural engineering largely focuses on challenging and sophisticated issues like expert systems, artificial intelligence, neural networks, etc. Practical application of this valuable research cannot be expected in the near future, whereas the urgent needs of practitioners are often not adequately addressed. In practice there is no need for computers to do engineering. The engineers would, however, welcome the support of computers to free them from dull tasks and allow them to concentrate on creative work like design, assessment, analysis, etc.

2 Unique information

The strength of computers is in their ability to store, share and process huge amount of data. Data documenting planned or existing structures can be adequately stored in a integrated computer database and managed by computer programs. In this manner they can be made accessible for participants in the building process. Furthermore, the compatibility among the documents that are furnished by various disciplines can be guaranteed.

The structural documentation consists of geometrical and semantic information. The semantic information encompasses characteristics of structures, structural elements and materials. For different disciplines semantic information can be very different. For instance, a slab opening for structural engineer is a service shaft for HVAC engineer. The geometrical representation is perhaps the only **unique representation** for all disciplines. It is free of semantics (e.g. material properties, physical properties, etc.) and can be furnished by means of a three-dimensional (3D) model. This 3D model is pivotal for all other applications. The semantics of different disciplines can be added furnishing different applications. CAD Software, Facility Management Systems as well as FEM Software can be based upon this model. A 3D model allows not only integration of building process, but it also supports the utilisation phase as well.

To exploit these potentials, the following issues have to be addressed in future:

- Computer presentation of 3D models has to be used throughout the building process. It would be ideal if all products would support the same binary computer format for 3D representation.
- Currently available CAD systems have insufficient support for 3D modelling. 3D modelling is a cumbersome and tedious task. With growing computer capabilities, it has to be transformed into an intuitive task simulating real building activities. For instance, the user would be able to design complex geometrical forms by means of Boolean operation on existing 3D elements.

A standardised native binary format is hardly an achievable goal. Nevertheless, CAD producers should try to agree on a common binary format, before Microsoft introduces its own.

3 Developments in Information Technology

The rapid development of IT and the flood of different concepts makes it difficult to identify developments of benefit to the structural engineer. In the author's opinion, component-based software can find rational deployment in structural engineering. A component is a piece of software with an interface, through which foreign software can use its functionality. This approach may reduce the costs of development of individual software in structural engineering. In this manner, for instance, a customised dimensioning program can be combined with a FEM Software.

Furthermore, given that there is an established, standardised binary format for 3D models, components for handling them may become available. In this manner individual software may be assembled from components. Examples of such component-based software would be CAD programs, cost management programs, management systems, etc.

Quality, Erection Speed, Cost Reduction : Keys for the Future of Civil Engineering

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Summary

Structures of the Future will be impressive, light and heavy, deep and high, wide and long. They will be challenging major issues, mitigating natural disasters, fighting the power of the wind, of the sea, of the earth, but linking people, countries, continents. The way this is going to be achieved can be seen from the most recent progress made in construction methods. Gigantism is a new tendency ; it is a need to erect major structures, quickly, economically, and safely.

But this progress has been made possible by taking into account the way the structures are going to be built at the design stage. Strong interaction between design and construction methods is the only way to get simultaneously both efficiency and a high quality level of the final structures.

Quality, Erection Speed, Cost Reduction will be the keys for the Future of Civil Engineering if and only if these objectives are taken in the right order.

1. Introduction

The past ten years will mark undoubtedly the history of Civil Engineering with an impressive series of prestigious projects. High Rise Buildings, Towers, Stadiums and Bridges, have broken successively a lot of world records, in terms of height, slenderness or span length.

These new structures would not exist yet without the fantastic development of unusual and spectacular construction methods using the power of engines and all the latest refinements of a modern technology. Moreover, perfection in construction methods leads to Quality in terms of Feasibility, Erection Speed as the result of an Integral Design Process, Efficiency in terms of Cost-Savings. This can be illustrated by examples coming from trends in the field of large foundations or from the recent construction of the largest immersed tunnel in the world.

2. Quality in terms of Feasibility

Generally speaking, Quality means aesthetics, comfort, structural serviceability, structural safety and durability which apply mainly to the final structure. From this point of view, Quality means Sustainability.

But the quality of the completed structure highly depends on the quality of the fabrication process and therefore the quality of the works.

This is what the Search for Quality means, in terms of Construction Methods to be used in the future, and this is the reason why prefabrication of steel and concrete components has been developed and intensively used for more than 40 years in all fields where it was applicable.

Challenges for the next millennium will lead unavoidably to the construction of long links. In this context, Quality of structures to be built in a difficult environment will generally be the result of a Search for Feasibility.

3. Erection Speed as the Result of an Integral Design Process

Erection Speed has more and more become a major objective in important projects as the whole decision process, which involves many components of various authorities, takes a long time when the design and construction period is reduced to a challenging minimum.

But the Search for Erection Speed could lead to the worse results in terms of Quality if considered as a priority. It should not be anything else than the result of an Integral Design Process where production and work are organised with the aim of simplicity and efficiency; in other words with the aim of reaching regularly perfection, without any deficiency along the whole production line of the Design and Construction Process.

4. Cost Reduction in terms of Efficiency

It has to be emphasised that the Search for Feasability, in terms of Quality and Construction Speed, lead to the design and erection of heavy and costly temporary site installations. As a result labour efficiency compensates the investment and time spent at the earliest stages of the allocated construction period and leads to important savings.

Efficiency means Cost-Control and even more Quality. It is the result of a long preparation period, whatever the extra cost can be, because finally it has to be understood that extra costs are the path to cost reduction and therefore to Competitiveness without neglecting Quality.

5. Conclusion

The way the structure is going to be built is therefore a fundamental aspect of the Design Process.

This is not new and should not be surprising as large Engineering Structures have always been designed taking into account a certain number of parameters of which, geographical location, available materials, known and practicable or proven construction methods, are the most usual.

But this should apply to any structure and the design phase should never be limited to the selection of a Concept, of the Materials to be used, of adequate Design Criteria, on the basis of a fit for purpose approach, without taking into account construction methods.