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最適スペクトル曲線を与える津波の陸棚への入射角

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要旨

津波の来る方向を指定する量が入射角である。これは一般の種々の波と同様，波の法線すなわち波面に直角な方向と，境界面の法線とのなす角度で定義される。スネルの法則によると，2つの異なる媒質つまり波の速度の異なる媒質の境界では，波の進行方向は屈折し，その角度は入射角と両媒質の速度比に関係する。津波は長波理論によって，その速度は$\sqrt{gh}$で近似される。ここでgは重力加速度，hは静水時の水深である。海では一般に海岸に近い程浅いので，速度は小さくなる。速度が小さくなるとスネルの法則から屈折角は小さくなる。こうして津波は海岸に近づくとともに入射角は小さくなり，波線の方向は海岸の法線方向に近づく。津波にくらべ波長の短かい水の波でも，海岸近くでは水深が小さくなり，長波近似が成立し，同様のことがおこる。このことは海岸にうち寄せる波を航空写真で撮るとはっきりわかる。このように入射角は海岸近くでは刻々変化し，一定値として定義するのは困難である。しかし外洋のように一定水深の所では速度は一定で進行方向は不変である。このような所では入射角は一定量として明確に定義できる。ここでは一定水深の外洋から，一様に傾斜した陸棚に津波が入射する場合を考え，これに対する計算結果から入射角の影響を考え，観測結果との比較において最適な計算結果を与える入射角を決める。

阿部・石井（1980）によれば，平らな陸棚が一様に傾斜したすそ野をもって，平らな外洋につながっている海底断面を考えた時，これに対して外洋から一定の入射角で単位振巾の正弦平面波を入射させ，海岸での長波の振巾スペクトルを解析的にもとめることができる。そこでこのスペクトルの形が入射角によって変化することを利用して，これと観測さ

れたスペクトルの包絡線との比較から最適な曲線を与える入射角を決める。どれが最適かの判断は両者間の相関係数によって決める。この方法を1964年新潟地震津波の江差・岩崎・三国の3点の観測結果に適用して入射角を決めた。計算のもとになるパラメーターは，それぞれの観測点についてその付近の海図を参考にして決めた。入射角を仮定して計算したスペクトルと観測結果の間で相関係数を求め横軸に入射角，たて軸に相関係数をプロットした。これによると上に凸の曲線が得られ最大値が1個求まり，これに対応する入射角が1個決まる。この値は江差で5°，岩崎で65°であって，波源から遠い程入射角が小さくなるという，屈折図から求めたものと傾向が一致している。又三国では82°で入射角はかなり大きく求まる。屈折図を利用して作図から求める方法では，作図の出発点として波源がわかっていなければならないが，この場合はその必要がない。又この方法は観測スペクトルを説明する最適モデルを決めるという立場からも有用である。

Incident angle identification from the spectrum for a tsunami invasion to the shelf

Abstract

Spectra were obtained at Esashi, Iwagasaki and Mikuni for the 1964 Niigata earthquake tsunami. They were compared with the spectra calculated on a linear sloping model of shelf. The similarity between the two spectra was estimated from a correlation coefficient. The maximum value of it versus incident angle in the model makes it possible to identify an incident angle. It is useful to discriminate the best fit model with an appropriate incident angle in applying a linear sloping monel.

Introduction

When a wave arrives at a boundary dividing into two media with different velocities, it is reflected and refracted. As for the refraction it is well known that Snell's a law holds good between incident angle and refraction one. The refraction in the multi-layered media is approximated with a repetition of it for two different media. Since a tsunami is a kind of long waves propagating in the sea, the velocity is approximated with the relation of

$$v=\sqrt{gh}$$

in which g is an acceleration due to gravity and h is a sea depth. In this case differences of velocity are due to differences of a sea depth. When a tsunami propagates toward the coast, it is refracted because of shoaling. An incident angle becomes smaller with a wave approach to the coast. Generally an incident angle is constant for the sea of an even bottom but is variable for the sea of an uneven one.

