DISCUSSION OF PAPERS

These discussions are transcribed from recordings taped during the Symposium.

Discussion of the Paper: "Elementary Seismology and Seismic Zoning"
by: J.H. Hodgson

Question: Reports on the 1925 and 1944 earthquakes in the Province of Quebec mention that in some cemeteries tombstones fell down parallel to each other after a rotation of about thirty degrees. Can you explain the ground motion?

Dr. Hodgson: You have a very complicated motion in the focus of the earthquake. This affects the ground surface in a very complicated way; in addition you have the physics of a column mounted in some manner. To me, the significant feature obtained from these reports is that close to the epicenter the tombstones moved vertically, showing that the focus was immediately underneath, causing the stones to jump off their pins.

Question: To what extent are fault deformations being surveyed in Canada?

Dr. Hodgson: The San Andreas fault, which is being surveyed almost constantly, is moving at the rate of the order of half an inch each year. Our Committee for Seismic Regionalization has attempted to set up a similar program in areas where we think there is danger of earthquakes. We are just beginning to get control between the mainland and Vancouver Island and across the St. Lawrence. We are also searching the records of the Geodetic Survey to see if there is any evidence of breaks in lines that cannot be explained except by a shifting of the ground. There is nothing to report yet.

Question: The focus of an earthquake is always given as a point. It is supposed to be caused by a movement within the rock. If there is movement, movement cannot happen at a point but must take place along certain lines. Would you comment on this?

Dr. Hodgson: There is an error of a few kilometers in the location of that point even in the best determination and if you study the energy released in a big earthquake, or even a moderate earthquake, you find that, in fact, the point must have dimensions of the order of 50 kilometers. Some work has been done in Japan on the shape of this and they have experimented with elliptical areas, etc.

Question: The elastic rebound theory indicates that a change in the ground level prior to an earthquake will occur over a period of time. Does this, then, give you an indication of when the earthquake is likely to occur?

Dr. Hodgson: Survey studies, such as noted above, are being made to try to indicate when a break is likely to be reached. Obviously this is not going to give you very close control.

Question: What was the depth of the focal point of the Queen Charlotte earthquake.

Dr. Hodgson: The Queen Charlotte earthquake was, we think, about normal, which means a focal depth of about 25-30 kilometers.

Question: Do all seismic instruments record acceleration?

Dr. Hodgson: The instruments that we are discussing with an engineering application record accelerations. The instruments of the seismologists do not record accelerations and you cannot derive with suitable accuracy the accelerations of the ground from the records obtained with the instruments used by seismologists. This is one of the reasons why we need these special instruments in earthquake engineering work.

Discussion of the Paper: "Ground Motion Measurements in Earthquake Engineering" by: Donald E. Hudson.

Question: How much money is involved in the installation of one of these strong motion instruments?

Dr. Hudson: There are really three commercially available instruments: the U.S. Coast & Geodetic Survey instrument, which is also manufactured in Canada, the UED AR240, and the Japanese instrument. All these cost about $4,000 each. One of the reasons for this is that they are made in lots of only two or three. It is reasonable to think that the price could be cut in half if you could order instruments in lots of 50 or 100. The cost of installing the instrument is trivial and only a very small space is needed.

Question: There exists on the market some piezoelectric transducers which measure acceleration and which might be applied for measuring the accelerations due to seismic motions. With such instruments the response could be registered on a tape recorder and the optical system could be eliminated. Has any consideration been given to their use?

Dr. Hudson: Such instruments have been used in aircraft work and other areas where a fairly sensitive accelerometer is required. In earthquake work tremendous amounts of energy are available and we do not have to look for the ultimate in sensitivity. It is possible that such a system might lead you more directly to a magnetic tape recording instrument, and I would agree that these are ideas that should be much further explored.

Question: How do the accelerographs measure the ground accelerations with the same degree of accuracy in all directions?

Dr. Hudson: The instrument contains three component accelerometers, two horizontal and one vertical, so that you get the complete three-dimensional motion.

Question: Is it possible to detect torsional ground motions with these instruments?

Dr. Hudson: I do not believe that there is any instrumental evidence to suggest there are strong torsional components which could cause us any structural concern. It is felt that the apparent torsional response of monuments and tombstones can be explained by a successive rocking motion.

Question: When a number of strong motion instruments are installed in a building, do they operate from one starter or independent starters?

Dr. Hudson: In the United States we contemplate independent instruments, each having its own starter and all wired together so that any one of them starting will start the others, even if some of the starters should fail. Then we will have a synchronized record on all the instruments and just some extra reliability on the starting.

