BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 47 (1969), pp. 99-105

6. *Electrical Conductivity of Strained Rocks. The Fifth Paper.*

Residual Strains Associated with Large Earthquakes as Observed by a Resistivity Variometer.

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(Read Nov. 26, 1968.—Received Nov. 27, 1968.)

Summary

The resistivity variometer now at work at Aburatsubo has recorded step-like changes in association with earthquakes of large magnitude including the 1968 Tokachi Earthquake on May 16, 1968. Close examination of records leads to a conclusion that residual strains of the order of 10^{-7} were detected as resistivity jumps with a duration of a few minutes.

1. Introduction

An unusually sensitive resistivity variometer has been developed by Yamazaki[1),2)]. During a running test of the variometer at Aburatsubo, a near-shore station about 60 km south of Tokyo, a few records of resistivity change which are possibly correlated with residual strains associated with earthquakes of large magnitude have been obtained. This paper is aimed at reporting on such changes.

2. The 1968 Tokachi Earthquake and its aftershocks

A strong earthquake of magnitude 7.8 occurred off the southern coast of Hokkaido Island at 9 h 49 m JST on May 16, 1968. The magnitude has later been corrected as 8.0 by the Japan Meteorological Agency which also named the earthquake the 1968 Tokachi Earthquake.

As has already been reported by Yamazaki[2)], the resistivity variometer at Aburatsubo recorded a change in association with the earthquake. Fig. 1 shows the traces of the change as observed by the high as well as low sensitivity channels. A jump of about 0.7×10^{-4} in resisti-

1) Y. YAMAZAKI, *Bull. Earthq. Res. Inst.*, **45** (1967), 849-860.
2) Y. YAMAZAKI, *Bull. Earthq. Res. Inst.*, **46** (1968), 957-964.

vity rate can be clearly seen on the record. Meanwhile, a slow change which is also seen on the record is caused by tidal loading. On closely examining the record, we see that the jump is not quite instantaneous. The recorder working on a principle of multi-channel plotting, the time-interval between successive plots on a trace is 30 sec. As eight plots can be counted during the jump, the change seems to be completed within a time-interval of about 5 min.

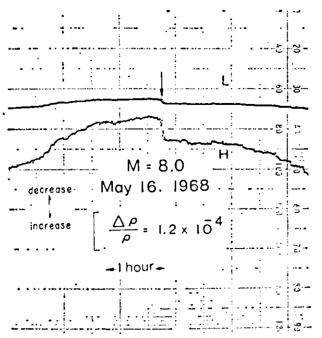

Fig. 1. Change in the resistivity at the time of an earthquake of magnitude 8.0 on May 16, 1968 as recorded by high (H) and low (L) sensitivity channels. The epicentral distance amounts to 680 km.

If the resistivity change ($\Delta\rho/\rho$) is interpreted in terms of a change in length ($\Delta L/L$) in the direction of a straight line along which the electrodes of the variometer are placed (N 81°W), the jump corresponds to an extension of the ground in the N 81°W direction amounting to 2.2×10^{-7}. The sensitivity of the variometer being determined by making use of changes associated with tidal loading, the strain thus calculated may be subjected to an error by a factor of two or so, because of the phase difference of unidentified origin between resistivity change and linear strain.

An after-shock of magnitude 7.5 occurred at 19h 39 m on the same day. The jump of the variometer trace is in this case a little smaller than the resistivity step for the main shock, but it is clearly observed as can be seen in Fig. 2. The direction of the jump indicates a decrease in the resistivity, i.e. a ground contraction in the N 81°W direction this time. The corresponding strain is estimated as 0.7×10^{-7}.

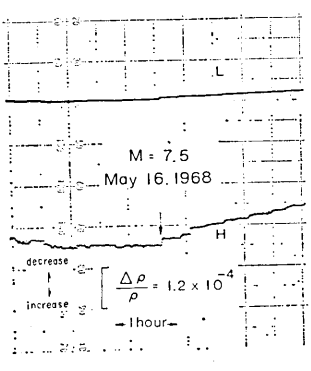

Fig. 2. Change in the resistivity at the time of an earthquake of magnitude 7.5 on May 16, 1968. The epicentral distance amounts to 700 km.

