Quality and economy

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Quality and Economy

Qualité et économie

Qualität und Wirtschaftlichkeit

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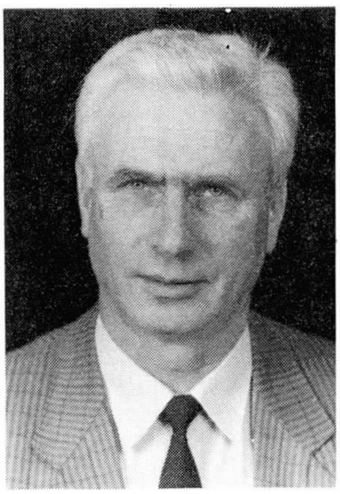

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SUMMARY
Quality and economy make up the main theme of structural engineering. Substantial improvements have been achieved in recent years. There are, however, certain aspects which, though no less important, have not yet been adequately discussed, because they cannot be quantified in a scientific way : Functional quality and economy – Quality through replaceability? – Quality through imaginative design – Aesthetic quality – Political decisions and quality.

RÉSUMÉ
Qualité et économie sont le thème principal dans le domaine des constructions de génie civil. De nombreux progrès ont été réalisés dans ce domaine au cours de ces dernières années. Il y a cependant quelques aspects qui – quoique non moins importants – sont moins discutés, car ils ne peuvent pas être quantifiés d'un point de vue scientifique : qualité fonctionnelle et économie ; amélioration de la qualité par la possibilité d'échanger des parties ; amélioration de la qualité grâce à des idées de conception ; qualité et esthétique ; décisions politiques et qualité.

ZUSAMMENFASSUNG
Qualität und Wirtschaftlichkeit sind das zentrale Thema des Ingenieurbaus, und in den letzten Jahren wurde auf diesem Gebiet Wesentliches verbessert. Gewisse Gesichtspunkte wurden aber weniger diskutiert, weil sie sich nicht wissenschaftlich erfassen lassen ; trotzdem sind sie wichtig : Nutzung und Kosten – Qualitätsverbesserung durch Auswechselbarkeit? – Qualität durch Entwurfsideen – Gestalterische Qualität – Politische Entscheidungen und Qualität.

1. THE THEME

The theme "quality and economy" of the first session of this symposium is in fact all-embracing. How could structural engineering be defined better than by the search for quality within the framework of economic fesibility? This definition, of course, takes for granted that we see and understand both, quality and economy, in their widest possible sense, as fortunately most of us have started to do, at least in recent years. The decline of the predominantly quantity-minded postwar reconstruction period has been greatly accelerated by the awareness that natural resources, including land and the beauty of nature, are exhaustible.

"Quality" in a structure, of course, means that it has to fulfil functional requirements, that it must be safe and durable during a reasonable lifetime. Beyond that, we know today that quality also includes the architectural appearance of a structure, its adaption to the environment and the landscape, its physiological and psychological impact.

As far as the interrelationship between quality and economy can be measured and quantified, i.e. where it is clear that with additional financial input a defined amount of additional quality can be achieved, we have indeed made substantial progress in recent years: We have improved our knowledge of the behaviour of reinforced concrete and our concept of safety. We know that temperature variations or chemical corrosion affect a structure much more than traffic loads, as defined by codes. It is well known today, though only after a painful process of purification, that durability is not a property of concrete structures per se. It depends first of all on dense concrete and sufficient cover. Density comes mainly from a well planned concrete composition and a low water/cement ratio. To achieve the latter, plastifying additives are the correct solution. Durability also requires careful detailing of the reinforcement, including crack control (which does not mean full prestress), though the crack width itself, within the aesthetically acceptable limits, is not the criterion. For very exposed parts of a structure coated reinforcement may also be a good idea. Finally, durability requires good workmanship, including such obvious points as water-tight and perfectly grouted cable ducts. We are learning to quantify these parameters to the extent that we can directly relate them to the life of a structure, and since they are all connected with additional costs, we have become aware that the cheapest is not the best. Quality and economy is a timedependent interrelationship: it is better to invest more initially, in order to save later through reduced maintenance. We have further become aware that whatever measures we may take, there is no absolute guarantee for their success. Human insufficiency cannot be excluded from design and workmanship and therefore all parts of a structure must be accessible for inspection, maintenance and, if necessary, repair.

