

Learning from Earthquakes

Reconnaissance Report on the Umbria-Marche, Italy, Earthquakes of 1997

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Introduction

The Umbria-Marche earthquakes of September and October 1997 heavily damaged the Basilica of S. Francesco (St. Francis) in Assisi, one of the most important artistic and religious monuments in the world. Hundreds of medieval vernacular dwellings and scores of palaces, towers, churches, convents, monasteries, and city gates were damaged, some severely. Modern engineered structures escaped almost wholly unscathed. The importance of the damage is that it is concentrated in the core of the preserved medieval centers of Umbria, justly famous for their beauty and cultural significance. At stake is the loss not only of major buildings, but of entire cityscapes in which every building may have suffered severe structural damage. Obvious questions arise regarding the pattern of failures, the extent

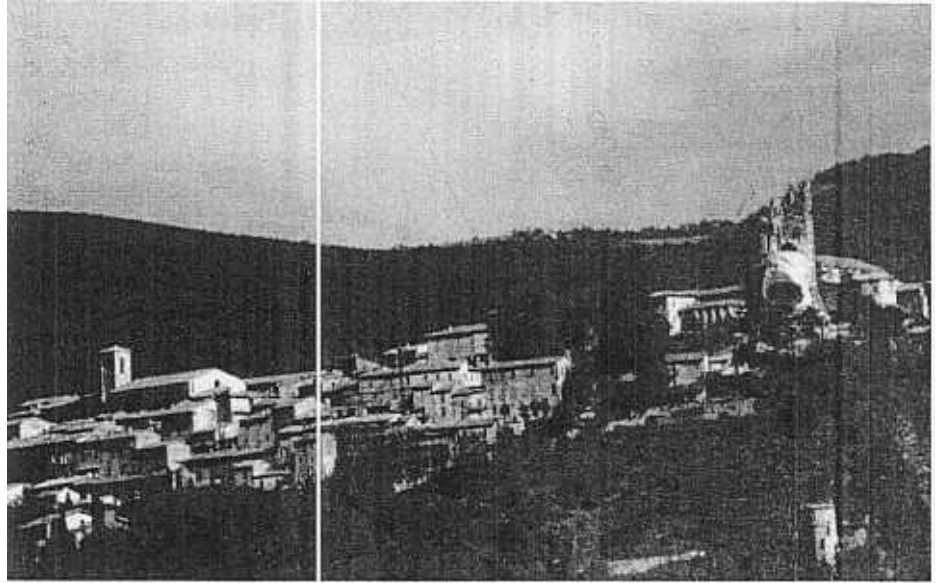


Figure 1 - Nocera Umbra, the old city. The city tower at the right collapsed in the earthquake. Seen from afar, the town seems largely intact, but in fact many of the structures are damaged. Most exterior walls remain upright, but many are cracked. Roof tiles have fallen, and some roofs have collapsed. In general, the interior damage in each building is far greater than the exterior damage.

(photo: Tobriner)

of seismic retrofits in the past, and the efficacy of future repair and retrofit. What can be done to insure the survival of historic stone masonry structures in earthquake country? In spite of the intense initial media attention, neither the extent nor the nature of the damage to the Basilica of S. Francesco, its convent, or the churches in Umbria were accurately described, nor was the damage to vernacular buildings analyzed. This reconnaissance report presents an overview of the damage, the history of earthquakes and seismic mitigation in the area, and an assessment of the effect of the earthquakes on the people of Umbria and the Marche. We were in the field from October 13 until October 19, 1997, and received

information in Italy and subsequently from Italian colleagues and contributions from EERI members without which this report could not have been written.¹ As in all such reports, our observations and conclusions should be regarded as preliminary.

Seismic and Geotechnical Observations

Geographical Setting: The general location of the earthquakes is an area approximately 50 km east of Perugia in the Region of Umbria. Of the twenty regions of Italy, only Umbria is landlocked. It borders on Toscana (Tuscany), Lazio (Latium), and the Marche (Marches) in central Italy.

