in seepage, cloudiness of seepage water, visible cracks, boils downstream of the dam, the smallest leakage emerging on the downstream face, slumping or sloughing, sudden change in instrument readings and formation of sink holes or vortices in the reservoir. The spillways and outlets, and their control equipment must always be in perfect working order. Downstream of spillways specially those provided with ski jump buckets, the scour in the riverbed is to be carefully watched, and defensive measures immediately taken if it tends to travel towards the toe of the dam.

These are, of course, usual precautions well known to all dam engineers. The intention of reiterating them here is to emphasise the need to make the presumably young engineers posted at small and medium dams aware of them, and to stress the importance of constant alertness.

4. 10. Dam Break Analysis

By this process it is possible to predict flood depths and flood arrival times, and to identify areas affected by the flood wave, if a failure were to occur. Such a study not only enables preparation of emergency plans, but also evaluates the magnitude of the hazard and hence the justifiable margins of safety in dam design. The numerical modelling technique involves calculation of the breach hydrograph by continuity equation, and routing this hydrograph through the valley downstream. Several computer programmes are now available for doing this work. Data for dam components, the reservoir, and for the cross-sections, slopes and hydraulic roughness of the valley is necessary for flood wave computation and demographic and economic data for damage assessment. A plot of such a study carried out for Aparan Dam was seen in the Civil Defence Office. It is suggested that similar studies be carried out for important existing and new dams. Such maps not only indicate areas liable to inundation but also warning times available to them, and are most helpful in planning emergency relief, and for zoning purposes in urban and industrial development.

4. 11. Emergency preparedness

This aspect is discussed at length in section on Civil Defence Aspects. However, some aspects which are specially important for dam failure are briefly mentioned below (Das and Thite 1989).

It is important that access to site should remain available inspite of a breach. This means that at least one road should entirely run above submergence levels. There should be alternative and failure proof communication systems from and to the dam site. (The absence of these two was a major contributory factor to the tragedy of Machhu dam failure in India with a loss of more than 2000 lives.) Moreover, it is necessary to maintain auxiliary power at instant readiness at all times to operate controls, to provide illumination, and for communication systems, if the main grid power is not available. The dam site should be watched and patrolled day and night, whenever a threat is perceived, and should be well illuminated for this purpose.

If a disaster occurs, the steps to warning, evacuation, and other relief measures are similar to other disasters and are separately discussed in Civil Defence Aspects.

4. 12. Dam Safety Commission

As far as could be ascertained, there are more than one organisations dealing with the design, construction and operation/maintenance of dams and reservoirs in Armenia. In most countries with a number of dams it is considered necessary to have a Dam Safety Commission, separate from and autonomous of the design, construction and operation agencies. It is recommended that such a Commission should be established for Armenia as well to serve as a watch dog agency with the following functions:

(a) To review and approve designs of all new dams.

(b) To review existing dams and advise on measures of strengthening them or improving their safety, as considered necesssary.

(c) To periodically inpsect all dams of 15 m height or more, and even of lesser height, if located above popoulation centres, to ensure that they are being maintained in a safe condition.

The Commssion itself should consist of three to four members with different specialisations from among Hydrology, Geotechnical Engineering, Dam Engineering, Instrumentation, and Civil Defence. It should be assisted by a small staff of not more than about twenty engineers and technicians. The Commission should not normally take up detailed field studies or analyses itself, but should ask for these to be carried out by the existing organisations, and should then review the results, and recommend appropriate action.

The advantage of an autonomous commission, is that not being involved in design, constsruction, or operation, it can take a detached view and would have no interest in covering up of any weaknesses.

4. 13. Methodology for Assessment of Flood Damages

The methodology described below is as for a flood having actually occurred. For a potential flood, the flood scenario has to be modelled by flood forecasting or dam break analysis, and the data taken from detailed maps showing extent and period of submergence as discussed in the main chapter on flood hazard.

Flood damages can be assessed by complete enumeration or by sample surveys. To be reliable, the latter technique requires expert statistical guidance. In view of the fact that flood damage in Armenia is not frequent and extensive, complete enumeration is preferable.

The methodology of assessment can be considered separately for

(a) damage to crops

(b) loss of human life, damage to housing and domestic goods and loss of animals like cattle, sheep etc.

(c) losses to industries, public utilities, Government offices, hospitals, schools, roads railways etc.

4. 13. 1. Assessement of Crop Damage

The information regarding crop damage is to be compiled using village, or perhaps more correctly for Armenia, a collective farm or a cooperative farm, as a unit. In assessment of crop damage the following criteria are normally accepted.

1. When a cropped area is submerged for such a period and depth that the crop is totally lost, and when the flood occurs at such a time of the season that replanting is not possible, the loss is assessed as potential yield from that area. In monetary terms, the loss will be the total yield which could have been obtained, multiplied by the market value of the crop.

2. When crop area is submerged as in case 1., but the flood occurs early in the season, so that replanting is possible, the monetary loss is considered as the cost of additional inputs of labour and material necessary for replanting, plus the reduction in yield due to late planting, if any.

3. When a crop survives submergence, and is only partially damaged, the loss is counted as reduction in yield.

It is possible that due to retained moisture, part of the loss may be recouped through increased yield in the next crop, but that is generally neglected.

4. 13. 2. Loss of Human and Animal Life, Damage to Housing and Household Goods

In case of an actual flood these losses are assessed by actual surveys. The loss of human life can only be enumerated in numbers; if conversion to money terms is needed then practices followed by insurance companies, or for accident compensation can be employed. Money value can be easily obtained, for animals according to curent prices. Damage to housing is assessed as the money needed to repair the house to its original condition, and of household goods as the price of replacement.

The situation is more uncertain for potential floods. Assuming that flood forecasting and warning systems are functioning, there should be no loss of human life in a natural flood in Armenia, and loss of animals also should be small. In case of dam breach, however, for locations where the warning time is small, say less than 30 minutes, some loss of human life, and considerable loss of animal life may take place. This can only be based on judgement of persons experienced in relief and rescue operations.

The loss to buildings depends on the nature of their construction, and the period and depth of submergence. Normally concrete and stone block buildings should be able to withstand considerable submergence, but rubble masonry in weak mortar is likely to fail. The damage to house hold goods has to be assessed as a percentage of the average value of the possessions of a family.

4. 13. 3. Public Property

The basis of assessment is the same as for 4. 13. 2. The only difference is in the mode of enumeration. Whereas loss in 4. 13. 2. will be assessed habitat-wise, that of public property will normally be accounted in accordance with the Organisation or Department responsible for it. Industrial plant and machinery subject to submergence, even for a short time, is likely to suffer a total loss.

For integrating the total losses, two parallel approaches are necessary. For administrative and budegetary purposes, the losses may be first integrated for each of the 37 administrative territories, and then for the entire Armenian Republic. However for river basin planning, the losses should be integrated for each sub-basin and basin of the rivers of Armenia.

4. 13. 4. Indirect Damages

The types of damage considered so far are those caused directly by the flood waters. However, damage may also be caused by cessation of normal economic activity, e.g. stoppage of production in industrial plants, interruption of transport service, etc. Such losses may occur even outside the flood effected area due to interlinkages in the production processes

These losses are significant for industrialised, urban areas only, and in such situations, these can be approximately estimated as the net loss in production and wages.

4. 14. RECOMMENDATIONS

4. 14.1. Floods

General remark added by the editor: The potential effect of trends must be carefully evaluated. The most important issues are: Climatological changes, changes in land use, changes in number and vulnerability of elements at risk.

