EFFECT OF FUTURE NEW MADRID REGION EARTHQUAKES ON OKLAHOMA

James E. Lawson, Jr.[1]

Abstract

The New Madrid seismic zone was the location of three destructive earthquakes in 1811 and 1812, and probably the site of other large earthquakes in the past 2,300 years. Because Oklahoma's east and west borders are 450 and 1,200 km (280 and 750 mi) from New Madrid, a recent scientifically unsound prediction for another large New Madrid earthquake caused much interest and concern in the State. This paper is an attempt to quantify risk to Oklahoma from future New Madrid earthquakes.

New Madrid earthquakes of four different magnitudes (expressed as mb) and their effects (expressed as Modified Mercalli intensities) on Oklahoma are defined:

1) Expected earthquake: magnitude (mb) 6.0. Intensity IV to V in Oklahoma.
2) Likely earthquake: magnitude (mb) 6.6. Intensity V to VI in most of Oklahoma.
3) Possible earthquake: magnitude (mb) 7.0. Intensity VI to VII in Oklahoma.
4) Worst-case earthquake: magnitude (mb) 7.4. Intensity VII to VIII in Oklahoma.

Intensities of IV to VIII have been experienced during this century in various parts of Oklahoma from earthquakes within the State. Preparations for New Madrid and Oklahoma earthquakes should center on ways to minimize injuries the instant an earthquake is felt. An example of these preparations is the "drop" drill practiced in schools. Even in a worst-case earthquake located at New Madrid, extended disruptions of utilities or emergency services are not likely to occur.

Introduction

The New Madrid seismic zone is of particular interest to Oklahomans, because of its relatively high seismic activity and its proximity to Oklahoma. Interest in the effects of large New Madrid earthquakes on Oklahoma increased in November 1990, because of a scientifically unsound, but widely publicized, prediction for a damaging New Madrid earthquake during the first 5 days of December 1990.

Location of the New Madrid Seismic Zone and Its Proximity to Oklahoma

Figure 1 shows earthquakes in the New Madrid region recorded by St. Louis University during a 4-year period. The earthquakes seem to define a three-segment fault in Missouri, Arkansas, and Tennessee, with the northern segment (between seismograph stations LST and DWM) less noticeable than the other two. The three segments of the New Madrid fault zone have not been mapped directly, because they are covered by 1 km (3,300 ft) or more of unfaulted sedimentary rock and river-deposited alluvium.

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[1]Chief Geophysicist, Oklahoma Geological Survey.