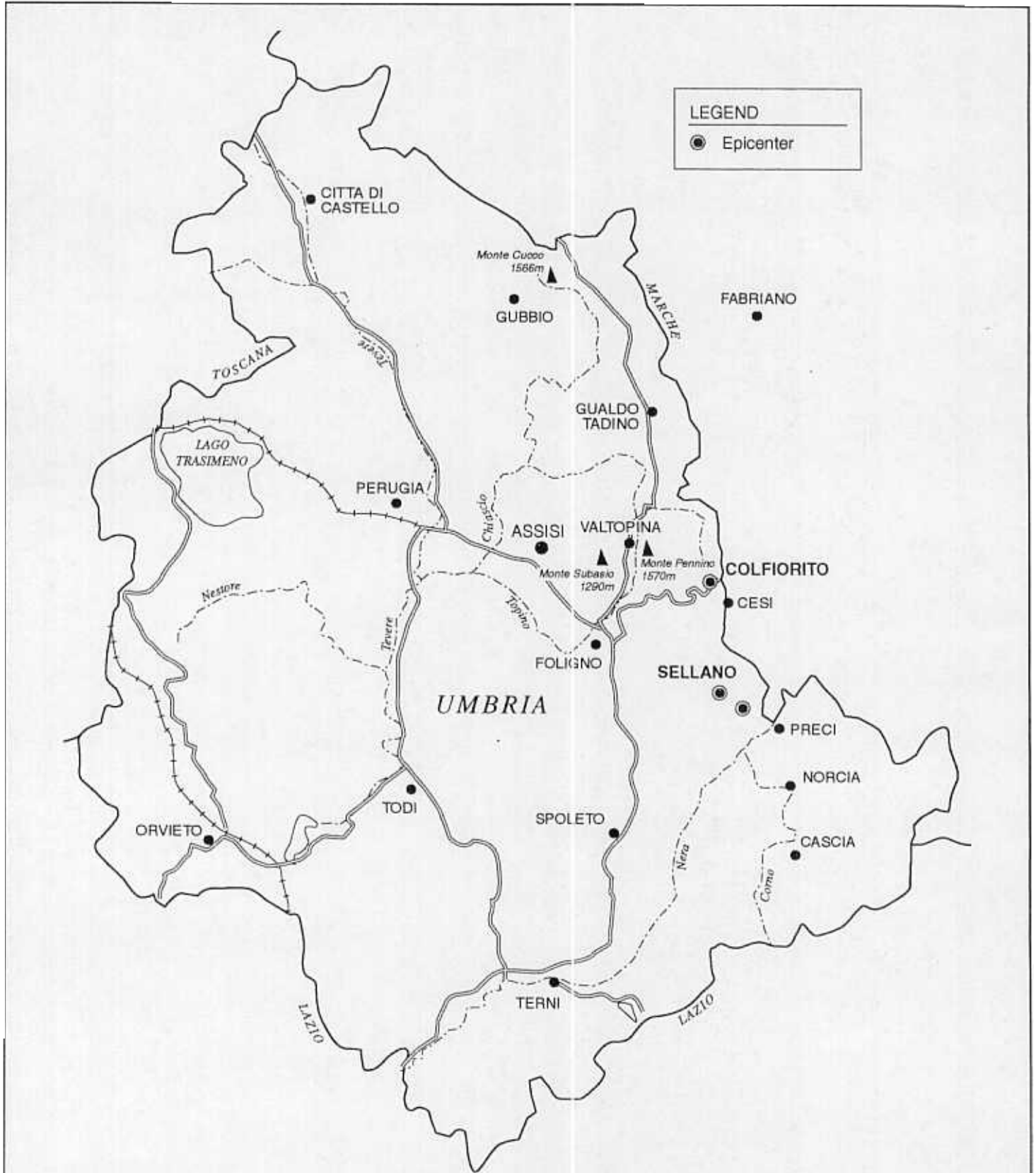


Figure 2 - Map of Umbria showing the epicentral areas of the earthquake series that affected the region throughout the fall of 1997. The epicenter for the first two shocks, on September 26, was Colfiorito. Colfiorito was the epicenter for two more shocks on October 3 and 7. Sellano was the epicenter for shocks on October 12 and 14. On November 9, the Sellano-Preci area was at the epicenter of yet another quake.

The epicenter of the first earthquake was reportedly near the village of Colfiorito. The earthquake sequence started on September 26, 1997, with a shock of magnitude of $M_L = 5.5/M_W = 5.7$ at 2:33 AM local time (epicenter $43^{\circ}01.75'N$ $12^{\circ}51.08'E$). A larger earthquake, $M_L = 5.8/M_W = 6.0$, occurred about 10:40 AM local time, again with the epicenter at Colfiorito.

These earthquakes were part of an ongoing sequence of shocks. Colfiorito was the epicenter for a $M_L = 5.1/M_W = 5.3$ event on October 3, 1997, and again on October 7 ($M_L = 5.3$). On October 12 the epicenter shifted to Sellano where a $M_D = 4.5$ event occurred, followed by a $M_L = 5.4/M_W = 5.7$ event on October 14. The most recently reported earthquake was a $M_D = 4.5$ event on November 9, 1997, with the epicenter in the Sellano-Preci area.

Ground Motions: The as yet unofficial peak ground accelera-

tions at Colfiorito for the first shock were 0.38g and 0.44g horizontal and 0.38g vertical; and at Nocera Umbra 0.56g and 0.33g horizontal, 0.20g vertical. The peak ground accelerations for the second shock at Colfiorito were 0.28g and 0.17g horizontal, and 0.31g vertical; and at Nocera Umbra 0.56g and 0.50g horizontal, and 0.42g vertical.²

Geotechnical Framework The epicentral area is in the Apennines, which run generally north-south in central Italy. The general area consists of folded and thrustured limestones, cherty limestones, marly limestones, marly clays, and marls which are part of the Umbria-Marche unit. The formations, which outcrop in elongated occurrences, date from the Upper Triassic-Lower Miocene and constitute the bedrock. The more recent formations are Upper Pleistocene-Holocene materials. They are discontinuous to the previously noted material and occur typically in the topographic low troughs of



Figure 3 - This building in Nocera Umbra illustrates typical damage to stone buildings in the region.

(photo: Tobriner)

the mountain range. In the broad epicentral area the geologic formations are cut by a number of faults of general NNW-SSE direction. These are parallel to the main direction of the formations. There is a second system of faults with a transverse strike and important horizontal component of movement.

Several geotechnical phenomena occurred. There were several surface ruptures in the epicentral area and in villages near the epicenter. The ruptures have a general orientation NNW-SSE and display a vertical displacement of from 2 to 15 cm.

A number of rock falls occurred as a result of the earthquake. Many of these caused minor temporary disruption of traffic on roads, such as the closure of highway 209 on the slope of Mt. Galloro. Near Foligno, authorities were afraid an entire hillside, the site of a hermitage and a beautiful forest,



Figure 4 - In Assisi, significant cracks had opened in the Piazza Inferiore di S. Francesco, indicating earthquake-caused subsidence. The cracks had been covered with plastic (foreground). In this photo, soldiers are beginning to string cables to stabilize the arcade to the right in the photo.

(photo: Comerio)

might slip in the direction of the small town of Pale and evacuated the town.

Subsidence apparently occurred in the town of Assisi, where significant cracks had opened in the Piazza Inferiore di S. Francesco (Figure 4). The west side of the outcrop on which the old town of Nocera Umbra is built appears to be slipping. Cracks have opened in the pavement and along the arches of the arcade on the hillside.

History of previous earthquakes:

Eastern Umbria has suffered numerous high intensity (Modified Mercalli VII or above) localized earthquakes. The areas in which earthquakes have occurred are the valleys between mountain ranges, such as the Tiberina valley (the location of Gubbio, Gualdo Tadino, and Nocera) and the eastern edge of the Umbra valley (the location of Foligno, Trevi, and Spoleto); and in the Martani mountains and the high Nera valley to the southeast, where Norcia and Cascia are located.

Norcias and Cascia have sustained repeated strong earthquakes including shocks in 1328, 1567, 1703, 1730, 1859, and 1910. Multiple earthquakes struck Gubbio between 1465 and 1466 and again in 1736. Norcia was leveled in 1703. Gualdo Tadino and Nocera Umbra were both badly damaged in 1751. Assisi suffered major earthquakes in 1832, 1854, and 1915; Foligno in 1831 and 1832; and Spoleto in 1246, 1277, 1571, 1594, 1667, 1767, 1833, 1853, 1895, and 1957.

