Fig. 4 . The illustration shows some of our observations of predominant periods of ground shaking and the respective depth of soft layers above hard strata. As explained in the main text and in Fig. 25 it can be expected that the most important parameter determining the frequency of the force that shakes the buildings is the depth of soft layers. The predominant period of the soil under Mexico City, which has a configuration about similar to the one shown under A in Fig. 2, and that in smaller similar depressions, follow this general rule. This is not surprising, because not only the frequency of a simple pendulum but also that of a bar clamped on one side (cf. Fig. 2) depends on its length. Each column of material underneath of a building can be considered as such a bar. In order to avoid designing buildings which are in resonance with the subsoil, or to change them properly during upgrading or repairs one should therefore assess the depth of soft layers. This is neither difficult nor costly with the technology nowadays available. As more refined models become available one can correct for the influence of the physical properties of the soft layers. In this respect the first parameter to be considered should be hardness.

Fig. 4

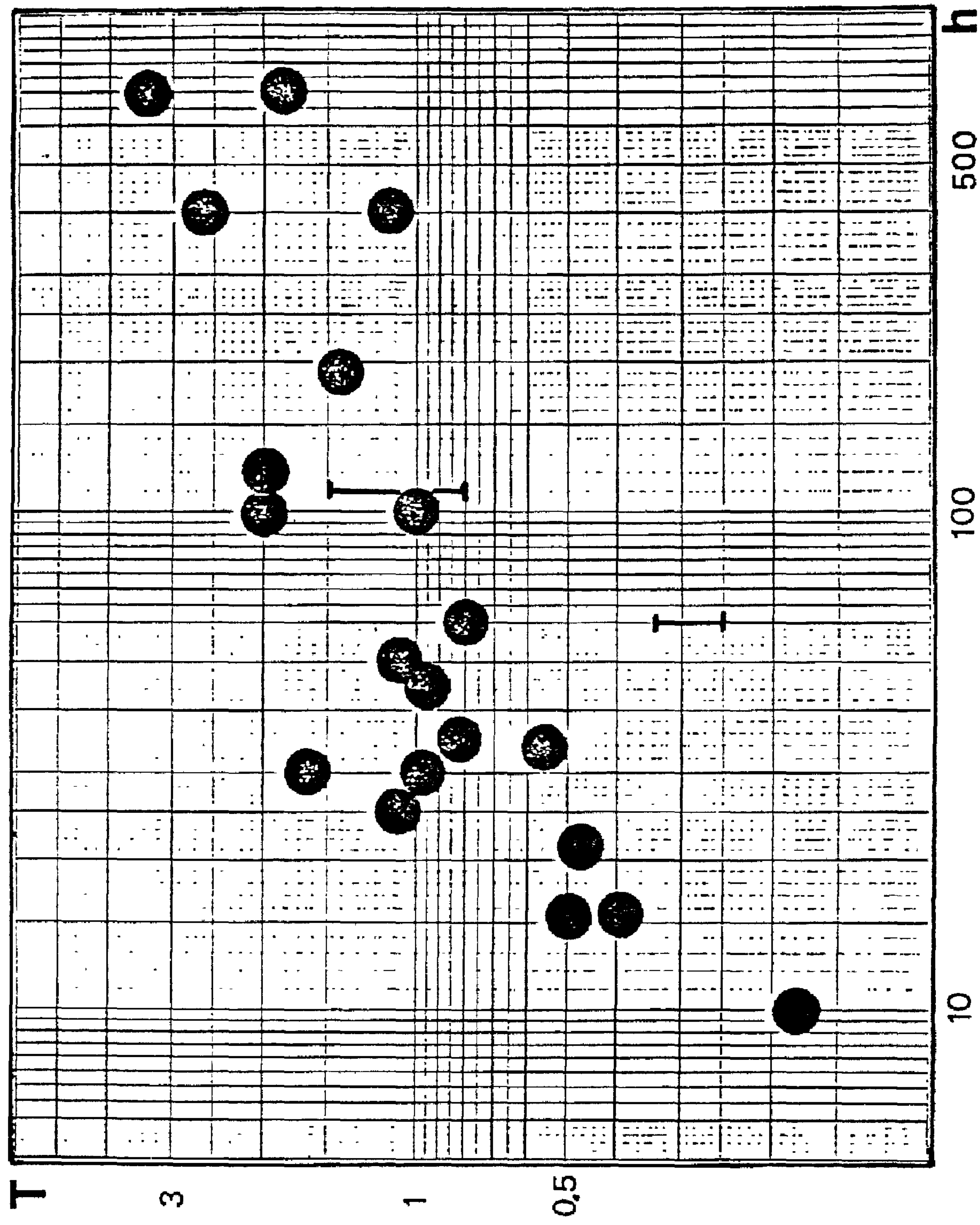


Fig. 5. After the San Salvador earthquake of 1986 we analysed the performance of all the larger modern buildings in the capital of El Salvador, which experienced about MM VIII or slightly more (1). This illustration is a simplified version of the data reproduced in the reference mentioned and it serves mainly to show the influence of regularity, irregularity and stiffness on the mean damage ratio (MDR). The strength of the buildings is represented by their base shear (BS) in percent of gravity. Graph A shows the BS : MDR-correlation for the complete sample, i.e. the overall average. Graph I indicates how much higher the MDR was for irregular buildings. It must, however, be noted that these buildings in San Salvador were not particularly asymmetrical and irregular, i.e. one should be prepared for even higher MDR's if extravagant designs are hit by earthquakes. On the other hand, regular buildings (R) had much lower mean damage ratios and the MDR was particularly low if buildings were not only regular but stiff as well (R & S), for instance, because of resistant fill-in walls. It should be noted that the valley of San Salvador is filled with deposits from volcanic eruptions and that the ground-water level was low at the time of the earthquake. Soft and irregular buildings of about 3 - 4% g suffered about seven times the MDR of regular and stiff ones - irrespective of all engineering efforts. This lesson is not new . A second lesson is that MDR-statements must be handled with care unless they are accompanied by an explanation of all parameters influencing damage.

