the uncertainties regarding the casualties resulting therefrom are dealt with more specifically elsewhere in this report.

Number of Casualties

Everybody who has tried to obtain precise information on casualties will have found the task in general very difficult and often impossible. Damaging earthquakes are exciting events and this may be one of the reasons that the number of casualties is often exaggerated, in particular by the popular press. But even "official" figures may be wrong, and for a number of reasons. The author has therefore tried to introduce as many cross-ckecks as possible, such as consulting different sources and persons known to be reliable and not given to exaggerations, correlating these figures with the number of collapsed and partly collapsed buildings, and allowing for the average number of persons per building and room, etc.

If casualties have been caused by different "agents" such as the failure of buildings, fire, tsunami, cold weather, and in the case of historic earthquakes disease, epidemics, and starvation, the result becomes even more uncertain, in particular if a strong tsunami occurred because many of the corpses may have disappeared. Although it was not a tsunami generated by an earthquake, the severe tsunamis generated during the cataclysmic eruption of Krakatau are a case in point. Only a fraction of the number of corpses were ever found.

How difficult it is to obtain precise data on casualties caused even by earthquakes that happened not too many decades ago, can be illustrated with the help of the M 7½ earthquake which devastated Messina and Calabria at about half past four in the morning of December 28, 1908.

A large encyclopedia claims that 84,000 of the 120,000 inhabitants of Messina were killed. A different source states that in all, i.e. on both sides of the Straits of Messina, 58,000 people were killed, and another source gives the number of victims as 75,000. Continuing the search in the literature one finds reference to 83,000 killed in Messina out of a population of 138,000 and 20,000 out of 40,000 in Reggio, and one source even states that more than 100,000 persons were killed without giving further details. One realizes that precise and consistent figures cannot be obtained whether for the overall loss of life, the total per town and the casualties caused by collapsing buildings, those caused by the 3 m tsunami in Messina which allegedly reached 10.6 m on the Calabrian coast and at least 7 m at quite a number of places, or those caused by exposure or disease. This situation still prevails in many regions of the world, rendering risk assessment very difficult and uncertain.

Another source of uncertainty regarding the percentage of people killed or injured can be the number of people present in the area when the earthquake occurred. Typical cases are San Salvador (1986) and Spitak, Armenia (1988), because of the unknown number of refugees in these towns at the time of the earthquake.

Moreover, one must differentiate between people killed and people injured. Whereas the first is a "binary issue" viz. dead or alive, injuries can range from a simple scratch to very severe trauma, like loss of a limb or paraplegia. As it is already very difficult to obtain accurate figures on loss of life, one can imagine how uncertain figures are on the number of people injured. Let us discuss some factors which contribute to the uncertainties in assessing cases of injury.

Even if those seriously injured have been treated by doctors it is not certain that the data will be fed to a central register. The worse the catastrophe and the greater the demand on medical facilities the less likely is reliable reporting.

An ideal data bank would permit access to information in the form of an injury probability distribution or matrix. This would require detailed reporting. Knowing the difficulties that doctors sometimes have in attending to their routine reports it can be imagined what happens during and after a severe earthquake, when they may have to attend to thousands and even hundred thousands of injured people (Tangshan) within a short time.

Another problem is that there is no standard concept of where injury starts and how degrees of injury are to be classified. As in the assessment of intensities, an issue which will be discussed later, one will have to be prepared for personal and national bias. When the author, for instance, questioned the rather low ratio of people injured to those killed by the Tangshan earthquake he was told by Chinese experts that only cases of severe injury were included in the corresponding figure. Anyone familiar with the attitude of the Chinese towards a trauma will correctly guess that something considered a serious wound in many parts of the world would be put aside in China as a mere scratch.

Even when applying all care one should be prepared for a residual margin of error. As regards persons killed it can be as small as ten to twenty percent, but it may occasionally amount to a factor of two or three. Information on the numbers of persons injured is much more uncertain.

5. 3. Casualties as a Percentage of the Population

The total number of casualties, even if precisely known, will only yield useful information in connection with a few questions, and it will not, for instance, assist in well-directed risk optimization. The next problem arises when trying to establish the number of people living or present in the area experiencing certain earthquake intensities, assuming for the time being that the isoseismals are not debated, which in itself is often not the case.

The number of people per city, town or village are accurately known in only few countries. Even there modern mobility and, in particular, large numbers of commuters can introduce a sizeable margin of error.

5. 4. Problems from Intensity Assignments

Because of the very limited sample from any one country or region one is compelled to use the data from as many earthquakes, i.e. countries as possible. This introduces particular problems as regards estimates of intensity per location. Intensity estimates are always uncertain because of the personal bias of those investigating the damage. Another problem is introduced by national bias, and to make matters worse there are different intensity scales, some of which are not only very imprecise and/or difficult to apply to strong modern buildings (1) but also introduce errors when translating intensities from one scale into another one.

If there are large towns or densely populated rural areas which must be considered isoseismal borderline cases, such data can be used only if one has a large data-bank which permits intelligent interpolation.

5. 5. Population and Casualties per Category of Buildings

To produce standardized data on casualties which take into account the quality (vulnerability) of buildings one must also know the number of people exposed within buildings satisfying certain quality criteria and "within their range".

This is a very difficult task which can be handled by inspecting all buildings exposed to an earthquake and recording all relevant details of the buildings proper and of damage to all essential building components.

5. 6. Parameters affecting Casualties due to other Earthquake Phenomena

To begin with fire following earthquake, a set of very different parameters should be known. The distribution, quantity, and nature of combustible material must be taken into account. In industrial facilities it would be important to study the types of the processes used, the failure probability of apparatus containing combustible or explosive material, etc. Moreover, information should be available on "natural" ignition sources as well as on any additional ones generated by the earthquake. This in itself shows that the concept of fire-blocks as used by fire underwriters can only be used if it is suitably modified (extended). These parameters must obviously also be analysied when estimating direct and indirect losses due to fire and explosion following earthquakes.

The initial development of a fire and of an explosion, and the chance of other areas being engulfed including the potential victims' chances to escape from the exposed area, depends also on meteorological conditions as will be seen later.

