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I. INTRODUCTION

1. GENERAL INTRODUCTION

The idea of the multi-sectoral comprehensive study on disaster preparedness and mitigation for Armenia was put forward by Mr. Nikolai Ryzhkov, Chairman of the Council of Ministers of the USSR, in Erewan, when he was discussing the consequences of the disastrous earthquake of 7 December 1988 in Armenia with a Special Representative of the UN Secretary General.

Thereafter and as a preparatory step UNDRO sent to the field two delegates to assess the scope of such work and co-ordinate it with the USSR-Organizations concerned, such as the Civil Defence of the USSR and Armenia, the Academy of Sciences of the USSR and the Academy of Sciences of Armenia and to start organizing a multisectoral disaster preparedness planning mission to Armenia.

The resulting mission was composed in such a way that each UNDRO consultant was assigned to a particular hazard prevailing in the territory of Armenia, i.e. earthquakes, floods, landslides, mud flows, and industrial hazards with special attention to disaster preparedness and management planning. The five top level international consultants came from the Federal Republic of Germany, Japan, India, the United Kingdom and the United States of America. A UNDRO staff member, assigned to the mission was acting as the Executive Secretary for the mission.

The mandate of the Mission included the assessment of the probability and magnitude of destructive events, review of risk zoning maps, identification of techniques which could be applied to reduce the vulnerability of existing and planned structures, elaboration of plans for disaster preparedness and mitigation, preparation of recommendations on development of early-warning systems.

As became evident the mandate was too complex to be fully met during the mission which lasted from 11 to 30 September 1989.

The concerned central authorities in Moscow assigned senior specialists from the Civil Defence of the USSR, the Joint Council on Seismology and Earthquake Engineering of the Academy of Sciences as full-time counterparts to the UNDRO mission. The respective authorities in Armenia also assigned specialists from the Civil Defence of Armenia, the Academy of Sciences and technical institutes involved to work with the mission as full-time counterparts.

The background information requested by the mission included:

1. Physical Data:

Maps of surface geology, detailed maps for entering distribution of buildings, population statistics per region, maps of utilities, life-lines and hospitals, maps and capacities of local chemical plants and factories, probabilistic maps of wind speeds showing directions, topographic maps, rainfall records, inventory of natural and industrial disasters, the monitoring system in operation and planned, hazard zoning and vulnerability assessment for different elements at risk, existing arrangements for hazard mitigation, regulations and laws, control mechanism, emergency plans and the corresponding organizational structure.

2. Counterpart-Personnel:

This item concerns national experts to work on a full-time basis with the team, and it was suggested that that the national counterpart-personnel include the following specialists:

One civil and one hydraulic engineer, one geophysicist, one geologist, one hydrologist, one civil protection/disaster management planner, one expert in slope stability and soil mechanics.

Specialists were suggested by the State Committee of Construction, which was also handling the similar disaster preparedness and prevention planning task, the Joint Council on Seismology and Earthquake Engineering of the Academy of Sciences, Red Cross and Civil Defence to be associated with the team.

3. Equipment and Facilities:

Working rooms, office equipment, local transportation and communication facilities were requested.

It was understood that the usefulness and efficiency on the team s work depended in large measure upon its having in addition access to all existing documents on disasters and management experience and also upon the assignment of national personnel to work with it (a general pre-requisite to all UN technical co-operation projects).

As these requirements could not be met to the desired extent the experts had to base the following report on the data they could collect, on their experience and on certain general assumptions.

The cost of the mission were covered in large part from the UNDRO Trust-FUND, using a contribution by the Federal Republic Germany made for the case study of the Armenian (Spitak) earthquake of December 7, 1988. The in-country costs were covered by the USSR and Armenian host authorities.

After receiving briefings in the Ministry of Foreign Affairs of the USSR, the Academy of Sciences, and the Civil Defence of the USSR the mission departed for Erevan to attend to the specific work.. Each consultant together with the national specialists was to produce the output in his particular field of specialization, including disaster preparedness and management.

The report of of the mission reflects the personal views of the consultants whose main preoccupation was that the lessons of the recent disaster be learned in order to avoid or reduce losses from future disasters.

The report is mainly designed for decision makers but it has been written in such a way that a general benefit may be derived on the local and national level and under various settings. Sufficient material and data on essential parameters has been included to render the report of value as well for experts in the respective field.

I.B. INTRODUCTION TO THE REPORT

Any report made up of several contributions and in particular if compiled by experts with different but overlapping interests is bound to incorporate particular problems. The situation is rendered even more difficult if a report is to be produced within a comparatively short time which deals with multi-sectoral aspects of disasters, their assessment, preparedness and management. For such reasons some introductory remarks appear to be appropriate.

As mentioned in the general introduction the report is mainly designed for decision makers at various levels and operating in rather diverse organisations. It is, however, apparent that such a report must also contain a host of information and data which are of interest to specialists in different faculties. It has therefore been tried to satisfy the expectations of the organizations and experts concerned and to organize the report in such a manner that the importance of a comprehensive, broad-spectrum approach to disaster prevention and management is emphasized.

The contributions of the experts in the various fields have been kept as units and not rewritten or reassembled in the form of a uniform product. Thereby the homogenity of the individual sections is maintained and the usefulness of the report is maintained even for experts in the particular field. Moreover, this form retains the individuality of each contributors' report and opinion enabling the reader to arrive at a balanced evaluation.

