Seismic research in the area of GRSS seismological sites

The seismic research has been carried in the areas of instalation of the GRSS sites in order to identify the geological construction of superficial layers, determination of V_{s30} parameter, perform the land classification according to the Eurocode 8 European norm, as well as to determine the coefficient of vibrations' ampflification.

The measurements were performed using the method of the shallow refraction and the method the MASW surface waves. Due to the high seismic noise in some of the measurement areas, the quality of the obtained recording could not be classified as satisfactory for the needs of their interpretation by the refraction method. The material collected at the "Marcel" site did not allow to be properly interpreted.

1. MASW method of the analysis of the surface waves

The MASW method of the multichannel analysis of the surface waves is commonly used in geotechnics and geophysics since 1999, and the developmental versions appeared in use few years earlier (Park at al., 1999a). MASW is a seismic method, allowing to determine the distribution of velocities of the wave S in the depth scale by analysis of the Rayleigh's surface waves. Basing on the determined velocity average for the superficial layer, the ground classification basing on the Eurocode 8 could be performed, what is used, inter alia, for predicting the influence the seismic occurrences could have on the structures located on the ground. This method applies the way of data recording and processing, which is commonly used since many years in the reflection seismology for the needs of the petrol industry. Although in the traditional seismology Rayleigh's waves are classified as a seismic noise, the MASW method considers them to be a useful signal. The method requires a slightly different approach at the stage of data collection and processing. The MASW procedure consists of the three stages:

- Data acquisition,
- Calculation of dispersion curves for the particular records
- Inversion of the dispersion curves in order to calculate the distribution of velocities.

The registration is carried using the multichannel seismic apparatus. The amount of channels can be different, however cannot be lesser than 12. The scheme of a typical measurement chain is presented on the Fig. 1.

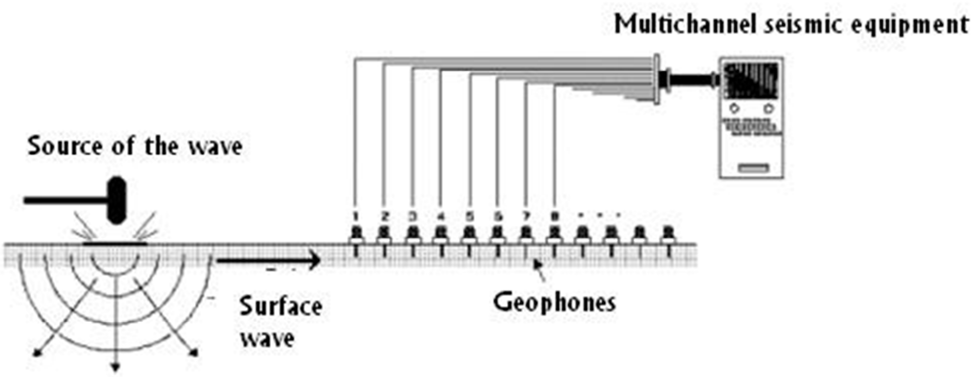
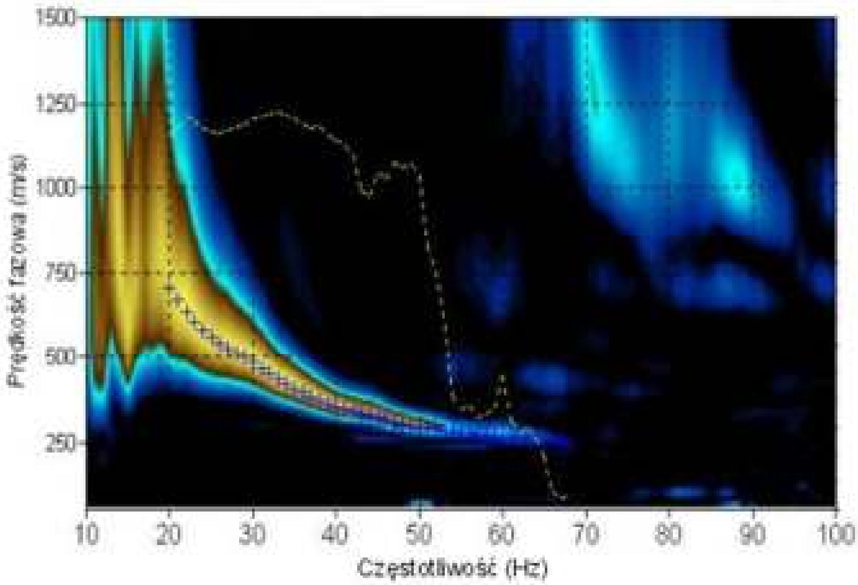


