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Our times are characterized by an ever increasing aversion to and fear of technology. We could also say that technology has become a permanent source of uneasiness. Our fellowmen are disturbed by technology's claims to power. They regard themselves as being helplessly at the mercy of its massproduction and massconsumption. They fear both the production- and the working-world of technology. And finally they are at a complete loss when faced with the fact that they just cannot fully grasp technology.

In the center of these developments is the civil engineer, and thus IABSE. As a result we are called on to apply ourselves to these problems, which are clearly political in character. This goes far beyond the specialised knowledge of our subject. Therefore, our responsibility extends beyond technology itself.

We also have a responsibility to society as a whole, not simply to the building and civil engineering industries. We should seek to influence decisions taken and implemented at an early stage. We have the task of making the problems intelligible and acceptable to our fellowmen. In the end, this could lead to a new sympathy with and understanding of progress. Our organisation as an "International Club of competent civil engineers" is obviously in a position to assume this role. As a result, it can only stand to gain in reputation. It will require effort at all levels to make the necessary urgent steps in the right direction and I call upon you all, within the scope of your possibilities, to do your part.

Formerly, it was a tradition for the president of IABSE to use the three official languages of the organisation in his speech of welcome. I would like to take up this gesture of politness.

C'est maintenant en français que je voudrais vous exprimer mes souhaits de bienvenue et vous remercier de votre présence. Vous montrez ainsi votre attachement à notre Association et donnez un caractère de fête à la séance d'ouverture du Symposium.

Je désire, en particulier, saluer les dames qui illuminent par leur présence les activités du programme social du Symposium. Les personnes accompagnantes sont les bienvenues à nos manifestations, et nous ne voudrions en aucun cas manquer leur présence et leur charme.

L'image de l'Association Internationale des Ponts et Charpentes est le résultat du nombre et de la qualité des participants. Les nombreux auteurs de contributions, les présidents de séance et les membres du Comité Scientifique sont les garants du haut niveau de notre Association. Qu'ils acceptent notre reconnaissance et l'expression de nos sincères remerciements!

Die deutsche Sprache scheint mir für die Verleihung von Ehrungen sehr geeignet. Die IVBH war lange Zeit damit sehr zurückhaltend, doch haben sich in der letzten Zeit Traditionen eingebürgert, die wir mit Freuden und Ueberzeugung fortsetzen.
Wir verleihen die Internationale Auszeichnung auf dem Gebiet des konstruktiven Ingenieurbaus für das Jahr 1986 an Herrn Prof. Dr.-Ing. Masatane Kokubu. Die IVBH anerkennt damit seine hervorragenden Leistungen auf dem Gebiet der Betontechnologie und sein grosses Engagement bei der Förderung der internationalen Zusammenarbeit und ehrt gleichzeitig einen Menschen von hoher ethischer Gesinnung.
Wir verleihen weiter den IVBH Preis 1986 an Frau Dr. Marita Kersken-Bradley in Anerkennung ihrer hervorragenden Beiträge zu einem einheitlichen Sicherheitskonzept für das Bauwesen sowie ihres unermüdlichen Einsatzes bei der internationalen Harmonisierung technischer Regelwerke des konstruktiven Ingenieurbaus und des baulichen Brandschutzes.

Finally, I would like to address our hosts, our Japanese friends, and especially the organisers of this symposium. It is for all of us a notable event, ten years after the outstanding Congress, to be able to meet again in your country. We are all fascinated by the tremendous achievements, not only in the field of civil engineering, which your country has accomplished, and will accomplish in the future. We are deeply impressed by the overwhelming welcome which you have given us, and we know that many interesting events are still awaiting us, which will then become unforgettable memories. For this, I would like to express to you our deep respect and gratitude.

Welcome Address

Discours de bienvenue

Willkommensansprache

Yutaka TAKEDA
Chairman
Japanese Organizing Committee
Tokyo, Japan

It is a great honour and pleasure as Chairman of the Organizing Committee to be able to welcome such a distinguished gathering of renowned researchers and engineers from both inside and outside Japan to the opening of the IABSE Symposium. This conference would never have materialized without the generous cooperation and selfless efforts of President von Gunten, the members of IABSE, Chairman Tokodo Ishikawa of the Japanese Finance Committee as well as the devotion provided by all others concerned. I hereby express my sincere gratitude to you all.

The 10th IABSE Congress was held in Japan exactly ten years ago, but much has changed in a decade. Against the back-drop of dwindling economic growth and diminishing public works, demand in the construction industry, chiefly for civil engineering structures, has decreased. Many related industries, including the iron and steel industry, where I serve as the Chairman of the Japan Iron and Steel Federation, are also faced with grave difficulties. Nevertheless, there is no doubt that the field of your expertise, namely Civil Engineering and Construction, comprise the very foundation of social capital without which effective utilization of land and improvement of life itself would not be possible. Particularly in Japan advocates appeal for a more positive role for structural engineering on the grounds that it is the essential driving force behind the national objective of sustained economic growth focused on stimulating domestic demand. Under such circumstances the IABSE Symposium is convened today on the theme of Safety and Quality Assurance of Civil Engineering Structures. The theme is appropriate and important because civil engineering structures must be safe and durable over a long period of time despite the unpredictable severity of mother nature. Furthermore, it is extremely significant that this Symposium is held in Japan, as Japan is one of the most vulnerable countries in the world to earthquakes and typhoons.

