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INDUCED SEISMICITY AND DAM RESERVOIRS --- THE CASE OF MAIN DAM IN JAPAN ---

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SUMMARY

This paper is the report of the seismicity induced by the impoundment to dam reservoirs with the height 80m and more, in Japan. The induced seismicities of 81 dam areas are surveyed by the test of statistical hypothesis. The result of the test shows that active seismicity is induced by the impoundment in 13 dam areas and seismicity turns quiescent in one dam area.

SEISMIC DATA

The Seismological Bulletin of JMA (The Japan Meteorological Agency) has been published since 1926. The seismological data of JMA make epochs at 1961 and 1976 (see Fig.1). The detectability of seismic events improved from each epoch, and especially it rise remarkably from the latter epoch. Moreover, the result of reexamination of the seismological data for the period 1926-1960 by JMA (Ref.1), shows that the yearly frequency of seismic events in the period rises almost equal to the yearly frequency found during 1961-1975 (see the dotted line in Fig.1). The yearly frequency of events of $M \geq 3.5$ after 1976 is almost equal to that of events for the period 1961-1975, too (see the broken line in Fig.1). Therefore, if the events of $M < 3.5$ after 1976 eliminated from the data, it is possible to consider as the seismological data are almost homogeneous throughout the period 1926-1986.

This means that it is possible to analyze seismicity quantitatively. The new seismic data are available for the statistical test of time-spatial change of seismicity around the dam areas effected by impoundment.

DAMS CHOSEN AS THE SUBJECT TO THIS STUDY

Rothé (Ref.2) says that reservoirs showing seismic effects have invariably depths of 100m or more. But, Simpson (Ref.3) reports that reservoirs having depths less than 100m show also seismic effects.

Therefore, the dams that the height is 80m or more and that 10 years or more have passed since the impoundment started, are chosen as the subject to this study. The second criterion mentioned above will account for the cause in the following section.

In Japan, the dams fitting the criterions are 81 in 115 dams including underconstruction. Table 1 shows the dam's name, the height and the starting date of the impoundment of the 81 dams. Fig. 2 shows the map of the dam locations.

STRESS DISTRIBUTION BY RESERVOIR

When the weight acts on the half-space elastic body, the vertical stress distribution is as shown in Fig. 3. Fig. 3 shows the case that the weight is water of width 2km, length infinite and height 100m, and the numbers in the figure are the percentages for the stress just under the weight.

STUDY AREA

The study area in each dam is a cylinder with radius 10km centering a dam and depth 25km. The adoption of this study area comes from the stress distribution as shown in Fig. 3. The stress within the study area is more than 5% for just under the reservoir.

WEIGHTS FOR SEISMIC EVENTS

It is thought that the induced seismicity has close connection with the distance between dams and earthquake foci. So, weights are given to every seismic events. The weights, as shown in Fig. 4, depend on the locations where seismic events occur. The values of the weights in Fig. 4 come from Fig. 3 showing stress distribution.

ANALYZING METHOD

Statistical analysis applied Thompson's method (Ref.4) for the test of statistical hypothesis. Fig. 5 is an example (the case of Ikawa dam area) of statistical test. This dam become quiescent after the impoundment. Abscissa is year and ordinate is weighted frequency of seismic events. Vertical chain lines show the starting date of the impoundment. The upper figure is the time series of seismic events within the study area. The horizontal segments show 10 years, respectively. In the lower figure, vertical bars show the total weighted frequency of every 10 years of seismic events within the study area.

Thompson's method is applied for the detection of significant difference between the frequency distribution of every 10 years before the impoundment and the frequency of 10 years after the impoundment, as shown in Fig. 5. The percentages shown in Fig. 5 are the confidence limits.

As is obvious from Fig. 5, no earthquake occur in the period 10 years after the impoundment. The seismicity within the study area after the impoundment is an outlier against the seismicity before the impoundment.

This hypothesis test by Thompson's method is applied for 81 dam areas.

RESULT

The result of the hypothesis test shows that seismicity after the impoundment become active in 13 dam areas and quiescent in one dam area.

In Table 1, the symbol (++) of the right side means that seismicity after the impoundment within the study area becomes active with the probability 99% or more, the symbol (+) means that the seismicity becomes active with probability 95% or more, and the symbol (--) means that the seismicity becomes quiescent with the probability 99% or more.

