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Challenge of Innovation in Materials for Structural Concrete

Défi des nouveaux matériaux dans les structures en béton

Herausforderung von neuen Materialien in Betonbauwerken

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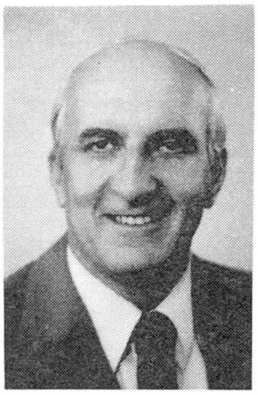

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SUMMARY
This introductory statement defines and illustrates the nature of innovation in structural concrete materials. The challenges due to the rapid innovations in this field are shown to be more related to overcoming institutional barriers than to spurring scientific development. Examples are cited to illustrate that the dramatic changes taking place in the space travel and electronic computer fields have direct parallels in structural concrete. Recommendations are made to help both individuals and the profession in adjusting to these rapid changes.

RÉSUMÉ
Cet exposé définit et illustre les possibilités d'innovation dans le domaine des matériaux pour les structures en béton. Ces innovations rapides font apparaître les problèmes à surmonter les obstacles institutionnels plutôt que d'encourager le développement scientifique. Des exemples présentés montrent que les progrès spectaculaires réalisés dans les domaines des vols spatiaux et de l'électronique ont leurs équivalents dans le domaine de la construction en béton. Des recommandations sont faites pour permettre aux individus et à la profession de s'adapter à ces changements rapides.

ZUSAMMMENFASSUNG
Dieser einführende Bericht erläutert die Möglichkeiten von neuen Baumaterialien auf dem Gebiet des Betonbaus. Es zeigt sich, dass die Schwierigkeiten eher mit institutionnellen Hindernissen verbunden sind als mit der Förderung von wissenschaftlichen Entwicklungen. Anhand von Beispielen wird aufgezeigt, dass den spektakulären Fortschritten auf den Gebieten der Raumschiffahrt und der Elektronik auch ähnliche Entwicklungen auf dem Gebiet des Betonbaus gegenüberstehen. Es werden Empfehlungen gegeben, die dem Einzelnen und dem gesamten Bauwesen erlauben sollen, sich diesen raschen Entwicklungen anzupassen.

1. INTRODUCTION

1.1 Innovation

It is a great pleasure and honor to share in the opening of this session: Innovation in the field of materials. In the papers which follow, we will learn details of the incredible variety of new developments in the various materials and processes incorporated in structural concrete. In contrast, I will highlight the basic nature of innovation and describe some of the challenges which recent innovations are posing to the vast structural concrete industry.

A typical dictionary [1] defines innovation as "that which is newly introduced: a change." This gives little insight into the process of innovation. A much more useful distinction has been made by Strassman [2], who suggested that "The word invention may therefore be used as the contrivance of a new device with certain technical features, and the word innovation as all activities of a business enterprise in developing a product and production method to the point at which it gives reliable service and allows sales at a price greater than the cost." I prefer this latter definition because it not only addresses the technological or scientific domain, but clearly indicates the need for serviceability, reliability, and economy.

Toffler [3] suggests that techological innovation consists of three stages which are interactively linked to a self-reinforcing cycle:

First, there is the creative, feasible idea
Second, there is its practical application
Third, there is its diffusion through society

The first of these stages is that of invention while the second and third stages are what distinguishes an innovation from an invention.

1.2 Rate of Innovation

We live in an age of almost frighteningly fast change. In Science and the Crisis in Society, George [4] reminds us ". . .that in the next thirty years we shall achieve, scientifically, more than in the last million years." Evidence of this accelerated development abounds in our daily lives. Many flew to this Symposium from far-flung continents, traveling to Paris in a matter of hours. Fig. 1 shows the development of the speed of human travel. The speed records of the camel caravans of antiquity (13 km/hr) gave way to chariots (30 km/hr) [3]. The speed of human travel remained basically unchanged until the development of the steam locomotives, followed by the automobile. In this century, man learned to fly, to conquer the sound barrier, to ride the rockets, and to orbit in space at speeds over 30,000 km/hr. The rate of innovation during the last half of this century is difficult to comprehend.

