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ADVISORY MISSION ON USING RUBBER BASE ISOLATION TECHNIQUES IN ASEISMIC CONSTRUCTION

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MEXICO

Technical report: Findings on Mexico earthquake and Presentation on rubber base isolation*

Prepared for the Government of Mexico
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of M. Kelly and A. Tarics,
experts in earthquake engineering

United Nations Industrial Development Organization
Vienna

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When the 8.1 Richter magnitude earthquake struck Mexico City on September 19, 1985, it killed an estimated 10,000 people, left a quarter of a million homeless and destroyed several hundred buildings. Failure of the national telephone system due to collapse of its building meant that all communication to regions outside the City was lost and rescue operations were severely hampered.

The earthquake was the most severe to hit a densely populated area in this century and at first sight it was viewed from the outside as a completely widespread disaster. Later assessment has revealed that the area of damage was a small part of the entire city and in the area of most severe damage only a fraction of the total number of buildings was damaged. In many cases buildings immediately adjacent to collapsed buildings were completely undamaged. The earthquake thus presents a challenge to the engineer to explain why some buildings performed well while others apparently designed to the same codes and in the same area collapsed.

In December 1985, three months after the earthquake, UNIDO sent a team of experts to Mexico City to view the damage and to determine to what extent the research and development work on construction sponsored by UNIDO could be used in Mexico and other Latin American countries to reduce loss of life, suffering and property damage in future events of this kind and to what extent this work could be useful to the structural engineering profession in Mexico City on the rebuilding of the city in the aftermath of this earthquake. This report is that of two members of the visiting UNIDO team, James M. Kelly and Alexander G. Tarics, and describes their contacts with Mexican engineers and contractors and their impressions of the earthquake damage and the implications of that damage to the UNIDO project. The aspect of the Mexico City mission of most immediate interest and importance to Tarics and Kelly is the question of the potential use of seismic isolation techniques for the protection of buildings in earthquake regions of the world and in particular the lessons that can be learned from the Mexico City earthquake for the application of the technique.

Seismic isolation is a new approach to earthquake protection which has the possibility of greatly increasing the safety of housing and public buildings in underdeveloped countries. It has been studied at the earthquake engineering laboratory of the University of California (UCB) and at the laboratory of the Malaysian Rubber Producers' Research Association (MRPRA) in England. The work in California was sponsored by the National Science Foundation and that in England by UNIDO. Seismic isolation achieves its effect by interposing a flexible layer between a building and its foundation. The flexible layer is a system of laminated rubber isolators and the approach is particularly effective for stiff heavy structures. Such buildings are very common in underdeveloped countries and are extremely susceptible to earthquake damage and many thousands of lives have been lost in past earthquakes when they have collapsed. If used appropriately the technique of seismic isolation can greatly increase the safety of a building at a negligible increase in cost.

It is clear that the amount of damage by the earthquake in Mexico City was due to the nature of the soil underlying the city. Most of the downtown area of is built on a former lake bed. Below a surface layer of fill is a layer of very deformable clay which varies in depth from 20m to 60m. The water content of the clay is extremely high (> 400%). Although the event was large in the seismological sense (M_R = 8.1) it was 400 km (250 miles) from Mexico City and at that distance the ground movement would have been anticipated to be negligible. In fact the maximum accelerations recorded on rock in the grounds of the Universidad Nacional Autonoma de Mexico (UNAM) were as low as 0.04g, a level that would be only just perceptible rather than damaging. However the record of the ground motion at the rock site shows a strong periodicity at around a 2-second period. This is not unexpected since the predominant period of ground motion at a given point on the earth's surface lengthens with distance from the epicenter of the earthquake generating the ground motion. However the soil layers in the region of the old lake bed have vibrational periods that vary up to about 4 seconds. The areas where the clay is around 30m deep have periods around 2 seconds and these regions were set into resonance by the incoming motion at the rock base. In the regions of highest intensity where the soil period is 2 seconds the maximum recorded acceleration was 20% of gravity whereas for the deeper soils with periods of 3 or 4 seconds the accelerations were much lower, and even lower accelerations were recorded on the transition zone between the old lake bed and the adjacent firm ground. Since the earthquake occurred a concerted effort has been made to identify the dominant period of the soil over the area of ancient lake bed. In all areas the regions of damage have periods close to 2 seconds.