The problem is not less complex when assessing the likely number of casualties caused by tsunami. This issue is not included in this report as Armenia is not exposed to tsunami.

One of the most problematic issues is probably the assessment of the casualties that may be caused by landslides, lahar-like flows (mud-flows), subsidence, or failure of glaciers. Whereas the probability of a certain earthquake magnitude can often be estimated, albeit with error margins which may vary much from place to place, the failure probability of a certain slope can at best only be guessed, and it should be realized that such a guess generally incorporates an enormous error margin.

5. 7. Parameters Controlling the Death Rate

5. 7. 1. Buildings

In view of the various difficulties in establishing data on people killed and injured and because of the need to have separate data on each we shall discuss the parameters separately, beginning with the death rate, i. e. the percentage of the population which may be killed by an earthquake.

In the most general form one may write

$$\mathbf{DR = f(I, Q, T, S, W, H, M, ...)}$$

in which DR is the death rate, i.e. the percentage of the sub-population killed. The DR is a function (f) of the earthquake intensity (I), the quality or resistance of the building (Q), the hour of the day (time) when the earthquake occurs (T), the season of the year (S), the influence of any warning received by the people (W), local habits (H), quality and number of rescue and medical facilities treating those affected by the catastrophe (M), and other less important variables. It is noted in passing that this algorithm (one may also consider it a primitive checklist) can be expanded quite conveniently to include other perils like tsunami, fire, explosion, landslide, etc., and even sub-parameters controlling the respective perils. The following discussion will concentrate on only the most critical variables.

Intensity

Intensity scales are at present the only yardstick to indicate the severity of shaking, albeit a crude one. In addition one can say that their general usefulness breaks down above MM IX (1). Moreover, the limited data on failures of buildings constructed according to the most resistant modern codes (e.g. Japan or New Zealand) means that assessments of casualties in such towns are bound to be uncertain.

Quality of the Buildings

The quality of a building, that is its resistance or strength determines its vulnerability. This has been discussed in an earlier section. A detailed account of the parameters contributing to earthquake damage of buildings and therefore implicitly to loss of life and injuries has been provided elsewhere (1, 3 - 22). We repeat here those factors which are important in connection with casualties:

- Resonance between predominant frequencies of the foundation material and of the building or structure.
- Quality, i.e. predominantly hardness of the foundation material.
- Shear strength of the building resulting from the combined strength of structural and non-structural parts.
- Compatibility of behaviour of building materials and components under dynamic loads.
- Regularity and symmetry as regards floor plans, elevations, shear strength, distribution of masses and damping.
- Design philosophy and quality of design.
- Quality of workmanship,
- Arrangement and fastening of non-structural elements.
- Hammering between buildings
- Orientational sensitivity.
- Liquefaction

As the influence of some variables is very critical a detailed assessment is warranted if exposure is considerable (40). Such an analysis is to long to be discussed here and we will limit ourselves to presenting a general methodology and relevant data, also as the basis for a more detailed approach.

The starting point for casualty assessments is the behaviour of buildings during earthquake shaking of a given intensity. As many parameters determine this behaviour we have standardized our data using the most common condition, viz. moderately irregular and asymmetrical buildings which are founded on alluvium of medium hardness (cf. e.g. 6, 12). In more refined assessments these data can be corrected to alow for the beneficial or detrimental influence of specific parameters as illustrated in ref. 41. It is stressed that such corrections are very important if buildings or foundation material differ appreciably from the basis mentioned. Leninakan and Yerevan are towns founded on subsoil which is softer than medium-hard alluvium and therefore attract a malus (cf. Fig. 3).

The mean damage rate (MDR) to be expected is shown in Fig. 1. It demonstrates that building quality is an immensely important variable. It should be noted, moreover, that at least in the case of buildings of reinforced concrete structure, rescue operations in resistent buildings are much easier than in those which collapse partly or completely and make access to victims very difficult and dangerous. If buildings of reinforced concrete are designed and/or built in such a manner that they collapse catastrophically, like during the Spitak earthquake, rescue becomes extremely difficult.

As the DR (death rate) very much depends on partial or total collapse of buildings it is interesting to know how high the percentage of such buildings is. Let us look, for instance, at the behaviour of the 390 modern buildings of a sample analysed by us after the El Asnam earthquake of 1980 (Fig. 10) (cf. also 3).

It will be seen that the percentage of buildings sustaining damage of more than 90% of their new replacement value, which is the category which contains most cases of partial or total collapse, depends greatly on the quality of the buildings. This figure, however, also indicates that the uncertainties are very large if the sample does not comprise literally many hundreds of such buildings.

The accuracy of the assessment can be further improved if damage probability distributions (cf., e.g. 5) or damage probability matrices are available. For the benefit of those readers who are predominantly interested in casualties we repeat Table 1 which shows such a damage probability matrix (DPM) for the behaviour of moderately irregular and asymmetrical buildings on medium-hard alluvium, i.e. those represented by Fig. 1. The matrix can also be of use when estimating the equipment needed for rescue operations.

TABLE 1
DAMAGE PROBABILITY MATRIX FOR BUILDINGS

DAMAGE CLASS	MEAN DAMAGE RATIO (%)									
% of value	1.5	3	5	10	25	37.5	50	60	70	85
0 - 1.5	83	73	60	36	9	2				
1.5 - 3	17	25	26	23	9	3				
3 - 6		2	10	18	11	5	2			
6 - 12.5			3	12	18	12	6	2	1	
12.5- 25			1	8	24	24	15	7	3	
25 - 50				3	19	28	29	23	18	10
50 - 100				1	10	29	48	68	78	90

The percentage of buildings in the upper damage class (50 - 100% damage) cannot be used without correction for casualty assessments. Let us illustrate this with a simple example employing the information provided so far.

