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The Rann of Cutch Earthquake of 21 July 1956

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ABSTRACT. A seismometric study of the earthquake of 21 July 1956 in the Rann of Cutch, which caused destruction to life and property at Anjar, has been made. The epicentre and origin time have been determined by the method of least squares and are Lat. 23°20′N, Long. 70°00′ E and 15^h 32^m 26^s GMT respectively. The shock had a magnitude of 7 and a depth of focus of nearly 13 to 18 km.

1. Introduction

An earthquake of severe intensity shook the whole of the State of Saurashtra and portions of Gujarat, soon after 9 P.M. on 21 July 1956, causing considerable damage to property at Anjar and a number of villages in the central mainland of Cutch. Soon after the earthquake a party of geologists from the Geological Survey of India visited the affected area in and around Anjar. A complete report describing the effects of the earthquake at various places in and around the epicentral tract, has been published by Balasundaram, Poddar, Sahasrabudhe and Oza (1956). This report also contains an isoseismal map of the earthquake in which isoseismals from 4 to 8 of the Modified Mercalli scale are delineated. It indicates that an area of about 750 sq. miles in central Cutch suffered the greatest damage. Maximum damage was done at Anjar. Ratnal, Chubdak, Sukhpur, Tapar, Jhuran, Dhamadka. Bhimasar, Bhujpur, Jhikadi, Dudhai and Lodia. The earthquake took a total toll of 115 lives and caused injuries to hundreds of people. About 1350 houses were destroyed in Anjar alone, and nearly 2,000 suffered minor damage. This damage was mostly confined to the eastern portion of the town as it is located on weak foundations; the western portion of the town with trap rock foundations suffered much less. Earth fissures occurred along the Bhuj-Anjar Road and near the northern boundary of the Cutch mainland. According to the newspaper reports the phenomenon of fissures was not very widespread. The railway track near Anjar was damaged as the earth gave way over a length of nearly 50 ft.

From the published reports it becomes apparent that the damage was mostly confined to those houses which were built of stones with weak mortar. Pucca buildings in Anjar as elsewhere either remained unaffected or suffered very minor damage. Newly constructed houses at Kandla town, Gandhigram and Adipur escaped without damage, or with only minor cracks in the walls. The port installations at Kandla escaped damage as they had been designed to resist earthquakes causing a horizontal ground acceleration upto 1/10 gravity.

The map of Cutch and neighbourhood in Fig. 1 shows the probable areas over which damage was caused, and over which the shock was felt. The data published by Balasundaram and others (1956) in their report, and a few voluntary observers' reports received from stations in the felt area have been used in the preparation of the map. The numerals plotted against each station give the probable intensity in the Modified Mercalli scale experienced at the station. In many places the shock was reported as felt but it has not been possible to assess the intensity. For such places the intensity has been indicated by F. Due to scarcity of data it has not been possible to delineate the isoseismal lines very accurately specially for