1. The storage reservoirs may be operated keeping in view the possibility of floods late in the season.

2. The marginal flood walls or banks be designed for 1000 year flood plus a safety margin of 25% for urban centres and for 100 year flood for agricultural and rural communities. The conveyance capacity of the canalised Kater River throug Yerevan be checked accordingly.

3. The conveyance capacity of river channels be re-evaluated and maintained, if necessary by excavation of heavy influx of debris during floods.

4. A phased programme of improvement of river drainage basins be taken up on a high priority basis. It would be a good policy to re-afforest the higher ranges of slopes with species which are adapted to local climate and are drought resistant and deep rooted. Where possible lower slopes may be grassed or used for close growing crops. For the latter, contour ploughing and contour bunding (dikes) should be mandatory.

5. The existing net work of Hydrometeorological stations in Armenia be examined according to W.M.O.-requirements, and adjusted where necessary.

Yerevan Hydromet station be entrusted with flood forecasting work during the high flow season, for important urban centres and dams. It should be provided with required scientific manpower, equipment and data input to fulfil this objective.

6. The economic development in flood plains of streams, and in areas immediately downstream of dams be carefully regulated in accordance with zoning plans.

4. 14. 2. Dam Safety

1. As far as possible, impervious zones of dams be securuly tied to sound rock. No dam should be built on a saturated uniform, sand deposit, susceptible to liquefaction during earthquakes, or on faults assessed to be active.

2. Unstable slopes along the reservoir shore line, particularly those in the vicinity of the dam should be stabilised, cut back or treated by whatever methods are considered feasible.

3. Dams, the failure of which could result in loss of human life and/or heavy economic damage should be designed for Probable Maximum Flood.

4. Open chute spillways would be safer in comparison to tunnel spillways in seismic areas.

The possibility of flood crests from ungated spillways on tributaries coinciding on the main stream should be examined in overall planning of the river basin.

5. Small and medium height embankment dams may have a natural period of the same order as the predominant period of primary earthquake waves. Thus they may suffer high displacements and need to be protected by standard methods of crack control, particularly in selection and placement of core material, thicker transition zones, and free draining down stream shells.

6. Instrumentation in the dams should be carefully maintained and watched.

7. Dam break analysis be carried out for important existing and new dams. These will indicate areas liable to inundation and warning times available.

8. Emergency preparedness plans be worked out and kept available for important dams above population centres.

9. An autonomous Dam Safety Commission be established for Armenia, with the following main functions:

9. 1. To review and approve designs of all new dams,

9. 2. To review existing dams and advise on measures to improve their safety,

9. 3. To periodically inspect all dams of more than 15 m height, and of lesser height if located above population centres, to ensure that they are being maintained in a safe condition.

APPENDIX I

Annual peak water levels and discharges of River Araks near V. Syemalu from 1964 to 1988.

Year	H (cm above 912.05m)	Q (m^3/sec)
1964	501	1010
1965	358	509
1966	364	525
1967	394	643
1968	578	1320
1969	669	1690
1970	314	402
1971	290	275
1972	377	617
1973	452	735
1974	365	478
1975	316	353
1976	432	698
1977	364	510
1978	434	705
1979	328	417
1980	518	1082
1981	332	434
1982	424	710
1983	275	250
1984	357	180
1985	385	526
1986	327	324
1987	490	880
1988	476	743

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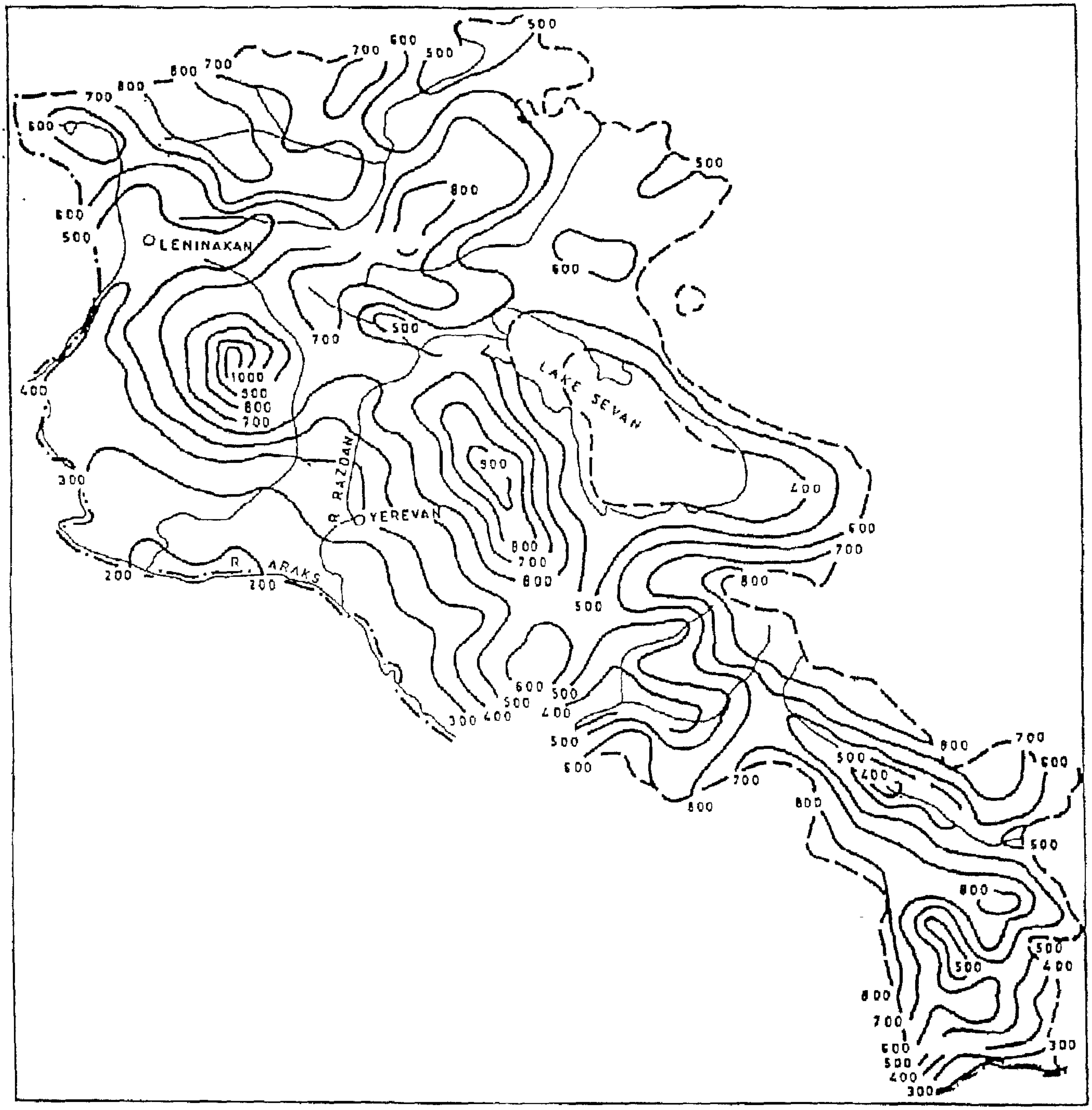