This, and much more, are the topics to be further discussed during this session. Let us therefore here try to throw some light on certain further aspects of "quality and economy" which are less often discussed, because they cannot, or cannot yet, be quantified in a scientific way - the reader may judge whether they are therefore less important.

2. FUNCTIONAL QUALITY AND ECONOMY

Usually a building or a structure serves several purposes and has to be designed for a sequence of load cases. Modern safety concepts like the CEB/FIP Model Code consider the probability of their simultaneous occurence and their order of importance by combination factors. However, this concept is not at all satisfactory if, as is frequently the case, a structure is built to serve predominantly one single requirement, which is nevertheless of only very insignificant influence on the forces. The satisfaction of this requirement then governs the quality but is of no influence on the economy. If now the effect of this single requirement on the structure, e.g. its loads, is uncertain or varies extremely, only nominal additional costs will be incurred in strengthening the structure with respect to its resistance to this factor, and thus its value or quality will be increased, perhaps dramatically.

Two examples may illustrate this:
A young industrialist builds his first factory. The structure is a frame, mainly there to support a crane running on two rails, which rest on corbels (Fig. 1). For cost reasons, a crane is chosen with a capacity just adequate for current production requirements. Accordingly, the consultant designs the corbels, columns and foundations for this load. The firm flourishes and after some time the industrialist wishes to install a crane of greater capacity, but he cannot - because the corbels will not take the additional load. The columns and foundations, on the other hand, could take it easily because they are designed for a most unlikely superposition of wind, snow and crane loads, the latter contributing the least. The whole building has become obsolete because its designer did not foresee this eventuality, in view of which he should have overdesigned the corbels - only the corbels - with the effect of negligible additional costs but a tremendous advantage for his client. One may argue that the client, if he was asked, might not permit the overdesigning of the corbels at his expense, because it is not required for safety reasons or by codes. An engineer, however, must try to understand the psyche of his client and should not ask him, if he cannot expect the right answer. Quality and economy sometimes cannot be quantified and engineering is more than following prescriptions; it demands some imagination.