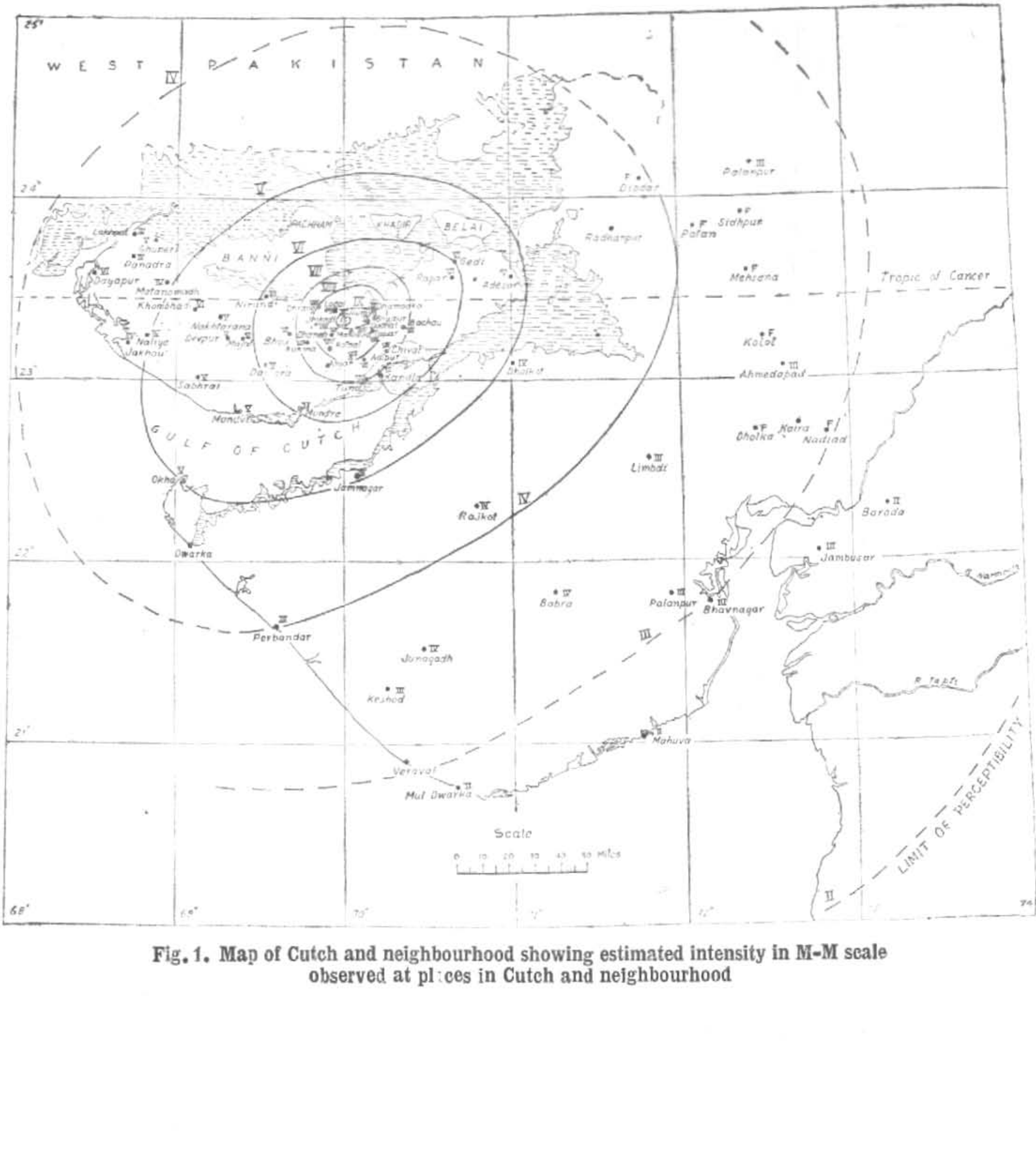

Fig. 1. Map of Cutch and neighbourhood showing estimated intensity in M-M scale observed at places in Cutch and neighbourhood

the outer isoseismals. The isoseismals generally agree with those given by Balasundaram and others except for the fact that the major axis of the elliptical isoseismals is inclined in an NE-SW direction, indicating the possibility that the fault along which slipping took place was inclined in that direction. From the description of damages caused by the earthquake, it seems that the intensity reached was VIII on the Modified Mercalli scale at most of the places within the epicentral tract. The intensity at only two places, *viz.* Dhamadka and Jhuran could be assessed as IX. It will be seen that the epicentre of the earthquake is situated near the northern boundary of the Cutch mainland and is several miles away from thickly populated centres. No detailed reports of the damage caused by the earthquake near the epicentre are available except for the fact that the dams at Jhuran and Lotianala developed fissures and cracks along earthen sections. Reports from village Dhamadka, which is not far from the epicentre said that all the 189 houses there were destroyed, showing that an intensity of M-M IX was reached there. It is, therefore, inferred that even very close to the epicentre the intensity of the shock did not exceed figure IX of M-M scale. The line marked II in Fig. 1 indicates the limit to which the shock was felt, giving an average value for the radius of perceptibility as 330 km nearly.