Serial earthquakes in Umbria: The Italian media as well as the local inhabitants were puzzled and frightened by the serial nature of the low-magnitude high-intensity earthquakes which struck Umbria in September and October 1997. Just as recovery operations were about to begin, a new shock

returned the operation to emergency status.

The serial array of shocks should have been no surprise. Multiple tremors have occurred before in Umbria, even in recent memory. On the morning of October 17, 1982, the inhabitants of the zone between Gubbio, Gualdo Tadino, and Assisi felt the first of a series of earthquakes with epicenters in Valfabbrica.

Three years before, in 1979, in the zone of Valnerina a similar series occurred. Between September 19 and 20, 1979, numerous shocks were felt, the worst having an intensity of VIII or IX on the Modified Mercalli scale with a magnitude of 5.8. The small towns of Norcia, Cascia, Preci, Sellano, Valle di Nera, Pioggiodomo, S. Anatolio di Norcia, and Scheggiano were badly damaged. Eight hundred and eighty-one buildings were destroyed or demolished, and another 1,731 were gravely damaged. As in the present earthquake, stone masonry structures suffered the worst from these repeated shocks.

Similar series occurred in:

- 1854 (epicenter Assisi),
- 1833 (epicenter Spoleto),
- 1832 (epicenter Foligno),
- 1767 (epicenter Spoleto),
- 1751 (epicenter Gualdo Tadino),
- 1730 (epicenter Norcia), and
- 1703 (epicenter Norcia-Cascia).

The impulse to get out of buildings as soon as possible after the initial shock is a particularly relevant strategy for Umbria. An example of the efficacy of this response can be seen in the reaction of the people of Gualdo Tadino to the earthquake of July 26, 1751. Reports say they ran from their houses and remained outside. Subsequent shocks leveled much of their town.

Emergency Management and Response

Casualties and Injuries: In total, only 10 people were killed in the series of earthquakes and approximately 500 were injured. The casualty rate is particularly low because people were awakened in the early morning hours of September 26 by the first shock, and went outdoors. Many remained there, too frightened to return to their homes, when the second, more damaging earthquake struck.

Response Issues in an Earthquake Series: At 5:25 PM on October 14, 1997, 18 days after the first earthquake, a 5.0 shock of about 10 seconds duration destroyed many buildings in Sellano, caused the dramatic collapse of the tower of the Palazzo Publico in Foligno, and caused further damage in towns such as Nocera Umbra. This was one of many in a continuing series of aftershocks which were of similar magnitude to the initial pair of earthquakes. That same evening at the Disaster Field Office located in the Police Headquarters in Foligno, Engineer Antonio Pugliese, head of the engineering inspections for the *Servizio Sismico Nazionale* and the *Gruppo Nazionale per la Difesa dai Terremoti* (GNDT) told the American team: "We are continuing to be in an emergency mode, and cannot give people relief They are afraid because the earthquakes do not calm down."

The earthquake series had significant implications for traditional emergency services such as fire, police, search and rescue, medical, and sheltering services. Local fire and police units, as well as those sent from other regions as mutual aid, remained on emergency alert for weeks. Non-traditional policing agencies, such as the *Guardia Finance*, were called in to patrol vacated towns such as Nocera Umbra.

Similarly, hospitals continued to treat newly injured people over a long period. This was particularly difficult in Foligno because the main hospital was damaged and was operating from a temporary Red Cross facility. At the same time, buildings had to be re-inspected and re-evaluated for safety multiple times, and relief workers from the *Protezione Civile* could not ask people to go back into their homes until they felt secure that the aftershocks were diminishing. This was not the case until the end of October, more than six weeks after the first earthquake.

Temporary Housing: About 13,000 people were housed in tents and small camper trailers. That number is about 12 percent of the 110,000 inhabitants in 15 communes (city/county areas). The government is building 28 sites for prefabricated housing, as people cannot stay in the tents and trailers in winter. At the end of October, the services for these sites were not complete and the central government would not allow the prefab homes to be inhabited without services. They attempted to move the tent dwellers to hotels temporarily, as the weather turned cold and it began to snow, but the victims refused to move. People were afraid to be far from their homes

and properties. They were concerned about vandals and deteriorating conditions, and they were afraid that once they moved from the tents, the more permanent prefabricated housing would not be given to them.

General Damage

Inspection statistics as of October 14, 1997, were made available to the reconnaissance team. In 65 towns (communes) in Umbria, 30,985 private buildings had been inspected. Of these, 8,396 were structurally damaged and uninhabitable. This is roughly the equivalent of the American "red tag" buildings. The Italians use a rating system with 5 categories:

- A = inhabitable
- B = inhabitable with some provisions
- C = partially usable
- D = needs re-review
- E = unusable.

Public buildings, schools, and churches were inspected and tallied separately. Data were available for 18-22 towns in the region, and are described in the table below. It is important to note that about 24 percent of the public buildings and 17 percent of the schools were seriously damaged, while more than half (54 percent) of the churches were unusable because of severe damage.

For the approximately 900 private buildings damaged in Assisi, the value of the damage was estimated to be about \$1 billion. Extrapolating this to the roughly 9,000 private buildings damaged in the region, the value of damage is approximately \$10 billion, not counting the cost to repair public buildings and churches.

Past Mitigation Efforts

The patina of age and our delight with the picturesque medieval nature of Umbria can be deceptive. Even the most famous monuments should not be regarded as having been built in a single campaign and embalmed as perfect examples of their time. They have been altered and adapted, repaired and re-shaped. When the church of S. Chiara threatened to collapse in 1351, flying buttresses were added to save it. They might be missed if they were now removed, but the buttresses were added as an *ad hoc* expediency. Similarly in the old town of Nocera Umbra, brick buttresses and abutments, now beautifully weathered and textured, were added to brace buildings which were at risk.

