SYNOPSIS OF PANEL DISCUSSIONS ON STRUCTURAL DESIGN IN SEISMIC AREAS: PRACTICES, CODES, AND PROBLEMS

John A. Blume, Moderator

Panelists:

Jorge Pinzon B. (Colombia), Colombian Society of Engineers.

J. K. Minami (Japan), Department of Architecture, Waseda University.

V. A. Murphy (New Zealand), New Zealand Railways, Wellington.

K. Muto (Japan), Department of Engineering, Tokyo University.

S. Okamoto (Japan), Tokyo University.

E. Rosenblueth (Mexico), University of Mexico.

S. B. Barnes (United States), Consulting Engineer, Los Angeles, California.

J. E. Rinne (United States), Standard Oil Company of California, San Francisco, California.

J. A. Blume (United States), Consulting Engineer, San Francisco, California.

Question: In designing to resist earthquakes, whether it is a building or any other structure, what is your philosophy about the amount of damage that you would tolerate? In other words, are you designing for total prevention of damage including cracks, or are you worried about loss of life only, or loss of property?

Muto: In Japan we would tolerate damage to the extent of 10% of the structural cost of the building.

Rinne: I believe that the damage to be tolerated depends upon an evaluation of the hazards or consequences of that damage. For example, a power plant that would disrupt activities with consequent losses far above the value of the plant itself should be designed more conservatively than, say, a barn.

Murphy: I think we would agree with Mr. Rinne. The New Zealand code does step up the earthquake coefficients on transformers to between 25% and 50%, as a result of extensive damage in the 1931 Nikra Earthquake. The structures holding or retaining water essential for fire fighting are also designed for higher coefficients. In general, the New Zealand code calls for seismic coefficients of from 1/12 to 1/10 g, with the higher coefficient applying to public buildings and places of assembly such as theaters.

Blume: Do you not have a code requirement in New Zealand where a maximum coefficient of 12% is applied at the top and zero at the bottom, giving a triangular distribution of forces on the structure?

Murphy: Yes, we have that as a permissible alternative.

Rosenblueth: Mexican practice has several points in common with those of New Zealand in that the seismic coefficient is made to vary with the number of people that may be affected by collapse. Theaters and temples are designed for higher coefficients. The damage that should be tolerated should depend also upon the intensity of the earthquake; for a very mild earthquake one would not like to have cracks develop even in the plaster, whereas for an extremely strong earthquake, the criterion would be simply to prevent total collapse.

Pinzon: We do not have a definite code established and it is largely up to the constructors to judge how much protection against an earthquake will be given a certain building. Our materials are expensive and attention is given to the statistical probability of certain damage occurring. We will not design for very large tremors which are not likely to occur in many years. However, we do build theaters and churches with higher earthquake factors due to the hazard to many people. In economical housing, however, the criterion is primarily to prevent the loss of life.

Barnes: I think every design is a compromise between safety and construction cost, and our codes are probably an average of those compromises. Most engineers don't worry too much about non-structural damage. Yet I was interested when a year ago last January one of our newer buildings in Southern California had no structural damage but had about $40,000 damage in plaster cracking, etc. I think there is room for research along that line, just to protect the owner's investment.

Blume: Summing up, apparently the general philosophy is that the risk is evaluated and the design prepared accordingly.

Question: How do you compute the stiffness of brick walls and on what tests do you base these computations?

Minami: The basic concept of estimating stiffness of walls of brick or reinforced concrete was developed by Dr. Naito. The theory is not entirely satisfactory because it assumes elastic action whereas stresses are frequently beyond the elastic range in a major earthquake, developing cracks and modifying the elastic characteristics of the wall. Based upon elastic considerations only, a wall might have a relative stiffness factor of 20, 30, or 40. Under actual conditions these might be 4 to 5 times too high. The Architectural Institute of Japan has recommended a maximum ratio of stiffness of a solid wall to an open wall of 15 and the maximum stiffness of any wall with openings to be 10. Again, these are maximum values and in practice we use 7 or 8 for solid walls, 4 or 5 for walls with openings, both compared with a stiffness of unity for an open bent.

Blume: In the United States there have been many statical tests of lateral stiffnesses of brick masonry and concrete.

Question: Building codes, such as the Uniform Building Code of the Pacific Coast Building Officials Conference, treat of earthquake forces as a statical problem. Papers at this conference have been concerned with the dynamic approach to the problem. What is the greatest deficiency in the present statical method?