Question: What type of motion is recorded on the seismologist's instruments?

Dr. Hudson: The record obtained by an instrument is simply an instrument response. You have to know the characteristics of the instrument, or the instrument response curves, in order to make a calculation from them about the ground displacements or ground accelerations. If you start with a sensitive instrument with a relatively long period, about your only chance is to record ground displacements. If you assumed that the motion was pure sinusoid you could then calculate accelerations, otherwise not. You have to make a great many assumptions in order to do that. For earthquake engineering purposes you must start with the acceleration itself because we are no longer dealing with nice sine waves but rather a super-position of many of these waves which gives a very complicated wave shape.

Question: Why cannot the records obtained with the seismologists' instruments be used for earthquake engineering design?

Dr. Hudson: The motions obtained with these instruments are many orders of magnitudes smaller than those which we are concerned with in relation to building damage. The seismologists have primarily been concerned with arrival times. They want to measure the time in which a wave arrives, and whether the instrument records that wave shape exactly or not is not of much concern to them. In earthquake engineering work we require the exact true ground motions, since these are essentially used as input forces for our structures.

Question: It has been said that when the P-waves arrive the building tends to lean to one side and with the later effect of the S-waves, the building leans to the other side. Could you comment on this separation of waves as they effect the structure?

Dr. Hudson: By definition, any damaging earthquake is a local earthquake and for a real local earthquake close by you do not have significant surface waves and all the P and S waves come in together in one grand mixture. Ordinarily, therefore, for a large earthquake, in the immediate vicinity, you are not concerned with separating out these waves in the way the seismologist does; you get all of them all at once.

Discussion of the Paper: "Earthquake Activity in Canada"
by: W. G. Milne

Question: There is a fallacious saying that lightning never strikes twice in the same place. Do these remarks apply to earthquakes? Are there any recorded earthquakes at exactly the same epicenter as previous events?

Dr. Milne: Near Baie St. Paul, down the St. Lawrence River from Quebec City, there have been several earthquakes since 1534 of apparently the same magnitude, and nearly at the same epicenter. I think we can assume that the same fault broke in all these cases, but whether the same exact geographical coordinates are obtained for each epicenter is another matter. For earthquake engineering purposes the epicenters can be taken as being identical because the area within which damage could occur would be the same. It would seem to me that when one earthquake occurs, the fault can lock in place again. Then if the area is subjected to the same strains as before there is no reason why an earthquake cannot occur in the same place when the breaking strength of the rock in the fault zone is again reached.

Comment: I was thinking along the opposite line, that once the tension was released, the next time it would be released further along the fault. On a broad scale, is that not the case at the foot of the Himalayas where there has been a succession of earthquakes along a fault?

Dr. Milne: If it is accepted that earthquakes occur as a result of a fault break, then we assume that the break in the fault is a relief of tension, or accumulated strain in the rock. If the strain is accumulated in the same area as before, the earthquake will be near the same place. If, however, the area subjected to strain migrates along a line, then the earthquakes too will migrate.

Question: On the maps that you have shown us, with the dots recording earthquakes, the events are restricted to certain areas. Nevertheless, they are scattered and I did not get the impression that any two were overlapping in general.

Dr. Milne: An earthquake epicenter is determined from seismograph records and in general from the very first phase on the record. This coincides with the release of energy at the initial break along a fault. This initial break can move along a fault, yet the fault may break over the same area, and there also may be errors in determining the exact location of this initial break. Thus, we obtain a scattered distribution of dots on our map.

Question: I note that the bulk of recorded earthquakes in British Columbia are west of Vancouver Island but the larger earthquakes are east of that, in the Straits, such as the 1946 earthquake and the Seattle one. Do you place any significance in this, or any interpretation on this?

Dr. Milne: It is quite true that the larger events are closer to the continent. Far west of Vancouver Island we find many earthquakes with magnitudes up to 6 1/2 or 7. Within the inside passage near Vancouver Island there are fewer earthquakes but there have been events with magnitudes of 7 to 7 1/2. Along the west coast of the Queen Charlotte Islands we find all magnitudes up to 8. I would prefer to present this as an observation without attaching any significance to it. The period of observation is very short.

Question: In the documentations supporting the four seismic zones, using the statistics for earthquakes in the St. Lawrence Valley, the conclusion was reached that the maximum possible earthquake can have a lower intensity than an earthquake which has already occurred. How is this justified?