According to Fig. 1 unreinforced brick buildings will suffer a MDR between 50 and 60% if exposed to MM VIII and 2-3% g buildings with a (monolithic) frame of reinforced concrete can be expected to have a MDR of 50% if the intensity reaches MM IX. The above table tells us that about 50% of all buildings with the latter MDR will be found in the 50-100% damage class. Among the buildings suffering 50-100% damage there will, however, be some with only non-structural damage (cf., e.g. 15), and many sustaining heavy non-structural and some structural damage but not killing many of the people in them. Using Fig. 10 we may estimate that of the 2-3% g reinforced concrete buildings only about 10% will probably collapse but that about 40% to 50% of the unreinforced brick buildings will.

Even if buildings collapse in a spectacular manner only a percentage of the people in them will be killed (cf. for example Figs. 21 & 22 in ref. 15). In this case a department store collapsed completely and killed about 70% of the people in it. This is not the rule, however, because mostly only one or a few storeys will fail, in general only the ground floor. The behaviour seen in buildings in Mexico City after the 1985 earthquake (13,16) where several upper storeys collapsed, is not typical and is due to the special conditions prevailing there.

Assuming that most of the buildings in a given town have a monolithic reinforced concrete frame of 2-3%g shear strength, that the average number of floors is five and that people in them are uniformly distributed, we could guess that if in ten percent of the buildings the ground floor collapses, only 20% of the people will be exposed to grave danger and that only a percentage of them, say 30%, will be killed. Such an approach is very crude indeed and open to considerable errors and omissions. In particular the approach will produce far too optimistic results if we are dealing with prefabricated buildings of low quality, or with rural building (mud-brick, vulnerable brick, etc.) which generally suffer near-complete collapse.

People are not uniformly distributed between buildings and throughout each individual building. During shopping hours, for instance, many will be in buildings which have a soft ground floor and other features increasing failure probability. In some buildings not only the ground floor will collapse. Moreover, people are killed by partial structural failure, by non-structural failure and by falling objects. The estimate given earlier would neglect all such aggravating factors and therefore only produce a lower limit in most cases. We have therefore evaluated our global statistics in order to enhance the accuracy of casualty estimates, and the result is shown in Fig. 5. It must be stressed that the graphs should be used with great care because of the general uncertainties afflicting such data as discussed earlier and because of the many variables which must be considered when allowing for specific conditions. The spectacular failures of pre-fabricated (tilt-up) buildings in several countries, or of buildings constructed according to certain unsuitable methods and of unsuitable material, underscores this need. Many of these buildings failed during past earthquakes in a dramatic manner not anticipated by those designing and building them.

The references mentioned show how corrections can be applied if buildings are not of moderate irregularity and stand on harder or softer strata than medium-hard alluvium. After discussing parameters controlling injuries we will therefore look at the other variables mentioned earlier.

We will not discuss the quality of material and workmanship although these parameters are of paramount importance. Anyone experienced in this field can estimate to what extent workmanship and quality of material found during inspections influence the strength of buildings, and apply suitable corrections to MDR- and casualty estimates.

5. 8. Parameters Controlling Injuries

The assessment of the number of injuries presents additional problems. The percentage of people suffering injuries of various degrees depends not only on structural characteristics of buildings but also on the behaviour of non-structural items.

To start with building quality, it can be said that the correlation between the vulnerability of buildings and the total number of injuries, as well as the ratio of the people killed to the people injured, is a very complicated matter. Whereas the DR increases very much as vulnerability grows, the injury rate (IR) decreases.

Buildings which incorporate a high or very high collapse probability, like those of adobe, torquezal, rubble masonry and those having soft rc-frames with little strength, a soft ground floor and other grave irregularities, or badly assembled prefabricated buildings, will kill many people as they fail and leave few to be injured. An extreme example of adobe buildings are those in eastern Turkey, in Iran and in central Asia, which have not only collapse-prone walls but also very heavy roofs. When collapsing they tend to kill most of the people in them. This general characteristic is seen most clearly when correlating the number of people killed to those injured with intensities and building strength.

In this respect our studies provided a similar picture which to the behaviour of structural and non structural damage. As the quality of buildings goes up the importance of structural failure dwindles while the contribution of non-structural damage grows (5). Similarly, as buildings get better, less and less fatalities are observed and most casualties are injuries. Whereas the "normal ratio" of people killed to people injured is about one in three to one in six, it can be very much higher if building standards are high (or if the earthquake intensity is low). A case in point is the Miyagi-Ken-Oki, Japan, earthquake of 1978, which affected a densely populated area. In this case the ratio was 1 : 39. This exceptional ratio is, however, not the consequence of high building standards alone, and the low number of people killed, in spite of some spectacular building failures, is due to several fortunate circumstances.

We have so far not been able to produce reliable standardized graphs for injuries, because of statistical uncertainties and the many details and variables determining the number of injuries to be expected. If, for instance, buildings with very resistant frames incorporate failure-prone non-structural parts, like heavy elements used to facade buildings, suspended ceilings, and collapse-prone partition walls, the number of injuries in and around such buildings will be much higher than in buildings of similar or even lower strength which are without such features.

The Alpstadt earthquake of 1978 in Wuerttemberg, FRG, showed what minor details can matter. The earthquake dislodged innumerable roof tiles on the steep roofs of the houses. These heavy tiles would have injured and even killed many people, had the earthquake not happened at 6 o'clock on a Sunday morning. Less inclined roofs would also affect injury rates quite considerably.

Table 3 underscores some uncertainties.

Table 3
Casualty rates of the Guatemala earthquake of 1976
(In permille of the respective population)

PLACE	EPIC. DISTANCE (km)	KILLED	INJURED
Guatemala City	150	2.2	11
El Progreso	90	26	100
Sancatepéquez	180	15.5	85
Chimaltenango	170	67	160
Sololá	200	0.8	2.3
Quiché	30	6.3	18
TOTAL		5.3	18

In this case, particularly the number of persons injured is uncertain. Moreover, except for Guatemala City there is little scatter in building quality, but casualty figures are still far from uniform.