Recently Abe and Ishii (1980) dealt reflection and refraction for a linear sloping model between two flat regions and analytically showed the amplitude ratios as functions of incident angle and period for an invasion of sinusoidal plane wave. They calculated the spectra expected at Onahama in north east Japan and compared it with one observed in the 1952 Kamchatka tsunami. It was shown that the observed spectra were well approximated with the computed ones. Since the depth of outer sea is assumed to be constant in their model, an incident angle is given as a constant value. Therefore, their model is very useful to discuss the effect of an incident angle to the observed spectra. The method to identify an incident angle will be obtained by calculating the correlation coefficient between the spectra observed and one calculated. It is applied to the case of the 1964 Niigata earthquake tsunami.

Observed spectra

The tsunami accompanying the Niigata earthquake of June 16, 1964 was observed at many observation points which face to the Sea of Japan. Three distant points were used for a spectral analysis among them. Those are Esashi, Iwagasaki and Mikuni from north to south. The former two points belong to Japan Meteorological Agency and the latter one does to Geographical Survey Institute. The time histories of sea level were obtained with the same amplitude ratio of 0.10 and the same time scale of 2cm/hour. The original histories were digitized from an initial arrival of the tsunami to 6 hours after its arrival without eliminating a daily tide. The digitation was carried out with a x-y reader resolvable into 0.01 inch and the time histories punched out in the paper tape were analyzed into spectra with Goertzel method. The period spectra were obtained for the components from 10 to 50min. The results are shown in Fig. 1.

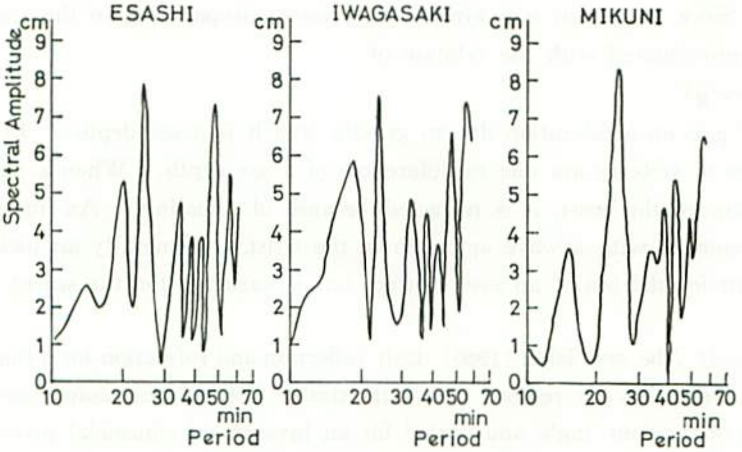

Fig. 1 Spectra observed at Esashi, Iwagasaki and Mikuni for the 1964 Niigata tsunami.

Calculation on a linear sloping model

A linear sloping model by Abe and Ishii (1980) was used for obtainning an expected spectrum and it is illustrated in Fig. 2. The model consists of a flat shelf in width of l, depth of h_1 with a linear slope in dip angle of θ and a flat outer sea in depth of h_3. Their method makes us possible to calculate an ampli-

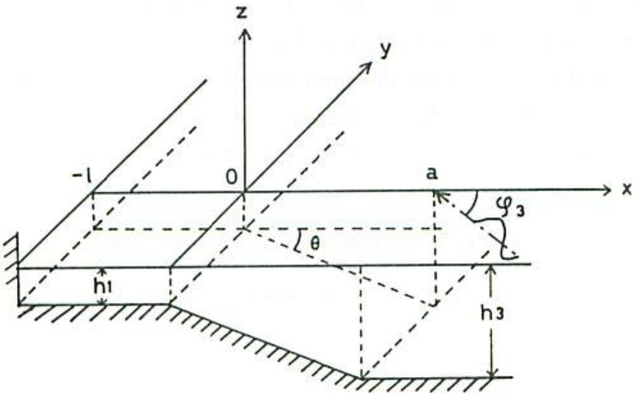

Fig. 2 Geometry of a linear sloping model after Abe and Ishii (1980).

