SURFACE WAVE PHASE VELOCITY DISTRIBUTION OF TURKEY

Taciser ÇETİNOL* **Supervisor: Kazunori Yoshizawa****
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ABSTRACT

The crustal and upper mantle structure beneath Turkey is investgated by using phase velocity of fundamental-mode Rayleigh waves working with a two-station method. We used vertical component seismograms of 72 broad-band seismic stations in Turkey and surrounding areas from 172 teleseismic events from April 2005 to June 2007. The average dispersion curve of the entire region of Turkey is estimated from path-average dispersion curves in a period range from 20 to 160 s. The average phase velocity of Turkey is found to be about 3-9 % slower than the global average even if we consdier a crustal correction for Turkey. We generate path coverage maps as a function of frequency indicating the path-specific phase velocity with colors, and perform two kinds of analysis using the paths with high accuracy to clarify the regional variations of phase velocity in Turkey. Both the phase velocity coverage maps and two studies on localized phase velocity distributions indicate that the fastest phase velocities are observed in the north-western part of Turkey (i.e., the Marmara Region) and the phase speed becomes slow in the eastern part of Turkey. We may explain the observed fast phase velocities in the northwestern part of Turkey by the cooling of the upper mantle, which can affect the immersion of oceanic lithosphere of the Black Sea beneath southward margin of the Marmara region and the slow phase velocities in the eastern Turkey by the presence of conjugate strike slip fault system (EAFZ) and Bitlis thrust zone as well as partially molten litospheric mantle which can be inferred from the wide spread of young volcanism (< 2Ma). The previous geological (i.e. heat flow, volcanism and tectonics) and seismological (i.e. Pn-wave velocity distribution, Sn-wave attenuation) studies strongly support our results.

Keywords: Surface waves phase velocity, crustal and upper mantle structure of Turkey

INTRODUCTION

Turkey is located in the Alpine- Himalayan earthquake zone at the Eurasian Geological Plate which causes the numerous destructive earthquakes. The tectonic framework of Turkey is controlled by the northward motion of Arabian Plate against Eurasian Plate which contributes the westward motion of Turkey towards the African Plate (McKenzie, 1972). Turkey accommodates a wide variety of tectonic processes such as major strike slip faults (the North Anatolian Fault Zone –NAFZ & the East Anatolian Fault Zone –EAFZ), continental collision (EAFZ), continental extensions (Western Turkey Graben Complex, Marmara sea) (Ketin, 1969; McKenzie, 1972; Barka and Reilinger, 1997; McClusky et. al., 2000). Turkey has a high level of seismicity due to these tectonic activities and has suffered from noteworthy loses of life and property as a result of earthquakes in its long history. Many researchers (e.g. Canıtez and Toksöz , 1980; Horasan et al., 2002; Gök et al., 2003; Barış et al., 2005; Zor et al.,2006) investigated the different parts of the Turkey using various types methods, only several structural studies were completed for the entire Turkey (e.g. Midevalli and Mitchell, 1989; Villasenor et al, 2001; Al-Lazki et al, 2004; Maggi and Priestly 2005). In this study, we investigate

* Kocaeli University, Engineering Faculty, Department of Geophysical Engineering, Kocaeli, TURKEY
** Hokkaido University, Graduate School of Science, Department of Natural History Sciences, Sapporo, JAPAN

the phase velocity distribution of the fundamental-mode Rayleigh waves to clarify the regional variations of the crust and uppermost mantle beneath Turkey.

DATA and METHOD

The seismograms are retrieved from broad-band seismic stations of the Boğaziçi University Kandilli Observatory and Earthquake Research Institute (KOERI). The locations of the 72 broadband seismic stations (66-KOERI, 2-IRIS, and 4-GEOFON) are given in Figure 1.

The stations of the KOERI consist of the Guralp product seismometers (CMG 3TD-3ESPD-6T-40T). The stations of the IRIS and GEOFON include STS type (STS1 and STS2) seismometers. In this study, vertical component seismograms of each station are used.