With an active participation and an exchange of views by researchers from throughout the world, the Conference is bound to pave the way for advancement in the field of structural engineering. The Organizing Committee also takes this opportunity in offering you a variety of Japanese structures. Indeed, it is very fortunate that this Symposium is held at a time when numerous bridges between the islands of Honshu and Shigoku are at the height of construction in a national project that may well be unparalleled in the world. We have prepared post-Symposium study tours and we hope that you will avail yourselves of the rare opportunity. We think we have also prepared exciting social programs for the participants and their families as an introduction to Japan where themes and customs both old and new co-exist. Those of you who have already been here ten years ago may be surprised with the newer aspects of Japan.

Finally, I would like to end by wishing us a very successful and fruitful conclusion of this IABSE Symposium here in Tokyo. Thank you very much for your attention.

Quality Assurance – Professional Ethics, Management or Common Sense?

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1. OUR PROFESSIONAL CHALLENGE AND REPUTATION

The contribution to the introductory report for this symposium by Walter Bosshard, Jörg Schneider and myself on this subject was considered rather provocative by some colleagues. In this second attempt I will take up a more positive attitude and start with a fairly subtle question:
What is our Professional Challenge? Obviously, we all wish to design and build *exciting structures, manifesting engineering art and skill, arousing public esteem.*

There are many examples for exciting structures, but only a few per generation. The majority of us is only concerned with very common structures: Warehouses, industrial buildings, office buildings or even only with the rehabilitation of existing structures. But as concerns these moderate projects, we may at least attempt to design and build *excellent structures.*

What is excellent? We may say that structures should function adequately at reasonable costs - but there is more to it: Maybe structures should also be simple, optimal, beautiful, perfect, ... The best description in this respect was coined by Walter Bosshard referring to structures having *'Gestalt'*. Originally, this is a German word, but according to Webster's Collegiate Dictionary, 'Gestalt' is *a structure so integrated as to constitute a functional unit with properties not derivable from its parts in summation.*

It is difficult to give examples for excellent structures and even more difficult to give example slides. The reason may be that 'Gestalt' simply cannot be reflected by photographs.

Presuming that the audience has at least some perception of excellency or 'Gestalt' in relation to structures and that all of us would like to sign responsible for many excellent projects, we may return to reality. Reality is truly reflected by *our professional reputation.*

If we are honest, we are actually considered to be more or less specialized technicians for limited tasks. Of course, there are exceptions, but the majority of us obviously has precisely the reputation we deserve.

We could accept this reputation in view of the general trend towards an increasing degree of specialization in all engineering faculties. However, recent accidents - not necessarily referring to the structural field - urgently suggest that engineers extend their scope of professional concern. With regard to accidents with world-wide consequences, the issue of professional reputation is less than marginal, but a certain relationship between professional conduct, tasks and reputation nevertheless exists.

For more moderate building projects consequences of inadequacies of the project are generally less disastrous. But as is generally acknowledged, inadequacies may often be traced back to the allocation of only limited task and, correspondingly, only to a limited scope of professional concern.

2. RELATION TO QUALITY ASSURANCE

The foregoing reflections may be considered as rather self-evident and the audience may be wondering whether this contribution will miss the topic, i.e. *Quality Assurance?* This relation is clarified if we consider *how to achieve excellent structures* or in semi-scientific terms: What is the probability for realizing excellent structures? Referring to the individual operations of the building process, realizing excellent structures requires that
- specifications
- investigations
- design
- construction documents
- construction
- maintenance

are excellent. If the individual operations were independent of each other, we may obtain a rather low probability for obtaining excellent structures, simply corresponding to the product of the probabilities for the excellent individual operation.

Considering the individual operations in more detail, however, it can be recognized that e.g.
- the probability for an excellent construction may depend on the degree to which construction documents, design detailing, structural design, etc. are excellent, or
- the probability that construction documents are excellent may depend on the degree to which design detailing, structural design, architectural design, etc. are excellent, or
- the probability for an excellent structural design may depend on the degree to which the architectural design, investigations and specifications are excellent.

Vice versa it may be concluded (from probability theory or common sense) that e.g.
- the probability for an excellent construction is only increased by an excellent design, if design considers construction constraints, or
- the probability for an excellent structural design is only increased by an excellent architectural design, if the architectural design considers structural rules,

thus introducing additional criteria for assessing the excellency of the individual operation.

For the purpose of giving a definition - which these introductory lectures are expected to do - the following definition is offered: *Quality Assurance implies increasing the probability for obtaining excellent structures by increasing the probability for an excellent individual operation for given preceding operations and simultaneously increasing the probability for excellent successive operations.*

For obtaining structures performing adequately at minimum costs this involves
- sound technical solutions as the "conditio sine qua non"
- technical means for control, referring to sensible, cost-effective and timely methods
- more or less formalized control procedures to an extent which is appropriate to the job

supplemented by an organization of the building process ensuring
- cooperation among parties
- information flow
- clear responsibilities

and - most important - a mangement, or better, leadership supporting
- motivation
- education
- efficiency.

