Definitions of intensity degrees

Arrangement of the scale:

a) Effects on humans
b) Effects on objects and on nature
(excluding damage to buildings, effects on ground and ground failure)
c) Damage to buildings

Introductory remark:
The single intensity degrees can include the effects of shaking of the respective lower intensity degree(s), also when these effects are not mentioned explicitly

I. Not felt
a) Not felt even under the most favourable circumstances.
b) No effect.
c) No damage.

II. Scarcely felt
a) The tremor is felt only by a very few (less than 1%) individuals at rest and in a specially receptive position indoors.
b) No effect.
c) No damage.

III. Weak
a) The earthquake is felt indoors by a few. People at rest feel a swaying or light trembling.
b) Hanging objects swing slightly.
c) No damage.

IV. Largely observed
a) The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair etc.
b) China, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.
c) No damage.

V. Strong
a) The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture.
b) Hanging objects swing considerably. China and glasses clatter together. Small, top-heavy and/or precariously supported objects may be shifted or fall down. Doors and windows swing open or shut. In a few cases window panes break. Liquids oscillate and may spill from well-filled containers. Animals indoors may become uneasy.
c) Damage of grade 1 to a few buildings.

VI. Slightly damaging
a) Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.
b) Small objects of ordinary stability may fall and furniture may be shifted. In few in-stances dishes and glassware may break. Farm animals (even outdoors) may be frightened.
c) Damage of grade 1 is sustained by many buildings; a few suffer damage of grade 2.

VII. Damaging
a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.
b) Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.
c) Many buildings of vulnerability class B and a few of class C suffer damage of grade 2. Many buildings of class A and a few of class B suffer damage of grade 3; a few buildings of class A suffer damage of grade 4. Damage is particularly noticeable in the upper parts of buildings.

VIII. Heavily damaging
a) Many people find it difficult to stand, even outdoors.
b) Furniture may be overturned. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.
c) Many buildings of vulnerability class C suffer damage of grade 2. Many buildings of class B and a few of class C suffer damage of grade 3. Many buildings of class A and a few of class B suffer damage of grade 4; a few buildings of class A suffer damage of grade 5.
A few buildings of class D suffer damage of grade 2.

IX. Destructive
a) General panic. People may be forcibly thrown to the ground.
b) Many monuments and columns fall or are twisted. Waves are seen on soft ground.
c) Many buildings of vulnerability class C suffer damage of grade 3. Many buildings of class B and a few of class C suffer damage of grade 4. Many buildings of class A and a few of class B suffer damage of grade 5.
Many buildings of class D suffer damage of grade 2, a few suffer grade 3. A few buildings of class E suffer damage of grade 2.

X. Very destructive

c) any buildings of vulnerability class C suffer damage of grade 4. Many buildings of class B and a few of class C suffer damage of grade 5, as do most buildings of class A.
Many buildings of class D suffer damage of grade 3. a few suffer grade 4. Many buildings of class E suffer damage of grade 2; a few suffer grade 3. A few buildings of class F suffer damage of grade 2.

XI. Devastating

c) Most buildings of vulnerability class C suffer damage of grade 4. Most buildings of class B and many of class C suffer damage of grade 5.
Many buildings of class D suffer damage of grade 4; a few suffer grade 5. Many buildings of class E suffer damage of grade 3; a few suffer grade 4. Many buildings of class F suffer damage of grade 2, a few suffer grade 3.

XII. Completely devastating

c) Practically all structures above and below ground are destroyed.

Note:

Vulnerability classes A-F are intended to represent approximately linear decreases in vulnerability as a result of improved earthquake resistance or level of antiseismic design (ASD). Because of the up to now limited knowledge and experience on the the systematics of earthquake damage patterns of engineered buildings vulnerability table has to be regarded as a compromise solution. The tentative character of definitions has been indicatad by italics within classification of intensity degrees for buildings of vulnerability classes D-F

The full version of the EMS-92 of the EMS-92 contains moreover an extensive Guide to the Use of the Intensity Scale. The recommendations given there should urgently be applied to ensure a proper intensity assignment. Additionally, the full EMS-92 includes several Annexes: Annexe A gives examples illustrating classifications of vulnerability and damage used in the scale; Annexe B provides basic ideas about the implementation of engineered structures incorporating a certain level of antiseismic design (ASD).

Topic 6.2 : Intensity and Seismogeological Effects

The effects of earthquakes on the ground, here summed up as "seismogeological" effects, have often been included in intensity scales but are in practice quite hard to use to advantage. This is because these phenomena are complex, and are often influenced by various factors such as inherent slope instability, level of water table, etc, which may not be readily apparent to the observer. The result is that most of these effects can be seen at a wide range of intensities or that they may have little correspondence with intensity. Therefore, these diagnostics have been deleted from that part of the scale which is now referred to as the core scale (Topic 6.1). They are presented within Annex C of EMS-92 and summarized in Table 6.2.

For each effect, three different signatures are drawn to show:

1. Lines - the possible observation range;
2. Open circles - the range of intensities that are typical for this effect;
3. Full dots - the range of intensities for which this effect is most usefully used as a diagnostic.

These lines are terminated in arrows to show a potential for extreme observations even beyond the limits shown in exceptional cases, different geological settings, or special sensitivity. For some effects, not all three categories are plotted where there is thought to be inadequate experience to formulate an opinion. It should be remembered that for most of these effects, the severity of the observation will increase with higher intensity. Care must be taken, especially when dealing with ground breaks, to discriminate between geotechnical observations, ie those caused by shaking, and neotectonic observations, ie those caused directly by fault rupture.
The effects listed in the table are grouped in four categories: hydrological, slope failure, horizontal ground processes and convergent processes (complex cases). This latter group covers instances where more than one type of process is involved in producing the effect. It will be noted that landslides appear both as slope failure effects and convergent processes effects. This is because some landslides are straightforwardly the result of shaking dislodging rocks, whereas others only occur because slope instability is compounded with certain hydrological conditions. Discriminating between these may not be easy; this is an illustration of the problems that arise in dealing with this sort of effect.

seismogeological effects, landslides, rockfalls, liquefaction.