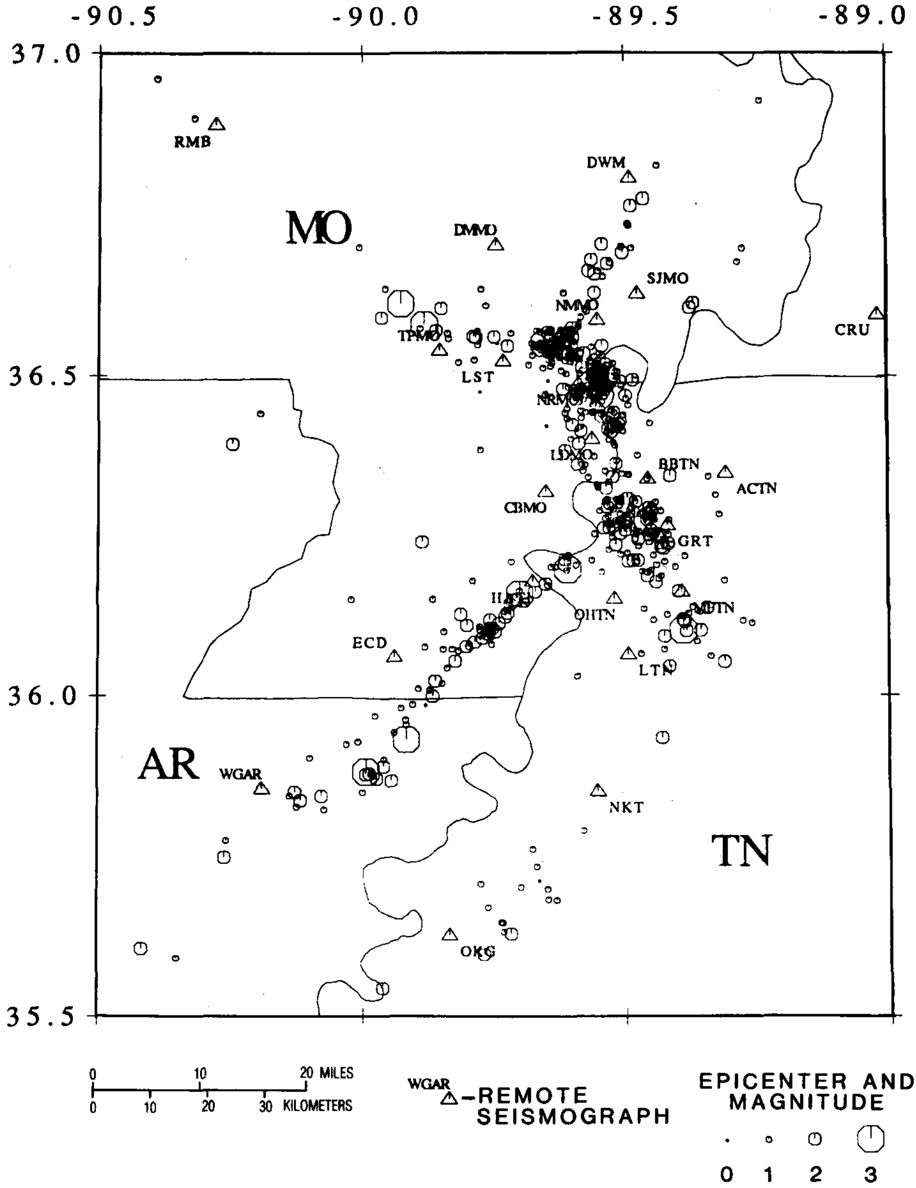

Figure 1. Earthquakes in the New Madrid region located by St. Louis University from July 1, 1982, to June 30, 1986. (From Central Mississippi Valley Earthquake Bulletin, no. 63.)

Distances from the New Madrid earthquake zone to Oklahoma are measured from the town of New Madrid, which is near the center of the three faults, and very near the most intensive seismicity. The northeast corner of Oklahoma is 453 km (281 mi) and the western boundary of the Oklahoma Panhandle is 1,200 km (746 mi) from New Madrid. Tulsa is 588 km (365 mi) and Oklahoma City is 735 km (457 mi) from New Madrid.

Past Seismicity in the New Madrid Seismic Zone

In 1811 and 1812 three large earthquakes occurred in the New Madrid region. The estimated magnitudes on the mb scale (body wave magnitude scale) by Nuttli (1973) were 7.2 (December 16, 1811), 7.1 (January 23, 1812), and 7.4 (February 7, 1812). Mr. Jared Brooks of Louisville, Kentucky, cataloged 1,874 earthquakes which he felt between December 16, 1811, and May 5, 1812 (Fuller, 1912). Otto Nuttli (1973) considers 547 of these to be aftershocks of the December 16 earthquake, 163 aftershocks of the January 23 earthquake, and 1,161 aftershocks of the February 7 earthquake. Nuttli (1973) estimates that 25 of the aftershocks had mb magnitudes from 6.3 to 6.7. Some sources, such as Hamilton and Johnston (1990), list an additional earthquake of mb 7.0 on December 16, 1811. Between 1843 and 1895 Hamilton and Johnston (1990) list three other New Madrid area earthquakes which were larger than the April 9, 1952, El Reno, Oklahoma, earthquake of magnitude mb 5.5, and they list a 1968 New Madrid area earthquake as large as the El Reno earthquake. The same authors list 24 "damaging" earthquakes in the New Madrid region between 1838 and 1987, with magnitudes of mb 4.2 to 5.4.

The three large New Madrid earthquakes, plus the 1,871 other events felt by Brooks, plus many more which probably occurred but were not cataloged by Brooks, may be considered one major "slip event," which relieved most of the accumulated strain along the three fault segments. Russ (1979), who examined near-surface sediments in the New Madrid region by trenching, believes that two similar slip events occurred within the last 2,250 years. These previous events may have had one or several principal earthquakes. This suggests that the recurrence time for such major slip events may be as large as 750 years (2,250 ÷ 3).