2. Earlier seismic history of the region

The whole of the Cutch and the State of Saurashtra lie in a seismic belt, where destructive earthquakes have occurred in the past. The frequency of major earthquakes, however, does not appear to be much. In the list of Indian Earthquakes compiled by Oldham (1883) mention has been made of an earthquake in May 1668 in the delta of the Indus, during which the town of Samaji is reported to have sunk into the earth with 30,000 houses. The next destructive earthquake about which details are available in seismological literature occurred on 16 June 1819 (Oldham 1926). It is said that with the exception of the Assam Earthquake of 12 June 1897, this earthquake is the largest Indian earthquake of the last century. It was felt over an area of nearly 1,000,000 square miles, practically over the whole of the Indian subcontinent. According to Captain Macmurdo the total loss of life was 1543. In Bhuj alone, the Capital of Cutch, nearly 7000 houses were overthrown and in the eastern portions of Anjar 1500 houses were destroyed and an equal number damaged; the western portions built on rocky foundations having escaped with very little damage. The meizoseismal area extended from Jaisalmer in the north to Porbundar in the south and possibly to Ahmedabad in the east. Large scale dislocations of the crust were observed due to the earthquake, the most significant being the formation of "Allah Bund" extending in a general east-west direction from a belt northwest of Sindri to a length of nearly 80 to 90 miles. A survey of the region revealed that the land to the north of the bund was elevated to a maximum height at 15 to 20 ft and subsided to the south of it to a maximum depth of 10 to 15 ft.

There are no records to show that any major earthquake occurred in the Cutch area after 1819, the latest being the present one. The whole of Saurashtra, however, had been experiencing earthquake tremors of slight intensity from time to time. In Table 1 are listed some of the important minor tremors from 1909 to date.

3. Epicentre and origin time

In Table 2 are listed the times of arrivals of the *P* and *S* phases of this earthquake at the various Indian and foreign seismological observatories. With the help of this data the epicentre and origin time of the shock have been calculated by the method of least squares. These are, epicentre Lat. 23° 20′N, Long. 70°E and origin time $15^h\ 32^m\ 26^s$ GMT. The calculated distance of the observing stations, their azimuth with respect to the calculated epicentre, and the residuals in seconds (observed travel time—calculated time) are also listed. In the calculation of the epicentre and the origin time, only the *P* readings for a surface focus have been used.

Jeffreys and Bullen's (1940) tables have been used for calculating the travel times.

The epicentre of the shock has also been calculated by the station pair method which is independent of travel time tables and depth of focus. It will be seen from Table 2 that the P waves arrived simultaneously at a number of pairs of stations. These stations along with their direction cosines are listed in Table 3.

A solution of the following equations by the method of least squares gives the values of $\frac{B}{A}$ and $\frac{C}{A}$

$$+0\cdot8627\ \frac{B}{A} - 1\cdot1058\ \frac{C}{A} = 1$$

$$-0\cdot2254\ \frac{B}{A} + 1\cdot2120\ \frac{C}{A} = 1$$

$$-0\cdot0673\ \frac{B}{A} + 0\cdot9672\ \frac{C}{A} = 1$$

$$0\cdot0497\ \frac{B}{A} + 0\cdot7579\ \frac{C}{A} = 1$$

$$0\cdot3628\ \frac{B}{A} + 0\cdot0059\ \frac{C}{A} = 1$$

$$0\cdot4308\ \frac{B}{A} - 0\cdot1534\ \frac{C}{A} = 1$$

$$0\cdot3418\ \frac{B}{A} + 0\cdot0459\ \frac{C}{A} = 1$$

$$0\cdot0360\ \frac{B}{A} + 0\cdot7545\ \frac{C}{A} = 1$$

$$-17\cdot5934\ \frac{B}{A} + 39\cdot2271\ \frac{C}{A} = 1$$

$$0\cdot3949\ \frac{B}{A} + 0\cdot0536\ \frac{C}{A} = 1$$

$$\frac{B}{A} = 2\cdot7285 \text{ and } \frac{C}{A} = 1\cdot2492$$

$A = \cos\phi' \cos\lambda$, $B = \cos\phi' \sin\lambda$ and $C = \sin\phi'$ where ϕ' is the geocentric latitude and λ the longitude of the epicentre. From the calculated values of B/A and C/A we get, $\phi' = 23° 9'$, $\lambda = 69° 53'$ and the geographical coordinates of the epicentre are $\phi = 23° 18'$ and $\lambda = 69° 53'$. These values are in good agreement with those obtained by the least squares method.

