EARTHQUAKES AND HISTORIC BUILDINGS

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Earthquakes cause immense damage to cultural property. Much damage can be prevented by prior inspection and simple strengthening of weak points in the typical construction of historic buildings in each country. The strengthening can be carried out economically as part of the maintenance strategy for each building. Historic buildings should be identified and fully documented before a possible earthquake, using photogrammetry techniques if available.

After an earthquake it is essential that an architectural conservator be attached to advise the rescue organization and prevent unnecessary destruction of what cultural property remains.

This paper embodies ICCROM's experience of the Guatemala, Friuli and Montenegro earthquakes.

Earthquakes cause immense damage to cultural property. In recent years the study of earth movements and tectonics has shown that the earth's land masses are attached to plates, which move slowly over the earth's substrata of molten magma. Seismic zones, where earthquakes are frequent, occur where adjoining plates moving in different directions meet. The plates tend to lock together so that relative movement takes place only intermittently with sudden releases of stored energy causing the earth to tremor. Major tremors causing serious destruction are infrequent, but minor tremors (with smaller relative movements and energy releases) are more frequent: there are over two thousand such per year in Guatemala and these may well adversely affect the durability of historic buildings in seismic areas. At the moment the timing of earthquakes seems almost unpredictable, although due to increase in ground pressure it has been noticed that ground water levels rise in wells before an earthquake and animals show uneasiness. However, by the end of the century a warning of about one week may be possible. Study of past occurances show that a great deal of loss of life and damage to cultural property can be prevented if suitable measures are taken well in advance in seismic zones.

Seismic shocks arrive by direct primary waves, by secondary waves and surface ripples of Rayleigh waves. The resultant ground shaking causes dynamic movements in all three dimentions of a building: height, length and breadth. In considering these movements and the associated loading one must think dynamically and not in terms of normal statics. Loadings and energy input are related to the mass and stiffnesses of the building. The ability of a historic building to absorb the energy input without damage is crucial.

The total energy release or magnitude of an earthquake is measured by

seismographs or accelerometers on the Richter Scale, whilst the Modified Mercalli Scale classifies the observable effects of the ground shaking. The Richter Scale as used by seismologists is logarithmic to the base of thirty two, increments of one unit representing thirty two times the energy release, so even an increment of 0.1 represents a considerable increase in energy and in consequential damage. The Modified Mercalli Scale is based largely on the damage to existing buildings and installations, including all types of cultural property. Though, in principle, it is also an objective scale it must, in practice, be based on subjective assessments of typical damage and it is certainly less precise and correlates only approximately with the Richter Scale. This is because damage caused by an earthquake of a given magnitude depends on many things: the condition of the buildings affected (i.e. whether they have been well maintained, the quality of their workmanship and of previous earthquake repairs); their form and design; local ground conditions; and the direction and type of the seismic waves and the distance from the epicentre. It is not surprising therefore that with unfavourable ground conditions the 1977 Friuli earthquake of 6.4 Richter produced as devastating results (Modified Mercalli IX and X) as the 1976 Guatemala earthquake of 7.6 Richter, one of the most intense recorded, with over thirty two times the energy input of Friuli. The possibility of a series of earthquake shocks must also be borne in mind, for in Friuli the second major shock, following a whole series of minor tremors, caused great havoc to buildings already severly weakened.[1]

The collapse of buildings is the primary cause of loss of life, so preventive measures to strengthen historic buildings will also save life and limb.

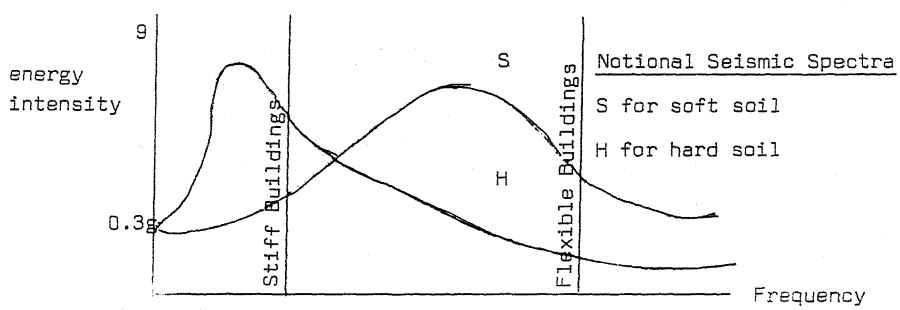
The secondary effects of earthquakes such as landslips, road fractures, bridge failures, floods and ground movement with changes of underground water levels and flow can also be devastating. Their first effect is to disrupt communications and make rescue more difficult. In addition an earthquake site is generally held in a pall of dust.