Fig. 6 shows the time series of seismic events within the study area of the 13 dams that seismicity after the impoundment become active. Abscissa is year and ordinate is frequency of seismic events. Arrow shows the starting date of impoundment. Thick horizontal segment shows the period 10 years after the impoundment. From these figures, it is clear that earthquakes within these study areas are induced by the impoundment.

Fig. 7 shows the location of the dams that the seismicity change is found between the pre- and post-impoundment. The large solid circles show 13 dams that seismicity within the study area becomes active after the impoundment, the large open circle shows the dam that seismicity becomes quiescent and the small open circles show the dams that no seismicity change throughout the pre- and post-impoundment.

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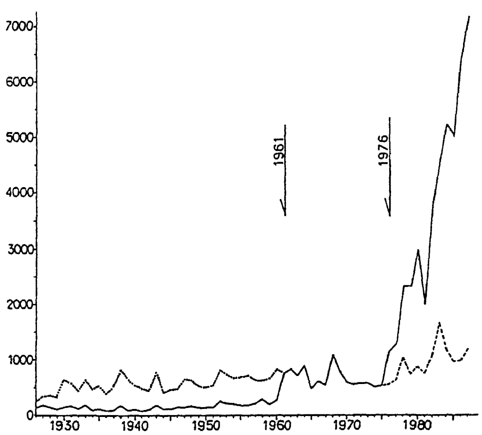

Fig. 1: Yearly frequency of seismic events in and near Japan. See the text about solid, dotted and broken lines.

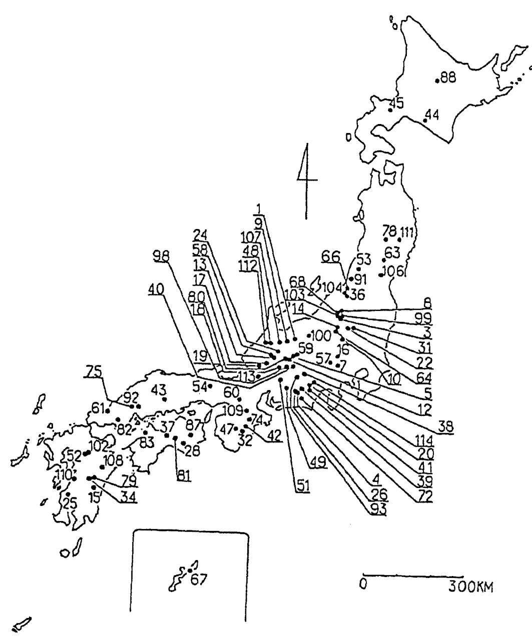

Fig. 2: The map of dam locations surveyed on this study.

