Earthquake destruction of adobe villages in Iran

(Effect of the earthquake of 31st August 1968 on the villages of the Nimbluk Valley)

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Summary. — The Nimbluk Valley, situated in the epicentral region of the Dasht–e Bayaz (Iran) earthquake of 31 August 1968, contains several types of adobe villages which are typical of many other parts of Iran and the Middle East. After the earthquake both primary and secondary ground fractures were observed in the form of large scale surface faulting and lurching. Many of the villages were destroyed, and over 2,500 people killed in the Valley alone. Conventional intensity studies were found to be too subjective and misleading for the study of destroyed villages. Instead, the destruction is analysed in terms of the distance of the villages from the fault-break, their proximity to lurch fractures and the existence of particular local sub-soil conditions.

Riassunto. — Nella valle di Nimbluk, sita nella regione epicentrale del terremoto del 31 Agosto 1968 di Dasht–e Bayaz (Iran), molti sono i villaggi con case in mattoni, tipici di molte altre parti dell'Iran e del Medio Oriente. Dopo il terremoto furono osservate fratture nel terreno sia primarie che secondarie sotto forma di faglie e deviazioni superficiali molto ben evidenti. Soltanto nella Valle furono distrutti molti villaggi e morirono 2500 persone. Lo studio dell'intensità con metodi convenzionali è risultato troppo soggettivo e tale da indurre in errore se applicato ai villaggi distrutti. Al contrario, la distruzione di detti villaggi è stata analizzata tenendo conto della loro distanza dalla faglia, della vicinanza alle fratture e dell'esistenza di particolari condizioni del locale sottosuolo.

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INTRODUCTION

By the number of people killed and made homeless (about 10,000 and 70,000 respectively), the Dasht–e Bayaz earthquake of 1968 constitutes one of the major single natural catastrophes of the last decade. In terms of the history of Iran, however, it was by no means an exceptional earthquake. The 1962 earthquake in Buyin Zara (west of Tehran) claimed an approximately equal number of victims, and, for earlier times, there are many documented cases of similarly devastating earthquakes. Detailed documentation of these catastrophic events provides an essential basis for the minimization of future disasters by suggesting ways of improving local building techniques, layout and location of new villages. The Nimbluk Valley, situated in the epicentral region of the Dasht–e Bayaz earthquake, displays many of the geographical and human characteristics found in other seismic parts of Iran. A detailed study of the effects of the 1968 earthquake in this restricted region is therefore pertinent to the country as a whole.

The Dasht–e Bayaz earthquake occured at $10^h47^m39^s$ GCT on the 31st August 1968 in a southern region of Khorassan known as the Qayen-Birjand Highlands (Fig. 1). The epicentre (33.97°N 59.02°E) was located in the Nimbluk Valley, a small elevated closed basin north of Qayen. The average magnitude was 7.2 and the focal depth about 13 km, and it was felt over an area of about 400,000 square kilometres. The earthquake was associated with an 80 km long surface fault which crossed the northern part of the Nimbluk Valley, and showed maximum relative displacements of 450 cm in the horizontal direction. Extensive non-tectonic ground deformations in the form of lurch fractures were also found south of the surface fault.

The main shock and the strongest aftershock (1st September, 1968, Magnitude 6.4) destroyed or damaged houses within an area of about 10,000 square kilometres in a region having a population density of about 9 persons per square kilometre. The number of people killed is not known precisely but is about 10,000. Approximately 12,000 housing units in 180 villages were destroyed or damaged beyond repair, rendering 70,000 people homeless. The largest settlements completely destroyed or heavily damaged were Ferdows (*),

(*) Ferdows was in fact at the limit of the area damaged by the main shock, but was severely damaged by the aftershock of 1st September, 1968.

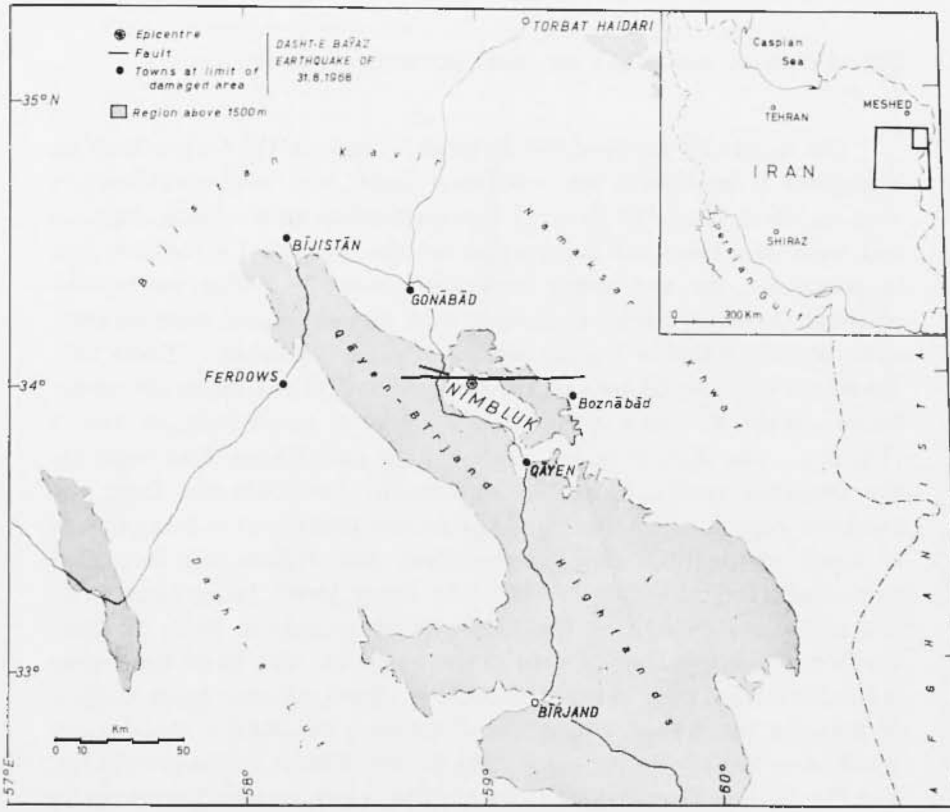

Fig. 1 – The Qayen-Birjand highlands — Situation of the Nimbluk Valley and the Dasht–e Bayaz earthquake of 31.8.1968.

Kakhk and Dasht–e Bayaz. Gonābad, Bejestan and Qayen were situated at the limits of the earthquake area, and suffered little or no damage at all.

The present study is restricted to the damage which occurred in the Nimbluk Valley. For a more general appraisal of the earthquake and its effects, the reader is referred to Niazi (16,17), Ambraseys and Tchalenko (3,4,5), Bayer, Heuckroth and Karim (6), Crampin (8,9,10), Tchalenko and Ambraseys (22), Eftekhar-Nejad, Hagui-poor, Davood-Zadeh (12), Pakhdaman (18), Day and Wright (11), Gansser (13) and Subuti (20).

Geographical situation of the Nimbluk Valley

The dominant trend of the mountain ridges in the Qayen-Birjand Highlands is northwest on a regional scale, and west-northwest to west on the more local scale of the earthquake area. Both regional and local directions are determined by the geological structure, and in particular, by the major fault directions (4,5). The earthquake reflected these directions in as much as it was associated with an east-west surface fracture having west-northwest branches. These two directions can also be seen in the arrangement of the mountain crests which divide the area into three distinctive sub-regions or basins (Fig. 2). The Kūh–e Kalat, Kūh–e Siah and Kuh–e Tun separate the Gonabad region which drains towards the northeast from the Ferdows region which drains towards the southwest. For reasons of water availability and climate, these two regions are inhabited only along the mountain borders, the lower levels being formed by the salt-waste deserts of Hadjiabad Kavir (Dasht–e Lut), Bijistan Kavir and Daqq–e Hajj–is–Haq (Figs. 1 and 2). The third sub-region is the Nimbluk Valley, a small and nearly closed endoreic basin wedged in between the Kuh–e Tun in the southwest, the Kūh–e Meysūr and the Kuh–e Meykay in the north, the Kuh–e Mahiar in the northwest, and the Kūh–e Waraz in the south. The southwestern barrier, with the Kuh–e Tun culminating at 2840 m (9327 ft), is the highest; the northern and southern borders are much less elevated and provide the main outlets, towards Gonabad in the north and Qayen in the south. The floor of the Nimbluk Valley varies in altitude from 4659 ft to 5000 ft.