3. DECISION MAKING

Where procedures are too complex to be comprehensively appraised by engineering judgement, aids for decision making are available. These aids or tools generally involve analytical methods, often referred to as "system analysis".

System analysis may be performed at various levels of sophistication, ranging from a pure qualitative assessment or a subjective allocation of quantities up to the application of reliability methods in conjunction with a detailed analysis of data. System analysis may be pursued for various purposes, e.g.
- writing specifications
- hazard identification
- deciding on investigations
- optimizing design
- weak point identification
- specifying control plans
- planning maintenance.

4. PATHFINDING

These methods and provisions obviously are of support for achieving an adequate performance of structures. But what about excellency or 'Gestalt'? Will this remain *a reservat for the grand engineers?* Clearly, aids for decision making alone do not render 'Gestalt'. If decision making involves the left part of our brain, 'Gestalt' strongly requests the right part of it. The Stanford business professor Harold Leavitt considers the managing process as an interactive flow of three variables: Pathfinding, decision making and implementation - as quoted in "The Search of Excellence" by Peters and Waterman. This may also apply to the managing of the building process and 'Gestalt' is strongly related to pathfinding. It follows that pathfinding should be supported by
- *improving working conditions*
- *educating engineers in the art of design*
- *promoting design aids*

to make 'Gestalt' possible.

5. THE WAY TO GO

Threats to the inherent possibilities of Quality Assurance are imposed by
- a retreat to the soft sciences on the one hand and an over-emphasis of the purely analytical approach and formalized procedures on the other hand
- an overstressing of conceptual matters including verbal exercises on common sense generalities (therefore, this contribution comes to its end)

hence, this is not the way to go. I would suggest

1 - *Definition of the implications of QA;*
  QA is more than
  - *material control*
  - *design checking*
  - *organization charts*
  - *check-lists*

2 - *Missionary/persuasive stage*
  explaining the ideas,
  general concepts,
  inherent possibilities for
  convincing the profession

3 - *Gradual implementation of the concepts into*
  everyday practice supported by ...

4 - *Education:*
  - *engineering students and professionals*
  - *clients*
  - *authorities*

5 - *Critical appraisal of the regulatory background*
  for engineering activity
  - *codes*
  - *standards*
  - *contracts*

6 - *Development of aids/tools/methods*
  - *technical*
  - *decision making*

Concluding I should like to state that Quality Assurance should not be considered as a new discipline or a research subject on its own. It is only a framework for reflection supporting our professional conduct and challenge.

Contributions of the Reliability Method to Structural Safety

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Civil engineers have always been aware of the uncertainties (natural and man-made) that they must negotiate with in their practice of planning, design, analysis and construction. In particular, structural engineers have dealt with this problem by making allowances for them through safety factors. While the safety factor approach to structural engineering has worked remarkably well in practice, it is not entirely without problems. One of these problems stems from the fact that the process to specify key design parameters such as design loads and allowable stresses is based primarily on collective professional judgment of a subjective nature. Among other things, this makes it rather difficult to evaluate structural safety in quantitative terms. Obviously, the safety factor itself can be used for comparison purposes. Such a comparison, however, makes sense only in extremely simple situations.

In civil engineering, particularly in structural engineering, probabilistic concepts were first introduced in the 1940's in an attempt to develop a quantitative measure of structural safety. Over the last four decades or so, they gradually evolved into what is currently known as the structural reliability analysis method. More recently, some of the existing design codes were reexamined and modified on the basis of these probabilistic concepts, as exemplified by the introduction of reliability-based load and resistance factor design (LRFD) codes in various countries.

The emphasis of structural reliability analysis has been placed on the estimation of structural safety in terms of the probability that a structure subjected to loads and other adverse environments will perform its specified mission without failure. In the classical approach, this probability is defined as the structural reliability. It is classical in the sense that the reliability is estimated under the following assumptions: All possible failure mechanisms under the projected operational conditions and all the pertinent parameters involved are known and at the same time, the probabilistic characteristics of all these parameters are also known. Indeed, the theory of reliability analysis in this context is often referred to as the full-distribution theory. The full-distribution theory, however, is unrealistic not only because of its requirements for a substantial database, but also because of the enormous numerical chore that could entail. Nevertheless, it permits a sensitivity analysis with respect to the specific probability models assumed for design variables and therefore provides an analytical base for the engineering application of reliability concepts.

At an early stage of the development of reliability analysis methods, the necessity to examine the level of confidence of such a reliability estimate was recognized only implicitly; it was usually implied that the highest level of confidence could be obtained by taking advantage of all available data and by making use of state-of-the-art probabilistic and statistical techniques. More recently, the task of establishing such a confidence level in terms of a confidence interval became more of a routine, however crudely that might have been done. Reinforcing a reliability estimate with a confidence statement represents active recognition of uncertainties other than those arising from randomness. Reliability theories that recognize this are no longer classical.