While few of us were shot in rockets to Paris, the more affluent could ride the Concorde at supersonic speed across the ever-shrinking oceans. This suggests that the almost asymptotic speed curve has practical limits for mass travel slightly below the speed of sound. These limits are both economic (design, manufacturing, and operation costs for supersonic aircraft tend to be very high) and environmental (jealous neighbors will not permit the shock caused by supersonic flight over their land masses).

A similar but much more recent phenomenon can be seen in the development of the electronic circuits that have made the computer feasible. Fig. 2 shows the dramatic change in the density of electronic circuits as the mechanical switches and relays of the nineteenth century gave way first to the vacuum tubes and then rapidly to the transistors of the 50's, the integrated circuits of the 60's, and today's third generation very-large scale integrated circuits. We can see that in this century the density of electronic switches has evolved through a number of orders of magnitude, resulting in almost zero length paths for electrons to travel.

1.3 Participants in Innovation

If we examine the role players in the development of electronic circuits from the perspective of the three stages of an innovation suggested by Toffler, we can draw an interesting analogy for innovations in structural concrete materials.

The first stage is the creation of a feasible idea. In electronic circuits this involves physicists and electrical engineers. In concrete materials development we see the roles of physicists, metallurgists, chemists, and some materials engineers.

The second stage is the practical application of the idea. None of us buy electronic circuits as such. We want a personal computer, a compact disc player, or some other convenience of the digital revolution. The practical utilization of electronic circuits involves product development by some physicists but many more electrical engineers, mechanical engineers, and computer scientists, who transform the basic circuits into a machine with a useful function and a reasonable cost. In concrete materials development, we see the roles of the materials engineer, the industrial and chemical engineers, the sales and distribution specialists who must transform the "test-tube" product into a viable field product.

The third stage is the diffusion through society. The ways of utilizing the electronic circuitry are brought about by a combination of computer programmers, systems analysts, and engineers. They know very little of the basic manufacture of silicon wafers, but they do know how to utilize the resultant hardware and software combinations to make life easier, faster, more efficient, or more entertaining. Without the knowledge, skill, and imagination of these programmers who are able to use the basic computer for a myriad of tasks, the products would never be sold. A direct parallel in concrete materials technology are the roles of the structural engineer and the constructor. The structural engineer must make the technical decision to use a new material in some structural application. The constructor must correctly place the new material in service. Thus, innovation requires communication between multiple disciplines. Any of the participants can destroy the effectiveness of the new development if they do not clearly understand its potential and its limitations. The consequences of a structural concrete system failure can be catastrophic as shown by the Ronan Point collapse.

1.4 Time Lags in Innovation

Careful study [3,5] has shown that while the lead time between invention and first practical application has shortened somewhat, it is still usually measured in decades. However, what has accelerated appreciably is the diffusion process, the time between introduction of a new product or process into the market and its general adoption [5]. For example, a study of the diffusion rate of electrical appliances introduced in the first half of this century as compared to those introduced in the second half indicated that the lag time between first commercial introduction and peak production had shrunk by more than 76% from 34 years to only 8 years. In our structural concrete industry one sees similar phenomena. In a comparatively short time the high range water reducing admixtures (superplasticizers) went from a demonstration novelty to a major market force. Our traditional codes and standards regulating structural concrete are often revised using volunteers who work slowly but steadily with schedules which often span a decade. These were acceptable periods when innovations required decades for diffusion, but are far too long in today's world.