Assisi is famous for its beautiful ironwork which decorates the exterior of most masonry buildings, another mitigation technique (Figure 5). Iron tie bars (*tiranti* or *catene*) and exterior wall anchors (*chiavi*) were in use in the middle ages to insure structural stability. Documents record that they were used to repair seismically damaged structures after the Gualdo Tadino earthquake of 1751 and the Camerino earthquake of 1799. By the time of the Valle del Topino earthquake of January 13, 1832, *tiranti* and *chiavi* were standard repairs and mitigation. Both were liberally used on the badly damaged church and Basilica and convent of S. Maria degli Angeli below the old town of Assisi.

Table 1
Public Building Damage in the Foligno Region

Building Type	Damage Category					Total
	A	B	C	D	E	
Public Buildings	66	15	20	2	30	133
Schools	98	37	13	2	28	178
Churches	153	35	13	11	227	439
Total	317	87	46	15	285	750



Figure 5 - Exterior anchors and tie bars on masonry buildings are a distinctive feature of Assisi vernacular architecture. These early mitigation efforts demonstrated their effectiveness in this quake. In this photo, the wall on the right, with anchors and tie bars, is intact and plumb, while the un-anchored wall on the left is cracked and bowing outward.

(photo: Tobriner)

More modern mitigation is often hard to observe or evaluate. Many of the roofs of churches in Umbria have been strengthened by the use of reinforced concrete, a practice which is presently being debated in Italy. In the Basilica of S. Francesco, a damped steel beam was added to the nave side walls to prevent cracking in earthquakes. Some masonry structures were retrofitted with reinforced concrete foundations, ring beams of reinforced brick or concrete, and steel reinforced apertures.

Engineered Structures

In the affected zone there were no high-rise buildings. Most tall structures were mid-rise, in the four- to nine-story range. All large, multi-story buildings were constructed of reinforced concrete. No large, multi-story steel frame buildings or wood buildings were located in the area principally affected by the earthquake.

Typical modern concrete construction in the area consists of a concrete frame with a masonry infill of hollow clay tile (HCT), called terra cotta. The HCT was visible on the exterior walls. In many cases the bare HCT was the exterior finish. There was no seismic separation or joint between the HCT and the concrete frame. We were unable to observe any interior wall construction.

There were a number of industrial type buildings with concrete frames and walls. These buildings were constructed of pre-cast girders, roof and wall panels. Other industrial buildings were constructed of concrete frames with walls of hollow clay tile infill. These buildings were one and two stories in height. In the general observation of these buildings no damage was observed and none was reported to us. There is one steel frame building in Spoleto, but no reports of damage were received.

Damage Observed: The area of major shaking was a rural region in the mountains. There were some newer one- and two-story concrete frame buildings, but no damage to them was observed.

The buildings were typically residential structures, some with commercial uses on the first floor. The observed damage was limited to cracking between different materials, i.e. the concrete and the infill hollow clay tile (HCT). The damage was minor and in no case was out-of-plane movement of the HCT infill noted.

In Fabriano in the Marche Region, several four- to six-story structures in public housing projects (representing 300-500 units) had this type of damage and the buildings had been vacated (Figure 6). One of the vacated buildings in Fabriano had a vertical crack in a column. This might have been a pending spall. At a beam-column joint, the reinforcing steel was exposed and spalling occurred.

In Foligno, we observed an eight-story concrete hotel building. We noted one column that had a vertical crack at the second floor line. This crack may have been a pending spall. It did not appear to be due to deformation of the beam-column joint. In addition, minor spalls due to pounding were noted. Minor pounding was noted between other concrete buildings in the built-up urban areas.

Most of the damaged concrete buildings appeared to have been constructed in the 1960s or early 1970s. No information was obtained on the type of joint and column detailing used in that era. No shear wall buildings were noted.

Most of the concrete buildings were a significant distance from the epicenter. The magnitude and frequency of the earthquake

shaking was therefore too small to do major damage to these buildings. The construction of the concrete frame buildings using the infill masonry could potentially create a short-column condition under a large earthquake.

One project under construction was observed from an adjacent site. The concrete work was just coming out of the ground. A number of columns had been constructed. At the completed columns, where a beam will intersect them, only a couple of column ties were noted. Due to lack of site access we could not determine if 135-degree seismic bends were used on the ties. It was reported that Italian law specified that the engineer had liability if there was damage to the concrete (cracks) but no liability from cracking between dissimilar materials.

Findings: In Italy the modern design standards are better than those in the past. The use of HCT infill will continue to create "non-structural" damage that will require repair in small to moderate events. Without joints between different materials a crack will always occur. The installation of HCT as infill could create a short column condition for the frame, and the collapse of the HCT due to the pressure of the concrete frame poses a potential injury or life safety threat. Quality control remains a concern.

Vernacular Architecture

Typical Construction: In a typical village in the shaken area, most buildings are two stories in height. Many villages are in hillside locations and in these cases the buildings may be taller on the downhill side. The construction is relatively consistent: stone masonry bearing walls with a wood roof structure.

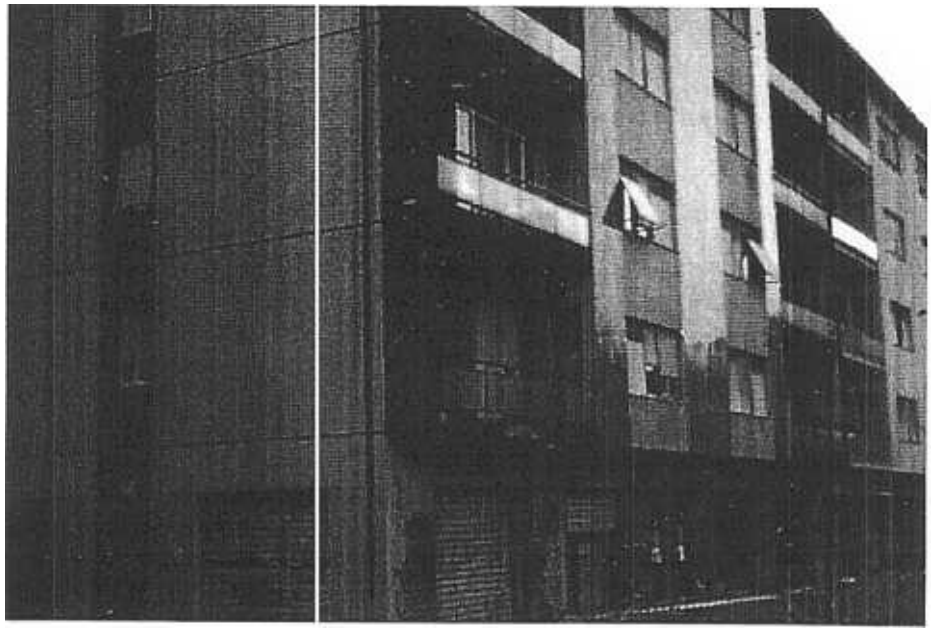


Figure 6 - These modern concrete apartment buildings had been vacated. Exterior damage consisted of spalled and cracked concrete. (photo: Tobriner)

Typically the walls are of two or more wythes of rubble or ashlar stone construction, which did not appear to be bonded between wythes. Mortar was usually a soft lime material.