In estimating the reliability and associated confidence level, we must keep in mind that the degree of analytical sophistication should be consistent not only with the quality and quantity of the pertinent information available but also with the current analytical and other capabilities of the profession in the following areas: (a) structural and stress analysis - linear, nonlinear, static and dynamic; (b) failure analysis for various modes of structural unserviceability and collapse; (c) environmental and load analysis; (d) durability analysis considering the effects of in-service inspections and repairs; and (e) quality assurance procedures covering the entire spectrum of planning, design, analysis, construction and maintenance. It is precisely in this context that we often recognize the results of first-order and second-moment analyses as as credible as those obtained by applying the full distribution theory.

Reliability analysis methodology has made and can further make genuine contributions toward enhancing the structural safety and integrity of constructed facilities. One might add that these contributions have so far been made primarily through such conferences as ICOSSAR and ICASP. Indeed, through these contributions, we have made it possible to (a) establish the correlation between structural safety and design parameters such as safety factors, stress allowables and inspection periods, (b) achieve balanced designs among structures with differing degrees of importance, (c) allocate the desired reliability performance to each component within an individual structure, (d) identify the additional information needed to upgrade the confidence of reliability estimates, and (e) develop a consistent and systematic procedure in which a safety analysis can be made logically. In accomplishing all these, the sensible and well-disciplined use of subjective engineering judgment in the Bayesian framework is considered beneficial in bringing about the compromise required and even desired for a reasonable blending between analytical rigor and availability of pertinent information.

Recently, reliability analysis has become an integral part of the risk assessment and management procedures for a wide variety of structures including such risk-sensitive structural systems as nuclear power plants. This demonstrates an added dimension of the usefulness of reliability concepts beyond their applicability to traditional engineering structures. Since the perception of risk stems from the recognition of the possible occurrence of undesirable events with grave consequences, a risk assessment and management procedure is usually built around a reliability methodology with one more analytical component, i.e., consequence analysis, integrated into it. Parenthetically, one might add this is precisely where the cost-effectiveness issue should be addressed. The acceptable level of risk is correlated to acceptable reliability levels of the components of the system for which the risk is to be evaluated and managed. In this sense, the difficulty in arriving at a consensus on the acceptable level of risk, translates into the same difficulty in determining acceptable reliability levels, although the latter can be somewhat lessened by means of calibration at least for traditional civil engineering structures.

Having made these observations, it is appropriate to point out a number of major issues that have not really been resolved in the structural reliability analysis methodology. First, it is by no means easy to obtain a consensus on the target levels of reliability even for traditional civil engineering structures. For example, when we attempt to develop the Load and Resistance Factor Design approach, a question still remains as to how we can specify target reliability levels for various load combinations. This specific issue is the main theme of this author's preliminary report for this symposium. Second, the reliability analysis methodology developed so far presumes that we can somehow formulate everything in terms of probability. Obviously, not everything is always probabilistic. In this respect, fuzzy set concepts are advocated by some to provide an alternative interpretation of uncertainty. Third, even if we somehow agree that we can interpret everything as probabilistic, the casual fashion in which the source of the variability is often divided into that arising from "randomness" and that from "uncertainty" could give the false impression that such a division is easy, while it certainly is not. Fourth, we often get carried away in constructing the simplest possible analytical model out of a structure for the sake of wider applicability of reliability analysis methodology. The case in point is severely nonlinear structural behavior that must be dealt with for the analysis of structural integrity against collapse, say, under earthquake acceleration. A reliability analysis using too simplistic models in such a situation will not only produce a grossly wrong answer but also cost us credibility in such a way that even those credible structural reliability analysis results we endeavored to derive on the basis of carefully constructed models will be placed under suspicion.

Two more items should be added to this list. Fifth, the confidence interval we evaluate for the reliability estimate is often too wide to be useful. Sixth, so far the reliability methodology has been unable to properly incorporate human factors, managerial as well as technical. This is particularly important in view of such unfortunate recent events as the Three Mile Island accident, the Chernobyl accident, the Challenger explosion and the Japan Airlines' crash last year. At least for these accidents, managerial factors, rather than technical factors, appear to be more crucially responsible. In many cases like these, however, engineers are also guilty at least to the extent that they have not asserted themselves strongly enough to change managerial decisions or improve managerial procedures, on the basis of their technical knowledge.

In the remainder of this paper, the author wishes to comment on the issue of quality assurance, since it is part of the theme of this symposium. The issue is particularly important to the medical and civil engineering profession, and, to a lesser extent, for that of architects, although the implied commonology may appear farfetched. The medical profession deals primarily with the physical nature of human bodies, whereas the civil engineering profession with mother nature itself. In either case, nature challenges the profession with its unpredictability. Also common to these professions is the fact (well known even before the current craze for often frivolous liability suits lodged against them particularly in the United States) that they are both highly vulnerable to poor judgment, incompetence and mismanagement. In spite of such a similarity, we tend to accept the following statement which suggests the different ways in which each profession handles its affairs under distress. "Doctors bury their mistakes, architects cover them with ivy, engineers write long reports that never see the light of day, and contractors call their lawyers and notify their insurance carriers." Even though doctors nowadays find themselves in a liability bind more often than before, the statement requires a modification which is even worse for engineers. It now reads: "Doctors bury their mistakes, architects pass the buck to engineers, contractors declare bankruptcy, and engineers write long report that will be used against them in courts of law."