FIG 1 – HYETOGRAPHS OF AVERAGE ANNUAL RAINFALL

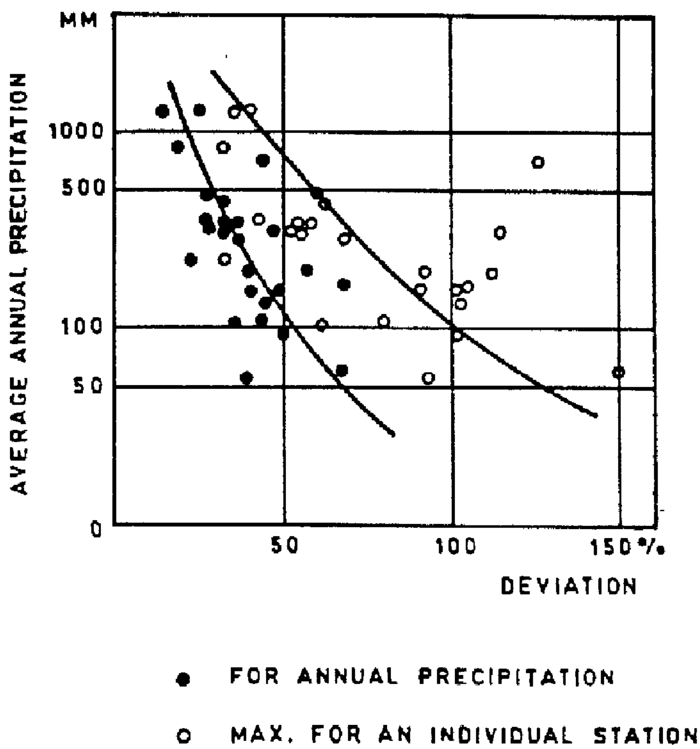

FIG. 2-STANDARD DEVIATION OF ANNUAL PRECIPITATION

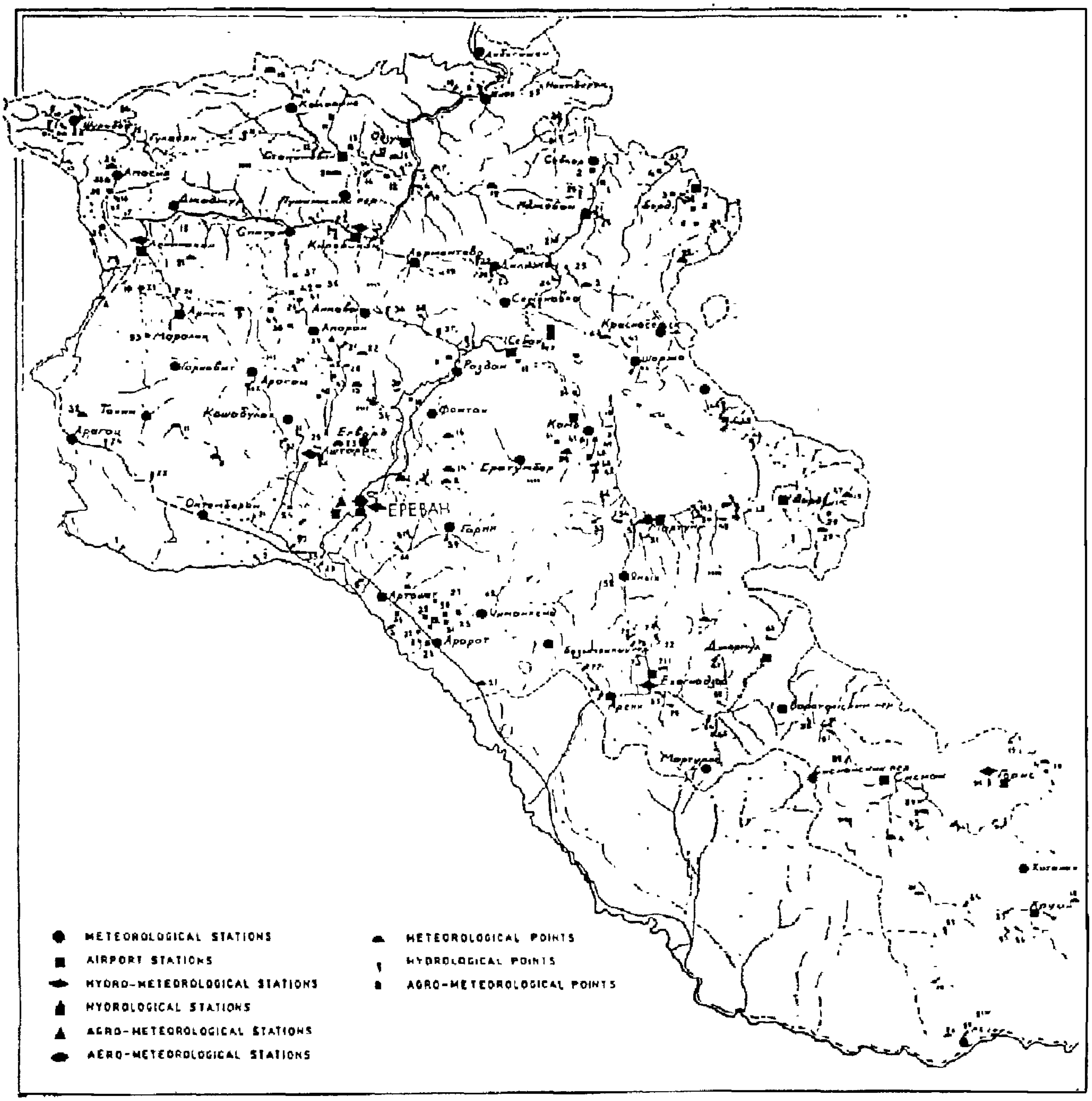

FIG. 3 HYDROMETEOROLOGICAL NETWORK OF STATIONS
IN ARMENIA

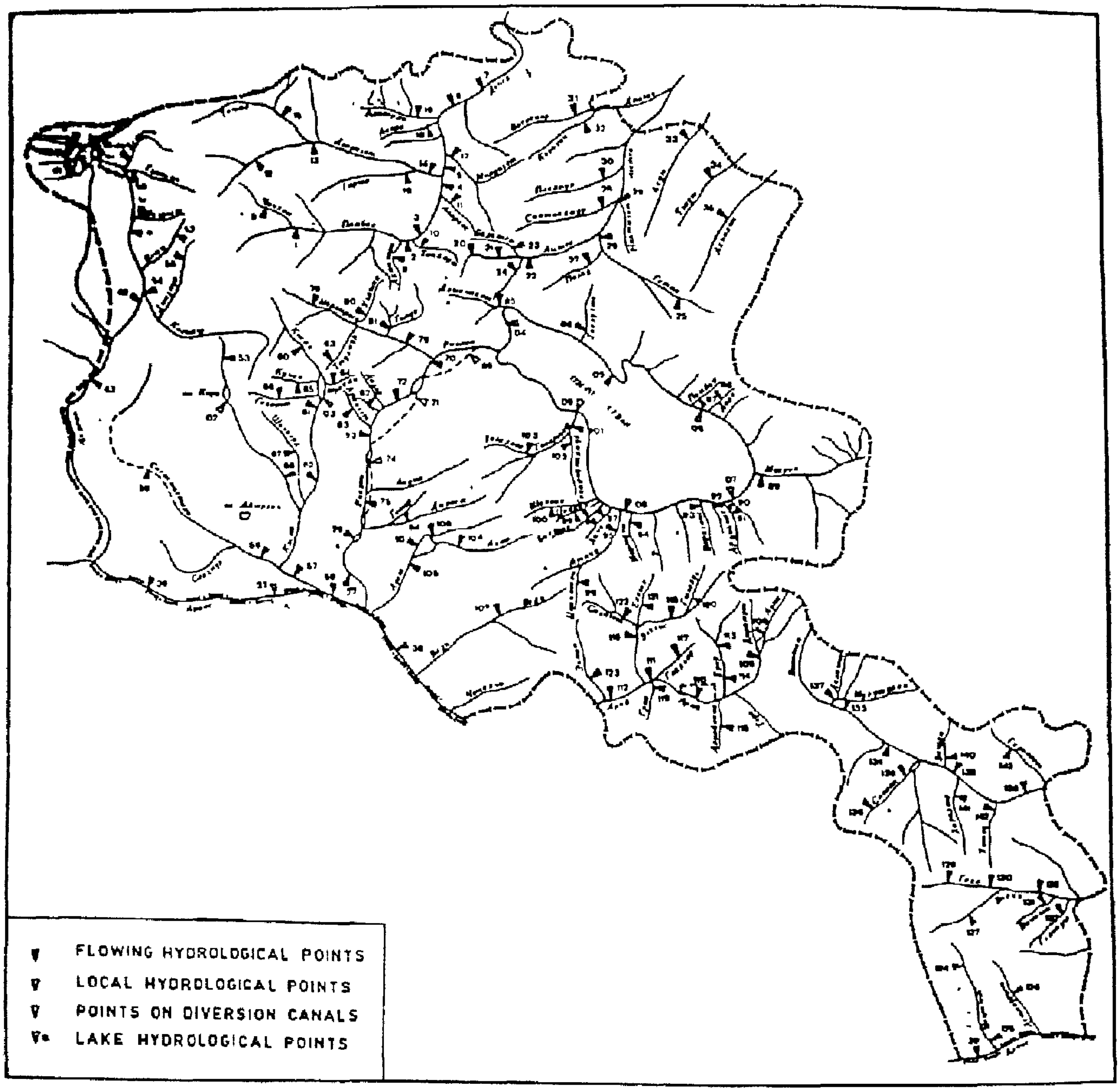

FIG. 4 STREAM GAUGING STATIONS OF ARMENIA

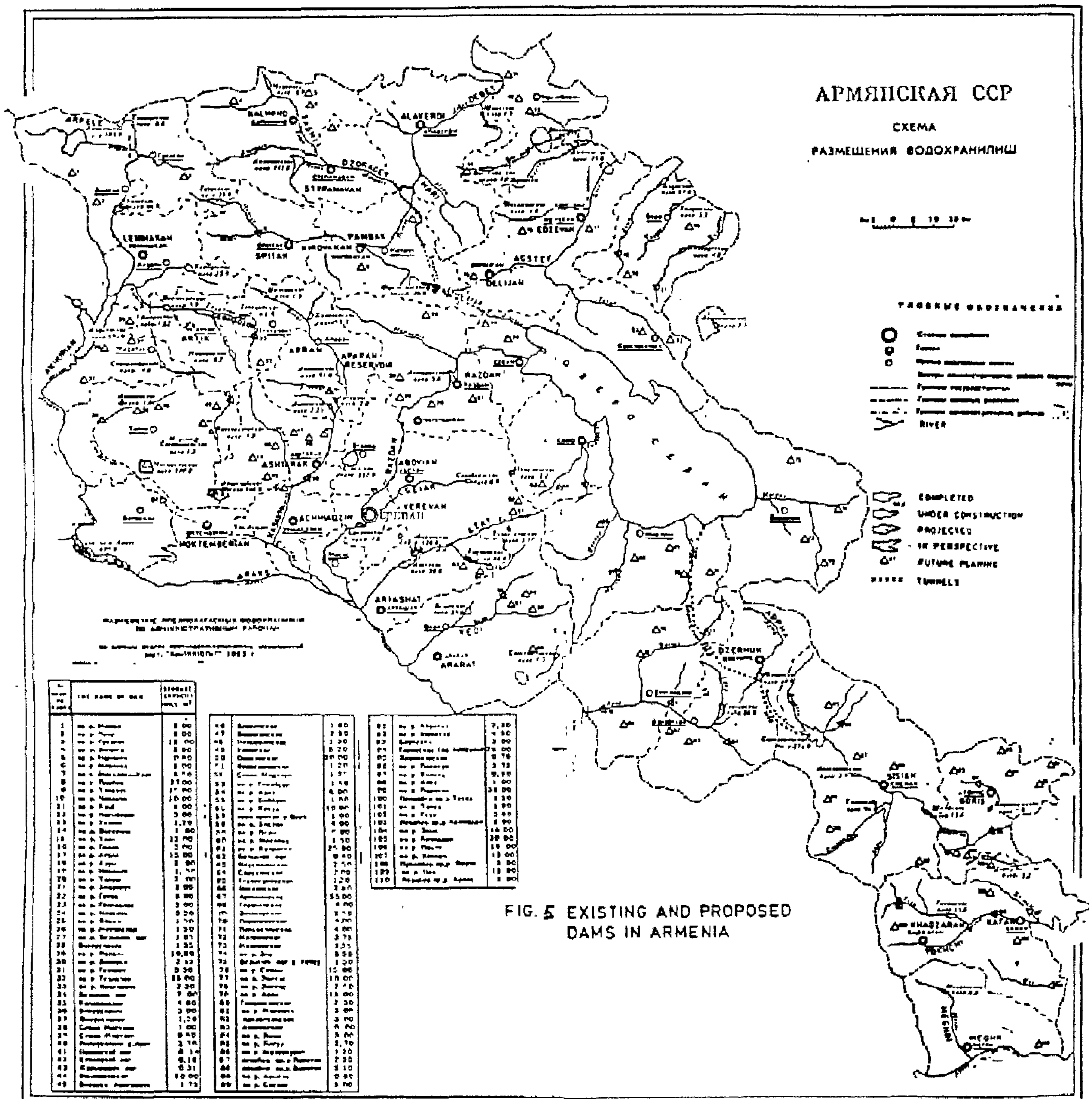

FIG. 5 EXISTING AND PROPOSED DAMS IN ARMENIA

АРМГИПРОВОДХОЗ 1987 г

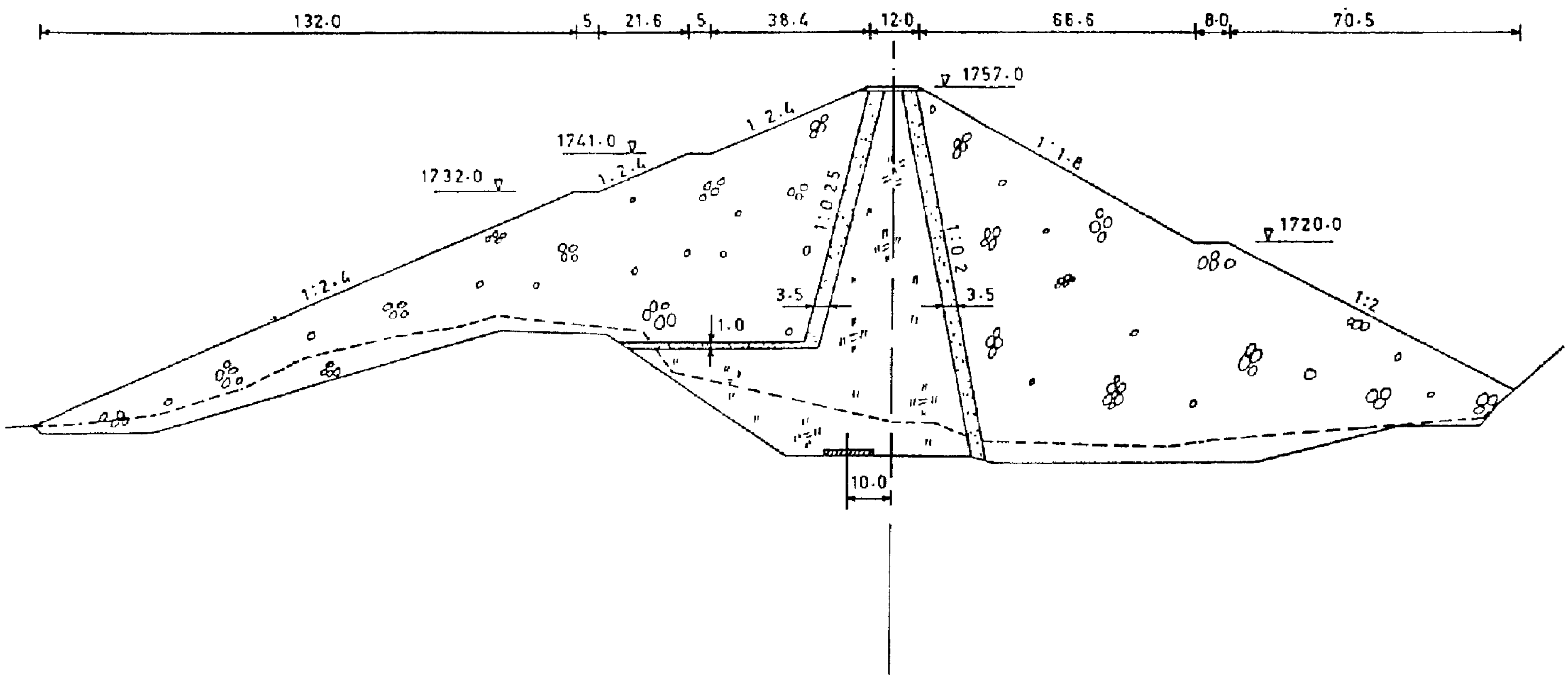

FIG. 6- PROPOSED SECTION OF KAPS DAM (NOT FINAL)

III. A. 5. LANDSLIDES

OVERWIEW AND GENERAL ISSUES

Soils

The subsoil of Yerevan, Leninakan, Kirovakan and other plateaus, basins or valleys, which are the social and economic centers of Armenia, is predominantly alluvium generated from pyroclastic flows, volcanic breccia and volcanic ash. It was formed mainly during the Neogene and Quaternary periods. In general the hardness of the subsoil is relatively high and there are no extensive areas of soft subsoil. Yet, the subsoil in areas with much ground-water is soft and easy to fail.

The annual precipitation ranges from 300 to 1000 mm in Armenia, but it is 300 to 500 mm on the plateaus. Normally the ground-water level of this region is not near to the surface, and the stability (against earthquake action) seems to be rather high. However, it is estimated that there is high possibility of slope failure after heavy rainfalls in the valleys or on steep slopes of high volcanoes.

In the fractured zones of the northern or southern mountainous regions, tuff breccia or tuffacious rocks are strongly weathered, which tend to incorporate the risk of landslides or large-scale rock falls.

Topography

The geomorphology of the Lesser Caucasus including Armenia can be described as a mountainous region of an arch shape extending from north-west to south- east, bordering the Anatolian fault. The topography is governed entirely by this and other major fault systems which run about parallel to the former one. The tectonic movements characterized by these faults have generated the topography of this region, that is the generally 1500 - 2000 m high mountain ranges which run from north-west to south-east. The base rock of this mountaineous region is of paleogene and Jurassic origin.