Rosenblueth: To get a rigorous solution by statical methods which would coincide with dynamic analyses seems nearly impossible. However, by varying the distribution of the seismic coefficient, one can get a static analysis much closer to the results of a dynamic analysis. We might get better results by resorting to approximate influence lines for dynamic loading.

Rinne: It wasn't many years ago that we applied constant coefficient static lateral forces for design. The Uniform Building Code later adopted a variable coefficient provision, which was a step forward and which might be called a code-dynamic solution. I am in favor of introducing the period of the structure as a criterion for determining the design forces, to further rationalize the static method into at least a semi-dynamic approach.

Murphy: In New Zealand we haven't had enough experience to know what periods to assume in this dynamic approach. I know that the U. S. Coast and Geodetic Survey has done a lot of work measuring periods of structures in the United States and we could adopt this work to our structures also. But it will be a long educational program, at least four or five years.

Blume: We recognize the low, rigid structure to which the static analysis applies reasonably well, and the high, slender structure to which a dynamic solution is best. We have the problem of defining what we do in between these extremes.

Question: In design analysis the coaction of the soil and the structure, that is the effect of the structure on earthquake waves, is usually ignored. Is there experimental or other evidence that the reflection and refraction of waves can be ignored, or is this merely done to simplify the design?

Muto: In Japan, after great shocks, the ground around buildings is often cracked or disturbed, indicating the existence of the building creates discontinuity in the earth waves. Conditions are not entirely elastic. Although design analysis does not yet consider these phenomena, it has been clearly observed and should be considered in response analysis.

Blume: Experimental work has indicated that energy of structure vibration is radiated back into the ground. Certainly in alluvial soils at least the earth waves affect the building and the building affects the waves. These matters require additional investigation to be considered in normal design practice.

Question: What is the effect of an earthquake on structures supported only by skin friction piling?

Okamoto: It is recognized in Japan that the skin friction will be decreased during earthquakes, but this is normally not taken into account in design.

Pinzon: In our practice we design the piles to take the vertical surcharge resulting from the horizontal thrusts of the earthquake.

Question: Would it seem advisable to recommend increases in soil bearing pressures when resistance to earthquakes is being analyzed in view of the fact that some soils decrease in strength when disturbed?

Okamoto: I concur that the bearing capacity of soil does decrease during vibration. Quay walls frequently slide during earthquakes.

Blume: Many sand deposits will tend to consolidate under vibration. Individual cases must be evaluated by borings, tests, and judgment.

Barnes: Some years after the so-called Long Beach earthquake (1933) a building was planned for a site which contained up to thirty feet of debris fill from that earthquake. Explosives were used to settle the fill. A three-story concrete building was erected on this material, and the building stands today without a crack or sign of settlement distress.

Minami: The committee on foundations of the Architectural Institute of Japan held lengthy discussions about the bearing capacity of soils under sustained load and under temporary loads due to earthquake or wind. Many of us wanted to increase the allowable bearing load for such soil types as clay but not for granular types such as sand. It so happened that under formal vote those who felt that 100% increase of bearing capacity for temporary loading of soil was proper won out by one vote. That is how it stands now, but not all of us are happy about the situation.

Question: What would be the shear in a building with a fundamental period considerably longer than that of an earthquake, as compared to a building with a period less than that of the earthquake?

Rosenblueth: It is difficult to speak about the natural period of an earthquake except for special conditions, such as very soft ground. In the range in which structural engineers are interested, however, the shear is very roughly inversely proportional to the fundamental period of the building, that is, the longer the building period, the smaller the shears. However, the amplitude increases with natural period, so that people would feel more uncomfortable, and non-structural damage would tend to be greater with the longer natural period.

Question: Can any instance be quoted where a slender steel frame building, of say 20 stories in height, with light curtain walls, has actually failed or was damaged under earthquake conditions, and if so, in what manner?

Barnes: I don't know of any of that height that suffered failure. In the 1933 earthquake a flexible 2-story steel frame building apparently hammered an adjacent rigid warehouse. The steel columns were bent but were later repaired.

Blume: There has been little earthquake experience with tall slender steel frame buildings having light (modern) curtain walls. In the 1906 San Francisco earthquake many buildings with steel frame and filler type masonry curtain walls were exposed. The damage to the steel framing proper was nominal, with actual rupture apparently confined to the few cases of X-bracing in walls. There was other damage, however.

Question: What is the basis for the Japanese code penalizing wood construction on soft ground by a factor of 1.5?