2. IMPORTANCE AND ACCEPTANCE OF INNOVATION

2.1 Attitudes Towards Innovation

In Future Shock, Toffler tells us that change is the process by which the future invades our lives [3]. Like all invasions, change threatens those who have become comfortable with the status quo. Managers often fear and oppose change. It disrupts continuity and forces them to new decisions. It destroys reliance on past experience and increases risk of error and failure. Generally, firms dealing with an established product are not inclined to introduce an innovation unless the prospective profits are large enough to not only cover the development and marketing costs of the new product but also to write off the capital costs invested in the manufacture of the old product [6]. In a specific purpose material like concrete, it is difficult for the new material sciences to dramatically change the fundamental nature of the material. Many of the basic applications of concrete are as bulky surfaces--i.e. pavements, floors, roofs, and walls. The exceedingly low unit cost of the present material in bulk form makes it very difficult for new materials to supplant it. Concrete has generally fine performance characteristics within its normal range of application. Basic innovations tend to target specialty product areas where these ranges can be profitably extended. High strength compression materials for building columns and prefabricated sections, fiber concretes for strengthening complex joints, polymer concretes for toughening surfaces subject to abrasion and chemical attack such as bridge decks and chemical tanks, are all examples of important specialty innovations. The use of chemical retarders to improve placement in hot climates, air entrainment to improve freezing and thawing resistance, and pumping as a placement tool are examples of more general innovations.

In society in general and in our little world of structural concrete, change is here. In Figs. 1 and 2, the accelerating nature of a few typical changes in society were traced. An almost direct parallel can be seen in the development of the two basic ingredients of structural concrete. Fig. 3 indicates the general development of metals over the last six centuries. The coppers and bronzes of the Middle Ages slowly gave way to the cast irons and low grade steels. The lowly reinforcing of Lambot and Monier gave way to the more sophisticated reinforcing bars and prestressing steels of today. Again, almost an order of magnitude of improvement in strength has taken place in our century. The improvement in concrete strength shown in Fig. 4 is even more dramatic. The 10 to 15 MPa concretes one reads about in the pioneering research works of Ritter and Morsch have become the 100 MPa concrete columns widely used in Chicago and the 140 MPa concrete columns now under construction in three buildings in Seattle [7].

Many in the industry are completely unaware that these changes have occurred. We tend to be blinded by the everyday surroundings in which we find ourselves. We become what Drucker calls "prisoners of the familiar" [5]. Designers become used to certain material ranges which their experience indicates work well. Specifications are repeated successfully from job to job. Mix designs work well. Concrete is made with familiar ingredients from the same sources. Regardless of real cause, any difficulty on a jobsite is always blamed on any

