The Nature of Cracking in Concrete

By Felix Kulka
Former president (retired)
T. Y. Lin International

Our firm has been involved in the design of high-rise buildings for some time. T. Y. Lin International is probably better known for its expertise in concrete and prestressed concrete, particularly in long-span structures and high-rise buildings, and it seems most of our work is in California and other earthquake-prone regions.

The seismic design of high-rise buildings has been not only of deep concern to owners, architects, engineers and contractors, but also one fraught with much controversy, because earthquake design relies heavily on the observation and interpretation of buildings which have experienced earthquakes.

Like so many other engineering firms involved with the design of high-rise buildings, we have concerned ourselves with the problem is of earthquakes and have developed methods of analyses, and definitely a philosophy of approach.

Earthquakes have occurred in Venezuela, Mexico, the Philippines and Nicaragua, areas heavily committed to concrete construction, simply because concrete is an indigenous material to those countries, while steel has to be imported. For that reason, most of the failures in earthquakes have been in concrete buildings - not because concrete buildings are necessarily inferior or subject to larger damage - but because there are so many more concrete buildings.

By the very nature of the dynamic forces in earthquakes, energy imparted upon the building has to be resisted by the building; i.e., it has to be absorbed. That absorption of energy takes movement. A building resting on the earth which shakes must absorb energy through movement in order to ride out the shaking.

Steel buildings or slender buildings can move and therefore they absorb energy through the very deflection of its floors. This is a better action for the structure, but tends to cause larger deflections and therefore larger amounts of damage in non-structural or architectural items such as ceilings, windows and non-structural walls. A concrete structure which is stiffer and cannot move as much has to absorb energy through cracking.

Cracking is a most misunderstood aspect of earthquake behavior. When a concrete structure cracks in an earthquake it is often immediately declared as having failed. But a structure is not necessarily considered to have failed if it merely cracks.

A crack in a concrete building is nothing more than a manifestation of the building having absorbed energy. As long as the building is not unduly deformed, has not leaned or manifested large foundation failures, is considered safe from total collapse, is largely reparable, there is no reason to declare the building as having failed.

What this means is when concrete buildings are economical to be constructed, when they are on the economic scale such as in many parts of the United States and almost all other parts of the world, there is no reason not to build concrete buildings in earthquake countries for the simple fear of cracks. We should expect that cracks will occur in concrete structures because there is no concrete which is entirely free from cracking.

Felix Kulka

In Nicaragua, the many cracked buildings evidenced the absorption of energy created by the earthquake. A good example was the Edificio Empresas Nacional de Luz y Fuerza (ENALUF), a shear-wall building extremely well designed by engineer Franz Sauter of San Jose, Costa Rica. The shear walls cracked in three stories. The cracks were considerable, but except for very few places of localized failure, the reinforcing steel had not yielded, the structural damage was minor in nature, and the building was in perfectly good shape to be used.

Shortly after the Nicaragua earthquake of 1972, our firm was invited to investigate a number of buildings, three of which have been investigated in great depth by means of computer analyses, testing in the field of frequency of vibration, and other methods of evaluation.

Note from the editor

The founders and employee-owners of ChemCo Systems, who were the former managers at Adhesive Engineering Company, are often asked to reprint some of our best historical articles. Here is a small collection of repair case histories, most relating to earthquake damage. Also included are some early studies showing the effectiveness of epoxy injection to restore structures to approximately original strengths.

I went to Managua mainly to see the Banco de America building on which our firm had been the consultants. The building is 18 stories high, it sits almost directly over the epicenter, and has a large fault running right in front of it. The earthquake motion was extremely high and the base shear was approximately 5 or 6 times greater than that for which the building was designed. Nevertheless, the building survived the earthquake in the way we had expected it to, and was in nearly perfect condition except for large cracks in the tiebeams that tie the 4 elevator shaft, together.

Those tie-beams had to crack. They were designed to do just that but in the cracking they absorbed the energy mentioned earlier. Structural damage to the building other than those tiebeams was negligible and the architectural damage very little. It is now occupied again.

We feel that since cracking is a very necessary and recognized behavior in a concrete structure, concrete cracking is no sin and the successful repair of cracked concrete is no crime. That includes not only cracking due to earthquake forces, but cracking caused by shrinkage, temperature movement, differential settlement and other situations such as poor casting of concrete resulting in rock pockets. Cracking of concrete is not the responsibility of the engineer, nor realistically can the engineer possibly foresee all of the movements which will take place in a structure and will cause cracking.

The most effective method of repairing cracks in concrete is a process of injecting high strength epoxy adhesives into the deepest recesses of a concrete structure This repair restores to a large degree the compressive, tensile and shear strengths of the original concrete. Thus, it was quite apparent to us that in nearly all of the buildings we inspected in Managua, there were thousands of cracks which could be repaired successfully by epoxy injection.

To implement those observations, we suggested to Mr. Max Rivas Davies of Pro-Con S.A., Managua, that he visit California and discuss epoxy injection as a means of reconstruction with the technical experts and engineers of Adhesive Engineering Co. He did so and now a large number of concrete structures in Managua have been returned to near design strength by epoxy injection.

I believe it is about time that owners, architects, engineers and contractors recognize that cracking of concrete is not the responsibility of one single person. To be sure, there are some cracks that occur as a result of faulty design or construction. But I also believe that the vast majority of cracks being repaired today are those which occurred because of the natural movement of the concrete, which most often can't be prevented from cracking if the building is to follow a modern design.