As the individual reports were maintained as integral units it is unavoidable that certain aspects and problems are treated more than once. Also this will help the reader to arrive at a balanced view. Moreover, illuminating certain problems from different angles will not only deepen the understanding but aid in the multi-disciplinary appreciation of disaster assessment, mitigation and management. One of the problems of present handling of disasters is the appalling lack of co-operation and co-ordination, of correlative information and of learning. One of the resulting shortcomings of present ""disaster-science"" is the lack of information and data in the individual fields. That the disaster potential is generally underestimated is to a considerable extent a consequence thereof. In the contribution on Seismicity a paper is mentioned (reference (1)) which discusses the most blatant errors in Catastrophe assessment.

In view of the complicating factors mentioned earlier the editor hopes that the authors will be excused if they fell short of the expectations of some of the readers. It is not only a substantial but an unusual task to try to compile a report which covers a very broad spectrum of risks and problems and which addresses the general reader as well as the expert.

In conclusion it must be mentioned that the respective section of this report can only give a general picture of industrial risks. The reason is that the team had no opportunity to inspect industrial plants. This is to be regretted as a unique chance was missed to point out which properties contribute to failure, in particular in connection with earthquakes but nalso due to fire, explosion and human failure. It will be remembered that the Spitak earthquake caused much damage to industrial plants leading inter alia to considerable indirect losses, like loss of employment and production.

I.C. THE SPITAK EARTHQUAKE (7 DECEMBER 1988) CONSEQUENCES AND LESSONS TO BE LEARNT

IMPACT OF THE EARTHQUAKE

The catastrophic earthquake of 7 December 1988 (Wednesday) occurred at 11.41 hours local time near the town of Spitak in Armenia. It was located at 40.9N 44.2E at a depth of approximately 14 km with a magnitude of M 6.9. Its intensity was assessed as 7-9 in the town of Leninakan, and 9-10 in the town of Spitak. Maximum fault displacements were 1.6m vertically and 1.6m horizontally. The intensity was very variable due to the high level of ground water in certain locations. The earthquake was one of the most important instrumentally recorded in the Caucasian region. The earthquake consisted of a series of shocks. During the first 30 seconds three shocks were recorded followed 4 minutes 20 seconds later by another important shock with a magnitude of around 5.0, the epicenter of which was situated 6-7 km to the south of the main epicentre. The earthquake was felt on nearly 40% of the territory of Armenia (12,800 square km), with a total population of approximately one million people in the strongly shaken area. More than 515 thousand were made homeless. Spitak, a city with 18,500 inhabitants situated about 15 km from the epicentre, was the most affected by being almost 100% destroyed. Search teams working in Spitak concluded that there was not a single house in the city which remained inhabitable. In Leninakan, the damage mainly resulted from the collapse of about one hundred high-rise buildings, recently constructed of prefabricated concrete elements. However, 16 nine-story buildings made of large prefabricated concrete elements resisted rather well and suffered only a few cracks. Nevertheless, all of them were later demolished or are due to be demolished because they were judged inappropriate for this seismically active area. According to the pre-1982 building code, buildings in Spitak and Leninakan were to be designed to resist a possible intensity of up to 8. (The Building code of 1982 reduced the design intensity for these towns to 7). Therefore, it was no suprise that they did not resist the violent shocks of greater intensity in 1988.

PHYSICAL PARAMETERS BY DESIGN INTENSITY

Intensity	Acceleration	Velocity cm/sec	Displacement of Standard Seismometer	Power j/cm2
7.	0.05-0.10g	4.0-8.0	2.0-4.0	0.3-1.5
8.	0.10-0.20g	8.0-16.0	4.0-8.0	1.5-7.0
9.	0.20-0.40g	16.0-32.0	8.0-16.0mm	7-35

Many individual one-story houses were damaged but did not collapse, thus saving the lives of many inhabitants. Particularly heavy losses were inflicted on children, students and workers i.e., the active part of the population. More than 8,000 persons became partially or fully disabled.

Within a few minutes, a flourishing area with a population of several hundred thousand inhabitants became the scene of one of the world's largest catastrophes in recent years. Heavy losses were also inflicted on industrial and agricultural plants in the area. It would be appropriate here to recall that a disaster situation is a result of a vast ecological gap between man's activity and nature. Thus, natural disasters delete this artificially created gap.

The human and material damage inflicted by the earthquake is summarized in the following table:

(Source: USSR Civil Defense as of 31 December 1988)

Affected Area	Population		Dwelling Houses		Industrial Agr'l Plants		Social Structure		Rate Destrd
	Total	Killed	Built	Destrd	Built	Destrd	Built	Destrd	(%)
Spitak	18500	9733	433	433	9	6	28	24	100
Leninakan	232000	9974	12450	11250	40	40	669	323	75
Stepanavan	21000	63	2134	1430	9	1	134	12	67
Kirovakan	171000	420	7162	2333	34	6	456		25
Rural Area	146500	4352	29533	20094	1404*	1293*	581	186	34
All Areas	589000	24542	51712	35395	1496	1348	1868	540	60

*) Includes agricultural production totalling 1365 units. This loss in the agricultural area does not include the death of 76,500 animals out of 343,000 recorded before the event.

USSR RESPONSE TO THE DISASTER

The Government of the USSR took immediate steps to meet the emergency needs of the population. The Prime Minister of the USSR was designated to head a Special Commission of the Polibureau of the Party and he chaired the daily sessions to review the course of operations and mobilize emergency relief. It is essential to note that 90-95% of all relief assistance came from within the USSR. Emergency aid including grants is assessed at SU Roubles 4.5 billion (US$ 7.3 billion). Most of this assistance came by rail. For instance, it was reported that by 19 December 1988; 27,000 rail coaches (20-60 tons each) had reached the area.