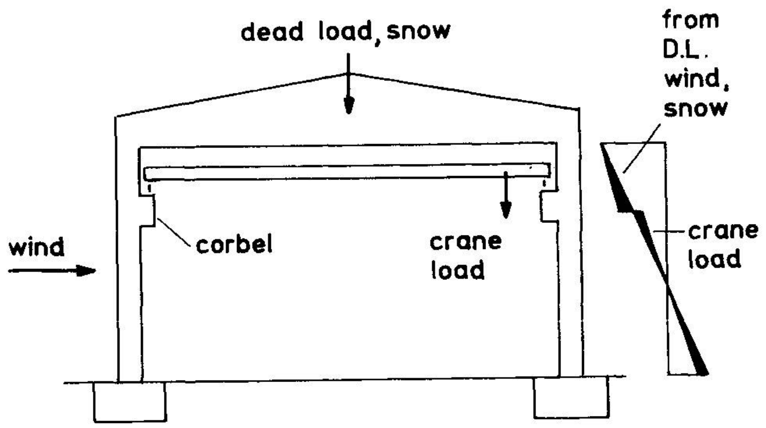


Fig. 1: Moments in the columns of an industrial building

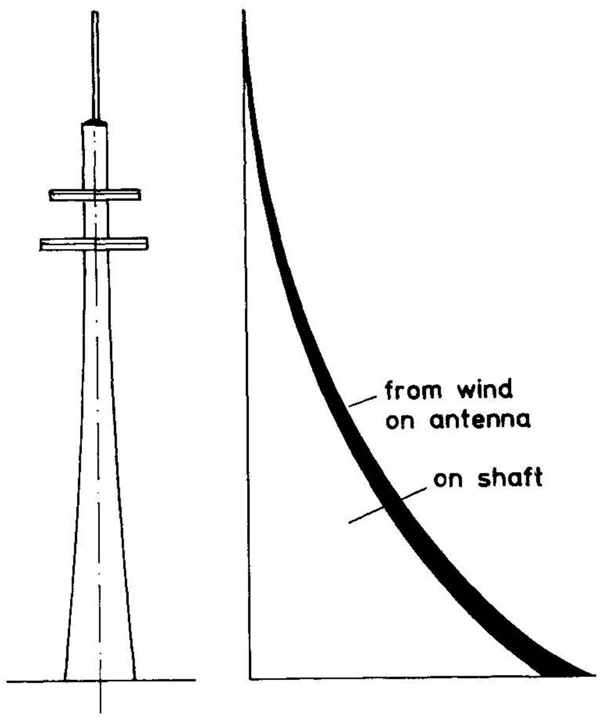


Fig. 2: Moments in a TV tower due to wind

A TV station needs a cylindrical antenna, height 15 m, diameter 1.2 m, on top of a concrete mast, height 200 m (Fig. 2). The predominant load is wind, but the contribution of the antenna itself to the wind moments of the design is of significance only at the topmost part of the mast, further below it disappears as against the contribution of the mast itself. This is even more the case for the vertical loads. Therefore a far-sighted designer will give some extra strength, which costs almost nothing, to the top of the mast and thus improve its quality by preparing it for a quite likely desire on the part of the client at some time in the future to have a longer antenna installed; that's what the mast is there for. On the other hand, the client's representative himself will not ask for that extra strength right from the beginning, because he does not know the financial consequences and is afraid of being held responsible if the extension should not be required. Engineers must sometimes assume other people's responsibilities.

3. QUALITY THROUGH REPLACEABILITY? - BUILDINGS ARE NOT MACHINES!

There is a tendency today not only to make structures accessible for inspection but also to design certain parts with respect to a possible or even planned replacement after some time. Typical examples are the pot-bearings or the externally applied prestressing tendons for bridges. Paints or plastic covers are proposed to ensure durability of concrete, which also need to be renewed after some years. (We shall not discuss dangerous extravagances, such as providing a building with a snow thawing system instead of designing it for snow loads, as if this machine or its electricity supply could not fail precisely during or due to heavy snowfall.)

Agreed, such ideas should not be condemned generally, e.g. the railings and kerbs of a bridge subject to intensive salt spray must be replaceable without having to build a whole new bridge; paint and plaster in a house is another obvious example. However, a word of warning must be spoken against such tendencies being carried too far. A building or a structure should first of all be designed and built to last. Such is its character as against a machine. This is what the user expects of it. If the trend continues, the designer will concentrate on replaceability instead of quality. If negligence has no serious consequences, it will be encouraged. If the surface of concrete is the painter's job, the concrete contractor will not care. The outcome will be a disaster from the point of view of quality, including architecture. Buildings and structures will become a stockyard of individual spare parts which need not be compatible because they can be exchanged. We can already observe a trend to separate the superstructure of a bridge from its piers by means of replaceable bearings - any superstructure fits on any pier -, and thus bridges are losing their character, their individuality, their cachet. In Germany, though the single-cell box girder for 6-lane highways was developed there, it is forbidden today in favour of two individual box girders on separate piers, so as to be able to repair or replace one half of the bridge with the traffic running on the other. Or the railroads prescribe standard-type simply supported beams for the new high-speed trains, which are replaceable overnight. The result is unsatisfactory, not only from an aesthetic point of view but also with respect to durability: these structures will not only be repairable, they will indeed need repair.

This sort of thinking is conservative, going in the wrong direction, what is needed instead is

4. QUALITY THROUGH IMAGINATIVE DESIGN

To discuss this point, we must start with a statement which should be, but still is not for many, a commonplace: the quality and the economy of a structure in the widest sense are above all prescribed and governed by its design. This is not to exaggerate the role of the designer or to undervalue the necessity of excellent workmanship or to let the contractors evade their responsibility, but it is a fact that a large number of deficiencies which are attributed at first sight to errors or negligence on site can be traced back to the design. We all know numerous examples of this, from the most trivial case of overcongested reinforcement which does not allow the concrete to penetrate, to such monumental failures as the partial collapse of the Berlin Congress Hall.