In the mountain ranges there are several 3500 to 4000 m high dormant volcanoes like Aragats, Azdaak, Vardents. Pyroclastic flows formed wide volcanic plateaus. This mountain belt includes several lakes. The largest one is Sevan Lake with a surface of about 1400 km2 . It lies at an elevation of about 1900 m above sea level. The Razdan River flows southwards from the Sevan Lake and crosses a large volcanic plateau. This plateau is the predominant economic zone of this country centering around Yeravan. The next most industrialized region is the northern basin and the valleys that developeded from the fractured zone along the geotectonic line extending from Leninakan at the northern foot of the volcano Aragats, which extends along the upper Dabed River beyond Kirovakan to the Sevan Lake.

Most of the rivers in the Armenian mountainous region belong to the Araks River system, which flows along the southern border toward south-east. Some part of the northern area belongs to the Kura River basin into which tributary rivers in Armenia, like the Debed River and the Akhsmeb River discharge in an about northernly direction.

Fractured zones are also present in the south, and one can clearly find them in the region of the lineaments that extends from Yerevan and Garni, through Nakhichevan to Kafan.

SPECIFIC RISKS AND RELATED ISSUES

1. Terminology and General Aspects

The landslide phenomena can be classified into deformation, slide, and fall of material. The latter is in generally only encountered in connection with the fall of rock. From the scale point of view slides can be divided into large slides and small-scale slope failure.

From the viewpoint of heavy damage or disasters one must consider debris flow or mudflow caused by a slide or slope failure arising from heavy rainfall in the upper river regions in the mountainous area. Such events are often called lahars and they are particularly frequent and damaging in volcanic regions of explosive volcanic eruptions.

Slope failures occur on 35 to 70-degree steep slopes and its thickness mostly ranges from 1 to 5 m. Clays and loess may, however, slide on much flater slopes. The movement takes place all of a sudden with a rapid displacement of soil. In general the amount of the soil involved is not so large ranging from 200 cubic metres to several thousands of cubic metres.