Dr. Milne: The values which have been calculated for the maximum expected intensity in any zone are less than some of those experienced. The assumptions in this work are that the sixty-year period is typical, that the observer is on solid granitic rock, and that the intensity distribution is similar to that in California. If the observer is on anything else than solid rock, the intensities will be higher by values up to +2. We also have reason to believe that in Eastern Canada an earthquake of a given magnitude will be felt with a higher intensity and at a greater distance than thecorresponding California earthquake. Thus, for two reasons, most observed intensities will be higher than those on the map.

Comment: Could this be why the National Building Code calls for Zone 3 in Montreal, while here you talk of Zone B?

Dr. Milne: This is part of the answer. Montreal, however, still falls in my Zone B, if you increase the intensity as much as reasonable in these two cases. However, prior to this sixty-year period Montreal did experience a large earthquake nearby. It is by including geological, and historical evidence that Montreal is considered as a Zone 3 area. You must realize that my work is still a research paper with very strict limitations and data from other disciplines must still be added.

Question: Most of the earthquakes that have occurred off the west coast of Canada have been out in the ocean. With the measuring instrument at a fixed land station, how can they accurately determine the magnitudes of the earthquakes? Do they take into account the depths these are below the ocean?

Dr. Milne: The magnitude of an earthquake is determined by measuring the amplitude of the seismograph record and by allowing for the instrumental constants, and the distance from the station to the epicenter in the calculation. Thus, it does not matter whether the earthquake is under the ocean, or on land, as long as the epicentral distance is known. The depth of the earthquake beneath the surface of the ground is allowed for, and again it does not matter whether it is under the ocean or not.

Question: What is the significance of adopting the natural period of the seismometer in changing from amplitude to acceleration since the frequencies of acceleration, velocity, and amplitude are all different? The maximum amplitude occurs at something like ten seconds.

Dr. Milne: I have had a great deal of difficulty deciding what to do for frequency in this calculation. To do a proper computation one should use a frequency band but this is difficult to present to a reader. Thus I have sought for a compromise. I have chosen that frequency which records with the largest amplitude on the Wood Anderson seismograph. I have said this too is the frequency which produces the largest acceleration. If a higher frequency is chosen, the factor to change from displacement to acceleration is higher, but because of the above assumption on amplitude the net result is less. I think a frequency of 1.25 c.p.s. is a good compromise.

Discussion of the Paper: "Engineering Implications of Seismic Geology"
by: Clarence R. Allen

Question: Why is it that certain areas are more prone to earthquakes than other areas?

Dr. Allen: This fundamentally comes down to the question, "why do we have earthquakes? What are the fundamental processes within the earth that are causing tectonic strain?" There are many theories available but the honest answer is that "we do not know."

Question: Could you comment on research under way in the field of earthquake prediction?

Dr. Allen: A great deal of research is under way in this field right now by people interested in rock mechanics. It is quite clear that materials under high pressure are failing in ways that are quite different from those we normally visualize. In almost every case there are certain preludes to failure. The question is to be able to recognize these preludes. A great deal of effort will be going into laboratory studies by solid state physicists, by engineers, and by rock mechanics' people on the problem of the mechanics of failure. Many people are optimistic that this is an avenue of approach that is more promising and superior to the seismology and geology avenues.

Question: Has there been any attempt made to correlate earthquake magnitude with fault displacement?

Dr. Allen: There have been graphs drawn of this and there is considerable scatter of points. Basically we can say that the larger the earthquake the greater the displacement. Fault displacements of ten, fifteen, or twenty feet are almost invariably associated with earthquakes of magnitude greater than seven. There is a scatter of points partly because they reflect different senses of displacements, different depths of focus of the earthquakes, and earthquakes taking place in different types of materials. Whether the faulting is in alluvium or bedrock apparently has considerable effect on the type of break you see at the surface and even on the total length of the break.

Discussion of the Paper: "Basic Dynamic Principles of Response of Linear Structures to Earthquake Ground Motions"
by: S. Cherry.

Question: If you have a three-storey structure and you apply horizontal forces on the top joint and then let go, will that structure vibrate in only the first mode?

Dr. Cherry: If you apply the forces so as to cause the initial configuration to correspond to the first mode shape then the structure will vibrate in the first mode. The forces cannot be arbitrarily imposed, they must be applied in a certain prescribed manner in order to cause the structure to vibrate in the first mode alone. In general, under earthquake excitations, all the modes would be excited and they are excited in different proportions according to the modal participation factors.

Question: Is it possible to assess a certain amount of damping to a structure?