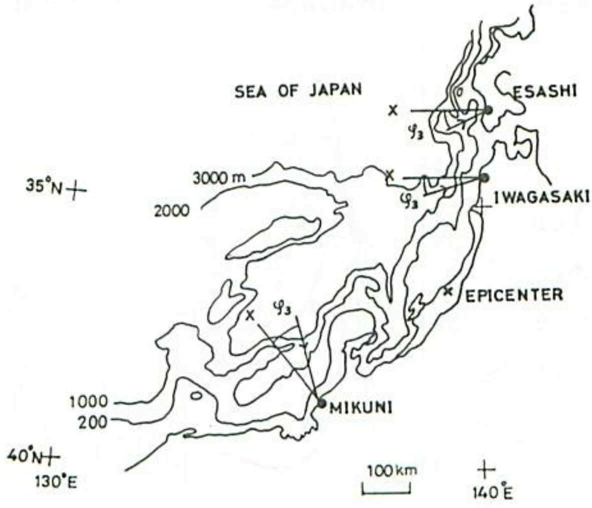

Fig. 3 Shelf topography of the Sea of Japan.

Solid straight lines indicated over the shelf correspond to x axis of the model. Incident angles are assumed as the illustration in taking account of the direction of epicenter.

tude ratio at the coast ($x=-l$) to the incident wave as functions of period and incident angle.

The topography is shown in Fig. 3 for the shelf of the Sea of Japan. When a linear sloping model is applied to this topography, it is necessary to assume x direction of the model. The directions are indicated as x axes in the figure. An incident angle is assumed to be which is measured from x axis toward the epicenter for each observation point. Parameters of the model are determined as they represent a cross section of the sea bottom under the x axis. The shelf parameters thus determined are listed up in Table 1. Using these parameters amplitude ratios were calculated for three models and are shown against period in Fig. 4. It is found from this figure that the amplitude ratios decrease and the resonance periods move to the left with an increase of incident angle. It is possible to identify an incident angle consistent with the observed spectrum since the curve

Table. 1 Parameters used in the model

	h_1 (km)	h_3 (km)	l (km)	$\tan\theta$
Esashi	0.15	1.4	10	0.27
Iwagasaki	0.15	2.6	10	0.054
Mikuni	0.40	3.0	43	0.022

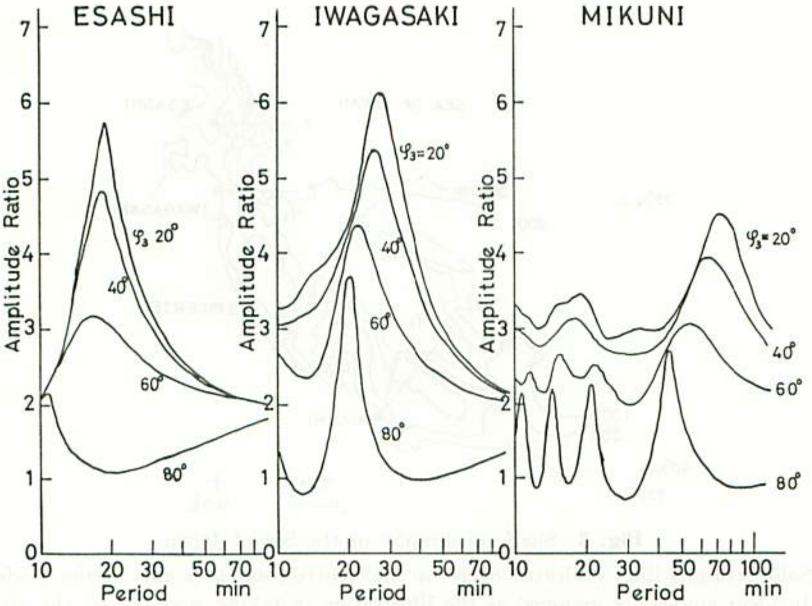

Fig. 4 Calculation on the model

changes in the form with variation of incident angle. As the incident wave amplitude is an unknown factor, an absolute value of amplitude is not obtained from calculation. So it is impossible to compare the observed amplitude with the calculated one directly. But we can discuss a correlation coefficient between the observed amplitude and the calculated ratio since it is a constant for any incident amplitude.