Roof framing consists of beams, usually round logs spanning to bearing walls. Purlins span

between beams and subpurlins between the purlins. "S" shaped tiles hang over the subpurlins as the roof covering. The roof "diaphragm" is very flexible.

Typical Damage: There was extensive damage to buildings of this type of construction (*Figure 7*). In some cases only individual struc-

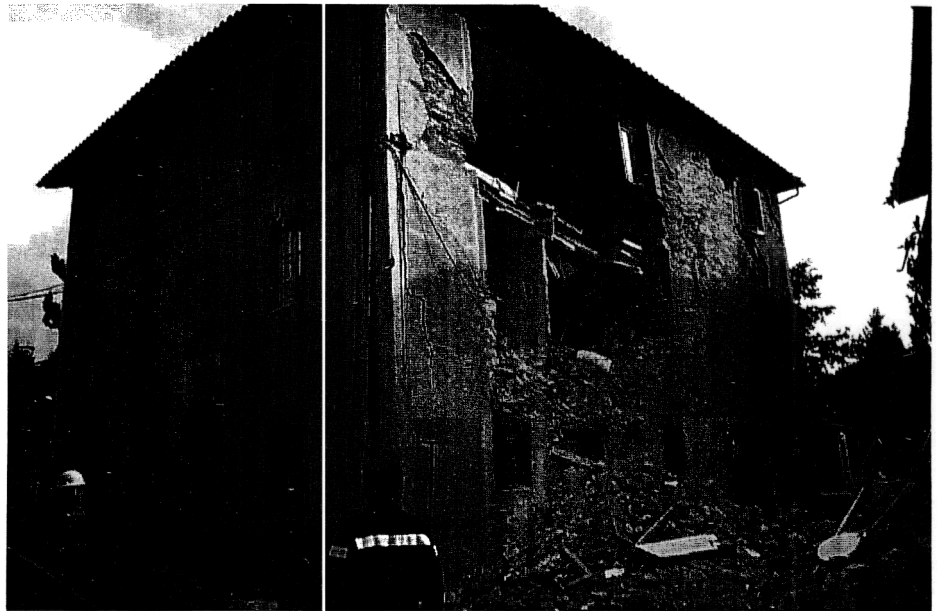


Figure 7 - This building in Cesi illustrates typical damage suffered by the area's vernacular architecture: exterior wall failures in stone masonry buildings. (photo: Tobriner)

tures were damaged. In other cases the extent of the damage in the community was so great that the entire town was vacated.

Nonstructural damage usually included the loss of roof tiles at the low end of the roof at the exterior wall. Plaster spalling from the exterior walls was also observed. Both of these conditions created a situation where the sidewalk, street, or highway adjacent to the buildings was blocked off. In the case of major roads, this resulted in controlled one-way traffic in the area.

One resident of Assisi invited us into her house to observe the damage. The building interior was composed of plastered masonry walls decorated with frescos. Diagonal shear cracks appeared in most of the walls and there were plaster spalls. It was clear the walls and plaster could be cosmetically repaired, but structural strengthening of the building would be extremely difficult.

While repairs may take time for individual residents, we observed another approach to repair occurring on one of Assisi's finest hotels. The building's age was unknown but the exterior was cement plaster. (We assume stone construction.) On the first day we visited the site, crack patching was underway with plaster patch or spackle. On the second day the material dried. On the third day the cracks were repainted and the building showed no visible damage.

Structural damage included many items that would result in a threat to life. The damaged walls we observed were two or more wythes in thickness. The masonry was unbonded between wythes. The typical failure was in the outward movement of the wall, due to the deflection of the diaphragm pushing the wall outward. This,

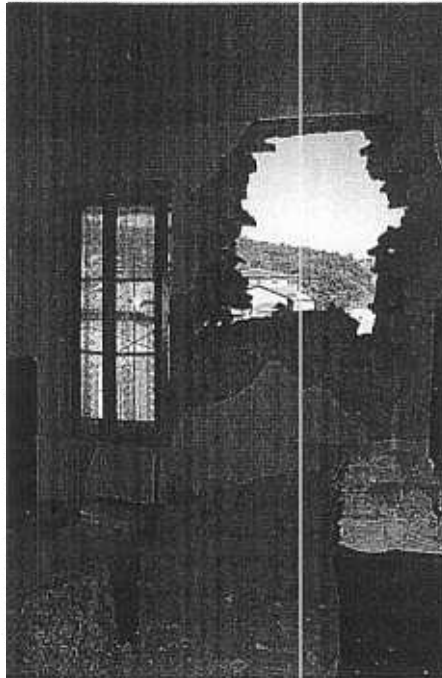


Figure 8 - An example from the town of Valtopina of the collapse of an exterior wall from the roof line to a level above the floor line.

(photo: Tobriner)

coupled with inadequate anchorage between the walls and roof, resulted in the wall collapse. Typically the collapse was from the roof to a point above the floor line (*Figure 8*). In some cases portions of the walls were blown outward. With a collapse of this type, when there was major loss of support for the roof due to wall failure, portions of the roof also collapsed.

Some walls contained a chimney, and these were damaged in a number of buildings. Where damage to a chimney occurred, the wall that created the chimney was only one wythe in thickness.

