Tsunami propagation on a seismological fault model of the 1952 Kamchatka earthquake

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1952年カムチャッカ地震津波の伝播

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要旨

1952年カムチャッカ半島沖に発生した地震はマグニチュード8.3で日本の太平洋岸に約1m の高さの津波をもたらした。この地震について金森（1976）は最近，地震波のデータにもとづいて断層モデルを求めた。津波の発生も断層モデルで説明できることが判っているのでこれをもとにして津波の発生，伝播に関する数値実験を行った。これによって津波の伝播に関する性質を明らかにすることができる。なおこのような広域を対象とした数値実験例は Hwang と Divoky（1970）による1964年アラスカ津波の例があるだけである。

その方法は海底の地殻変動の垂直変位場は彼らの場合，観測から得られているのに対し，ここでは Mansinha と Smylie（1971）によって得られた傾斜断層に対する変位場の式—断層モデル—によった。これは静的変位場の式であるが，この変位場は断層の破壊速度で震源から全方向に伝わり，立ち上り時間（Rise time）をへて変位場が完成されるとした。

まづカムチャッカ半島と日本を結ぶ線から太平洋の沖あい 1400km までのく形領域をとりその 3/4 を 40km，のこりの 1/4 を 80km の巾の格子できざみ，波動方程式をこの値を差分とする差分式に変換する。時間間隔を60秒にして電子計算機で逐次解をもとめた。境界条件は陸と海の境界では完全反射，海の計算上の境界に対しては完全透過の式を用いた。こうして各点での水位の時間変化をもとめるが，このうちから一定時間後の水位分布，最大水位の分布，日本での検潮記録と比較するため相当する地点の水位の時間変化などの情報を取り出して議論の対象とした。

第1にカムチャッカ半島で調査された最大水位の分布図と断層の位置の関係をしらべた。それによると最大水位は台形状の分布曲線を描くが，この平坦な部分と断層の長さがほぼ一致していることが判る。次に5分後，10分後の水位分布図から波の放射の特徴をし

らべた。それによると南北方向で先頭波面の進み方にわずかな差が認められる。これは断層がユニラテラルでかつ長いために生ずる津波の異方性と考えられる。さらに初期水位の1/2の2つの波が陸及び海方向へ伝播するという1次元伝播の性質が波源の中心付近でみられる。又断層が長いため両端から出た波が中心の延長線上で重なり合い，この方向に最大水位の等水位線がのびることが認められた。最大水位の距離による減衰をしらべてみると，断層の長さの0.7倍の所で減衰率が急に大きくなる減衰曲線の折れまがりがみられた。これはこの点を境にしてそれ以前では1次元伝播，それ以後は2次元伝播と伝播の性質が変わることから生ずるものである。

最後に日本の釧路，宮古，鮎川，小名浜，布良の5点で検潮記録と計算で得られた波形の比較が行われた。観測記録の方は先頭部分で長周期の波が表われしだいに短囲期の波が卓越する正分散の性質を示すが，計算波形では格子間隔が 40km と粗いのが原因で短周期成分を再現できない。到着直後の数波に着目すれば，初動方向，周期などの点では一致する。しかし到着時刻は計算の方がすべて早く，振巾はすべて小さい。時刻のずれは各点についてほぼ一定であることからみると，その原因は波源にあるとするよりも観測点にあるとする方が合理的である。これは格子間隔が粗く，海岸付近で水深が急に小さくなることによる速度の減少，振巾の増大を説明できないためと考えられる。これらの結果はこの方法が格子間隔にくらべ十分に大きな領域を考える場合にのみ有効であることをあらためて示している。

Tsunami propagation on a seismological fault model of the 1952 Kamchatka earthquake

Abstract

A numerical experiment was carried out for the 1952 Kamchatka earthquake tsunami on a seismological fault model. The problems investigated are the relation between the fault length and the distribution of the inunduation height, radiation mechanism toward the outer sea and reproducibility of the tide gage records observed in Japan. As the result some interesting facts were found. They are the effect of a finite rupture velocity, the existence of a critical point for a decrease of the maximum amplitude and the possibility of following the wave to Japan.