One cannot design with and work with a material which one does not know and understand thoroughly. Therefore, design quality starts with education. Structural engineering is a practical profession and therefore no student should be admitted without a practical training, no university curriculum should fail to include courses in sketching, drawing, modelling. Students must be taught how to live with computers, but to use them only after getting approximate results by rule of thumb calculations, and to keep good company with their future architectural colleagues. This is the best investment for quality. It also calls for translucent and consistent design concepts for reinforced and prestressed concrete. They can be derived only from physical models, and we must get away from empiricism. The proposal to use strut-and-tie models, a generalized truss analogy, as an effective tool in this respect is fortunately finding more and more followers. Let us hope that CEB-FIP will use the chance to prepare a modern Model Code on this basis. It could bridge the gap which is liable to open between engineers in practice, who need handy tools, and those researchers who only believe in computer results, by satisfying both: the practitioner will use it in daily design work and the researcher will derive from it the input which he then elaborates on his computers.

A better understanding of the behaviour of reinforced concrete and of the context of the structures made from it will certainly make us aware that we have directed our efforts in the past too frequently to factors of secondary importance with respect to quality and economy: it makes no sense to fight the shear battle for years if the savings in stirrups are negligible in comparison with the outcome of other design parameters. It makes no sense to calculate crack widths with extreme accuracy if their influence on durability can only be measured in broad terms. It makes no sense to infinitely refine a FEM analysis it the material properties or the geometrical imperfections origin from an uneven building site.

However, it does make sense to apply imagination to design and structural detailing. Quality thus achieved does not cost, but results in savings:

When selecting the materials - concrete, steel, wood, plastics - we should be governed only by the question whether their specific properties are appropriate for the given purpose, not by affiliation on a lobby. It is a pity that most civil contractors and also many university institutes (and even this symposium) are material-oriented and not simply construction-minded. The joint use of different materials in one structure, a hybrid solution, promises better results. The composite girder for long-span cable-stayed bridges is superior to the pure concrete or the pure steel girder. High-rise buildings erected in steel and encased in concrete are the most economical. Box girder bridges with concrete top and bottom slabs and steel webs open new possibilities: it is not just politeness to state that particularly our French hosts are developing more imagination in novel bridge design. This symposium will provide evidence.

The quality of concrete itself is best brought out if the design does not deprive it of its monolithic nature.No joint is the best joint, no bearing is the best bearing. If we know and utilize the ductility and ability of reinforced concrete to compensate for stress due to settlement or temperature effects, we will approach this goal. Latest research, such as on the effect of confining reinforcement on rotation capacity, or on the capability of concrete to transfer forces over cracks with the help of aggregate interlock, is really useful for a move in this direction.

We should also be more aware of the possibilities of shaping concrete consciously to optimize behaviour: smooth, open sections are better than filigree, undulated and hollow ones. They permit a better control of concrete cover, avoid temperature stresses between inside and outside, are easier to inspect and maintain and, last but not least, need fewer or no construction joints. A pure slab is superior to an open T-section, and the latter to a closed box girder. The slab, due to its low bending stiffness, may now be connected homogeneously to the supporting columns, thus avoiding bearings. Why, if flexibility requires it, should these columns not be made of steel and be directly bolted to the concrete slab and concrete foundations (Fig. 3)?

