OBSERVED AND CALCULATED SHORT-PERIOD *PKIKP/PKP1* AMPLITUDE RATIO

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Резюме: *Сделано сравнение отношений амплитуд короткопериодных волн PKIKP и PKP1 от глубоких землетрясений Тонга, записанных сейсмической стацией KHC, с соответствующими теоретическими величинами, рассчитанными для вероятной геометрии зоны субдукции в районе Тонга и модели PREM. Наблюденные и рассчитанные величины дают количественно хорошее согласие. Обсуждается влияние вариаций периодов T и уклона λ на величины рассчетных амплитуд PKIKP и PKP1.*

Summary: *The ratio of short-period PKIKP and PKP1 amplitudes of deep earthquakes in the Tonga region observed at the seismological station KHC is compared with the theoretical ratio computed for the probable geometry of the Tonga subduction zone and the Preliminary Reference Earth Model. Quantitatively good agreement of observed and calculated values was attained. The influence of the period of the signal and of a broad range of the source parameter rake on the calculated PKIKP/PKP1 amplitude ratio is investigated.*

1. INTRODUCTION

In paper [1] we compared the theoretical ratio of short-period *PKP1* and *PKP2* amplitudes with the observed amplitude ratio at station CLL for deep foci in the Tonga region. The theoretical ratio was calculated for the PREM model [2] and the double-couple radiation pattern corresponding to the supposed geometry of the Tonga slab. Qualitatively good agreement of observed and theoretical ratios as a function of epicentral distance was found in both the level and the slope of the ratio for the source parameters within their presumed ranges.

Both *PKP1* and *PKP2* waves bottom in the outer Earth's core with a relatively high value of the *P*-wave quality factor *Q*. The *PKIKP* waves reach the inner core where the *Q* factor is low. It was therefore of interest to compare the theoretical and observed amplitude ratios for *PKIKP* and *PKP1* short-period waves. The observed amplitude data were taken from station KHC.

The first part of this contribution deals with the comparison of the theoretical and averaged observed *PKIKP/PKP1* amplitude ratios of deep earthquakes in the Tonga region. The double-couple radiation pattern corresponding to the likely geometry of the Tonga slab was considered [3] with two fixed values of rake $\lambda = 45°$ and $\lambda = 135°$.***)

In the second part we study the influence of the rake which cannot be derived directly from the slab geometry but can, in some cases, strongly affect the investigated ratio.

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2. COMPARISON OF THEORETICAL AND OBSERVED *PKIKP/PKP1* AMPLITUDE RATIOS

The zero-order approximation of the ray theory was used to obtain the theoretical amplitudes. More details about the calculation and the model parametrization can be found in [1, 2, 4]. Due to the caustic and diffraction effects, the amplitudes of the *PKP1* waves were only computed in the distance range D from 145° to 151°.

The foci used in this study are located in the same part of the Tonga slab as are those in [1]. This fact together with the negligible azimuth difference from the Tonga region to KHC and CLL ($<2°$) allowed us to use the same average source parameters and their possible ranges as in [1], i.e. dip $\delta = 45° \pm 7°$, strike $\Phi_S = 225° \pm$ $\pm 10°$ (measured from the direction to station KHC instead of to the north) [3] and two values of rake $\lambda = 45°$ and $\lambda = 135°$. The depth range of 56 events used is 422–650 km, the average depth being 572 km. For the computation, this value was rounded off to 550 km as in [1].