Table 6.2: Relation of Seismogeological Effects to Intensity Degrees.

Seismogeological and hydrological effects	Intensities 1	2	3	4	5	6	7	8	9	10	11	12
Hydrological effects												
level of well water - minor changes [1]	●	●	○	○	○	○	- -	- -	- -	→		
level of well water - substantial changes [2]						●	●	●	- -	- -	→	
long period waves on standing water [3]	—	—	—	— -	- -	- -	→					
waves on standing water from local shaking						●	●	●	- -	→		
lake water made turbid [4]		←	—	—	—	—	○	○	○	—	—	—
flow of springs affected [5]				←	○	●	●	—	—	—	—	—
springs stop and start						←	●	●	●	—	—	—
water thrown from lakes										←	—	—
Slope failure effects												
scree slopes move					←	●	●	—	—	—	—	—
small landslips [6]					●	●	●	—	—	—	—	—
minor rockfalls [7]					←	●	●	○	—	—	—	—
landslides, massive rockfalls							●	●	●	●	●	●
Horizontal ground processes [8]												
minor cracks in ground					←	●	●	●				
large fissures in ground								●	●	●	●	●
Convergent processes / complex cases												
landslides (hydrological) [9]					●	●	●	●	●	●	●	●
liquefaction [10]							← -	●	●	●	●	●

Legend: ●—● most useful range as intensity diagnostic; ○ intensities also typical for this effect; —— - - possible observation range; ——→ potential for extreme observations beyond the given limits

Notes to the Table on Seismogeological Effects

[1]) detected by automatic instruments only
[2]) easily observed changes
[3]) resulting from distant earthquakes; possibly with wave-induced turbidity
[4]) from disturbance of bottom sediments
[5]) rate changes or spring water made turbid
[6]) in loose material in natural (river banks etc.) or man-made (road cuttings) sites
[7]) minor rockfalls in natural (cliffs) or man-made (rock cuttings, quarries) sites
[8]) these two categories blur into one another. The warning is repeated
about not confusing ground rupture breaks with fissures caused by shaking.
[9]) Landslides with predominant hydrological causes (may be delayed effects)
[10]) Liquefaction (e.g. sand craters, mounds formed, etc.)

Topic 6.3 : Earthquake magnitude

The earthquake magnitude is a logarithmic measure of the amount of energy released by an earthquake, estimated from the amplitude of the seismic waves it produces. It was introduced by C. F. Richter in 1935 to rank the 'size' of shallow earthquakes in California. It has come to have very widespread usage, and has been developed to several definitions using different types of waves.

Definition of Magnitude

C.F. Richter (1935) defined the magnitude as the logarithm to the base 10 of the largest trace amplitude measured in microns (.001 mm) on the record made by the standard Wood-Anderson seismograph at a distance of 100 km from the epicenter of the earthquake. Thus, a reference earthquake would write a trace of one micron at a distance of 100 km. An earthquake producing a trace of 1 mm at 100 km distance would be assigned a magnitude to 3.

Magnitude is a parameter of an earthquake, denoting its size, and determined by recorded ground motion amplitude. It is dependent on the amount of energy released at focus and is independent of the place of observation. It is quite distinct from the intensity of an earthquake which depends upon three parameters:

1. The amount of energy released at the focus;
2. The distance of focus from the place of observation;
3. The nature of the intervening ground.

Magnitudes are determined from the logarithm of ground displacement or velocity, added by a term describing the further distance which account for geomtric spreading and attenuation.

There exist different empirical magnitude formulae for different seismic waves and for different distance ranges. Fig. 6.3 (Bolt; 1978) illustrates the procedure of calculating the Richter local magnitude ML. Other types of magnitude being used are: the body wave magnitude m_b, the surface wave magnitude M_S, moment magnitude *M* and the macroseismic magnitude M_m ($M_m = M_S$).

Practical limits to magnitude

The magnitude defined by C.F. Richter provides no upper limit to the value that can be assigned to earthquakes. A zero magnitude earthquake is finite size earthquake, which will write an one micron record on a standard Wood-Anderson seismograph (W. A.) at a distance of 100 km.

Earthquakes which would not be recorded by W.A. at 100 km would thus be assigned negative values of magnitude However, earthquakes whose amplitudes would be comparable to the noise at the quietest sites, magnitude approximating to -3, would be the smallest to be recorded. In the past, the largest earthquakes recorded on the globe have not exceeded magnitude 9. In spite of the magnitude scale being by definition open-ended, there is a practical lower limit as well as upper boundary; for the smallest recordable M = -3 and for the largest ones M = 9, respectively.

Magnitude-intensity relation

Earthquakes with one and the same magnitude but in different depths have differing epicentral intensities connected with a different distance-varying intensity gradient. With known focal depth h the parameters magnitude and maximum intensity at or near the epicentre can be related. One of the proposed empirical relations is that by Karnik (1969):

$$M_m = 0,5\ I_{max} + \log h + 0,35 \qquad h \text{ in km}$$

Note:

An increase by 1 magnitude unit is equivalent to a factor of 10 in ground displacement or a factor of 30 in energy. It has to be stressed that many factors have to be considered for a proper use of magnitudes.