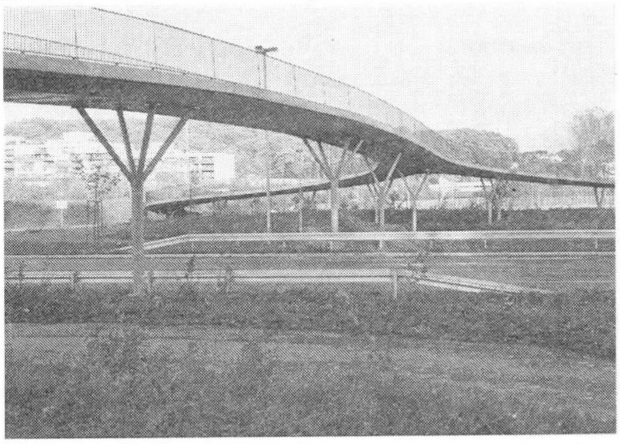


Fig. 3: A pedestrian bridge, slender steel tubes supporting a concrete slab

Without any question, concrete is the material of our times. It complies with the demands of modern architecture and manufacture: it can be freely shaped on site, independent of a shop. Nevertheless, it has lost friends in recent years, because we have exaggerated its application and distorted its natural beauty by imitating, for purely economic reasons, the shapes and production methods which are typical for steel and wood: plain and straight members, cut in pieces and joined again, boring and clumsy instead of free, threedimensional plastic forms, manifold and animating.

In this context concrete shells, the most genuine concrete structures, need to be mentioned. If we are interested in structures which derive the natural beauty of their forms logically from their flow of forces and which require material properties unique to concrete, then we must deplore the fact that they have almost disappeared. This is, of course due to the excessive cost of their formwork, with the effect that the indisputable quality of shells does not go hand in hand with criteria of economy. However, in view of the fact that today we have more advanced shuttering techniques, more effective

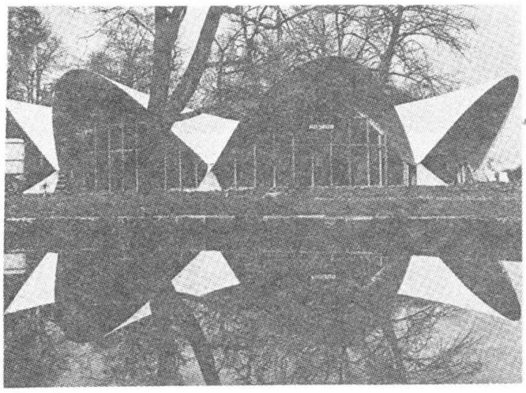


Fig. 4: Glass-fibre reinforced concrete shell
diameter 31 m, thickness 12 mm

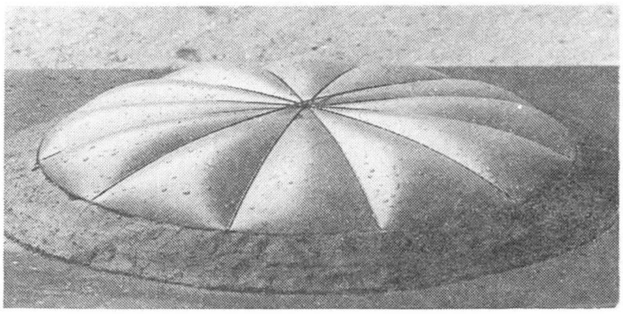


Fig. 5: Pneumatic formwork for a concrete shell

cranes and concrete pumps, and new materials like high strength concrete, it appears to be the consequence of a lack of imagination in design that there are not more shells being built. The use of glass-fibre reinforced concrete (Fig. 4) or of pneumatic formwork (Fig. 5) are examples of efforts to revive shell construction.

5. AESTHETIC QUALITY - A MEASURABLE QUANTITY?

This is, of course, not a directly measurable quantity. But nevertheless it has a real value in several respects.