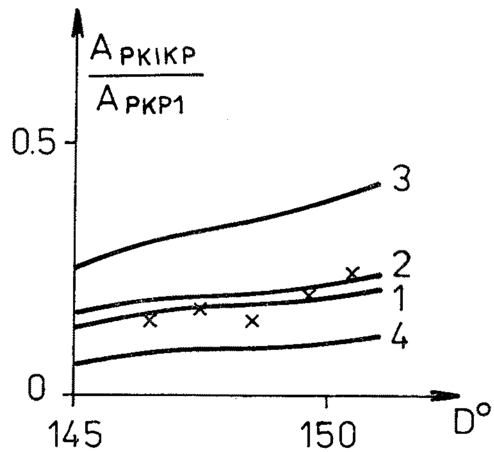

Fig. 1. Comparison of theoretical curves and averaged observed values (crosses) of short-period *PKIKP/PKP1* amplitude ratios. The comparison relates to deep foci in the Tonga region and station KHC. Individual observed ratios were averaged in the distance interval of 1°. Parameters of calculation for the individual curves: 1 — rake $\lambda = 45°$, strike $\Phi_S = 225°$, dip $\delta = 45°$, depth $h = 550$ km, period $T = 1{\cdot}2$ s. 2 — $\lambda = 135°$, other parameters as for curve 1. 3 — $T_{PKIKP} =$ $= 1{\cdot}6$ s, $T_{PKP1} = 1{\cdot}2$ s, other parameters as for curve 1. 4 — $T_{PKIKP} = 1{\cdot}2$ s, $T_{PKP1} = 1{\cdot}6$ s, other parameters as for curve 1. D denotes the epicentral distance.

The periods T of the observed *PKIKP* as well as *PKP1* waves vary from 1·0 to 1·6 s with the prevailing value of 1·2 s for both waves. In one third of the events, the periods of both waves were the same. In other cases, the difference $T_{PKIKP} - T_{PKP_1}$ lies between $-0{\cdot}2$ to $0{\cdot}4$ s.

The theoretical ratio of the *PKIKP* and *PKP1* amplitudes was calculated first for both values of λ under the assumption that the parameters dip, strike, depth and period equalled their average values. Both average curves (curve 1 for $\lambda = 45°$, curve 2 for $\lambda = 135°$) are compared in Fig. 1 with the averaged observed values (depicted by crosses) obtained at station KHC by averaging the individual observed amplitude ratios at distance intervals of 1°. The individual observed ratios display a larger scatter and lie between the minimum value 0·075 and the maximum value 0·428 considering the whole investigated distance range. Curve 1 fits well the averaged observed value, curve 2 lying only slightly above curve 1.

The theoretical ratio changes by varying the individual parameters in their assumed ranges. The influence of the dip, strike and depth on the ratio is very small (keeping all other parameters in their average values), the increase or decrease not exceeding $\pm 0{\cdot}015$ for both values of rake. The joint influence of these three parameters does not exceed $\pm 0{\cdot}04$.

The period T exhibits a larger influence on the theoretical ratio due to different attenuation. For example, by using period $T = 1{\cdot}6$ s for both waves, the increases may amount to as much as 0·047. An even more pronounced influence on the ratio is obtained by using different periods for *PKIKP* and *PKP1* waves. Curve 3 in Fig. 1 represents the example of $T_{PKIKP} = 1{\cdot}6$ s and $T_{PKP}1 = 1{\cdot}2$ s, curve 4 demonstrates the opposite case, i.e. $T_{PKIKP} = 1{\cdot}2$ s and $T_{PKP}1 = 1{\cdot}6$ s ($\lambda = 45°$ for both curves). The difference in the level of curves 1 and 3 is 0·208 and thus curve 3 deviates significantly from the average observed ratios of the *PKIKP* and *PKP1* amplitudes. But curve 3 as well as curve 4 still lie within the scatter of individual observed ratios.

The above-mentioned small influences of the dip and strike on the theoretical amplitude ratio are connected with their narrow ranges which were adopted for the computation. Generally these two parameters can affect the ratio in a more pronouned way which is partly demonstrated in the next section.

3. THEORETICAL AMPLITUDE RATIO A FOR BROADER RANGE OF RAKE

The source parameter rake is not directly connected with the geometry of the slab. In the previous calculations we, therefore, used two fixed values of λ without considering a possible range of this parameter. To evaluate the influence of other values of rake on the theoretical *PKIKP*/*PKP1* amplitude ratio, we calculated this ratio in a broader range of λ for fixed distance $D = 148°$, period $T = 1{\cdot}2$ s and depth $h = 550$ km. The range of dip was broadened from 30° to 60° and the whole possible range of strike was used in this calculation. Only absolute values of the amplitude ratio are considered.