The issue of quality assurance has always been at the heart of civil engineering, particularly of structural engineering. However, the recent concern for potential liability problems has made the profession even more acutely aware of the importance of quality assurance. These days, quite extensive efforts are probably needed to assure the delivery of high-quality products. This is particularly so because the profession must currently operate in an environment where excessive competition, tighter fiscal maneuverability, inferior workmanship, and a less productive labor force are likely to prevail. Moreover, the profession at large appears to command less prestige and fewer financial rewards than other professional groups, and as a consequence, suffer from a decline in the quality of the human resources it must depend on. These contemporary non-technical issues certainly influence the quality of the overall performance of the profession, of which the technical quality assurance issue is possibly a small part. Therefore, the profession, and in particular, its leadership are well advised to address themselves to these non-technical issues and map out strategies for improving the environment in which they must survive and prosper.

The Honshu-Shikoku Bridge Project

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1. PREFACE

The Honshu-Shikoku Bridge Project is to link Honshu and Shikoku which are separated by the Seto-Inland Sea through three routes of highway and railroad as part of the country-wide trunk traffic network.
It is expected that when this Project is completed not only will the flow of traffic between Honshu and Shikoku be drastically improved, but it will also greatly contribute to the balanced development of the nation and the improvement of the economy and standards of living of the regions affected.
The concept of linking Honshu and Shikoku with bridges goes back as far as a century ago, and the feasibility study for it was started from the latter half of the 1950's both by the Ministry of Construction and the Japanese National Railways. Investigations and studies conducted for about 10 years verified that the Honshu-Shikoku Bridge Project would be feasible both technically and economically.
Subsequenty, in 1970, the Honshu-Shikoku Bridge Authority was established by law to be the public corporation which would be responsible for executing comprehensively and efficiently the construction and management of highways (toll roads) and railroads relating to the Honshu-Shikoku Bridge Project.
Following a postponement of the Project due to the oil crisis in 1973, work was started again in 1975 from Ohnaruto Bridge of the Kobe-Naruto route, Ohmishima Bridge, Innoshima Bridge, Hakata-Ohshima Bridge of the Onomichi-Imabari route, and Kojima-Sakaide route which are combined highway-railroad routes first connecting Honshu and Shikoku. These are collectively called the "1 route and 4 bridges". At present Ohnaruto Bridge, Ohmishima Bridge, and Innoshima Bridge have already been put into service and the Kojima-Sakaide route will be completed toward the end of the fiscal year 1987 and Hakata-Ohshima Bridge toward the end of 1987. For this fiscal year, more private capital was going to be introduced into the Project and the construction of Akashi Kaikyo Bridge of Kobe-Naruto route (3-span highway suspension bridge with center span of 1,990 m) and Ikuchi Bridge of Onomichi-Imabari route (highway cable stayed bridge with center span of 490 m) were newly approved as the government's policy to expand domestic demand.

2. ENGINEERING AND SOCIAL PROBLEMS PECULIAR TO THIS PROJECT AND SYSTEMS IMPLEMENTED TO SOLVE THEM

The Honshu-Shikoku connecting roads and railroad constitute an important section of the country-wide trunk traffic network. Each route makes its own peculiar demands on traffic and therefore no alternative path can be taken as would be possible on a land route. The Project includes the construction of many long span bridges on an international scale under severe natural conditions and in a peculiar social environment. The following are major engineering and social problems of distinctive features [7]:

(1) Prominently susceptible to earthquakes and typhoons

In a long-span suspension bridge, in particular, its stability against wind and its earthquake resistance would greatly affect the safety of the completed structure.

(2) Combined highway-railroad bridges on which high-speed trains are running

The effects on a suspension bridge caused by the passing of trains and the effect on the safety of train operation due to the behavior of suspension bridges are to be evaluated and adequate measures must be taken. Also, prudent measures must be taken against fatigue in the welded joints, because thick quenched high tensile strength steel plates are used in quantity.

(3) Safe and reliable construction methods of foundation

Construction methods of foundation should conform to the site condition in a strait of great depth and strong tidal currents. In the case of Akashi Kaikyo Bridge, even though the center span was extended to 1,990 m, it was necessary to construct foundations reaching as deep as 70 m below sea level under the severe natural conditions of a sea depth of 40 m and a maximum tidal current speed of 4.5 m/sec.

(4) Method of erecting the superstructure in severe meteorological and marine conditions

The method of reducing the volume of work at site, shortening the construction period and selecting safe and secure methods of construction, greatly affect the safety and quality of the completed structures.

(5) Navigational safety

As the strait over which the Honshu-Shikoku Bridges are constructed constitutes a main navigational route, including international vessels, it is congested with shipping, in addition to fishing boats operating in the peripheral sea region. Therefore, prudent safety measures for navigation must be taken during construction and even after its completion.

