EARTHQUAKE RESISTANT DESIGN, CONSTRUCTION, AND REGULATIONS

SUMMARY REPORT*

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Oral presentations of papers classified under the present theme and their discussions have rewarded us with several interesting concepts and some outstanding contributions. Aside from earthquake engineering proper, matters pertaining to two allied fields were described: earthquake insurance and architecture.

To those unfamiliar with New Zealand's unique practice in earthquake insurance coverage, Bennett's presentation was most interesting. Fallen chimneys notwithstanding, the positive aspects of New Zealand's experience may serve as a source of inspiration to many.

It is reassuring to learn that some architects at least, are beginning to desire that buildings not only be earthquake resistant but that they look it as well. The change in trend comes as a relief to many structural engineers.

From the point of view of introducing a fresh outlook in earthquake resistant design of buildings, two papers are noteworthy: the one by Borges and that by Matsushita and Izumi. The approach used by Borges for the direct design of reinforced concrete buildings is limited to structures having a single degree of freedom and, of necessity, incorporates many simplifying assumptions, but it undoubtedly opens new lines of thought worth exploring. The use of randomly excited, nonlinear physical models, too, is a promising method of research much to be encouraged.

From the economic, more than from the theoretical, point of view the solution proposed by Matsushita and Izumi of introducing a very flexible basement to decrease earthquake forces in buildings may be debatable in many cases. But the proposal has merit in its freshness of approach. Business administrators suggest that problems that are difficult to solve, one should endeavour to dissolve. This is much the point of view adopted when, rather than attempting to resist high seismic forces, one decreases them. Of even greater value is the method of design described orally by Izumi, in which story stiffnesses are chosen, with the aid of a computer program, so as to satisfy design limitations on drift under the action of a family of earthquakes. Widening of the program, to include nonlinear behaviour, torsion, axial deformations and other important refinements and to incorporate other design limitations, opens numerous avenues leading to rational criteria of design.

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Even if progress in research may rarely be as rapid as one would want it, it is far faster than the evolution of building codes can hope to be. The lag of codes relative to research will necessarily widen with time, as evidenced by many of the papers and discussions presented in this and other sessions - on overturning moments, whip effects, analysis of shear walls, nonlinear behaviour, etc. - unless building codes become truly of the performance type, to a much more pronounced degree than they have yet been.

The practice of competent individual engineers or even of institutions, on the other hand, can and does incorporate results of research at a fast pace. Witness the papers on design of nuclear installations, New Zealand multistory buildings, several special structures and foundations, a blast furnace and a spectacular suspension bridge.

Perhaps the most significant discussion expounded was the review of present knowledge and present doubts on the behaviour and design of earth and rockfill dams to resist earthquakes, done brilliantly by Ambraseys. Bustamante's report of model tests and analog solutions of rockfill dams stresses the importance of nonlinear deformations in these structures and clarifies certain features of their behaviour. Disquietingly enough, the work of Patel and Arora constitutes, apparently, the only major effort published to date to study the dynamic pore pressures set up in earth dams by seismic disturbances. Now that the problem, and our ignorance thereof, are out in the open, it would be desirable to be in possession of a theoretical treatment comparable to, and more comprehensive than the one developed by Matuo and Ohara for fills retained by quay walls (presented in Session I) supplemented with adequate measurements. The implications of dynamic pore pressures in earth structures and in foundation soils and the need for research in this field had never been so dramatically and clearly brought to the attention of engineers as in the recent Chilean, Anchorage, and Niigata earthquakes.

It became apparent in this session that there are experts in earthquake engineering who actually regard some materials as earthquake resistant per se, and other materials or types of construction as inadequate to resist earthquake motions; and, even in a quantitative manner, some materials as better suited than others to meet seismic contingencies. Yet the truth of the matter is so obvious that it is almost embarrassing to utter it; practically every material and system of construction can be made to afford practically as large a resistance to earthquakes as desired, provided one is willing to pay the cost, and willing and competent to design, manufacture, and build properly. Assuming competence and sense of responsibility the question of preferring one material or system to others is merely a matter of economics, and it changes from one location to another and changes with time. Further, the extent to which one should spend funds to resist earthquakes is also conditioned by economic considerations. There are vast regions of the world where it is economically feasible only to build in adobe, but Ramirez in Columbia has shown that adobe can be made to behave in a sufficiently satisfactory manner. The point was aptly put by Krishna in connection with the use of reinforced masonry in India. The various papers presented on the use of brick and concrete blocks repeatedly referred to the merits of reinforced masonry, and the record of this form of construction in California has been unquestionably satisfactory whenever properly designed and built. Clearly it is not the adequacy of the material which is at stake and no further waste of time on this matter is warranted. Rather, let us concern ourselves with the general lessons to be learned from an objective examination of earthquake damage.