To facilitate estimates we repeat Table 2 hereunder showing the percentage of homogeneous buildings in the 80-100% damage class depending on the MDR of the sample. It is stressed that approximate average values are shown and that actual observations can be very different, in particular if samples are small. We have, for instance, collected samples with 7% of the cases in the 80 - 100% damage class although the MDR of this sample was only 8%, and with the same 7% in this damage class although the MDR was 34%. This underscores the warning stated at a different place: it is very dangerous to base conclusions on limited samples, in particular if one cannot assess the relative contribution of the different damage parameters.

As a rule of the thumb one may assume that about one quarter to one eigth of the population in the 80-100% damage class buildings will be killed.

PERCENTAGE OF BUILDINGS WITH 80 - 100% DAMAGE DEPENDING ON MDR

MDR (%)	10	20	30	40	50	60	70	80	90
PERCENTAGE	.25	3.5	10	20	30	45	56	70	85

5. 9. Time, Day of the Week, Season, and Local Habits

In order to avoid repetitions we shall discuss these variables under one heading.

The number of casualties depends much on the time of day when the earthquake occurs. Some examples will illustrate this.

The earthquake which devastated Agadir in 1960 occurred in the middle of the night when most people were in bed. Because of the many collapsing buildings a very high percentage of the population was killed or injured. The lesson herefrom is that casualties during the Spitak earthquake would even been more numerous had it not occurred about at noon but late in the night.

The Tangshan earthquake (1976) occurred at 3:43 a.m. and anyone familiar with the Chinese style of life would correctly guess that except for people who worked in factories and mines operating in three shifts, most of the others were in bed although it was summer.

The Friuli earthquake, Italy, (1976) occurred about at nine o'clock in the evening, when most factories had closed. As many of the pre-fabricated factory buildings suffered partial or total collapse, the casualties would have been much higher had the earthquake happened during working hours. On the other hand, loss of life in the old rubble masonry buildings of Gemona and other places would have been lower had the earthquake occurred when many people were out working, shopping, or attending school.

We have already mentioned the absence of important casualties during the Alpstadt earthquake, FRG, which happened early on a Sunday morning. The same earthquake occurring on a workday and in particular during peak shopping or rush hours, or indeed during the Christmas shopping period, would have caused many casualties.

With respect to the seasonal variability of casualties one mostly thinks of a rural society with work in the fields from spring to autumn and attends to chores at home during the winter. This is, however, only one of the many alternatives.

Thessaloniki, Greece was shaken by an earthquake during the summer of 1978. Although the earthquake happened an hour before midnight it is not likely that all inhabitants of this town were already asleep.

Managua, Nicaragua, was destroyed in 1972 by an earthquake which occurred shortly after midnight. As late-night open-air life is common in warm Latin American countries, and probably even more so on a Saturday just before Christmas, we can assume that this variable reduced casualty rates.

The Montenegro, Yugoslavia, earthquake of 1979 serves as a warning against assuming over-optimistic casualty rates and as an illustration of seasonal influence. It occurred on a Sunday morning when most people were up and at a time of the year when most tourist hotels - a category of buildings which suffered spectacular cases of collapse - were still empty. As it was a holiday most other places which can contribute dramatically to casualties, like department stores, large offices, etc., were also empty.

In regions with harsh winters the death toll can be increased by exposure, perhaps exacerbated by delayed rescue.

5. 10. Medical and Rescue Facilities

It is an unfortunate fact that hospitals in general are not often built according to special standards so as to make their survival very likely and to keep them in operation. This was evident, for instance, after the Mexican earthquake of 1985 and the M 5.4 earthquake which killed and injured many in San Salvador in 1986 (15). Many more examples could be added. The generally inadequate safety margin in the design of hospitals requires immediate attention.

If as is argued in technologically advanced societies, the death toll from traffic accidents would be much reduced if medical help were available very soon after the accident, it is evident that this variable is just as important after a catastrophic earthquake, which is bound to put strain on the medical facilities of any society, and most of all in the less developed regions.

The Tangshan earthquake of 1976 showed that the victims' chance of survival depends dramatically on the time that elapses between the earthquake and rescue. Those rescued within the first 30 minutes after the quake had a 99% chance of survival. For those rescued on the second day it dropped to about 34% and to only about 7% for those rescued on the fifth day. These figures must be taken with a pinch of salt, because "contaminating" factors cannot be ruled out. It is, for instance, possible that many of those rescued soon after the earthquake were easily accessible and had suffered less severe injuries. Contaminating factors are suggested by fluctuations in the survival rate. On the second day, for instance, 1,638 people were rescued, 562 of whom survived (33.7%). On the third day 348 victims were extracted alive and 128 survived (36.7%).

In all about 8,500 people were rescued, compared with about 255,000 people killed by the earthquake. About 5,300 of them survived (2.1%) and of these 85% were survivors rescued on the first day. About 52% of the survivors rescued during the first day were in fact freed during the first

30 minutes. Most probably, though, these were the victims who could be found most easily and could be rescued without heavy equipment.

According to data provided by the Civil Defence of the USSR the result of rescue operations after the Spitak earthquake was as follows:

Date	7. 12	8. 12	9. 12	10. 12	11. 12	12. 12	18/19.12	Total up to 25. 12
Rescued	1,382	1,660	4,825	5,479	1,757	150	1	15,254

The type of building affectsthe chances of rescue and therefore casualties. Whereas the debris of buildings of adobe, rubble masonry and brick can be removed with primitive tools, reinforced concrete poses grave problems, in particular if not enough special and heavy equipment is available. The Armenian earthquake of 1988 showed this again but it should be noted that facilities in almost any country will be overtaxed after a destructive earthquake. In this connection one must remember that those seriously injured or exposed require help within a very short time. This requires detailed catastrophe programmes and constant drills, but a much better method is to build or to reinforce existing buildings in such a way that only few suffer severe damage. Such an approach will not only protect the inhabitants but positively influence the overall impact of earthquakes on the national economy and on society (20). It is stressed again that building properly and reinforcing vulnerable buildings is in general not a costly enterprise.