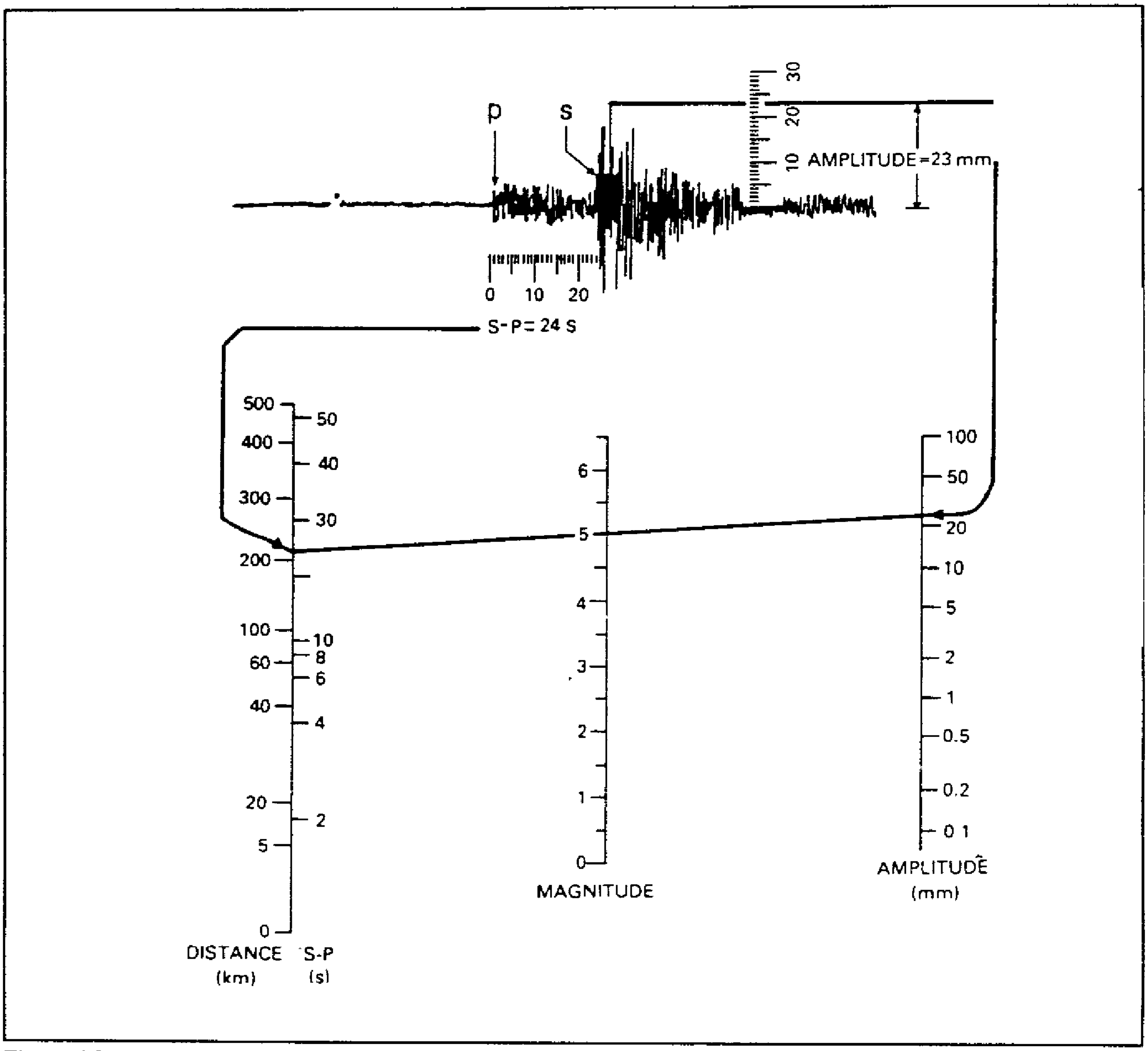


Figure 6.3 Illustration of the procedure for calculating the Richter local magnitude ML (after Bolt 1978).

? a. The effects of earthquakes can be measured with two methods Explain the two methods. What are the measurement instruments ?

magnitude, magnitude-intensity relation, Wood-Anderson seismograph.

SESSION 7: IMPACT ON BUILDINGS

Topic 7.1 : Behaviour of buildings during earthquakes

Over recent years, engineers and architects have learned that certain building types are particularly vulnerable to seismic forces and that certain building designs offer improved resistance. Whether a structure will emerge without damage or whether damage will be slight or severe depends on the behaviour of the building during strong ground shaking. The behavior of a building structure can be evaluated on the basis of its dynamic characteristics and the predominant parameters: mass, stiffness and damping.

Behaviour of a simple single-storey frame

The behaviour of a single-storey frame is easiest to understand because it represents a good approximation to the simplest dynamic system, the single-degree-of-freedom oscillator (SDOF-system). A simple frame abstraction in one plane is given in Fig. 7.1-1.

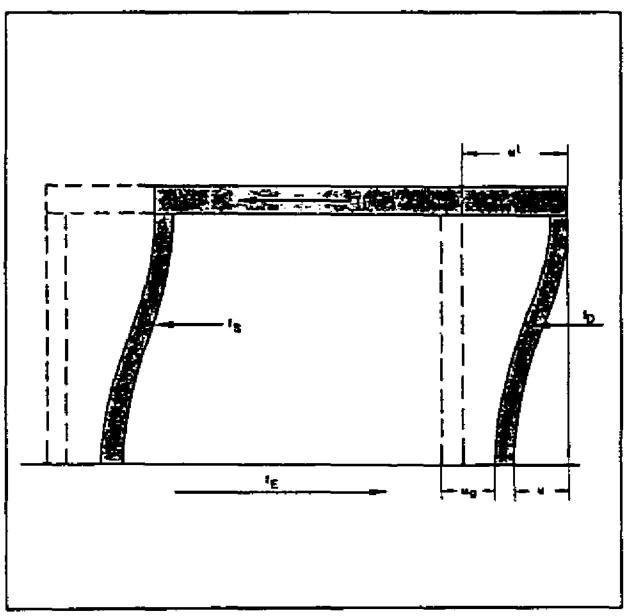


Figure 7.1-1 Idealized single storey frame on one plan. The earthquake force f_E is balanced by inertia force f_I, elastic restoring force f_S, and damping force f_D.

The mass of the entire dynamic system is assumed to be concentrated in the floor slab, the columns account for the stiffness (elasticity) and damping. The resistance to damage causing deformation is provided by the two columns which are interconnected by a beam and/or floor slab. Obviously a wall of strong elements which fills the frame can greatly reduce the amount of deflection and therefore of damage. It is clear that the behaviour of the structure is influenced by the stiffness ratio between beam and columns and by the rigidity of joints.