Taking the 5000 ft contour as reference, the shape of the Nimbluk Valley is nearly a perfect rectangle 15 by 40 km, with the largest side in the west-northwest direction. Drainage is from the bordering ranges, essentially from the southwestern mountains, towards the centre of the basin and then towards the lower southeastern outlet near Qayen. The geomorphology is characteristic of endoreic basins. From the mountainous rim towards the centre of the basin one finds the succession of contemporary and fossil outwash fans of coarse gravel, a flatter region of finer silty sediments, and the *kavir* or salt marshes periodically flooded during winter. This sequence shows a greater development at the western and southwestern sides of the

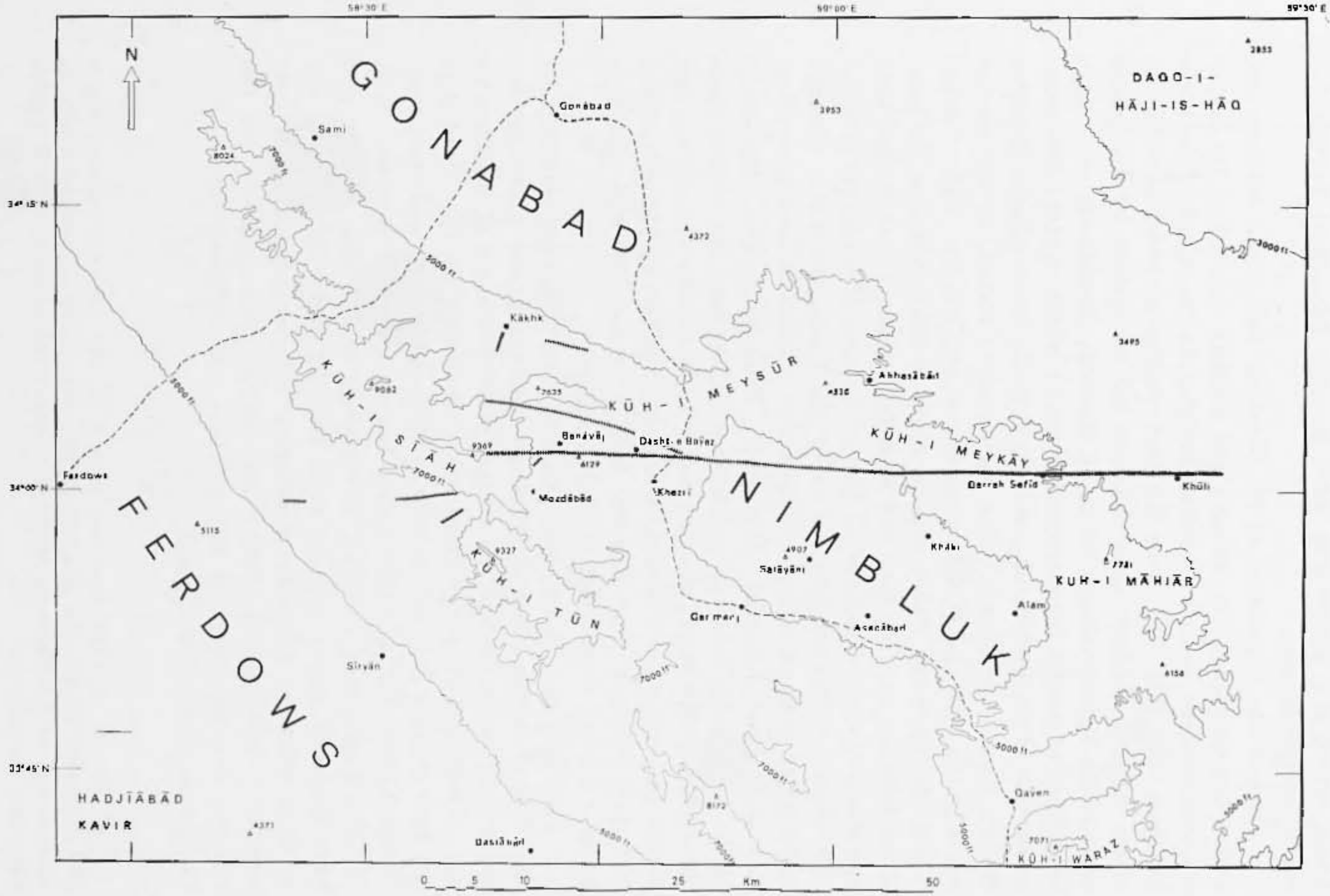

Fig. 2 – The Gonābād, Ferdows and Nimbluk basins — Barbed lines are surface faulting associated with the Dasht-e Bayaz earthquake. Altitudes are indicated in feet.

basin, where the higher and more massive mountains provide the main catchment area.

Most of the population of the Nimbluk Valley was concentrated before the earthquake, in villages and hamlets situated at the northwestern, western and southwestern margins, in the region of the lower outwash fans (Fig. 3). Here the best quality of water is obtained, either directly through open channels fed by springs located above some of the highest villages (Deheshk, Benavaj, Mozdabad), or through long lines of *qanats* (underground tunnels) which capture the water at the foot of the mountains and bring it to the lower villages (Dasht–e Bayaz, Khezrī, Gerimenj). The northwestern corner, at the convergence of the NW and WNW mountain ranges, had the highest population density of the Valley, due no doubt to the fact that as the transition between outwash fans and mountain slopes is here gentler than elsewhere, the site combines all the advantages of topography, water and climate. Towards the centre of the basin, the water becomes increasingly charged in mineral salts, but can still be used for cultivation as at Chah Khūndri, Alamdasht, Miamdasht, etc. The depth of the water table below ground level decreases from the edge towards the centre of the basin, and the water table reaches the surface just east of the villages of Salayani, Asadābād, Noghab, Hadjiābād. These last three villages must however rely on qanats for their drinking water. Beyond them start the salt marshes.

Until the end of the 19th century, the mountains surrounding the Valley provided protection from Turkoman and other raiders, and consequently some of the villages studied here are of considerable age. Dasht–e Bayaz, for example, is mentioned by Ibn Hawkal in the 10th century A.D. ([14]), as well as the neighbouring and chief town of the Valley, Faras, which today can no longer be located. Most of the villages were certainly in existence in the 19th century and have probably grown slightly since then (*). Agriculture seems also to have remained basically unchanged, with irrigated crops of root vegetable, water-melon, barley and saffron grown around the fan villages, and non-irrigated spring wheat and irrigated sugarbeet in the flatter parts of the basin.

(*) Bellew in 1874 described nearly all the pre-earthquake villages and estimated at 200 the number of houses in Gerimenj and similarly in Khezrī, and at 300 those in Dasht–e Bayaz. The equivalent 1968 figures were 180, 550 and 680.