A seismicity map of the world shows by far the greatest number of recorded events round the coast of the Pacific Ocean from New Zealand, Japan, Alaska, California to Central America and the Andean range of South America. Tsunamis, or waves originating in earthquakes under the ocean are frequent and endanger costal property and dwellings. Waves as high as 20 m have been recorded and each event consists of several waves. A warning centre has been established in Hawaii. A map giving seismic risks related to density of cultural property as proposed by ICOMOS will be most valuable in drawing attention to these hazards. Such a map should show geological fault lines in as great detail as possible.

Dowrick in his most useful book "Earthquake Resistant Design"[2] lists those countries with a low, medium or high risk, the latter being Afghanistan, Albania, Argentina, Burma, Chile, China (in parts), Colombia, Costa Rica, Cyprus, Dominican Republic, Ecuador, Greece, Guatemala, Honduras, India (in parts), Indonesia (in parts), Iran, Iraq, Italy, Japan, Mexico, Nepal, New Guinea, New Zealand, Nicaragua, Panama, Peru, Philippines, Taiwan, U.S.A. (high in parts), U.S.S.R. (high in parts). The few countries considered by Dowrick to have above average codes are India, Japan, Spain and U.S.S.R. and he states all could benefit from major improvements.

The art of designing to resist earthquakes being in its infancy, all codes are still based upon gross simplifications, using subnominal horizontal loadings or base shears as the design criterion for new buildings. It is the considered opinion of experts that such codes should not be applied to historic buildings of very different structural types. It must be therefore stressed that no historic building should be condemned to destruction or taken out of beneficial use solely because it does not or cannot comply with the current official code. Many factors outside the code must be taken into consideration, starting preferably with a ground movement seismic spectrum, which can be predicted by a seismologist for a given site.

The seismic spectrum for any particular site will take local ground conditions into account, such as soil types, the slope of sedimentary soils, the existence of any bedding planes and their angle of slope, horizontal changes in soil types, the depth of soil over bedrock and the topography of bedrock including ridges and deposited soils. Water content and the level of the water table are also important for with a water table less than about 8 m depth there is a danger of soil liquefaction in an earthquake. Dowrick gives advice on the best field and laboratory tests in Tables 3.1 and 3.2, page 50.



Examination of earthquake damage shows that the direction of the waves has a considerable effect on the resistance of the building. The following is an imagined scenario of earthquake damage. First roof tiles begin to slip and fall and weak timber joints break. The roof timbers batter the walls. Then cracks form at the corners in walls and where stresses concentrate around door and window openings and in vaults and arches. The centre portion of an arch or vault may slip downwards, wedging and battering the structure apart. The roof falls in and portions of vaults and domes fall. Columns vibrate and crack and batter each other. Pinnacles and towers rotate, shift and fall down causing damage and façades split apart. The structure disintegrates into large lumps if well built and rubble if badly built. With simple vernacular buildings the front walls fall out into the street and the roofs and floors crush the occupants. From examination it can be deduced that square, circular and octagonal buildings have the most resistant forms; rectangles, particularly if long, may have differential behaviour at opposite ends, whilst projecting wings and features produce weaknesses. It is quite common to see buttresses sheared off walls.

The basic causes of damage are relative ground displacements and the inertia loads that result from ground accelerations. The factors affecting the seismic performance of a historic building are its mass, stiffnesses, periods of vibration (all of which affect the loading), damping capacity or ability to absorb energy, stability margins, structural geometry, structural continuities and distributions of mass and resistance. Historic buildings usually lack the ductility and structural continuity which can be designed into new buildings. The compatibility of the various structural elements and the availability of alternative structural actions, when some elements fail, are important considerations.

Last but not least is the general condition of the structure - has it been well maintained and carefully repaired in the past. Earthquakes seek out the hidden weaknesses in a building, so are often blamed for what was a faulty repair, bad workmanship or lack of preventive maintenance.

Structural performance of historic buildings in earthquakes.

Having examined the risk to the historic building we can now consider its resistance in general terms and available methods of improving this resistance. The resistance depends upon the form of the structure, the strength and workmanship of its construction and its material and its dynamic performance. Simple and symmetrical forms are best, not too elongated and with uniform and continuous distribution of strength.