The total displacement of the frame is determined by the ground displacement which is independent of the structure and the relative displacement contribution which is strongly dependent on the response of the structure to incident seismic waves. Buildings, their components and interiors are shaken during earthquakes by ground motion. The forces which occur in a building come from the inertia of its mass. The inertia forces acting on any mass can be described by the formula $F = m\ddot{u}_g$, where $\ddot{u}_g = a =$ acceleration effectively acting on the mass (Fig. 7.1-1).

A further simplification of the frame in Fig. 7.1-1 leads to a lumped mass resonator (single-degree-of-freedom (SDOF) system) with stiffness (spring constant) k and top mass m (Fig. 7.1-2). The frequency f and the natural fundamental period T of the undamped system can be estimated by formulae (7.1):

$$f = 1/T = 1/(2\pi)\ \sqrt{k/m} \quad (7.1)$$

Two types of systems can be distinguished: stiff oscillators and soft ones (Fig. 7.1-2).

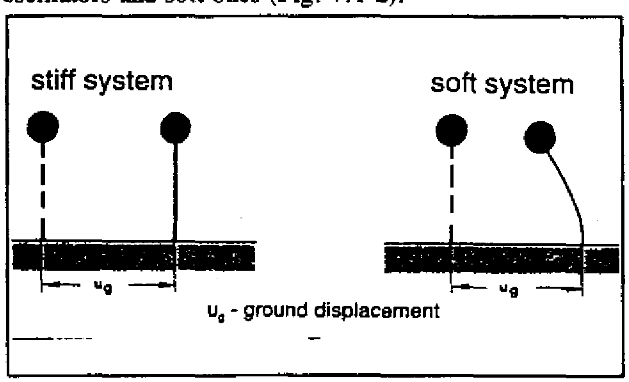


Figure 7.1-2 Types of single-degree-of-freedom systems.

The stiff SDOF resonator would have a high natural frequency f (low natural period T) and would practically only move with ground motion (displacement u_g). With respect to the frame model in Fig. 7.1-1 it can be assumed that columns carrying the mass would be deformed very little, but the forces could, however, be very high.

The soft or flexible system would have low frequency f (high period T) and deform to a large extent. With respect to the frame model in Fig. 7.1-1 it can be expected that in the case of brittle infill walls the deflection relative to the rigid base would probably result in serious damage of columns or infill. Furthermore, slab or beams can loose anchorage and fall down.

Behaviour of simple multi-storey frames
Contrary to the simple lumped mass frame model, the behaviour of a real building depends not only on mass and stiffness but also on their distribution in the building.
The building is not only vibrating to its fundamental period, it can also oscillate in higher modes depending on the number of storeys or its height. Fig. 7.1-3 illustrates typical free vibration forms of an idealized three-storey structure. The response histories of displacement indicate that there is no damping.The response of a building can be understood as a superposition of all vibration modes because buildings do not shake in one mode only. Although the fundamental period of a building is the decisive one, damage is most severe in the upper storeys of conventional buildings with uniform characteristics over its entire height.

It is important to note that the response of the building strongly depends on the resonance between the dominant ground motion frequencies and the natural frequencies of the building.

Behaviour of buildings dependent on subsoil conditions and ground motion

With the help of simple empirical rules by formulae like:

T = 0,5...1,0 n; for frame structures;(n-number of storeys).

or

T = 0,09H/√B; for wall structures, (H-height; B-dimension of the building in the direction of seismic action);

Resonance conditions between predominant frequencies of building, foundation material and ground motion can be estimated. When a seismic wave matches a structure's natural period, the building (and possibly the ground) enters into a resonance mode, amplifying the shaking with catastrophic results. The extent of damage to a buildingdepends as much on its strength and the type of soil supporting it as on the intensity of earthquake ground-motion and resonance. Resonance appears to constitute a major problem. When the predominant

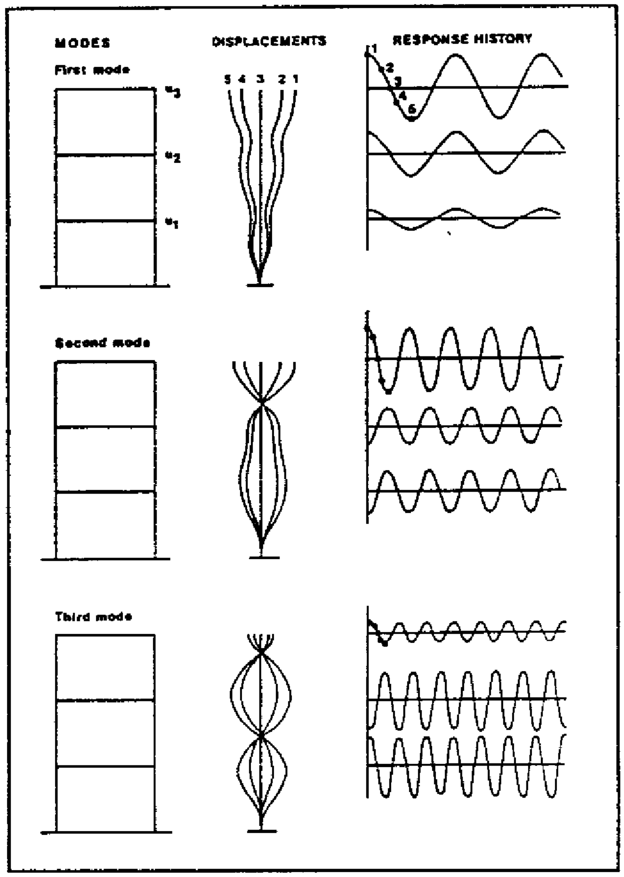


Figure 7.1-3 Free vibration of an idealized three-storey structure in the fundamental, second and third mode.

frequency of a strong earthquake enters into resonance with soils and/or buildings that have the corresponding natural period, the amplitude of shaking increases dramatically. Arguments have been put forward in favor of flexible (or ductile) buildings that have sufficiently long natural periods to fall in the less amplified low frequency range of ground motion. While those buildings may suffer comparatively less structural damage, the cost of repairing damage to internal, nonstructural elements such as partitions, ducts etc., is often greater than the cost of replacing the building. The strongest argument is for inherently stiff structures with an even distribution of forces and a degree of ductility.