Struder and others (1990) summarize 16 years of monitoring by St. Louis University's Central Mississippi Valley Seismic Network. In a rectangular area centered on New Madrid (556 km [345 mi] along a north-south line, and 357 km [222 mi] along an east-west line), the network detected 2,047 earthquakes of magnitude mbLg (considered to be equivalent to mb) ≥1.5, or an average of one each 2.85 days.

New Madrid Earthquake "Prediction" for December 1990

Iban Browning (Davis and others, 1990) predicted that there was a 50% probability that a magnitude (scale unspecified) 6.5 to 7.5 earthquake would occur in the New Madrid area within ± 2 days of December 3, 1990. I can find no published statement of Browning's prediction, and newspaper articles give conflicting statements. Therefore, I relied on the "Evaluation of the December 2–3, 1990, New Madrid Seismic Zone Prediction" (Davis and others, 1990) to determine what Browning's prediction actually stated. There has been discussion in the media as to whether Browning's statement(s) were prediction(s), forecast(s), or projection(s). I will follow the terminology of Davis and others (1990) by using only the term "prediction." This prediction was given much publicity because Browning (or others) apparently claimed he had successfully predicted other earthquakes in the past, and because Browning apparently stated that the earth-tidal potential (a real physical effect) would trigger the earthquake.

Earth-tidal potential is the normal gravitational attraction of the moon and sun upon the Earth. This attraction stresses the solid earth sufficiently to cause its surface to rise and fall, changing the distance from the Earth's center to its surface by as much as 360 mm (14.2 in.) (Melchior, 1966). The primary tidal cycle is repeated nearly twice per day (12 hr 20 min per cycle). The magnitude of the rise and fall from the 12 hr 20 min cycle increases to a maximum and decreases to a minimum twice a month. The twice-daily cycle is caused by the Earth's rotation with respect to the sun and moon, and the twice-monthly cycle is caused by the revolution of the moon about the Earth. Variations in the Earth-moon and Earth-sun distances, and other changes in the relative position of the Earth-moon-sun, cause many other variations with periods of months, years, or decades that are superimposed on the twice-daily tides.

The Davis and others (1990) evaluation found that Browning's predictions of other earthquakes in the past were no better "than . . . random guessing." They specifically "[rejected] the claim that [Browning] predicted the Loma Prieta (Santa Cruz–San Francisco) October 17, 1989, earthquake."

Davis and others (1990) state that there is no theoretical or empirical basis for tidal potential triggering earthquakes. They determined that the peak tidal right-lateral shear strain on a vertically dipping plane striking N. 45° E. at New Madrid on December 3, 1990, would be 1.186×10^{-8}, or 30 millibars of stress. Greater stresses may be produced in the New Madrid area by the change in air pressure from the passage of a weather front or a change in water level in the Mississippi River. Also, the tidal shear strain reached 1.177×10^{-8} in January 1988, and frequently reached 1.10×10^{-8} between January 1988 and December 1990. No damaging New Madrid earthquakes were caused by these previous tidal peaks (B. J. Mitchell and A. C. Johnston, personal communication, 1990).

Mitchell and Johnston (personal communication, 1990) note that one of the three 1811–12 New Madrid earthquakes occurred at the time of a tidal maximum, but that it was no higher than the typical maximum occurring every 2 weeks. The other two 1811–12 earthquakes occurred closer to tidal minima. They also noted that the two largest New Madrid earthquakes since 1812 (mb 6.0 on January 4, 1843, and mb 6.2 on October 31, 1895) occurred closer to tidal minima than to maxima.

There is no clear evidence for tidal triggering of earthquakes, and large past earthquakes in the New Madrid area have not correlated with higher-than-usual tidal maxima, or even typical maxima which occur every 2 weeks. In addition, the tidal maxima of December 3, 1990, did not trigger any detectable earthquakes. St. Louis University's network of 17 remote seismographs can reliably detect and locate earthquakes of magnitude 1.5 (mbLg) or larger, but no earthquakes were detected during the period between November 30 and December 7 (Bob Hermann, personal communication). As these small earthquakes occur about every 3 days on the average, their absence during the prediction period suggests that earth-tidal potential is not a significant earthquake triggering process.