It has been observed after numerous earthquakes that solid furniture will often support the collapsing elements of buildings well enough for many spaces to remain in which victims can survive. This points the way to a solution in cases where very collapse-prone buildings cannot be retrofitted or abandoned. If, for instance, schools and officesof this kind were equipped with solid desks made of steel and the inhabitants trained to hide under the furniture in the case of an earthquake, many could be saved at minimum cost, in particular if they also covered their nose and mouth with a piece of cloth to protect their respiratory system against excessive dust. This, obviously a measure of last resort, can even be introduced without difficulty in vulnerable rural and residential buildings.

5. 11. Fire, Explosions and Toxic Materials

In this connection a very large number of parameters must be considered. The important aspects are treated extensively in (1), and we shall here not discuss individual categories of elements at risk individually but rather concentrate on some important parameters.

An analysis of the exposure may start with the investigation of the physical and chemical properties of all dangerous material, and whether such material is installed or available in the form of raw material, feedstock, semifinished or final product. The physical properties include the phase, i.e. gaseous, liquid, or solid materials, the quantity and in the case of solids the surface to volume ratio. Chemical/biological properties are, for example, calorific value, ignition point, toxic or irritating properties, corrosiveness, stability, oxidizing, reducing, basic, acidic, and reaction velocities.

In industrial facilities in particular, the pressures of stored or processed liquids and gasses must be considered.

The release of dangerous materials is determined by many parameters, in particular by the failure probability of tanks, pipes and other equipment in which they are contained, but also by the characteristics of structural elements, building components and devices which are supposed to contain the liquids if the tanks fail. Vehicles transporting dangerous material should also not be overlooked.

When considering ignition sources not only those normally present in buildings and plants but also additional sources generated by the earthquake should be considered.

"Exogenic" parameters which can trigger or contribute to a catastropheshould not be overlooked. Such factors include liquefaction, slides, failure of power or water supply, meteorological conditions, and tsunami.

Last but not least we must allow for human failure or error if the course of an event is determined by the reaction of operators. The reliability of human beings is much reduced under severe stress unless they have been very well trained.

The Tokyo earthquake of 1923 is one dramatic example of the fact that enormous casualties can be caused because of the presence of much combustible material and of many ignition sources. This earthquake occurred at a time when many meals were cooked on open fires. The severe shaking spread the burning fuel, and allegedly 277 fires broke out, 133 of which spread. The most important single factor, however, was the strong wind, initially blowing at a speed of 45 km/h. It changed direction repeatedly and reached velocities in excess of 75 km/h. The conflagration killed more than 100,000 people, 38,000 lives were lost in an open area of Tokyo to which the people had fled for refuge.

Modern construction materials have replaced much of the wood used decades ago, introducing other fuels which may cause devastating fires and a large number of casualties. This is true of both industrial plants and of buildings. A case in point is the department store in San Salvador which collapsed; quite a number of the victims were not due to the crumbling building but caused by a fire which later engulfed the site.

In many industrial facilities today there are numerous tanks and even large tank farms storing liquid fuel, and many facilities where liquified gas is stored. A few years ago a comparatively small facility of this kind caused the death of about 500 people in Mexico City. If a devastating earthquake shakes an area where many such installations are to be found many failures in the equipment are buond to occur, and fires and even conflagrations are likely to result. Cylindrical gas tanks are known to cause disastrous BLEVE's with fire-balls reminiscent of nuclear blasts. When exploding such large tanks have been known to travél like rockets over distances of up to a mile. If they impact on a critical facility further fires and explosions may result.

Moreover, one must be prepared for burning liquids and gasses heavier than air to spread rapidly along roads, ditches and topographic features. It must be stressed that the average retaining facilities available today will not stop such massive reieases of combustible and explosive material. As multiple failures of containments are probable during an earthquake unless special precautions are taken, the ensuing loss of life can be very severe.

In conclusion, it must not be forgotten that events like the tragedy at Bhopal, India, where about 2,500 people were killed by the release of toxic material and where many more were seriously injured, become far more likely if such plants are shaken by earthquakes. If the worst comes to the worst casualties can be caused by the combined action of several hazards.

5. 12. Tsunami

We shall not discuss tsunami because the region studied by the group of experts is not exposed to this risk. If it should be decided that this report will be used in tsunami-prone regions a corresponding special section would have to be prepared.

5. 13. Landslides and Mudflows

Landslides and mudflows (which should more properly be called (seismic) lahars because the flow consists only in part of mud but mostly of boulders, stones, tree trunks and debris picked up by the flow on its way) are, like tsunami, indirect earthquake effects. The earthquake triggers a slide and this slide causes the damage and the casualties.

Probability assessments are very difficult because of the compounded uncertainties of the parameters playing a role. Briefly, the probability assessment of seismicity proper in the respective region is not free of uncertainties. Next, the stability of the slopes in the vicinity of human populations must be assessed. If it is not easy to establish the general stability of slopes it is even more difficult to state with certainty what characteristics an earthquake must have in order to cause slides of different magnitude on a particular slope. Moreover, slides are also controlled by hydrological parameters and by other factors (42). Whereas an earthquake occurring after a long dry summer may not cause a slope failure, the same earthquake will cause a slide if it occurs after an extended wet spell. Also for such reasons the Spitak earthquake was not a worst-case event.

There have been many earthquake-induced slides in the past. Some of them have killed people and a few have resulted in catastrophic loss of lives. We will discuss a few examples involving casualties. It must, however, be stressed that even a complete list of earthquake-triggered slides will not produce a precise description of the exposure of human life. This is evident if one considers the very many *parameters influencing* slides, the limited number of large earthquakes in regions exposed to dangerous slides, and demographic developments.

Quite a number of old gigantic slides have been found by scientists (42). Several of them occurred in seismic regions and it is therefore not improbable that they were triggered by earthquakes.

Perhaps the most massive mountain slide in history in the European Alps buried 17 villages and hamlets near Villach, Austria, in 1348. 5,000 people were killed. An earthquake had rendered huge quantities of limestone unstable on the south wall of the 2,167 m high Dobratsch and sent it thundering down 1,500 m into the valley. A similar prehistoric slide has been discovered. Today a much larger number of people live in the exposed region than in 1348.

In 1911, after an earthquake of about M 7 in Pamir, 2.5 billion cubic metres of material blocked the Murgab river in Turkestan and buried the village of Usoy, with its 54 inhabitants.