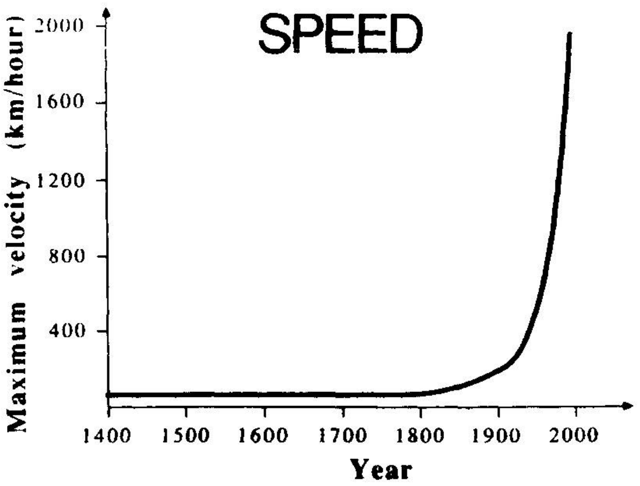

Fig. 1 Development of speed of human travel

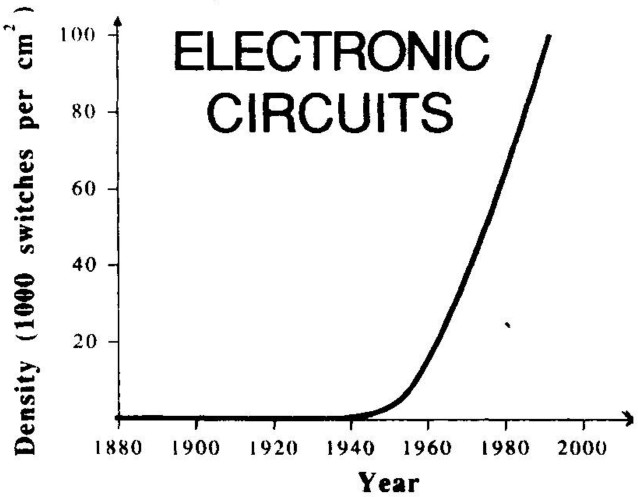

Fig. 2 Development of density of electronic circuits

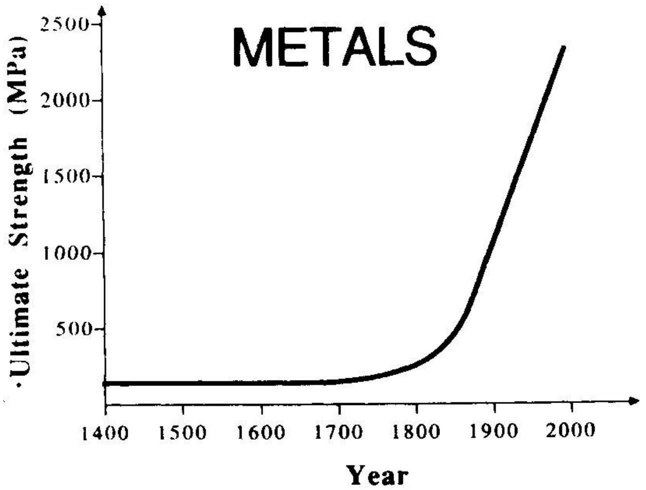

Fig. 3 Development of metal tensile strength

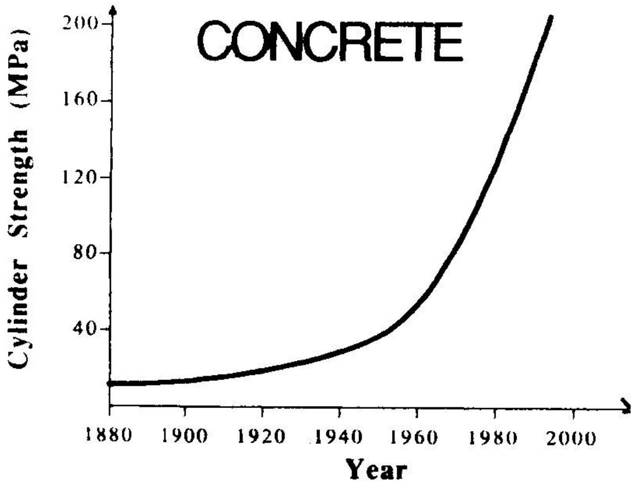

Fig. 4 Development of concrete compressive strength

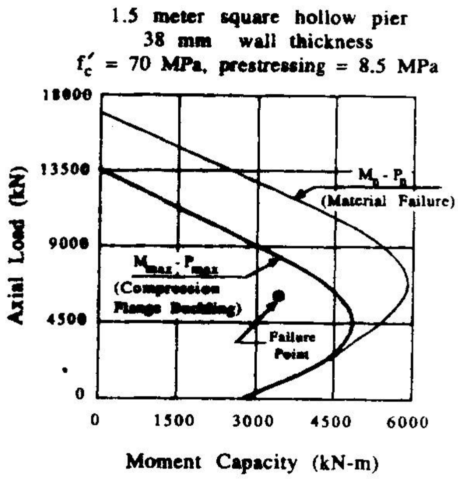

Fig. 5 Local stability effects on a thin wall pier section

innovation present. Often when a major innovation is introduced in a traditional industry such as construction, it must come from outside. Often it comes from a chemical firm, or an equipment manufacturer. Seldom does it come from within the concrete industry, which is fragmented and penurious in its research and development expenditures. This innovation by invaders tends to be a characteristic of traditional industries. Synthetic fibers were developed by the chemical industry and not by the cotton and wool-based textile industry.