Introduction

A fault model of the earthquake is a base of studying the tsunami generation. Recently Kanamori (1976) refined the fault model of the 1952 Kamchatka earthquake on the seismological data which had been originally studied by Ben-Menahem and Toksöz (1963). It is significant that the tsunami generation is investigated on the model for explainning the character of tsunami. For this problem it is scarcely investigated how the tsunami which was generated on the shelf radiates its energy toward the outer sea on the realistic model. Hwang and Divoky (1970) followed the 1964 Alaska tsunami to the outer sea on their numerical model. Since the Kamchatka peninsula has a comparatively straight coastal line in comparison with one of Alaska, it is expected that a simple pattern will be obtained for radiation.

Numerical model

It is not suitable to use an instanteneous generation model because of the large fault length. This is the case that it is impossible to neglect the time for a tsunami to propagate from the epicenter in comparison with one for the rupture to propagate from the same point in the fault generation. Since Hwang and Divoky

(1970) showed one of the propagation models, it is used after the basic equation is linearized. It is necessary that we take care of using their model about the characteristic time. It is a time to be taken for its completion of the permanent displacement at a point and they determined it on the seismogram. It is considered that its time corresponds with a rise time in the fault model. A permanent displacement field is computed from the static fault model of Mansinha and Smylie (1971). Only the vertical component is useful since the horizontal one scarcely operates the tsunami generation. The vertical displacement field of Kanamori's model is computed. His model is a low dip-angle, reverse fault and it is considered to be a typical one which generates near the trench. It has a length of 650km and it takes 3.5 min for the rupture to propagate from the epicenter near a margin to another one of the fault. A unilateral fault takes a long time to complete itself in comparison with a bilateral one. A numerical experiment is carried out on this model. A total reflection and complete transmission are assumed for the sea-land boundary and open-sea end, respectively. The computation area is shown in Figure 1. It is devided into a grid space with an interval of 40km for the shelf region and one of 80km for the open sea of a uniform depth. These values are determined in consideration of a computing time and the resolution. A shorter one in the two intervals is smaller than 0.1 of the fault length. The time interval is selected to be 6 sec before the accomplishment of the fault and 60 sec after it.

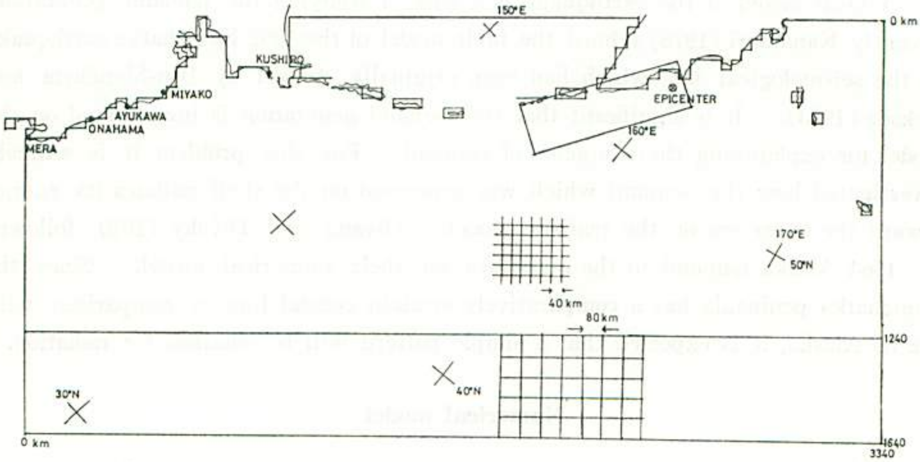

Figure 1. The computational grid and the horizontal projection of the fault by Kanamori (1976) shown with a rectangle. The locations of the points at which wave histories are shown.

Results

As Abe (1977) showed for the 1964 Niigata tsunami, the distribution of an inunduation height reflects the fault length. When the fault strike is parallel to the coastal line, the idea is useful in estimation of a fault length. The fault position derived from Kanamori (1976) is shown in Figure 2 and at the same time the inunduation height obtained by Kucherov and Abaev, cited by Savarensky et al. (1958), is shown after only the data in the coast facing to the open sea are selected from their data. It is found to be a coincidence of the fault length with the distance of a uniform height.