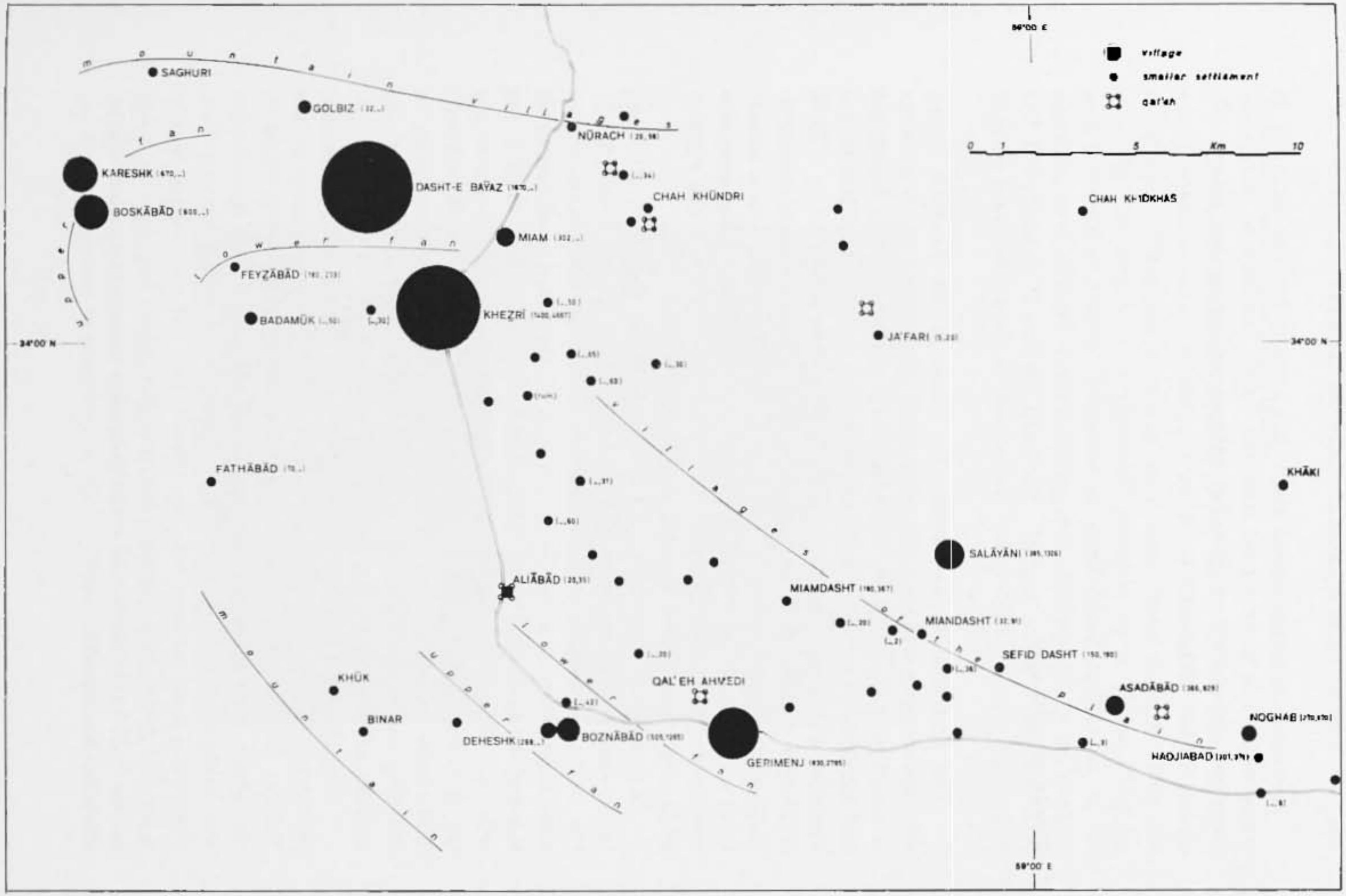

Fig. 3 – Population distribution before the 1968 earthquake — Size of black circles is proportional to number of inhabitants of each village, except for smaller settlements for which number of inhabitants is not known. First figure is population, second figure is number of domes counted on aerial photograph.

A recent hydrogeological study has shown that the quantity of water which can be extracted from the Valley can only be marginally increased (from 1600 to 2500 l/s) without exceeding the rate of recharge of the alluvium [11].

Types of villages

The area studied here covers the whole of the Nimbluk Valley with the exception of two villages and two hamlets for which no maps or aerial photographs were available; these are respectively Mozdābād and Benāvāj in the extreme northwest, and Khaki and Alam in the extreme southeast (Fig. 2). Aerial photographs taken on a 1:7,500 scale were used to analyse damage distribution and ground fractures: these photographs were joined without ground control into a mosaic from which the maps of Figures 3 and 5 were traced. They were also used to examine systematically all the villages and count the number of houses which had collapsed or survived in each.

Apart from some very rare official buildings made of kiln-fired brick, such as the gendarmerie in Khezrī, all the houses in the Nimbluk Valley were made of sun-dried mud bricks. In most cases, houses were single floor constructions, and, due to the scarcity of timber in the region, nearly all roofs were of the dome or barrel vault types (Fig. 4). The low resistance of these houses to seismic forces is the major cause of high casualty rates in recent Iranian earthquakes [1]. The reader is referred to Wulff [25] for an excellent description of building techniques and styles and to Razani and Behpour [19] for a study of their behaviour during earthquakes.

The Nimbluk villages differ significantly following their geographical location and position with respect to the topography of the Valley. For convenience of description, they have been grouped in this study into Mountain and upper fan villages, Lower fan villages and Villages of the plain (Fig. 3). There are of course various transitions and combinations between these types, but each village retains a marked social and economic individuality which can become a key factor in the relocation and rebuilding of a community after a catastrophic earthquake.

Mountain and upper fan villages

The highest settlements in the Nimbluk Valley are small villages and hamlets situated at about 6,500 ft on the slopes of the border mountains. They are generally built near small springs which are used for the irrigation of vegetable gardens, as in Golbiz, Saghuri and Badamuk. Nurach, described in more detail further on, is exceptional as it obtains water from a qanat, has practically no gardens and lives mainly from its livestock. Larger villages are found at slightly lower altitudes, in the narrow valleys of the upper fan region

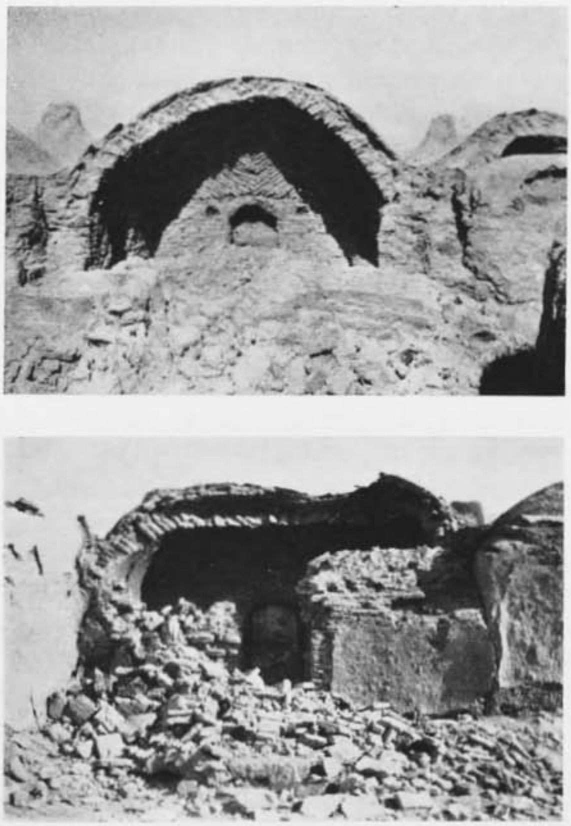

Fig. 4 – House types in the Nimbluk Valley — Sun-dried brick houses in Salayani. Dome and barrel vault roofs partially collapsed after the earthquake. The layers of mud-straw mix added each year to the roofs for impermeability greatly increase their weight. Photographs taken Sept. 1968.

where water supply is more abundant: Mozdabad, Benavaj, Kareshk and Boskābād in the north, Boznābad and Deheshk in the south. These villages have always been amongst the more prosperous ones of the Valley. Boznabad, for example, was the abode of the governor of the Province in the 19th century ([21]), and Kareshk, despite its modest size, had a large mosque before the 1968 earthquake. The inhabitants have a strong sense of independence, and they resisted, in some cases successfully, the post-earthquake collectivization drive of the plain.

Lower fan villages

The largest villages of the Nimbluk Valley are sited on the lowest slopes of the outwash fans where both water supply and soil quality are best. Water is brought by qanats which originate at the base of the mountain ridges where the water table is free from mineral salts, and the slopes are gentle enough to be entirely cultivated. The higher villages, Dasht–e Bayaz and Feyzabad, are located well in the fan zone and display a characteristic pattern of irrigated fields around them. The lower villages, Khezrī, Miam and Gerimenj, are in the region where the lower fans merge with the central plain.

Villages of the plain

A number of small villages and hamlets are located near the 5000 ft contour in the western and southern parts of the Nimbluk Valley (Fig. 2). Many of these settlements, and in particular those between Chah Khundri and Sefid Dasht (Fig. 3), are built around deep water wells and pumping stations, and vary in size from a single house to an agglomeration of several hundred houses. The larger settlements are Chah Khundri, Alamdasht, Miamdasht, Miandasht and Sefid Dasht. In the southern Nimbluk, four large villages border the limits of the salt marshes: Hadjiābad and Asadabad, and the much older settlements of Noghab and Salayani. Noghab has a compact plan with narrow streets, whereas Salayani has a much more open structure unique to the Valley; its behaviour during the earthquake presented interesting peculiarities which will be seen in detail in a later section.

Geographical distribution of casualties and damage

General

2552 people out of a total population of 10610 were killed in the Nimbluk Valley, representing about $^1/_4$ of the total casualties for all the areas affected by the earthquake. The majority of casualties were in the north, where the five villages of Boskabad, Kareshk, Dasht–e Bayaz, Khezrī and Miam accounted for about 85% of all the people killed in the Valley (Table 1).