The accelerogram of the earthquake recorded on the soft soil shows a very regular 2-second period which rises steadily in acceleration for 40 seconds and then decreases for the next 20 seconds. There are in the record around 30 cycles of significant motion. The perceptible motion lasted for at least three minutes.

In the region of greatest damage the buildings that collapsed or were irrecoverably damaged were between 7 and 15 stories high. The periods of these buildings would lie in the range of about 0.75 to 2.0 seconds. These buildings could be expected to vibrate quite significantly under the 2-second input motion, would suffer some damage, thereby lengthening their periods and bringing them progressively closer to resonance with the ground. This resonance and the long duration of the earthquake with many cycles of strong motion led to the collapse of many buildings.

Most of the collapsed and severely damaged buildings were reinforced concrete structures. Reinforced concrete structures are designed to resist earthquake loading through the development of ductility. In a short duration event with a dominant period that is shorter than that of the building, ductility acts to lengthen the period of the building and to increase the damping in the structure both of which act to reduce the effects of resonance. Under a few cycles of alternating load the ductilities of beams and columns can be sustained if the elements are well detailed. Under a long sequence of cycles the strength of the concrete drops substantially and the ductilities required cannot be sustained. Also, in the Mexico City earthquake the lengthening of the period of the building acted against the structure in contrast to the intent of the structural code by which the buildings were designed.

The design code for the city before the earthquake was a fairly stringent code comparable to code requirements in California but it allowed designers to assume ductility factors of up to 8 which in essence allowed the engineer to reduce the calculated earthquake stresses by a factor of 8 to allow for the effects of inelastic action in the structure. The emergency code that has been imposed since the earthquake on new construction and on repair allows ductility factors no higher than 4.

Very few buildings lower than 5 stories were damaged although the great majority of existing buildings in the area of highest shaking were in this category. Also very few older masonry buildings were damaged although all of these will have been constructed without the benefit of seismic design. These buildings would have periods very much shorter than the dominant period of the ground motion and would not amplify the ground motion.

An interpretation of the structural reasons why a given building collapsed or performed well is greatly complicated by uncertainties about the ground motion at the foundation, the nature of the soil under the building and the details of the structural system. The building-by-building assessment will take many years and may never be complete, but some general principles can be declared from the visit which are significant for the UNIDO project.

There were many failures in waffle-plate and flat-slab structures. These were caused by the low ductility capacity that exists at column-slab intersections. Under a few stress reversals the connections are safe but when there are a great many cycles of large inelastic deformation the joint fails and the slab drops. Impact on a slab below causes it to fail and leads to a progressive collapse and the entire system ends up as layers of slabs. Slab-column structures are very popular in Latin America. They are cheap to build and allow internal spaces with good architectural flexibility, but the structural system lacks ductility. If used with a seismic isolation system at the base the ductility demands on the system would be considerably reduced and the safety of this type of construction greatly enhanced.

The visiting UNIDO team was struck by the large number of corner buildings which were damaged in Mexico City. Many corner buildings had walls on two adjacent sides and open facades on the street facing sides. This leads to an extremely unbalanced stiffness distribution for the building and in an earthquake this would lead to large torsional response. This, in turn, puts very high displacement demands on the corner columns and leads to progressive failure through $P-\Delta$ effects. In discussion with the staff at UNAM it was learned that 42% of the severely damaged and collapsed buildings were corner buildings. The implication of seismic isolation for this situation is that an unbalanced building if isolated can be made to act as if it were symmetrical by proper design of the isolation system. The designer has the freedom to select the center of stiffness of the isolation system in such a way that it coincides with the center of mass of the superstructure and thus the effects of torsion on the building can be eliminated while retaining the architectural features that make the conventionally designed building so unsafe. It should also be noted that very substantial torsional displacements were evident in one steel frame building which was severely damaged. Here the bracing of the frame was very unsymmetrically detailed and the result was torsional response with failure of the corner columns.