Slides occur most often during or after heavy rainfall and they are related to the intensity of the rainfall. Moreover, they easily occur on weak slopes, for example, on slopes where a thick topsoil has developed or if the subsoil is heavily weathered.

Slides also occur when the clayey rock formation becomes instable because of the existence of faults or fractured zones. Water from extended rainfall or melting snow is also in this case the triggering factor. Heavy valley erosion, e. g. the undercutting of slopes, in particular if combined with plenty of ground-water can also cause slides. Slope instability can build up from a sequence of individual failures. As instability grows a large slide may take place.

The scale of slides ranges from a few meters to 50 m (sometimes over 100m) in thickness, 10 to 25 degrees in gradient, and 10,000 to tens of million of cubic meters (sometimes over hundreds of millions of cubic meters) in volume.

Rockfall takes place on steep fissured rock slopes of 45 to 90-degree gradient.

Debris flow, mudflow or lahars occurs mostly in the upper range of valleys or upper slopes during or after heavy rainfall, and a large amount of the mixture of rock fragments and soil flows out towards the lower river, sometimes at high velocity and devastates villages or farmland. These phenomena are likely to occur if the river bed gradient is steeper than 1/8.

2. Earthquakes and Landslide

Earthquakes have often caused landslides and rock falls. Such displacement of material depends directly on the seismic intensity and takes place almost at the same time when shock occurs. The relationship between earthquakes and the slides caused by them are, however, so complex that it is impossible to state simple rules.

Predominant factors are the intensity and acceleration of ground shaking, the wave length (frequency), the vibration distribution as well as their relation to the nature of the subsoil. In Japan the following relations are often cited:

a) Slides are likely to occur when epicenters of earthquakes are located near landslide areas, especially, where a big slide has occurred in the past.

b) Slides tend to occur at the time of after-shock rather than at the time of the main shocks.

c) For a period of several years the possibility of slides occurrence after a big earthquake is in general very high. Heavy rain, snow melting, or other causes are also in this case aggravating factors.