As all the houses were made of sun-dried brick and were of the same dome or vault type construction, comparison of the damage each village sustained during the earthquake is directly relevant to the assessment of intensity of ground movements. Damage varied greatly (Tables 1 & 2): in Dasht–e Bayaz, not a single structure survived, and the maximum height of walls which remained standing did not exceed about one metre. Boskabad and Miam were destroyed nearly to the same extent, with only a few walls remaining at their original height. Next in the scale of damage is a group of villages in which the percentage of collapsed domes varied between 85% and 35%: Maindasht, Kareshk, Miamdasht, Khezrī, Salayani, Feyzābād and Sefid Dasht. And, finally, the villages with less than 38% collapsed domes and with a very small number of, or without any, casualties: Nurach, Deheshk, Asadābad, Noghab, Boznābād, Hadjiabad and Gerimenj. The distribution of the different degrees of damage seems at first unrelated to the geographical position of the villages (Fig. 5), and previous studies (see the Introduction) have not found any significant trends. These studies were however based on intensity assessments which, it has been shown, can be very misleading [2,26]. Indeed, a comparison of the isoseismal maps drawn independently by different authors for the Dasht–e Bayaz earthquake (Fig. 6) shows how sensitive the method is to the impressions of the observer and the means and time at his disposal. In cases such as the Nimbluk, it was of more interest and immediate consequence to enquire why certain villages resisted better, or worse, than others. To do this required a detailed study of the particular conditions of each village, and when this work was undertaken a certain pattern emerged in which the dominant factors were: the distance from the fault zone, the influence of lurch fractures, and exceptional local subsoil condi-

TABLE 1 - CASUALTIES AND DAMAGE IN THE VILLAGES OF THE NIMBLUK VALLEY.

VILLAGE	POPULATION			DOMES		
	Killed	Total before earth-quake	%Killed	Collapsed	Total before earth-quake	% Collapsed
Aliābād	0	20	0	0	35	0
Asadābçd	0	366	0	93	829	11
Basamuk	0	235	0	48	50	96
Benāvaj	380	1800	21	—	—	(32)
Boskābād	400	600	67	?	?	100
Boznābad	7	505	1	61	1265	5
Boznābād teahouse	?	?	?	6	42	15
Dasht-e Bayaz	1230	1670	74	?	?	100
Deheshk	1	268	1	300(e)	600(e)	50(e)
Feyzabad	8	108	7	114	263	43
Gerimenj	0	830	0	66	2795	2
Golbiz	0	32	0	—	—	(25)
Hadjiabād	0	207	0	17	378	5
Ja'fari	0	5	0	20	20	100
Kareshk	135	670	21	?	?	80(e)
Kehzrī	230	1400	16	3057	4667	65
Miam	120	302	40	?	?	100
Miamdasht	1	180	1	244	367	67
Miandasht	2	32	6	77	91	85
Mozdābād	10	350	3	—	—	(25)
Noghab	0	270	0	70	870	8
Nūraeh	0	20	0	17	58	30
Saghuri	20	152	13	—	—	(75)
Salāyāni	8	385	2	715	1326	54
Sefid Dasht	0	150	0	70	190	37
TOTAL NIMBLUK	2552	10610				

(*) Indicate field assessment only; (e) not all domes distinguishable due to heavy damage; estimate on basis of aerophotograph; ? number of domes not known due to total destruction.

tions. These factors will now be examined separately and illustrated with a few examples.

Fault Zone

The fault zone associated with the Dasht-e Bayaz earthquake has been previously described in detail (see references quoted in In-

TABLE 2 – DAMAGE IN THE SMALLER SETTLEMENTS.

Catalogue No.	Approximate location		DOMES		
			Collapsed	Total before earthquake	% Collapsed
006	33.88N	59.08E	5	10	50 (*)
010	33.81	59.01	2	15	13 (*)
042	33.89	59.02	0	3	0
076	33.89	58.98	3	5	60 (*)
095	33.90	58.81	0	4	0
111	33.90	58.92	0	1	0
115	33.91	58.95	1	10	10
117	33.91	58.96	1	7	14
119n	33.91	58.97	1	36	3
119s	33.90	58.97	15	15	100 (*)
189	33.92	58.87	1	20	5
198	33.92	58.93	2	4	50
202	33.92	58.91	2	2	100
229	33.94	58.86	2	5	40
232	33.94	58.89	0	5	0
267	33.94	58.86	5	12	42
346	33.96	58.85	20	37	55
405	33.99	58.82	1	6	16
410	33.97	58.86	60	60	100
435	34.00	58.84	1	9	11
437	34.00	58.85	60	65	95
441	33.99	58.88	30	30	100
462	34.00	58.82	0	5	0
489	34.01	58.78	30	30	100
500	34.01	58.84	50	50	100
548	34.03	58.94	1	6	17
580	34.03	58.93	6	6	100
612	34.05	58.87	30	34	88
650	34.06	58.87	2	10	20

(*) Indicates less reliable data.

troduction). Its total length was about 80 km and it crossed from east to west the northern part of the Nimbluk Valley (Figs. 1, 2, 5 and 18), with a maximum horizontal displacement of 450 cm ([22]). The distribution of damaged villages when examined with respect to their distance from the fault presents some interesting peculiarities (Fig. 5). In general, heaviest damage is found in villages nearest to the fault (Dasht-e Bayaz, Boskābād, Kareshk, Miam) but there are exceptions. Feyzābād, for instance, situated about halfway between the fault and Badamuk, was destroyed to about 43%, whereas Ba-

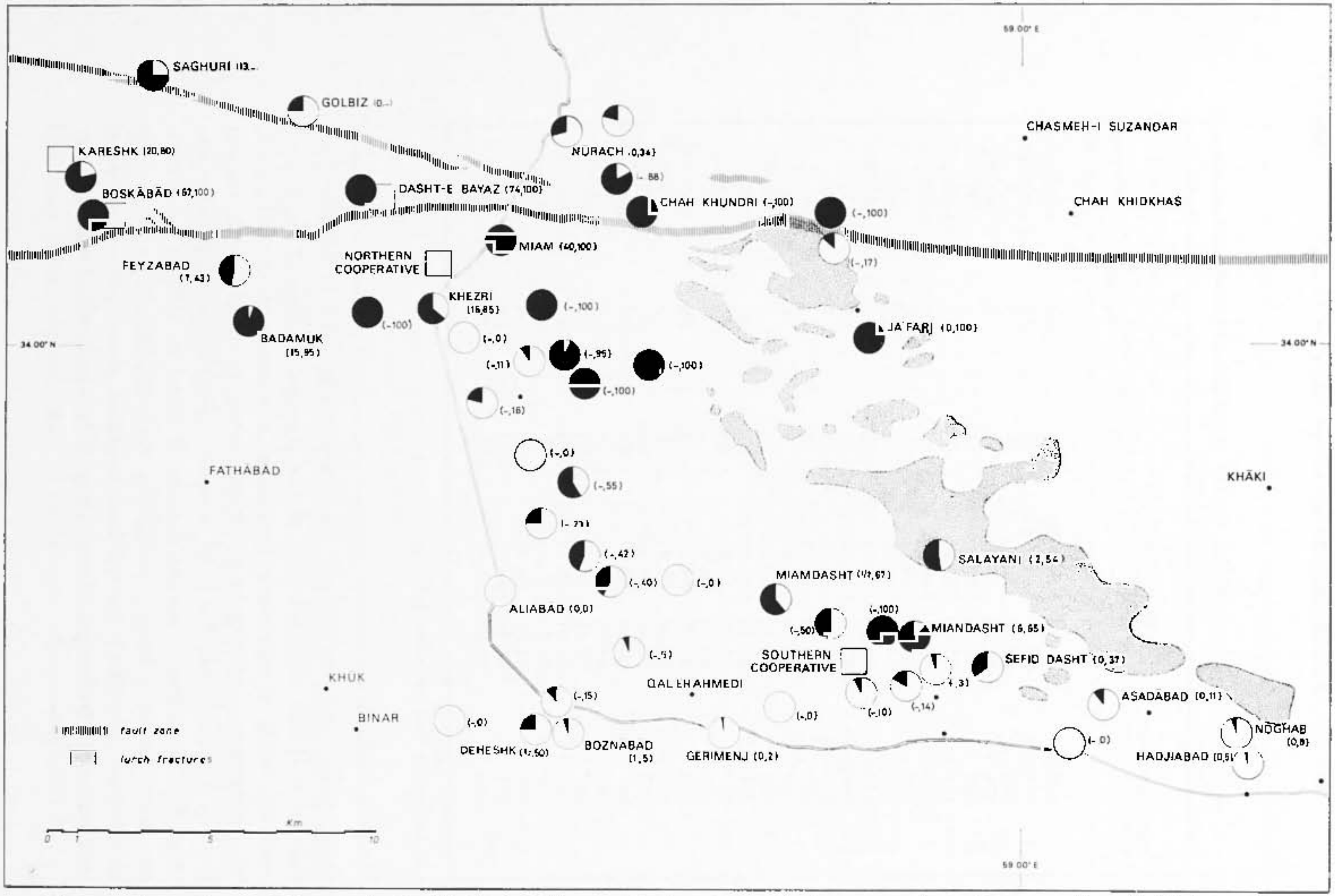

Fig. 5 – Casualties and damage in the Nimbluk Valley — Black sector indicates proportion of domes collapsed. First number indicates casualties, and second number collapsed domes, in percentage. Absence of figure indicates information lacking. Fault zone shown hatched, area of lurch fractures, shaded. New villages built after the earthquake are shown as squares.