Identification of an incident angle

The amplitude ratio is obtained for a unit amplitude of an incident wave with each period component. On the other hand the incident wave in observation has an original spectral component. It is well known that each tsunami has a different

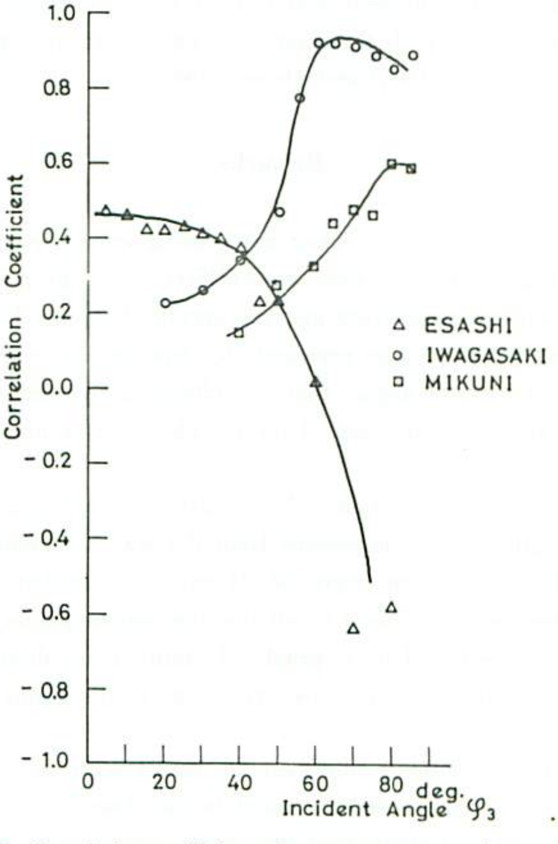

Fig. 5 Correlation coefficients between spectrum observed and one calculated against incident angle assumed.

spectrum characteristic of each generation mechanism. The observed spectrum is approximated to be a product of the original spectrum and the shelf response. The latter is obtained in calculation. In observation a notable peak is found in the period component of 24 min for all the points. It is difficult to consider that the spectral peak was caused by the shelf response. It is rational to be due to the generation mechanism. So it is necessary to exclude this component hereafter. All the other components in observation are assumed to be due to amplification by shelf response and have an equal amplitude component as the incident wave. Thus we can discuss the correlation relation between some observed spectral peaks except the original component of 24 min and the calculated amplitude ratios. The coefficients were calculated and showed against incident angle in Fig. 5. It is reasonable to identify the maximum value as an incident angle. The value is determined to be 65°±5° with a high accuracy for Iwagasaki. The coefficients are found for incident angles of 5°±5° in Esashi, 82°±2° in Mikuni. The deviation added is taken from a decreasing condition of coefficient to 0.01 for convenience. These solutions are qualitatively consistent with the graphical ones from the refraction diagrams by Watanabe (1964), Iida (1965) and Hatori (1965).

Remarks

1. It is possible to identify an incident angle using an incident angle dependence of the amplitude spectrum. One of identifications is the maximum correlation between the observed spectrum and the amplitude spectral ratio calculated on a linear sloping model. The resoluvability depends on a sensitivity of the curve calculated to an incident angle, that is a changing rate against incident angle. It is inferred from a comparison of the calculated curve of Iwagasaki with one of Esashi.
2. Comparison between observation and calculation in spectrum is useful to discriminate the original wave components from the wave components amplified on the shelf. The component wave of 24 min is considered to be due to an original one because it is found in all the observation points.
3. This method is better than a graphical solution in obtainning an incident angle without determining the wave origin and in discussing the value quantitatively.
4. It is useful to discriminate the best fit model with an appropriate incident angle in applying a linear sloping model to the observation.
5. The assumption of a straight coast line is reasonable for a long period component of spectrum but is less reasonable for a short one. Accordingly the

more accurate identification is expected with increase in period of spectral peak in calculation.

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