Recommendations:
1. Build tall buildings on rock or well compacted soils whose natural period is significantly shorter than that of the building;
2. Build low-rise, short natural-period buildings on relatively loose soils

Damage contributing factors
When designing a building one should consider the essential factors contributing to damage or to an increase of damage. When assessing intensity using non-engineered structures and modern engineered structures, these factors

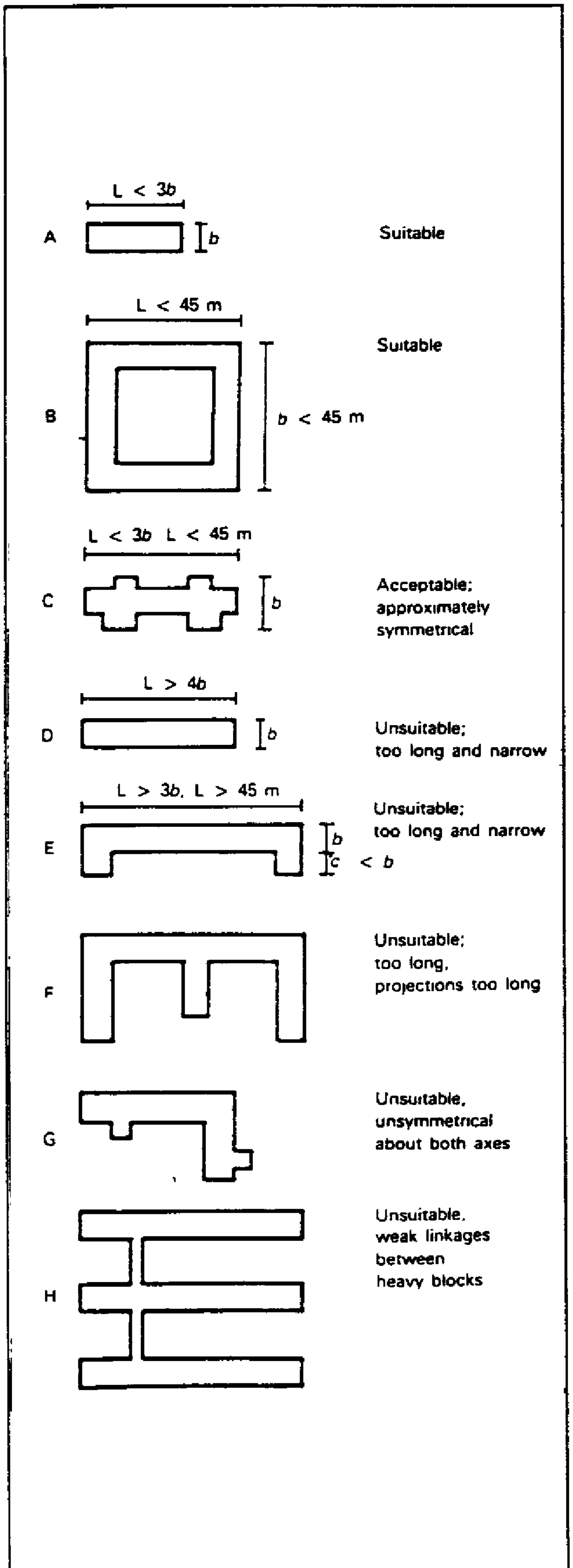


Figure 7.1-4 Suitability of typical school building plans.

have to be taken into account. Otherwise, a misleading interpretation of the real situation can occur resulting in an overestimation of the intensity of ground shaking. The most important damage contributing factors are the resonance conditions between the building and the ground motion, the building configuration (regularity) of the building, the quality of materials and workmanship.

Building configuration

An important feature is the regularity and symmetry in the overall shape of a building. A box-shaped building is inherently stronger than L-shaped or U-shaped or building with wings. An irregularly-shaped building will twist as it shakes thus increasing the damage.

Fig. 7.1-4 shows different types of school building plans. Two of these plans, "A" and "B" (with restrictions) are perfect since they are symmetrical along both their axes. With respect to "B" the building should be separated into rectangular parts by joints or weak connections. "C" approaches symmetry and is tolerable. Plans "D" and "E" are too long and narrow; plan "F" has excessively long projections while plan "G" is unsymmetrical along both axes, and plan "H" has weak linkages between strong wings. Plans "D" to "F are not suitable.

More generalized quantifications of the influence of irregularity and asymmetry on damage in relation to floor plans, elevations and internal features of buildings are given in Figures 7.1-5, 7.1-6 and 7.1-7 respectively (after Tiedemann 1993).

Construction quality

In many instances, failure of buildings in earthquakes has been attributed to poor quality of construction, poor workmanship and improper and inadequate detailing.

Stiffness and strength

The stiffness of a building should be distributed uniformly. Changes in the structural continuity from one floor to the next will increase vulnerability. Best results are obtained when columns and shear walls run continuously from foundation to roof. Vertical elements (columns, walls) should be made stronger than horizontal ones (beams, slabs). However, very strong vertical elements with weak horizontal forms also have problems. Stiffness of the structure is necessary to limit deformations and damage to nonstructural elements. The orientational sensitivity of buildings with different dimensions and stiffness in the perpendicular axis of ground plane should be considered concerning regularity and building configuration (Figs. 7.1-4, 7.1-5).

Ductility

Ductility is the ability of a building to dissipate seismic energy and to react (deform) in the post-elastic range without collapsing. The ductility of a construction depends partially on the building materials and details. If buildings have ductility the vulnerability is decreased. The opposite condition of ductility is called brittleness. Brittle materials crack under load; some examples are adobe, brick and concrete blocks.

Separation of buildings

Adjoining buildings and building sections of different characteristics in plan and elevation may interact to cause damage, which is called hammering or mutual pounding. These effects should be avoided by stipulating minimum distances between buildings or by an expansion joint running through the entire structure.