Fig. 5

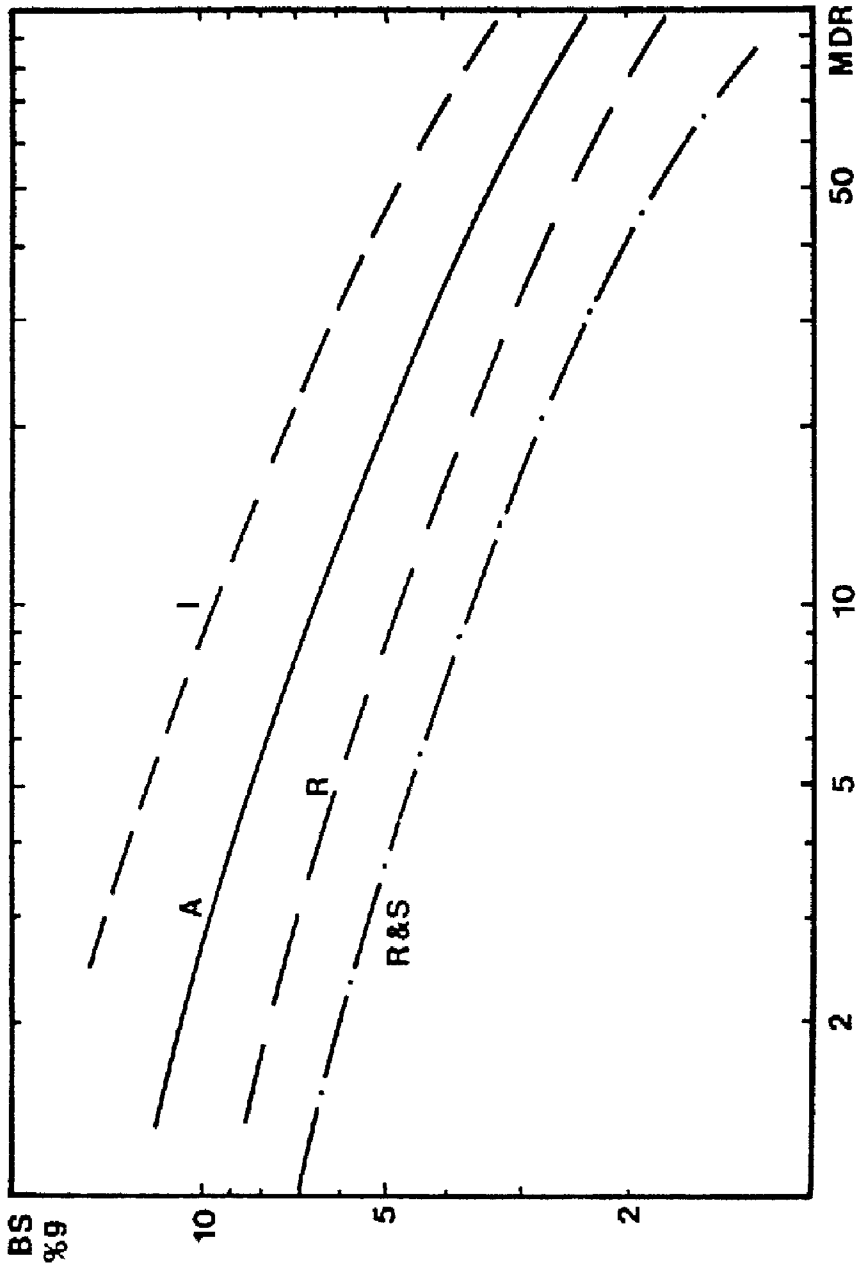


Fig. 6. Approximate run-up height to return period correlations for various places. Graph A represents the situation of a very exposed region, like the north-eastern coast of Honshu, Japan. B represents the exposure of a region corresponding approximately to Hilo, Hawaii, C indicates the risk for a place like Humboldt Bay or San Francisco, both in California. Graph D gives an approximate indication of exposure in the more exposed part of the Mediterranean Sea. On graphs A and B maximum runup heights observed in Japan and Hawaii have been indicated, showing that the graphs do not present possilble maxima. This is equally valid for the Mediterranean coasts, where much higher runups than indicated by graph D have been recorded during the short observation period of only lone century.

Fig. 6

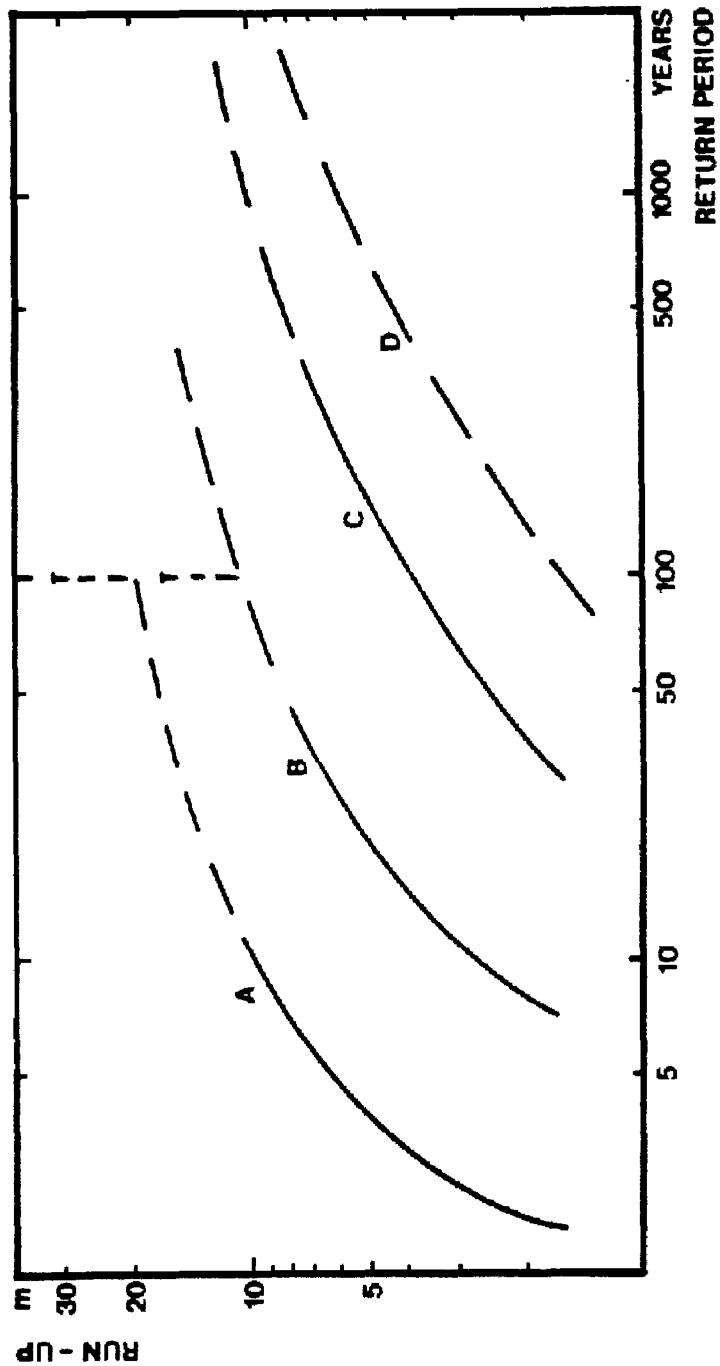


Fig. 7. The graphs show the correlation between the MDR of moderately irregular buildings founded on medium hard alluvium and building quality expressed as base shear (BS) and MM intensity. The example entered corresponds to the one discussed in the text. It is assumed that buildings of about 4% g base shear are to be optimized considering orientational sensitivity. The general MDR of buildings of such resistance is about 18%. We assume that the MDR's differ by 4 : 1 for buildings experiencing the maximum shaking in the direction of their short (weak) axis as compared with buildings about perpendicular to them. For the more exposed buildings the MDR would therefore be about 36% and for the others 9%. An MDR of 36% implicitly means substantial non-structural damage and even damage to structural members. According to our damage probability matrix (Table 1) about 28% of these buildings would suffer damage between 50 and 100%, and this would imply the possibility of partial or total collapse. We assume that in view of this it is decided to strengthen the buildings along their weak axis to such an extent that the MDR is halved. Keeping the damage ratio at 4 : 1 the MM VIII graph tells us that the buildings' structure should be designed for 8% g for earthquake forces acting along the short axis. In a more detailed analysis one would have to study the project with reference to other parameters mentioned in the paper as determining the MDR in order to see whether such buildings conform to those on which these graphs are based (moderate irregularity and medium-hard alluvium). The main text discusses an example of optimizing the design of an asymmetrical building. A second investigation must address the most important intensity. Details are discussed in reference (1); it may suffice to state here that MM VIII contributes most to damage from all possible intensities for buildings of medium strength and configuration and the subsoil assumed here. The better the conditions are (stronger buildings, harder foundation material, nearly perfect symmetry, compatible materials, etc.) the more important become the (much less likely) higher intensities, and vice versa. The pragmatic method shown here for correcting the adverse influence of different strengthening from fill-in walls, irregularity, etc. has the advantage of being based on data from a very large sample.