In a *San Francisco Chronicle* interview (Carroll, 1990), Browning suggested that if a destructive earthquake was not triggered on December 3, 1990, it might be triggered by a higher tidal potential on January 18, 1992. Any future Browning earthquake prediction, for January 1992, or any other time, should be evaluated with due consideration to the lack of any theoretical or empirical basis for tidal triggering of earthquakes. The lack of any detectable New Madrid earthquake during the first week of December 1990 also should be considered in assessing such a future prediction.

Probability of Future Destructive New Madrid Earthquakes

In 1985, Arch Johnston and Susan Nava reviewed past studies of New Madrid seismicity (Johnston and Nava, 1985). Using both historical and instrumental data, they estimated recurrence intervals for earthquakes of various magnitudes. They applied a variety of statistical methods to the recurrence intervals to determine a range of probabilities for occurrence of earthquakes of different magnitudes by 2035 A.D. Table 1 consists of data taken directly from their table 7.

I consider their estimates to be the best available, and doubt that there will be improved estimates any earlier than 2000 A.D. when 10 more years monitoring of instrumental seismicity will be available. Even at that time, large changes in the probabilities are unlikely.

From the numbers in Table 1, a magnitude 6.0 New Madrid earthquake seems almost a certainty by 2035. This should be considered the "expected earthquake," and Oklahomans should be prepared for its consequences. Magnitude 6.6 should be considered the "likely earthquake." Oklahoma should take adequate steps to be prepared so that the likely earthquake would cause no serious structural damage and would cause few if any injuries. Even though a magnitude 7.0 earthquake seems to have no more than a 4% probability of occurrence by 2035, it should be considered the "possible earthquake." Preparation for the possible earthquake should ensure that no serious damage occur to any building. Finally, a "worst-case earthquake" the size of the largest 1811–12 New Madrid earthquake of magnitude 7.4 should be considered. Preparations should ensure that no building with a

TABLE 1. — REPEAT TIMES AND PROBABILITY OF OCCURRENCE OF MAGNITUDE (mb) 6.0, 6.6, AND 7.0 EARTHQUAKES IN THE NEW MADRID REGION*

Magnitude (mb)	Average repeat time (years)	Probability by 2035 A.D. (%)
≥6.0	70 (±15)	86–97
≥6.6	254 (±60)	19–29
≥7.0	550 (±125)	2.7–4.0

*Taken directly from Johnston and Nava (1985, table 7).

number of occupants (schools, office buildings) should experience major damage, no lifeline services (roads, electricity, oil and natural gas pipelines, emergency services) should be disrupted, and no critical structures such as dams or nuclear power plants (if any are built in Oklahoma) should be damaged significantly by the worst-case earthquake.

Modified Mercalli Intensity in Oklahoma from the Expected, Likely, Possible, and Worst-Case New Madrid Earthquakes

The Modified Mercalli (MM) intensity scale, as revised by Brazee (1978), is a list of earthquake felt effects for 12 intensity levels. Intensity refers to the felt effects of an earthquake at a particular location. In general, intensity decreases with distance from the earthquake epicenter. Brazee's lists are more detailed than the original Wood and Neumann (1931) MM scale, and they are included in the Appendix because they give a very accurate and precise description of actual effects.

Otto Nuttli (1973) published an isoseismal (intensity) map for a large New Madrid earthquake, the December 16, 1811, mb 7.2 earthquake. Because of a lack of reports by observers, his isoseismal lines, which extend to the East Coast, are not drawn farther west than central Arkansas. Other maps, such as that in Hamilton and Johnston (1990), use the 1843 and 1895 New Madrid region earthquake-intensity data to construct hypothetical intensity maps for the 1811–12 earthquake series. The maps of Hopper and others (1983) for the 1843 and 1895 earthquakes show intensity falling off much more rapidly west of New Madrid than east of New Madrid. However, both maps include only one observation between Little Rock, Arkansas, and the Oklahoma border, and no observations in Oklahoma. Data do not exist to indicate clearly that intensities in Oklahoma would be six units less than epicentral intensity, as shown on the maps by Hopper and others (1983).

For this article, a mathematical formula is used to determine intensity as a function of magnitude and distance (Nuttli and Hermann, 1978):

$$I = -0.4 + 2mb - 2.46 \log (R)$$

where I = MM intensity,
mb = body-wave magnitude,
R = distance from epicenter in kilometers with $R \geq 20$ km.