Minami: We have found that rigid buildings on soft soil usually fare pretty well. Wooden buildings on rock also do well. However, our wood buildings (which are of quite flexible construction as compared to buildings in the United States) on soft soil undergo dynamic conditions which produce poor results, hence the 1.5 factor as compared to 1.0 for rigid structures.

Question: Does vertical acceleration of the ground occur? Why is it not mentioned, if so?

Blume: It certainly does occur, although it is often ignored in design because of reserve strength of the framing for vertical loads. In my opinion, however, it should be considered, particularly on soft soils or for special structures.

Barnes: I quite agree, it should not be overlooked. It is also a factor that may reduce the dead weight resisting overturning.

Rinne: In tall stacks the combination of shears and moments from lateral forces and the diminution of vertical load by vertical acceleration can cause cracking, particularly in the upper sections. This can occur in the fundamental mode of vibration, as well as in the higher modes.

Question: What fire-resistant features should be incorporated as a part of proper earthquake design?

Muto: In Japan gas pipes have broken, and fires from not only gas but from cooking stoves of all types have created serious fires. Most modern office buildings are provided with automatic sprinklers.

Blume: The automatic prevention or control of fires from earthquakes is a vast problem. Shut-offs for gas and even power are often provided in this country. Much more needs to be done, however.

Question: Please review briefly the development of the dynamic method of estimating lateral force coefficients proposed in A. S. C. E. Separate 66 and give the pertinent features of the new San Francisco code as it utilizes these provisions and recommendations. How is damping estimated?

Rinne: "Separate 66" report of the Joint Committee on Lateral Force of the San Francisco Section, ASCE, and the Structural Engineers Association of Northern California, is based on the development of earthquake spectra in recent years. Several investigators have worked on this, especially Professor Housner and his colleagues at the California Institute of Technology. The method applies the earthquake spectra (responses of simple one-mass structures to recorded earthquake ground motion), to more complex buildings and structures. It brings in the flexibility concept by introducing the natural period of the structure to be the criterion by which the total lateral force coefficient is determined. Admittedly, the method includes an element of judgment as to what the coefficients should be to arrive at practicable and reasonable design basis for structural design of earthquake resistance. But, in general, it gives a more rational approach to the situation then has been used heretofore. Rather than try to outline the details of the method, may I refer the conferees to the Transactions, ASCE, Vol. 117, 1952.

Blume: Damping is considered as a judgment factor in the coefficients.

Rosenblueth: In general this code is an important step forward. The fact that it can still be improved and will merit modification in the future does not mean that at present it should not be considered as adequate. It is certainly, of all the codes I have seen, the more nearly rational, by far.

Blume: Nobody realizes more than those on the joint (code) committee that the code should be improved from time to time as knowledge increases. Incidentally the higher modes, although not considered directly in codes, can be most useful in research.

Murphy: This lateral force code is very much appreciated in New Zealand; it is a definite step forward.

Question: What lateral force should be used in calculating the overturning moment on a tall, slender building, say 20 stories, and where should it be applied?

Muto: In Japan we have limited height buildings and therefore generally low slenderness ratios. Since we use rather large seismic factors in design, we arbitrarily reduce the overturning moment by 50%.

Newmark (from audience): It takes time for a building to overturn. The pulse of the ground motion on the building is reduced thereby and the danger of overturning is considerably smaller than one might compute using the same coefficients for which one designs a building for shear. A flexible building is in less danger of overturning than a rigid building because it absorbs energy in a different way. I don't know of any simple approach to this. May I ask what the San Francisco code does about this overturning?

Blume: The San Francisco code requires the determination of the cantilever (overturning) moment from the lateral forces on the upper 10 stories. The overturning moment may be assumed constant from the 10th story (from the top) to the foundations. This is the same as the Separate 66 paper.

Question: How is the effect of time delay between impulse application at the base of a structure and at a higher point introduced in analysis by means of electrical digital or analog computers?

Murphy: We have not considered that in our work. I recall, however, a paper on the design of the Pitt River Bridge (California) considered the time of travel.

Housner (from audience): It can be taken into account from the mode and travelling wave standpoint.

Barnes: That problem also applies in the horizontal direction when shear is to be transferred to a remote rigid element.

Question: Since it is anticipated that buildings will not behave statically during an earthquake, are we justified in basing an earthquake code on a spectrum which assumes elastic action?