The identity of the amplitude ratio for $\lambda = \alpha$ nad $\lambda = \alpha - 180°$ allows the calculation to be restricted to the interval $0° \leqq \lambda \leqq 180°$. Further, there is the symmetry of the amplitude ratio in this interval relative to the strike for $\lambda = \alpha$ and $\lambda = 180° - \alpha$ with the axis of symmetry at $\Phi_S = 90°$ and 270°. Thus, the amplitude ratio was only calculated in the interval $0° \leqq \lambda \leqq 90°$. The resultant theoretical amplitude ratios are shown in Figs. 2–4 for dip values $\delta = 30°$, $45°$ and $60°$, respectively. The value of rake is used as the parameter of the individual curves. However, each curve also represents the ratio for the symmetrical value of the rake $\bar{\lambda} = 180° - \lambda$ ($\bar{\lambda}$ is given in brackets). For $\bar{\lambda}$, the lower coordinate values along the $\bar{\Phi}_S$-axis must be taken.

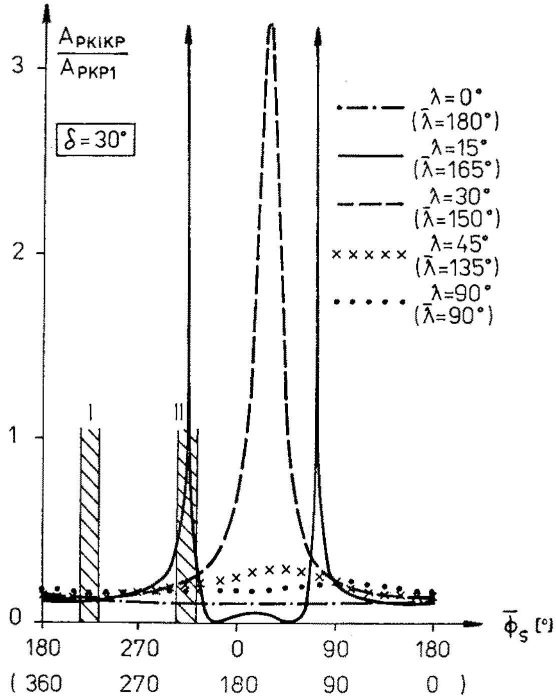

Fig. 2. Theoretical short-period A_{PKIKP}/A_{PKP1} amplitude ratio as a function of $\bar{\Phi}_S$ for different values of rake $\lambda.D = 148°$, $h = 550$ km, $T = 1{\cdot}2$ s, $\delta = 30°$. The lower $\bar{\Phi}_S$ scale is valid for $\bar{\lambda}$ (see text).

For all three values of the dip, the amplitude ratio curves as the function of strike exhibit similar features, i.e. with increasing λ the form of the curves changes from flat to a curve with one to two sharp high maxima and again to flat. The value of the dip affects the shape of the curves, too. For example, see the different shapes of the curves for $\lambda = 30°$ obtained for $\delta = 30°$ and $45°$ or, on the other hand, similar shapes of the curves for $\lambda = 15°$, $\delta = 30°$ and $\lambda = 7{\cdot}5°$, $\delta = 60°$. The two sharp maxima can occur only in the strike range of $\bar{\Phi}_S$ 90°–270° for $\bar{\lambda}$ or 270°–90° for λ.

But we have to keep in mind that the high maxima of the amplitude ratio curves are obtained only for those rays coming to the receiver as *PKP1* waves which lie close to the minimum of source radiation. Dure to a small difference in the take-off angles of the *PKP1* and *PKIKP* waves (about 0·089 rad in our case), also the *PKIKP* amplitudes are small. Therefore, for these relatively small amplitudes of both waves to be observed, higher magnitudes are necessary.

In Figs. 2–4 the ranges of strike $\bar{\Phi}_S$ adopted for the Tonga region and station KHC are depicted by the hatched area I for rake λ and by hatched area II for rake $\bar{\lambda}$. The theoretical amplitude ratios are small and almost constant in area I for all values of λ.