3. Distribution of Landslides in Armenia

Large-scale slides are concentrated in the mountain ranges of the Pliogene formation located in the north and the south which are directly affected by large tectonic activities.

It is apparent that these slides are concentrated along the faults and fractured zones. In other areas of the mountains slides occur much less frequently.

We have been told that more than 800 cases of slides have occurred all over Armenia. In the northern mountains, they are concentrated in the region of the River Panvak, River Akhsmeb (Dilijan valley) and on the mountainsides on the north bank of Lake Sevan, where a series of fractured zones is found.

In the south, they are distributed in the region of River Arpa (Middle Arpa valley), river Voromman and River Vokhchi (Kafan valley), starting from the river Azam located near Yerevan.

The northern landslide area is located near Spitak where the recent earthquake caused new cracks and slide movements on some mountain sides.

The scale of large slides in this area ranges from tens of thousands of cubic metres to millions of cubic metres, and people in some of these areas have already evacuated the area. There is a possibility that after heavy rains more cases of slides may take place in the near future.

4. Slope Failures and Rock Falls

Slope failures and rock falls occurred in the slopes of deep valleys, at the end of lava flows, and on the slopes of dormant volcanoes, such as volcanoes Aragats and Azdaak. More specifically, on the slopes of volcano Aragatz, volcanic mudflow or debris flow occurred in connection with heavy rain.

In the earthquake of Spitak no large disasters occurred due to slope failures, but it is supposed that on the slope of both sides of the deep valley, they might have occurred. It is also presumed that many cases of small-scale rock falls might have taken place on the northern mountains slopes.

DETAILED STOCKTAKING

1. PROCEDURE AND METHODOLOGY

1.1 Landslides

During our visit to the region, shortage of petrol did not permit us to carry out a detailed inspection of sites. We could visit only the regions of Spitak and Dilijan and the upper range of the River Azam in the southern mountains. Besides, we had only a short time for these inspections at our disposal.

The mechanisms of the slides seen during these inspections are as follows:

It is generally said that the older the geologic strata where slides occur are, the bigger their scale may become, often taking the form of weathered rock slides or rock glides. In the above-mentioned Paleogene regions, many cases of weathered rock slides occurred. As a consequence, the scales of these slides were larger than those of Neogene origin, with a slope inclination of 20 to 30 degrees and with a depth of 30 to 50 meters. These slides moved to the valleys which were eroded in U or V shapes. The speeds of movements appear to have been very slow, and are presumed to be about 10 cm or below per year. It is after several years that some cracks or deformation are detected in the ground. The groundwater level is located about 20 to 30 meters below the surface. Particularly in the Dilijan slide area, the groundwater level is located about 700 meters below the water surface of Lake Sevan which is only 15 km from Dilijan. Theoretically speaking, the ground water is affected by the lake water level but according to the actual inspection, there was no such evidence because the level is very deep.

Generally, slides are caused by much rain. But in this region, annual amount of rain fall is only 500 mm. It is also said that rain showers with only 30 mm of rain in thirty minutes can cause slides in this area.

The change in the level of ground-water in this region is said to be 1.5 to 2 meters, i. e. very small. The level of the ground-water is rather high compared with that in Japan which is about 5 to 20 meters.

It is frequently stated that big causes are necessary to render a large ground mass unstable. For example, in cases like a heavy rainfall of several hundred millimetre, rapid melting involving several metres of snow, large-scale engineering works or large river erosion by a big flood, large scale slides tend to occur.

However, if slides occur after rain showers, the slopes in the region are very weak and prone to slide as compared with general conditions.

In any case, one may say that slopes in Armenia are very unstable and therefore prone to slide. It is quite possible that a slope becomes activated, i. e. unstable, when even a small external force acts. Therefore it should be considered that the influence of earthquakes on slide probability is also far greater in Armenia than in general. It constitutes a great problem in the future development of the mountain areas in this country.

If the destabilization of the slopes is directly caused by rain, the following facts also control slide movements:

1. Ground-water might increase not only by rain, especially during heavy showers in the area but by inflow of surface water from other regions.

2. Slopes which are slide-prone may become unstable also due to erosion of the banks or the river beds by a rapid increase in the river discharge.

The following measures are suggested to solve the above-mentioned problems:

1. Channelling work and covering of cracks should be taken up. Surface water drainages should be installed so as not to permit the infiltration and percolation of much water.

2. River beds should be stabilized by carrying out erosion control, e.g. by means of check dams or slope protection.

It is obvious that groundwater drainage by horizontal borings, drainage wells and drainage tunnels are effective in preventing slides. And although such work is being done effectively in this region, the effect will be much greater if the two above mentioned methods are added.

Many kinds of slides of various origin and magnitude are found in the area of the northern and southern mountains of this country. It is an important issue to understand exactly these slides and take proper measures against them.

As to the problem of slope failures, afforestation and re-forestation of the slopes of the mountains is one of the most important measures for preventing them.

RECOMMENDATIONS

Armenia is a densely populated area of the USSR. Important infrastructures like power plants and minings, production of many kinds of construction materials, as well as various kinds of industries like aluminum, chemicals, etc. are concentrated in Yerevan, Leninakan and Kirovakan. It is expected that they will make a great progress in future. Such a progress will exert a great influence on the land use in the regions. Even in mountainous areas, additional infrastructure like roads, railways, dams, power plants and other manufacturing equipments will be required, constructed and/or improved.

Natural disasters like slides and slope failures effecting such elements at risk will constitute one of the greatest problems. As a result of the recent earthquakes, slopes in the northern part of the mountains near Spitak, Kirovakan and Dilijan have become very unstable. As mentioned before, slopes in Armenia have a tendency toslide easily as a result of heavy rain or other natural and artificial causes such as construction works.

Therefore, prediction of disasters and regulations of development of mountainous area should be done by making a hazard map on landslides all over Armenia.

1. Making Hazard Maps for Landslides

Slides were investigated by the Institute of Geological Science and the Universities, while debris or mudflow was investigated by the scientists of the Universities, or the Institute of Geomorphology, and the Meteorological Institutes. Good research work has been done by them. However, the scale of maps used by them or the preciseness of the study are different for each. Besides they don't cover the whole territory of Armenia, a comprehensive hazard map is not yet available and such a uniform map should be prepared as soon as possible. This problem should be approached from a comprehensive technological viewpoints including socio-economic problems.

Slide prediction should be started with airphoto interpretation, which lay emphasis on topography and landform and after that it should be confirmed by site inspection and instrumentation. Topographical maps better than of a scale of one in twentyfive thousand will be needed. In Japan, for instance, topographical maps of the scale of 1 : 10,000 are used as hazard maps. The result of the research should be evaluated for such disastrous phenomena as slides-slope failures, rock falls, debris or mudflow, including theoretical aspects like the possibility of occurrence, the scale, movement features as well as socio-economic values of the areas likely to be hit by the disasters. Thus the hazard map should be completed by taking into consideration the grading of the exposure of each area.

2. Effective use of Hazard Maps

A dangerous slope regarded as important from the viewpoint of the possibility of future development, social characteristics and other administrative criteria (emphasis on human lives) should be identified formally by a public organization. These identifications might be according a law associated with certain authorities and some budget (such as the Japanese Landslide Prevention Law of 1959). In such a law provisions should be incorporated like, limitations on the usage of dangerous slopes and construction works like excavation, earth filling and waterwork, and establishment of monitoring and warning system, urgent remedial measures and long-term stabilization measures.