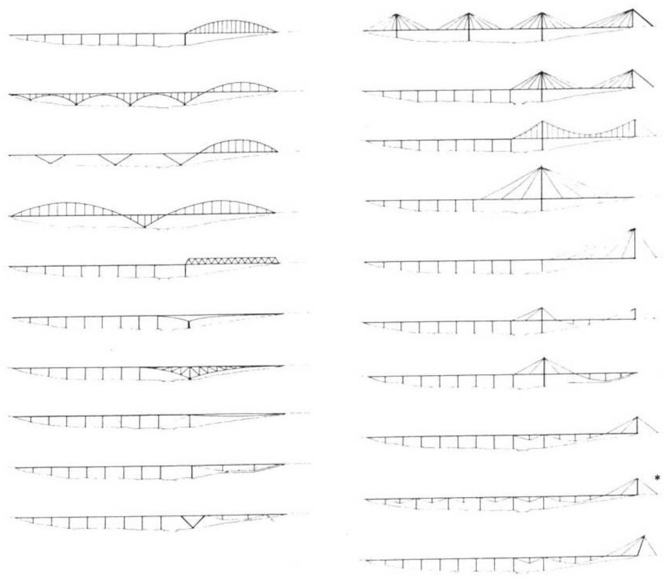
We mentioned above that there are some grounds for improving the aesthetic quality of concrete structures, and we must now add that this is of course true for structures of all materials. In fact, we witness a tragic schizophrenia as far as architecture is concerned: a few types of building enjoy interest and affection, the rest are treated as functional and technological objects. For the first, important administrative buildings, museums, etc., even some kindergartens or private houses, we arrange design competitions, discuss them in public and spend money lavishly. The latter, factories, offices, shopping centres, etc. the so-called functional or utility buildings, have only to serve their purpose and be cheap. Though we structural engineers can and should not evade from any responsibility as far as architecture and buildings are concerned and should try to improve our collaboration with the architects by creative contributions, I want to refer here mainly to these "functional buildings", - as if there could be a building or structure without function. For the bridges, the communication and cooling towers, the traffic facilities, the silos and containments, etc. we are primarily responsible - and they are often of an unutterable ugliness, pure products of construction technology, of a primitive materialism, built without imagination or affection.

Why should we bother? What is the value of aesthetics? First of all: architecture, the art of building, is indivisible. If we exclude certain areas from it, we act against culture! What if our ancestors in times of much less wealth had treated these structures as we do? Would we then admire their cities and bridges today and would it then be worth preserving - as we fortunately started doing some time ago - the architectural heritage of early industrialisation? Further: Can we ignore the fact that these monstrosities, which have made concrete the synonym of ruthless and misused technology, contribute to a large extent to this immanent hostility towards technology as a whole, which mankind can certainly not afford, since it largely depends on technological processes and progress? Could we advertise our profession worse than by our badly styled products? Other branches have long since realized the importance of industrial design, some companies even advertise their products today with the so-called high tech architecture of their buildings. And what about our most important capital, our professional recruits or coming generation? Shouldn't we reflect on the fact that our architecture schools are overcrowded, whereas we are troubled by a dearth of young talent? If a profession is unable to prove that it seeks for creativity, it will not attract creative young men and women, a vicious circle!

How can we change this situation? First of all by education, as already mentioned above with respect to design in general. Then by making structural engineers aware that they produce architecture and that they have to learn how, by offering the necessary courses and training at our schools and universities.
Further, by creating a demand for such creativity, which would die again if it were not encouraged. To this end we must advertise our structures, make

aware of the possible beauty of a bridge, of its impact on its environment, ask architectural critics to take note and to discuss in their media these types of structures also.

This propaganda in aid of a better acceptance of the "functional structures" is further necessary to make the public willing to accept that in this field also, quality has its price. For this is absolutely necessary to overcome a prejudice or misapprehension, which for some reason is also shared by a few respected colleagues, namely that aesthetic quality in structural engineering costs nothing extra. It is argued that for these structures the good forms automatically follows the good technical solution. This is not true! Even a unifunctional structure under given prerequisites, a bridge over a particular valley for example, has multiple solutions (Fig. 6), and the choice will always