Foundations

Certain types of foundations are more vulnerable to earthquakes than others. For example, isolated footings of columns are likely to be subjected to differential settlement,particularly where the supporting ground is soft or consists of different soil types. Mixed foundations within the same building may also lead to damage due to differential settlement.

Liquefaction

In the case of loose and sandy soil as well as a high water table, the soil loses much of its shear strength when it is shaken. Under severe conditions it can lose its strength and behave as a viscous fluid. This is called liquefaction. In general soft, weak soils should be avoided. (If such sites have to be used, field investigations and laboratory testing should be carried out to determine the ideal type of foundation)

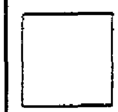
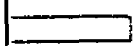
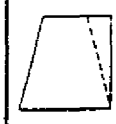
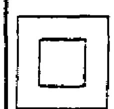
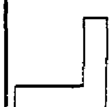
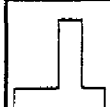
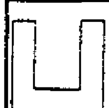
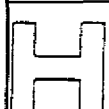
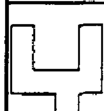
Floor Plan	Remarks
	Symmetrical lay out. If no other aggravating factors are found the risk belongs to the best category.
	Although this building is by itself regular, the non-uniform arrival of earthquake energy can lead to problems in long buildings.
	Buildings with angles different from rectangular ones are sometimes found at street corners. Such plans invite torsional shaking.
	Buildings with a yard in the center or a patio may increase damage probability if differential shaking between the limbs may cause dangerous distortions in the corner sections.
	L-type floor plan with an enhanced risk of damage in the corner region.
	T-type plan with increased damage probability at both sides of the intersection
	U-type plan which leads to an enhanced exposure in both corners.
	H-type plan with higher damage probability in the corner regions.
	Complex floor plan. The more wings are interconnected to a «back-bone» building the more likely becomes damage in general and at places of intersection.

Figure 7.1-5 Generalized quantification of the influence of irregularity and asymmetry on damage in relation to floor plans.

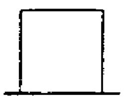
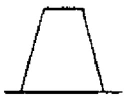
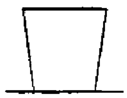
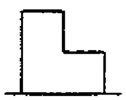
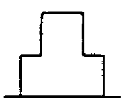
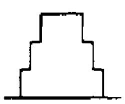
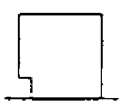
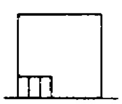
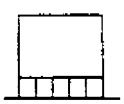
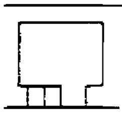
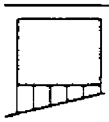
Elevation	Remarks
	Both views are absolutely regular and symmetrical. If this holds for the entire building's structure and important non-structural parts, and foundations the risk is best.
	Building in the shape of a pyramid for one or both elevations. If symmetry is observed in all other aspects, risk is similar to 1.1, ore even slightly better.
	Inverted pyramid, sometimes with vertical walls for the ground floor. This structure is top-heavy and therefore not the best risk.
	L-shaped elevation which results in an elevation of exposure in the transition zone, particularly where the lower section is attached.
	Building of the shape of an inverted T. Enhanced exposure at the regions where the lower parts meet the tower.
	Building with several setbacks leading to transitions of masses, stiffness, and damping at various floors and higher exposure there.
	Upper floor protruding. Frequent in rainy tropical regions for commercial buildings to cover part of the footwalk. Depending on relative importance of upper section risk may be increased quite substantially
	Soft first floor on one side, more stiff on other one where walls fill space between columns. Depending on amount of irregularity this design can be dangerous.
	Mostly free-standing columns on ground floor resulting in soft storey there and stiff, top-heavy structure on top. Dangerous design Very dangerous in case of resonance.
	Free standing columns on one side, protruding upper storeys on other one. Considerable asymmetry results in substantial exposure. Dangerous to very dangerous design.
	Building on sloping ground. Considerable asymmetry results high risk of collapse.

Figure 7.1-6 Generalized quantification of the influence of irregularity and asymmetry on damage in relation to elevations.

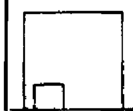
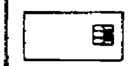
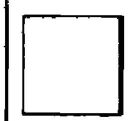
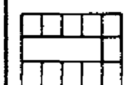
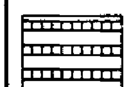
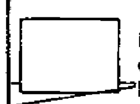
Internal properties	Remarks
	Asymmetric opening in shear wall. This is a simple case of irregularities which may be introduced into shear walls by size and arrangement of openings.
	Asymmetric arrangement of staircase and elevator well with enhanced stiffness of one side. If this structure would be attached to the outside of the building asymmetry would be even more pronounced.
	Shear wall or retaining wall on one side makes building much stiffer there introducing torsional loads.
	Different spans or irregular arrangement of substantial internal walls renders building irregular. If the hall assumed here in second floor would be large this could produce a soft storey.
	If continuous window-bands interrupt fill-in walls and produce short column effect, damage probability is substantial
	Substantial transitions in stiffness leads to increased demage probability.
	If columns are offset producing a cantilever action on beams vertical accelerations and overturning moments enhance the probability of serious damage.
	In the case shown here the right side of the basement sits on hard ground whereas the left one is supported by soft material (piles there to hard strata could represent 1.11).

Figure 7.1-7 Generalized quantification of the influence of irregularity and asymmetry on damage in relation to internal features.

vibration period, natural frequency, resonance of buildings, regularity, rigidity, strength, ductility, damage.

Topic 7.2 : Vulnerability of building types in earthquake-prone areas

The correlation between damage and severity of ground shaking (macroseismic intensity) is clearly illustrated in Fig. 7.2-1. The low resistance of adobe, stone masonry and unreinforced brick masonry buildings to earthquakes becomes evident. Also Fig 7.2-2 clearly indicates that wood and steel constructions generally have the best earthquake resistance.