Each historic building is a case for individual study involving a meticulous inspection of the fabric. A study of its previous repair history and preventive maintenance are the first steps, followed by such strengthening

against dynamic forces as is practicable and economic in conjunction with its overall conservation plan, which gives a reasonable approach to prolonging its life and reducing the earthquake hazard to its occupants.

Besides the effect of the direction of the shock wave, the predominant frequency of these waves and the natural frequency of the building and ground are vital questions. The stiffness of the building in relation to the properties of the subsoil should be assessed by a seismic engineer. The whole building may vibrate in a certain frequency due to its form and stiffness and if there is a dynamic resonance the structural damage will be much greater. Cracking and other disruption of the structure may accidentally increase this resonance or decrease it. In a severe earthquake badly bonded elements act like battering rams oscillating in different modes. It has been observed that a masonry building can survive a few shocks of great intensity, but that vibration of long duration is damaging.

Historic buildings are generally stiff; if they are not also very massive they will have short periods of vibration and will be safer if they are on 'long period sites', i.e. resting on soft soils of some depth. The exceptions are tall towers, spires and minarets which are relatively flexible and more affected by the longwaves which can reach up to 1000 km from an epicentre. Architectural elements such as asymetrical towers should be completely separated from the main structure by a gap of 100 mm, if possible, to avoid battering.

Prevention of earthquake damage can only be practiced within the context of the past history of the conservation of the building. In seismic zones the strengthening of valuable cultural property should be included in the general programme of preventive maintenance, as and when made economically possible in conjunction with other major building repairs such as renewal of roofs or strengthening walls and foundations.

Methods of strengthening historic buildings.

Timber structures are considered the most earthquake resistant among traditional forms, provided their joints are sound and the timber is not attacked by insects and fungi, but unfortunately it is vulnerable to fires which often follow earthquakes. Masonry structures are generally less resistant unless the masonry is reinforced. It is interesting to note that the Nabataeans reinforced the masonry of their principal temple in Petra, Jordan, now called the Qasr el Bint, with longitudinal timbers which were effective in preventing the collapse of its walls but not the roof.

Unfortunately, apart from those with timber framing, most historic buildings come in the lower grades of resistance, being stiff structures made of brittle material. Mercalli quite rightly lays great emphasis on the

quality of the workmanship of the original building and we must add the way subsequent repairs have been done. The damping effect of the structure is increased by the use of lime mortars (and avoidance of Portland Cement).

Mercalli distinguishes between four categories of structure: (Masonry A, B, C and D as used in the Modified Mercalli Scale given in Table 1)

Masonry A. Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.

Masonry B. Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.

Masonry C. Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.

Masonry D. Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

Perhaps he is unduly critical of adobe, which if mixed with long straw or tough grasses can achieve remarkably high tensile strength and toughness, but the mud mortar between the blocks may be the weakest element.

The condition of the mortar is as important, or possibly more so, than the quality of the original workmanship, for over the centuries lime mortar can deteriorate and become denatured. Repointing grouting and replacement of defective mortar are the practicable remedies, but in extreme cases reconstruction may be the only course open.

Examination of earthquake damage shows that bonding of walls together at the corners is vital, together with the tying of floors and roofs to walls. The insertion of tensile reinforcement with some degree of prestressing to bond elements together gives the masonry of historic buildings greater earthquake resistance. Experiments have shown that adobe, or mud brick, with diagonal prestressed cables anchored top and bottom has much greater resistance to dynamic forces. In existing adobe buildings reinforcement in the form of diagonal galvanized steel wires might be added under the layer of mud plaster that is normally renewed and anchored with small elements of reinforced concrete at the top and bottom.

For simple two storey masonry houses built with lime mortar, Kolaric[3] recommends reinforcement in both directions with 16 mm steel ties fixed to the floor joists and anchored with 15 x 15 plates, 5 mm thick, which are recessed into the external walls and then covered with plaster. Similar strengthening should be done at roof level where the anchoring of wall plates and tying of roof timbers together should be given special attention, as earthquake damage often starts at this point: the falling of heavy roof tiles and collapse of roof and floor timbers are perhaps one of the major

causes of loss of life, generally preceding or promoting the collapse of walls. The roof structure should incorporate diagonal ties, which can be used to strut gable walls.