(6) Maintenance

The structures are extremely large scale and unique in nature, thus making it difficult to rebuild or replace their members. Consequently, an important factor is the maintenance of the bridges to secure their safety and quality over a long period of time.

(7) Environmental consideration

Since the routes are running in the beautiful and charming Seto-Inland Sea National Park, the harmonization of the structures with landscape and the preservation of natural and living environment are extremely important.

The engineering problems mentioned above cover some fields where technological experience is lacking and which basically affect the safety and quality of structures and their safety during construction. The basic concept to meet this challenge to solve those problems are as follows:

(1) Integrated consideration should be taken in all phases at planning, design, construction and maintenance, which are closely interrelated.
(2) Standards and specifications should be established for design, construction and maintenance, incorporating wide and interdisciplinary knowledge.
(3) As the construction must be performed in the strait and under severe natural and social conditions, the methods of construction should preferably be designed so that they are simplified, labour saving, large scale and quantitative.

To meet these requirements, investigations, research and technical development have been in progress for many years and in this Project the following approaches have been adopted for execution to ensure safety and quality [7]:

(1) With regard to comprehensive and fundamental technical matters and individual problems or subjects, the Technical Advisory Board and the Special Technical Committees, respectively have been organized. This Board and Committees are to point out ways of solving problems, investigations, tests, technical development, etc., and to evaluate and suggest on the results of investigations or examinations performed and proposals made by Honshu-Shikoku Bridge Authority. The Authority, based on these results, prepares 51 types of Standards and Specifications, some of which examples are as follows:
    (a) Standards for Structural Design of Superstructures,
    (b) Standards for Structural Design of Substructures,
    (c) Standards for Wind Proof Design
    (d) Standards for Aseismic Design,
    (e) Standards for Fabrication of Steel Bridges,
    (f) Standards for Fabrication of Cast and Tempered Steel Products,
    (g) Standards for Coating of Steel Bridges,
    (h) Standards for Pavement on Steel Plate Floor,
    (i) Standards for Construction of Mass Concrete Structures,
    (j) Honshu-Shikoku Bridge Standards of Material for Steel Plates, Cable, High-strength Bolt, Paints, etc.
    (k) Specifications for Buffer Structures
    (l) Specifications for Tower Design
    (m) Specifications for Transition Girders

(2) With regard to newly developed method of construction, experimental constructions, and testings are to be performed to verify their workability, safety, quality achieved, accuracy, etc., and their adoption is determined depending on the results.

(3) The design for the structures is let out to the Consultants. In this case, the design methods are specified and they are bound to conform to the above Standards and the results are examined by the Authority. In concluding the Contract for Construction, the methods of construction are specified as required, and in addition, the Particular Specifications are provided supplementing the above standards to make certain that the safety and quality are ensured.

(4) Prior to the commencement of construction, the Contractors are asked to submit the construction plan, which will be thoroughly examined and they are bound thereby. The Contractors are held responsible for quality assurance of the construction. In turn, the authority will confirm the safety and quality through the supervision and inspection of the construction [8].

3. SOME CONSIDERATION ON ENGINEERING ACHIEVEMENTS FROM THE VIEWPOINTS OF SAFETY AND QUALITY ASSURANCE

In this Project many structures are to be constructed concurrently, safely, surely and in a short period and put into service meeting strict internal requirements and satisfying various external conditions. In view of this situation, prudent investigations and research on safety and reliability of construction through experimental work, simplification of on-site works incorporating shop fabrication by a large margin, development of construction techniques aiming at labour saving, introduction of a diagnosis system of soundness of structures both on the spot and over the long term, etc., were performed. In this section, specific examples of the above are introduced and their effects are examined.

3.1 Aseismic design and wind-proof design standards

In the design of substructure, it is necessary to determine static behavior of the substructure at the time of an earthquake and conditions for stability must be met. For this purpose, earthquakes to be subjected for investigation were selected from the earthquake activities records in the Seto-Inland Sea region as those occurred at slightly longer range and with higher effects (epicenters located between 100 and 150 km from the site), assuming a recurrence interval of 100 years and a magnitude of about 8 in Richter scale. In the design, a whole system model of the superstructure and substructure was used to perform spector analysis and the reaction obtained was substituted onto the substructures model as the external force for stability calculations.

Meanwhile, the wind-proof design was the design consisting of the static design placing emphasis on the section design of structural members and the dynamic design performed using a wind-tunnel test to avoid self-excited oscillation which is catastrophic in case of storm and to control vortex-induced oscillation when the bridge is put into service. The basic wind velocity used that becomes the basis of these designs was the mean wind velocity for 10 minutes at 10 m above seal level assuming the recurrence interval to be 150 years, which is 43 m/sec in the Akashi Strait. The design wind is calculated by the structure incorporating its elevation, response characteristics, space characteristics of wind, etc., into the basic wind velocity. The sections of members determined for static loading conditions under normal conditions and abnormal conditions, such as typhoon, earthquake, etc., were improved in the section configuration, etc., using the wind tunnel testing by reference within the range of 1.2 times the design wind speed, as well as verifying the coefficient of aerodynamic force assumed in the static design. The validity of the Wind Tunnel Testing Standards has been confirmed by large scale model experiments in the natural environment (scale 1/10). In addition, the confirmation of vibration characteristics by the compulsory vibration tests after the completion and the behavior observation have also been performed to verify the modes, frequencies and damping ratio so that a consistent safety of structure can be pursued.