With respect to earthquake resistance building types can be classified into non-engineered (traditional) and engineered (modern) structures. Among these different types of structures, those incorporating a certain level of antiseismic design have the lowest vulnerability. The description and classification of engineered buildings can be based on different qualitative parameters. In seismic codes engineered buildings are subdivided according to:

1. Their main (primary) structural system (frame, wall, core or dual systems)
2. Their structural material (steel, reinforced concrete, wooden or masonry) or
3. A combination of both (structural system and structural material).

Locations of damage and damage patterns are different for engineered and non-engineered structures. Therefore, one should carefully distinguish between:

1. Damage to the primary (load-bearing and structural) system;
2. Damage to secondary (non-structural) elements (like infills, curtain walls);
3. Damage in special plastification zones (coupling beams in wall structures, joints in buildings of prefabricated wall elements or beams in joints of frame structures).

Lessons from past earthquakes can be summarized for widespread non-engineered (traditional) buildings as follows:

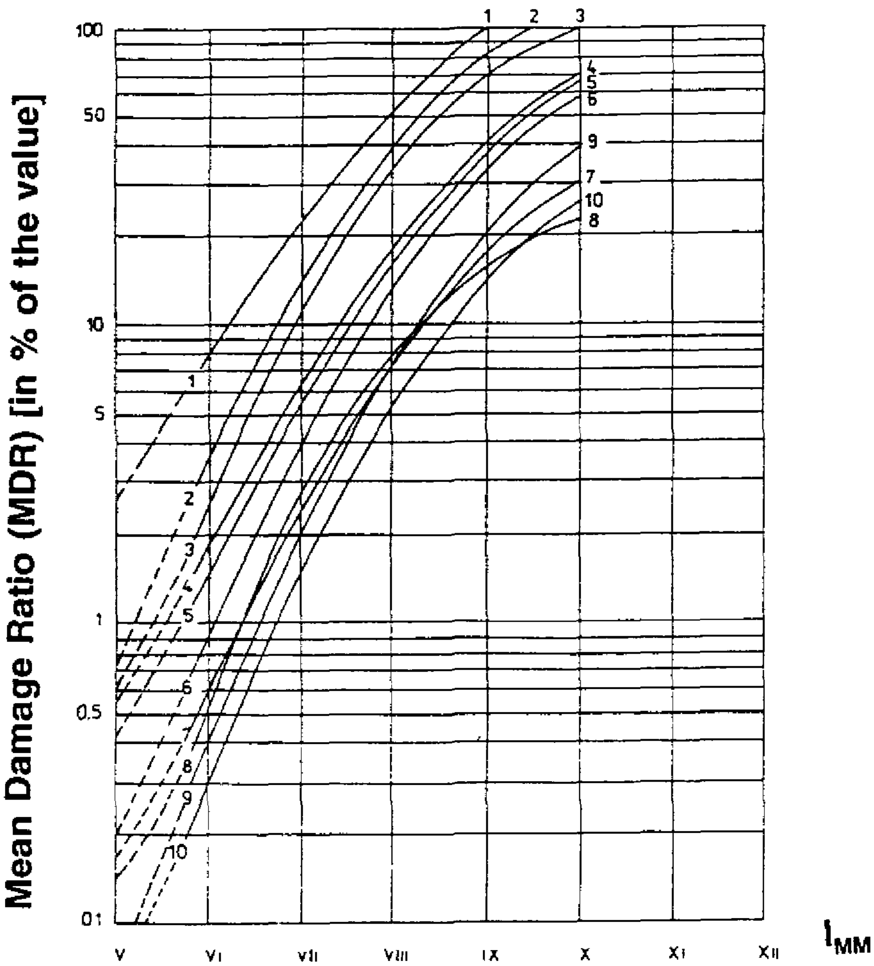
Adobe buildings
Adobe buildings are usually low, massive and brittle and very vulnerable to ground shaking. Their natural period is short and they usually suffer a great degree of damage on firm, well compacted ground where the higher frequency content of earthquakes is amplified. Conversely, where adobe buildings are built on soft soils, the strong low frequency content of ground shaking filters through, thus reducing adobe vulnerability.

Masonry buildings
Random rubble and half-dressed stone buildings suffer extensive damage or complete collapse during many earthquakes. The main reasons and ways in which such buildings are damaged are:

1. Separation of walls at corners or T-junctions;
2. De-lamination and bulging of walls;
3. Collapse of bulged walls;
4. Outward overturning of stone walls after separation at corners;
5. Big openings in walls
6. Lack of bracing walls or binding belts.

In general, openings in the walls of a masonry building tend to weaken the walls and provide zones of damage concentration. The fewer and the smaller the openings the less vulnerable the building will be during an earthquake. Openings should be not placed very near to corners or junctions of walls.

Wooden buildings
Wood has a high strength per unit weight and is therefore very suitable for earthquake resistant construction. However, heavy cladding walls impose high lateral load on the frame. Although seismically suitable, the use of timber is declining in construction. In many cases the destruction of wooden buildings during earthquakes has been due to fires.



Types of structures (buildings):

1 Adobe
2 Unreinforced masonry, non-seismic design
3 Reinforced concrete frames, non-seismic design
4 Steel frames, non-seismic design
5 Reinforced masonry, non-seismic design (medium quality)
6 Reinforced concrete frames, seismic design
7 Shear wall structures, seismic design
8 Wooden structures, seismic design
9 Steel frames, seismic design
10 Reinforced masonry, seismic design (high quality)

Figure 7.2-1 Vulnerability of different building types under earthquake conditions (mean damage ratio of buildings; after Shah and Sauter, 1978). Curves refer to mean values of entire portfolios, i.e. the damage of an individual building can fluctuate over a wide range for a specific intensity. Other factors (regularity of building, material, subsoil conditions, executives quality) are of significant influence.