The displacement field of Kanamori's model shows a small deviation from the

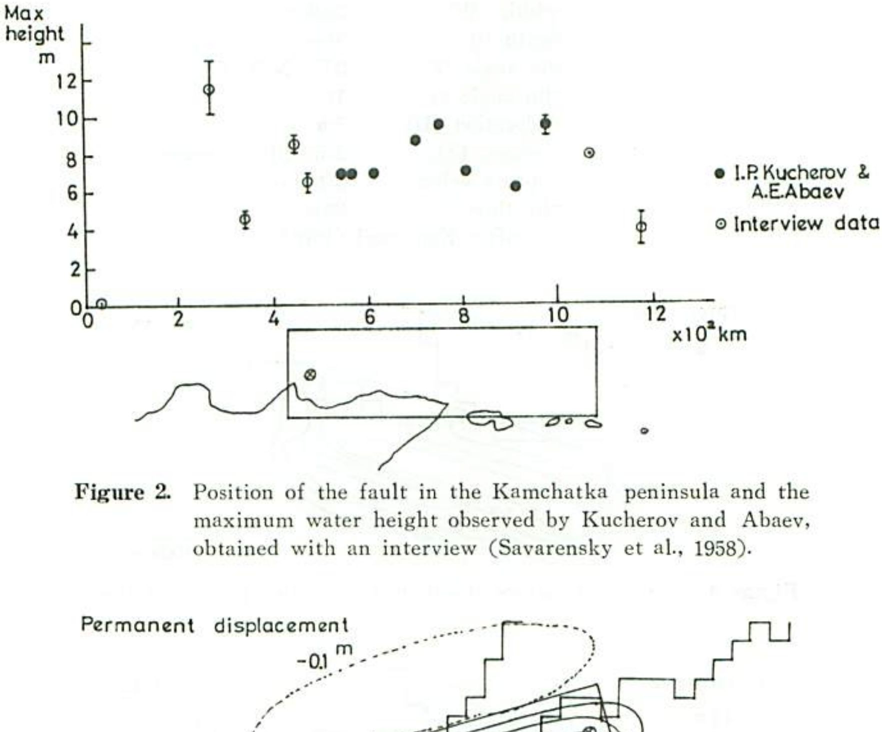

Figure 2. Position of the fault in the Kamchatka peninsula and the maximum water height observed by Kucherov and Abaev, obtained with an interview (Savarensky et al., 1958).

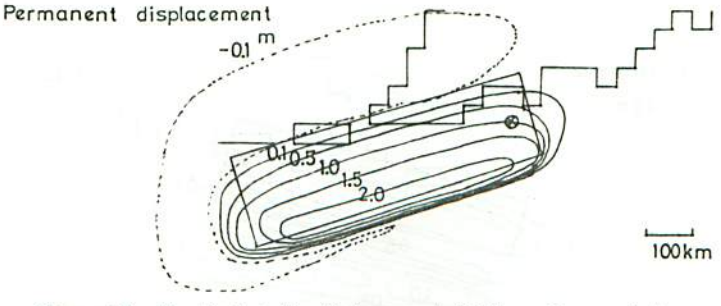

Figure 3. Vertical-static displacement field on the sea bottom computed for Kanamori's model. Solid and dotted line show the elevation and subsidence, respectively.

symmetrical pattern about a center line normal to the strike. It is shown in Figure 3. The fault parameters of his model, which were used for the computation, are shown in Table 1. This is a permanent field on the sea bottom and it is completed after the additive time of the rupture propagation to a rise time.

The contor map of the sea level elevation are shown in Figure 4 and Figure 5

Table 1. Fault parameters.

1952 Kamchatka Earthquake

Origin time	$16^h\ 58^m\ 22^s$ Nov. 4, 1952 (UT)	
Focus	52.6°N 160.3°E −53km	
Fault model	length (L)	650km
	width (W)	200km
	depth (d)	5km
	dip angle (δ)	30° (N 56° W)
	slip angle (λ)	110°
	dislocation (D)	5m
	moment (M_0)	3.5×10^{29} dyne-cm
	rupture velocity	3.0km/sec
	rise time	20sec

after Kanamori (1976)

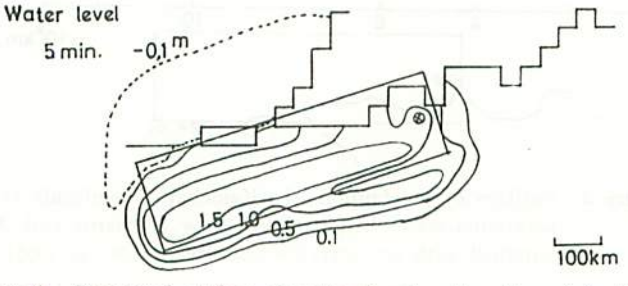

Figure 4. Computed surface elevation 5 min after the origin time.