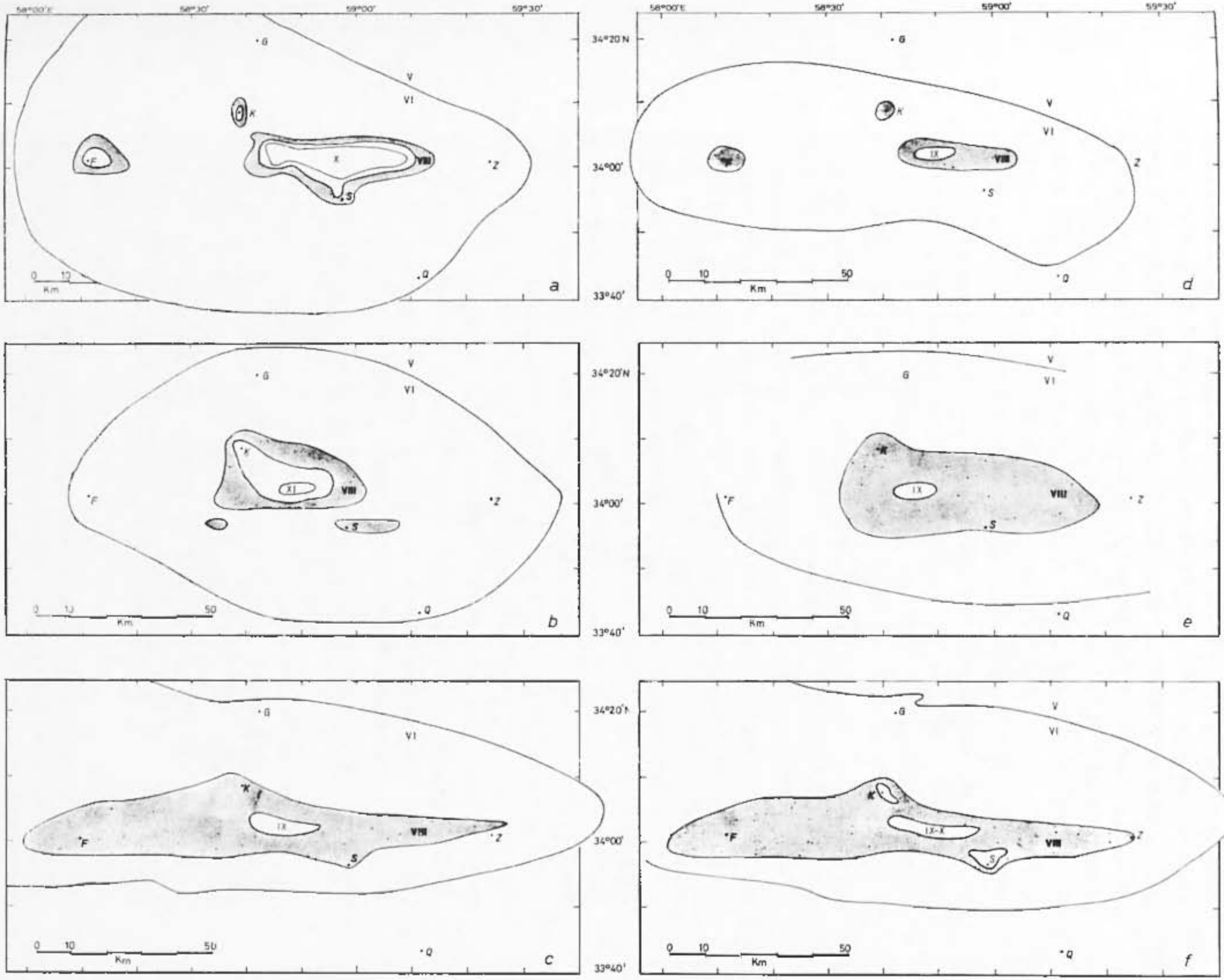

Fig. 6 – Comparison of isoseismal maps for the Dasht-e Bayaz earthquake — a) Bayer, Heuckroth and Karim, 1969. b) University of Tehran, 1970. c) Eftekhar-Nejad, Hagnipoor, and Davoudzadeh, 1968. d) Pakhdaman, 1968. e) Moinfar, 1969. f) Gansser, 1969. Outer limit is between isoseismals V and VI. Shaded area is from VIII to IX. Central figure is maximum intensity proposed. (F = Ferdows, G = Gonabad, K = Kakhk, Q = Qayen, Z = Zigan).

damuk to 95% (*). In the case of Nurach and Khezrī which were situated on either side of the fault and at approximately equal distance (2 to 3 km) to it, Nurach was destroyed to about 30% whereas Khezrī to 65%. Similarly Golbiz and Saghūri, for which however damage

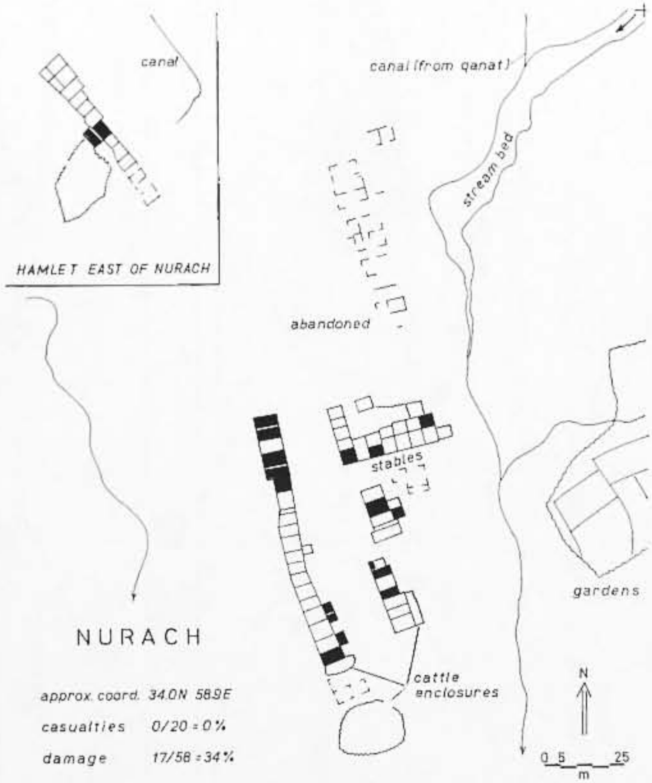

Fig. 7 – Nurach — Mountain village in the north of the Valley. Plan showing collapsed domes (black).

figures are less reliable, were both located on the northern fault branch, and had respectively, no casualties and 15% casualties. Isolated houses and hamlets also showed inconsistency in damage with respect to distance from the fault: north of Ja'fari, two hamlets facing each

(*) The percentage refers to the ratio of the number of domes collapsed to the number of domes standing as counted on the enlarged aerial photographs.

other across the fault, and at a distance of about 500 m from it, showed collapsed domes to the proportion of 17% for one, and 100% for the other. Further away, at about 10 km from the fault, Miamdasht had 85% of its houses collapsed, whereas in a small village about 150 m to the southeast there were only 3%; and about 15 km from the fault, Deheshk and Boznābād which were only 500 m apart suffered respectively 50% and 5% destruction.

In some cases, irregularities in damage distribution such as the ones mentioned above can be clarified to some extent by a closer observation of the ground conditions and village type. Nurach and Khezrī were entirely different settlements built on different foundations materials. Nurach was a small mountain village situated on a spur of relatively hard marls on the southern slopes of the Kūh-e Meysur. The houses were built in two widely spaced rows aligned along the crest of the spur; a *qanat* arriving from the north provided just enough water in spring for a few small vegetable gardens (Fig. 7). Khezrī on the other hand was a lower fan village much bigger in size, built on soft silty clay in the region where the fan slope grades into the central plain. It was supplied by several qanats, and irrigation of the extensive cultivations around the village was supplemented by pumping wells. The village had a dense structure with narrow winding streets from which escape during the earthquake was difficult (Fig. 8). The comparison of Nurach and Khezrī provides a characteristic example of a fairly common observation in Iran, i.e. that the smaller settlement built on the harder material away from irrigated fields often resisted better than the larger and more compact village built on soft soil and surrounded by cultivations. The somewhat similar cases of Dehsehk, where the destruction was due mainly to waterlogging, and Miandasht, where it was due to lurching, will be returned to further on.