4. Magnitude and energy

The India Meteorological Department maintains standard Wood-Anderson seismographs at Dehra Dun, Bokaro, Tocklai, Vizianagram and Shillong. The Shillong instruments were out of commission due to repairs to the underground room, and so the magnitude has been calculated with the record of the Milne-Shaw seismograph. The recorded trace amplitudes at these stations on standard Wood-Anderson seismographs and the calculated value of magnitudes are listed in Table 4. Gutenburg and Richter's (1942) original method has been used in the calculations. It will be seen that the magnitudes as calculated from the records of stations having weak foundations are larger than those having rock foundations. Since the station corrections for all the stations are not available, it is not possible to reduce the values to those of standard site. It is considered that the shock had a magnitude between 7 and $7\frac{1}{4}$. The magnitude of the shock as calculated by the seismological observatory, Pasadena was $6\frac{1}{2}$ which seems to be too low a value. Taking the magnitude to be 7 the energy released in the earthquake was $3\cdot5 \times 10^{21}$ ergs according to Gutenburg and Richter's (1956) latest formula

$$\text{Log } E = 9\cdot1 + 1\cdot75\, M + \text{Log } (9 - M).$$

5. Depth of focus

The presence of large surface waves in the records of all the Indian observatories show that the earthquake focus was not at a great depth. In the absence of instrumental data of a number of stations very close to the epicentre, the only method to calculate the depth of focus seems to be from macroseismic evidence. The following empirical formulae given by Gutenburg and Richter (1942) connecting the radius of perceptibility r, the maximum intensity I_o in M-M scale with the focal depth h have been used for calculating the depth.

$$\frac{r}{h} = \left\{ 10^{I_o/3 - 1/2} - 1 \right\}^{\frac{1}{2}} \tag{1}$$

TABLE 1

List of minor tremors in Saurashtra from 1909 to date

S. No.	Date	Remarks
1	1919, April 21	Felt at Bhavnagar Para and several villages at 9 h 53 m GMT. R. F. intensity VIII. Felt also at Wadhwan, Sougadh, Chok Jhana and Bhoika.
2	1922, March 13	Felt at Patdi (Jhalawad Prant and Rajkot)
3	1935, July 20	Felt at Bombay —R.F. Intensity IV Surat —R.F. Intensity III Kapadvaj —R.F. Intensity III
4	1938, June to August	A series of earthquakes was observed during the period near Paliyad (22°15′N, 71°33′E). The shocks varied greatly in intensity but were on the whole slight—a few of them, however, caused some damage. Although the intensity of the shocks at Paliyad was small, almost all of them were preceded by loud rumbling noises. Many noises unaccompanied by any shocks, were also heard.
5	1938, July 19	Paliyad in Saurashtra. Damage to houses in Paliyad. Felt in many places in Saurashtra.
6	1938, July 23	Epicentre 22°·4 N, 71°·8 E. Origin time $12^h\ 04^m\ 50^s$ GMT. Damage to buildings in Paliyad, Wadhwan and Limbdi. Felt all over Saurashtra.
7	1940, October 31	Epicentre 22°·5 N, 70°·4 E. Origin time $10^h\ 44^m\ 15^s$. Moderate. Felt at Dwarka, Barmo, Radhapur, Bhuj, Sheo (Jaipur), Rajkot and other places in Saurashtra.
8	1950, June 14	Epicentre 24° N, 71°·2 E. Origin time 04h 24m 40^s. Felt at Bhuj.