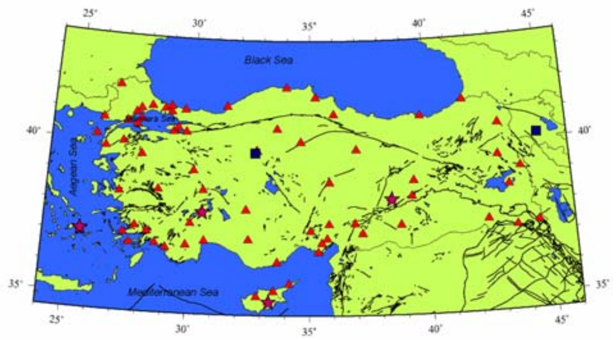


Figure 1 The locations of the broadband seismic stations (the red triangles: KOERI stations-KO, the blue squares: IRIS stations-IU, the violet stars: GEOFON-GE).

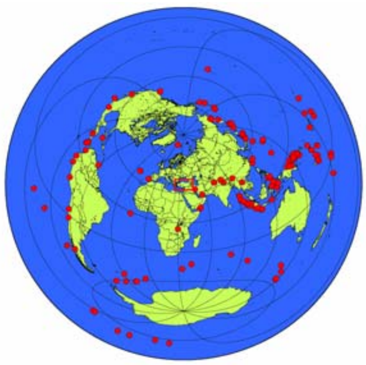


Figure 2 The distribution of the events (red circles). The red frame indicates Turkey and surrounding area

We employed 172 events with moment magnitude greater than 6.0 and focal depth shallower than 100 km which occurred in the world between April, 2005 and June, 2007 (Figure 2).

In this study, we estimate the dispersion of the Rayleigh waves employing two-station method that is one of the most classical but useful technique to determine regional variations of surface-wave phase velocities, which should be of great help to delineate the crust and upper mantle of Turkey. We employed the phase difference aproach (Dziewonski and Hales, 1972) to determine the phase velocity of the fundamental mode Rayleigh waves.

We can summarize the automatic procedures for data processing in the four steps as follows;

1. In the first step, the instrument responses are corrected so that the effect of the instrumental phase shift of each station can be eliminated.
2. In the second step, a proper time-window for the fundamental-mode Rayleigh wave is chosen by using theoretical arrival times based on a range of group velocities between 2.6 km/s and 5.1 km/s.

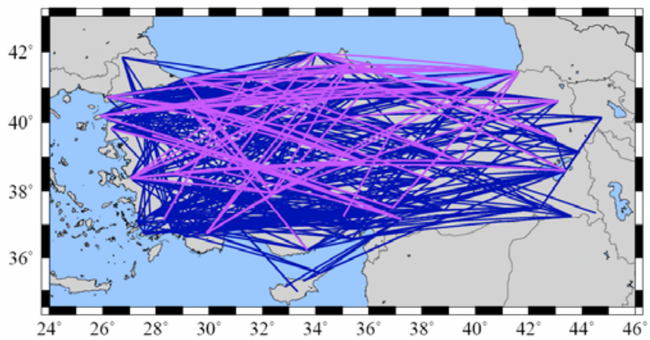


Figure 3 The distribution of the paths which are obtained using two-station approximation. The used profiles are overlapped on the retrieved profiles using lilac color.

3. A list of station-pairs located on or near a common great circle path are created. The phase speed for each station-pair is then calculated as a function of frequency from unwrapped phases of two stations based on a great circle approximation.
4. In the final step, we check the results visually and choose a proper frequency range in which the calculated dispersion curve is smooth enough with smaller variance.

It should be noted that phase velocity measurements for two closely located stations exhibit significant errors in the longer period for which the scale of wavelength is close to the propagation distance. On the contrary, for the excessive long distance paths between two stations, the dispersion curves may be affected significantly by 2π ambiguities in phase cycles. To obtain satisfactory results based on a plane-wave approximation, the station pairs should not be too close nor too far.

Although 687 great circle paths for station pairs can be derived from 172 events, only 104 dispersion curves are employed to construct the average dispersion curve of turkey in the next section. The numbers of the events and the paths are given in table 1. The distribution of all the analyzed paths as well as employed paths are shown in Figure 3.