3.2 Some features on combined highway-railroad bridges

The problems associated with combined highway-railroad bridges of large scale are safety of train traffic and fatigue design.

(1) Assurance of train traffic safety

Large scale suspension bridges have structures that are subject to deflection and, in particular, at the ends of girders large expansion/contraction and angular bend tend to occur. To permit trains to travel safely on structures such as these, the continuous girder was adopted as the stiffening girder structure to reduce the locations where expansion/contraction and angular bend would occur and by shortening the side span length their values were minimized as much as possible. And as a system to absorb expansion/contraction and angular bend, a buffer girder was developed and its contribution to safety was confirmed by experiments using actual traveling trains, thereby making it possible to allow the expansion /contraction and angular bend caused on the anchorage to ±75 cm maximum and 10 ‰. Also, in the design the deformation that is caused by running trains and its dynamic effects were analyzed and it was discovered that the coefficient of impact of approximately 0.2 would be suitably used. For the Bannosu Elevated Bridge on the shore, as the bearing stratum was deep sandy ground and the pile foundation had to be penetrated deep into the ground (max. 74m), and also the bridge pier was high (max. 72 m) the possibility of train derailment was avoided by staggering the vibration cycle of the structures and that of the trains in case of an earthquake.

(2) Use of high-tensile strength steel and some considerations on fatigue of welded joints [4],[5]

As the bridges had to be combined highway-railway bridges, the structures inevitably became larger in scale and the use of quenched high-tensile strength steel plates of large thickness was necessary for the major structural members, i.e. maximum tensile strength of 80 kgf/mm^2 class on thickness of 160 mm class.

Because of the sensitivity and brittleness of the material, quenched high-tensile strength steel plates, consideration on the fatigue of welded joints due to the repeated travel load of trains had to be made in the design and fabrication.

Therefore, in the standardization of the design, provisions were made for confirming the fatigue strength of welded joints through the testing of each joint using a fatigue testing facility with dynamic loading amplitude of 400 tonf and an allowable value of initial defects of welded joints incorporating the safe-life concept in the fracture mechanics and testing methods. As the fabrication of stiffening girders for the three suspension bridges of the Kojima-Sakaide route, about 110,000 tons in quantity, had to be divided among the fabrication shops of 24 companies and performed almost concurrently and required uniform in quality, a full-sized member was fabricated experimentally at each fabrication shop prior to the actual manufacturing and a welding method to meet the required quality was established. Automatic supersonic inspection was performed on the welded joints at frequencies corresponding to the fatigue classification and it was confirmed that the required quality had been obtained. The data for this inspection will be reflected in the follow-up investigation of defects in the maintenance of structures, contributing to assuring of safety against destruction by fatigue.

(3) Method of main cable installation [2]

Demands for large scale suspension bridges and combined highway-railway bridges have made the main cables larger both in length and diameter. Consequently, labour saving in the site construction and shortening of construction period became necessary resulting in the development of construction techniques of the Prefabricated Parallel Wire Strand method, Aerial Spinning method.

The PS method is the method in which a shop fabricated strand that is made up of 127 plies of wire socketed at both ends delivered to the site and stayed. This method is resistant against a variety of weather conditions, such as wind, etc., and effective in reducing volume of the site work and shortening of construction period, enabling us to install the high quality parallel cables of diameter reaching as large as 1 meter with low percentage of voids.

Also in the AS method, non-adjustment of sag of wires during composing a strand and simultaneous drawing of four wires, etc., were performed, achieving reduction of the site work and shortening of construction period compared with the conventional AS method. Cables of quality as good as those obtained by the PS method, were obtained.

3.3 Selection of construction methods making use of the characterisitics of marine works

Marine works are characterized by disadvantages such as transportation of equipment and materials, raw materials, and labours had to be dependent upon meteorological and marine conditions, but on the other hand, by making positive use of the sea enviroment, the construction of large scale structures was made possible. As a result, prefabrication of members in the shops was accelerated and a new method of civil engineering construction was created. In this Section, some of the features and examples of technology development achieved which were derived therefrom are introduced.

(1) Laying-down caisson method [1],[3]

In the Kojima-Sakaide route 11 undersea foundations, for suspension bridges and cable stayed bridges, were constructed. As one of the methods of construction common to these the laying-down caisson method was developed in which a steel caisson fabricated in the dock was installed on the sea bed which had been blasted, excavated and finshed in advance. Then coarse aggregate was thrown in the caisson followed by mortar injection to complete the foundation. This method made marine works at deep sea level possible to be constructed, safely, reliably and in a short period. Problems in this method are the undersea blasting and the prepacked concrete method. The latter is technology related to safety and quality assurance. Therefore, since the time of the feasibility study, large scale experimental works had been performed to confirm that high quality construction was possible. A mortar plant barge was developed by the Authority and was lent to the contractors to provide stable supply of mortar. (Capacity: 240 m^3/hr). For placement of concrete volume of maximum 230,000 m^3 per foundation (mortar injection of 12,000 m^3) and 85 hours of continuous injection operation was performed.