Dr. Cherry: To my knowledge it is not possible to do this theoretically for structures that we are building in the field. We are, however, able to assess the value of damping for real structures experimentally. This has been done using vibration-exciting equipment. From the response curves obtained one is able to infer the amount of damping present. By examining typical structures we are able to get an estimate of the damping values involved. It has recently been found that the amount of damping present in modern structures is not as great as was previously imagined. Fortunately, it does not require a great deal of damping to significantly reduce structural response. Damping values to be assigned to typical structures is an area of research worthy of a great deal of study. It depends, in part, on the type of construction and on the level of excitation.

Dr. Ward: Measurements taken in the Canadian Bank of Commerce Building in Montreal, which is a forty-five storey steel structure, indicate that the damping was 1.8 per cent in the first mode and about three per cent in the third mode. This gives an approximate idea of the amount of damping in a steel structure of this type. Very similar results were obtained in the C.I.L. Building, also in Montreal, which is about thirty-five storeys high. There the damping was slightly less because the connections were welded connections.

Question: Have you any comment to make regarding the use of shock absorbers to reduce damping?

Dr. Cherry: I believe that dampers have been used in one or two instances in Japan. It is a rather difficult and expensive procedure, and I do not think very practical.

Discussion of the Paper: "Influence of Inelastic Behavior on Dynamic Response"
by: A. C. Heidebrecht.

Question: Would you comment on special problems one might get into because of inelastic column buckling?

Dr. Heidebrecht: This problem is the subject of much research, but at the present time we cannot incorporate the results of such studies in design methods. About all we can do now is to restrict the column length so that yielding, in the bending sense, occurs prior to any inelastic buckling.

Question: You have shown certain curves in which the response of an elasto-plastic system actually increased after a certain amount of time, indicating that for certain structures this elasto-plastic behavior would induce greater structural damage than the elastic analysis indicated. Would you comment on this?

Dr. Heidebrecht: I think the interpretation is probably at fault. That one curve is an exception; usually it is only when the ductility factor gets very large that we can expect a marked increase. Perhaps another reason why you might say we observe damage when we do not expect it is that we may have been over-conservative in choosing our model to be used in analyzing the structure.

Question: In the last graph shown us, where the structure entered the inelastic range, the upper storeys had a permanent equilibrium set all in the one direction. Would you clarify the assumption leading to this particularly, or was this only concerned with the first mode of the structure?

Dr. Heidebrecht: I mentioned that from the shape of the vibration it appeared that the motion was primarily in the first mode. However, the curves shown were for the total response which had been calculated by a method not employing modal analysis. Since the principle of a superposition is not valid in the inelastic range, modal analysis cannot be applied and numerical or other types of analyses must be employed.

Discussion of the Paper: "Earthquake Load Provisions of the National Building Code of Canada"
by: H. S. Ward.

Question: Could you state the differences between the National Building Code and the Uniform Building Code in relation to allowable overstress factor for earthquakes?

Dr. Ward: The Uniform Building Code allows a 33 1/3 per cent increase. The National Building Code allows no increase.

Comment: Then a building designed by the Canadian Code would have heavier members?

Dr. Ward: Yes. The philosophy here is that if any allowance for increase in design stress is considered justifiable, it should be accounted for through the K-value; the K-value should be decreased. If you are going to design for earthquake loads, what is the point in allowing an increase in design stress? What is the reason behind it? Either you design for earthquake loads or you do not.

Question: You mentioned that a stiff structure might be better founded on a compressible foundation rather than on an incompressible foundation. Would you comment further on this?

Dr. Ward: I believe the only code that incorporates this factor is the Japanese Code. A great deal more research will be required before we can expect to see anything of this type included in the National Building Code.

Question: We have heard a great deal here about the important role played by damping. Is damping taken into account in any of the factors given in the National Building Code?

Dr. Ward: Tests have shown that most modern structures are very lightly damped. For this reason we did not feel justified in decreasing the 1960 earthquake load factors. Damping is explicitly included in the Roumanian Code, but this is the only code in which it is done.

Question: Do you know which country specifies a drift limitation of 0.001 of the height?

Dr. Ward: I believe the Mexican Code contains this clause.

Discussion of the Paper: "Basic Approach to Structural Design for Seismic Forces"
by: S. B. Barnes.

Question: Can you give us some idea about isolation joints between block partitions and structural frames?

Dr. Barnes: One simple way is to take a channel anchored to the supporting diaphragm above and arranged with the legs down so that they come below the top of the masonry wall. With enough clearance, this will allow the masonry wall to move up and down and there will not be any shear connection between the wall and the channel. At the same time, the channel will offer a lateral resistance to earthquake forces resulting from the weight of the wall.