From this, specific isoseismal maps of Oklahoma from different New Madrid earthquakes may be drawn.

The use of this formula can be tested on some recent New Madrid earthquakes. The March 25, 1976, earthquake of mb 4.9 would be calculated as intensity III in Tulsa and Oklahoma City. Intensity II was reported for Tulsa by Coffman and Stover (1978). The November 9, 1968, mb 5.3 earthquake was reported as causing intensity "I–IV" effects in Durant, Oklahoma City, Tulsa, and elsewhere in Oklahoma (Coffman and Cloud, 1970). The formula would predict intensity III as far west as Oklahoma City. Thus, based on these two observations, the Nuttli and Hermann (1978) formula seems to give values as high as one intensity greater than observed.

In this article it is assumed that the intensity given by the formula could be experienced at some locations in an area, but that much of the area will experience intensities one unit lower than given by the formula. If an intensity is V according to the formula, an intensity range of IV–V will be listed; if it is VI by the formula, V–

VI will be listed, etc. The upper intensity (e.g., VII, if VI–VII is listed) is liable to be the maximum experienced at any location. The lowest intensity experienced at any location in an area may be a full unit below the lower number.

Expected Earthquake, mb = 6.0

The expected earthquake would produce effects of intensity IV–V from northeast Oklahoma to the eastern part of the Panhandle. Few or no injuries would be expected, and no damage should occur. No preparations at all should be necessary for the expected earthquake. On September 16, 1990, an earthquake very near Haileyville, Oklahoma, produced MM V effects in Haileyville and Hartshorne. In 26 letters received from persons who felt this earthquake, the only physical effect noted was a vial of straight pins tipping over.

Likely Earthquake, mb = 6.6

Areas east of Muskogee and north of Poteau might experience effects of intensity VI–VII. Some injuries might be caused from falling bricks, particularly if persons ran from buildings when the shaking occurred. Some structural damage would be expected. The rest of Oklahoma might experience intensities as high as MM V–VI. Very slight damage and a few minor injuries may occur. Oklahoma experienced intensities of MM VI in Garvin County on November 15, 1990, and in Kingfisher County on December 8, 1987, from earthquakes in those counties. In Kingfisher County, Christmas trees fell over, knickknacks fell off shelves, and large furniture was disturbed but did not fall. In Garvin County, at least six persons fell out of bed or were knocked out of bed. Knickknacks fell, and pictures were tilted or knocked off walls. One bookcase fell, and merchandise on store shelves fell into aisles. Some cracked plaster was reported.

Possible Earthquake, mb = 7.0

Intensities might reach VI–VII in all of Oklahoma except the western two-thirds of the Panhandle, where intensity V–VI could occur. This would be similar to the intensity in the epicentral region of the April 9, 1952, El Reno, Oklahoma, earthquake of mb 5.5. Damage and several minor injuries could be expected. Preparation should center on what to do immediately when shaking is felt, such as not to run into or from a building, but to stand in an inner doorway or under heavy furniture. Schools should consider the "drop" drill in which students immediately get under their desks when the teacher instructs them to do so. Evacuating a classroom before the shaking ceases would increase the chances of students being hit by falling light fixtures or plaster.

Worst-Case Earthquake, mb = 7.4

Intensities could reach MM VII–VIII in Oklahoma as far west as Lawton and Woodward, and MM VI–VII farther west. Considerable damage, as described in the Appendix, may occur. Oklahoma has probably experienced intensity MM VIII at a few locations from the April 9, 1952, El Reno earthquake (Lawson, unpublished data) and at Ft. Gibson on October 22, 1882 (*Cherokee Advocate,* 1882).

Intensity VIII should be considered a possibility, in spite of the rarity of earthquakes causing this intensity with epicenters near New Madrid or in Oklahoma. Preparations should emphasize protection from falling objects at the time of the earthquake. Utility services are not likely to be severely disrupted for any extended period, and emergency services are not likely to be interrupted.

Conclusion

With respect to the New Madrid seismic zone, Oklahoma should be prepared for an "expected earthquake" (mb = 6.0, MM IV–V), and a "likely earthquake" (mb = 6.6, MM V–VI), and at least some planning should be made for a "possible earthquake" (mb = 7.0, MM VI–VII) and a "worst-case earthquake" (mb = 7.4, MM VII–VIII). Those same intensities also could be produced by earthquakes that might occur inside Oklahoma, but the Oklahoma earthquakes would have smaller felt areas.