The Government of the USSR officially notified UNDRO that international assistance would be accepted and to this end took the following steps:

- Exempted international assistance from customs and duties;
- Authorized umlimited access to airports in disaster areas;
- Granted visas to relief workers and journalists at Yerevan airport;
- Provided free transportation for international relief assistance by Aeroflot, etc.

As to the management of the disaster, decisions were concentrated on the following priority actions:

- Tracing and salvation of trapped people;
- Organization of medical care;
- Provision and distribution of emergency food, water, and power;
- Organization of security measures in the area;
- Evacuation of vulnerable groups of the population.

The initial emergency relief aid was spontaneous and came from Armenia and Georgia. Up to 90% of the rescue work was claimed to have been carried out by neighbors, but this could not be confirmed due to lack of statistical data. Locally organized assistance arrived on a large scale from Armenia and Georgia 4-6 hours later when the first groups of workers from Yerevan reached the scene equipped with cranes and bulldozers. Within two hours of the earthquake, the Civil Defense of Armenia organized reconnaissance flights by helicopter over the area and started mobilization of its non-regular forces. Unfortunately, at a later stage the Civil Defense of Armenia had not found its place in the huge administrative and management scheme.

USSR RESPONSE TO THE DISASTER

Affected Area	Deployed Civ Def Forces	Extricated Persons	Evacuated Persons	Mobilized Equipment			
				Cranes	Bulldz	Excav	Lorries (10 Ton)
Spitak	7,300	13,990	8091	415	187	103	897
Leninakan	39,300	16,959	58642	974	301	167	2389
Stepanavan	1,650	108	-	91	77	29	170
Kirovakan	3,500	4,317	34720	178	124	65	474
Rural Areas	9,600	4,421	17865	333	299	275	1391
Total	61,315	39,795	119318	1991	988	639	5321

The tracing and extrication of trapped people in the first hours after the earthquake was carried out mostly by the local population or by people coming from neighbouring Armenian and Georgian villages. The first professionally qualified rescue workers began arriving from within the USSR on the afternoon of 8 December, becoming operational 36 hours after the disaster. The number of professional foreign relief workers is estimated by UNDRO to be around 1000 daily. In total, 135 relief teams from 45 countries were operational in Armenia. The teams came from the countries of France, Italy, Switzerland, UK, and the USA for a week of non-stop work and were replaced in most cases by new ones. Many teams came self-sustained in energy, spare parts, and even interpreters, which proved to be very useful. International teams managed to extract about 50 people alive from the debris. Records show how the salvation work progressed on a day-by-day basis.

RESCUE OPERATION
(Day by day)
Source: Civil Defense of the USSR

Total Extricated	7.12	8.12	9.12	10.12	11.12	18.12	19.12	25,12	Total
Alive	1382	1660	4825	5479	1757	150	1		15,254
Total	4328	9634	8243	6437	4419	6316	418		39,795

There is some contradictory information on the subject of human losses. The Ministry of Internal Affairs of the USSR explained that the calculation of losses was reliable, as the procedure was strict and included necessary identificaition, photos and registration. In cases where it was impossible to identify the victim, the photograph and the recorded location of the victim were kept in a special file for future possible identification. This procedure became effective 8 December 1988.

Emergency medical services were organized on the basis of available facilities in the area. It was quickly understood that the existing medical facilities were insufficient. One thousand one hundred fifty (1150) hospital beds were made available in the stricken area. Ten more temporary hospitals were brought into the area. Subsequently, the injured were first evacuated to Yerevan where an additional 10,000 hospital beds were made available for treatment. The injured were also evacuated to other hospitals inside the Soviet Union. The evacuation proved to be a very difficult problem, as the affected area is linked to Yerevan by a mountainous road of about 100 km. In many cases the medical evacuation was organized by air through helicopter services.

Food distribution was undertaken by volunteers of the Armenian Red Cross and was free of charge for the first 12 days after the earthquake.

Security measures were taken to close off access to the area. For security reasons, (collapsed banks, savings of residents) it was decided to close the area to civilians not immediately concerned with the situation (effective 9 December 1988) and to bring heavy building machines into the affected area. The area was closed off with the assistance of regular military forces.

Evacuation of vulnerable groups of the population from the area was decided by 13 December 1988. In total, 120,000 women, children, and elderly (and those psychologically exhausted) were evacuated from the area.

UNDRO'S ACTIVITIES

As soon as information on the earthquake was received, UNDRO fielded a two-man mission which arrived on the scene 32 hours after the earthquake. The main objective of the mission was to help identify relief needs and co-ordinate international response. The mission provided assessment reports on the spot, on the basis of which UNDRO prepared its situation reports and distributed them to all potential donors and authorities concerned (i.e., almost 550 addresses around the world). The total foreign relief mobilized by UNDRO amounted to US$ 117 million, as of 31 January 1989. This amount does not include contributions in kind and services such as rescue teams, specialists, search dogs, etc. Relief supply were sent on 348 flights from 45 countries. Cash contributions amounted to US$ 18 million (UNDRO Emergency Relief Report). UNDRO and USSR technical organizations concerned (Civil Defense, Academy of Sciences, Red Cross Organizations) organized a training seminar on lessons learnt from management of earthquakes in the USSR in October 1989. The experience gained from the management of recent earthquakes was discussed in depth. In total, UNDRO sent 14 highly qualified lecturers who along with their colleagues from the USSR technical organizations covered all the technical issues set out in the work programme. Later in 1989, at the request of the Government of Armenia, UNDRO launched a multi-disciplinary consultancy mission on disaster management planning for Armenia. The mission consisted of 5 internationally known consultants from the Federal Republic of Germany, Japan, USA, UK, and India. The terms of reference of the mission included the assessment of hazards (earthquakes, floods, slope instability) and industrial hazards. The three week mission was actively supported by the Civil Defense and Academy of Sciences of the USSR.