Probably one of the most devastating slides occurred in Peru after an earthquake. The M 7.5 earthquake in 1970 triggered an ice/rock avalanche about 100 million cubic metres in volume on Huascarán. Travelling at an average speed of 170 km/h, but with a maximum speed of 400 km/h, it raced towards Yungay, 15 km away, jumped over a mountain ridge several hundred metres high in its path and buried the town with its 18,000 inhabitants.

Allegedly, the great earthquake in Assam in August, 1950 (M 8.7) led to landslides and consequent loss of life in the Himalayas.

5. 14. Failure of Dams

In conclusion we would like to discuss a special issue: the failure of dams and/or reservoirs. Such a failure may be due to several reasons, for instance,

- very severe shaking of the dam by a nearby earthquake,
- large faulting traversing the dam and damaging the dam proper and/or its foundation
- substantial deformation of the dam in its vertical plane by wave-like deformation of the dam's foundation in the course of earthquake wave propagation,
- slope failure in the vicinity of the dam causing substantial damage to it, and
- sliding of a large volume of material into the reservoir causing the water to spill over the dam.

If the water from a large reservoir is released within a short time because of such phenomena it can cause enormous casualties in the valley below the dam. Under certain circumstances the devastation will extend over dozens and even hundreds of kilometers

Unless the dam proper is fairly safe (a rockfill dam, for instance, is for intrinsic reasons much safer than an earth dam, or can be rendered safer by later modifications) it will in general be difficult to protect the people in the valley below the dam. Urban development schemes should take this into account. Because of the high probability of failure of comunication systems during an earthquake, evacuation will often not be possible. Moreover, the time available for warning will generally be shorter than in the case of excessive rain endangering the dam.

If towns, big factories with a large work-force, big camping sites, etc. are situated only many kilometres downstream of a reservoir, a warning system similar to a tsunami warning system can be installed. It must be fail-safe, and proper information and training of the people is necessary to guarantee correct reactions and to avoid chaos.

It is very difficult to estimate the casualties due to the sudden failure of a dam or reservoir. A prerequisite is a detailed zoning map indicating the possible water level for the exposed regions. Next, the vulnerability of the buildings must be estimated for each sub-zone, as well as their type.

Whereas people on roads are most exposed and a very high percentage of them may be killed (cf. (42), p. 76-77), the exposure of people staying inside buildings depends on the resistance of the structures and on the number of storeys. Single storey buildings normally offer little protection. Multi-storey buildings will only reduce casualties if they do not collapse. Protection is only afforded by strong buildings with a frame or shear walls of reinforced concrete and with foundations which are not endangered by scouring.

To sum up, it must generally be assumed today that the sudden failure of a dam or reservoir will cause the death of a substantial percentage of the people exposed to the torrent.

6. The Influence of Earthquake Prediction or Warning on Losses

Here we define prediction as the reliable statement of narrow windows related to magnitude, epicentral region and time of occurrence of future earthquakes.

Even if reliable short-term prediction should become possible, an inspection of the various loss items of the examples given earlier shows that the overall economic consequences would not be reduced much. A specific warning appears to be appropriate here. The primordial intention of earthquake building codes still is to reduce the chances of injury and of loss of life. Codes do in general not address the items which contribute more than 80% of the earthquake loss (18), viz. non-structural damage and indirect losses. There is a risk that if successful earthquake prediction were possible one day this could induce some parties to be less concerned with proper design and construction. Therefore relyance on earthquake prediction would not mitigate the economic impact of earthquakes.

Earthquake warning, e.g. general statements about impending earthquakes, but not allowing for the constraints mentioned above, would result in even less savings. At any rate the consequences of unsuccessful cases and of the general unrest introduced by the method must be considered.

Earthquake alarm, i.e. the "on time" warning of more or less distant populations that an earthquake of a certain magnitude has happened in a particular epicentral region can on the other hand reduce the overall loss. A prerequisite would be earthquake awareness and training of the population and the existence of detailed catastrophe plans which are very well known to anybody concerned. Such a situation would reduce the casualties very noticeably. Even in this case one should not expect a dramatic reduction of the total economic consequences of an earthquake, except in plants where immediate proper steps reduce, for instance, the chances of fires and explosions resulting from the earthquake.

A more detailed discussion of what can be gained from earthquake prediction and what not is available in reference (43).

7. RECOMMENDATIONS

The careful reader will have noted that a very large number of issues and parameters has been included in this section of the report. It is therefore not possible to reiterate all of them in this paragraph, and particularly not in detail. Moreover, the importance of damage parameters depends on the particular case. Therefore it is strongly recommended to use the information presented in the main text and not to rely on the following recommendations only.

1. The most important conclusion is that physical and economic losses and casualties depend most prominently on building quality. Therefore the predominant task is to raise building standards in general and specific requirements if the architectural design introduces "penalties" like soft ground floors, pronounced asymmetry, etc.. The most pressing and important task, however, is to ensure an impeccable and reliable quality controll. The best codes and the best design are of no value if buildings are constructed not following sound engineering practice.

2. In most seismic countries very much could be gained if pragmatic earthquake engineering would be made a compulsory subject at the university level and in addition introduced in the training of craftsmen. A first step to achieve this would be the creation of more risk awareness (40). As regards training of skilled labour the importance of excellent workmanship cannot be overemphasized.

3. In many towns or villages there are buildings which were constructed before earthquake building codes were introduced. In some places such buildings are likely to produce most of the casualties. In such cases a detailed stock-taking is advisible which should, however, include modern buildings which are important elements at risk because they are either large, of asymmetrical design, or constructed on soft subsoil. Such buildings should be suitably reinforced whenever possible.

4. As regards loss, damage and casualties from a conflagration and/or explosions following an earthquake a detailed stock-taking with risks maps will indicate the possible impact of these hazards. This holds for the release of toxic material as well. Thereupon risk improvement can be organized in an economic way.

5. Because it is impossible to stabilize large slopes one should concentrate on shifting property and people in the course of time to less exposed regions.

