THE EARTHQUAKE CHALLENGE TO THE STRUCTURAL ENGINEER

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ABSTRACT

The science and technology of earthquake engineering has advanced very rapidly in the last quarter century. However, both the scientist and the engineer face challenges of major importance to achieve better understanding of earthquakes and, more especially, to be able to apply that understanding toward achieving better earthquake-resistant structures. The science needs further development, but the art of earthquake-resistant design and construction seems most in need of reappraisal to decide whether it now best serves the interests of the public and the profession.

INTRODUCTION

The rapid pace of technological development is apparent in many fields of man's endeavors. One is the field of earthquake engineering, which has advanced spectacularly since the first strong motion ground motion records were obtained about thirty years ago. That is to say, the science and mathematics that form the basis upon which the profession is built have advanced spectacularly. Aided by the development of mathematics and computers, understanding of earthquakes and their effect on structures have certainly improved. The art of designing and constructing aseismic structures, unfortunately, has not kept pace with the science. In fact, in some respects, we seem to have retrogressed rather than progressed. Without detracting from the fine developments in the science and their contributions to engineering, it is the art that presents the structural engineer with his principal challenge.

THE SCIENCE AND THE ART

Immediately the question comes to mind: How do we distinguish between the science and the art of earthquake engineering? For the purposes here, the understanding of the earthquake itself and the analysis of its effects on structures and other man-made facilities is assigned to science. In effect, this is analyzing past earthquakes. The projection of this understanding to the design and construction of structures to be resistant to future earthquakes, at unknown times and of unknown intensity, is assigned to art.

The art must apply the understandings that science makes available, but the professional practice of the art by the structural engineer also involves making judgments which are outside science and mathematics. Furthermore, the challenges of the art are more apparent when it is acknowledged that rigorous design of structures for even past-recorded earthquakes is an impracticably complex, time-consuming task, even with the most

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modern electronic computers. It cannot be done at all for a future unknown earthquake. What must be done, must be done with a design effort compatible with the total engineering effort required by the project. What must be created is not an earthquake-proof structure in an absolute sense, but an earthquake-resistant structure in a practical and economical sense, with due regard for human and property values.

CHALLENGES TO THE SCIENCE

It is not to be inferred that challenges exist only to the art of earthquake engineering. There are several areas that challenge the scientist. These are primarily in the province of the scientist, but the structural engineer has a strong interest as these affect his ability to discharge his responsibilities.

First, and most obvious, there is an urgent need for world-wide uniform instrumentation of ground motions. Some steps toward this end have already been taken under the sponsorship of United Nations Educational, Scientific, and Cultural Organization (UNESCO). In all probability, action will also be taken by IAEE in this Third World Conference on Earthquake Engineering. Instruments of several types are now available. The principal problem is to decide upon the desired instrument characteristics and the selection of instruments. The instruments need not be identical, but they should record comparable data, just like a pressure gauge will measure pressure uniformly around the world in convertible units.

Second, and this may be considered to be corollary to the first, there is an equally urgent need for adequate instrumental coverage of the actively seismic areas of the world. A broad coverage should be obtained for basic ground motion instrumentation, and a selected and more detailed coverage should be provided for certain kinds of structures. There are times when all of us get "penny wise and pound foolish" and it is most unfortunate that despite fairly reasonable coverage of seismic areas in parts of the United States, there was not a single instrumental record of ground motion in Alaska in the March 27, 1964, major earthquake. Such instrumental records as obtained of the many lesser aftershocks are not a good substitute for the irretrievable record of the damaging major tremor.

Third, there is need for more timely geological and geophysical evaluations of sites for the development of cities. Some such reports have been made in the past, but these warnings of potential hazards of landslides or subsidence have usually been much too late and have been duly filed, unheeded and unnoticed by the public. We are much more aware of the need for joint scientific and engineering evaluations of sites following earth movements in the Chilean Earthquake of 1960, and, more recently, in the Alaska and Niigata, Japan, earthquakes of 1964.

Fourth, there is a continuing need to analyze different kinds of structures and their response to recorded ground motions, as a guide for future design. By the very nature of such analyses, they tend to become lengthy mathematical tomes. Computer solutions, in much more detail than normally required in design calculations, can be invaluable in furthering our knowledge of the action of structures in response to the dynamic ground motions of earthquakes. There is a real service to be performed by someone, bridging the gap between mathematical analysis and engineering design. It is desirable and useful to interpret the mathematical conclusions in terms that have significance in design. Who should do this, the scientist or the structural engineer? Perhaps it could be either, or the two working jointly to reach the practical interpretation of what otherwise may only be a fine mathematical exercise.