CONCLUSIONS

1. Concentration of production capacity in settlements makes these more vulnerable. An increase in vulnerability of human settlements is a new characteristic feature of modern society. The recent earthquakes affecting urban areas (i.e., Mexico, Nicaragua, San Salvador, El Asnam, Bucharest, China, Nepal and Armenia) prove the need to give priority to disaster mitigation work, which should include the following:

- Training the population to respond appropriately and to perform elementary rescue techniques in an emergency situation;
- Adopting structural measures appropriate to local environmental conditions;
- Development of disaster management plans on the basis of risk analysis to ensure appropriate responses to natural and man-made disasters.

2. The first priority in relief work should be to organize the tracing of trapped people. The effective implementation of this operation must not exceed several days. Some sources indicate that the probability of survival in debris drastically declines after three days of captivity.

3. People may survive in collapsed buildings. The probability depends on the physical condition of the person trapped, the aeration and temperature, which is normally 5-10 higher inside than outside. The best chance of survival is in basements and ground floors. All this data on precise conditions and on the possibility for survival should be carefully recorded for further study and should be available for exchange between relief services.

4. The methodology for tracing and extricating trapped people should be developed. It may be appropriate to mention that making passages at ground level with heavy jacks may turn out to be more effective than salvation with the help of heavy cranes. The experience of many recent earthquakes in urban areas shows that the proportion of survival of people on ground floors may be higher. Some sources indicate that it is approximately 3.5 times higher. Therefore, extrication by ordinary building techniques (cranes, bulldozers) may be inappropriate and should be discouraged as this cannot be done without disturbing the debris which may kill survivors. The work of heavy building equipment should be restricted in the area until the end of the rescue operation. Rescue with jacks is easier to organize as it does not require large transportation support; and secondly, the unloading capacity at terminals should be kept free for the urgent procession of emergency relief goods, appropriate to each stage of the operation.

5. Civil Defense Organizations should become more responsible for civil protection and, therefore, shift from military scenarios to emergency scenarios caused by natural and man-made disasters.

6. Emergency units and plans prepared for the area should be continued, reassed and implemented, according to their functions (even, if they suffered loss). They should be reinforced but should not be replaced, as they are the only authority which accumulates experience and knowledge of local conditions, the factor which can be decisive in the effective implementation of rescue work.

7. Emergency grants and funds should concentrate first of all on the creation of reliable communication with the disaster area. The best solution would be the acquisition of a communication facilities via satellite.

II. OVERVIEW AND GENERAL ISSUES

II. A. CLIMATIC ASPECTS AND PHYSICAL CONDITIONS

Climate plays a major role in emergency preparedess and emergency management considerations in Armenia. If a major disaster occurs in the months between mid-April an mid-October, the weather will not usually affect relief operations, and most assistance and response can be carried out on site. If, however, a disaster occurs after mid-October, there is a good chance that temperatures will be low and rain, fog, snow and associated low-lying cloudes could impede essential tasks such as disasterassessment, search and rescue, evacuation and logistics. In the emergency operations after the 1988 Spitak earthquake, one cargo plane crashed in fog while attempting to land at Leninakan airport and another aircraft crashed during an approach to Yerevan.

Low temperatures may also necessitate variations in emergency response doctrines. If a massive earthquake should occur during warm or mild temperatures, immediate evacuations would not be required. On the other hand, if another winter earthquake were to occur, some portion of the population would need to be evacuated until on-site shelter could be provided.

Rainfall in Armenia is seasonal, most of the precipitation being concentrated in the months of March, April and May. In some years there may be appreciable rainfall in other months as well, particularly in February, September and October. Annual rainfall varies from a maximum of 1,000 millimeters to a minimum of 300 millimeters, with an average of about 700. Although the average rainfall is moderate, there may occasionally be heavy precipitation. The maximum monthly rainfall in Yerevan since 1955 occurred in 1959 and was 181 millimeters. The maximum one-day precipitation recorded in Yerevan is 51 millimeters for September 1974. In southeast Armenia and Kafan a maximum daily rainfall of 176 millimeters has been recorded.

In common with other semi-arid areas, there is large variability in anual rainfall. The ratio of maximum to minimum annual rainfall in Yerevan over the period of almost thirty years from 1958 to 1985 is 3.06.

Due to steep slopes and lack of vegetal cover, the runoff factor is high and the time of concentration is low. Thus, there is a tendency for rainfall to cause floods, though the areas exposed to flood danger are limited due to the incised nature of rivers and as the locations of inhabited areas are usually at higher levels.

It appears that most of the mud flows and landslides are caused by heavy short-term or sustained rains. Only a very small fraction can be attributed to snow melt. Major landslides may be activated by earthquakes. Such slides are, however, much less frequent. In adition, in the aftermath of earthquakes, slopes loosened by the earthquakes could be saturated by heavy rainfall and slip, although this risk is not estimated to be too great as regards human settlements. It may, however, affect access to the area. Table II-A presents the recent rainfall records in Yerevan. Figure 1 depicts average rainfall patterns for Armenia.