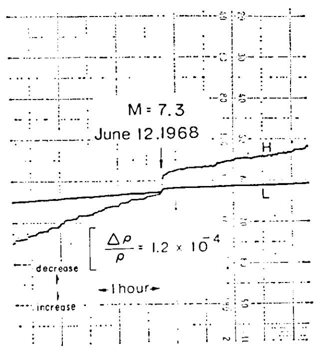

Fig. 3. Change in the resistivity at the time of an earthquake of magnitude 7.3 on June 12, 1968. The epicentral distance amounts to 580 km.

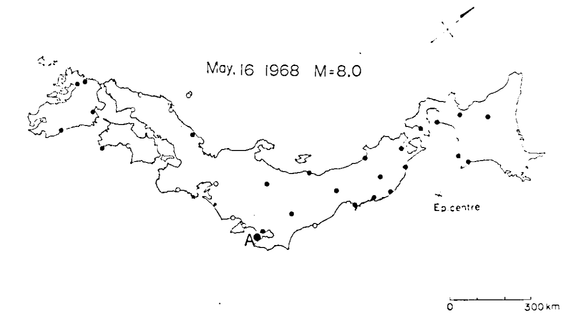

Fig. 4. The "push-pull" distribution of initial motion for the May 16 earthquake of magnitude 8.0. Solid circles denote the "push" and hollow ones the "pull".

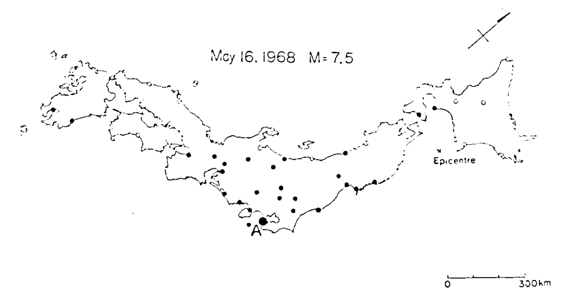

Fig. 5. The "push-pull" distribution of initial motion for the May 16 earthquake of magnitude 7.5.

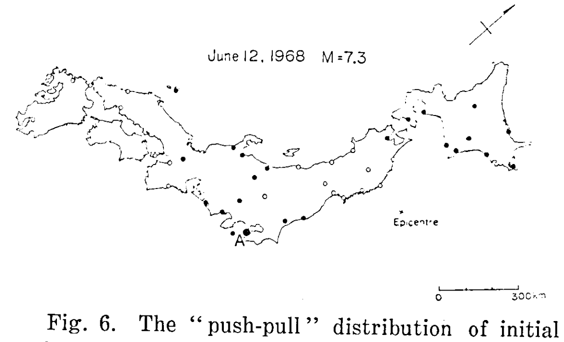

Fig. 6. The "push-pull" distribution of initial motion for the June 12 earthquake.

It is also of great interest that a similar jump ($\Delta\rho<0$) (Fig. 3) was observed at the time of an earthquake of magnitude 7.3 that occurred off north-eastern Japan in the Pacific Ocean at 22h 42 m on June 12, 1968. In this case the epicentral distance was considerably smaller than those of the former two earthquakes. The jump in mechanical strain is estimated as 1.5×10^{-7} this time.

Figures 4, 5 and 6 show the "push-pull" distributions of initial motion of the above three earthquakes as determined by the Japan Meteorological Agency[3]. It is clear from the figures that the observation point as denoted with a letter A is situated in an area in which the initial motions are "push" both for the M=7.5 earthquake on May 16 and the M=7.3 one on June 12. The situation seems greatly different for the main shock (M=8.0) on May 16. The observation point seems to lie in a "pull" area although a station close to A reported a "push" motion. At any rate, it may be said that the observation was in this case made at a point which is fairly close to a nodal line.