Many buildings had large numbers of masonry walls in the upper floors, some structural, some nonstructural, but all contributing an excessive strength compared to the first story which was generally open, for parking or for open plan stores. In this type of structure the ductility demands are concentrated at the first story and this leads to large forces and large displacements in the lower floor columns. Base isolation can reduce these demands on the first story columns since in an isolated structure the large displacement demand is concentrated in the rubber isolators which have the ability to undergo many cycles of large displacements without deterioration.

Other causes of damage such as unrepaired damage from previous earthquakes, soil failure and pull-out of friction piles were observed. To what extent these could be alleviated by the use of isolation is not clear at this time.

The use of seismic isolation in Mexico City itself will have to be approached with care. If an isolation system with a 2-second period had been used in the region of extreme damage where the ground period itself was 2 seconds. no benefit would have been obtained. However, the period distribution of the ground in the ancient lake bed area is now very precisely known and the design of an isolation system could be tied to such knowledge of the period of the site. For example, if the site period is close to 2 seconds, it would be possible to design a system to give a period of 3 seconds. Due to recent developments in rubber technology at MRPRA, it is now possible to design a bearing in a high damping rubber elastomer for a 3-second period. Such a bearing would provide at least 10% damping and would provide substantial protection to a building in that area.

A 3-second system if subject to the ground motion recorded at the region of highest intensity would experience a relative displacement of 35 cm (14 in.) which is within the capacity of such a bearing. The maximum acceleration of the structure for such a system and for the soft soil earthquake record would be 15% of gravity, well within the capacity of any standard structural system.

In the course of the visit the UNIDO team members contacted members of the construction industry in Mexico City through the Camara Nacional de la Industria de la Construccion. Two lectures on the development and application of seismic isolation were given to this body and much discussion with the audience took place. The team members (Kelly and Tarics) made contact with practicing structural engineers, at least one military engineer and with two editors of construction engineering publications. The application of base isolation in the United States, the developing code requirements for isolated buildings, recent research and the potential use of isolation in Mexico were discussed.

Contact was made with the structural engineering faculty at UNAM, in particular Profs. Luis Esteva and Roberto Meli. They were helpful in assisting the team to locate damaged buildings of particular interest to the team. The team also gave two lectures at UNAM to large audiences and with much response and discussion from the audience. Again films and slides were used to illustrate the lectures. In these lectures we catalogued the possible systems for use in Mexico City and outlined methods of circumventing the problems caused by the unique soil conditions of the city. There have been continuing contacts with UNAM people present at the lecture and there is a distinct possibility of future collaboration between the University of California at Berkeley and UNAM on the development of isolation systems.

The Mexican earthquake of September 19, 1985, will provide information on the earthquake resistance of many types of structural system as study of the damage continues. The focus of the study to date has been the modern high-rise office and hotel buildings in the downtown area of Mexico City. There was however substantial damage to housing in other parts of the city. Adobe houses collapsed in a Northern region of the city and there was considerable damage to housing, both adobe and masonry, in Cuidad Guzman, a city 150 km from the epicenter of the earthquake. In general it is adobe and masonry structures which lead to the greatest loss of life when earthquakes occur in Latin America. And these are the structural types most likely to benefit from the use of isolation. Even a very simple low-cost rubber pad system would result in a very large reduction in the earthquake forces experienced by such buildings and since the structural systems are heavy, brittle and without ductility, the flexibility introduced by a rubber pad system would have a major effect on the safety of the buildings. The South American countries, Chile, Peru, Colombia, and Ecuador, are in a region where earthquakes are generated on subduction zones. Subduction zone earthquakes are deep-focus earthquakes, poor in surface waves and consequently with lower spectral ordinates at long periods. They have higher accelerations in the short period range than earthquakes generated on faults where two plates slip past each other, as is the case in California, and they tend to be felt over a much wider area than this latter type.

In these countries then it is expected that earthquake damage will be concentrated on the stiff heavy structures that have short periods and these are the adobe and masonry buildings used as housing, small stores and small office buildings. Thus for these buildings the use of seismic isolation could be most effective.

The results of this Mexico City visit by the UNIDO team could, if research and development of low-cost low technology isolation systems is pursued, lead to very substantial reductions in the risk to the people of these countries and make a major step forward in mankind's continuing quest for increased safety in earthquake prone regions of the world.

Professor James M. Kelly

Dr. Alex G. Tarics

Date: 2/26/86