Fig. 7

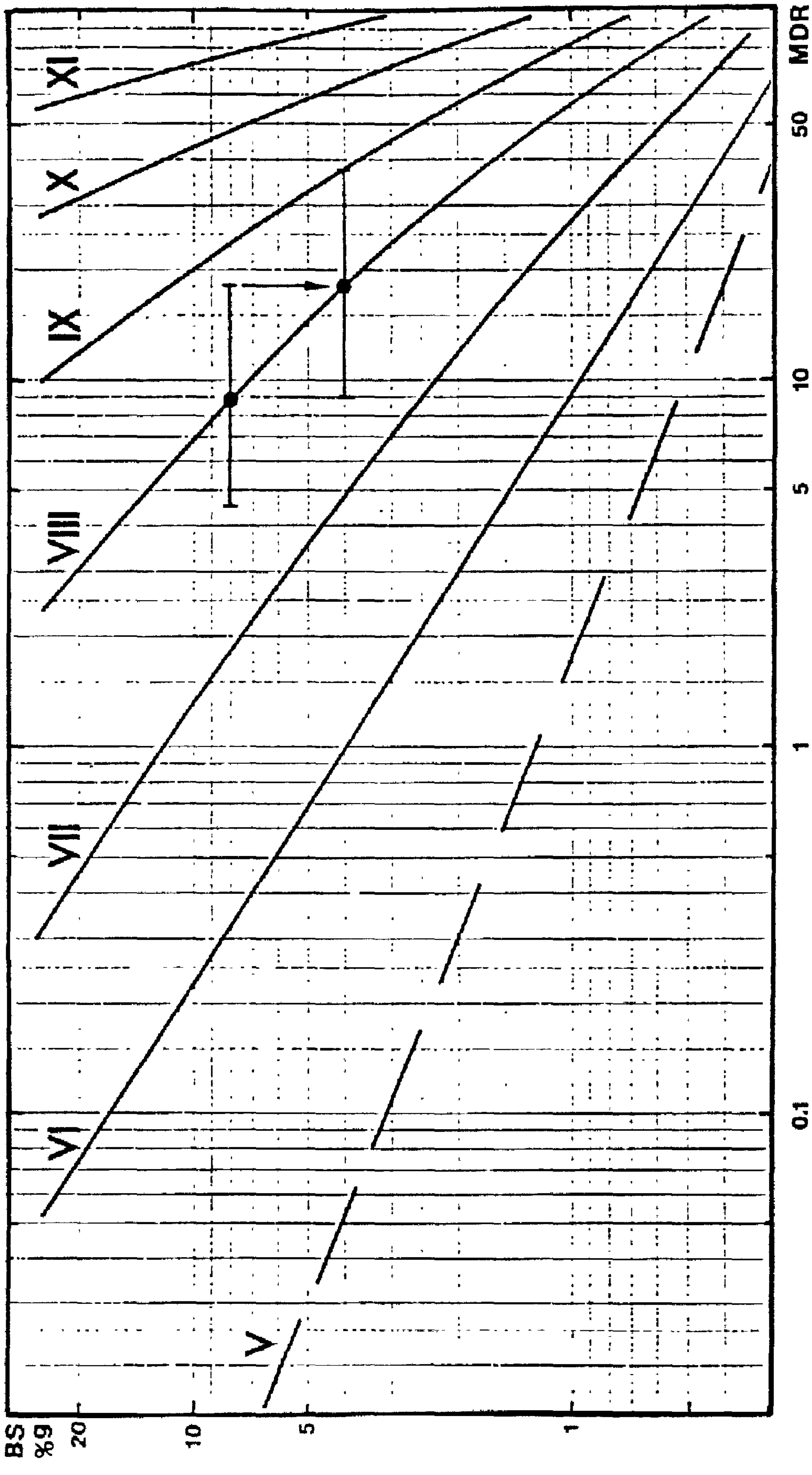


Fig. 8. Approximate correlation between quality or vulnerability of buildings (graphs A - E) and death-rate (DR) in percent of the population, depending on the intensity (MM) of earthquake shaking. The graphs represent: A = buildings of adobe and vulnerable rubble masonry, B = unreinforced brick buildings, C = 2.5% g buildings with a structure of reinforced concrete, D = similar buildings of 6% g, and E = similar buildings of 20% g. The death rate among, for instance, the occupants of brick buildings hit by MM VIII may be about 10% but only 0.07% in buildings of 6% g. These graphs are valid for average medium hard alluvium and moderately irregular buildings. As explained in the text these graphs should be used with the utmost care, not only because of the substantial uncertainty which afflicts the samples and sub-samples, but also because of the many parameters determining the behaviour of buildings and hence the number of victims. It should be noted that the catastrophic failure of a small number of buildings with many people in them when they collapse can, for instance, very much affect the DR. Moreover, the DR is influenced by the hour of the day, the day of the week, and the season when the earthquake strikes.

Fig. 8

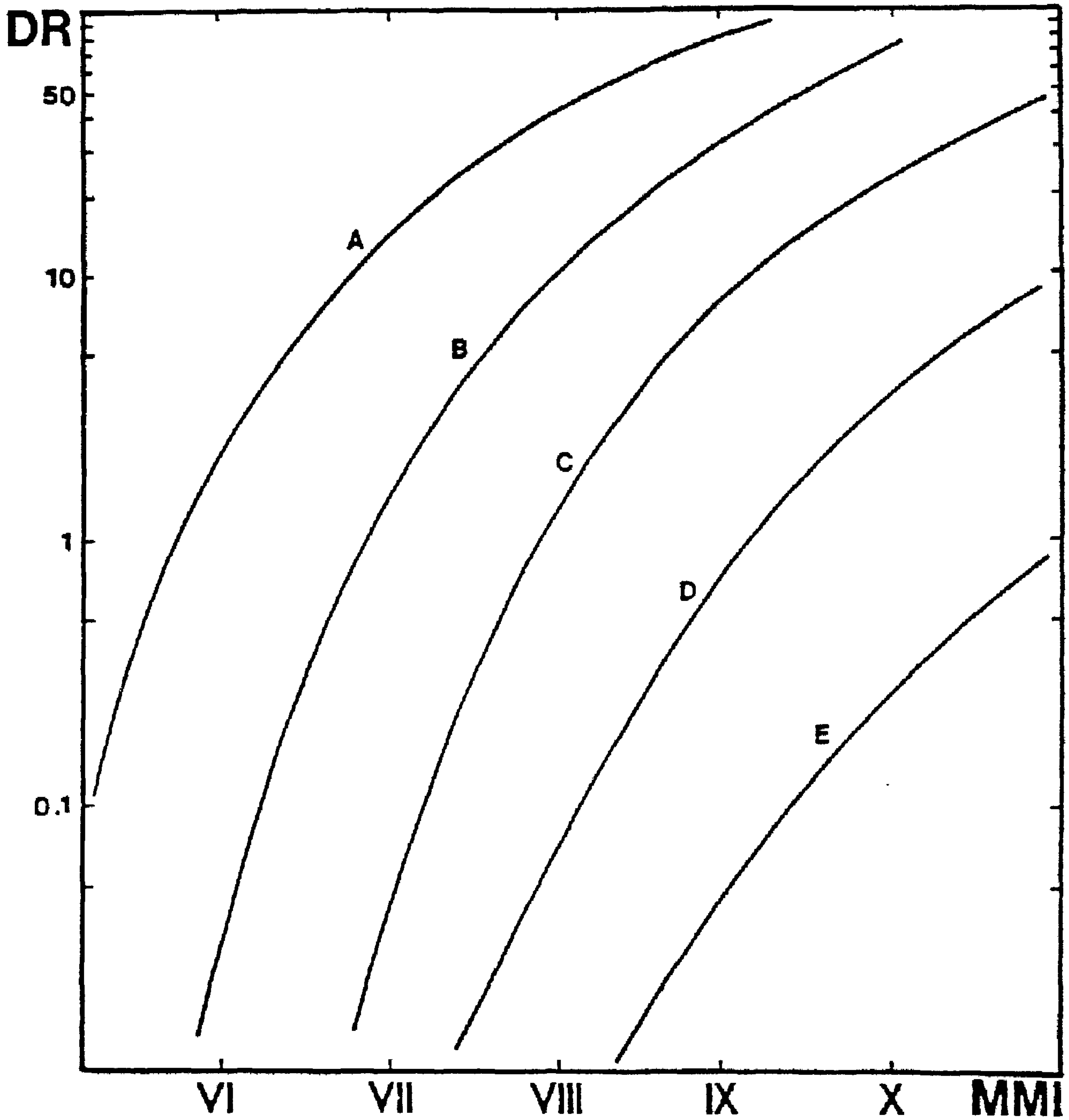


Fig. 9. This sketch shows on the left the orientation of 8- and 9-storey buildings and on the right that of 14- and15-storey buildings in a very large housing colony in Mexico City which we analysed after the earthquake of 1985 (9). The floor plans are shown to scale. The percentages indicate the mean damage ratios (MDR) related to the new replacement value of the buildings. It is seen that buildings which had their long axis running approximately E-W suffered much less damage than those standing perpendicular to them. The MDR-ratio is about 100 : 1 for the 8- and 9-storey buildings and about 3.6 : 1 for the 14 & 15 storey buildings. The latter difference would, however, been larger had those orientated approximately E-W been as wide as those pendicular to them. This sample also illustrates the effect of damage saturation. For the sake of completeness values of ground shaking recorded on the extinct lake of Texcoco are added. It should not, however, be assumed that these values represent the actual behaviour at all places in this large area.

DIRECTION	ACCELERATION cm/sec^2	VELOCITY cm/sec	DISPLACEMENT cm
NS	98	39	17
EW	168	61	21