Snow covers the higher elevations of Armenia during the winter months. None of the major cities experience prolonged periods of deep snow, although snow may remain on the ground for several weeks at a time. The principal concerns are icy roads in the mountain passes which can affect relief operations as well as create extremely dangerous conditions for movement of hazardous material by lorries. As mentioned earlier, if a winter earthquake were to strike during a snow storm, the immediate emergency operations could be severely constrained.

Other than these hindrances, snow poses few other obstacles. The snow does not accumulate in patterns that would create large-scale avalanches, and snow melts are gradual and unlikely to cause serious flooding problems.

II. B. GENERAL EARTHQUAKE PROBLEMS AND ADMINISTRATIVE ISSUES

In reviewing existing emergency plans and discussing the response of various government ministries and departments in the aftermath of the 1988 earthquake, a number of adinistrative concerns were identified which need to be addressed in order to successfully implement a broad vulnerability reduction strategy, to improve emergency preparedess and response capabilities, and to enhance overall coordination. These include:

1. Compartmentalization

A major constraint is the degree of comparmentalization that exists between the various ministries charged with vulnerability reduction and emergency management. Interministerial coordination is often minimal, scientists are not fully integrated into the implementation process, and key departments are often unaware of the activities of others. For example, scientists working on geotechnical aspects of an earthquake have little direct input into urban and regional planing. Engineers conducting research on seismic resistant designs are only minimally involved in actual construction. Civil Defense is often unaware of activities being carried out in technical fields related to its work.

If vulnerability reduction efforts are to be successfully accomplished, it is imperative that closer coordination be achieved and that the entire effort be brought under a unified system of management.

2. Failure to Follow Existing Plans

In reviewing the emergency response, there is evidence that leaders at all levels disregarded existing emergency plans. While many elements of the earthquake plans were inadequate, failure to use the systems that had been set up created greater confusion, and many valuable resources were not properly or fully utilized.

While improving existing plans is important, they canot be implemented successfully unless community leaders at all levels actually follow them in an emergency. Increasing their utilization is a function of the way the management structure of the plan is designed, the degree to which leaders are familiar with the plans, and the provision of training using drills and simulations to demonstrate to leaders how plans can improve their ability to manage emergencies.

The fact that political leaders from outside the repulic took command of the situation is not unusual - the greater the disaster, the more political attention it will attract. Planners must anticipate this phenomenon and:

- design the plan to rapidly integrate high-ranking political leaders into the plans at a policy-making level and, to a lesser degree, in operational matters, and

- design the plan to permit small, specialized teams to operate relatively autonomously.

Major policy decisions should be left to politicians, operational and technical decisions should, however, be carried out automatically with minimal supervision from the emergency operation centre.

3. Poor Quality Cotrol

Throughout the mission, the team was dismayed at the apparent lack of quality control in the building process. At the most fundamental levels, critical building components are improperly manufactured and routinely installed in such a manner that they will fail under seismic loadings. Well-designed buildings will not stand up in earthquakes if they are not properly made. There appears to be much interest in building codes; yet these will have little impact unless closer attention is paid to the actual production of building components and standard of workmanship. The catastrophic failure of modern buildings would not have occurred to such a great extent if the present building standards had been followed.

4. Over-Reliance on Technical Solutions to Building Problems

As a consequence of the widespread failure of modern buildings, there is much interest in finding new designs, equipment or building techniques to improve the quality of construction. For example, one organization has proposed investing in sophisticated concrete testing equipment to determine the quality of precast concrete beams.

For the most part, little new technology is required. Most of the problems are extremely basic. Concrete is poorly made because aggregate is improperly screened, the mix of sand, cement and gravel is not properly monitored, and far too much water is used. Many other problems were observed that could easily be corrected by proper training and quality control. Until these problems are corrected, investments in sophisticated testing equipment will not yield tangible results.

5. Aparent Lack of Cross-checking in the Quality Control Process

Related to the problems of compartmentalization and disregard for standards is the lack of cross-checking and verification in the building process. Low-quality components have become the norm. Many of the builders interviewed by the team could not recognize blatant faults and deficiencies in building materials. From discussions with builders and personnel of the various construction organizations, it is apparent that responsibility for quality control lies with the manufacturers of building components. If quality control efforts are to be successful, an efficient system of cross-checking at all stages of construction is required.

6. Lack of Owner/Occupant Inputs

The ultimate way to achieve quality control is to ensure that the future owners or occupants of buildings are involved in the design and construction process. The people who are going to be living in the buildings must have a say as to whether or not the buildings are properly made. With forethought and planning, a committee system can be devised whereby future occupants can review the building process. They can choose technicians to represent them in negotiations with construtors and can collectively review the building process and quality of construction. Most important, they should have the right to challenge the construction of buildings deemed to utilize unsafe components or construction techniques. Without owner and/or occupant inputs at all levels of construction, successful quality control will be difficult to achieve.

RECOMMENDATIONS

1. Emergency plans should be reviewed to ascertain that contingencies are included which allow for:

   - The adverse influence of low temperatures at the time and after an earthquake.
   - The potential effects of damaged bridges, mud flows and landslides on access to the area.
   - The effects of icy roads and snow storms.

2. It should be studied in which way the coordination of all ministries, departments, scientific branches, engineering faculties, etc. can be improved, which are directly or indirectly involved in any activity which contributes to the earthquake risk.

3. Everybody supposed to act according to emergency plans should familiarize himself thoroughly with such plans to make sure that they are followed diligently. Regular drills and simulations should be introduced to guarantee that plans can be implemented efficiently.

4. Plans should be prepared to describe in which way high-ranking political leaders should be integrated in case of an emergency.