Table 1 The distribution of the paths against to years.

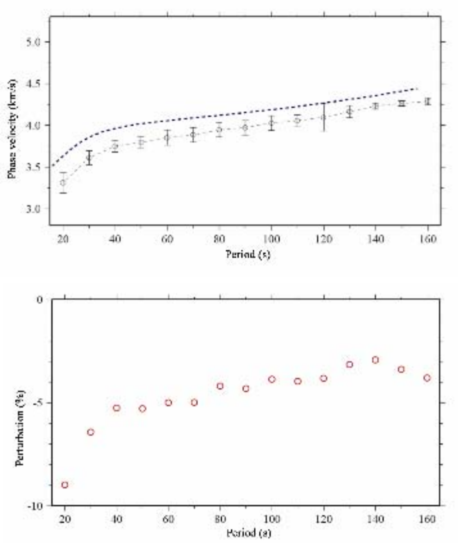
Year	Total events	Employed events	Total dispersion curves	Employed dispersion curves
2005	71	--	63	--
2006	61	6	220	13
2007	40	13	404	91
April 2005 - June 2007	172	19	687	104

The stability and reliability of the two-station measurements depends on the distance between the stations and the wavelength of surface waves to be considered. Moreover, the impacts of non-plane waves on two-station measurements may not be neglected. The non-plane waves may affect observed seismograms as a summation of the plane waves propagating with a variety of amplitudes and directions.

RESULTS AND DISCUSSION

Average dispersion curve of Turkey

To determine the average phase velocity of the entire Turkey, we first calculate the moving averages of phase velocity for a single dispersion curve in a frequency domain. Then, the average phase velocities of the entire region of Turkey as well as corresponding standard deviations are estimated from all the averaged dispersion curves. The average dispersion curve of Turkey is shown in the Figure 4a between 20 and 160 seconds of periods. The perturbation of the average velocity dispersion from a global average model is also calculated (Figure 4b). The reference global average model is created using PREMC (a modified version of PREM (Dziewonski & Anderson, 1981) to better represent the continental structure) for the mantle structure and 3SMAC model (Nataf & Ricard, 1996) for the crustal structure of Turkey.



(a)

(b)

Figure 4 Comparison of the average velocity dispersion curves of Rayleigh waves
(a) Dashed blue line : Global model velocity (PREMC and 3SMAC), Black circles and error bars: Average phase velocity of Turkey (this study).
(b) Perturbation of the average phase velocity of Turkey from PREMC

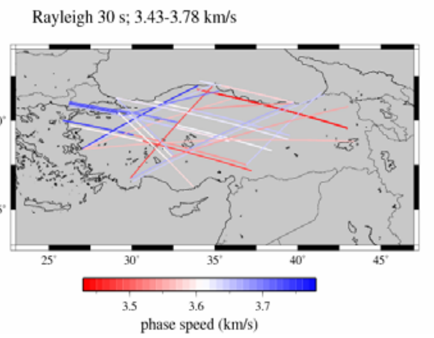
The average phase velocity of Turkey is slower than the global average with perturbations of about 3 - 4 % at period over 100 seconds, 4 - 6 % at 30 - 100 seconds and about 9% at 20 seconds (Figure 4b). Previous studies reveal that the average velocity of entire Turkey is significantly slower than the global average. Global and large scale phase velocity (Ekstrom et al, 1997, Villasenor et, al, 2001) and shear wave velocity (Debayle et al, 2001, Maggi, A., and Priestley, K., 2005) studies support our result.

Phase speed distribution of Turkey

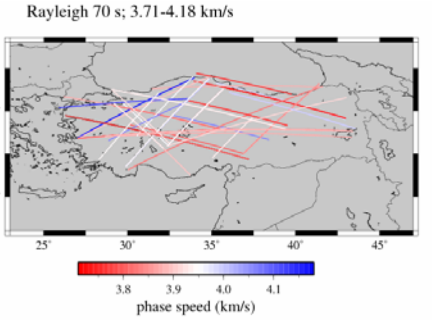
Now we investigate regional variations of the Rayleigh wave phase velocity distribution over Turkey. We observe that the majority of the obtained dispersion curves tend to be more stable (less scattered) in the period range between 20 and 160 s.

