Learning from Earthquakes

Preliminary Observations on the Al Hoceima, Morocco, Earthquake of February 24, 2004

Following the earthquake, Ahmed F. Chraibi, Ingema, Inc., Rabat, Morocco, accompanied by EERI Member T. Leslie Youd, traveled to the epicentral area to investigate the damage. The investigators visited the city of Imzouren, the locality of the most severe building damage and the most casualties, and investigated the Mohamed Ben Abdelkrim El Khattabi Dam and the Joumoua Dam (conducted independently by Ahmed Chraibi). This brief report also contains observations of building damage and information gleaned from news reports and several web sites.

The publication of this report is supported by EERI's Learning from Earthquakes Program under National Science Foundation grant # CMS-0131895.

Introduction

On February 24, 2004, at 02:27:48 UTC (also the local time), an earthquake of moment magnitude Mw 6.4 (USGS) struck north central Morocco near the Mediterranean Sea (epicentral coordinates are 35.235 N, 3.963 W). The epicenter was about 3.5 km southwest of the undamaged coastal city of Al Hoceima, about 14 km northwest of the most damaged city of Imzouren, and about 320 km northeast of the capital city of Rabat. The focal depth was 12.6 km (USGS). The earthquake was felt at distances as great as 200 km from the epicenter. As of March 8, 2004, 622 casualties were reported.

Seismicity

The affected region is very seismically active, with hundreds of small earthquakes in the past 20 years

Figure 1. *Location and rapid moment tensor solution for earthquake (USGS).*

under the Mediterranean Sea to the northeast. The area also lies within the North Atlas fault zone, which trends northeastward across Morocco to the epicentral region.

The general location and moment tensor solution (USGS) for the earthquake is plotted in Figure 1. This solution indicates that the earthquake was generated by strike-slip motion along either a north-northeast trending left-lateral fault or a west-northwest trending right-lateral fault. The nearest strong-motion instrument to the epicenter was located near the right abutment of the El Khattabi Dam, 21 km southeast of the epicenter. A peak horizontal acceleration of 0.25 g was recorded by that instrument. Strong ground motion at the dam had a duration of 9 s and high frequencies with a predominant frequency of about 4 Hz.

Mohamed Ben Abdelkrim El Khattabi Dam

The El Khattabi Dam is one of the major engineered structures in the epicentral area. It is 27.5-m high

Figure 2. *Post-earthquake view of the El Khattabi dam from right abutment (near the strong-motion instrument) (photo: Youd).*

Figure 3. *View of reinforced concrete face of the El Khattabi Dam from right abutment (photo: Youd).*

Figure 4. *Junction between gravel embankment and concrete gravity sections of the El Khattabi dam (photo: Youd).*

and composed of two primary segments, a 160-m long reinforced concrete gravity section containing the outlet works and spillway, and a 460-m-long reinforced concrete-faced gravel-fill embankment (Figures 2-5). Following the earthquake, the safety of the dam was of great concern to the population living downstream and to the Moroccan Ministry of Water, the owner and operator of the dam. Because of this, the Moroccan government asked the investigators to make a reconnaissance visit to the area to evaluate the condition and stability of the dam.

The only earthquake-related effects noted were two small transverse cracks in the asphalt-paved roadway surface on the crest of the dam. The southerly crack was approximately above the contact between the eastern edge of a buried concrete slab in the spillway structure and above the southern contact between bedrock on which the spillway structure is founded and the valley alluvium on which most of the embankment section is founded. The northern transverse crack was similarly located approximately above the contact between valley alluvium and bedrock contact beneath the northern part of the embankment. Neither crack was wider than a few millimeters. The cracks were caused either by differential response of the embankment to ground shaking, or by slight settlement within the valley alluvium or possibly within the embankment. A re-survey of benchmarks on the crest of the dam indicates that as much as 10 mm of settlement occurred between the two cracks during the earthquake. The cracks were assessed as superficial and insignificant with respect to the performance and safety of the dam.

The exposed reinforced concrete face of the dam was also examined. The reservoir was at its maximum operating level at both the time of the earthquake and the time of the visit, so only the upper 3 m of the face was exposed. There was no visible distress to the concrete slabs or the joints between the slabs. The lack of damage to the exposed face is an indicator that the submerged face was also undamaged. Had there been significant damage to the concrete face or to the junction between the face and the underlying slurry-trench cutoff wall, leakage through the dam would have increased, but the operator of the dam reported no increase of leakage.

Joumoua Dam

A 60-m-high roller-compacted-concrete (RCC) dam (Figure 6), located almost 30 km (straight line) southwest of the epicenter, was also inspected. This dam, which has been operational since 1990, contained a full reservoir at the time of the earthquake, with water flowing over the spillway structure. A close inspection of this structure revealed no observable damage, not even minor cracks.