There have been a number of caulking-type isolation joints that I think have not been big enough. We found a number of government buildings in Anchorage where this type of detail had been used: the joint width there was some 3/8 inches and possibly when compressed there might have been 1/8 inches. This apparently was not enough in some cases, so I suggest that if you use this type of joint it should be widened a bit.

Comment: If you provide this isolation around a block wall how would you provide stability of the block within its own frame?

Dr. Barnes: With the channel detail mentioned above. Suppose that we have vertical reinforcement in this wall so it can span as a slab from floor to floor. The channel legs coming down will take that. In California we design such a wall for 20% of gravity or, in some codes 5 lbs./sq.ft., whichever is the worst. In any case it is a very small horizontal force that you have to provide for. The channel can be attached to the floor above with bolts at the calculated spacing. This makes a good detail, but not a very sightly detail if visible. So, you can also perhaps just depend on dowels if you can get the dowels so that in bending in an inch of height they can take care of the load.

Question: What procedure should be followed in considering the restoration of buildings which, although they did not collapse, are significantly damaged by earthquakes? For example, the badly damaged buildings in Alaska.

Dr. Barnes: I do not think you can draw hard and fast conclusions or generalities. In almost all Californian cities we have a building department policy which requires that if the repair amounts to more than 50% of the cost of construction, the entire building must be brought up to present-day code requirements. This line has been arbitrarily drawn.

Question: It seems we know very little about the earthquake; considerably more is known about the materials from which we build our structures. The codes seem to allow a margin of safety over dynamic analysis and yet we are still working in terms of moment resistance of concrete with a very high factor of safety and still coming up with failures. Could you comment on this?

Dr. Barnes: The dynamic analysis includes a ductility factor which anticipates that the structure goes into the plastic range. If we were to design or run a dynamic analysis without that factor it might show a different relationship. My general feeling has been that on most buildings we are designing, within the working stresses allowed, for a good deal less of the horizontal force than we might expect if we were to get something of the order of the El Centro earthquake.

Comment: Then what you are saying is that we are designing for forces which are really guess work and may not, in fact, be the maximum forces which are being applied to the building.

Dr. Barnes: I think you have said it reasonably well. There is a lot of guess work in it.

Question: Since the data on which we attempt to base precise analysis is so approximate, would not earthquake resistance be more appropriately provided by thorough attention to detail rather than application of precise analysis?

Dr. Barnes: Let us use them both. Let us use what theory we do know as best we can. The more precise we can make an analysis the better off we are; I do think that attention to detail is more important than whether we apply a force of, say, ten or twelve units. It is important to make sure that the forces we are using go through the proper paths and ultimately get into the foundation.

Question: Some codes contain a clause requiring foundations to be tied together. How important is this?

Dr. Barnes: My opinion is that the better we can tie the foundation together, the better off the building will be.

Discussion of the Paper: "Current Trends in the Seismic Analysis and Design of High Rise Structures"
by: Nathan M. Newmark

Question: You mentioned a particular building originally designed as a shear wall structure, and then designed as a composite building. This was obviously done to make a comparison of cost. What was finally decided?

Dr. Newmark: The building was designed, and is now being constructed with a composite design. It was originally intended to be built as a concrete shear wall building, using slip forms. The composite structure was intended also to accommodate the shear wall construction with slip forms but then because of the desirability of building this during the cold weather period, it was decided to use a braced steel frame instead for the upper part. The weights and behavior were substantially the same. The cost of the braced steel frame was somewhat greater than that of the concrete shear wall construction, but it was felt this would be recovered by the earlier completion of the building.

Question: Would you say it is an advantage to introduce in shear wall buildings a weaker lower section?

Dr. Newmark: Not a 'weaker lower section', but a more resilient lower section. In this particular case I though so. I would have increased the design level for a shear wall building extending to the base somewhat over the value for the building as finally designed because I felt that, taking into account the lower period and the lower ductility, I would want it designed for a higher shear value. In other words, I think that the base shear value that one uses should take into account the ductility, the method of construction, the means of achieving this ductility, the difficulty in doing so, and one should not use the code provisions without adequate consideration of these factors.

Question: For the building that was designed partly as a rigid frame and partly as a flexible frame for the lower six storeys, the deflection of the first six storeys was of the order of about 5 1/2 inches, and the upper portion was about 5 1/2 to 7 inches. In Professor Tezcan's paper he applied the ductility coefficient of four in the case of a flexible building with moment resistant connections, and he assumed a corresponding coefficient of ductility of two for what was virtually a braced frame. What is the normal relationship between a braced frame and moment resisting frame? I see a variation between your treatment and that presented by Professor Tezcan.