5. The responsibilities of small, specialized teams should be defined in such a way that they can operate autonomously.

6. Emergency plans should be reviewed critically and amended if necessary after an emergency.

7. A reliable procedure for quality control of plans, designs, material, manufacturing premises, and workmanship is of primordial importance. One should first and foremost ensure such quality control before embanking on developing new standards and technology.

8. It is recommended to involve owners, occupants or users in the control of designs, construction and manufacturing.

RAINFALL IN YEREVAN

1. Annual Rainfall in mm

1955	256
1956	416
1957	336
1958	231
1959	309
1960	310
1961	138
1962	243
1963	481
1964	300
1965	299
1966	293
1967	365
1968	263
1969	428
1970	157
1971	303
1972	335
1973	303
1974	310
1975	324
1976	231
1977	252
1978	389
1979	232
1980	239
1981	263
1982	263
1983	231
1984	252
1985	251

2. Maximum Rainfall per Month in mm

Month	mm	Year
I	74	1893
II	84	1913
III	103	1942
IV	104	1915
V	181	1896
VI	76	1957
VII	47	1936
VIII	68	1923
IX	79	1907
X	133	1946
XI	79	1907
XII	72	1969

3. Year with highest Rainfall

1946 469mm

4. Maximum Daily Rainfall per Month in mm

I	21	1944
II	23	1975
III	34	1964
IV	29	1915
		1972
V	42	1896
VI	31	1957
VII	29	1915
VIII	26	1912
IX	51	1974
X	35	1896
XI	36	1948
XII	28	1892

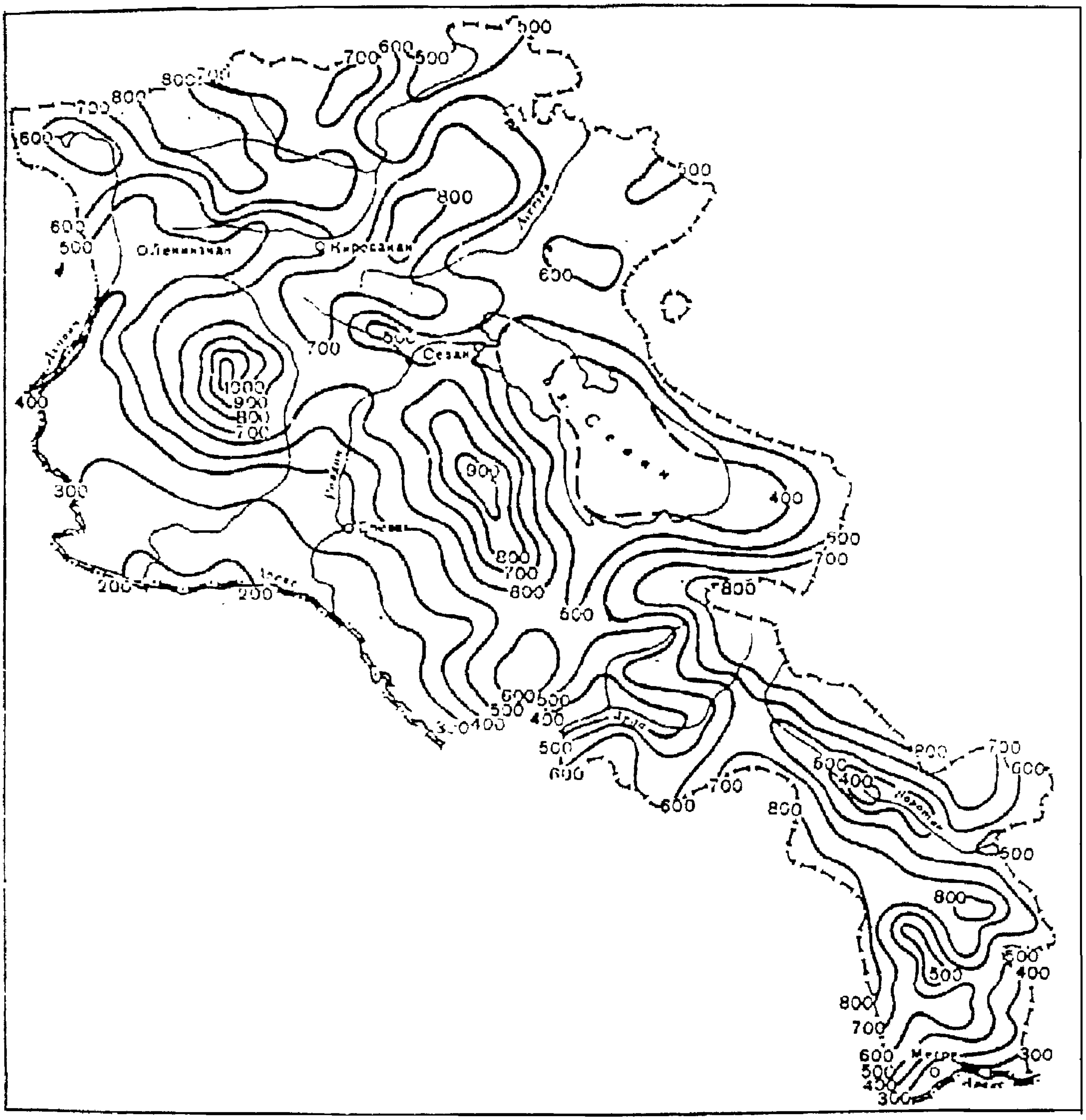

Fig. 1. Average annual rainfall for Armenia.