Rinne: Whether the structure acts elastically, plastically, or ranges between the two, it must start off elastically. It would seem in the light of present knowledge and current design practice that a "spectrum" type code based on elastic response is at least a start in the right direction. Judgment must, today and very likely for a long time to come, play a big part in the consideration of these complex dynamic phenomena, all knowledge cannot be codified.

Blume: The design and construction of buildings and other structures cannot wait for the perfect solution, but improvements should be applied currently as experience and research knowledge develop.

Question: What is the approximate range in per cent for damping to be expected for various types and materials of building construction?

Muto: Damping is not only elastic but plastic. Many lineal damping factors have been found in the laboratory and published. Design and laboratory work are not yet fully reconciled.

Rosenblueth: From American literature we may cite figures in the order of 3% for the steel frame and 7 to 14% for concrete buildings, with the greater amounts for more brick partitions.

Blume: My paper on the Alexander Building, a steel frame fireproofed with concrete or masonry, and with masonry filler walls, indicates from 2% in the fundamental mode up to 4 and 5% in higher modes, all under small amplitudes.

Question: Is building design to resist earthquakes often done with the aid of dynamic methods including dynamic model experiments?

Minami: Only in exceptional cases.

Pinzon: In Colombia we do not as yet design by dynamic methods, although I understand Venezuela is conducting some research along those lines.

Barnes: Until dynamic methods are available which can be done in the time for which engineers can get compensated, I think the nearest approach which static methods can provide will be generally used.

Blume: In the United States the codes are being modified to simulate dynamic conditions for average structures by static methods. Special structures require special treatment for satisfactory and economic results.

Question: In Japan, do you ever set out to design beyond the elastic limit or is compliance with the building code the usual limit of design?

Minami: The use of basic seismic coefficients of 20% of gravity or more and allowable steel stresses of 34,000 psi bring us to the yield point. However, if some earthquakes are more severe than we anticipate, the steel would go into the plastic range.

Rinne: Many of us feel that a better balanced design will be obtained with higher coefficients and higher allowable stresses. This, of course, approaches a kind of limit design.

Blume: It can be shown by simple arithmetic that members carrying only lateral forces have less residual strength, not to mention energy absorbtion value, compared to other basic members under the low stress increases in codes.

Rosenblueth: The Mexican code generally follows American codes, but some engineers raise stresses up to 100% or to the yield point, often with greater seismic coefficients. There are various practices.

Question (Binder from audience): Mr. Blume, in the December 23, 1948, Engineering News Record you listed some unsolved or controversial problems. Have these matters been resolved in the meantime?

Blume: A copy of that article is here. I shall first read and then comment briefly on each problem listed.

(1) "*Design of all structures on the basis of a percentage of weight as an* assumed lateral force." This has been discussed a great deal at this conference. Modern codes vary the percentages for various conditions to better simulate dynamic phenoma. Great progress has been made.

(2) "The percentages required by various codes for such forces." This has also been discussed, especially in the last panel question. Damping, energy absorbtion, allowable damage, etc., are all involved.

(3) "The way such percentages are reduced according to the number of stories for high buildings, regardless of width or other dynamic characteristics." Same reply as for (1) above.

(4) "The amount of live load required by various codes to be included in the weight used in seismic computations." Progress is being made on this also. The trend in recent codes is to approach actual average live loading.

(5) "The variation of coefficients for soft ground conditions." This item is still controversial no doubt because many generally unrecognized factors enter the problem. American codes have in recent years tended to eliminate or reduce former variations in coefficients with ground conditions.

(6) "The amount of stress increase permitted under earthquake motion." This has been widely discussed at this conference, particularly on this panel.

(7) "The handling of the overturning (cantilever) moment problem for high buildings or units thereof which act structurally for many stories." This item, which is still controversial, has also been discussed on this panel. More research is indicated.

(8) "Design practice does not adequately differentiate between flexible and rigid structures." This is still a problem although recent codes, particularly the new San Francisco code, approach the matter more realistically.

(9) "The definition of a diaphragm as a horizontal distributing element." This problem has been worked on perhaps more than the others. I'll ask Mr. Barnes to discuss this.

Barnes: A diaphragm is essentially a horizontal girder to distribute horizontal forces to the various vertical resisting elements. In addition to strength, there should be certain limitations on deflections of these diaphragms in order that the vertical elements not be subjected to movement which would cause distress or failure.

Blume: In summary, may I say that progress has been made on these problems as well as others. This conference has also contributed in no small degree toward the ultimate solution of many important matters in seismological engineering. There is, however, a great deal more to be done.