(2) Prefabricated large block erection

An example of labour saving and simplification of the site work and shortening of construction period was the erection of prefabricated large blocks using a large floating crane (hereinafter referred to as F.C.), which was adopted for construction of many superstructures and substructures of the Honshu-Shikoku Bridges. The most typical examples were erection of cable anchor frames, towers and girders, the largest of which was 6,100 ton (185 m long) which was erected using two FC's. Also, the aerial jointing of girder blocks using F.C. was performed with a careful construction plan and an advanced barge maneuvering techniques, which has now become one of the most representative construction techniques used in the construction of bridges in the strait. Use of the prefabricated large block erection resulted in the improvement of quality and accuracy in construction, saving in cost due to reduction of weight by reducing splices and reduction of the numbers of construction equipment and materials. Also the prefabicated large blocks are, in principle, shop painted, resulting in improved durability of the coating film.

(3) Successive full-splice jointing method in stiffening girder erection

As construction sites of the Honshu-Shikoku Bridges are located in a region susceptible to typhoons, it is necessary that their wind-proof safety must be assured at the time of erection of stiffening girders for suspension bridges. Therefore, the successive full-splice jointing method in which the blocks to be erected are rigidly jointed one after another, was adopted. In this method, however, as excessive stress is caused with diagonal members and hanger at the tip of erection and the stiffening truss, erection hinges were provided to reduce the stress.

In the construction of Ohnaruto Bridge, as the fequency of strong wind is high, if not of typhoons, further wind-proof consideration during the erection was required, it was decided not to use the erection hinges, becuase they could be a weakness in case of strong wind. Instead, the tip of the block being installed was drawn simultaneously using two or three hangers, the adoption of which resulted in the shortening of erection period.

3.4 Various coordinations of structure with navigation

The Seto-Inland Sea where the Honshu-Shikoku Bridges are to be constructed has a complicated waterway topography, and severe meteorological and marine conditions from the viewpoint of navigational safety. In addition, as the Sea forms an important route for marine traffic it is necessary that safety of ship navigation be secured both during the construction and after the completion of bridges. In this connection, establishment of the construction zones, posting of alert boats, provision of information to construction boats (barges) from the information control center, etc., have been made during the construction and the following measures will be taken after the completion.

(1) Measures against radar interference

A forecast was made on the occurrence of false image due to the mirror reflection phenomenon caused by a bridge constructed at sea or the false image of multiple reflection caused by repeated reflection of radar waves among the bridge members, and measures for their abatement such as pasting wave absorber materials on parts of the main tower and the stiffening girders or providing multi-stage slopes on wall faces of the anchorage, etc., are being taken.

(2) Buffer structure [6]

To minimize damage to the hull and the bridge pier should a ship collide with the undersea foundation, buffers will be provided around the foundation.

(3) Navigational aid system

To help make navigation safe in foggy weather, a navigational aid system, such as visibility automatic response system, automatic detecting and indicating system for ship's movement, etc., will be provided.

3.5 Maintenance system

The bridge portion of the Honshu-Shikoku Bridges are taken up a large percentage of about 40% and the long-span bridges are concentrated on the strait. As there is no alternative to this route, the traffic control and the maintenance of the road to keep the bridges in good operating condition becomes a matter of extreme importance.

For this reason, consideration is given for it to be centrally monitored and controlled by providing a traffic monitoring system and weather observation system in addition to accelerometers, seismometers, displacement gages, etc., as its movement observation systems. In particular, the movement observation system follows the secular change of the bridges and judges their soundness, and in addition, detects damage and its location shortly after the occurrence of abnormal conditions (e.g. earthquake, typhoon, etc.) making it possible to resume the service of the bridges as soon as possible.

To make inspection, maintenance and repair operations of the bridges which are composed of multi-functions and multi-members easier, many passages for inspection and inspection vehicles with high accessibility to various locations are provided.

4. CONCLUSION

The Honshu-Shikoku Bridges Project have constructed and are presently constructing combined highway-railroad bridges of large scale and is managing them under the severe natural conditions and environment of typhoons, earthquakes, large water depth and strong tidal currents, etc., and the social conditions of navigation, among others.

The Honshu-Shikoku Bridge Authority, through the execution of the entire undertakings of design, construction and management of the bridges, has been performing comprehensive and efficient operations, securing safety and quality at each stage. The technological development achieved and established in the design and construction of these bridges are as follows:

(1) Establishment of aseismic and wind-proof designs based on the assumption of 100 year durability.
(2) Standardizing safety against travelling of trains and fatigue destruction of the combined highway-railway bridges.
(3) Selection of the laying-down caisson method and the prefabricated large block erection method making use of the marine works and aiming at improving safety and quality and shortening of construction period, and the PS method in the installation of the main cables, the full-splice jointing method in the erection of stiffening girders.
(4) Various coordinations of structures with navigation of ships from the viewpoint of safety both during construction and after its completion.
(5) Development of a maintenance system to secure constant soundness of the bridges.

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