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Learning from earthquakes – The Armenia earthquake

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ABSTRACT: The December, 1988 earthquake in Armenia has provided insight into the response of a large number of engineered structures. The performance of these structures was, unfortunately, not good. Design and construction deficiencies are discussed and it is concluded that these deficiencies could be avoided in future construction.

The December 7, 1988 earthquake in Armenia, known as the Spitak earthquake, devastated the Northern region of the country, causing more than 25,000 deaths and leaving more than half a million people homeless.

UNESCO sponsored a seminar in May, 1989, where results of preliminary investigations were discussed. Continuing studies by European, Japanese, and American investigators have made it clear that the major conclusions of the UNESCO Seminar remain unchanged. In a joint paper by J.R. Filson, E.R. Noji and M.S. Agbabian, presented at the Seminar, it was stated that the technical issues which needed addressing covered the entire spectrum from ground shaking and seismology, through performance of structures to rescue activities and management of casualties. An important consideration was the management of the reconstruction and retrofitting of structures in the damaged area. Optimistic estimates of completion schedules were announced during the Seminar, but political and economic realities showed that estimates of fast track reconstruction were entirely unrealistic. Reconstruction came to a halt, the homeless from the earthquake are still homeless, and they are living in temporary huts.

In the meantime, engineers in Armenia are working on a new building code and a government commission is looking into ways of introducing better quality control in construction.

Let us examine the types of structures that performed so poorly during the December 7, 1988 earthquake. Their classification may be found in the literature. The source that the author has used is the compilation of data by the Earthquake Engineering Research Institute (EERI).

A significant number of the structures that collapsed or were badly damaged were reinforced concrete buildings that were constructed in the last twenty years. A summary statement from the EERI report is repeated here.

"The causes of building failure are not yet clear on a site-specific and building-specific basis. The most likely causes include: poor quality of construction; lack of redundancy; poor detailing; lack of ductility; and site amplification." The above causes exist collectively in most buildings that collapsed or were severely damaged. It is, therefore, very difficult to isolate a single cause for a specific building, but a predominant cause may be possible to determine in many cases.

The first and the last causes mentioned, namely poor quality of construction and site amplification, may be separated from the other causes. These may be lumped together as structural design deficiencies. It is hard to believe that the principles of redundancy, good construction joint details, and ductility could be overlooked in the design of reinforced concrete structures. In reviewing the design process, however, it becomes evident that the buildings that performed so poorly in the seismic region of Northern Armenia were not originally conceived for their earthquake resistance but for rapid construction in order to meet the housing demands of the Soviet Union. In most cases, these structures were designed as typical buildings that could be constructed anywhere in the vast Soviet Union, with the stipulation that they should be modified in the seismic regions to make them earthquake resistant.

Let us consider the requirement for redundancy. If the original concept of the structure is based only on gravity load considerations and does not include redundancy for the effect of lateral loads, a major design modification would be required to make it earthquake resistant. Since such major modifications would not be acceptable from the viewpoint of standardized and rapid construction, the designers were limited in their ability to improve the standard design developed in a central office.

Another factor to consider is the detailing of the connections. The earthquake resistance of precast concrete frame structures depended almost entirely on the beam-column connections, and yet the joints were poorly conceived and poorly constructed. This deficiency was aggravated by the fact that there was no diaphragm action at the floor levels. The floor slabs consisted of panels placed side by side and resting on beams at their ends. There was no transfer of horizontal shear forces and the slabs acted merely as dead weights.

The lack of ductility was a major factor in the failure of the structures. The designer assumed ductile behavior and designed the buildings accordingly. The building code incorporates a ductility factor, a coefficient, that accounts for the yielding and energy absorption at the structural connections, but the structure was neither designed nor constructed to confine the reinforcing steel to perform in its yielding range.

A reference to the list of the causes of failure shows site amplification as one of the causes. In Kirovakan, which was closer to the epicenter, there was less damage than in Leninakan (Gumri). Site amplification was clearly evident in Leninakan. However, a reduction factor was used in the computation of the lateral forces on the assumption that no amplification was anticipated as the structures in Leninakan would be placed on rock foundations. That was the case in Kirovakan, but not at Leninakan.

Finally, poor quality of construction has been a major cause of building failures. There was indisputable evidence that quality control was absent during construction.

This paper is accompanied by the presentation of slides for the following categories of structures:

- load bearing stone masonry wall buildings,
- composite stone and frame buildings,
- precast concrete panel buildings,
- nine story precast concrete frame buildings, and
- concrete lift slab buildings.

It is noted that copies of these slides may be obtained from the Earthquake Engineering Research Institute in California. These buildings illustrate the various design concepts that were used in the post 1970 period. Precast panel buildings generally survived with minor damage. As relatively stiff structures with adequate shear resistance, they remained standing when structures around them collapsed.

A statistical survey of the earthquake region shows the following (EERI data):

	Precast panel				Precast frame			
Cities	A	B	C	D	A	B	C	D
Spitak	-	-	-	100	-	-	-	-
Stepan-avan	-	-	-	-	-	-	-	-
Kirov-akan	-	-	-	100	-	-	81	19
Lenin-akan	-	-	-	100	54	41	5	-

	Composite				Stone			
Cities	A	B	C	D	A	B	C	D
Spitak	73	15	12	-	80	8	12	-
Stepan-avan	14	23	59	4	29	-	26	46
Kirov-akan	7	16	72	5	19	22	59	-
Lenin-akan	12	50	29	9	5	33	31	31

Note: A = collapsed (%)
B = heavily damaged, to be demolished (%)
C = damaged to be repaired (%)
D = no significant damage (%)

In addition to the above types of structures, there were two lift-slab buildings in Leninakan, a single core 16 story building and a double core 10 story building. The former was in category B (heavily damaged, to be demolished) and the latter was in category A (collapsed).

It is important to note that it was the conclusion of the seismologists that the epicentral region experienced Intensity IX, whereas the structures were designed mainly for Intensity VII. The code regulations show that Intensity IX corresponds to a peak acceleration of four times the peak acceleration for Intensity VII. However, it would be a mistake to blame the poor performance of the structures entirely on the lower values of lateral forces used in the design of the buildings. Redundancy, good connection details, and ductility would have reduced the damage considerably. It is the author's opinion that most structures in the A category would have fallen in the B category, and that would have saved many lives.