Taking into account such cases of "explained" irregularities, and using only the villages having more than 10 domes, the relation between number of collapsed domes and distances from the fault shows a definite trend (Fig. 9). The majority of the data is for the more heavily and more lightly damaged villages for which it can be said that those where 95% to 100% of the domes collapsed were all within 5 km of the fault, and that those where less than 15% of the domes collapsed were further than 11 km from the fault. There are fewers villages in the intermediary range, but as the data obtained by the method of counting domes on enlarged aerial photographs is con-

Fig. 8 – Khezrī — Aerophotograph taken after the 1968 earthquake. The northern entrance west of the road is being bulldozed. Damage is sporadic throughout the village. At the western edge of the village, Government houses built from kilnbricks are standing undamaged. Note the narrow winding streets and compact structure of housing.

sidered to be particularly reliable, those villages for which data is available can be used with confidence. They show that, with the exception of the anomalous cases mentioned above, damage decreases approximately linearly with distance from the fault. It must be stressed however, that this trend should be considered as specific to the case of the Nimbluk Valley during the 1968 earthquake, and that it does not necessarily hold for other regions or other earthquakes. The usefulness of the graph presented in Fig. 9 is that it points out

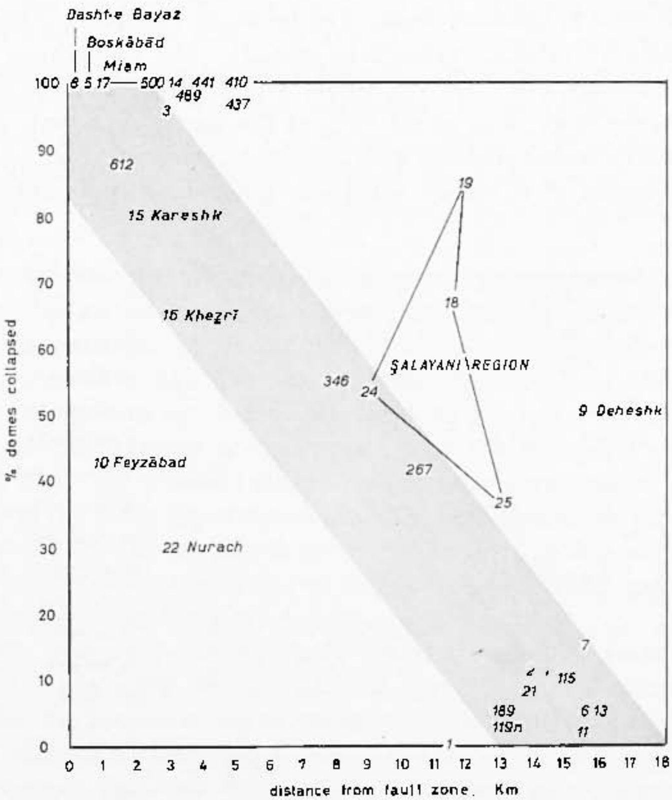

Fig. 9 – Relation between damage and distance from fault zone — Numbers refer to Table 2. For analysis, see text and Fig. 10.

the villages which behaved anomalously and which are therefore worthy of special attention. For example, in the case of Nurach and Khezrī described above, it shows that it was Nurach which showed exceptionally light damage whereas Khezrī was well within the average for the earthquake. It also points to the exceptional behaviour of the Salayani region and of Deheshk which will now be seen in greater detail.

Lurch Fractures

A pocket of unusually high damage was observed away from the fault zone in the Salayani region (Figs. 5 and 9). It affected the villages of Salayani, Miamdasht, Miandasht, Sefid Dasht and several small hamlets in between them. The peculiarity is further emphasized when casualty rates are taken into account. The comparison of casualty to damage rates for the whole Valley shows that people were killed where more than about 30% of the domes collapsed, and that casualties increased steadily with greater destructions (Fig. 10). When all the domes of a village collapsed, the casualties varied between

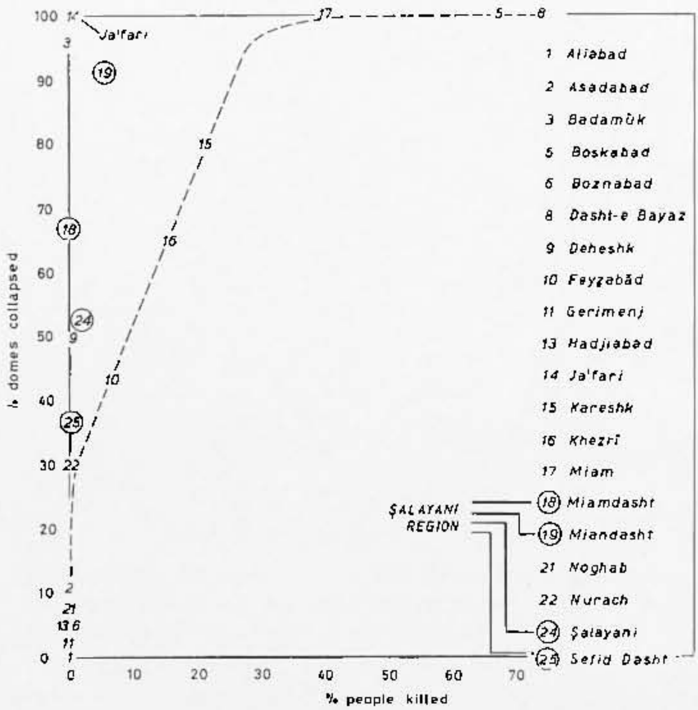

Fig. 10 – Relation between casualty and damage rates — For analysis, see text.

40% (Miam) and 74% (Dasht–e Bayaz), the exact number depending now on the severity of the collapse. As in the case of Fig. 9, the trend should be considered as specific to the Nimbluk Valley in 1968. The villages which did not conform to the general casualty-damage trend were Badamuk and Ja'fari in the north and the Salayani group in the south. For these villages the number of people killed was very much smaller, and furthermore seemed unrelated to the amount of damage to houses. As all the houses were basically identical, and as the proportion of the inhabitants which were indoors when the earthquake happened (14^h15^m local time) did not vary significantly from one village to another, these abnormally low casualty figures presumably indicate that the houses collapsed sufficiently slowly to allow the occupants to escape. The assumptions is reinforced by the observation of lurch fractures in Ja'fari and especially in Salayani, suggesting a mode of destruction different from that which prevailed elsewhere in the Nimbluk Valley. The case of Salayani is particularly instructive.

Salāyani was the village of the Nimbluk Valley situated nearest to the centre of the plain where water and climate conditions were the least favourable. In plan it showed a very open structure unique for the region (Fig. 11). The earthquake caused 54% of the domes to collapse, but the number of people killed (8) was well below the average for this amount of destruction. On the ground it could be observed that the houses collapsed essentially there where ground fractures of the lurch type crossed the village. As these fractures have not been described in any length by previous papers on the earthquake, and because of the uncertainty of their origin and their importance to the damage, they are given below in some detail.

Lurch fractures were generally found grouped in zones a few metres wide and a few tens of metres to several hundred metres long. Each zone was formed by up to about one dozen sub-parallel fractures showing vertical displacements only. Throws of all the fractures in a zone were in the same sense which, for curved zones, was usually concave side downwards. The slabs of soil between the fractures of a zone were often tilted towards the fracture scarp. The vertical throw of a fracture could vary from a few centimetres to about one metre but was compensated by this tilting in such a manner that the net vertical movement of one side of the zone with respect to the other seemed to be nil or insignificant. In plan, most zones were arcuate or sinuous (Fig. 12), and a few examples were found of closed

Fig. 11 – Salayāni — Maximum damage in the village seems to be associated with lurch fractures. Large structure at the Gerimenj entrance is a school, completely destroyed. Collapsed domes shown in black.