Technological change often depends on the decisions of senior management. In the United States we see important structural concrete usage changes as almost generational changes. Technology changes as senior management changes. New managers are less tied to old experiences and are more open to experimentation. We must constantly improve our lifelong educational systems to bring about an openness to new ideas in our managers. Fig. 4 dramatically indicates a rapid development rate which can no longer be tied to the experience of a generation.

Many feel that they should not interrupt present practice, retrain personnel or change equipment in order to take advantage of technological innovations in the construction industry. Based on a comprehensive study of modern industries, Crowther [6] has concluded that "In the short term, higher productivity is more important than technical innovation, but in the long term, the contrary is true." It is a challenge for each of us to determine what are the appropriate short term cycles and what are the effective longer term cycles in which we are engaged. New materials, new processes, new designs should continually evolve with these longer term cycles so that we continue to make effective use of our resources. Gilbreath [8] tells us that "Change seldom sneaks up on our companies or attacks without warning. Astute managers constantly peer into the future, over the horizon of their immediate needs, in order to sense impending change and better prepare for it."

2.2 Resistance to Innovation

A detailed study of techological innovations by Crowther [6] indicates that economic and sociological factors were most important in stimulating or obstructing innovations. In the Western World, the basic criterion for filtering out certain technical innovations, and applying others remains economic profitability [3]. In the highly fragmented concrete industry this poses a difficult problem. The chemical company which introduces a new chemical admixture must make a series of multiple sales in order to actually sell its product. It must convince the architect and engineer representing the owner that the product will improve the concrete performance and that the product will have no detrimental side effects. It must convince the ready mix concrete supplier that it is dependable, repeatable, easy to dispense, and will produce a positive economic return. It must convince the constructor that he will profit by its use, that it will not delay placement or finishing operations and that it is thoroughly dependable as far as setting and strength characteristics. In order to sell the innovation, the proponent must develop a win-win-win-win situation, where everyone involved sees an advantage from their point of interest. Few industries have such diverse and fragmented multiple decision-makers.

Concrete construction often involves strongly organized labor forces. Innovation tends to threaten the uninformed within an industry. In Great Britain during the period from 1811-1816, the "Luddites" were a group of textile workers who rioted and destroyed textile machinery because they believed its introduction into textile mills would diminish employment. In The Challenge of Hidden Profits, Green and Berry [9] describe "Contemporary

Luddites" who "include balky workers and union leaders, as well as white-collar managers who ignore the need to innovate." Thus, one of the great challenges to innovation is to inform and educate the labor and managerial forces involved with the innovation.

Education is needed to overcome industry's resistance to innovation. Gilbreath [8] indicates that to come to grips with change, we must come to grips with those whose business fantasy is a world stopped and standing still for them. The world of structural concrete today is a far cry from that of the 1950's. The vastly higher strength concretes, the dramatic impact of prestressing, the heightened awareness of the importance of durability and corrosion resistance, the more efficient forming and placing techniques, all mean that professional and managerial leaders, originally educated in the 50's and 60's, must be continually "retooled" to be aware of today's problems and opportunities. Particularly in some public sector positions, continuing education has been neglected and decision-makers have become outdated. It is particularly important that our national and international regulatory standards stay abreast of innovation to place pressure on these laggards to allow proven technological developments.