6. Risk maps alone will not do. A catastrophe plan must be developed and introduced. Those responsible for its execution must be trained well enough and regularly to ensure that nothing important goes wrong even under the enormous stress caused by a catastrophe. The chance of casualties will in general be reduced much if all people are properly informed and trained repeatedly.

7.Unless all important different scenarios of earthquake catastrophes have been worked out it is impossible to estimate the loss and damage, the exposure of persons in the affected zones and the casualties to be expected from the various "sources". Only if the "casualty scenarios" have been developed will it be possible to determine the number and type of rescuing equipment and trained staff needed. It would be unwise to work without safety margins, if only because under extreme stress nothing functions as smoothly as during a peaceful drill.

8. It is strongly recommended not to rely too much on earthquake prediction nor on rescue but first and foremost to reduce the vulnerability of buildings.

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Fig. 1 . The graphs show the mean damage ratio (MDR) in percent of the new replacement value depending on the earthquake intensity (MMI) and the building quality. The intensity is given according to the Modified Mercalli scale (MM 31). The MM intensity can be converted to other suitable scales like MSK and JMA using the conversion tables found in the literature. The quality of buildings of reinforced concrete is stated as base shear: C = 2 - 3% g, D = 3 - 4% g, E = 6% g, F = 12% g, and G = 20% g. Graph A represents buildings of adobe and frail rubble masonry, graph B is for unreinforced brick buildings having solid, i. e. not cavity walls. The graphs are valid for medium-hard alluvium, i.e. a bonus must be allowed for harder subsoil and a malus for softer (cf. Fig. 24). Liquefaction requires special consideration as discussed in the main text. The graphs are valid for buildings which are only moderately asymmetrical and for different buildings Figs. 33 and 34, and reference (7) give approximate information; details are to be found in (12). The graphs or those shown in Fig. 36 can also be used, for instance, for improving designs which are exposed to orientational sensitivity and for assessing damage/vulnerability relations of other structures and items. If, for instance, the MDR of an element at risk can be estimated with reasonable precision, e.g. 50%, 10%, or 1% at MM VIII, one of the curves shown in this graph or a new one fitting their general characteristics can be used. This approach is possible because we have learned from the analysis of very large numbers of different elements at risk that the damage or loss distribution is very much determined by the MDR; in other words, irrespective of the kind of the element at risk and the hazard causing loss or damage, one will find that the distributions are comparable if MDR's are similar.