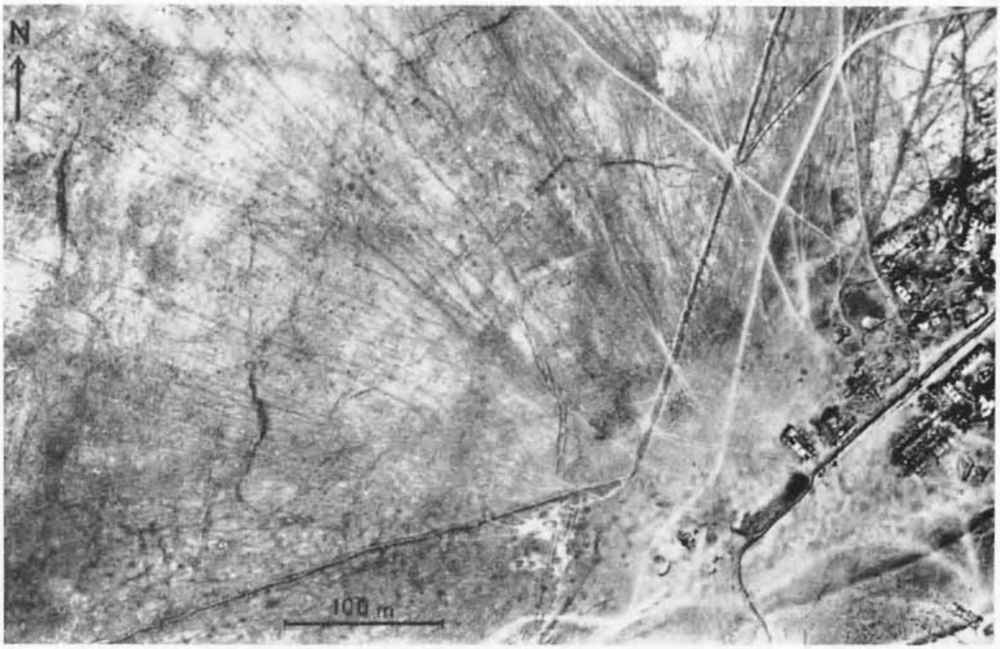

Fig. 12 — Lurch fractures at Salāyāni — Southwest entrance to the village (see plan, Fig. 11). Note sinuous and discontinuous trace. Lines converging on village are cattle tracks.

zones forming ovals measuring about 50 m in largest diameter and resembling giant footprints. Lurch zones were often accompanied by sand blows and small mud and silt volcanoes.

A great number of lurch zones were formed in the Salayani region, especially to the north and east of the village (Fig. 13). Their orientation is on average north to northeast. Several of these zones passed through the village, causing various degrees of damage to houses. For example, the school at the southwestern entrance to the village was completely destroyed. In other cases, however, houses which were cut by fractures collapsed only partially or even not at all (Fig. 14).

On the scale of the entire Nimbluk Valley, lurch zones covered most of the central part of the basin in a broad NW-SE bank 3 to 8 km wide, and extended over 20 km, from the fault zone near Ja'fari to Noghab (Fig. 5). The borders of this band followed approximately the 4900 ft contour line, and the area covered was the part of the basin where the water table was less than about 3 m from the ground

Fig. 13 – Lurch fractures in the Salāyāni region — Note parallelism of general fracture direction with stream bed, and "footprint" structures about 1 km North of village. (After uncontrolled aerial photographs).

Fig. 14 – Salāyāni – View of the easternmost houses of the village (north of Khaki road, see plan, Fig. 11). Lurch fractures in the foreground cross mud walls and houses with only partial collapse of the latter.

surface. The most important fact to note is that the lurch zones followed everywhere the direction of the surface drainage. They were NW-SE north of Ja'fari, E-W south of Ja'fari, N-S to NE-SW around Salayani and E-W near Asadābād and Noghab. This observation provides a clue as to their origin. As the average slope in this part of the basin is of the order of 1%, surface drainage of the flush floods in the rainy season (winter) conforms with the greatest slope on the large scale but meanders considerably in detail. This produces numerous very shallow streamlets, which, because of the low gradient and near surface water table, soon lose their velocity and deposit the fine material that they carry. Further material is deposited during the dry period in the form of wind blown sand. During seismic shaking, this very loose material filling the temporary streamlet beds failed by a series of shallow step-slides and slumps, probably detached at the level of the ground water table, with ejection of water, sand and silt. In this manner the lurch zones followed faithfully the local drainage directions. In particular, the oval "footprints" have all the geometric characteristics of contemporary cut-off meanders found in the region.

The ground fractures in the central Nimbluk Valley were thus interpreted to be a consequence of the seismic shaking, i.e. they were 'non-tectonic' or 'secondary' fractures. This type of earthquake effect has been observed for other earthquakes, such as the 1948 Ashkhabad earthquake and the 1952 Kern County earthquake ([24]). The mechanism suggested by their aspect in the Nimbluk Valley is that they were initiated at the start of the shaking, but attained their full development only some time (seconds or minutes?) later. This would explain that the occupants of the houses in the Salayani region had time to escape before their houses collapsed. The lurch fractures were confined to the central part of the basin where the slope gradients are lowest and the water table is nearest to the surface. Similar geomorphological conditions are met in many basins of Iran and the Middle East, and the mechanism of seismic lurching has important enough effects on local constructions to warrant future study.

Local sub-soil conditions

A very local change in sub-soil properties can have an important influence on the degree of damage, and in this respect nearly every site can present its own exceptional conditions. Some are however specific to a type of village, and have been observed in other earthquakes: for example, the variation of foundation material from river bed alluvium to rock encountered in many upper fan and mountain villages built near mountain streams. The example chosen here to illustrate this case is Kareshk. Exceptional conditions may also arise as a consequence of man's activity, as will be seen by the example of water-logged foundations in Deheshk.

Kareshk was situated in a narrow upper fan valley between hills of Neogene marl. The centre of the village was built on river gravel on either side of a stream bed, but the northern and southern edges of the village encroached on the Neogene hills (Fig. 15). A qanat system arriving from the northwest irrigated the cultivated fields downstream of the village during the summer season when the stream dried up. The earthquake killed 135 inhabitants and nearly completely destroyed the village. About 80% of the houses were destroyed to such an extent that it was impossible to identify individual ground plans from the air; the remaining 20% which had not collapsed were situated at the northern and southern edges of the village, on the Neogene marl. As no indications were found to suggest that these houses were of better construction, the unevenness in damage distribution must be taken to reflect the difference in sub-soil conditions.

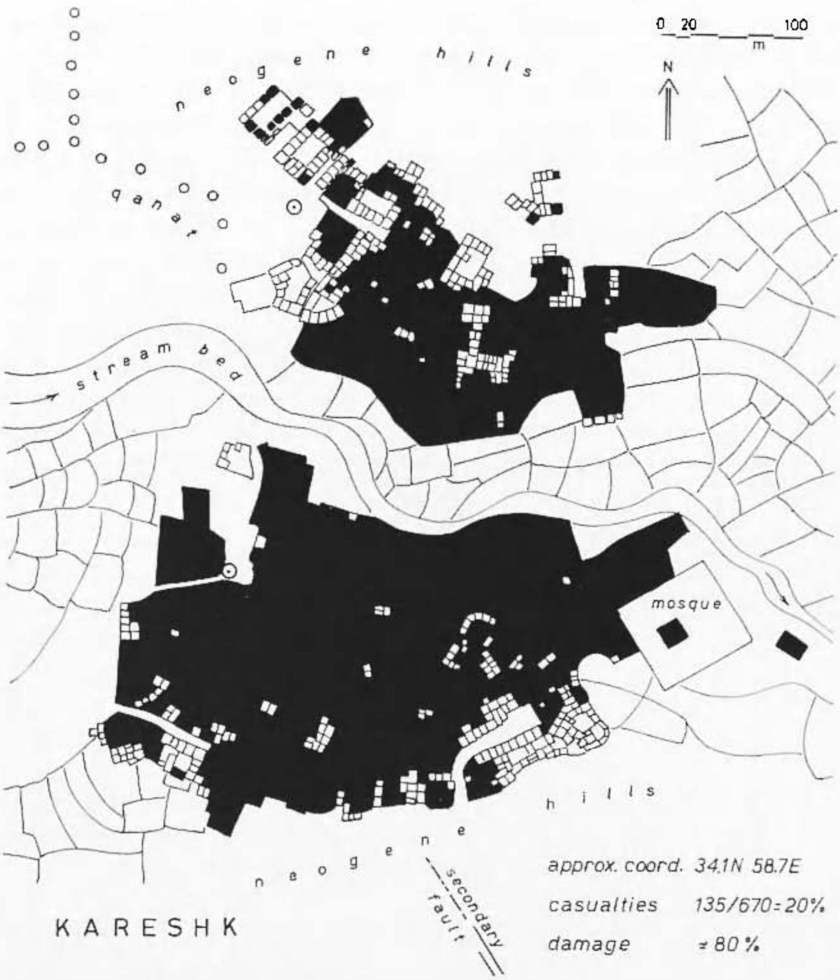

Fig. 15 – Kareshk — Plan showing collapsed domes (black). The houses that survived are situated on the marl hills, away from the stream bed.

This difference would influence both the stability of the foundation and the response of the structure to seismic shaking.