Dr. Newmark: I was much more conservative because I felt that the lower six floors were doing the very important part of the work of holding the whole building up. It was very heavy construction, subjected to very high vertical compressions. Therefore, I would not permit as much ductility, or as much inelastic behavior, as I would in a building which was designed with a different concept. I think I would agree with his ductility factor for a braced frame of the order of 2 as being reasonable. I might possibly go slightly higher, but then one would begin to get into trouble if one went much beyond that. In general, I think a ductility factor of the order of four for rigid frame construction, is quite reasonable, but if the hinges have to be in the columns I would be concerned about that. I would want to have the plastic behavior occur in the girders, because I do not like to have plastic behavior occur in compression members that do not have a chance to straighten out, and ductility factors of the order of two at plastic behavior in compression members seem to be a reasonable figure. This, for example, is the figure I have recommended for use in nuclear blast resistance.

Question: Is there any difference in the behavior of a pile foundation and a footing foundation on alluvial soil under earthquake conditions?

Dr. Newmark: It is difficult to imagine how the soil can move without the piles moving with it. I cannot see how there can be any major difference. A local problem may arise if there is a settlement of the soil near the pile pad that would allow a foot or so of free-standing pile without adequate reinforcement to take the high movements that might exist and might cause cracking. However, that would not necessarily cause a serious failure. Ordinarily the piles in almost any type of soil, even a relatively soft mud, would have to move with the soil. There is no way in which the piles could move differently unless you have piles or caissons in very, very soft material.

Question: Although we have no physical proof of it, it seems that a fault follows the St. Lawrence River along which many of our main cities are situated. Do you not think that in our calculations we should consider vertical forces too?

Dr. Newmark: They would have to be considered, but in most cases the vertical forces are no problem at all and do not normally require special provisions in addition to those we generally use. I would expect that with the intensity of the earthquakes that we normally consider reasonable, this would not be a problem in that region either.

Comment: But, if you have a column and a floor you always have a difference of phase between the oscillations of the floor and column which can result in high stresses at the connections.

Dr. Newmark: This is a matter which I think can be taken into account in the design and it would automatically be taken into account if you used the response spectrum properly.

Comment: But, according to the information provided from reports of the San Francisco earthquake of 1957 the vertical oscillations increased in the ratio 1 to 4 when measured in the basement and 16th floor.

Dr. Newmark: Those were relatively small oscillations. There is no indication that they would increase by the same proportion in much larger earthquakes. In any case, the frequency of the major elements that carry vertical loads is much higher than that for the building as a whole. If we had spans that would give us frequencies of one cycle per second in our horizontal members then we might have some problems that we would have to deal with. Where we have normal floor construction I cannot imagine that we would not have enough factor of safety, just from our usual factor of safety for vertical loads, to resist the vertical oscillations.

Comment: You might have very heavy floors, for instance.

Dr. Newmark: Yes, but no matter how heavy the floors you are still not going to go over about 20,000 p.s.i. in your stresses. And if your dead load stresses are high you only have small live load stresses added to that, so if you increase the acceleration you have to have 2 or 3 G to even cause yielding.

Discussion of the Paper: "Soil and Foundation Behavior During Earthquakes"
by: H. Bolton Seed.

Question: You mentioned that liquifaction occurs most easily when the confining pressure is least and with most difficulty when the confining pressure is highest. Why then did liquifaction occur on a thin, sand seam in the Alaskan landslides with a depth of some fifty or sixty feet?

Dr. Seed: The soil conditions in the landslide zones were typically: some 20-25 ft. of dense sand and gravel, below that a layer of stiff clay, and then below that soft clay, and in the soft clay, near the surface, were many thin strata of sand. The sand surface was too dense to liquify - it is a relatively denser material. Stiff clay cannot liquify. The sand seams which are amenable to liquifaction are all those in the soft clay layer, and there are some sand seams down at the bottom of the layer also. If, in fact, all the sand seams that could liquify are in the soft clay layer, which would liquify first, those at the top or those at the bottom? On the basis of what I have presented, those at the top, so that one would expect the slip surface would always be along the top of the soft clay. I might add that this is completely the opposite to what you would predict if you use a seismic co-efficient method of analysis in which you take a slide mass, apply some lateral force to it, and find the critical surface of sliding. On this basis of prediction you would find that the slip surface would always be at the bottom of the soft clay. So we have two contradictory theories. One says that if liquifaction occurs most easily at lower confining pressures the slip surface would be on top of the soft clay. The other, which is the conventional design procedure, says that the slip surface would be at the bottom of the soft clay. One reason I advocate the low-confining pressure theory is that in the Anchorage landslides all the slip surfaces were at the top of the soft clay where the confining pressures would be where you at least get liquifaction easiest. That is one reason that I am so convinced that the slides were all in sand lenses and not in the clay itself.