DAM	HEIGHT (m)	START OF IMPOUNDMENT	DAM	HEIGHT (m)	START OF IMPOUNDMENT
1 KUROBE	186.0	OCT 1960	54 KUROKAWA	97.5	NOV 1973
3 OKUTADAMI	157.0	MAR 1960	57 FUTASE	95.0	NOV 1960
4 SAKUMA	155.5	DEC 1955	58 OHSHIRAKAWA	95.0	OCT 1963
5 NAGAWADO	155.0	MAR 1969 + +	59 MIDONO	95.0	AUG 1969 + +
7 OGOUCHI	149.0	JUN 1957 + +	60 KISENYAMA	95.0	MAR 1969
8 TAGOKURA	145.0	MAR 1959	61 ABUGAWA	95.0	SEP 1974
9 ARIMINE	140.0	APR 1959	63 NARUGO	94.5	APR 1957 + +
10 KUSAKI	140.0	MAR 1976	64 FUJIWARA	94.5	JAN 1957
12 TAKANE 1ST	133.0	FEB 1968	66 TAINAIGAWA	93.0	OCT 1976
13 MIBORO	131.0	NOV 1960	67 FUKUJI	91.5	JUN 1973
14 YAGISAWA	131.0	SEP 1965	68 KUROMATAGAWA 1ST	91.0	DEC 1957
15 HITOTSUSE	130.0	APR 1963 + +	72 AKIBA	89.0	NOV 1957
16 SHIMOKUBO	129.0	NOV 1967	74 MIYAKAWA	88.5	OCT 1956 + +
17 KUZURYU	128.0	DEC 1967	75 MYOJIN	88.5	MAR 1976
18 IWAYA	127.5	MAR 1976	78 YUDA	87.5	NOV 1963 +
19 MANAGAWA	127.5	DEC 1976	79 TSUKABARU	87.0	MAR 1939
20 HATANAGI 1ST	125.0	JUL 1961	80 ASAHI-GIFU	87.0	AUG 1953
22 KAWAMATA	120.0	OCT 1963	81 NAGASE	87.0	MAY 1955
24 SHIMOKODORI	119.0	MAR 1973	82 SUGANO	87.0	JUL 1965
25 TSURUTA	117.5	NOV 1964	83 ISHITEGAWA	87.0	MAY 1972
26 SHIN TOYONE	116.5	SEP 1972	87 NAGAYASUGUCHI	86.5	SEP 1955
28 YANASE	115.0	FEB 1965	88 TAISETSU	86.5	OCT 1975
31 IKARI	112.0	APR 1956 + +	91 MIOMOTE	85.5	OCT 1952 + +
32 IKEHARA	111.0	JUN 1964	92 NABARA	85.5	SEP 1975
34 KAMISHIIBA	110.0	APR 1955	93 MATSUKAWA	84.3	MAR 1974
36 KAJIGAWA CHISUI	106.5	OCT 1974	98 MIURE	83.2	OCT 1942 + +
37 SAMEURA	106.0	NOV 1971	99 OHTORI	83.0	OCT 1963
38 KOSHIBU	105.0	JUL 1968	100 SUSOHANA	83.0	MAR 1969
39 MISAKUBO	105.0	APR 1969	102 MATSUBARA	83.0	DEC 1970
40 MAKIO	104.5	MAR 1961	103 KUROMATAGAWA 2ND	82.5	NOV 1963
41 IKAWA	103.6	APR 1957 - -	104 UCHINOKURA	82.5	DEC 1972
42 SAKAMOTO	103.0	NOV 1961	106 OHKURA	82.0	JUN 1961 + +
43 SHIN NARIWAGAWA	103.0	JUN 1968	107 MUROMAKI	82.0	MAR 1961
44 NIIKAPPU	102.8	FEB 1974	108 KITAGAWA	82.0	JUN 1962
45 HOUHEIKYOH	102.5	MAR 1972	109 SHOHRENJI	82.0	JAN 1970
47 KAZAYA	101.0	MAY 1960	110 ABURATANI	82.0	DEC 1975
48 TOHRI	101.0	DEC 1965 + +	111 TASE	81.5	OCT 1954
49 YAHAGI	100.0	MAR 1970	112 UCHIKAWA	81.0	SEP 1973 + +
51 MARUYAMA	98.2	FEB 1954	113 YOKOYAMA	80.8	FEB 1964
52 SHIMOUKE	98.0	MAR 1969	114 AMEHATA	80.5	DEC 1966
53 YAKUWA	97.5	DEC 1957			

Table 1: Dam's name, height and the starting date of the impoundment of the 81 dams surveyed on this study.
The right side symbols (++, +, --) show that the seismicity after the impoundment turns active (++, +) and quiescent (--).

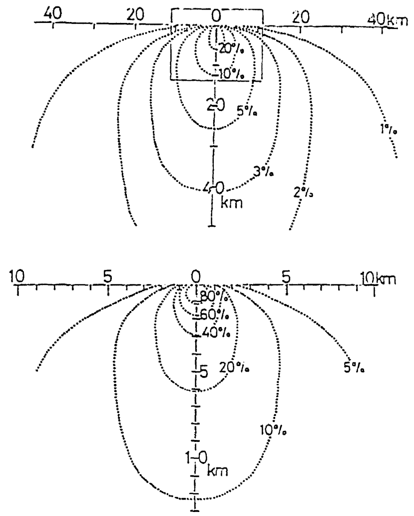

Fig. 3: Vertical stress distribution of the case that the weight is put on the surface of half-space elastic body. The numbers in the figure are the percentages for the stress just under the weight.

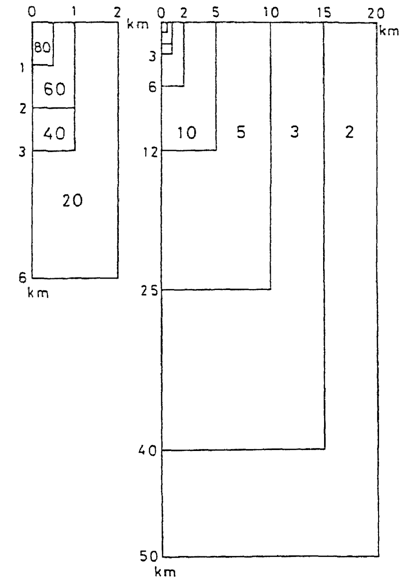

Fig. 4: Weight distribution given for the location of earthquake foci.