Many structures had earthquake tie rods visible on the exterior walls. In no case did we observe any wall collapse in buildings with wall ties. The team observed only a few structures which had some mitigation. For example, a building used for the Carabinieri office in

Casenove, and others in that village, had stone wall construction and pre-cast roof structures. Portions of these buildings collapsed among the more traditional wood and clay tile roof structures. While there have been reports from Italian engineers of widespread mitigation measures in various building types, the team did not see any such buildings.

Findings: Simple and traditional retrofits do work to improve life safety. Wall anchors to control out of plane damage should be encouraged for masonry buildings. Chimneys constructed in masonry walls should be carefully considered by the engineer as to the appropriate type of retrofit. The damage observed to vernacular buildings could be lessened by simple life safety retrofits that are applicable in all seismic zones and for all buildings other than bonded masonry construction.

Monumental Structures

Churches: The churches of Umbria we examined exhibited a consistent pattern of damage in spite of their diverse designs, periods of construction, or even retrofit history. These structures are constructed of limestone, ashlar, and rubble masonry which is typically 3 to 5 feet in thickness, varying with the wall height. The stone is of very good quality and is sometimes augmented by brick construction. Mortar quality, at least in the Basilica of S. Francesco, is high. Typically, the major cracks or failures appeared at the junction of facades and naves or naves and crossings where differences in building stiffness occurred.

Basilica of S. Francesco: The Basilica and its convent (Sacro covento) in Assisi suffered the most dramatic damage. S. Francesco consists of a lower crypt-like

hall church upon which a second more lofty hall church was built.

This Italian Gothic building is puzzling in many respects, perhaps the most curious being its buttressing system. The nave is buttressed by cylindrical towers and these are buttressed in turn by flying buttresses. The combination of the stubby cylinders and the elegant flyers represents two different buttressing strategies and aesthetics.

The roof of the church is supported by purlins which rest on stone arches. Below the roof is a series of quadripartite rib vaults which cover the nave. On the walls of the nave are a cycle of paintings by Giotto which are considered a turning point in western art from Byzantine iconic imagery to more naturalistic representation. The main (eastern) facade and transept facades are planar, with few projections, and are capped by simple triangular pediments.

The church had been seismically retrofitted. After an earthquake in 1984, prominent cracks appeared in the walls of the upper church threatening the Giotto frescos. The seismic retrofit included a damped steel beam inserted along the length of the nave below the clerestory windows and above the frescos. The beam was designed only to restrain out-of-plane bending in earthquakes and otherwise to "give" with the building. The roof had also been retrofitted with concrete purlins.

The worst damage occurred at the ceiling and roof levels. The webbing or infill of the east quadrant or cell of the quadripartite vault adjoining facade broke in the second earthquake (Figure 10). On the vault was a priceless Cimabue fresco which crashed to the floor killing four people. Down the nave, the webbing of the

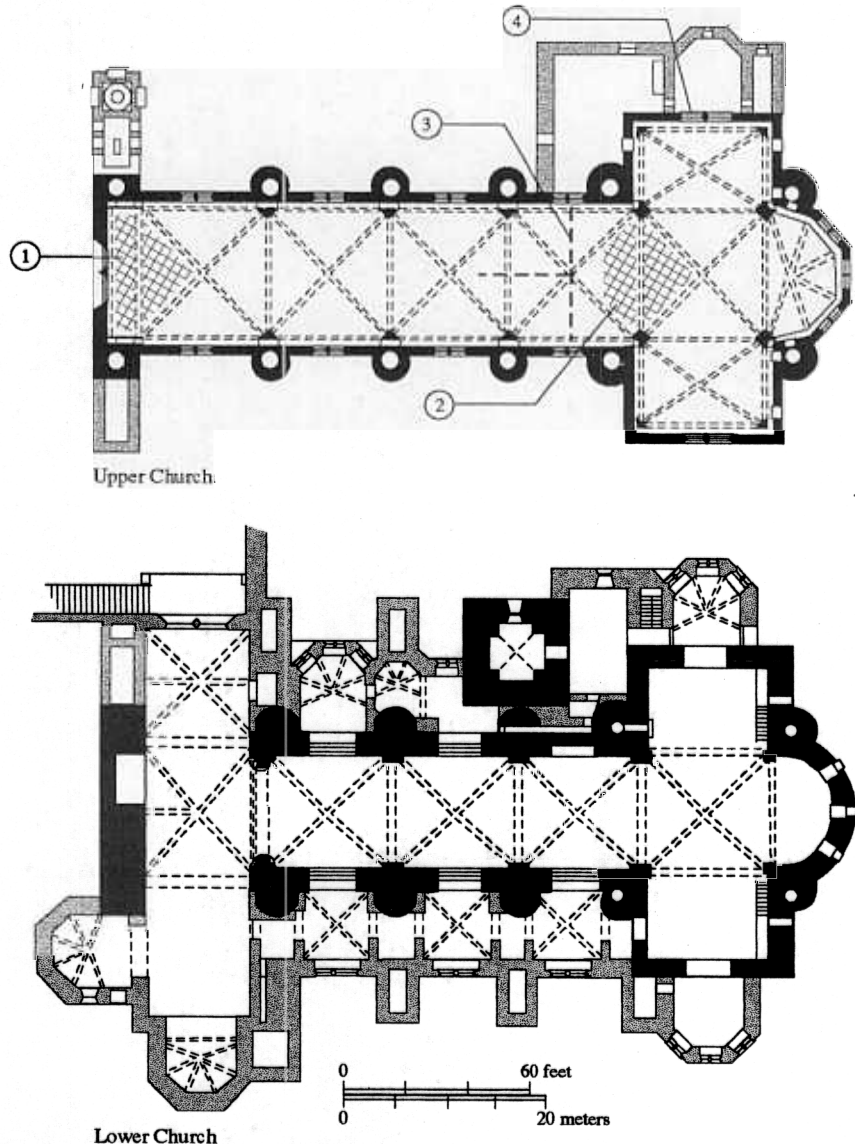


Figure 9 - The upper and lower churches of S. Francesco in Assisi
Diagram key: (1) Collapsed vault adjacent to entrance portal (where four people were killed). (2) Collapsed vault at crossing. (3) Major cracks in vault. (4) Cracked pediment, now braced by steel cage.

quadrant of the vault immediately in front of the crossing, the supporting cross vault, and the webbing of the east quadrant of the crossing vault, all fell (Figure 11).