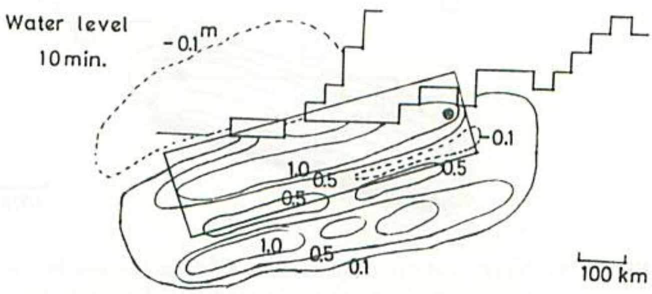

Figure 5. Computed surface elevation 10 min after the origin time.

for the time lapse of 5 min and 10 min, respectively. It is found that one dimensional approximation holds for a propagation on the fault. It is observed 10 min after the origin time that the initial elevation is splitted into two crests propagating toward an opposite direction and the maximum heights of the two are half of the initial one. This result is similar to that obtained by Honda and Nakamura (1959) for a uniform depth in one dimensional propagation is found in the pattern of the contor map. That is, the difference in the wave traverse for 10 min is found between the north and south side. This difference is due to the finiteness of the rupture velocity. It is shown that the fault is long enough to generate a directivity for the tsunami propagation. When it is compared with the result for the Alaska tsunami of 1964 by Hwang and Divoky (1970), this case has a simple radiation pattern and it is due to the straight coastal line and simple displacement field.

In the next place the contor map of the maximum sea level was obtained for the time lapse of 12 hours from the origin time. It is shown in Figure 6. It is found that the equi-displacement line of 1m expands toward the outer sea in the

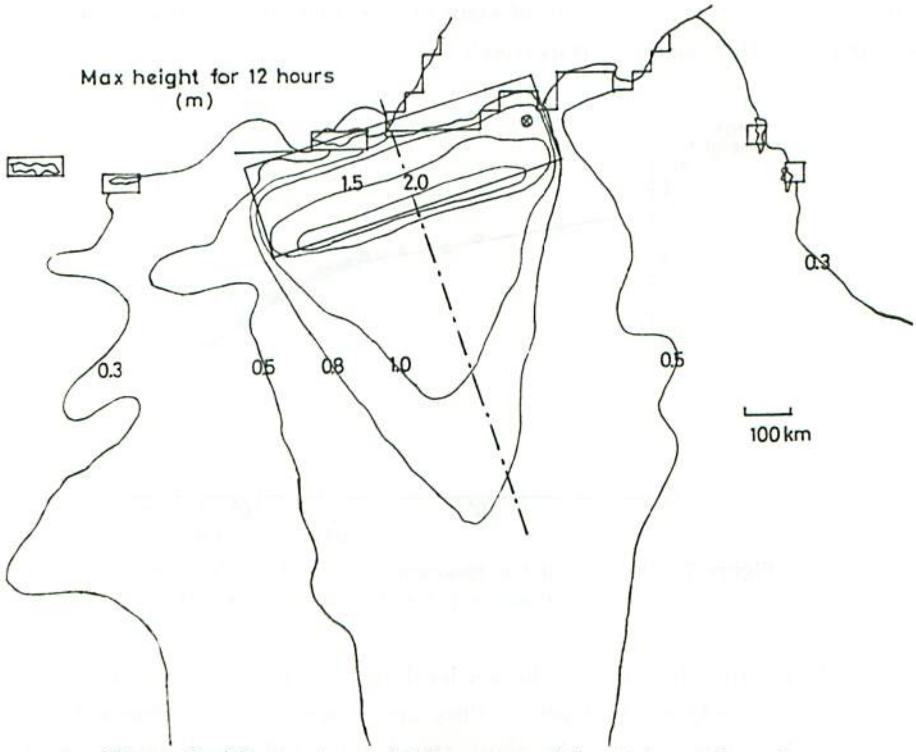

Figure 6. The maximum height computed for 12 horus from the origin time. A center line shown with a chain line.