Fifth, is the need for much better coordinated on-site, post-earthquake surveys. Local officials, understandably disturbed by the confusion following an earthquake of major proportions, must become thoroughly confused by survey teams of scientists and engineers--each a group of specialists in its particular field. The public, however, is not usually aware of the distinctions and it reflects to the good of no one when engineering questions are directed to the scientists, or vice versa, and are inaccurately or inconsistently answered. All of the needs of the scientists in such surveys cannot be covered by a single man; nor can those of engineers interested in the earthquake phenomenon. Hence, it would seem appropriate to have separate teams of scientists and of engineers, to make surveys from the standpoint of their respective interests. There are overlapping interests, so coordination between the groups is still needed very much.

Sixth, the interests of seismologists and structural engineers seemingly have gone the route of diverging paths. More and more of the seismological literature of recent years has been directed to subjects which may ultimately have direct bearing on the work of the structural engineer but which at present lose the engineer almost before it starts. Like the need for a bridge between the mathematical analyst and the structural engineer, there is also a service to be performed by someone to build an interpretative bridge between the seismologist and the structural engineer.

These are but a few of the challenges to the science of earthquake engineering, which challenges are of interest to both scientists and engineers. While admitting much progress in science, there is still much to be done.

CHALLENGES TO THE ART

The art of aseismic design and construction presents challenges to all the professional design services, including architects and engineers--especially the structural engineer. Since the structural engineer has a primary responsibility for the adequacy of the structure for vertical and lateral loads, this responsibility cannot be placed upon the work of others. For example, contemporary architecture is not conducive to inherent earthquake resistance which has characterized construction of earlier years. Rigid service cores, frequently eccentric in plan, surrounded by frames and prefabricated curtain walls, frequently largely glass, are not helpful to earthquake-resistant construction. To what extent should the structural engineer adapt his structure to the form given him to work with, and at what point must he stand firm on his judgment that a structure is not only undesirable but also inadequate? To a certain extent all design is a compromise between what is desirable and what is achievable. This involves the practice of the art of structural design.

Second, not only the form of structure influences its earthquake resistance, but in recent years innovation has introduced new methods of construction which, unfortunately, do not generally enhance earthquake resistance. Combinations of materials, prefabricated and composite forms of construction present new challenges to the art. They can be used successfully, but their success in a major earthquake depend upon attention to details in the design and construction. This attention is not always forthcoming, as experience in some of the recent earthquakes will attest. Pressures of costs too frequently dictate use of construction methods that might otherwise be inadvisable.

Third, there has been an increasing trend to design to loadings more closely akin to realized loadings, with higher stresses, with continuity in load-carrying members, and consequently with less reserve strength. Minimum sections provide disparities in structural rigidities and flexibilities which sometimes are not even satisfactory for normal loadings, much less for combined vertical and lateral forces. Factors of safety are reduced and this coupled with lack of inherent reserve strengths have resulted in failures in moderate to severe earthquake. Whatever the true reason for failures might have been, it is difficult to explain away structural inadequacies in damaged buildings when other buildings nearby were undamaged. It must be of concern to the profession that in many cases the structures most damaged in Alaska in 1964, for example, were newer structures. Their construction should have reflected our increased understanding of earthquake resistant design, but did not. This poses a serious challenge to the art of structural engineering that the profession cannot ignore.

Fourth, our attempt to reflect our better understanding of the response of structures in building code provisions has left a lot to be desired. Half a century ago, structural engineers in seismic areas were satisfied with design for wind lateral forces. Later, simple acceleration design criteria were introduced as being more appropriate for aseismic design. Still later, the variable earthquake design coefficient was specified to account, logically, for the effect of rigidity on response. In more recent years, the criteria have become increasingly complex, still to provide what, admittedly, is an over-simplification to a very complex problem. But the question can be asked: Are we, in fact, creating better earthquake-resistant structures? And the answer, in general, would seem to be "no". There is considerable evidence that too much reliance is being placed on the words in the code, without giving enough thought to creating a structure that can assuredly resist loads considerably in excess of those code-specified, without failure. There is merit in understanding and acknowledging that forces in major earthquake can exceed those specified. The problem and the challenge to the structural engineer is to provide reserve energy absorption capacity beyond that corresponding to design static forces to preclude failure. There is some disconcerting evidence that some designers feel that their main obligation is to satisfy the word of the code, not the intent of the code, nor the understanding of the more discerning to the complex problem.