41. IKAWA DAM

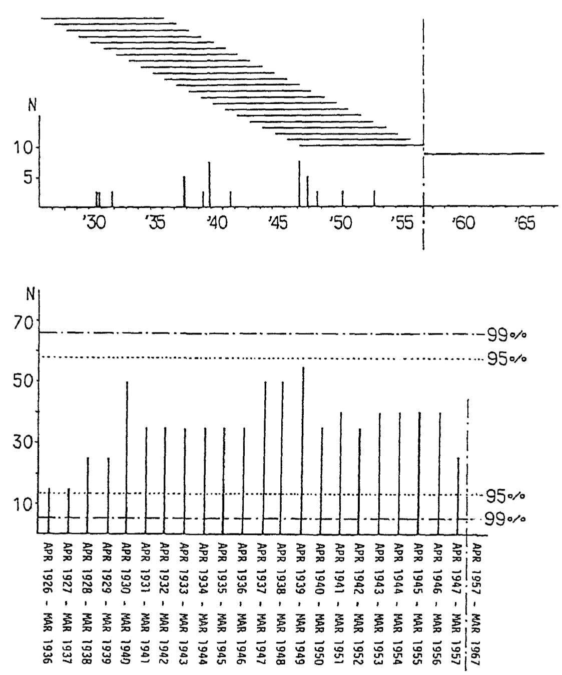

Fig. 5: An example of the test of statistical hypothesis. Refer the interpritation in the text.

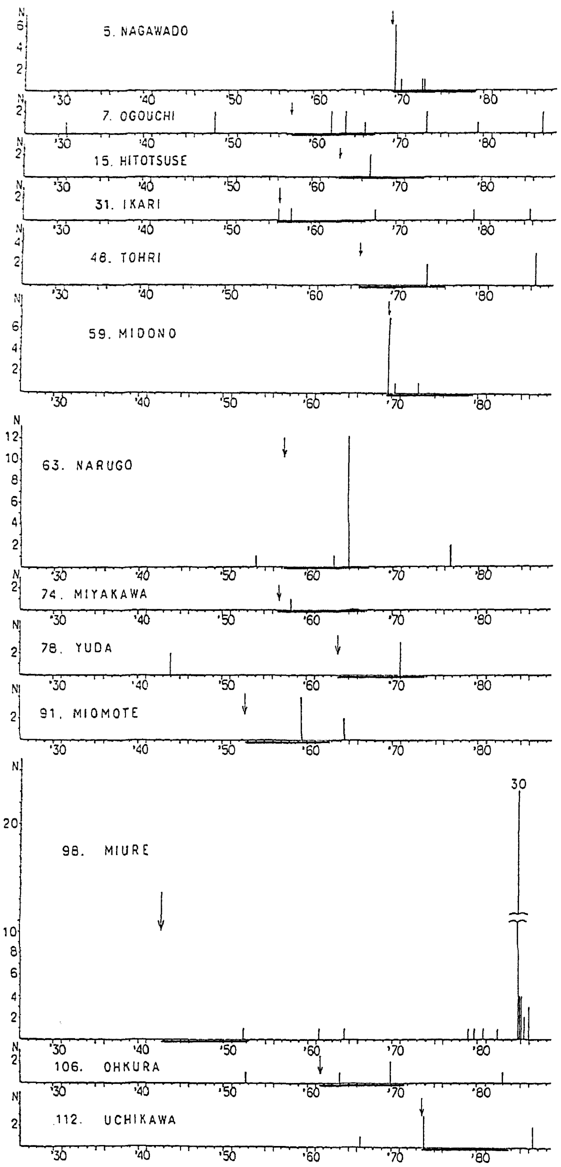

Fig. 6: Time series of seismic events within the study area of the 13 dams that seismicity after the impoundment become active.
Abscissa: year, Ordinate: frequency of seismic events, Arrow: the starting date of the impoundment, and Thick horizontal segment: the period 10 years after the impoundment.

Fig. 7:
The location of the dams that the seismicity change is found between the pre- and post-impoundment.
Large solid circles: the 13 dams that seismicity within the study area become active after the impoundment, Large open circle: the dam that seismicity become quiescent after the impoundment, and Small open circles: the dams that no seismicity change throughout the pre- and post impoundment.