Question: With respect to the Niigata earthquake, how often have similar earthquakes occurred in that area? Was that an extremely large earthquake?

Dr. Seed: No. They had an earthquake of similar magnitude in the same area about one hundred years ago; at least they had similar ground motions. They have had many shocks in the Niigata area in that one hundred year period.

Comment: With similar type damage?

Dr. Seed: Each time they had a major shock they had similar type damage. After sand has been liquified and become denser it does not necessarily inhibit liquifaction in subsequent earthquakes. By experience we find that wherever we have slides in one earthquake, we have slides in the next earthquake in sand, wherever we have liquifaction in one earthquake, we have liquifaction in the next earthquake. In fact, you can show that the amount of densification you get in any one earthquake is very, very small. In the Anchorage earthquake quite likely the deposits of sand are now 1 lb/cu.ft. denser than they were before. That is a very small densification.

Question: Were there any man-made compacted fills in the Niigata area and, if so, how did they fare?

Dr. Seed: There were some fills, particularly for oil storage tanks. As much as I could gather from the Japanese engineers, in areas where there was no fill there were many signs of liquifaction. Where the fill was placed, there was no evidence of liquifaction below the fill. I would argue that this would again be an illustration that the effect of this fill in providing surcharge pressure was to inhibit liquifaction of the loose sand below.

Question: Is the liquifaction a temporary matter or is this going to stay permanently after it has occurred?

Dr. Seed: It is temporary, but of course it will persist for a while. There are many reasons why sand liquifies; one is that in shaking, high pore pressures are generated. One can visualize a situation where you have a loose, flat sand layer at depths with denser overlying sand layers. The loose sand layer will liquify first with high pore pressures. Those high pore pressures must dissipate somehow. How do they dissipate? By water flowing to the surface. An upward flow of water, or a hydraulic gradient, is generated in the denser sand near the surface and this upward flow could then cause liquifaction of the dense sand. Not the ground vibrations, but the upward flow of water resulting from the vibration liquifaction of the lower sand layers would cause subsequent liquifaction of the upper sand layers. There would be a time lag, of course, between the liquifaction in the lower layers and the water showing up on the surface, and there are theories for calculating the time lag.

Question: What were the soil conditions like in Niigata?

Dr. Seed: Sand and gravel were the predominant soils deposited in the area. But there are boring data which show that there were in the sand and gravel some fine sand, or medium sand layers and although the mass that slid was primarily sand and gravel, the slide may have been caused by the performance of these fine sand layers in the midst of the sand and gravel.

Question: Would you expect sand and gravel to liquify?

Dr. Seed: You only get liquifaction if you develop high pore pressures and, of course, in pervious materials the pore pressures will dissipate very quickly, and if they dissipate there is no liquifaction. Sand and gravel is usually sufficiently pervious that it will not liquify. It is all a function of how big a mass of it there is. A one-foot pile of sand and gravel, to my mind, would never liquify during any earthquake, but a pile of sand and gravel half a mile in extent might liquify during an earthquake simply because it takes a finite time for anything to drain. The classic example of this, I think, is the large mass slide that occurred in China in an earthquake in 1920. This material was not saturated at all. There was mostly air in the voids but the sand compacted. Of course, all sands and gravels are much more pervious to air than they are to water. But here was a mass of soil that was big enough that even the pore air could not dissipate fast enough to prevent the liquifaction phenomenon. As an example, one can get liquifaction by pore air pressures in a bag of cement. If one takes a bag of cement and tips it up very rapidly and then pours it out, one finds that the cement will run out with ripples like a fluid, on account of liquifaction produced by pore air pressures which cannot get out of the cement fast enough. This is a very fine grade of material, of course.

Question: Would you tell us whether there is any difference in the response of buildings which have foundations to the same depth but of different types, such as, individual footings, rafts, grillages, etc.?

Dr. Seed: We do not know. There is no evidence for this.

Question: If one has to build on sand, is it possible to consolidate it first by vibrations?