Fifth, a further outcome of the increasing complexity of codes is that they are primarily directed to the unusual structure. There is need for guidelines of much simpler form to provide good engineering practices to the construction of small buildings and structures for which professional engineering services cannot be available. Just how such information can best be conveyed to those who need it--and it is different in different countries--is a challenge which the structural engineer through appropriate organizations must face realistically and with a full recognition of need for applying the art of aseismic design economically.

Sixth, the structural engineer, with the scientist and the soil mechanics engineer, must apply his best judgment as to the type of structure best suited to an area which may have potential large earth movements--assuming that the structure has to be built in such a location. There may be no good, assured solution to such problem structures. Economics may indicate that acceptance of the risks may be the only practical alternative to not building at all. In other cases, with a sound exploration of the subsurface conditions, it may be that pile or caisson foundations can avoid possible failure. This is understood to have been the case in Niigata, Japan. However, the question of whether all structures there, for example, justified pile foundations is very debatable, even with the large property losses that ensued with the earthquake of June 16, 1964. This is a challenge to the structural engineer as well as to the owner financing the structure. Much of the damage in Alaska and in Niigata, Japan, was attributable to large land movements--so large that there was really no practical structural solution by which the damage could have been avoided. This kind of damage must be distinguished from earthquake damage without landslides or land subsidence. The latter is within the province of the art of structural engineering; the former is connected to the site evaluation study in which the structural engineer's part is to support the views of the scientists and the soil mechanics engineers in calling attention to the hazards that are involved, and what, if anything, can be done structurally to avoid these hazards.

Thus it is seen that the structural engineer has many challenges which requires the exercise of great professional skill in applying both the science and the art associated with his profession. It is more than a one-man task, however. It is a responsibility which we all share--those of us who call ourselves structural engineers.

THE ROLE OF IAEE

Each of us, individually, has a responsibility to himself and to his profession to so conduct himself that he is a credit to the profession. There is also much to be said in favor of placing the prime responsibility for the development of sound engineering practices directly upon the profession within each country. The customs, the materials, the construction practices, just to name a few, are the kinds of influencing factors that can best be evaluated locally. Few areas are without the professional competence to do just this. However, there are also many phases of earthquake engineering that are common to all countries, and for which action on an international scale can be most helpful.

Mention has been made of the program being sponsored by UNESCO in the fields of seismology and earthquake engineering. Many international organizations are participating in this most ambitious program. IAEE is one of the cooperating groups and definitely has an interest. This program, however, is strongly oriented toward the earth sciences--geology, seismology, geodosy, and geophysics. While the program acknowledges the importance also of earthquake engineering, this is only a minor part of the whole, and mostly confined to those aspects that here have been called the science of earthquake engineering in contrast to the art. This is not to belittle the work being done. Not at all. On the contrary, the work is very important and our work in IAEE must supplement that of the UNESCO group, and avoid overlapping of efforts. This should not be difficult to do, since the people active in the UNESCO program as to earthquake engineering are also the people active in IAEE. But while maintaining an interest in the developments of basic sciences related to earthquakes, IAEE's main efforts should be in earthquake engineering, which is directed primarily toward professional engineering for the design and construction of facilities to resist earthquakes.

Our main purpose is not the development of the science, but rather to understand the science and, with artful professional judgment, to build today structures to resist the uninvited earth movements wherever and whenever they may occur. The engineering problem is a problem today; it was a problem yesterday; it will be a problem tomorrow. Our job is to do the best job we can now with the state of the science technology and art available to us.

Task committees of engineers and scientists from countries having similar problems can develop practices which will preclude each country studying its problem independently. This is not to take away any of the obligations and responsibilities of the local engineers, but frequently we can do together things that we cannot do alone.

Engineering damage survey teams of international stature can be formed under the organizing power of IAEE. Their financial sponsorship is a matter requiring study. These teams should analyze the effects of earthquake upon structures, leaving to the country inflicted with a damaging earthquake the organizing of special teams needed to rehabilitate devastated areas. This should be the function of the local government. IAEE can provide guidance as needed.

The art of earthquake engineering can be aided by an international approach sponsored by IAEE. Codes, by their nature, run into trouble when they try to discriminate between different materials and types of construction. But this kind of evaluation is needed, as well as cautionary notes to promote earthquake resistance in whatever material or combinations of materials may be contemplated.

We have a continuing need to disseminate knowledge, as we have witnessed here in New Zealand, and need to develop people who have the capabilities and the understanding of earthquake engineering, to create the kind of structures that are earthquake resistant in the practical, economical, and humane sense. For Edwin Markham, American poet at the turn of the century said,

"Why build these cities glorious
If man unbuilded goes.
In vain we build the world,
Unless the builder also grows."