Many charge our regulatory standards as being the "front line" of the resistance to change. It might be more realistic to think of them as a "Maginot Line," since the ingenious can penetrate them with relative ease. Regulatory standards must defend the public against ill-considered innovations. However, if the standards are well-developed and are basically performance-oriented, they should not be serious barriers to innovation. The fundamental conflict arises in that most structural concrete regulatory standards have been developed on a largely empirical basis from observations of both laboratory experiments and performance of actual construction. Elaborate theories have been developed to extend these empirical theories to general cases. The theories are only as good as the data bank on which they are based. Ritter, Morsch, Talbot and Richart never thought of 100 MPa concretes and 500 MPa reinforcing bars when they laid the foundation for reinforced concrete shear theory. Most tests of reinforced concrete beams have been run with concrete compressive strengths below 60 MPa. Our data bank is thin when we must extrapolate poorly defined, empirical theories to material strengths 200% and 300% higher than the preponderance of tests. The lack of comprehensive structural concrete tests on members with high strength materials is one of the great obstacles to liberalization of regulatory standards to permit full utilization of recent innovations.

3. CHALLENGES OF INNOVATION

3.1 Organizational

The concrete industry is a veritable beehive of activity. A glance at the papers to follow in this session will show that concrete materials and processes are evolving at a dramatic rate. Fly ash, silica fumes, pulverized slags, and improved mix techniques have revolutionized concrete compressive strengths. Latex modifiers, fibers, and polymers have dramatically improved tensile strengths. Stage post-tensioning is becoming commonplace. Glass and carbon fiber reinforcement can outperform steel reinforcement in some specialized applications. Coatings for reinforcement and for concrete slabs have made substantial inroads on corrosion and durability concerns. Our professional organizations must take a lead role in disseminating information about these innovations in a balanced, objective way. Conferences, symposia, proceedings, manuals, and committee reports must probe, evaluate, and synthesize this mushrooming experience. The rapid growth of information means it is no longer sufficient to publish only unrelated descriptions of innovations. Our professional organizations must stimulate development of fair, balanced synthesis reports that encapsulate the experience of many for the information of those considering use of a new innovation.

3.2 Individual

The rapid changes in structural concrete technology as we adjust to limit states design utilizing the full potential of the rapid changes in materials shown in Figs. 3 and 4 offer a personal challenge to each of us whether manager, designer, constructor, material supplier, teacher, writer, or researcher. The ability to effectively cope with these changes requires that we individually become more flexible and adaptable. We must change our outlook towards innovation from that of a mindset which discourages change to that of a mindset which looks and listens for change, correctly evaluates the opportunities in change, and chooses promising innovations for implementation.

3.3 Professional

The rapidity of change in our industry brings awesome new burdens. Drucker [5] clearly stated the challenge to our professionals as:

> "Knowledge, during the last few decades, has become the central capital, the cost center, and the crucial resource of the economy. This changes labor forces and work, teaching and learning, and the meaning of knowledge and its politics. But it also raises the problem of the responsibilities of the new men of power, the men of knowledge."

The essence of professionalism is that one has great skill or experience in a particular field or activity. These skills and experiences are built slowly and laboriously. As our materials change, so must the knowledge of our professionals. The rapid innovations in our industry means that serious and continuous self-study, experimentation and involvement are required of all of us who wish to remain "professionals" in structural concrete. To do less is to betray the public trust.

3.4 Side Effects

The most important challenge in my mind and the one which is frequently most neglected is the tendency to rush new innovations into use without carefully questioning their side effects on structural performance. Any new technology should be required to demonstrate in advance of its use the potential side effects on basic structural members and actions as well as the long term impact on durability. Seldom is such broad and comprehensive testing performed before the new innovation is brought to the market place.