Fig. 9

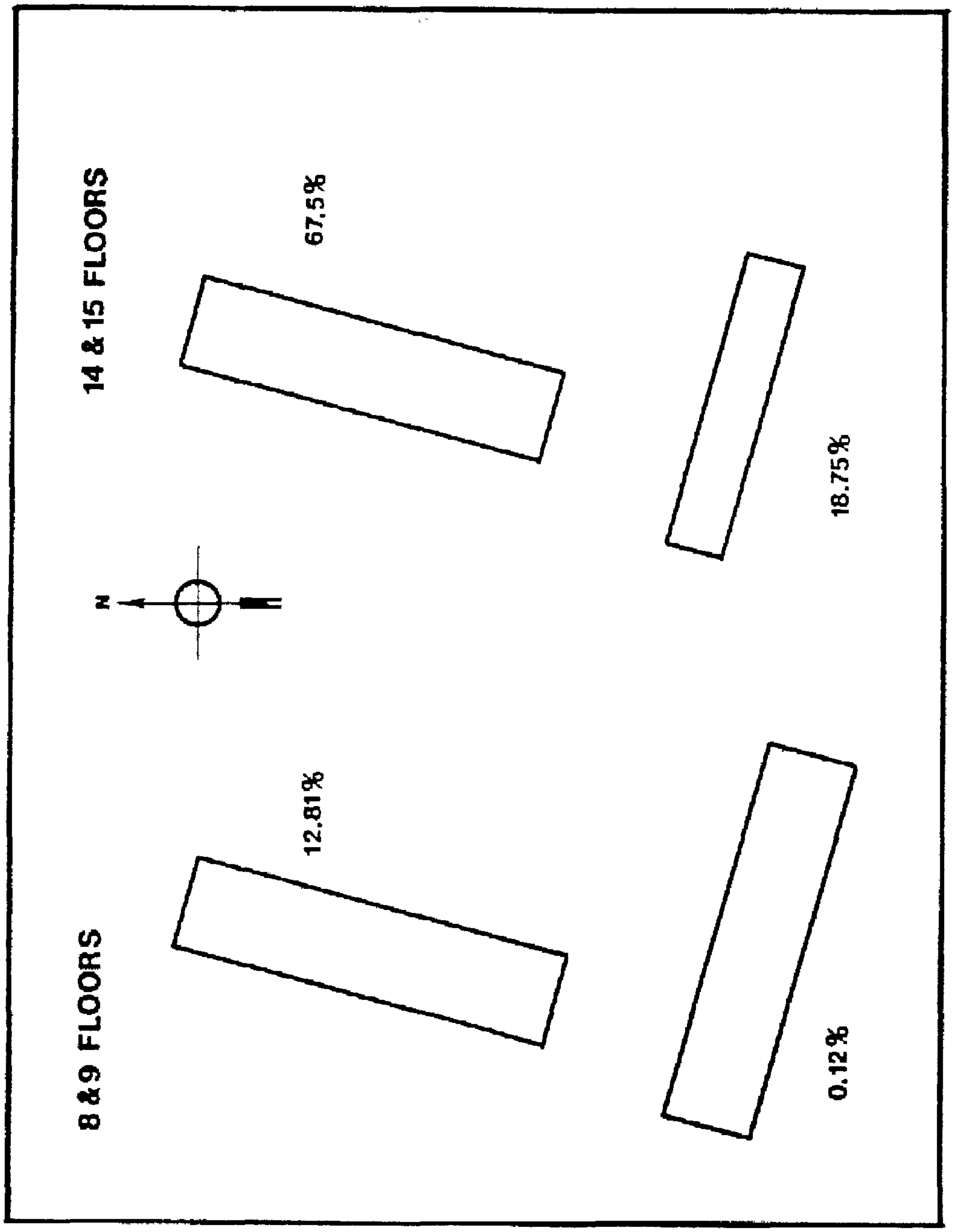
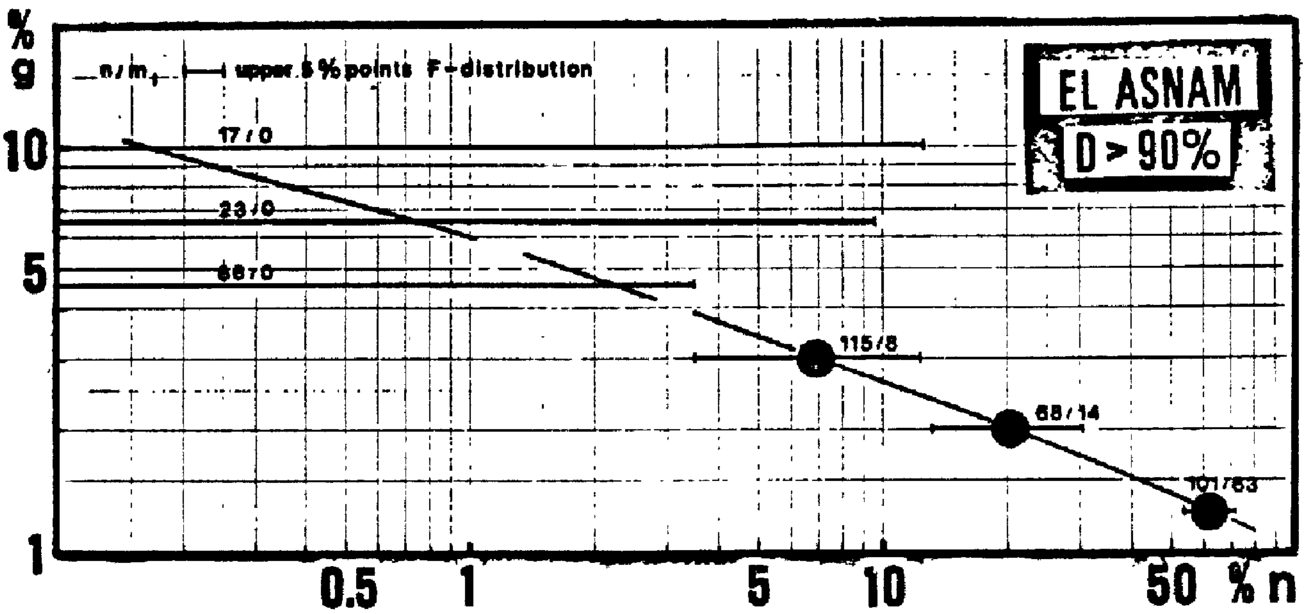


Fig. 10. This graph is based on a sample of 390 modern buildings which were investigated after the El Asnam, Algeria, earthquake of 1980. The curve shows the correlation between the base shear of the buildings (% g) and the percentage of the respective sub-samples which sustained damage in excess of 90% of their new replacement value. For each sub-sample the size of the sample is given first, followed by the number of buildings with D > 90%. The bars show the 95% confidence range employing the Fisher distribution which appears to produce more realistic results than the binominal distribution if the sample is small. It is seen that there was no case of collapse among the 106 buildings with a base shear of 4.5 % g or better. It must, however, be stressed that the modern buildings in El Asnam were for all practical purposes stiff and regular, a feature which reduces MDR's. The general experience is shown in Table 2.

Fig. 10



%
g
n/m
upper 5% points F-distribution
EL ASNAM
D > 90%
17/0
23/0
66/0
115/8
68/14
101/63
10
5
1
0.5
1
5
10
50
% n

III. A. 3. VOLCANISM

Introductory Remark

The Terms of Reference for the Mission did not include the risk related to volcanism. For this reason only an outline will be presented, and this decision was taken by the editor in view of his international experience with this risk. The main reasons are:

- Devastating volcanic eruptions are rare or even very rare events. Therefore the extent of the risk is often not appreciated.

- There are a number of volcanoes in Armenia which have produced very large eruptions in the past and as the average life-time of a volcano is of the order of ten million years, these volcanoes cannot be considered extinct, in particular as they are in a seismic zone.

- Although the return period of catastrophic eruptions is long the disaster caused by such events can be extreme.

- As the exposure is the probability of a disaster multiplied by the consequences of the eruption a short note is warranted, in particular if the reference for the mission is not interpreted in a parochial manner.

A Synopsis of the Essential Parameters to be Considered

Volcanology is still a very young science. Deductive investigations started about 150 to 200 years ago, but even today insight is limited; the chances of having experts and instruments on the spot when eruptions occur are small, the monitoring of volcanoes is deplorably thin, magmatic chambers are beyond our reach, and the very process of an eruption is dangerous to life. Therefore reliable data is scanty.

The problem of assessing volcanic hazards is componded by the fact that large eruptions may be separated by centuries or millenniums. The period between such eruptions may be devoid of any activity. In this respect it must be noted that there is no reliable way to distinguish between dormant and recently extinct volcanoes. Moreover, long periods of volcanic quiet are often terminated by very violent eruptions.

In volcanic risk assessment it is often not realized that volcanoes may remain active for 20 million years. A period of dormancy of thousands of years and longer does therefore not signify that a particular volcanoe is harmless. This is particularly true if the volcanoes in a region have produced explosive eruptions in the past. Explosivity is correlated with the acidity of the lava. The volcanoes in the Caucasian region belong to this type and the author has observed many substantial deposits of tephra of a bright yellowish and pinkish colour which are symptomatic for ejecta produced by violent eruptions. As a matter of fact, the stone masonry buildings in the region are constructed of tuff of this colour, that is of material from violent and even cataclysmic eruptions. As a general rule one should therefore assess this specific risk very carefully.

There are a number of large volcanoes in the Caucasian region and as products of eruptions may travel over large distances we cannot consider only volcanoes in Armenia. The volcanoes which are likely to have been active during the Holocene epoch are:

- Tendürük Dagi, distance to Yerevan about 100 km
- Ararat. distance to Yerevan about 50 km
- Kazbek, distance to Tbilisi about 105 km, to Yerevan about 280 km
- Elbrus, distance to Tbilisi about 260 km, to Yerevan about 390 km
- Aragats, distance to Yerevan about 45 km, to Leninakan about 35 km
- Agmagan-Karadag, distance to Yerevan about 70 km
- Dar-Alages, distance to Yerevan about 100 km

This list of volcanoes is far from incomplete and it does not include the many vents, and many of these features are much nearer to the populated centres than the distances given above.