II. C. METHODOLOGY USED

After a meeting at the Department of International Economic Relations, Ministry of Foreign Affairs of the USSR, during which general information on the purpose and aim of the mission was exchanged a first briefing with presentations and discussions was conducted at the Academy of Sciences of the USSR, Joint Council on Seismology and Earth Engineering in Moscow. Its main purpose was to familiarize the members of the mission with details of the Spitak earthquake and to establish contacts with other departments of value in connection with the mission. These meetings also helped to prepare the ground for the following visit to Armenia.

During our visit to Armenia we similarly first introduced our mission to the Academy of Sciences of the Armenian SSR in Yerevan. During these discussions the members of the delegation presented their respective lists of contacts to be established, data required and visits to be organized.

The task of collection of information was complicated by the wide scope of the mission and basically by the fact that it was the first co-ordinated investigation into a broad spectrum of hazards. As the diverse fields of science and engineering are dealt with by many distinct institutions which normally do not interact regularly the task of co-ordinating our mission was not as easy as anticipated. Such a future cross-co-ordination between departments is, however, an essential methodology in future catastrophe mitigation and management.

The field trips, i.e. the investigation of the places affected by the Spital earthquake, of dam sites and of regions exposed to floods or landslides had to be limited because of shortage of fuel for the vehicles.

Moreover, we encountered some difficulties in getting certain data required to assess the catastrophe potential, e. g. detailed maps and demographic information. It was also not possible to visit certain critical facilities like chemical plants, fire fighting services and hospitals.

The methodology used in the evaluation of the data received and of the lessons learned during our mission corresponds to the one generally employed by the members of our group in the fields of science covered by this report. In those areas of investigations where the data available to us is incomplete suggestions indicate in which way and according to which methodology such data can be evaluated on the spot.

The methodology of evaluation and presentation of the information collected and of the know-how of the members of the team aims at pragmatic solutions and proposals. The individual reports should not be taken as scientific papers.

RECOMMENDATIONS

1. Cross-coordination between departments and institutions should be improved in connection with future missions.

2. Data requested should be compiled before future missions arrive on the spot.

III. SPECIFIC THREATS AND ISSUES

III. A. 1. SEISMICITY

The general seismicity of Armenia is well known. It is therefore not necessary to discuss details. This section will try to bring out some essential issues which are of interest to the general reader as well as parameters and uncertainties which are often not discussed in specific publications but which must be considered in hazard assessments.

The tectonics of Armenia are dominated by compression due to the displacement of the Arabian plate towards the Eurasian plate. The result is a NS-compression at a rate of about 5 mm per year. At this rate a displacement of 5 m is reached within one thousand years. Experience with rates of displacement and seismicity obtained from many seismic regions of the world indicates that with such displacement a M 7.5 earthquake can be assumed to occur at a certain place ("point probability") on the average once in about every 1200 years. For a M 6.5 earthquake the return period would be approximately 500 years.

General large-scale plate tectonics implies that every part of the crust of the earth is subject to compression, i. e. energy input and that therefore earthquakes are in principle possible at any place within the zone of compression. For Armenia this is supported by scientific studies of historical seismicity (cf. Fig. 1). This general exposure is underscored by the fact that all ancient capitals of Armenia were destroyed by earthquakes.

The return periods mentioned above indicate a level of seismicity which does not provide a sufficient number of earthquakes per magnitude group within the period of observation to permit precise seismicity statements. This invites a discussion of specific problems of seismicity assessments which are often underestimated. In brief these problems are.

- The uncertainty arising from the fact that the period of complete and reliable earthquake recording is much shorter than the return period of large earthquakes.

- The intrinsic optimism of human beings leading to the assumption that future earthquakes will not be larger than those observed in the past.

- The difficulty in estimating the existence of seismic gaps, i.e. areas where earthquake energy release was below average during the period of observation leading to an above-average seismic risk until the seismic gap is closed.

- Below average global seismicity for most of this century because of global trends. This results in an observational sample of earthquakes recorded instrumentally in the Caucasian range which is not representative of long-term seismicity and in particular not of the high seismicity to be expected when the global gap is closed.

- The limited sample of isoseismals and the many parameters determining the areas affected by certain intensities, slides, and liquefaction.

We will now briefly discuss these problems in order to illustrate what uncertainties have to be considered and allowed for by introducing adequate safety factors when assessing castrophe potentials.

The Caucasian area is in earthquake regions 29 (eastern part) and 30 (western part). The number of years during which instrumental earthquake recording per magnitude group is now available is shown in Table 1.

Table 1
Average number of years for instrumental earthquake recording depending on magnitude

	M 5 - 5.9	M 6 - 6.9	M 7 - 7.9	M >8
Region 29	60	70	80	90
Region 30	65	80	90	90

This shows that the return periods of earthquakes which can cause catastrophes are thus much longer than the observation period. For an earthquake of about M 7.5 the return period is about 13 times longer than the average observation period for region 30 and for an earthquake of about M 6.5 the return period is still more than 6 times longer than the average instrumental observation period in region 30. Therefore the average chance of observing a M 7.5 earthquake during this century was only about 7.5% or about 16% for a M 6.5 earthquake. Theory of probability teaches that the observational uncertainty is therefore considerable.

The statistical observational uncertainty derived according to the stochastic model selected for "m" observations within "n" years is, however, only part of the problem. Mathematics teaches that if 10 events are randomly distributed over 10 centuries (producing an average return period of 100 years), about 35% of the ten centuries will not contain any event, 39% will produce one event, 19% two events, 6% three and 1% four (1). How correct would the probability estimates of assessors be who base their calculations on "abnormal" occurrence rates? Mathematics offers no aid in assessing whether one is experiencing an above-average or below-average occurrence rate!