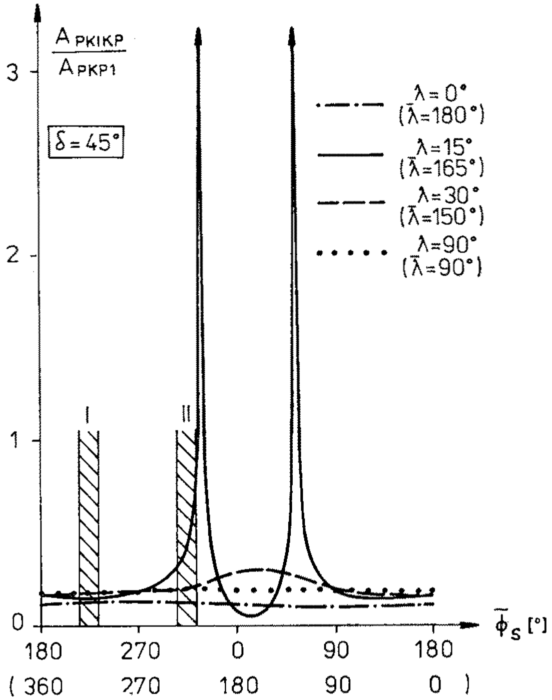

Fig. 3. Theoretical short-period A_{PKIKP}/A_{PKP1} amplitude ratio as a function of $\bar{\Phi}_S$ for different values of rake $\lambda . \delta = 45°$, other parameters as in Fig. 2.

Moreover, the theoretical ratios are close to the averaged observed ratio of about 0·17 (see Fig. 1). In area II, for the range of rake $\bar{\lambda}$ 160°–173° (depending on δ) considerably higher values of the theoretical ratio are obtained, which can even exceed the maximum observed individual ratio 0·428 mentioned in the previous section. For such $\bar{\lambda}$, the source radiation may be responsible for higher observed amplitude ratios besides the effect of different periods of *PKP1* and *PKIKP* waves discussed in Section 2. The occurrence of a very high amplitude ratio observed at station KHC (provided the periods of both waves are almost the same) should indicate that the rake is in the interval 160°–173°.

4. CONCLUSION

In the present paper, the ratio of *PKIKP* and *PKP1* short-period amplitudes of deep earthquakes in the Tonga region, observed at station KHC, was compared with the theoretical ratio computed for the Preliminary Reference Earth Model. The radiation pattern corresponding to the supposed Tonga slab geometry was used. Quantitatively good agreement of theoretical and averaged observed ratios was found in the investigated epicentral distance range for two values of rake used already in

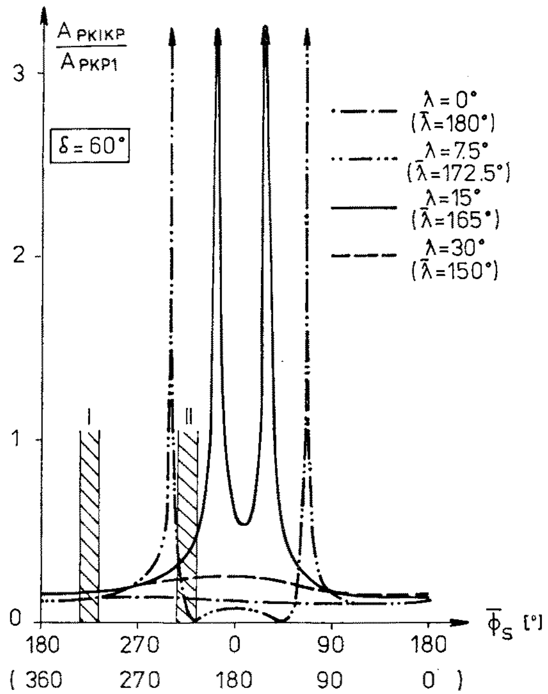

Fig. 4. Theoretical short-period A_{PKIKP}/A_{PKP1} amplitude ratio as a function of $\overline{\Phi}_S$ for different values of rake $\lambda . \delta = 60°$, other parameters as in Fig. 2.

[1]. The difference in the periods of the *PKIKP* and *PKP1* waves for the same event strongly affects the theoretical ratio due to the dependence of attenuation on period and, therefore, can account for the wide scatter of the individual observed amplitude ratio. Higher values of individual observed ratios could be further explained by the relatively pronounced differences in radiation for the *PKIKP* and *PKP1* waves provided the values of rake lie in the interval 160°–173°. According to ISC fault plane solutions [5], such values of rake were determined.

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