3. Establishment of a General Organization on Slope Stability

As landslides have many natural features, and are related to many fields or discipline, wide knowledge of many technical fields is needed to conduct investigation on landslides and take countermeasures against them. At present such studies are taken up individually in many research organizations, universities and the administrative offices. Because such studies often belong to or involve interdisciplinary fields, however, a center of study and technology to generalize such knowledges is needed.

Moreover, in order to control the use of land and construction work at identified dangerous slopes on the basis of the above-mentioned hazard map, a generalized organization is required.

Furthermore, this organization has to conduct disaster management like prediction of danger by monitoring, advisement of warning, and reducing and removal of elements at risk.

In addition, an organization to carry out the investigation on active slide areas, take urgent remedial measures as well as long-term stabilization measures is also required. These activities should be carried out in a comprehensive engineering organization.

Implementation of a comprehensive plan for practical and administrative measure is regarded as most important in dealing with natural disasters of this type.

Therefore the organizations recomended here need to perform the following functions.

3. 1. As an interdisciplinary scientific center (Geology, Geomorphology, Geophysics, Geochemistry, Meteorology, Hydrology, and Soil and Rock Mechanics).

3. 2. As a technological center (Civil Engineering, Geotechnics, Erosion control, Soil conservation, Forest and agricultural engineering and Instrumentation technology).

3. 3. Landslide Disaster Preparedness and Management

3. 3. 1. Production of Hazard Maps

3. 3. 2. Warning and providing instructions for precaution and evacuation from the dangerous areas.

3. 4. Limitations on the use of land and construction works. Limitation on construction works will fall into three kinds, such a excavation depth, earthfilling height, and watering work.

3. 5. Investigation of dangerous slopes and implementation of plans for stabilization measures

3. 5. 1. Investigation (borings and various kinds of survey and instrumentation)

3. 5. 2. Urgent remedial measures

3. 5. 3. Long-term stabilization measures.

III. A. 6. INDUSTRIAL AND MAN-MADE HAZARDS

Introductory Remarks

The above heading is to some extent a misnomer because hazards are nearly always seen in connection with man or man-made elements. It can therefore be said that in principle any hazard is man-made. We shall for such reasons have to restrict the discussion to some specifically selected man-made hazards.

This narrow selection is also required because of the enormously broad spectrum of man-made hazards which can not be discussed in any single paper, even a very extensive one. On the other hand the author tried to provide correlative and additional information to throw more light on the perils discussed in other chapters, and to include some aspects which are of basic importance in the field covered by this report.

The third constraint is due to our inability to inspect industries, hospitals and other facilities during our stay in Armenia. For such reasons the discussion must be confined to general aspects and issues. We shall predominantly concentrate on large industrial plants and/or projects because most (but not all) of the disaster potential is associated with such plants.

Analytic Models and Methodology

Risk assessment in general has to cover the entire probability distribution ranging from small and frequent losses to catastrophic events including those which are extremely improbable to occur, like the safe shutdown earthquake (SSE) entering design of nuclear power plants. Eficient risk optimization and disaster management is only possible if the entire spectrum is known.

It is common to differentiate between a deterministic and a probabilistic approach or to employ a combination of both if it is not easy to represent nature by a manageable and trustworthy model and if data is not good enough to be convinced that the selected probabilistic or deterministic tool is the proper one. This is particularly true in the range of exotic events like catastrophe risks. In particular the assessment of catastrophe risks is influenced by at least three prominent general problems, viz. the sample(s) available, trends which may affect exposure, and problems in the interpretation of data. Let us first discuss the observational basis as regards their objective value.

The entire spectrum of perils must be considered. For industrial palnts one may write

$$\mathbf{X = f\,[H_G\,(W, S, E, Ts, V, F, Ex, Tr, G, T, H_R)]}$$

that is, the risk (X) is a function (f) of the general qualification and risk awareness of the experts influencing the risk (H_G), the natural perils water, windstorm, earthquake, tsunami, and volcanism (W, S, E, Ts, V), fire (F), explosion (Ex), transportation (Tr), geological perils (G), technical perils (T), and the residual chance of human failure (H_R). As natural perils and landslides have been discussed elsewhere, we will enlarge to some extent on the important remaining perils.

If a sample is not very large it is not probable that it includes a catastrophe. Not only experience but logical considerations tell us that loss experience will lag behind "size-of-project-experience" very much. This is particularly true for large and very large losses which have - fortunately - a small annual probability of occurrence. Assuming that a pre-storage fire loss of, say, 15% of the project value has been observed once in 250 projects, its probability could be estimated with the aid of simple arithmetics to be about 0.4% per project. Even a large basis of experience, like a large international insurance portfolio which would contain 10 comparable plants at a time would bring the probability of one such event to only about 4%, i.e. we may have to wait on the average for about 25 years to experience such a loss.

This is, however, only part of the story; even a layman should realize that one observation among 250 projects is not really a good sample which may be trusted to a high degree of confidence to represent nature. Depending on the confidence interval selected and using a binomial distribution we may find that the incidence rate of such a loss may not be about 0.4% per project (1 in 250) or more precisely 0.3992% if the proper formula is used but 2.23% at a confidenoe range of 95%, or 3.317% at 99% confidence level, or 6.4399% at 99.99% confidence range, or as low as 0.07%, 0.047%, or 0.0234% at the same confidence ranges. The lower limit implies that one might have to wait for much more than 25 years when observing 10 plants at a time before such a loss would ocour.

This brings us to the question of how large a (homogeneous!) sample should be to permit deductions of a certain reliability. Using the formula developed for sequential testing which is given hereunder we may estimate the size of the sample which will produce a reliable answer at the confidence levels selected. Assuming, for instance that the vendor (designer, supplier, owner, broker, or insurer trying to place the risk) have decided to run the risk to be wrong in 5% of all such cases ($\alpha = 0.05$), that the consumer or buyer of the risk are satisfied with the same confidence level ($\beta = 0.05$), that is was decided that the desired reliability should be 97% ($R_u = 0.97$), i.e. that not more than 3% of the sequential exotic sample of catastrophic losses should exceed a certain percentage of the value of the project, but that we would be prepared to accept a margin of 2% when defining the minmum acceptable reliability ($R_l = 0.95$), the average sampling numer (ASN) should be about 543 cases. Even if vendor and buyer of the risk would be satisfied with a chance of being wrong of 1% ($\alpha = \beta = 0{,}1$) we would still find an ASN of 105 observations.

$$ASN = \frac{(1-\alpha)\ln[\beta/(1-\alpha)] + \alpha \ln[(1-\beta)/\alpha]}{(1-R_u)\ln[(1-R_l)/(1-R_u)] + R_u \ln(R_l/R_u)}$$

ASN = AVERAGE SAMPLING NUMBER

α = VENDORS RISK (e.g. 5% = 0.05)

β = CONSUMERS/USERS RISK (e.g. 3% = 0.03)

R_u = DESIRED RELIABILITY (e.g. 97% = 0.97)

R_l = LOWER RELIABILITY LIMIT (e.g. 95% = 0.95)

It is highly unlikely to have an original sample which is not contaminated, i.e. one where the catastrophic event is due to the same isolated cause or combination of causes of equal weight. If a HPI plant or refinery is ablaze from a normal cause or due to an earthquake, one will have to ascertain all contributing factors and their relative weight before comparing the event with a different one observed somewhere else. As the history and extent of large and catastrophic losses is often determined by many factors - passive safety designed into the project (distance between units in the case of fire, protective measures, redundancy, etc.) as well as active measures (speed and effectiveness of actions taken after an accident, etc.) their permutational and combinatorial appearance may produce a bewildering multitude of scenarios. If there are only 6 factors we get 720 possible combinations, if there are 10 the numer rises to 3,628,800. If important parameters are involved one should theoretically have the proper ASN for each combination. Even if consultants and builders of plants would proudly publish all failures and not only the successful cases, it would be difficult to assemble samples for modern, large, and exotic projects which would provide a sound basis for catastrophe assessment.