The evaluation of volcanic risks is made very difficult by the extreme shortage of literature on the hazard and the vulnerability. For instance, the books stated under (1 - 4) contain useful general information but, with the exception of (4) no quantified data on vulnerability. Even (4) is incomplete in this respect. No publication provides guidance in connection with volcanic hazard, i.e. the probability of eruptions. We have therefore endeavoured to close this gap (5).

Damage potential and extent of damage are decisively determined by the distance between the individual risk and the volcano. The accumulation of damage depends on the area which may be involved in one event, and the accumulation and degree of damage is also affected by the volumes ejected.

The distances reached by individual lava-flows will depend on many factors, such as the viscosity of the lava, the volume ejected and the time-history of the eruption, topographic features which may guide or disperse the flow, and the gradients of slopes.

Unfortunately there are not very many observations relating to the larger and therefore dangerous flows, and, in addition, inconsistent observations do not permit simple extrapolations from the frequent, i.e. numerous, smaller flows.

The distance over which ash falls, and the depth-distance distribution, depend on many factors. In this area too, information is scanty, which is deplorable, for ash-fall can cause serious problems.

A maximum distance scenario would about be represented by a very powerful and voluminous eruption with most of the energy released within a comparatively short span of time and happening at a time when a high velocity polar-front jet ($v > 100$ m/sec) is prevailing.

Depth-distance distribution do often not follow a simple pattern but may show, for example, a bimodal depth distribution or even a multimodal one. This introduces a further uncertainty which is also reflected in the exactitude of estimates of ejected volumes.

Volcanoes may throw out blocks and bombs, and these may cause damage. The distance reached depends on the muzzle velocity, the angle at which the projectile is fired and the size and mass of the missiles which may bombard the element at risk. All the main parameters which determine the trajectory are beset with uncertainties from lack of observation, the scatter resulting from inclination and length of conduit over which, e.g., blocks are accelerated, the pressure behind the explosive event, and the size and density of missiles ejected.

As risk assessment may benefit from actual data, Table 1 shows what ranges of volcanic projectiles have been observed so far. Again it is stressed that it is extremely unlikely that maximum ranges were accidentally among the comparatively few observations.

TABLE 1
EXAMPLES OF DISTANCES REACHED BY VOLCANIC PROJECTILES

VOLCANO	YEAR	DISTANCE (km)	SIZE OF PROJECTILE
Krakatau	1883	80	Pumice stones (1)
		40	Head size pumice (2)
		40	Fist size stones
Tambora	1815	40	0.15 m diameter
Asama	1783	11	0.5 m diameter
	1937	3.5	> 1 m diameter
Soufrière	1902	6	21 kg
Kilauea	1924	1.1	10 t
Stromboli	1930	3	30 t
Arenal	1938	0.3	340 t
	1968	>4	> 0.5 m diameter
Ruapehu	1945	1.2	0.9 m diameter
Usu	1977	2	0.3 m diameter
Karkar	1979	1.5	abt. 1 t
Iwojima	1986	abt. 0.5	10 m diameter

(1) Size of gravel
(2) It is not stated in Verbeek's report whether he refers to a human head, athough this appears to be logical.

In connection with massive projectiles there arises the question of the velocities at which such projectiles will hit roofs, etc.. A light bomb of 10 cm diameter (density = 0.62 g/cm^3) would have a terminal velocity of about 50 m/sec, a block of this size with a density of 2.5 g/cm^3 would have one of about 90 m/sec. If the diameter is 100 cm, one would find for these specific gravities a velocity of 110 and 230 m/sec.

In risk assessment we must also consider the distances which may be covered by lahars, in particular as elements at risk may be located in valleys close to water, sites particularly prone to damage due to lahars.

The next criterion of exposure is related to the area affected by one eruption for each product of eruption.

We shall mention first prehistoric plateau flows. Although this belongs to the realm of probabilities, it would be very wrong to interpret the term prehistoric in the same way as the evolution of species. There is no assurance whatsoever that super basalt flows are as prehistoric, extinct and therefore as unlike to reappear as Tyrannosaurus Rex.

A difficulty related to such plateau basalts is that individual flows have only been singled out in a very limited fashion. A further problem relates to the dating of such flows, as dating methods incorporate margins of error depending both on the accuracy of the experiments and on the intrinsic errors of the method chosen.

Data of area covered by modern lava flows are limited and the values given do not constitute suggestions regarding possible or probable maxima.

The complex of glowing avalanches, pyroclastic flows, and base surges is of particular importance where the explosivity index of volcanoes is high, like in Armenia.

As with plateau basalts, there are prehistoric examples of colossal ignimbrite flows. Just as with plateau basalts, there are far more regions where such flows have occurred. Most of the flows comprise rhyolitic material, a fact which together with their unstratified, welded, and poorly-sorted appearance attests to violent events. It can be assumed that eruptions which produce very large or resurgent calderas may also cause ignimbrite flows.

In view of the harm which may be done by explosive eruptions Table 2 is of particular interest. It lists examples of volume of material erupted. In general this material refers to total ejecta, i.e. including flows.

TABLE 2
LIST OF SOME LARGE CALDERAS

Volcano	Diameter or Dimensions (km)
Toba, Sumatra	100 x 35
Yellowstone region, U.S.A.	70 max. diam.
Kari-Kari Caldera, Bolivia	36 max. diam.
Cerro Galan, Argentinia	34 max. diam.
Taupo Volcanic Zone, New Zealand	35 x 23
" " " " "	35 x 22
" " " " "	19 x 12
" " " " "	11 x 9
Timber Mountain Caldera, Nevada	32 x 29
Long Valley Caldera, California	31 x 16
Bur Ni Geureudong, Sumatra	30
Atitlan, Guatemala	28
Kuttjaro Caldera, Hokkaido, Japan	26 x 20
Sabaloka, Sudan	25 x 15
Ata Caldera, Kyushu, Japan	25.5 x 12
Valles Caldera, New Mexico	25 x 20
Taal Lake, Luzon, Philippines	25 x 17
Aso, Kyushu, Japan	24 x 18
Me-Akan, Hokkaido, Japan	24 x 13
Creede Caldera, Colorado	23
Aira Caldera, Kyushu	23 x 17
Kikai Caldera, Ryukyu Islands	23 x 16
Tibesti, Chad	20
Ngorongoro, Tanzania	20 x 16
Pico de Teide, Canary Islands	20 x 12
Opala, Kamchatka	15 x 13
Vilyuchik, Kamchatka	15 x 13
Rabaul, New Britain	15 x 10
Piton de la Fournaise, Reunion abt.	15 x 7
Batur, Bali, Indonesia	13.8 x 10 7
Galloseulo, New Britain	13 x 10.5
Erebus, Antarctic	13 x 10
Gorley Khrebet, Kamchatka	13 x 10
Shikotsu, Hokkaido, Japan	12
Long Island, New Guinea	12 x 10
Ambrym, New Hebrides	12 x 9
Suswa Caldera, Kenya	12 x 8
Omuro-Yama Volc. Group, Honshu, Japan	11 x 10
Menengai Caldera, Kenya	11 x 9
Coatepeque Caldera, Guatemala	11 x 7
Masaya Caldera, Nicaragua	11 x 6
Santorini, Greece	11 x 5
Berutarube, Kurile Islands	10
Iturup, Kurile Islands	10

Toya, Hokkaido, Japan	10
Medvezhia, Kurile Islands	10
Mutnovsky, Kamchatka	10 x 8
Sierra Negra, Galapagos	10 x 7
Crater Lake, Oregon, USA	9.5
Ketoi, Kurile Islands	9
Damavand, Iran	9
Nemrut Dagi, Turkey	9 x 5
Tao-Rusyr, Kuril Islands	>8
Nemo Peak, Kuril Islands	>8
Kapi, Indonesia	8
Sukaria, Flores, Indonesia	8
Deception Island, Antarctic	8 x 6
Shimushir, Kuril Islands	7
Banda Api, Banda Sea	7
Krakatau, Indonesia	7
Cinco Picos, Azores	7
Tambora, Indonesia	6

The author feels that also the large Ararat may have a caldera as inspection with binoculars shows features on its shoulders which indicate a large old caldera.

Lahars may affect quite large areas. Prehistoric data have not been sufficiently segregated into individual flows. Therefore great care should be exercised when estimating exposure.

Probability Aspects

The estimation of the probability of eruption of volcanoes in general and of individual volcanoes in particular is beset with many problems. Estimates are hampered by the size of the sample. Even if we take about 9,000 eruptions over the last 10,000 years, this is only a small fraction of the number of instrumentally recorded earthquakes, and in addition about three quarters of the sample are from the last 230 years, which if compared to the average return periods of large and dangerous eruptions is too short a time for precise estimates. Moreover, the issue of a simple statistical nature is further complicated by the possibility of "volcanic gaps" and "volcanic trends". The situation may be somewhat better for certain individual volcanoes where long histories are available, but even then the margin of error in the estimation of the probability of a cataclysmic eruption is enormous. Long as such histories may be, they are only a very small fraction of the many million years during which a volcano remains active and capable of devastating eruptions.