Building Damage in Imzouren

Imzouren is a modern community of about 30,000 people located about

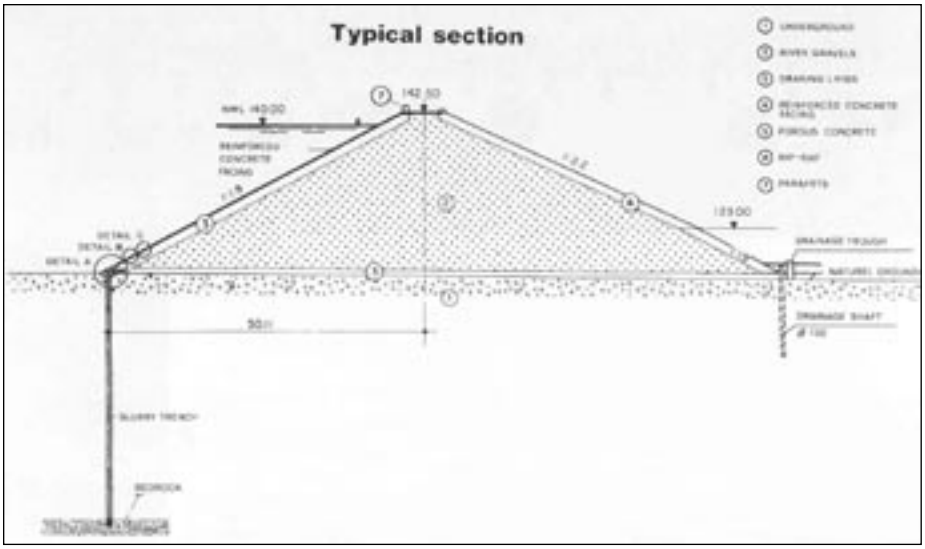

Figure 5 *Typical cross section of embankment segment of the El Khattabi dam (Moroccan Ministry of Equipment drawing).*

Figure 6. *Joumoua Dam, a roller-compacted concrete structure completed in 1990, was undamaged by earthquake shaking (photo: Chraibi).*

Figure 7 *Collapsed building in foreground and undamaged buildings with typical construction in background (photo: Youd).*

7 km northwest of the El Khattabi Dam and 13 km southeast of the epicenter. Most of the people in the community live in two- to three-story residential buildings constructed with ordinary reinforced concrete frames and clay-tile curtain walls. The building fronts are generally finished with painted stucco veneer (Figure 7). The community is underlain by eastward gently sloping Pliocene conglomeratic sandstone and alluvium. No evidence of liquefaction or ground deformation was noted within this community.

Local regulations require building permits and architectural drawings for each constructed building. Inspections are made to assure that the building is constructed in accordance with the architectural plans and that local safety regulations have been met. No engineering analysis or inspection of structural elements is required. Local contractors construct the buildings and are responsible for the sizing and reinforcement of beams and columns. The concrete used in construction is prepared in batch plants and trucked to construction sites. The contractors are unlicensed and unregulated. No education or special training in construction practice is available or required.

Newspaper reports indicate that approximately 40 residential buildings collapsed during the earthquake. Many additional buildings were cracked and structurally damaged to varying degrees (Figures 7-8). Collapsed and seriously damaged buildings represent only a small fraction of the total building stock, but they were the primary cause of the 622 reported casualties. No serious fires were ignited by the earthquake. The destruction caused much distress among the local population, with many people choosing to sleep in tents or other temporary shelters rather than return to their homes, damaged or undamaged.

Figure 8. *First-story collapse of several buildings (photo: Youd).*

Inspections were being made at the time of the visit to assess the damage state and safety of each building. Unsafe buildings were marked with a spray-painted red X (Figure 7). Governmental programs were being prepared to repair or replace damaged or collapsed buildings.

Damage Distribution

Several villages in the hills northwest of Imzouren were severely damaged. Although reports of casualties and collapse of adobe housing in these areas had been confirmed, no media reporters or official investigators had visited these isolated areas at the time of the reconnaissance visit, nor were the authors able to do so. The unpaved roads into the villages were impassible due most likely to recent heavy rains, but landslides may also have blocked some roads. Buildings in the rural villages were most likely constructed in typical indigenous style with rectangular plan, unreinforced adobe walls, and flat earthen roofs.

With respect to the distribution of damage, buildings near the El Khattabi Dam were undamaged, including a nearby mosque with a tall, slender minaret. In driving from the dam to the outskirts of Imzouren, the investigators noted small cracks in two- and three-story buildings typical of those in Imzouren. In the center of the city, there were numerous collapsed and damaged buildings as well as undamaged buildings. Nearer the epicenter, damage was slight to nonexistent, with the city of Al Hoceima (3.5 km northeast of the epicenter) strongly shaken, but reportedly structurally undamaged. Damage may have been greater at Imzouren because of a zone of seismic energy release located closer to Imzouren than to the epicenter, path effects that may have concentrated seismic energy in the Imzouren area, or local amplification of damaging ground motions.

Lifelines

Lifeline services were temporarily interrupted by the earthquake, but utilities were not badly damaged. The principal highways into Imzouren remained open to traffic with little, if any, obstruction, other than heavy traffic. The electrical power system failed or was temporarily suspended at the time of the earthquake, but was restored at least to undamaged areas within 24 hours. The water system apparently remained in service, because investigators could hear and see water leaking from damaged buildings five days after the temblor.

Response and Recovery

Socioeconomic effects of the earthquake were severe. The injuries generated demand that exceeded local emergency services and hospital capability. Aid was rushed to the area by Morrocan government agencies and military units. This aid brought greatly needed assistance to the damaged communities. Foreign supplies and personnel also came to the area within a few days, providing tents for shelter (Figure 9), clothes, food, medicine, and other essentials. Foreign financial aid, including a gift of $50 million from Saudi Arabia, has also been promised to aid reconstruction of the area. The promised assistance of the Moroccan government in rebuilding or repairing structures will be needed in Imzouren.

Figure 9. *Tent city erected in Imzouren to provide temporary housing for people displaced from their permanent housing units (photo: Youd).*