For this period range, the fundamental mode Rayleigh waves are mainly sensitive to the depth of the crust and uppermost mantle of the earth (i.e., approximately 30 - 300 km depth) reflecting the shear wave structure of the upper mantle beneath Turkey.

Two examples of surface wave paths at 30 s and 70 s of periods are presented in Figures 5a and b respectively, indicating the path-average phase velocity using colors. A general feature of the phase velocity distributions is that the phase velocity is apt to decrease from the west to east. The highest phase velocities are observed in the northern part of Turkey; i.e., the Marmara Region. The phase speed in east Turkey becomes slow. The number of paths in the southern margin of Turkey is not sufficient to make an accurate estimation. However, this area seems to be slower than the average velocity of Turkey.



(a)



(b)

Figure 5 The path coverage of Rayleigh waves phase speed distribution (a) at 30 s (58 paths), (b) at 70 s period (49 paths).

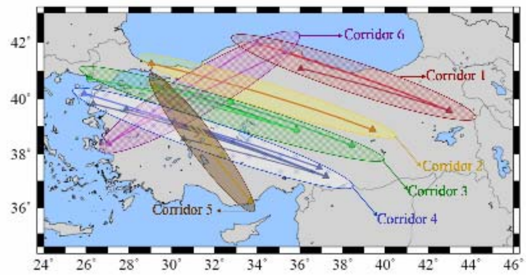
Regional variations of Rayleigh-wave phase velocity

Here we investigate the regional variations of phase velocity using the paths with high accuracy. To examine regional variations of the phase speed, we divide Turkey into some regions depending on the numbers of available paths. We have performed two kinds of analysis; i.e., study-1 and study-2 as follows.

Study-1: Phase dispersion in 6 corridors over Turkey

In the study-1, we selected the some stable velocity profiles which contain highly reliable dispersion curves and created 6 corridors of Rayleigh wave paths (Figures 6). The Corridors 1 to 4 have NW-SE trend and are aligned from north to south. The Corridor-5 is extending NNW-SSE direction traversing western Turkey. The Corridor-6 is extending NS-SW in an almost perpendicular direction to the others. The phase speeds of the Corridor-1 (northeast Turkey) and Corridor-4 (southwest Turkey) are the slowest among the 6 corridors, whereas the phase speed of corridor-6 (northwest part of Turkey) displays the highest phase speed. The dispersion curve for the Corridor-5 shows almost the same velocity as the average phase velocity of Turkey.

In Figure 6b, we can see a monotonically increasing trend of phase speed dispersion from 20 s to 40 s for all the Corridors. However, the Corridor-2 change its characteristics of the dispersion curve and show low phase speed anomaly in the period range over 40 s. We may expect that shear wave speeds of the upper mantle beneath this corridor may have a low velocity zone at about 60-100 km depth. The dispersion curve for the Corridor-3 shows relatively steady phase speeds at the period over 40 s, and is closer to the



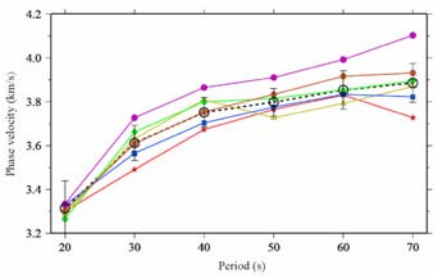


Figure 6 study-1

(a) Selected 6 corridors of Rayleigh-wave paths,

(b) Average phase velocities of the 6 corridors.

Red line and stars: Corridor-1, Yellow line and triangles: Corridor-2, Green line and diamonds: Corridor-3, Blue line and squares: Corridor-4, Brown line and hexagonals: Corridor-5, Purple line and circles:Corridor-6, Black circles and error bars : Average phase velocity of Turkey (this study).

average dispersion curves of Turkey. The phase velocities of the Corridor-1 and Corridor-4 show a monotonic trend of increasing phase speed with period.