A ring beam of reinforced concrete under the wall plate is an obvious improvement to the earthquake resistance of a masonry building; such a ring beam should be extended downwards with embedded columns and tied across the vaults and extended around the base of domes as has been done to reinforce the Church of La Merced in Guatemala Antiqua. Similar reinforcement has been placed in the adobe built chapel of the Convento di San Bernardo in Cusco, the columns having been inserted into vertical shafts in the centre of the wall. The mix of the reinforced concrete should have strength characteristics close to that of the masonry, so should consist of weak aggregates and mixes.

Considerable strengthening of masonry buildings can be obtained by grouting procedures of all types using hydraulic limes. In special cases the use of expensive polyester and epoxy resin grouts will be more than justified. Such grouts can be used following the normal injections, thus exploiting their penetrating power to fill fissures and fine cracks and avoiding the necessity of filling large voids with costly materials. They are specially valuable as they increase the tensile strength of masonry and consolidate friable lime mortar, which weakness was reported to be one of the principal reasons for the collapse of many historic buildings in the Montenegro earthquake of April 1979. Rough masonry walls that are plastered can be strengthened in the way suggested for mud brick or by applying wire netting onto both faces and tying the faces together at about one metre centres, then replastering.

Plaster or wattle and daub panels in timber constructions can be strengthened with galvanized expanded metal reinforcement applied to both sides and, if possible, nailed to the framing timbers if they are not exposed and such panels can also be consolidated by grouting. Cross walls and partitions must be securely attached to the main walls. Lintels over doors and windows should extend at least 40 cm beyond the opening to give extra protection. If doors and windows are so placed as to cause a weakness in a wall, long reinforced concrete ties may have to be inserted in a concealed way, so as to disperse the concentration of dynamic stress which occurs at their corners.

Tall chimneys present a hazard as they will have a different mode of vibration from the main building and are liable to collapse first, so causing damage and perhaps weakening a vital part of the structure. They should be strengthened if possible by vertical drilling and insertion of prestressed ties, or if in poor condition, by being rebuilt inserting vertical reinforcement anchored securely to the mass of the wall below.

Earthquake shocks are transmitted to the building through its foundations. If the foundations fail the results will be totally disastrous, so foundations should always be investigated. If the watertable is high the danger of soil liquefaction is much greater, so the possibility of natural drainage should be looked into when making the investigation.

If a building rests on sloping strata or variegated soils, i.e. peat and clay, special measures will be necessary, such as piling of varying depth to support the whole building on the same stratum which must be sound itself and not liable to liquefaction when an earthquake occurs. The pilecaps must be linked with horizontal beams and secured to the existing structure carefully. In other cases it may be sufficient to unify the foundations with ground beams around the perimeter.

In seismic zones archaeological sites will need special conservative action after having been excavated, unless after recording they are backfilled with earth. Archaeological monuments consisting of stone facing with earth fill are particularly vulnerable if the jointing of the stone is in poor condition. Indeed, many archaeological sites were reduced to mere rubble in the 1976 Quatemala earthquake, because they were exposed to risks that had not existed previously before being dug. Some taking down and consolidation by rebuilding may be necessary, in which case photogrammetric records and numbering of stones on an elevational grid, as done at Macchu Picchu, Peru, will be necessary.

To prevent mechanical plant from sliding, overturning and jamming during an earthquake from 20 - 40 mm clearances may be necessary. There must be flexibility in connections with pipes and wires and their fixings must be strong enough to withstand three dimensional movements. Electric mercury switches are dangerous, because vibration may activate them and heating boilers with firebrick linings are also liable to damage. Water and electric supplies to hospitals and fire fighting services need special protection and should be examined by specialists. Also sculpture and landscape ornaments will need special fixings to prevent them being thrown about during an earthquake.

Preventive action before an earthquake.

In high risk zones at least, there should be some preventive action before a possible earthquake. We have dealt with some structural possibilities of strengthening historic buildings. Fire fighting precautions rate highly also; public safety is the main concern of earthquake measures followed by minimizing the cost of any incidents. During the incident falling walls and roofs and glass breakage are the worst hazards. Where possible laminated glass should be used, especially in public buildings and museums. In addition to listing and marking all cultural property it should be fully

recorded using photogrammetry where appropriate, priority being given to property of high value in a high risk zone. Full documentation of all cultural property makes action after the emergency more certain and efficient and has proved most valuable in the Montenegro earthquake of April 15.

Emergency plans should be worked out in advance between the military and the civil authorities with the advice of conservators of cultural property. A depot or store for emergency conservation supplies should be created. Regular inspections at 5 year intervals will provide the basis for preventive maintenance, thereby reducing risks to life and property. In seismic zones museums, as the repositories of cultural property, should have a high priority for strengthening measures, especially as their conservation laboratories will be needed after a disaster.