shape of a triangle. The expansion is explained with a large fault length on the continental shelf. As the result a weak radiation toward the strike direction is also explained. It is a theoretical base for a good correlation between the fault length and the decrease of an inunduation height. It is inferred that the deviation between the top direction of the triangle and the center line of the fault is not due to the propagation velocity of the tsunami but is due to the unilateral generation because the contor map of an equi-depth line shows one dimensional arrangement. From Figure 6 the decrease of the maximum sea level due to the distance was investigated and shown in Figure 7. The maximum value is plotted as a function of the distance along the center line normal to the strike direction, which is shown with a chain line in the figure. In this amplitude-distance curve it is easy to find a critical point. The critical point, at which a decrease rate is varied, represents itself at the distance of 0.7L. From the figure the empirical formula are obtained in the form of

$$\eta = kr^{-0.2} \quad for \ r < 0.7L$$

$$\eta = k'r^{-0.7} \quad for \ r \geqq 0.7L$$

in which η, k, k' and r represent the maximum sea level, constants and the distance, respectively. Within the margin of error of $r^{-0.2}$ they are explained from one and two dimensional propagation, respectively.

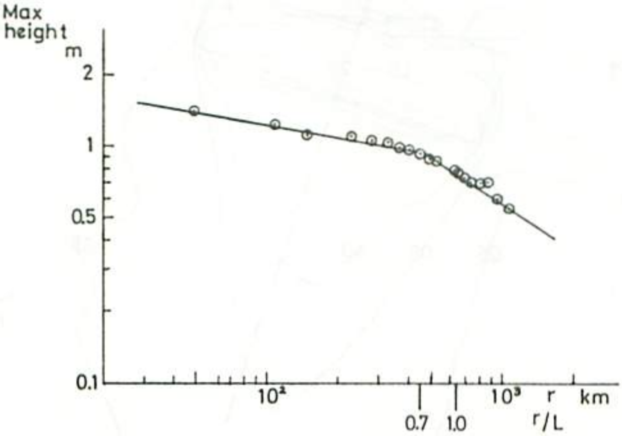

Figure 7. Decrease of the maximum height along the center line with distance (r) and distance ratio (r/L).

Finally the time histories of the sea level are computed for five points which faces to the Pacific Ocean in Japan. They are shown with the observed ones in Figure 8. It is inferred that the short travel time and small amplitude of the computed time histories are due to the coarse mesh. It is impossible to resolve