Taking these differences into account, the reversals in sign of $\Delta\rho$ as observed by the resistivity variometer may be attributed to the difference in mechanism between the earthquakes. Although the writers

3) M. ICHIKAWA, Personal communication.

believe that this sort of discussion should be made on the basis of earthquake mechanism determined from a study of long-period waves, no such study has been available yet.

3. An earthquake of magnitude 6.4 in Saitama Prefecture

An earthquake violently shook the Tokyo area at 19h 45 m on July 1, 1968, the magnitude of which being reported as 6.4. The epicentre is located in the middle of Saitama Prefecture about 40 km north of Tokyo and the focal depth is reported to be 70 km. At the time of the earthquake, the resistivity variometer at Aburatsubo indicated a step decrease which is interpreted to be caused by a ground contraction in the N 81°W direction amounting to 3.3×10^{-7} (Fig. 7). The "push-pull" pattern of the initial motion as determined by the Japan Meteorological Agency[3] is reproduced in Fig. 8.

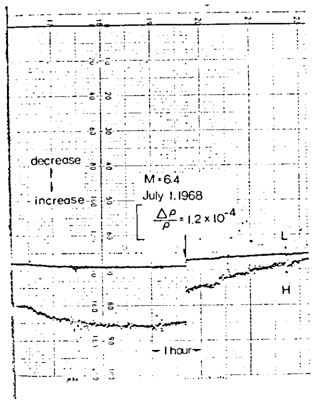

Fig. 7. Change in the resistivity at the time of an earthquake of magnitude 6.4 on July 1, 1968. The epicentral distance amounts to 100 km.

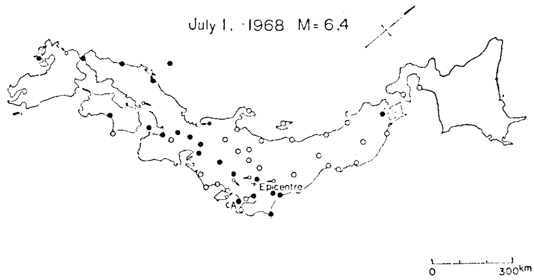

Fig. 8. The "push-pull" distribution of initial motion for the July 1 earthquake.

4. Discussion

Unlike usual strainmeters and tiltmeters, the present resistivity variometer is quite insensitive to short-period changes. As has been described by Yamazaki[2], the system is automated. A tacho-generator produces a voltage which is proportional to the rotation speed of the servo-motor. By feeding back the voltage to the amplifier, the system does not respond to a signal having a period shorter than ten seconds or so.

Residual strains in association with earthquake occurrences have been reported by a number of authors[4),5),6)]. As these reports rely on observations made by instruments which are not quite over-damped, it seems sometimes difficult to distinguish possible residual strains from the records superimposed by post-earthquake fluctuations of short period. In this respect the resistivity variometer seems advantageous for monitoring residual strains.

Wideman and Major[6)] presented a graph which indicates the magnitude of residual strain when earthquake magnitude and epicentral distance are specified. It appears to the present writers that Wideman and Major's graph was formed without paying attention to details of earthquake mechanism. But the graph is useful for making an order-of-magnitude estimate of residual strain associated with earthquakes. Residual strains at Aburatsubo for the four earthquakes described in the preceding sections are estimated according to the Wideman-Major graph as shown in Table 1 in which the strains calculated from the resistivity changes are also indicated.

Table 1. Residual strains estimated from the Wideman-Major graph and resistivity changes.

Magnitude	Epicentral distance	From W-M graph	From resistivity change
8.0	680 km	0.8×10^{-7}	2.2×10^{-7}
7.5	700	0.4×10^{-7}	0.7×10^{-7}
7.3	580	0.6×10^{-7}	1.5×10^{-7}
6.4	100	0.6×10^{-7}	3.3×10^{-7}

It is interesting to note that the residual strains obtained from the resistivity changes agree fairly well with those deduced on the basis of purely mechanical consideration although the former is systematically larger than the latter by a factor of three or thereabouts. As nothing about the earthquake machanism has been taken into consideration, it would be meaningless to go into further detail.