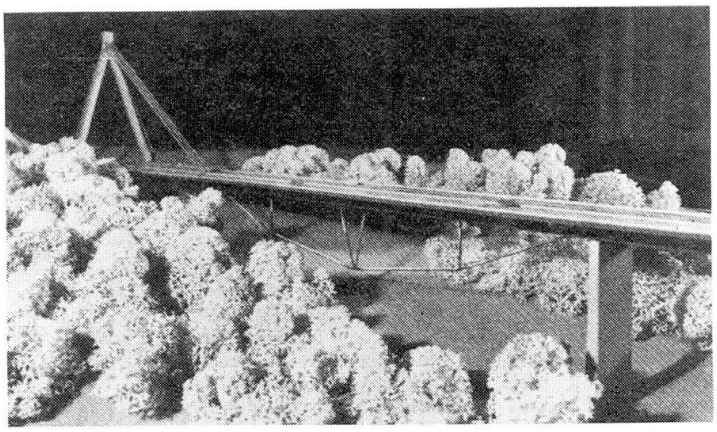


Fig. 6: Some alternatives for one and the same bridge design problem: Prerequisite: a 260 m side span at right because of adverse soil conditions

be subjective and lead to a conflict between aesthetic quality and economy. This is especially so in these times of high labour costs. It is cheaper to waste material and save labour. This leads to manufacture-oriented uniformity. The box girder of constant height, even if the span varies, fits every valley. This does not permit delicacy, lightness, variety, the indispensable attributes of beauty.

Our clients, mostly government employees, will need public endorsement and support if they are prepared to consider not the cheapest tender, but the best, where "best" comprises all ingredients of quality. Thus, the only remaining problem would be to determine what design for a given building or structure really balances quality and economy in the best way. It appears that more design competitions are the best solution, as it has been practised by architects for a long time, and also by structural engineers in certain cases with great success, not forgetting that both should join forces in the competition stage. By the way, this would also help the client to choose the "best consultant" for a given project, if he does not want to rely on other criteria like previous records. It is very regrettable that more and more clients select their consultant on lowest tender or fees. This is a case of false economy.

Tendering could then proceed on the basis of the result of the design competition, and contractors would mainly be asked to produce ideas for the best construction and execution of the work. Alternative designs should not be excluded, but would have to satisfy the overall criteria, quality and economy.

There is still a chance that the art of structural engineering may be awarded a quality and not just a quantity seal, as the situation stands now. It could even happen that engineers' structures will not only be tolerated but become again what they were in the last century: a genuine contribution to culture and the subject of pride for their creators and of admiration for those who see and use them.

6. QUALITY IS FREQUENTLY DETERMINED ELSEWHERE

We know today that the quality of a structure depends significantly on the continuity and coordination of design, construction and maintenance. But we are too little aware or at least have no remedy for the fact that very often the most important decisions on a building or structure are taken before engineers come into the picture. The decisions whether construction activities are to be started at all, where and how, under what social and economic conditions, decisions which may be much more significant than the design and construction itself, are taken by politicians.

This gap between decision-making and professional knowledge cannot lead to acceptable results, obviously not if a lack of coordination within the building process itself already causes problems. The situation may even become grotesque, if politicians use technical arguments to hide their inability or unwillingness to take unpopular political decisions, and if engineers supply infantile technical details and even contradict each other without seeing the political framework and what they are being misused for.

But can we change this situation and, if so, how? It is certainly too simple an answer, though often proposed, to tell engineers to engage in politics. If they did, at least at an early age, they would cease to be engineering professionals, and nothing would change. It is the peculiarity of scientific-technical professions that they demand the whole person, a continuous professional engagement. This is, it appears, not so within certain other professions, e.g. with teachers and other public servants, and they are therefore overrepresented in parliaments.

So for the moment we must be satisfied with having recognized the problem, and must try to improve things in small steps. We engineers should propagate our profession by writing popular papers on technical subjects. We should keep close contact with politicians, make them understand how we think, and above all learn how they take decisions. If all of us knew better what decisions are being taken, where and by whom, we could better intervene and submit proposals, and would not always be told that we are too late. Maybe at least some experienced engineers with a head for politics could at a later age, after they have gained sufficient professional satisfaction, "sacrifice" themselves and really enter into politics, with the support of their colleagues. Why should it be dishonourable to have an engineers' lobby?

This is a wide and important subject and it must be gratefully acknowledged that the IABSE leaders have decided to look into it.