Simplified description of structural types	*Relative damageability in order of increasing susceptibility to damage*
Small wood-frame structures, i.e., dwellings not over 3,000 sq. ft., and not over 3 storeys	1
Single or multi-storey steel-frame buildings with concrete exterior walls, concrete floors, and concrete roof. Moderate wall openings	1.5
Single or multi-storey reinforced concrete buildings with concrete exterior walls, concrete floors, and concrete roof. Moderate wall openings	2
Large area wood-frame buildings and other wood-frame buildings	3 to 4
Single or multi-storey steel-frame buildings with unreinforced masonry exterior wall panels; concrete floors and concrete roof	4
Single or multi-storey reinforced concrete frame buildings with unreinforced masonry exterior wall panels, concrete floors and concrete roof	5
Reinforced concrete bearing walls with supported floors and roof of any materials (usually wood)	5
Buildings with unreinforced brick masonry having sandlime mortar; and with supported floors and roof of any materials (usually wood)	7 up
Bearing walls of unreinforced adobe, unreinforced hollow concrete block, or unreinforced hollow clay tile	Collapse hazard in moderate shocks

NOTE: This table is not complete. Additional considerations would include parapets, building interiors, utilities, building orientation, and frequency response (Armstrong, 1973, p. 167).

Table 7.2-2 Earthquake ratings for common building types.

earthquake vulnerability, mean damage ratio, building type, adobe, masonry, reinforced concrete, steel.

Topic 7.3 : Infrastructures in earthquake-prone areas

Roads

Earthquake damage is likely to occur at active faults through ground motion, liquefaction and other types of ground failure. The most vulnerable elements of the road network are underpasses and overpasses, bridges, viaducts and tunnels, and mountain roads. In the presence of ground failures, most structures are exposed to virtually total loss, unless there is considerable investment in subsoil engineering. Otherwise, the determining factor is the ability of a structure to resist ground shaking.

Bridges

An important feature in the vulnerability of bridges is the extent to which a bridge is secured against lateral slide. Bridges are often not designed to resist lateral forces. Therefore lateral forces, caused by earthquake ground shaking, are likely to cause collapse of these bridges.

Railways

Railways networks have high vulnerability in earthquakes. Bridges and tunnels are likely to be damaged by an earthquake and small displacements of the rails can occur. Faults and ground failure will certainly have their effect.

Water supply systems

The vulnerability of centralized water-supply systems in earthquakes differs according to each component of the system. The vulnerability of pipelines depends on the flexibility of the pipes and the joints. Fig. 7.3-1. Installations for water treatment and transport have high vulnerability unless special earthquake resistant designs are incorporated. Water towers may form an essential link in the water supply chain. These structures are highly vulnerable due to their heavy load and high construction. Water treatment plants and distribution equipment (such as valve systems) are also vulnerable.

Underground pipelines in general

Flexible pipes: a high flexibility of the pipes may prevent breakdown in an earthquake. Differential settlement can be compensated for and ground displacement will not immediately lead to a breakdown.

Flexible joints: the use of flexible joints between the pipes will also help to improve earthquake performance. These joints help to compensate ground displacements.

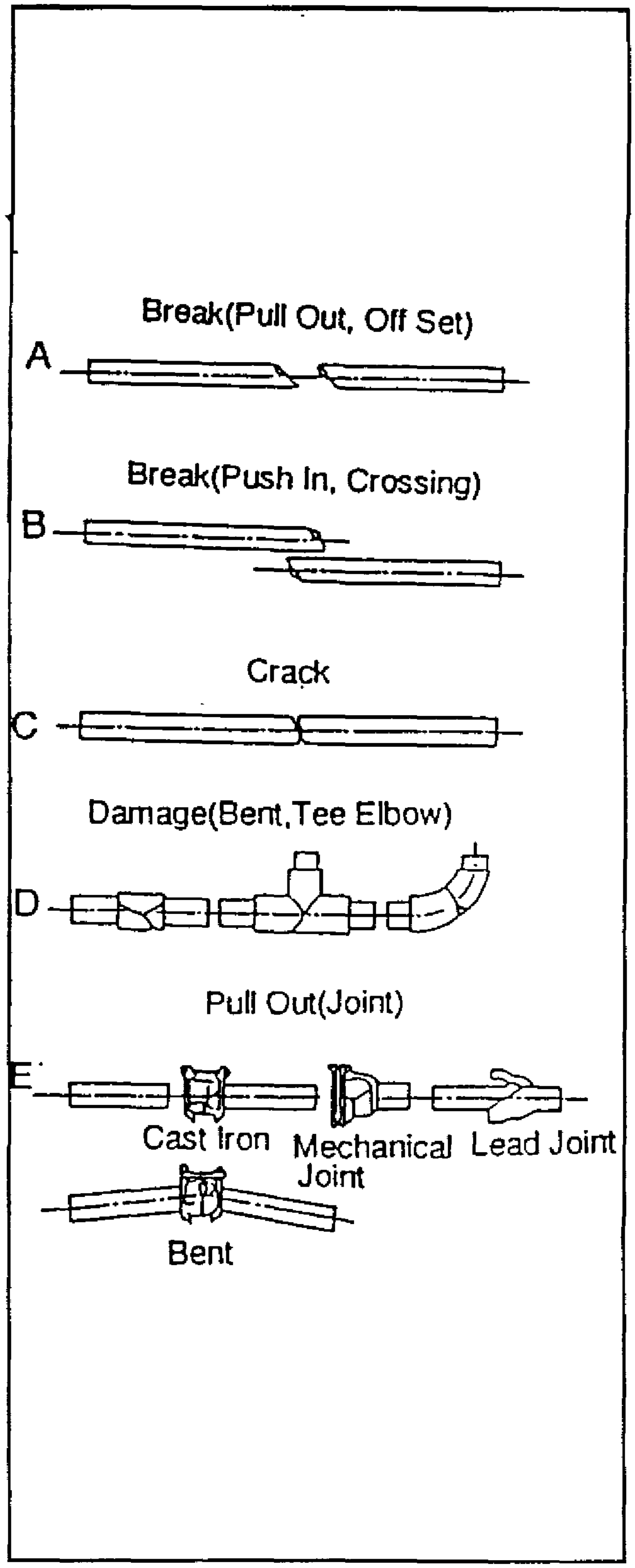


Figure 7.3-1 Failure Models of Buried Pipelines.

Infrastructures, roads, bridges, railways, water supply systems, pipelines.