Among all the dispersion curves in Figure 6, the Corridor 6 shows the fastest phase speed at all the period. Since the direction of this corridor is totally different from (or nearly perpendicular to) the other 5 corridors, this significant fast anomaly may imply the existence of azimuthal anisotropy in the north-western Turkey, although we cannot distinguish the effects of anisotropy and heterogeneity from the current analysis with small numbers of paths. Such complicated effects should be investigated in more detail in the future.

Study-2: Phase dispersion in 3 parallel corridors

In the study-2, all the corridors have the NW-SE trend (Figures 7). Corridor-A is the same as Corriodor-1, and Corridor B and C are the new versions of the Corridor 3 and 4 of the study-1.

The fastest phase velocities are observed in the Corridor B, whereas the slowest in the Corridor A. These results show that the phase speed of the northwest margin and the center of Turkey is higher than the northeastern margin and southwest region of Turkey. The phase speed of Corridor-B located in the central part become steady in the period range longer than 40 s, indicating a small variation in shear wave speed at the depth of about 60-100 km.

We may explain the observed fast velocities in the northwestern part of Turkey (Marmara region) by the cooling of the upper mantle, which can affect the immersion of the Black Sea oceanic lithosphere beneath southward margin of the Marmara region (Gülen and Kuleli, 1995). In this region, higher Pn velocities has also been found by Horasan et al (2002).

The lowest phase velocities in the eastern Turkey can be interpreted by the presence of conjugate strike slip fault system (EAFZ) and Bitlis thrust zone as well as wide spread of young volcanism (< 2Ma). The fissure-fed mantle-derived alkaline volcanism was observed until recent times (0.4 Ma) and litospheric mantle can be observed in the fault area as the presence of alkali basalt (Yürür and Chorowicz, 1998). The evidence from previous studies such as the low Pn velocities (Al-lazki et al., 2004), high Sn attenuation (Rodgers et al, 1997; Gök et al., 2003), and geological features such as hot rising asthenosphere (Yürür and Chorowicz, 1998; Şengör et al., 2003), thin litospheric mantle (Gök et al., 2007) and high heat flow (40-140mW/m^2-Tezcan, 1995) can be strong support for the observed slow velocities in this study.

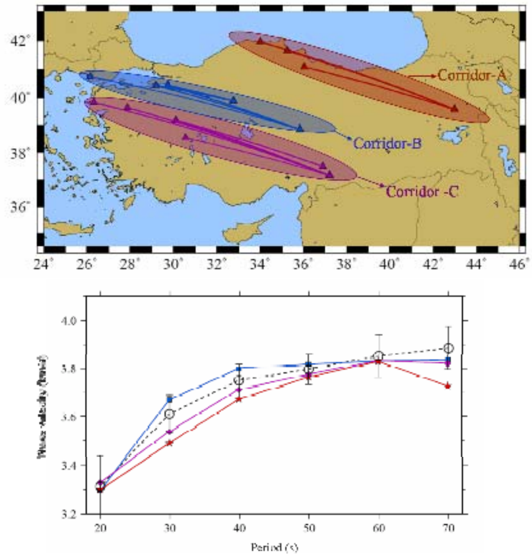


Figure 7 study-2
(a) Selected 3 corridors of Rayleigh-wave paths.
(b) Average phase velocities of the Corridor-A, Corridor-B and Corridor-C.

Red line and stars: Corridor-A, Blue line and squares: Corridor-B, Purple line and diamonds: Corridor-C, Black circles and error bars : Average phase velocity of Turkey (this study)

CONCLUSIONS

In this study, we have estimated the phase velocity distribution of Turkey using seismic records of the 72 broad-band stations located in Turkey and surrounding areas from 172 events with moment magnitude greater than 6.0 and focal depth shallower than 100 km which occurred in the world between April 2005 and June 2007. We determined 104 phase velocity dispersion curves by applying the two-station method for the vertical component of the fundamental mode Rayleigh waves.