If we consider cases of volcanic activity sustained over more than one year on an average annual basis, we have a sample of approximately 9,000 eruptions in 10,000 years. This is not much if we consider that between about 500 and 1,300 volcanoes are thought to be active, therefore the average annual observation per volcano is almost negligibly small. Moreover, the evaluation suffers from a very low frequency of observations during the early millenniums - only about 3% are from the first 6,000 years - as well as from uncertainties related to the known number of sources of eruptions.

As with earthquakes, the situation improved with time; for instance, the number of known eruptions per century increased from 3.4 for the period from 8,000 BC to the time of Christ, to 25.3 for the next 1,500 years; it reached 580 for the period 1500 - 1750, and 2,970 for 1751 - 1980. But even the last observational period provides a very thin foundation for probability estimates, because the 30 eruptions per year come from quite a large number of volcanoes of rather different nature, with varying products of eruption as well as magnitudes of eruption.

The most dangerous eruptions are rare occurrences and sometimes happen only at long intervals. This teaches us not to consider volcanoes as harmless if no eruption has occurred during the Holocene epoch. Volcanoes can produce devastating eruptions during a life time of about ten million years, much longer than the entire lifetime of mankind. There are many accounts of volcanoes believed to be extinct and even of mountains not considered to be volcanoes which suddenly erupted violently. To be on the safe side, most volcanoes in earthquake zones, particularly subduction zones, should be considered potentially dangerous and only dormant, but not extinct.

Assuming, for instance, that a volcano in dangerous proximity, composed of or containing deposits of acidic material, has not erupted for the last 10,000 years, we can calculate that, when selecting 99% confidence, it could have a return period of eruptions of about 1,500 years, or of only 662 years if the exposure is grave enough to warrant a confidence level of 99.99%. Such calculations are bound to be crude and even misleading because they implicitly assume that eruptions are random.

Moreover, probability estimates made for individual mountains are affected by the incompleteness of lists of events and by margins of error in dates. For instance, the Chronology of Eruptions in "Volcanoes of the World", published by the Smithsonian Institution, which is probably the best record available, does not show any entry for 1439, when the volcano Kikour allegedly became active after a violent earthquake in the Armenian part of present-day Turkey. There is an entry for an unnamed volcano in Turkey for 1450, with an uncertainty of ±50 years, but with a symbol indicating that the eruption is uncertain. From the co-ordinates one can assume that both dates refer to the same volcano.

An even more problematic issue is the magnitude of eruptions, as measured for example according to the Volcanic Explosivity Index. It is not to be assumed that lists of eruptions are of similar reliability for any given period of time for large, medium-sized, and small events. From this it can be inferred that large events are over-represented, and a less negatively skewed distribution should, therefore, be sought.

If we consider only the last 230 years, and if we disregard the fact that in 1750 something like 10 eruptions were recorded per year but 50 in 1950, the annual eruption rate for any one known volcano had risen from 0.057 to 0.08. This is only one aspects of volcanic gaps and/or trends, similar to those observed in seismology.

There is one general lesson to be drawn from such statistical reasoning based on the global sample. If the uncertainty is considerable for the entire sample, it will generally be even greater for individual areas. Moreover, it is very unlikely that all eruptions are known, even if we do not try to go back many millenniums. This implies that activity is higher and return periods shorter than indicated by the available sample. A detailed discussion of the probability of eruptions and many examples and of the damage caused are contained in (5).

RECOMMENDATIONS

1. The volcanoes in Armenia should be analysed as regards the hazard and the threat they pose.

2. A zoning map should be prepared at least for the most populated places

3. Selected volcanoes should be instrumentally monitored.

4. The risk from volcanic eruptions should be integrated in catastrophe plans (cf. (6).

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III. A. 4. PROBLEMS OF WATER HAZARD IN ARMENIA

4.1. Introduction and General Aspects

The terms of reference of UNDRO-mission to Armenia were to list the disasters which could affect populated areas, to assess their probability and magnitude, and to suggest measures for protection, forecasting and warning in order to reduce the damage as much as possible. Within this broad scope, the present writer's role was to assess the water hazards, and to recommend appropriate measures in this regard.

The area of Armenia is largely mountainous; two third of the area is covered by relatively recent volcanic action. The Lesser Caucasus Range running approximately NW to SE provides the water divide. According to the Hydro-meteorological station of Yeravan, there are, in all, 150 rivers in Armenia. The majority of these flow south of the Lesser Caucasus, and after flowing generally in a southerly or southeasterly direction join the River Araks which forms the border between USSR and Turkey. A few streams enter the large fresh water lake Sevan. North of the Lesser Caucasus, the flow is generally in a northern direction and joins river Karu, which flows eastwards outside the border of Armenia. The slopes to the South of the Lesser Caucasus are much steeper than those towards the North. Accordingly the rivers are in the nature of hill torrents with incised sections.

The nature of water hazard for Armenia falls into the following three categories:

(a) Natural Flooding. This means the over flowing of a river beyond its normal cross-section due to excessive runoff resulting from heavy precipitation. It also includes damaging erosion of bed or banks during a flood.

(b) Floods resulting from the release of water stored behind temporary natural barriers formed across rivers by land slides which occur quite frequently in most parts of Armenia

(c) Flood wave caused by a possible failure of man made dams, of which there area large number, existing and projected.

Each of these three categories are discussed below.

4. 2. Natural Floods

Due to the nature of topography and of the rivers, natural floods are not a major hazard for Armenia. Nevertheless, it will not be correct to presume that there is no such danger. The author was informed that the capital Yeravan, which contains one third the total population of the Republic, was flooded in 1946, and again in 1949. The town of Alavardi on river Debet in the North was also flooded in 1970. Many important towns are located on river banks and may well be susceptible to flood damage. A complete record of past flood damages in Armenia could not be obtained. Besides the towns, agricultural land located on lower terraces adjacent to the rivers may also suffer damage. The author was informed that River Araks causes problems by changes in meander pattern, and personally saw construction of bank protection works on River Agstef during a visit. Thus in a comprehensive plan of hazard protection, floods cannot be ignored.

The iso-hyetal map of annual rainfall is shown in Fig.1. It will be seen that the annual rain fall varies from a maximum of 1000 mm to a minimum of 300 mm. The variation is not systematic, though the general trend is of reduction from North to South. The annual average rainfall over the entire area may be a moderate 600 to 700 mm. Yet, this does not preclude occurrence of heavy precipitation. The maximum recorded rainfall for a single day in Yeravan is 51 mm which occurred in 1974, while in Kafan in the South East a maximum of 176 mm has been recorded in a day. Thirty years of annual rainfall data at Yeravan from 1956 to 1985 shows a variation from 157 mm to 481 mm. A study of rainfall trends shows (Fig.2.) that the standard deviation increases with reducing rainfall. For Armenia as a whole a deviation in any year of 30% may be expected while for an individual station it may be up to twice as high (Tiedemann 1988). The global sample contains many cases of "unexpected" heavy short-term rainfall which occured during recent years. In recent years freak heavy precipitations, and heavy flooding have ocurred, for instance, in western, semi-arid parts of India.

The author examined the annual peak flow data of River Araks for 25 years from 1964 to 1988 measured near village Syemalu (Appendix I). The discharges vary from a maximum of 1690 m^3/s to a minimum of 180 m3/s with a mean of 640 m^3/s and a standard deviation of 348 m3/s. The coefficient of variation comes to 0.54. The variability is evidently high. For smaller streams than Araks, the variability is likely to be the same or still higher. It follows that over the long term, floods much in excess of the mean can be expected. For example, using Gumbel's distribution for this data the 100 year flood will be nearly 1940 m^3/s, and the probability that a flood of this magnitude can occur during the next decade is only slightly less than 10%. The 1000 year flood, according to the same distribution, will be about 2,670 m^3/s, and will have a probability of a little less than 1% during the period of a dacade. Probablity predictions based on a limited peried of record do not take into account extraordinary meteorological conditions. It would, therefore, be safe to devise protection measures for a thousand year flood with some factor of safety to allow for freek storms, and more adverse climatological trends.

The area south of the Lesser Caucasus has already lost most of its vegetal cover, and future worsening of the already bad situation may not be significant so far as the magnitude of surface runoff and its time of concentration are concerned. However, increasing pressure on land may result in land use practices, e.g. over-grazing, or ploughing of sloping land, which will further aggravate the sedimentation problem. Sedimentation would cause aggradation of river channels, and raising of flood levels. It is now generally conceeded that there is a slow but recognisable trend towards the warming up of the atmosphere due the so called "greenhouse" effect. In the past century there was been an average rise of 0.60°C in atmospheric temperature. An increase in atmospheric temperature increases the water holding capacity of the air cover - and when there is more moisture there is always a chance of its rapid release under favourable conditions. Thus there is a normal expectation of more intense, and more frequent freak cloud bursts. This is a global problem and has no local solution.