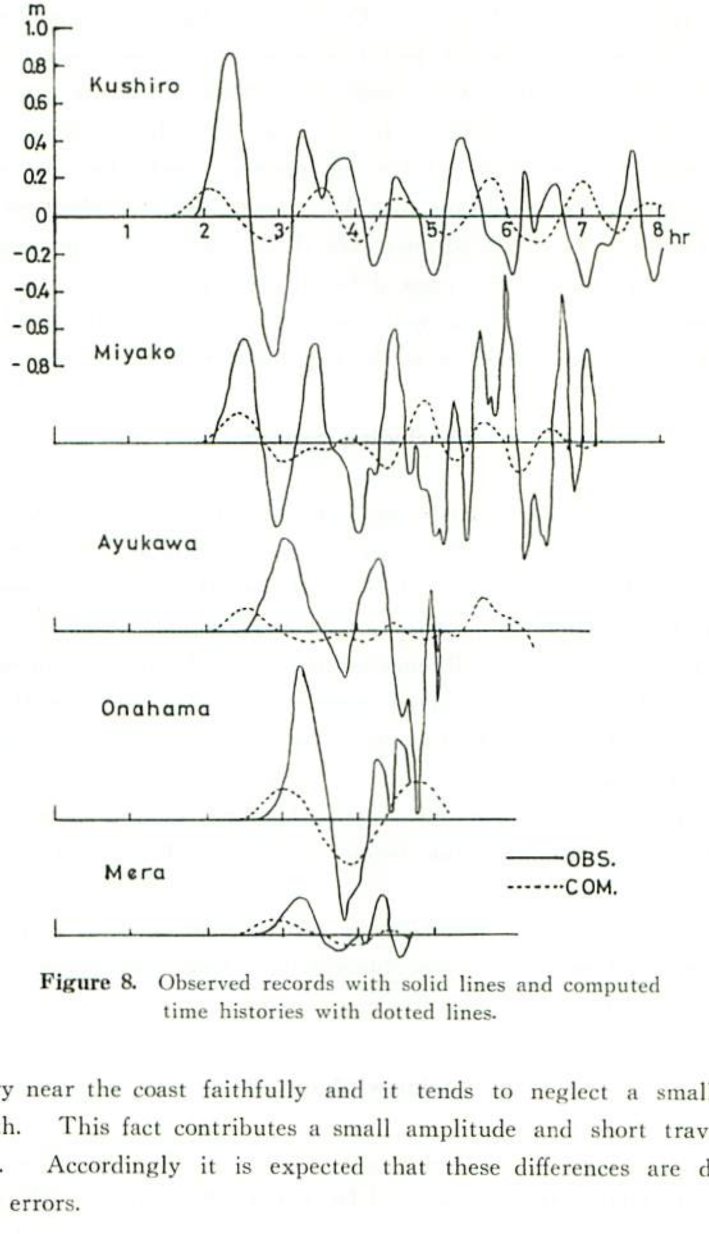

Figure 8. Observed records with solid lines and computed time histories with dotted lines.

a bathymetry near the coast faithfully and it tends to neglect a small value of the sea depth. This fact contributes a small amplitude and short travel time in computation. Accordingly it is expected that these differences are due to the computation errors.

Discussion

For the contribution of the tsunami data to the fault model a further discussion is necessary in a viewpoint that how this model explains the observed sesults. Nine parameters describes the complete fault model. They are a position, size and direction in three dimensional space. On the other hand it is considered that the source region, inunduation height and tide gage records are useful informations obtained from the observation of the tsunami. These data are sensitive to the fault size as shown by Abe (1977). In this case the fault length was discussed in comparison with the distribution of the inunduation height but the values of it were neglected from the discussion. It is noticeable that the observed values are too large to explain the computed ones even if the coase mesh intervals are taken into consideration. Abe (1977) showed for the 1964 Niigata tsunami that a larger dislocation is better in comparison with one of the seismological model to explain the tsunami. The same tendency is also expected for this case.

Concluding remarks

1. From this numerical model some interesting facts are obtained for the radiation of the tsunami on the shelf. An energy concentration toward the outer sea is obtained near the center line. The small deviation from the center line is explained with a unilateral propagation of the rupture and the finite velocity. A decrease of the amplitude with distance is approximated with one dimensional propagation for $r<0.7L$, in which r and L represent the distance from the fault and fault length, respectively. On the other hand that for $r\geqq 0.7L$ is approximated with two dimensional one.

2. A uniform dislocation model is applicable for a tsunami generation. The local distribution of the inunduation height is not contradict with the fault length of the seismological model.

3. It was shown to be a possibility for us to compare the computation with the observation in Japan, which was obtained for a long distance of one and two thousand km from the source area.

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References

1) Abe, K., 1977, A static fault model consistent with the tsunami generation of the

Niigata earthquake of 1964, Bull. Nippon Dental Univ., General Education, vol. **6**, 33–48.

2) Ben-Menahem, A., and M.N. Toköz, 1963, Source mechanism from spectrums of long-period surface waves 2. The Kamchatka Earthquake of November 4, 1952, J. Geophys. Res., vol. **68**, 5207–5222.

3) Honda, H. and K. Nakamura, 1951, The waves caused by one-dimensional deformation of the bottom of shallow sea of uniform depth, Sci. Rep. Tohoku Univ., Ser. 5, Geophysics, vol. **3**, 133–137.

4) Hwang, L.S. and D. Divoky, 1970, Tsunami generation, J. Geophys. Res., vol. **75**, 6802–6817.

5) Kanamori, H., 1976, Re-examination of the earth's free oscillations excited by the Kamchatka earthquake of November 4, 1952, Phys. Earth Planet. Inter., vol. **11**, 216–226.

6) Mansinha, L., and D.E. Smylie, 1971, The displacement fields of inclined fault, Bull. Seismol. Soc. Amer, vol. **61**, 1433–1440.

7) Savarensky, E.F., V.G. Tischenko, A.E. Sviatlovsky, A.D. Dobrovol'sky and A.V. Zhivago, 1958, The tsunami of 4–5 November 1952, Bull. Council Seismology Acad. Sci. USSR, No. **4**, 1–60 (in Russian).