If the building collapses around the occupants there should be a chance of rescue. Public safety is increased if there is preparedness for a disaster. Each house should have a safe place specially strengthened which can be reached quickly. Here there should be a container of water, emergency food, a torch and battery operated radio.

After an earthquake.

After an earthquake there is a great human shock. It is not this paper's role to amplify or describe this. Part of the unrecorded shock syndrome, however is to assist in the destruction of what is left, arson is common and wanton destruction of historic buildings that could have been saved is surprisingly frequent, although prior documentation could have prevented this. The confusion of the event compounds these additional dangers to cultural property. Some conservation organizations have attached Army officers whose duty is to organize security and fire fighting measures. Earthquake protection could easily be added to these duties in seismic zones. Such officers could liaise effectively with the rescue organization, which is generally in the hands of the military with field engineering units at their command.

Quick inspection of the damage is essential. Dangerous elements must be made safe. What can be saved should be shored and strutted to prevent collapse should there be further tremors as often happens. An international colour code is necessary. The following is suggested:

Red	:	demolish
Yellow	:	shore up and save
Blue	:	safe.

Architects with sound engineering judgment and wide cultural knowledge are necessary for this work. Also military engineers should receive special training for earthquake duties. Particular emphasis must be given to strutting and shoring techniques and structural first aid in earthquake situations. Often there is external difficulty and danger in making an

inspection, in such situations a mobile photogrammetric unit could be of immense assistance, as it could take measurements and produce drawings without risk to give general information. However, although technically possible, suitable equipment has yet to be developed, and this should include plant to facilitate detailed inspections.

Of course, the main effort must go into rescue, evacuation of casualties and providing temporary accommodation, but sufficient manpower and resources should also be given to emergency measures to save cultural property. The safety of working conditions will need constant monitoring. Helmets and dust masks should always be worn. If markets or cold stores are left too long, severe health hazards arise due to decomposition of perishable matter. Rats and other vermin increase and make the difficult work of cleaning much worse, so much so that gas masks and protective clothing become necessary. A similar but even more unpleasant risk occurs when it is the local custom to bury the dead in tombs above ground, for these disintegrate and scatter their decaying contents.

It is essential that an expert in architecturàl conservation is present to advise the military commander and has authority to prevent unnecessary demolition of cultural property and unthinking removal of archaeological material. He must have the authority and means to make safe historic buildings by temporary strengthening and shoring. Adjustable screwed steel Acrow struts together with salvaged timber are invaluable for quick work. Temporary roofing materials are urgently needed together with polythene sheets to protect valuable objects which cannot be moved. Works of art such as frescoes that are part of a historic building should be urgently protected against the elements and made structurally secure. Archaeologists and art historians should be invited to inspect the ruins when they are safe, as many important discoveries can be made in their fields of activity. It may be decided to leave some buildings as ruins to act as a memorial of the earthquake and a reminder that precautions are desirable.

The conservator must also have authority to organize transport of all moveable works of art and other cultural property to safe storage outside the earthquake zone. First aid can be given to frescoes by the application of surgical gauze using Paraloid B 72 as adhesive; similar treatment can be prescribed by a trained conservator for other materials. First aid to art objects will often be necessary and all organic material will need to be fumigated before storage in the depository. After fumigation, consolidation and reassembly will follow. A conservation laboratory with plenty of space, but simple equipment is an essential provision after an earthquake.

To avoid confusion a central control point must be established where all conservation volunteers can report, in order to ensure that their efforts are not frustrated. ICCROM can assist by coordinating international conservation

aid as was done in the case of the Friuli earthquake and the Florence flood.

Schools of architecture in seismic zones should be ready to send student volunteers to form a cultural property protection force, with tents and feeding arrangements.

Repairs after the emergency.

After the first phase there comes a long climb back to normality, which may last several years.

The quantum of the damage must be assessed, which means detailed inspection of all cultural property and grading of damage. The Jugoslav system used in the Montenegro earthquake has three main categories with subdivisions as follows:

USABLE - Green:
- Grade 1 - slight superficial damage virtually intact
- Grade 2 - superficial damage non structural
- Grade 3 - superficial and slight structural damage.

TEMPORARILY UNUSABLE - Orange:
- Grade 1 - structural damage, e.g. roofing and ceilings
- Grade 2 - serious structural damage to walls, etc.