4. 3. Structural Methods for Control and Management of Floods

The methods for control and management of floods fall into two catagories:

(1) Structural
(2) Non-Structural

The structural methods inlcude storage dams, marginal embankments or walls, river channel improvement to enhance conveyance capacity and diversion of a part of the flood to a natural depression or another stream.

There are a large number of dams, existing, under construction and projected, in Armenia. Indeed, there is hardly any important stream on which a dam has not been built or is not planned. These dams are primarily irrigation and hydropower dams. Yet by their very function, viz. to store water during the high flow season for use during the lean season, they have a moderating effect on floods, even though, no storage may be specifically earmarked for floods. The author could not ascertain if there is a flood moderation component of storage in any of the dams. It would be advisable to keep in view the possibility of late floods in the operation of important reservoirs upstream of population centres e.g. Aparan and Razdan dams. The river Ketar, which flows through Arsvan, has been canalised by construcion of marginal flood walls. In some reaches the river channel is covered over. The designed capacity of the river channel could not be ascertained. However, as discussed earlier, it should be adequate to carry, without over flowing, the extrapolated 1000 year flood with an extra safety margin of, say 25%. The moderate investment needed will be economically justifiable. The same applies to other urban areas. For protection of agricultural areas, where needed, embankments or walls may well be designed for a 100 year return period.

On account of steep slopes, and poor vegetation cover, heavy loads of sediment are brought into the rivers. A photograph of River Alavardi in flood in our possession shows the heavy debris in the river bed. To maintain the conveyance capacity of the channels, their longitudinal sections should be monitored after high flow season, and excavation or dredging carried out where necessary.

4. 4. Non-structural methods for control and management of floods

It has been experienced that when structural methods are adopted for flood control, there is a tendency for more intensive economic development in the flood plains of the rivers due to the sense of protection provided by such structures. This has resulted in the aomalous situation, that inspite of heavy investments in structural measures, the flood damage, in financial terms, rises instead of falling. In the United States, average annual flood damages continues to rise despite substantial Federal investment, and are now estimated at nearly three billion dollars per year (Steinberg 1984). In India, while the average annual damage during the period 1953 to 1960 was less than U.S. $ 90 million per year, it rose to about U.S. $ 1800 million in the period 1981 - 1988 . (Char N.V. V, 1989). During this period a sum of Indian Rs. 22,970 million (U.S. $ 2,300 million, approximately, taking an average exchange rate over the period) had been invested on structural flood control measures. Engineers and administrators have, therefore, come to the conclusion, that while structural measures are necessary, they are not enough. It is necessary to take non-structural measures, side by side with them.

A long term measure, which can have an appreciable impact on flood peaks, though it may also involve some small structrual works like check dams, is management and improvement of the drainage basin or water shed of the river. Besides reducing flood peaks and influencing the economic value of the forests themselves it has other important economic advantages like reduction of soil erosion resulting in better productivity, less sediment inflow into rivers and reservoirs enhancing useful life of the latter and to a limited extent controlling shallow land slides and mud flows.

In Armenian conditions, as seen by visits of the country side, the most important measure needed is afforestation of hill slopes, particularly the southern slopes of the Lesser Caucasus, which are mostly devoid of vegetal cover. An effort is already on in this direction as could be seen at several locations, but it needs to be intensified and sufficient funds should be allocated for the purpose.

The forest cover reduces the surface runoff by processes of interception, increased infiltration, and increase in time of concentration by obstructing surface flow. Interception can be as much as 20% of precipitation with a dense canopy - but such a canopy may be difficult to attain, and may not even be advantageous as moisture intercepted on the canopy evaporates back and is not available for watering the vegetation and as useful runoff. Permanent forest and grass cover may increase the infiltration rates by 2 to 3 times, and this water would ultimately re-emerge into the river basins. Close growing crops also increase infiltratlon rate by 1.5 to 2.0 times (Viessman et al 1977). A good policy would thus be to re-afforest the higher ranges of slopes, with species which are adapted to local climate and, as far as possible, are drought resistant and deep - rooted. Wherever possible the lower slopes may be grassed, or used for close growing crops. For the latter purposes it is important for grass lands to regulate grazing by controlling the number of animals, and for cropped land to ensure contour ploughing, and contour bunding. At present, it was possible to see, at a few locations, ploughing along the slope for small fields. This practice should be controlled.

Water-shed improvement is a long term measure, and benefits start accruing after 25 to 30 years, and full benefits may be achieved only after 40 or 50 years. However, it should be accorded a high priority in the economic plans, and depending on the resources available, the area extended from year to year.

The other important aspects of the non-structural measures are flood forecasting and warning arrangements and flood plain zoning. (Fram Ji, K.K., ed. 1983, Report of the National Flood Commission, and others).

Flood forecasting is based on the information provided by the network of Hydro-meteorological measurement stations. Armenia is served by a well distributed network of meteorological and stream flow gauging stations. Maps in Figs. 4 & 5, obtained through the courtesy of Hydro-meteorological station of Yerewan show the distribution of meteorological stations, and stream flow gauging stations respectively. We were informed that in 50 regular meteorological stations, observations are made every 3 hours. Three of the stations are self-recording and their information reaches Yerevan through telemetry. There are 125 stream gauging stations on which observations are made twice a day and sent to Yerevan. Seventy five of the rivers have self recording gauges. For Yervan area systematic records are stated to be available from 1882.

According to World Meteorological Organisation (Geneva 1970) the recommended densities of precipitation network are as follows :

1. For flat regions of temperate, mediterranean and tropical zones, 600 to 900 km^2 per station.

2. For mountainous regions of temperate, mediterranean and tropical zones, 100 to 250 km^2 per station.

The existing net work may be examined according to this requirement, and where necessary adjusted to bring it into conformity with W.M.O. standards. Self recording and telemetering stations should be provided at suitable locations affecting important population centres and dams.

After the field information is received by the Central agency, the next step is to make a forecast. The methods of making forecasts, mainly multi-variable curves, and watershed models are well known and need not be elaborated. Both have to be developed and tested over a period of time. Depending on basin size and shape, and stream length to vulnerable areas, the forecasts may be made upto 72 hours in advance, and improved progressively. For smaller river streams and steep slopes in Armenia it may be difficult to give forecasts earlier than 12 hours. Even so, these will be of great benefit to Civil Defence Authorities as well as to reservoir operators.

We were informed by the Hydro-meteorological committee of USSR in Moscow that there are four major regional centres for forecasting of catastrophic events, one in Moscow and the other three in the Far East. In view of the special susceptibility of Armenia to disasters like earthquakes, land slides, and floods etc., and a possible disastrous combination of such events, it is recommended that the Hydro-Meteorological station of Armenia should be equipped fully for regional flood forecasting for Armenia. This may involve additional scientific man power, as well as equipment, but is justified by the problems involved. The station should then be issuing flood forecasts for sensitive areas, i.e. major population centres and important dams during the high flood season.

After the forecasts are issued, further action will be the responsibility of Civil Defence organisation or the reservoir operators, as the case may be.

Flood plain zoning involves regulation of growth of human population and economic development in flood prone areas. (Jones, T. Earl, 1979). The first requirement is the classification af areas liable to floods of different frequencies in the vicinity of a river. These areas are then to be marked in large scale maps with close contour intervals and made known to the public. Further the activities in different classifications of flood plains should be regulated according to priorities. For example, the most important facilities, like defence installations, industries, hospitals and other important public utilities should be located above the 100 year probable flood, or the highest observed flood in the past, whatever the higher. Residential building offices etc. can be located above 25 or 50 year frequency flood with structural safety for temporary ingress of water at the ground level, and provision for shelter on higher floors. Parks, play grounds, regular agricultural farms can be located above 10 year frequency level, while below this and upto the mean annual flood level only seasonal agricultural operations may be permitted.

4. 5. Flood due to Temporary Blocking of a River by Land Slides

The problem of land slides has been discussed in detail by Prof. Watari, in the following chapter. It is mentioned here briefly in so far as it may serve as a mechanism for extra ordinary floods.

Approximately 45% of the territory of Armenia is susceptible to mud flows and land slides. These are generally caused by sustained or heavy rain fall, and may also be activated by earthquakes. Out of 37 administrative regions of Armenia, only 6 are free from these phenomena. There are old land slides in Armenia, and other areas of USSR which blocked rivers and created lakes. One of the most massive slides of this nature occurred in 1911 in Tadjikistan on Murghab river - the high natural dam which was formed by the slide, and the large reservoir behind it are still there. Unlike an engineered dam, such natural dams have no spillway arrangements or seepage control or other safety measures. Most of them fail after a relatively short period often causing extraordinary floods.