The average dispersion curve of Turkey is created by using observed dispersion curves covering the entire Turkey, and is compared with the global average with a correction for the crustal structure of Turkey. The estimated average dispersion curve of Turkey indicates about 3-9% slower phase velocity than the global average.

We generated the phase-velocity coverage maps depending on the frequency. A general feature of the phase velocity distributions varies significantly from the west to east of Turkey. The fastest phase speed is observed in the northern part of Turkey; i.e., the Marmara Region. The phase speed becomes slow in the eastern part of Turkey.

To estimate regional variations of the phase speed, we have done two kinds of analysis using several corridors of the Rayleigh wave paths. The phase speeds of the northeastern and southwestern Turkey are determined to be slower than the northwestern Turkey in both studies.

The fast velocities in the northwestern part of Turkey (Marmara region) may be interpreted by the cooling of the upper mantle due to dipping oceanic lithosphere of Black Sea under the southward Marmara region (Gulen and Kuleli, 1995). The slow phase velocities in the eastern Turkey can be explained by geological features of this area such as wide spread of young volcanism (< 2Ma), hot and rising asthenosphere or thin litospheric mantle and the presence of high heat flow (40-140mW/m^2) (Tezcan 1995; Yürür and Chorowicz, 1998; Şengör et al., 2003; Gök et al., 2007). A variety of evidences from previous studies can be strong supports for a significant regional variations of the Rayleigh wave phase velocity obtained in this study.

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REFERENCES

Al-Lazki, et al., 2004, Geophys. J. Int., 158, 1024-1040.
Barış, Ş., et al., 2005, Earth Planets Space, 57, 11, 1019-1038.
Barka, A., and R. Reilinger, 1997, Annali di Geofisica, XL (3), 587-610.
Canıtez, N., and M. N. Toksöz, 1980, , Eos Trans. Am. Geophys. Un., 61, 290.
Debayle, E. et al., 2001, , Earth and Planet. Sci. Lett., 193, 423-436.
Dziewonski, A., M. and A, L., Hales, 1972, Seismology, Surface W. and Earth Oscil., 39-85. Vol 11
Dziewoneski, A. M., and D. L. Anderson, 1981, Phys. Earth Planet Interr., 25, 257-356
Ekstrom, G. et al., 1997, J. Geophys. Res., 102 (B4), 8137-8157.
Gök, R. et al., 2003, Geophy, Res. Lett., 30, 24, 8042.
Gök, R et al., 2007, Geophys. J. Int., 169, 1029-1088.
Gülen, L., and H. S. Kuleli, 1995 , EOS, Trans, AGU, 76, 622-623.
Horasan, G. et al., 2002, Bull. Seis. Soc. Am. 92, 322-329.
Ketin, İ., 1969, Bull. Min. Res. Explor. Inst. Turkey, 72, 1-28.
Maggi, A., and K. Priestley, 2005, Geophys. J. Int. 160, 1068-1080.
McClusky, S et al., 2000, J. Geophys. Res. 105 5695-5719.
McKenzie, D., 1972, Geophs. J.R. astr. Soc., 30, 109-185.
Mindevalli, O. Y., and J B. Mitchell, J. B., 1989, Geophys. J., Int., 98, 93-106.
Nataf, H. C. and T. Ricard, 1996, Phys. Earth planet inter., 95, 101-122.
Rodgers, J. et al., 1997, Bull. Seis. Soc. Am., 87, 2, 396-413.
Şengör, A. M. et al., 2003, , Geophys. Res. Lett., 30, Issue 24, 8-1.
Tezcan, A. K., 1995, A., A. Balkema, Rotherdam, 23-42.
Villasenor, A. et al., 2001, , Phys. of the Earth and Planet. Int., 123, 169-184.
Wessel, P., and W. . F. Smith, 1995, , Eos, Trans. AGU 76,329.
Yürür, T. M, and J. Chorowiez, 1998, Journal of Volcanology and Geoth. Res., 85, 1-15.
Zor, E. et al., 2006, Geophys. J. Int., 167, Issue 1 213-222.