$$6 \log \frac{r}{h} = I_{\circ} - 1{\cdot}5 \qquad (2)$$

$$3{\cdot}6 \log \frac{r}{h} = M - 2{\cdot}2 \qquad (3)$$

In formula (3), M is the instrumental magnitude of the shock. If we presume a maximum intensity of IX in M-M scale near the epicentre, and a magnitude 7, formulæ (1) and (2) give values of 18 and 25 for r/h. Taking the radius of perceptibility to be 330 km as inferred from the map in Fig. 1, the depth from formulae (1) and (2) works out as 18 and 13 km. Formula (3) gives the value of depth as 16 km. The average value for h from these formulae comes out as 16 km which is about the normal depth of shallow earthquakes. The Indian stations Bombay, Poona, Dehra Dun, Bokaro, Vizianagram, Madras, Shillong and Tocklai recorded a distinct phase about 7 seconds after P. If this phase is assumed to be sP the depth of focus would come out to about 18 km below the surface. The original records of foreign stations have not been seen, but the tabulations of Strasbourg, Kew and Reykjavik show that a phase with an impetus was recorded at these stations 6·5 to 7 seconds after P. If this is assumed to be sP the depth of focus below the surface would be of the same order. Taking all the facts into consideration it seems very probable that the depth of focus was somewhere between 13 and 18 km below the surface, that is, near the base of the granitic layer.

TABLE 2

Station	Observed arrival time of P (GMT) h	m	s	Observed arrival time of S (GMT) h	m	s	△ (Degrees)	Azimuth (Degrees)	Observed travel time of P min	sec	P (O—C) sec	Observed travel time of S min	sec	S (O—C) sec
Bombay	15	33	46	15	34	46	5·10	148	1	20	0	2	20	0
Poona	15	33	58	15	35	05	5·95	143	1	32	0	2	39	—3
Quetta	15	34	16	15	35	41	7·40	340	1	50	—2	3	15	—3
New Delhi	15	34	30	15	35	59	8·30	47	2	04	—1	3	33	—7
Hyderabad	15	34	47	15	36	35	9·85	126	2	21	—5	4	09	—10
Dehra Dun	15	34	55	15	36	45	10·00	42	2	29	+1	4	29	+7
Vizianagram	15	35	38	15	38	12	13·60	107	3	12	—4	5	46	—4
Madras	15	35	46	15	38	20	14·10	134	3	20	—3	5	54	—8
Bokaro	15	35	52	15	38	25	14·50	84	3	26	—2	5	59	—12
Andidjan	15	36	32	15	39	45	17·45	6	4	06	0	7	19	—1
Namangan	15	36	35	15	39	42	17·65	4	4	09	0	7	16	—8
Shillong	15	37	02	15	40	39	20·05	79	4	36	—2	8	13	—5
Frounze	15	37	02	15	40	37	19·87	10	4	36	0	8	11	—3
Tocklai	15	37	27	15	41	27	22·23	73	5	01	+1	9	01	+1
Chemakha	15	37	55				24·90	319	5	29	+3			
Makhatchkala	15	38	10				27·02	322	5	44	—1			
Tbilisi	15	38	22	15	43	06	27·90	316	5	56	+2	10	40	+3
Ksara	15	38	57	15	44	05	31·60	297	6	31	+4	11	39	+4
Jerusalem	15	38	57·5				31·60	293	6	31·5	+4			
Sotchi	15	38	58	15	44	13	32·07	316	6	32	+1	11	47	+4
Sverdlovsk	15	39	17				34·15	356	6	51	+2			
Helwyn	15	39	23	15	44	55	35·05	288	6	57	0	12	29	0
Kandilli	15	39	51	15	45	45	38·58	307	7	25	—1	13	19	—4
Irkoutsk	15	39	57				39·00	34	7	31	+1			
Moscow	15	40	06	15	46	13	40·22	332	7	40	0	13	47	—1
Hongkong	15	40	09	15	46	(11)	40·60	81	7	43	0	13	45	—8
Athens	15	40	17	15	46	38	41·97	301	7	51	—3	14	12	—2
Bucharest	15	40	19	15	46	37	41·57	311	7	53	+2	14	11	+3
Beograd	15	40	50	15	47	34	45·59	309	8	24	+1	15	08	+3

TABLE 2 (*contd*)