When such a blockage by a land slide occurs, and creates a reservoir with a substantial volume, the sudden release of which will cause damage, it would generally be prudent to create a passage for water either by excavation or blasting, which would then enlarge itself and gradually erode away the obstruction.

4. 6. Dam Safety Problem

Since the rainfall in Armenia is seasonal, mostly concentrated in the three months of March, April and May, construction of dams for storage reservoirs is an economic necessity for agriculture, industrial and domestic water supplies, and for power. There are stated to be 80 existing dams in Armenia, and more are at various stages of construction, design or planning. Only one of these dams, viz. Akhurian is a 50 m high straight gravity concrete dam with a storage of 525 mill. m^3 behind it. All the rest are embankment dams, mostly of medium heights. The highest dam on River Azat is 76 m high and has a storage of 70 mill. m^3. A map showing the existing and future dams in Armenia is shown in Fig.5.

While USSR-technology for dam design is very highly advanced, as evidenced by the fact that no dam in Spitak earthquake area is reported to have suffered damage, current thinking does not regard any dam as one hundred percent failure proof. [The editor suggests not to take the experience from one earthquake as sufficient proof that dams are "earthquake-resistent". His opinion is that dams are vulnerable, and for a number of reasons, like violent and large-amplitude ground-shaking at the site of the dam, substantial temporary or permanent deformation of the foundation and/or of the dam, behaviour of the reservoir and its interaction with the dam, slope failure of the mountains of the reservoir and of dams susceptible to this risk, etc.]

Some of the noted failures of well engieered dams in recent decades which caused loss of human life are Malpasset Dam in France (1959), Teton Dam in USA (1976), and Machhu-II in India (1979). The catastrophe at Vajont Dam in Italy in 1963 was of a peculiar nature and has special relevance to Armenia. In this case a rapid massive land slide into the reservoir caused a wave 90 m high above the dam crest to crash into the valley below which killed more than 2,600 people though the dam stood intact. In Armenia itself, the bursting of the concrete plug of the diversion tunnel at Spandariyan dam caused the partially filled reservoir to break through. The prompt action by Civil Defence to evacuate 17,000 persons in one hour prevented loss of life.

Depending on the storage behind the dam, the rate of development of the breach, and the hydraulics of the valley below it, a dam failure may cause a flood wave far more devastating than any natural flood. A freak combination of improbable adverse circumstances may result in the possible failure of a dam and prove disastrous. In dam design and construction every precaution and safeguard needs to be made with utmost care, particularly in view of the highly seismic nature of almost the entire Armenian Republic.

The meaures involved for ensuring dam safety involve selection of site, design, construction, post construction operation, maintenance and monitoring. Emergency planning for the highly improbable contingency of an actual failure is done through analytical dam break studies, and consequent civil defence measures suggested by them. (E.g. see Jansen, 1983).

4. 6. 1. Siting

Dam sites are primarily controlled by topography and geology. Special care is needed in seismic areas like Armenia. It would be difficult to select a site in Armenia at a sufficient distance from an active fault or a potential epicentre. The seismic forces have to be accepted and accounted for in the design. However, location of dams on active faults should be avoided. As far as possible dams, and at least the impervious zone, should be founded on rock and not on alluvium. In no case should a saturated uniform sand deposit, which is susceeptible to liquefaction during earthquake, be allowed under a dam. If it cannot be economically removed, or densified, the site should be abandoned. Another aspect of siting is the stability of slopes around the periphery of the reservoir, particularly of the portion close to the dam. Armenia has high land slide hazard; a slide may block the spillway, and subsequent floods may overtop the dam before it can be cleared. A massive land slide may cause a Vajont-like situation mentioned earlier. Vajont stood because it was a concrete arch dam; an embankment dam would have failed (and probably even a rockfill dam)[bracket added by the editor]. Unstable slopes on the reservoir shore line have to be stabilised, cut back or treated by whatever methods are economically feasible.

4. 6. 2. Design

The most important aspects of the design are estimation of design flood hydrograph, the design of spillway, the structural design of the dam including seismic effects and crack prevention, filter zone and down stream drainage arrangements, and safety margins adopted for each. (See Sherard J.L., et al, 1967, Singh, B., & Sharma, H.D.1976).

As ascertained from Hydro-project Institute of Armenia, the standards adopted for design flood for embankment dams are as follows:

Percent Probability for Floods

Capacity	Cat. I	Cat II	Cat.III	Cat. IV
Criterion A	>100m	70 to 100m	25 to 70m	<25m
Criterion B	75 to 100m	35 to 75m	15 to 35m	<15m
Criterion C	50 to 75m	25 to 50m	15 to 25m	<15m
Normal Flood	0.1	1.0	3.0	5.0
Extreme Flood	0.01	0.1	0.5	1.0

Note: In each category, A stands for rock foundations, B for gravel boulder foundations, and C for alluvium. If a population centre is located close downstream, category is to be upgraded by one.

These standards can normally be considered quite adequate. However while extrapolating from relatively short period of available data to time periods of 1000 or even 10,000 years, the probability approach has the inherent shortcoming that extra-ordinary combination of events is not necessarily predicted. For example for the highest proposed dam, Kaps, now under design, the height is 96 m, and it is being founded on rock, (proposed section, not final, cf. Fig.6). Hence according to the above criteria the normal design flood will be 1 in 100 years, and with emergency capacity 1 in 1000 years. Available records are for 49 years. While it was mentioned in discussion that special consideration is given for particular situations, it was not quite clear if the concept of Probable Maximum Flood (PMF) is being followed. The estimate of PMF is based on "Probable Maximum Precipitation" or PMP which is obtained by maximising storm rainfall and snow melt to their upper physical limits, and then reassembling them into more critical but acceptable combinations and chronological sequences. The PMF may have never occurred before and would not be reflected in any frequency estimate. For major dams, and where loss of life is feared, it is now customary to adopt the PMF criterion. If it is already in use in Armenia, well and good; otherwise it should be adopted.

Two aspects of spillway design may be briefly mentioned. The spillways are generally chute spillways, but often incorporating tunnels. If rockfall occurs in a tunnel during an earthquake, the spillway is blocked, and it takes a long time to clear the tunnel. In the meantime a flood may endanger the dam. An open chute or trough can be cleared more conveniently and rapidly. This aspect may be given consideration in each case. Further, most of the spillways have no gate. This means lack of control and may result in maximum discharges from tributaries coinciding in the main stream. A study of flood routing on such basins to avoid or provide for such a contingency is necessary.

4. 7. Structural Design of the Dam Section

The usual design (see Fig.6) consists of an earth core with rockfill shells and filter zones in between. It is inherently a safe and stable arrangement, with good drainage on the downstream side. The moderate thickness of the core, and high frictional resistance of rockfill ensure good stability. The design practice in Armenia has been to account for MSK intensity 8, but after Spitak earthquake, it has been decided to increase it to 9. Important dam designs are finalised after model testing in centrifuge and on the shaking table. It is presumed that dynamic response analysis would be carried out, using an earthquake spectrum of Spitak earthquake or earlier recorded earthquakes of high intensity.

The problem of crack control during earthquake is however, not fully amenable to analysis. The predominant period of Spitak earthquake as recorded at Leninakan was 0.8 sec (*). The natural period of oscillation of many embankment dams of medium height will also be similar. This will magnify the amplitude and further increase the danger of cracks. Protection against cracks mainly involves selection of core material, its placement, type of filter zones and downstream drainage. Experience indicates that the best core material is a well graded matrix of material from 10 to 15 cms down to fine clay, with Plasticity Index of fines between 15 and 20. To attain better flexibility the material should be compacted at 1% to 2% above optimum moisture content. Instead of thin filters, thicker transition zones should be preferred. A rockfill downstream shell automatically provides good drainage.

(*) The editor warns not to use accelerograms or physical parameters related to ground shaking obtained at one site at a different one. The problems is particularly grave in Armenia in view of the lack of a satisfactory number of such records (cf. e.g. the Spitak earthquake). The predominant period of shaking at a site depends on many parameters, for instance, the rupture history, the distance between the site and the "epicentre" and the foundation material. The design of any important element must therefore allow for the scatter of design parameters and include a proper safety margin.

4.8. Quality Control during Construction

All the precautions taken in the design can be nullified by lax control on construction. It is essential to maintain close watch on moisture content and compacted density, on zone demarkations, prevention of contamination of filter materials and drains, and correct installation of instruments.

4. 9. Operation, Maintenance and Monitoring

Flow measurement and precipitation gauges in adequate numbers should be established in the drainage basin upstream of the dam to enable flood forecasts to be made in advance, as discussed in the section on natural floods. This will not only increase safety against flood but also enable operation for optimum maximum benefits.

Embankment dams have to be carefully monitored and maintained. The instruments installed in the dam section like piezometers, vertical and horizontal movement devices, seepage measuring arrangement should be carefully observed and recorded. Items to watch specially are sudden increase