Dr. Seed: Surely. The Japanese in Niigata had many oil tanks, some built on sand directly, some built on sand fill which had been ponded, some built on sand fill which had been compacted, some built on sand fill where the sand below the fill had been compacted by vibro-flotation. The tanks on a small pad of fill where the soil below had been compacted by vibro-flotation to a depth of about twenty feet behaved very well indeed -- settlements of the order of two or three centimeters. So densification of the sand is clearly the solution. It is simply a matter of economics.

Question: You implied that damage to one of the high rise structures in Anchorage was due to a foundation failure and one of the earlier speakers was inclined to the opinion that it was a horizontal shear failure. How do you reconcile these two points of view?

Dr. Seed: I did not say that the failure of that building was a foundation failure. I said that the cause of the building suffering as much damage as it did was due to the fact that it was a long-period building on a soil where peak response would develop in long-period buildings. But it was not a foundation failure problem. The foundations for that building were, as far as I know, in excellent shape. It was a building vibration problem which caused the building to be damaged. At the same site, if the building had been only four storeys high, the chances are that it would not have been damaged. That was the point I was trying to make.

Discussion of the Paper: "Earthquake Engineering Research"
by: G. W. Housner.

Question: Can you comment on the vertical vibrations of very tall buildings, especially when the earthquake occurs quite close to the building?

Dr. Housner: Vertical vibrations have been recorded in San Francisco in a sixteen storey building. This was due to a small earthquake so that the acceleration was not particularly large. This was clearly the case of the fundamental mode of the floors and columns. You can compute the various modes of vibration in the vertical direction and from the spectrum curves for vertical motion determine the maximum amplitudes of vibration.

Question: Have any studies been made to find the natural frequency of the foundations of buildings, that is, before the superstructure of the building itself has been constructed?

Dr. Housner: I have not seen anyone reporting on this question. The nearest thing would be some measurements by the Japanese on a nuclear reactor building which essentially is just a rigid block vibrating on the soil. A report of these studies will be coming out in the Proceedings of the Third World Conference on Earthquake Engineering.

Question: You mentioned four ways that the practicing engineer could contribute to applied research, such as the examination of earthquake damage and tests of actual buildings, etc. I wonder if you would add a fifth, which is the logging, or recording, of all bore holes for foundations? In Ontario it is compulsory to report all logs on water drill holes and oil and gas holes, but drill holes for foundations of structures, such as highways, tunnels, buildings, etc., usually remain the property of the client and the engineer, and this information is generally closely held.

Dr. Housner: Certainly footing tests is another area in which the practicing engineer could contribute. I would agree that boring holes and all information on soils and footing tests should certainly be made part of the professional literature and not held closely.

Question: For a building located in a remote area, would it be possible to use controlled blasting for anticipating damage due to earthquakes, or for finding the fundamental modes of buildings?

Dr. Housner: I think this is a very feasible way of making a test. The only difference between the motion excited by an underground explosion and an earthquake is that the spectrum curve will have a somewhat different shape, but this does not really alter the problem.

You would mere say that, given a spectrum with a particular shape, this is what you could do; you can easily transfer this to other spectrum shapes. In fact, the engineers in the United States are urging the federal government to make use of the underground nuclear testing for exactly this purpose, but so far not much has been done.

Question: What factors would you have in mind when estimating the damping of a building still to be designed?

Dr. Housner: That is a very difficult question. We do not really know at present the precise origin of the damping in a building. About all we can do is go on past tests. The tests would indicate that a steel building could be expected to have something like 1% of critical damping for elastic oscillations that reach 5 - 10% G at the roof level. For a reinforced concrete building it is something in the order of 2%. The general difficulty of this problem can be emphasized by reporting the results of tests carried out by Professor Beauchamp of the University of California. When the frame of a multistorey steel building was excited with a shaking machine the measured damping was of the order of 1%. When plain panes of glass in this all glass building were seated in a rubber grommet arrangement and the building re-tested, it was found that the natural frequency went up 30%, and the damping went up by a factor of 7 or 8. This means that the glass was built into the structure and indicates that from a source such as glass the damping was increased considerably. However, I do not think that you can count on that increased damping!

Question: Can you tell me how the shaking machine you described operates at between 3 to 5 second period, which is the range of very tall buildings?

Dr. Housner: It was designed to give about 1,000 lb. force at one cycle per second. The force provided by the machine decreases as the square of the period, which means that if you went to a period of 2 seconds you would be down to 250 lbs.. It would not be too suitable for a 5 second period building since the force would be extremely low. The tallest building in which it has been used to date is a steel frame structure of nine storeys.