UNUSABLE - Red:
- Grade 1 - severe structural damage, unsafe but capable of repair
- Grade 2 - partial collapse, e.g. roofs and floors
- Grade 3 - total collapse, requiring reconstruction of walls, etc.

The colours in outline or cross hatching or double cross hatching for the respective grades are superimposed on a large scale map, thus giving a global view of the problem.

A disaster also presents opportunities to correct defects either in town planning or historic structures. The recommendations with regard to prior strengthening should be incorporated in the repair programme as precautions against the next earthquake. At town planning level it may be the policy to up-grade dwellings or even change uses. The opportunity can also be taken to bury unsightly electrical wiring, especially if new trenches have to be dug for drainage.

A multi-disciplinary team will have to be assembled and this should consist of conservation architects, specialist engineers, archaeologists, historians, urban planners, art historians and conservator/restorers.

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(1) Schwartzbaum P., Silver C., Grissom C.: "Earthquake Damage to Works of Art in the Friuli Region of Italy", JAIC 17(1977), pp. 9 - 16.

Strongest Tremors of the 1976 Earthquake in the Friuli Region, Italy.

Trem or No	Date	Richter Magnitude
2	6 May	6.0
42	9 May	5.8
54	11 May	4.8
188	11 Sept.	5.1
189	11 Sept.	5.5
222	15 Sept.	5.8
232	15 Sept.	6.0

(2) Dowrick D.J.: "Earthquake Resistant Design" - A Manual for Engineers and Architects, John Wiley & Sons, TA 658.44.D67 624 76-26171, ISBN 0 471 99433.2, London, 1977.

(3) Kolaric M.: unpublished paper given at ICCROM in September 1977.

Table 1

MODIFIED MERCALLI INTENSITY SCALE

	grade	
Perceptible	I	Not felt except by a very few under exceptionally favourable circumstances.
Very slight	II	Felt by persons at rest, on upper floors, or favourably placed.
Slight	III	Felt indoors; hanging objects swing; vibration similar to passing of light trucks; duration may be estimated; may not be recognized as an earthquake.
Medium	IV	Hanging objects swing; vibration similar to passing of heavy trucks, or sensation of a jolt similar to a heavy ball striking the walls; standing motor cars rock; windows, dishes, and doors rattle; glasses clink and crockery clashes; in the upper ranges of IV wooden walls and frames creak.
Strong	V	Felt outdoors; direction may be estimated; sleepers wakened, liquids disturbed, some spilled; smaller unstable objects displaced or upset; doors swing, close or open; shutters and pictures move; pendulum clocks stop, start, or change rate.
Damaging	VI	Felt by all; many frightened and run outdoors; walking unsteady; windows, dishes and glassware broken; knick-knacks, books, etc. fall from shelves and pictures from walls; furniture moved or overturned; weak plaster and masonry D cracked; small bells ring (church or school); trees and bushes shaken (visibly or heard to rustle).
Serious damage	VII	Difficult to stand; noticed by drivers of motor cars; hanging objects quiver; furniture broken; damage to masonry D, including cracks; weak chimneys broken at roof line; fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments); some cracks in masonry C; waves on ponds; water turbid with mud; small slides and caving in along sand or gravel banks; large bells ring; concrete irrigation ditches damaged.
Heavy damage	VIII	Steering of motor cars affected; damage to masonry C or partial collapse; some damage to masonry B, none to masonry A; fall of stucco and some masonry walls;

		twisting and fall of chimneys, factory stacks, monuments, towers and elevated tanks; frame houses move on foundations if not bolted down; loose panel walls thrown out; decayed piling broken off; branches broken from trees; changes in flow or temperature of springs and walls; cracks in wet ground and on steep slopes.
Disastrous	IX	General panic; masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged; general damage to foundations; frame structures if not bolted shifted off foundations; frames racked; serious damage to reservoirs; underground pipes broken; conspicuous cracks in ground; in alluviated areas sand and mud ejected, earthquake fountains and sand craters appear.
Catastrophic	X	Most masonry and frame structures destroyed with their foundations; some well-built wooden structures and bridges destroyed; serious damage to dams; dikes and embankments; large landslides; water thrown on banks of canals, rivers, lakes, etc.; sand and mud shifted horizontally on beaches and flat land; rails bend slightly.
	XI	Rails bent greatly; underground pipelines completely out of service.
	XII	Damage nearly total; large rock masses displaced; lines of sight and level distorted; objects thrown into the air.