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APPENDIX: Revised Modified Mercalli Intensity Scale
(according to Brazee, 1978)

IV.
- a. Objects were disturbed.
- b. Frightened few; caused slight excitement.
- c. Motion was described as abrupt, sharp, jolting, or rapid.
- d. Hanging objects swung (no qualifying adjective used by observer).
- e. Felt by many. Felt by all in home or all in building.
- f. Felt outdoors by few or some.
- g. Dizziness or nausea was experienced by some.
- h. Dishes, windows, and doors rattled. Dishes and glasses knocked together on shelves. Walls creaked.
- i. Liquids in open vessels were disturbed.
- j. Awakened many or most. Awakened all in home.
- k. Noises like gusts of wind were reported.
- l. Described as moderate.
- m. Trees and bushes were shaken slightly.
- n. Direction of motion was noted indoors, or without specification of location (indoors or outdoors).
- o. Pendulum clock stopped, started, or changed rates markedly.

V.
- a. Rumbling, thunderous, or subterranean sounds were reported.
- b. Hanging objects swung in numerous instances. Hanging objects or doors swung generally or considerably.
- c. Described as strong.
- d. Trees and bushes were shaken moderately.
- e. Small objects were shifted from position; light furnishings were shifted from position.

f. Pictures were knocked against the wall or swung out of position.
g. Felt by practically all. Felt by most or almost everyone.
h. Sensation similar to that of a truck striking the building was reported.
i. Animals were frightened, stampeded, or broke out of their enclosures.
j. Disturbances of poles and other tall objects were noted in some instances. Buildings swayed.
k. Vibrations similar to those caused by the passing of a light truck were reported.
l. Plaster was cracked.

VI. a. Liquids were spilled from containers.
b. Roaring sounds were reported.
c. Direction of motion was estimated by observers who were outdoors.
d. Liquids were set in strong motion.
e. Slight damage was incurred. Poor construction was sometimes specified.
f. Small bells rang (church, chapel, school, etc.). Fire and burglar alarms were activated.
g. Buildings trembled throughout.
h. Many ran outdoors.
i. Felt by all (without qualification). Felt by all in community.
j. Many were frightened. Excitement was general with some alarm.
k. Small, unstable objects were overturned.
l. Knickknacks fell.
m. Some furniture of moderately heavy kind (chairs, tables, small sofas, small dressers, etc.) were moved from position.
n. Objects were thrown from shelves and mantles. Merchandise was thrown from shelves in stores.
o. Water or gas pipes were broken in isolated instances.
p. Trees and bushes were shaken strongly.
q. All were awakened.
r. Plaster fell in small-to-moderate amounts. Chimneys were cracked.
s. Some dishes, glassware, and windows were broken.

VII. a. Free-standing and exterior masonry walls were cracked.
b. All were frightened. There was general alarm.
c. Permanent or temporary changes in flow from springs and wells were reported; changes in temperature of water from these sources were noted.
d. Well-built ordinary structures were damaged slightly to moderately.
e. Cornices, brickwork, tiles, and stones fell from exterior walls and parapets of buildings.
f. Several landslides were reported. Small quantities or rocks and boulders were shaken from hillsides and embankments in single instances.
g. Chimneys were broken. Chimneys, with ratio of height above roof to lateral dimension at roof exceeding 5, were broken sharply at roofline.

VIII. a. Free-standing walls and exterior masonry walls of buildings fell.
b. Ordinary, substantial buildings were damaged considerably.
c. Furniture was broken in some instances.
d. Furniture was overturned. This includes that described as "heavy" as well as reports without qualifying adjectives.
e. Waves were seen on surface of ground.
f. Telephones were put out of service.
g. Chimneys, monuments, factory stacks, etc., fell. Monuments were rotated on their bases.

h. Doors and shutters were opened and closed abruptly (cabinet and cupboard doors included).
i. Poorly built or badly designed structures were damaged greatly. Panel walls were thrown out of frame structures. Poorly built or badly designed structures sustained considerable damage.
j. Railroad rails were bent slightly, moderately.
k. Numerous windows were broken.
l. Everybody ran outdoors.
m. Free-standing solid stone walls were seriously cracked and broken.