Press[4)] provided master-curves for estimating deformations and strains associated with strike-slip as well as dip-slip faults. If we presume the length of fault from the magnitude[6)], we may readily calculate probable strains at the observation points from these curves. If we do this, Press's curves indicate strains of the order of $10^{-8}-10^{-7}$ at the observation point for the earthquakes treated in Section 2. It is again meaningless to make detailed discussion because of unknown

4) F. Press, *J. Geophys. Res.*, **70** (1965), 2395-2412.
5) I. Ozawa, *Special. Contributions, Geophys. Inst., Kyoto Univ.*, **5**, (1965), 125-137.
6) C. J. Wideman and M.W. Major, *Bull. Seism. Soc. Amer.*, **57** (1967), 1429-1444.

parameters. The focal depth of the Saitama Earthquake as presented in Section 3 being 70 km which is comparable with the epicentral distance, it is not possible to presume the mechanism in a simple form, so that no discussion related to earthquake mechanism is tried in this case.

Ozawa[5], who observed residual strains with extensometers for eleven earthquakes, concluded that, when the observation point lies in the quadrants of " pull " of initial motion, the strain step in a direction connecting the epicentre to the observation point indicates a contraction and the " push " is associated with extension. In the cases of the examples given in Section 2, the direction of strain as measured by the resistivity variometer is roughly perpendicular to the direction connecting the epicentre to the observation point. The above-mentioned Ozawa's law seems to hold good exclusively for the examples in Section 2.

In the light of the above discussion, the present writers are inclined to believe reality of residual strains associated with earthquakes of relatively large magnitude as observed by the resistivity variometer. Possibility of sudden changes in contact between the electrodes and the surrounding ground is considered. But it is hardly likely that the contact condition is affceted by ground motions with a period of predominantly a few seconds as excited by a distant earthquake.

Attention has been paid to the anomalous change in the resistivity beginning about two hours prior to the jump associated with the 1968 Tokachi Earthquake of magnitude 8.0 (Fig. 1). The resistivity tended to decrease for about a two-hour period, the decrease having terminated suddenly with a jump which almost recovered the preceding decrease. One may consider that this is a precursory effect of the main shock. Since no such effect has so far been observed except the above one, nothing definite can be said.

5. Conclusion

The resistivity variometer now at work at Aburatsubo seems capable of monitoring residual strains associated with earthquakes of large magnitude. If variometers are set up in three directions, we may completely determine residual strains in the horizontal plane. A few sets of the variometer assembly covering Japan, if completed, would provide a useful means for studying mechanism of earthquakes occurring in and around Japan.

The writers are thankful to Dr. M. Ichikawa through whose courtesy the "push-pull" initial motions prepared by the Japan Meterological Agency became available.

6. 岩石変形と電気伝導度変化（第五報）
（比抵抗変化計で観測された地震に伴なう永久歪）

地震研究所 力武常次
山崎良雄

第三，四報で報告した比抵抗変化計は神奈川県油壺に於て作動中であるが，1968年5月16日の十勝沖地震およびその余震，6月12日の三陸沖合，さらには7月1日の埼玉県中部の地震に伴なって特異な変化を記録した．

これらの変化は，2〜5分の間に大地比抵抗が 10^{-5}〜10^{-4} の変化率で階段状に緩慢に変わることで特徴づけられる．この比抵抗変化計はその構造上，著しい over-damping になっているので，このような地震に際しての残留歪があるとすれば，通常の伸縮計，傾斜計などに比して，永久歪の記録に適していると考えられる．

変化量を歪に換算すると，10^{-8}〜10^{-7} のオーダーとなり，Press や Wideman-Major によって推算されている残留歪のオーダーと一致する．これらの地震の発震機構との関連については，じゅうぶんな考察ができなかったが，このような比抵抗変化計の記録によって震源の状態を推定することの可能性が示されたということができよう．