Several recent examples come immediately to mind. Epoxy-coated reinforcement has been put in wide usage in bridge deck construction in the USA because of the dramatic reduction in corrosion when exposed to deicing salts. In the pilot program research, the effects of the coating on bond strength were evaluated by tests in which the bars were pulled out of concentrically loaded cylinders. It was concluded that the bond strength decrease was slight and no changes in development length were required. The coated bars were put in wide usage with no tests in structural members. Literally thousands of metric tons are being placed monthly. Recent comparative tests in lapped splice beam tests indicate that the bond strength is severely effected when splitting type failures can occur, as is usual in beam applications. The splice and development lengths must now be dramatically lengthened. The rush to market with insufficient structural member tests results in a situation where we have an appreciable number of structures in place with somewhat suspect connection details.

Short term testing is also suspect. Sometimes accelerated durability testing gives mistaken indications. Often little such testing is done. The U.S. Army Corps of Engineers Station at Treat Island on the Bay of Fundy subjects concretes to daily salt water immersion and hundreds of cycles of freezing and thawing annually. Twenty-five years of exposure tests on post-tensioned beams have provided much information on proper protection of prestressing components. However, by the time we know what works, the systems tested have disappeared from the market. We were not visionary enough in formulating programs. Of even more concern is the behavior of some epoxy composite protection systems cast as end blocks. In the first ten years, this system gave the best protection and was highly recommended. Over the second decade, it broke down badly at the material interface. It is now obvious that it is a poor solution. We cannot always accelerate nature. Durability studies are expensive, time-consuming, and fallible. This is a major concern in bridge applications where we need to think more in terms of centuries than decades. We must do much more to improve our ability to foresee the side effects on durability.

A final example indicates that there are indirect limits on the development of concrete compressive strength which parallel the previously discussed practical limit of the sound barrier on commerical aviation travel. In an exploratory study of the utilization of very high strength concretes in bridge construction, Jobse [10] tested very thin wall hollow pier sections made from high strength concretes. The vastly improved concrete compressive strength allowed use of very thin cross sections However, as shown in Fig. 5, a very unwelcome side effect occurred. The outer interaction curve is the expected strength of the section based on our normal assumptions, measured material properties, and known dimensions. If the compressive strength of the thin plates is limited using plate stability theory, the column strength would be reduced to the interaction curve shown by the inner solid line. The actual test specimen failed at an even lower load after suffering a local buckling failure of the thin wall member. One of our greatest challenges is that of using the new material strength possibilities wisely and safely. As we go to thinner members, stability problems may prove to be concretes' "sound barrier." Our Codes and Standards must meet these challenges which were relatively unimportant when 20 MPa or 30 MPa concrete resulted in "automatically" stiff members.

3.5 Regulatory Standards

Perhaps the most difficult challenge to meet is that of adequate regulatory standards such as the code of practice or materials specification. On the one hand we need to encourage and reward innovation. On the other hand we need to protect the public safety and public interests. We need to make sure the innovations are safe, durable and serviceable. We must refine our systems of building regulations and standards to satisfy two conflicting purposes. We need to have comprehensive, performance-oriented regulations which will require adequate demonstration that new technology is reasonably safe and durable before allowing public usage. In fairness to the entrepreneur who must shoulder much of the cost and burden of demonstrating the suitability of this new technology, there should be clear incentives which encourage and reward those technological innovations which are safe and durable. There must be appropriate and timely government and private machinery developed to assist in the review of such new products. Once again, France has taken a leadership role in showing how such machinery can be made possible as in the agrément system.

4. CONCLUSIONS

The gaps which will give the structural engineer the most challenge in our coming century are not the highways, the rivers, or the seas which must be bridged. The gaps with which we must be concerned are the human ones. Our technology is changing at a rate that is outrunning our ability to fathom and control. Innovations in materials are being introduced with little demonstration of their effect on structural behavior. Codes and standards lag product development significantly. Our human shortcomings should not stifle creativity and innovation. We must change our control systems to be in harmony with development. We must not become the barriers to innovation. Through a conference such as this, we hope to learn of the new innovations. With the type of free and open technical interchange and discussion to be expected, with the type of excellent papers submitted for the proceedings, and with the participation of all registered for this symposium, I know that innovation will be advanced.

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