Moreover, although seismicity is often evaluated as if earthquakes were randomly distributed, their occurrence is determined by deterministic parameters like vectorial strain accumulation in a region, properties of the rock formations under strain, etc. Most of these parameters can at best be estimated. They are also a reason for the non-random occurrence of earthquakes and for seismic gaps, but before discussing such issues let us look at something even more disturbing.

Quite a number of seismologists seem to think that the earthquake magnitude possible in a region will not exceed the largest magnitude actually observed in the past. This notion is wrong and very dangerous. There are quite a number of cases showing that past seismicity is a very unreliable yardstick, even where the historical catalogue is long and fairly complete which is practically never the case. A few examples should be enough to warn everybody concerned.

The earthquake with the largest magnitude (M 8.5) ever observed in China happened in 1668 on the southern side of the peninsula of Shandong. Severe damage extended over an area about 400 km in diameter. Without this event the region would be considered only nominally seismic, far less seismic indeed than the Caucasian zone.

Near the confluence of the Mississippi and Ohio Rivers three very large earthquakes happened on 6th December 1811, 23rd January 1812 and 7th February 1812. They were felt from Canada to New Orleans and possibly at Boston. Over an area of about 100,000 km^2 uplifted and sunken land, fissures, slides and sand blows were observed. Had these three earthquakes not happened one would "know" today that the region is somewhat seismic but one would not think that a catastrophe could happen there.

On 9th and 23rd July 1905 M 8.4 and M 8.7 earthquakes occurred about 500 and 600 km west of Ulaanbaatar (Ulan Bator), the capital of Mongolia. Without these two earthquakes the region appears to be much less seismic than the region of Armenia.

The M 7.5 earthquake which killed about 23,000 people in Guatemala in 1976 occurred in a zone which had been free of any noticeable seismicity for several decades.

The greatest loss of human life caused so far this century, with more than 250,000 people killed and more than 800,000 seriously injured, was due to the M 7.8 and M 7.1 earthquakes in 1976 in the region of Tangshan. Until then the region was not considered particularly seismic by Chinese experts. On the basis of the catalogue of historical seismicity for this region where the first observation dates back to 421 AD, the area is not more seismic than Armenia.

When considering earthquake catastrophes one must not only estimate the average return period of such an earthquake, an assessment which as has been shown incorporates considerable uncertainties and therefore requires a proper safety margin, but one must also allow for seismic gaps in the various regions and for seismic trends.

As regards seismic gaps one yardstick is the distribution of numbers of earthquakes per magnitude. On the basis of a world-wide distributuion with steps of one tenth of a magnitude steps one may state as follows. For every earthquake of a magnitude of M 8 or more there occur on the average 19 earthquakes of M 7 to 7.9, 202 of M 6 - 6.9, and 1,823 ranging between M 5 to 5.9 (2). The average ratio of M 5-5.9 to M 6-6.9 earthquakes is therefore about 9 : 1, that of M 6-6.9 to M 7-7.9 earthquakes is about 10.6 : 1, and for M 7-7.9 to M 8 or more is as stated above about 19 : 1.

If one counts within a region, for instance, nine events of the M 5-5.9 magnitude category one earthquake of the M 6-6.9 class can be expected to occur in the coming years. On the basis of this general global earthquake magnitude distribution the author had concluded already several years ago that a seismic gap equivalent to one M 6-6.9 earthquake was developing in the general region of Leninakan (Fig. 2). This gap was filled by the Spitak earthquake of 1988.

Applying this yardstick to the entire Caucasian region (Fig. 3) one finds that a number of M 6-6.9 earthquakes has been reached which suggests that a M 7-7.9 earthquake is likely to occur. The great questions remaining are when and where. (It is noted in passing that the Ararat earthquake of 1840 may have belonged to this magnitude class.)

It must be stressed, however, that such estimates provide only a general indication. Global observations tell that large earthquakes have happened without an earlier "warning" by a corresponding number of smaller earthquakes. Such examples are, for instance, the M 7.5 earthquake in Guatemala and the M 7.8 and 7.1 earthquakes near Tangshan in 1976 cited above. Conversely in certain regions a large number of earthquakes of the, e.g. M 5-5.9 category has been observed but (as yet) no larger one.

If the ratio of earthquakes per magnitude class is, however, much larger than stated above it is not unlikely that one or even more earthquakes of the larger category are overdue. If the average number of earthquakes of one magnitude class have reached the stated figures and in particular if they are more numerous one should not assess the chance of an earthquake of the next larger category in this region on the basis of average return periods. The large loss of life and the economic consequences inflicted by earthquakes dictate a circumspective attitude and the initiation of proper steps.

Another interesting case is the absence of earthquakes likely to cause serious damage (generally M > 5.2-5.5) from a large region subject to tectonic energy input. Such a region is to be found in the western limb of the Bolshoy Kavkaz. In spite of the fact that this region has been sparsely populated historical earthquakes have been recorded there showing that the region is seismic. Therefore it would not be wrong to assume a seismic gap there.

A smaller but because of the population density much more important region extends from south-west of Lake Sevan to west and north of it. According to documents available to the author a zone of low historical and instrumental seismicity appears to extend from about the Turkish border west of Yerevan (Aragats) to Ararat, and from this plain to the north beyond Sevan and to the north-east of Ozero Sevan. In view of the extreme catastrophe which a larger earthquake near Yerevan could cause it is strongly recommended to subject the area to a detailed study.

A cautioning remark is appropriate with reference to the use of historical data for catastrophe assessments. Catalogues of historical earthquakes are practically never complete. Wars, fires and other