Station	Observed arrival time of P (GMT) h	m	s	Observed arrival time of S (GMT) h	m	s	△ (Degrees)	Azimuth (Degrees)	Observed travel time of P min	sec	P (O—C) sec	Observed travel time of S min	sec	S (O—C) sec
Djakarta	15	40	55				46·42	124	8	29	—1			
Astrida	15	40	56				46·93	242	8	30	—4			
Taranto	15	41	00				47·23	304	8	34	—3			
Warsaw	15	41	02	15	48	00	47·03	320	8	36	+1	15	34	+7
Tananarive	15	41	06				47·37	208	8	40	+2			
Lwiro	15	41	07				47·50	244	8	41	+2			
Baguio	15	41	09	15	48	07	47·87	89	8	43	+1	15	41	+2
Raciborz	15	41	12				48·13	317	8	46	+2			
Messina	15	41	13	15	48	17	48·43	301	8	47	+1	15	51	+4
Wien	15	41	13				48·92	314	8	47	—3			
Manila	15	41	16	15	48	18	48·80	91	8	50	+1	15	52	0
Dilliman	15	41	16	15	48	17	48·85	77	8	50	+1	15	51	—1
Trieste	15	41	26	15	48	35	50·30	310	9	00	0	16	09	—4
Praha	15	41	28·5				50·50	316	9	2·5	+1			
Rome	15	41	30	15	48	36	50·90	305	9	04	—1	16	10	—11
Upsala	15	41	34				51·48	326	9	08	—1			
Firenze Xim	15	41	35				51·90	308	9	09	—3			
Bologna	15	41	42				51·90	309	9	16	+4			
Jena	14	41	43	15	49	12	52·43	317	9	17	+1	16	46	+4
Cheb	15	41	43	15	49	02	51·80	316	9	17	+6	16	36	+3
Köbenhavn	15	41	47	15	49	17	52·85	322	9	21	+1	16	51	+3
Pavia	15	41	50	15	49	15	53·47	310	9	24	0	16	49	—7
Stuttgart	15	41	51·5	15	49	24	53·70	313	9	25·5	0	16	58	—1
Kiruna	15	41	52				53·80	339	9	26	—1			
Karlsruhe	15	41	54				54·25	314	9	28	—2			
Strasbourg	15	41	58	15	49	38	54·70	313	9	32	—1			
Monaco	15	41	48				54·67	308	9	32	—1			
Skalstugan	15	42	01				55·12	332	9	35	—1			
Besancon	15	42	05				55·75	312	9	39	—2			

TABLE 2 *(contd.)*

Station	Observed arrival time of P (GMT) h m s	Observed arrival time of S (GMT) h m s	△ (Degrees)	Azimuth (Degrees)	Observed travel time of P min sec	P (0—C) sec	Observed travel time of S min sec	S (0—C) sec
Witteveen	15 42 08		55·70	320	9 42	+2		
Koche	15 42 09	15 50 01	56·03	63	9 43	0	17 36	+5
De Bilt	15 42 13	15 50 08	56·65	317	9 47	0	17 42	+3
Uccle	15 42 14	15 50 10	56·98	315	9 48	—2	17 44	+1
Alger	15 42 23		58·43	299	9 57	—3		
Wajima	15 42 24	15 50 26	58·30	60	9 58	—1	18 00	+3
Tamanrasset	15 42 29	15 50 36	58·85	284	10 03	0	18 10	+2
Matsushiro	15 42 31	15 50 32	59·45	60	10 05	—2	18 06	—10
Nagano	15 42 33		59·43	58	10 07	0		
Kew	15 42 36		59·93	316	10 10	0		
Maebashi	15 42 36		60·15	60	10 10	—1		
Tortosa	15 42 37	15 51 00	59·95	305	10 11	+1		
Tokyo	15 42 38		60·82	61	10 12	—4		
Durham	15 42 41	15 50 57	60·72	321	10 15	—1	18 31	—1
Alicante	15 42 42	15 51 01	61·00	303	10 16	—1	18 35	0
Sapporo	14 42 43	15 51 02	61·10	53	10 17	—1	18 36	—1
Jersey	15 42 44	15 51 03	61·15	315	10 18	—1	18 37	0
Aberdeen	15 42 44	15 51 04	61·05	323	10 18	0	10 38	+2
Almeria	15 42 54		62·79	300	10 28	—2		
Toledo	15 42 59		63·52	303	10 33	—1		
Cartuja	15 42 59		63·62	301	10 33	—2		
Pretoria	15 43 (00)		63·40	222	10 34	0		
Malaga	15 43 03		64·35	302	10 37	—3		
Pietermaritzburg	15 43 11		64·97	218	10 45	+1		
Scoresby Sund	15 43 34	15 52 14	68·87	330	11 08	0	20 18	+6
Reykjavik	15 43 43		70·11	331	11 17	+1		
Resolute Bay	15 43 47		81·73	356	11 21	—1		
Rabaul	15 45 00		84·51	100	12 34	—2		
College	15 45 20		87·37	16	12 54	+4		
Brisbane	15 45 50		94·70	116	13 24	0		