The geomorphological situation of Deheshk was similar to that of Kareshk, the village being built on river gravels in a WNW-ESE Neogene valley (Fig. 16). Water was brought directly by open channel (or by qanat during the dry season) from one of several springs located in the hills to the west of the village. Irrigated fields covered the floor of the valley and extended all the way to the next village of Boznabād

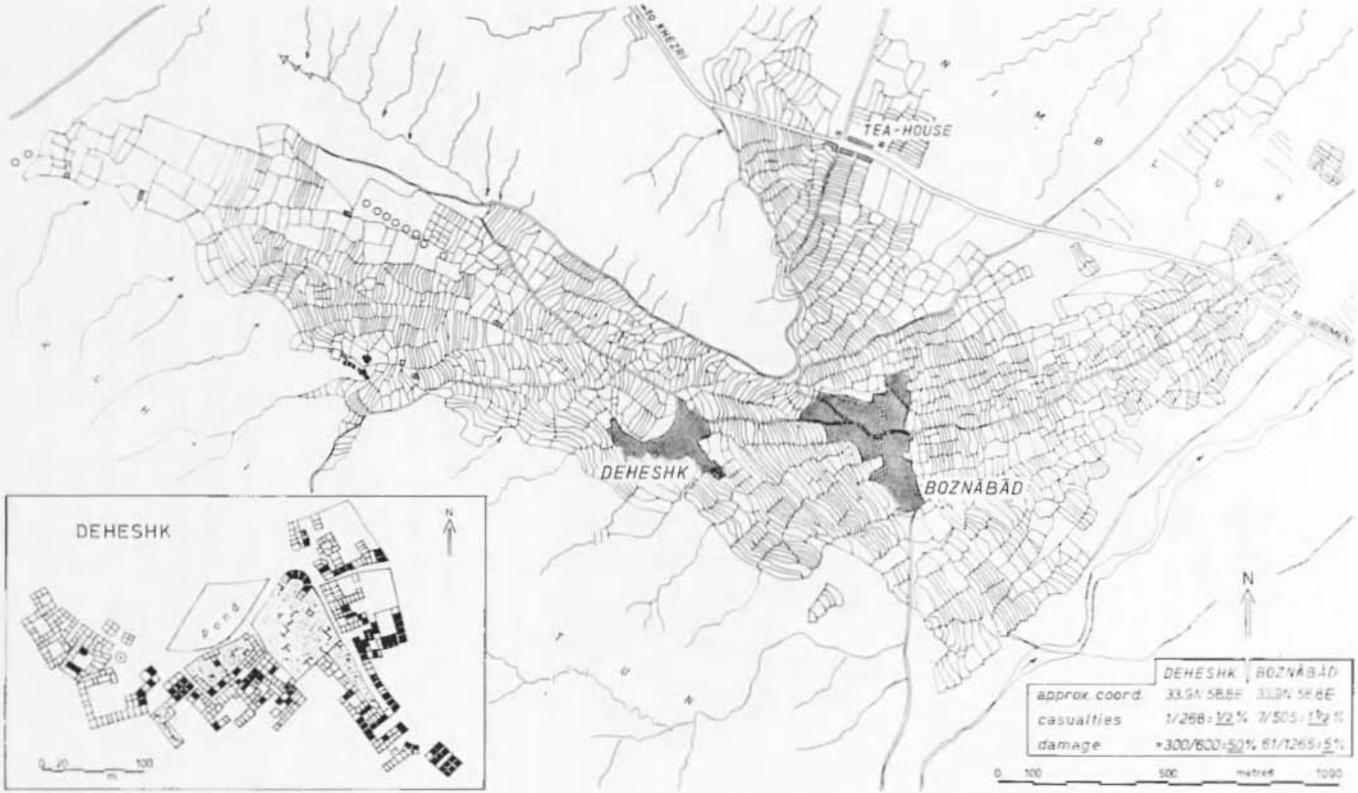

Fig. 16 – Deheshk and Boznābād — Irrigated fields cover the floor of the subsidiary valley, from the springs in the west to the Nimbluk plain in the northeast. Extensive damage at Deheshk (insert) was probably caused by waterlogging from the village pond. Collapsed domes shown in black.

and to the Nimbluk plain (Fig. 17). The central part of Deheshk was slightly lower than the rest of the village, but unlike Kareshk, the valley was wider here and all the houses were built on the river gravel. The earthquake damage in Deheshk was remarkable on two accounts. Firstly, although the fatalities were minimal (1 person killed), the damage was exceptionally high compared to the other villages of the area: in Deheshk about 50% of the 600 domes collapsed, whereas in the next village of Boznabad less than 500 m downstream, fewer than 5% collapsed. Secondly, the damage distribution in Deheshk showed a central section completely destroyed, and most of the undamaged domes located at the edges of the village (Fig. 16, insert). The undamaged houses were in a good enough condition to be reoccupied soon after the earthquake. The origin of the unevenness of damage distribution was here, however, different from Kareshk. Irrigation of the fields immediately upstream of Deheshk had produced a small pond, and resulted in extensive waterlogging in the centre of the village. Consequently poor foundation conditions seemed to have been the main cause of exceptionally high damage to the houses which were located downstream of the pond.

Concluding remarks

The Nimbluk Valley is a small enclosed endoreic basin situated in the epicentral area of the Dasht-e Bayaz earthquake of 1968. As in many other parts of Iran, the houses in this Valley are made of

Fig. 17 – Deheshk — View from the south. The neogene spur behind the village separates the subsidiary valley from the Nimbluk plain in the background. Maximum damage occured directly below cluster of trees which mark the village pond. Right background, Boznābād. Photograph taken July, 1970.

sun-dried brick and villages have characteristic plans which change with the altitude and the situation of the settlement with respect to the geographical subdivisions of the basin.

The earthquake killed 2552 people in the Nimbluk Valley alone, representing about one quarter of its inhabitants. It was accompanied by a major fault-break and lurch fractures. The distribution of damage in the Nimbluk Valley was irregular, with some villages much more, and others much less, damaged than the average. Nevertheless, the study of individual villages revealed a simultaneous influence of the fault zone, as well as particular sub-soil conditions leading to lurching and other special foundation problems. Lurch fractures in particular seemed to be associated with a much slower process which allowed the inhabitants to escape from their collapsing houses. Published data is however needed to compare these observations to other earthquakes in similar environments.

Towards the end of 1970, the construction of modern-type kiln-brick bungalows was nearing completion in five centres in the Nimbluk Valley. The largest of the upper and lower fan villages which were destroyed by the earthquake were reconstructed individually at their previous locations (Fig. 5). New Dasht–e Bayaz is situated between the old village and the fault zone (Fig. 18); new Kareshk

Fig. 18 – New village of Dasht–e Bayaz — In the foreground, a fracture of the 1968 fault zone, displacing field boundaries. Total displacement was here 270 cm left-lateral and 160 cm South side (observer) down. Photograph taken July 1970.

and Boskābād each overlap the fringes of the old settlements. In contrast, most of the villages of the plain were grouped into two agricultural co-operatives. The Southern Nimbluk Co-operative, built half-way between Gerimenj and the destroyed Miandasht, is made of Salayani, Miandasht, Miamdasht, Selid Dasht and the smaller hamlets of the region, as well as Deheshk; there seems to be some doubt as to the fate of Gerimenj, Boznabad and the villages near Asadābād which were practically undamaged in 1968. Soon after the earthquake, Salayani was completely bulldozed, and today the site of the former village is nearly indistinguishable from the surrounding fields. The Northern Nimbluk Co-operative groups Kheẕrī, Miam, Feyzabad and some of the smaller hamlets; it is situated about 1 km north of the destroyed Kheẕrī (*).

The immediate consequences of an earthquake can be measured in terms of casualty figures and statistics of destroyed housing units. But far-reaching changes have also been brought onto the population of the Valley by the construction of the two big agricultural co-operatives which replace many of the small villages. The idea of centralizing small villages into large agricultural units is expressed after nearly every catastrophic earthquake in the Middle East. The case for centralization is usually made on regional economic grounds, and in those terms it is nearly always a very strong case. Centralization rationalizes the productive process, and hence increases the agricultural yield and the wealth of the region. However, the possible adverse effects on the individual and social levels of the sudden imposition of a concept so strange to the history of a region must also be taken into consideration. In the long term the change will only succeed if it brings an improvement in the quality of life and tangible profit to each survivor of the catastrophe, and centralization alone does not automatically achieve either.

(*) Many of the 350 new housing units suffered minor damage as a result of a late aftershock on 3rd March, 1970 ($M = 5.2$). Vertical cracks were observed at the corners of the houses, there where the inner reinforced concrete pillar joined the brick walls. This aftershock was also felt in Kakhk and Gonabad but does not seem to have produced damage elsewhere than in the Northern Co-operative.

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