Large cracks appeared in the centers of the nave vaults which still survive. The south transept pediment cracked. The question is whether the roof and side wall retrofits helped the structure or contributed to the local failures.

S. Chiara: (St. Clare) The design for this Italian Gothic church in Assisi (built between 1255 and 1265) was based on the Basilica of S. Francesco. St. Clare was a follower of St. Francis and established the women's Franciscan Order, the Poor Clares. The aisleless hall church exhibits the same damage pattern as S. Francesco, only less severe. There is a crack between facade and nave arch. They have separated from

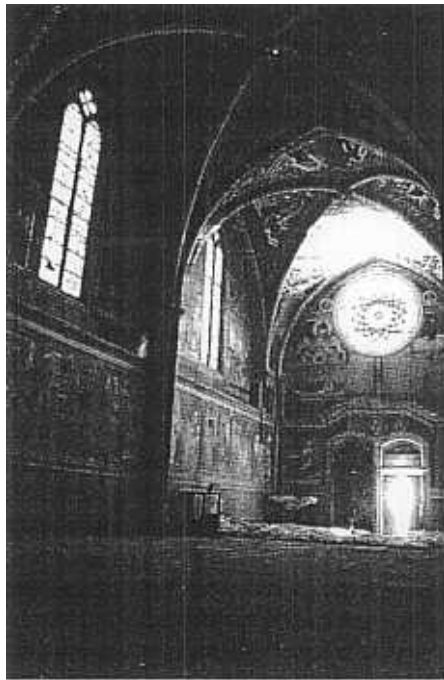


Figure 10 - The interior of S. Francesco in Assisi, showing the collapsed first vault (above the rosette window). (photo: Tobriner)

one another. The first quadripartite vault of the nave is badly cracked on all four quadrant webs. Its collapse seems imminent. Further, there are large vertical cracks down the sides of the nave walls below the vault. Proceeding down the nave, the second bay from the crossing is cracked. Pieces of stone and painted plaster fell in the nave and at the crossing. The stones in the exterior flying buttresses are unseated and loose.

S. Pietro: This church is a somber early Romanesque-Gothic structure (begun in 1029 and completed in 1268) serving a Benedictine monastery in Assisi. It has a nave flanked by side aisles. The roof is supported by a series of transverse arches. At the crossing is a low dome. There was cracking between front arch and facade from which stones and mortar had fallen near the interior front portal of the church. Large vertical cracks ran down the walls in the first bay after the facade. Cracks also

appeared in the southern support of the dome.

Diagonal cracks appeared in the top bell tower. The bells suspended on rods had been thrown off their supports.

S. Rufino: This building, the Cathedral of Assisi, begun in 1140, is distinguished by a beautiful Romanesque facade with a high pediment. Like the previous facades, it is relatively planar with a high pediment, wider and taller than the fabric of the building behind. The interior was completely remodeled by the Renaissance architect Galeazzo Alessi in 1571, with a barrel vaulted central nave and side aisles. Even though the barrel vault is reinforced by transverse tie rods, it suffered badly in the earthquake. A major crack runs down the center of the arches of the three bays from the facade to the crossing. The entire nave vault is severely damaged. The church's massive tower is intact with no visible cracks.

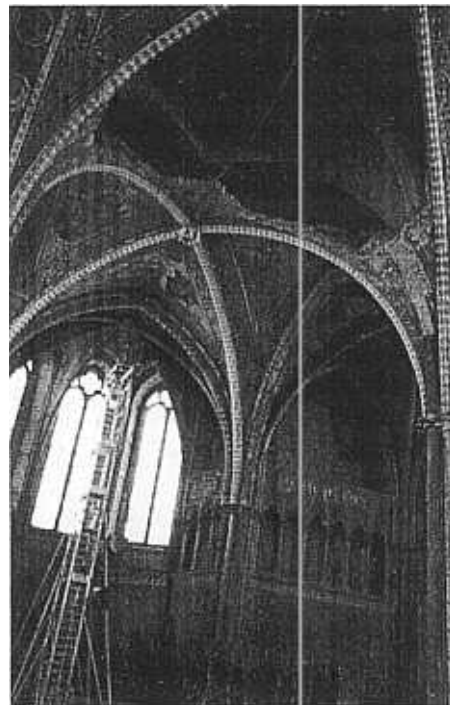


Figure 11 - The collapsed vault between the nave and the crossing at S. Francesco in Assisi. (photo: Tobriner)

S. Maria degli Angeli: The Basilica of S. Maria degli Angeli in the city of the same name below Assisi is a massive late Renaissance-Baroque church begun in 1569 to shelter and honor the small church where St. Francis taught and prayed, called the Cappella della Porziuncola. It is a sacred site and pilgrimage destination. The Latin cross plan has an arcaded nave with side aisles. The tiny Porziuncola is preserved under the lofty dome in the crossing. The nave vaults and left aisles were completely destroyed by an earthquake in 1832, but the Porziuncola and the dome above miraculously survived. Subsequently, the nave and side aisles were rebuilt with extensive iron and wood reinforcing above the vaulting in the roof. Iron bands were tied around the dome. The facade of the church was added in 1927. We saw cracks between the facade and the nave which had not moved in unison. Large cracks appeared at the crossing. There was a large crack through the left transept.

S. Maria Assunta: The Cathedral of S. Maria Assunta in Spoleto (begun in 1198) has a Romanesque facade altered by the addition of a porch during the Renaissance. The interior nave with side aisles was redecorated in the 17th century. The interior nave arch is dislocating from the facade. A significant crack can be seen. Plaster is falling from the dome where cracks and apparent water damage can be seen. Major lesions appear above the left transept.

All the convents and monasteries we examined were badly cracked. For example, the Sacro covento of S. Francesco suffered major damage: the southeastern pediment had collapsed and the northwestern facade is badly cracked in a location similar to one that sustained cracks in the 1984 earthquake. The southwest support arches are likewise

cracked. Vaults in interior rooms were damaged, frescos on the ceiling of the refectory fell, and diagonal cracks appeared in cells on the southeastern side of the complex. S. Pietro's Benedictine abbey had severe diagonal cracks and was perhaps subsiding down the hillside.