This is, unfortunately, not the end of the stochastic "drama". Any project and in particular a large one is exposed to a multitude of hazards, each and everyone having its own probability distribution. In view of this there is a chance that the project is hit by more than one calamity during its construction, erection, and testing phase, or during each year of later use. If the project is likely to engender public concern, e.g. a nuclear plant, a dam, or a chemical plant likely to release poisonous or obnoxious material, this combinatorial probability is of particular concern. Problems may, however, arise at a much lower level. The occurrence of more than one large loss within a relatively short span of time can cause considerable headaches to all parties involved. The probability of such a situation may be assessed with the aid of the following formula:

$$p = \frac{\binom{a}{1}\binom{\Sigma R - a}{a - 1} + \binom{a}{2}\binom{\Sigma R - a}{a - 2} + \binom{a}{3}\binom{\Sigma R - a}{a - 3} + \dots}{\binom{\Sigma R}{a}}$$

in which 'a' is the numer of loss categories having return periods (R) expressed as years.

In passing it is mentioned that although, e.g. an earthquake, a flood, a windstorm, etc. may have an annual probability of occurrence of, say, 1% (R = 100 years) we may under no circumstance expect one event in each century, because if 10 events are distributed randomly among 10 centuries there will be centuries with no observation and others with more than one (cf. section on SEISMICITY). This points at a psychological human problem because general human nature does not have an inborn instinct for probability concepts. The average human who has experienced decades without a catastrophe will take this as God-given blessing or as a confirmation that his feeling or estimate was correct.

If events are randomly distributed and if we let 'k' denote the numer of events (e.g. per century) we may write

$$P\ (k) = \binom{n}{k} \frac{(m - 1)^{n - k}}{m^n}$$

The number of events (per century) is denoted by k, n is the number of events per span of time selected (e.g. 1 event per century in the example used above), and m is the number of time units (e.g. 10 centuries) . If we now calculate for k = 1, 2, 3, etc. we find that on the average (and under the condition of randomness) about 35% of the centuries are without events, about 39% have one event, 19% produoe two, and 6% present us with three events, etc.

This brings us to the next important issue in connection with sampling and evaluation of samples, viz. trends. Whereas inflationary trends are quite evident, or increased cost of repair and/or replacement which may be caused not only by rising wages but by more stringent safety requirements (NPP's, chemical plants, etc.), it is generally not known that there are good reasons to consider seismic, or hydrological including climatic and meteorological trends. There is reason to think that there are not only seismic gaps, which means that the point (site) earthquake probability for the years ahead may be quite different from the one experienced during recent decades, but that there are considerable variations in global seismic activity which, in turn, reflect in the local seismicity as well.

In hydrology a carry-over phenomenon has been noted many years ago, and it should be pointed out that general climatological changes render the picture even more complex. Such climatological changes will not only reflect in changes of rainfall intensity, or discharge of rivers but also in windstorm and wave-height probability. As regards rainfall, runoff, and river discharge or stage there are additional factors like changes in land use or siltation during a period of comparatively low peak discharge. We still have to see an analysis of the hydrological exposure of a major project, even of dams which are comprehensively studied in this respect and which considers all these factors. This shows again that also this important exposure parameter, like those discussed earlier and many more to follow, are man-made.

The probability of failures (accidents) for technical and/or human reasons in a project is never constant over time. Teething troubles appear early during testing or the first phase of use of a project and this is not only due to technical problems but to human factors as well. As regards failures for technical reasons it is generally known that the early high failure rate decreases and stays at this low level for several years until ageing and wear and tear start taking their toll. In connection with accidents caused by human failure, however, one generally refers to learning curves which show that, as experience accumulates the general accident rate drops, but one overlooks that a certain percentage of any human population appears to be unable or unwilling to learn. This "kamikaze-type" causes up to about 25% of all serious accidents and, the more advanced the learning process the more important their influence.

It is evident that major projects employing a larger numer of people than ordinary ones incorporate a correspondingly higher chance to be affected by such persons. Moreover, the loss caused grows with the size of the project.

We shall now discuss the third critical issue which is the interpretation of data collected to enable assessment of catastrophe exposure. We shall start with the impersonal part, viz. mathematical models and, more specifically, probability distributions.

Although mathematics constitutes only a small part of general risk assessment, the models selected play an important role in the range of exotic, i.e. catastrophe exposure. Statistics of extremes is a problematic issue, inspite of Gumbel's famous book, and the lack of exposure of the average expert to a very large body of data and the inadequately honed mind associated herewith compounds the problem. Trying the Gumbel III distribution on an inadequate numer of observations which are, on top, not really representative, or selecting other distributions may result in mathematical acrobatics which is breathtaking but useless. Adequate experience is invaluable and cannot be replaced by mathematics.

In addition there is frequently some bias, not only the déformation professionnelle, as the French say, but some personal, and even some national bias. Many if not most of those exposed to risks appear to be prisoners of past experience which is often mirror-reflected into the future as if no different data could have resulted in the past or as if no different scenarios could arise in future. This attitude is reinforced by extreme specialization which prevents thinking in analogies or drawing on experience collected in other fields. The result may be excessive confidence and "hyperprecision" and lack of understanding problems not belonging either to ones own discipline or not or not fully covered by any discipline. How large such gaps may be or how different safety concepts are is, for instance, demonstrated by earthquake engineering.

Earthquake construction codes are concerned with buildings, they are mute about industrial risks. Earthquake codes and the professionals applying them or rules of design bother practically exclusively about how safe a structure is after completion. What happens during construction and/or erection appearsto be of no ooncern to them. Dams generally incorporate spillways designed to cope (hopefully) with a discharge likely to occur once in several thousand years. Even if forces generated by earthquakes were considered in dam design the exposure of such dams to this peril is an order of magnitude higher than to flood discharge.

Specialisation leads to neglecting the impact of forces considered in other fields of science. For instance the Delta Act of the Government of the Netherlands prescribes that the defences should withstand water levels associated with a probability of 10^{-4} per year for the 'heart of Holland', a probability which is comparable to the one used in spillway design of major dams. Irrespective of the fact that hydrological data is hardly in a position to warrant an uncertainty factor much below 3 to 5 (i.e. similar to the one proposed in the Rasmussen Report (1975) for nuclear power plants), any such small probability or long return period of a catastrophic event should consider not only water level data which is influenced by inadequate recording in the past, altered hydraulic parameters (e.g. by new dikes, dredging, etc) , but general changes in climate, for instance the transition since the little ice age and the changes observed during this century. Similarly, volcanism would have to be included as well in the assessment of extreme floods; an eruption of the size of Tambora's in 1815 which affected average sumer temperatures quite adversely in many parts of the world has a probability approximately of the order discussed here. But in order to influence meteorological parameters in such a way that catastrophic water levels are reached we do not need a volcanic eruption like the one