Many aspects in the philosophy of design are well covered in the paper by Blume. Those which I am to discuss now are partially based on remarks by G.W. Housner and by J.E. Rinne, to both of whom I am in debt. In the opening meeting of this session I emphasized the importance of apparently insignificant details of design and construction and said that the weakest link may be the only link that counts. These words I do not take back: they are especially true of statically determinate structures, such as inverted pendulums, and many a failure and much damage can be avoided by paying due attention to minute details. But it transpires from several case histories presented in this session and elsewhere that the engineer who examines a severely damaged building is often tempted to lay the entire blame for the damage on a single weak detail, and is it not true that every structure has one weakest link? With the number of details that go into every structure it is almost inconceivable that they should all be entirely well built, and, for obvious reasons, earthquakes systematically make the weakest points stand out with great noise. Rarely, however, is the engineer conscious that the total amount of damage undergone by a large variety of structures would not have been significantly different if the weakest point had been sufficiently strong. For a wide class of single-degree systems it is well established that the maximum deformation depends essentially on initial stiffness and on damping but practically not at all on the shape of the force-deformation diagram. With further limitations the same is roughly true of multidegree systems. Often, then, local structural failures will substantially modify the load deformation curves but will not materially change the total amount of major structural and nonstructural damage.

(The remark is not intended to minimize the seriousness that may be associated with minute defective details. In some structures, repair of those local failures may be extremely costly, and in others they may imply collapse, as the relationships mentioned are far from correct when the load-deformation curve contains a descending branch or, in other words, is associated with insufficient ductility.) The previous remark <u>is</u> intended to bring out the fact that earthquake forces during strong earthquakes may be many times greater than the values called for in the existing building codes and that deformations are nearly always of that much higher magnitude. The oscillations of buildings during strong earthquakes are of the order five or more times greater than many codes lead to believe.

The same holds for bridges. While most designers are concerned with computing the stresses set up by relatively small oscillations, the majority of bridge failures during earthquakes have involved sliding of the decks away from the piers, even in cases when the piers have been quite firmly founded. The oscillations that take place are not of the order of inches but of several feet.

The satisfactory behaviour of seriously underdesigned structures during major earthquakes does not necessarily always reflect a feeble ground motion but often our inability to compute actual structural strength.

Progress in the practice of earthquake resistant design demands that engineers become keenly aware not only of the nature of the problem but also of the order of magnitude involved.

Worded thus, the problem is one of education rather than research. But there are also aspects of ground motion requiring considerable study. One concerns the various components of ground motion; only in a remark by Ambraseys and in one of Despeyroux's papers is any mention made of at least a second (respectively, a second horizontal or a vertical) component, when even a rigid foundation has six (including three rotational components), and, besides, the deformations of the ground surface are important in many instances. The second matter requiring a large research effort is that of defining, statistically of course, the family of ground motions that must be designed for in each case; as one discusser remarked, it would seem from some current papers that all structures must be designed to resist the NS component of El Centro 1940, no more no less.

Not only ground motion but the motion of water in dam reservoirs is normally underestimated. As implied in a question by Mautz, fresh-water tsunamis have occurred often in the past; yet they are normally disregarded in the design of dams.

Information is lacking on the behaviour of connections. Only Bouwkamp reports on any tests on such structural components, and his tests were static. The behaviour of connections in actual structures is semi-virgin ground.

The paper by Nakano gives a lesson in a type of experimental research that is much needed.

Occasionally engineers are able to test real structures at various stages of construction, as exemplified by Chandrasekaran and Krishna's tests on water towers, Bouwkamp's supplementary results on the steel-frame buildings, and Meehan's report on vibration testing of school buildings. Such tests are necessarily limited to small amplitudes and tests to destruction of actual buildings are badly needed. Even so, the recent small-amplitude tests have already caused a drastic lowering of the official values of structural damping.

To summarize, there is pressing need for development in the following areas:

1. Pursual of recently developed, fresh outlooks on earthquake resistant design, and an imaginative attitude to open other new paths.

2. Research in the behaviour of materials, structural members, connections, and structures, and I emphasize the word <u>structures</u>, under earthquake-like cycles of loading. Of paramount importance

is the dynamic behaviour of soils, and understanding of this behaviour requires an investigation of pore pressures during dynamic and alternating quasistatic conditions.

3. Hydrodynamic phenomena involving large displacements of the water surface.
4. Recording of strong ground vibrations, with accurate time correlations of the six components of motion and of ground deformations.
5. Statistical studies of seismicity and of earthquake characteristics.
6. Awakening of the conscience of engineers to the nature of earthquake disturbances and of their order of magnitude.

May the Fourth World Conference witness accomplishments in all these fields!