Housing, Social, and Cultural Impacts

In categorizing the series of moderate earthquakes which struck Umbria and the Marche regions of Italy in terms of lessons learned, the series might well be considered one of "architectural impacts" earthquakes rather than one which had significant engineering impacts and lessons. What is unusual and special about this disaster is the substantial social, cultural, and economic impacts of what would normally be considered a very moderate series of earthquakes. Tourism and religious pilgrimage are the primary economy, not only in Assisi, but in the entire region. Locals estimate that 5 million people per year visit Assisi. With virtually all the major churches closed to the public for some time into the foreseeable future, there will clearly be a slowdown in visitors even if hotels, restaurants, and other private facilities are repaired and re-opened.

Hill towns such as Assisi and Nocera Umbra are reported to house only 500-600 local inhabitants. Property values are high (with real estate estimated at \$400 per square foot), and houses in town are owned as second homes by foreigners. It is not clear how quickly these owners will act to repair their properties, but it is clear that a long-term slowdown in tourism will hurt the locals who live in more modern structures in new flatland developments, but whose jobs and businesses depend

on tourist dollars.

The picturesque quality of the hill towns is one of the key reasons tourists come to the region, yet the decisions about how and when to repair properties will be either (1) in the hands of outsiders (in the case of the hill towns), (2) in the hands of the Catholic Church (in deciding a priority for restoration of monuments), or (3) in the hands of government officials attempting to provide housing solutions for a poor and rural population (in the case of the rural villages). In fact, the short-term decisions to relocate roads around damaged villages and to build prefabricated housing in the flat agricultural areas will hurt the limited tourist economies in the small villages, as these settlements will lose both access to local business and the charm of village life. Thus, the long-term secondary economic impacts of the earthquakes could be much greater than the initial costs of building repair and restoration of cultural monuments.

Important Issues and Recommendations

In Italy, modern design standards are clearly comparable to those in the United States, and so it is not surprising that the team found very limited evidence of significant damage in engineered structures. Similarly, stone vernacular buildings behaved much the same as do vernacular structures around the world, failing due to inadequate anchorage of walls to roofs, with heavy roofs and chimneys pushing outward. In these cases, simple and traditional retrofit techniques do work for life safety. Most damaged buildings can be repaired, but not upgraded significantly.

By contrast, monumental structures, particularly churches, have been through a number of earthquakes and a number of

"strengthening" attempts in their 800-plus year lifetimes. It is important to ask whether, over such a long period, earthquakes have contributed to a degradation of materials and the structure's ability to resist earthquakes. Questions about the maintenance of the buildings also play a role.

Extensive intrusions by engineers may not be warranted in monumental buildings. Although current thinking suggests that historic buildings be strengthened to a achieve a greater level of protection than regular buildings, the damage to churches in Umbria suggests intrusions should be kept to a minimum, and buildings should be allowed to crack and be repaired. Although there is much research to be done on analyzing the causes of the vault failure in S. Francesco, or the separation of roofs and facades in other churches, it seems clear that heavy engineered interventions will not be compatible with historic materials and building forms. While it is clear that efforts to preserve the priceless art work on walls and ceilings must be undertaken, the work must be done with concern for whether the retrofit and construction will harm the paintings in the long run.

Ultimately, the Umbria-Marche earthquakes are significant in that they represent the considerable impact that moderate earthquakes can have on important cultural properties and on the long term economic well-being of the region. Umbria without its churches and its hill towns has very little economic *raison d'etre*. Solutions to housing a poor and rural population and to restoring the monuments need to be seen as parts of a whole. The churches need the villages and the villages need the monuments to restore the economic health of the region.

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Figure 12 - Typical damage to vernacular architecture in Umbria-Marche, Italy. (photo: Tobriner)

Voices from the Past

Estimating Seismic Risk in Italian Hill-Top Towns, Circa 1930

"The Italian Earthquake of July 23, 1930, Notes of a brief inspection by John R. Freeman, Civil Engineer" as published in Earthquake Damage and Earthquake Insurance, John Ripley Freeman, McGraw-Hill, New York, 1932.

The loss of life in this earthquake as stated in the early newspaper reports was so appalling (upward of 1,800) that the writer, then in Germany on a tour of hydraulic laboratories, visited the scene as soon as practicable, in order to learn whatever lessons this disaster might present, as to safeguards for the information of American builders.

In this quake of July, 1930, the serious wreckage was almost wholly confined to ten closely-built hill-top communities. In general, the damage outside this narrow zone, 40 miles in length, of hill-top communities was relatively extremely small. The shocks were strongly felt in Naples and caused great alarm. A few weak walls and cornices fell in and near Naples and killed perhaps 5 or 10 people. The press dispatches of the next few days expressed a state of mind rather than the real extent of damage. The writer saw no outward signs of damage while motoring over many miles of city streets in and around Naples to Pozzuoli, Castellammare, Sorrento, Amalfi, and easterly Avellino. Although the newspaper reports indicated that damage was serious all through the Neapolitan district, the writer judged that the total structural damage within 25 miles of Naples was less than 1/20th of 1 per cent of the sound value within this region.

... A second lesson from these old records is that a very rough estimate, made by dividing the number of recorded destructive quakes in about 700 years by the number of village-groups damaged by one quake, indicates that to any one of the hundreds of hill-top communities the chance of disaster in any one particular year is of the order of hardly more than one chance in five hundred and that to any one particular house in any one year, the chance of destruction is of the order of perhaps not more than one in five thousand, taking all these Italian hill-cities into the average. It would be well worth while to an economist, while considering the apparent urgent need of rebuilding these houses constructed of weak rubble masonry, to confirm by careful research the above rough estimate of chance of damage. Estimates of that kind help toward obtaining earthquake insurance of a satisfactory kind at reasonable cost.

The recurrence of damage in Melfi after the lapse of 80 years, and also the recurrence at a few other localities in Italy, illustrates that the chance of damage may be much larger for certain localities, now fairly well defined by the record of 2,000 years, than that roughly estimated above for Italy as a whole.