Fig. 1

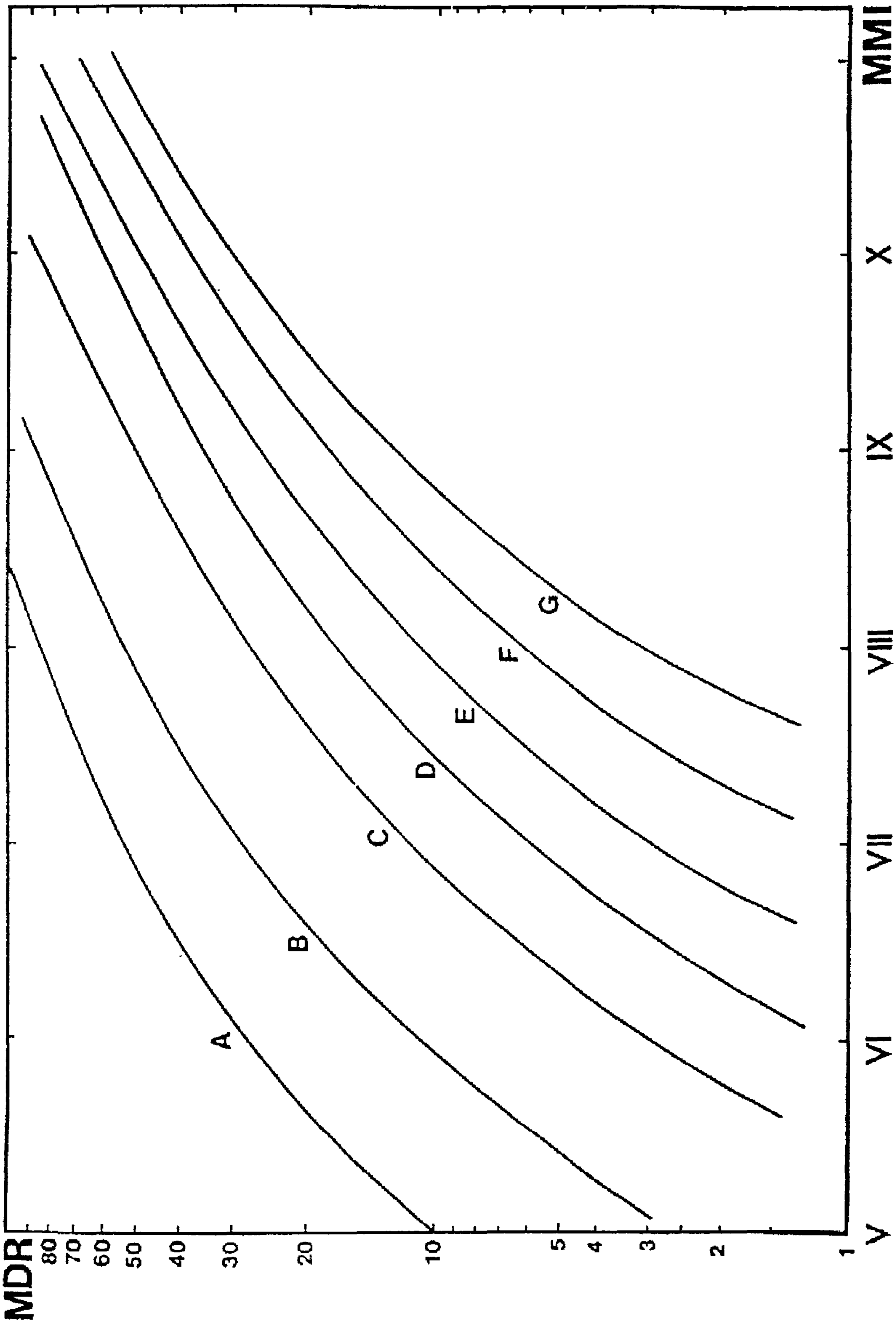

Fig. 2. Schematic and much simplified illustration of two different types of deposits of soft subsoil. HL stands for hard layers, e.g. bedrock, SD for soft deposits. The case shown in A is typical for extinct lakes which have been filled with sediments. It can also represent a cross-section of a river valley with alluvial layers overlying bedrock. The longitudinal section of such a valley would, however, be comparable to the case illustrated by B in which soft deposits are arranged more or less horizontally and are of approximately uniform or of a gradually changing thickness. If a "bowl" of soft material is agitated by an earthquake it will start oscillating. There will in general be further waves superimposed on the "natural frequency" of the soft deposits shown in this sketch. Large distant earthquakes which produce shaking of long duration and of low frequency are prone to produce particularly strong oscillations in such deposits. The natural frequency depends primarily on the configuration of such fills in depressions, and in particular on their depth. The depth to hard strata is the parameter predominantly responsible for the period of shaking of soft deposits depicted by B. Each column can be considered a beam which is more or less anchored at its lower end and deflected sideways. As the elastic and plastic restoring forces, masses, etc., discussed in the main text are approximately the same for comparable deposits it is clear that the natural frequency will very much depend on the length of the deflected column. The excitation of a building depends very much on the ratio of the frequency of the force to that of the structure which is excited. Therefore it is of paramount importance to know the predominant frequency of the force, namely that of the subsoil.

Fig. 2

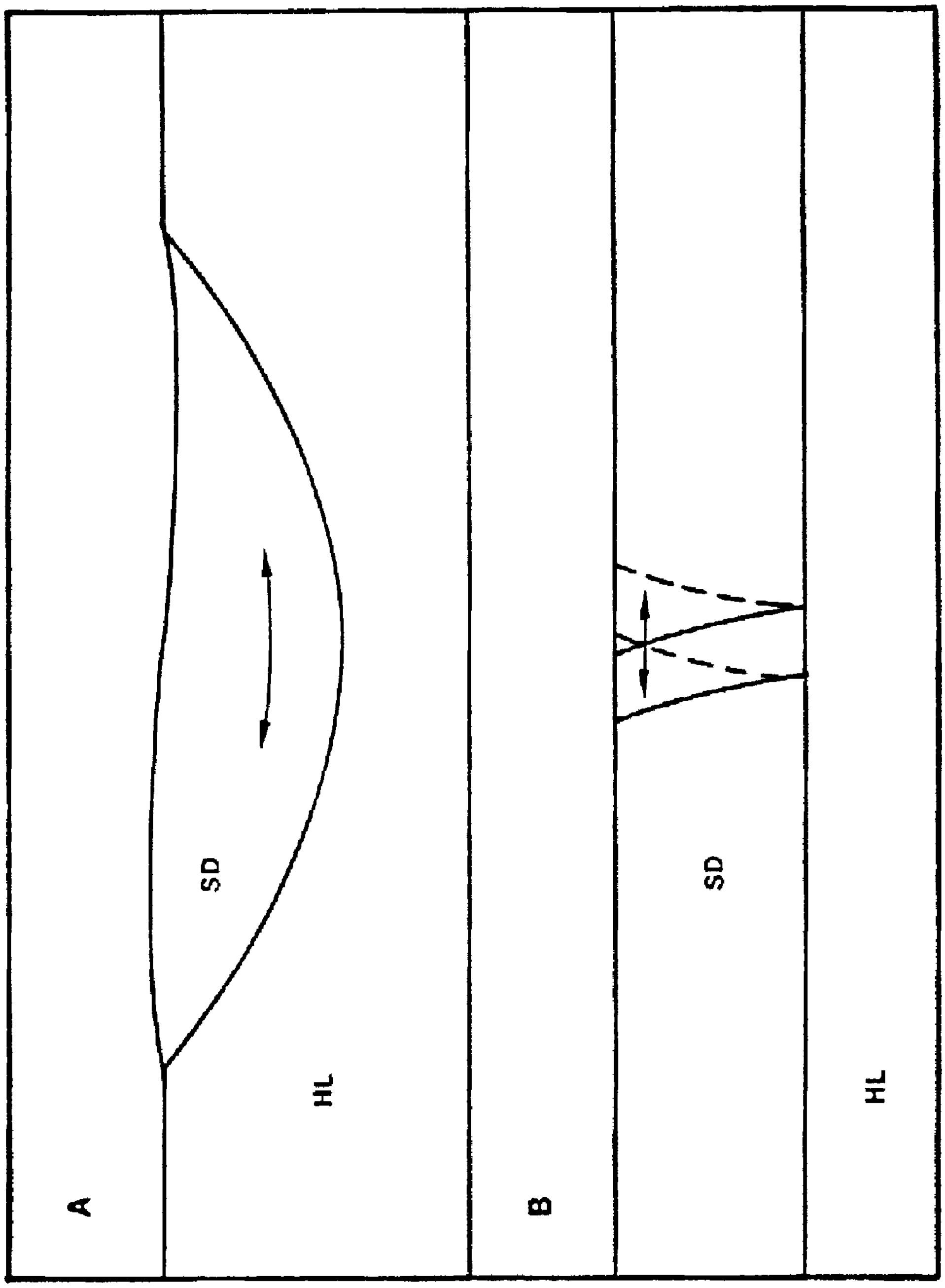

Fig. 3 . Approximate correlation between the hardness of subsoil (VS - H) or shear wave velocity and increase in MM intensity or amplification factor of ground acceleration. General hardness indications range from hard (H), i.e. good rock, over medium hard (MH), represented by soft rock and well-compacted, dry diluvial deposits, to soft (S) layers (alluvial deposits with not much groundwater), and very soft (VS). The latter corresponds to ordinary fills (man-made land) and soft alluvial deposits with the groundwater near the surface. The values, in particular amplification which depends on many other factors, are to be taken as indications only. The envelopes indicate the approximate range.

Fig. 3