TABLE 3

Station	Arrival time of P (GMT) h	m	s	a	b	c	Station	Arrival time of P (GMT) h	m	s	a	b	c
1 Shillong	15	37	02	-0297	9027	4292	11 Kew	15	42	36	6255	-0034	7802
2 Frounze	15	37	02	1953	7086	6780	12 Maebashi	15	42	36	-6095	5286	5908
3 Jerusalem	15	38	57·5	6934	4946	5241	13 Alicante	15	42	42	7862	-0067	6180
4 Sotchi	15	38	58	5590	4643	6870	14 Sapporo	15	42	42	-5723	4577	6804
5 Strasbourg	15	41	58	6579	0897	7477	15 Jersey	15	42	44	6556	- 240	7547
6 Monaco	15	41	58	7188	0938	6888	16 Aberdeen	15	42	44	5444	-0200	8386
7 Upsala	15	41	34	4810	1528	8633	17 Toledo	15	42	59	7676	-0543	6387
8 Firenze Xim	15	41	35	7103	1414	6895	18 Pretoria	15	43	00	7949	4260	-4322
9 Alger	15	42	23	8015	0425	5965	19 Djakarta	15	40	55	-2879	9517	-1070
10 Wajima	15	42	24	-5816	5443	6046	20 Astrida	15	40	56	8674	4955	-0451

TABLE 4

Rann of Cutch Earthquake of 21 July 1956

S. No.	Station	Lithological foundation	Amplitude in mm of Standard Wood-Anderson N-S	E-W	Mean	Epicentral distance from recording station (degrees)	Magnitude N-S	E-W	Mean	Remarks
1	Bokaro	Rock (Sandstone)	15·4	11·2	14	14·43	7·4	7·2	7·3	
2	Dehra Dun	Alluvium	47·6	68·6	58·1	9·92	7·5	7·6	7·5	
3	Shillong	Rock (Quartzite Sandstone)	..	..	..	19·91	7	..	7	Amplitude read on Milne Shaw record
4	Tocklai	Water soaked alluvium	..	14·0	14·0	22·09	..	7·7	7·7	
5	Vizianagram	Alluvium	8·6	5·6	9·9	13·50	7·1	6·9	7·0	Amplitude on N-S Compt. read on 2 sec Wood-Anderson
6	Pasadena	..	..	..	..	..	..	..	6½	Quoted by U.S. C.G.S.

6. Discussion

A few words may be said here about the destruction of property at Anjar. It has already been mentioned earlier that both in 1819 and also in the present earthquake, the eastern portions of the town built on soft ground suffered extensive damage while the western portions built on trap rock foundations escaped with only minor damage. This once again demonstrates that the effects of earthquakes are much disastrous on soft ground than on hard rock. In this case the eastern portions were located near the boundary of hard rock and soft ground. Under such situations there is a further concentration of energy near the interface and is responsible for greater damage. It may not be considered safe to rebuild the town on its old soft foundations, and an extension of the western portions with trap rock foundations would be proper.

7. Acknowledgements

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