Fig. 1. Scheme of the measurement chain in the MASW method

The distance between the source of the wave and the nearest geophone should be enough to ensure emergence of a proper surface wave. The furthest geophone is usually located in the place, where the seismic noise starts dominating over the useful signal. Considering the parameters of the registration, it is important to record low frequencies. The wave components of a low frequency increase the depth scope of the method and stabilizes the inversion process. Therefore it is particularly important not to use filtration during the measurements, as well as to provide a proper amplification of the low frequencies. The registered records undergo dispersal analysis. This stage is crucial, as it has the largest influence onto the final shape of the velocity curve. Only the dispersion curve is used for the inversion (fig. 2), so the more precisely would the curve for the each registered record be plotted – the more accurately the distribution of velocities in the given medium be determined.



(OŚ PIONOWA – phase velocity (m/s), POZIOMA – Frequency (Hz))
Fig. 2. Dispersion map with a marked dispersion curve for the Rayleigh's surface waves.
(www.kgs.ku.edu/software/surfseis/index.html)

The distribution of velocities V_S is calculated during the inversion process basing on the dispersion curve, density and a Poisson's ratio (Xia et al., 1999). In the subsequent iterations only the velocity of a wave S is modified – other parameters remain unchanged. The output model of the medium is defined by the velocity of the wave P and S, density and thickness of the particular layers. From each registered record only one V_S velocity distribution curve is being created. When moving the measurement system by a particular interval, we can create several such curves and construct velocity maps basing on them (Fig. 3). The size of the interval is determined by a level of details of the map.

(Source Geophone, OŚ PIONOWA – Measuring record, Velocity curve)

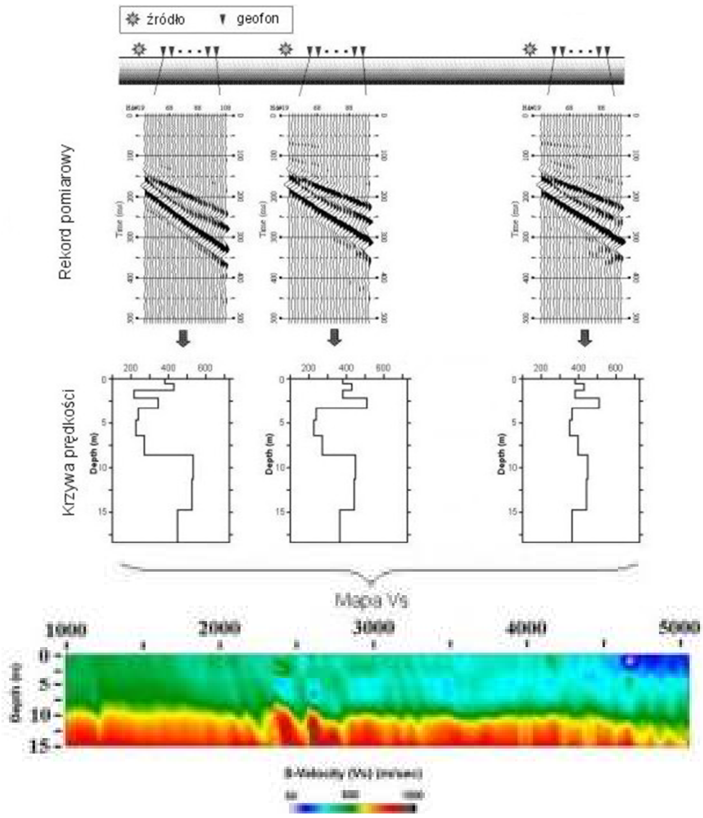


Fig. 3. Scheme of measurements and interpretations using the MASW method (www.kgs.ku.edu/software/surfseis/index.html)

2. Land classification according to the Eurocode 8

Results of large-area seismic measurements implementing the method of surface waves analysis could be used for determination of the class of the grounds according to the European construction norm Eurocode 8 *Design of structures for earthquake resistance* in the investigated area. The classification of grounds according to that norm is presented in the Table 1.

Table 1. Land classification according to the European norm Eurocode 8.

Type of the ground	**Stratigraphic description**	**$V_{S,30}$(m/s)**
A	Rocks or other rocky geological formations with no more than five meters of a faint superficial layer	> 800
B	Sands, gravels and hard clays, with at least over ten meters of thickness, which are characterized by a gradual increase of mechanic attributes together with an increase of their depth	360 - 800
C	Dense or averagely dense sands, gravels and hard clays, of a thickness from over ten to several hundred meters	180 - 360
D	Loose to medium cohesion formations	< 180

The decisive factor of that classification is an average velocity of propagation of the wave S in the 30 meters' superficial layer, therefore the MASW method, which enables to determine the distribution of velocities of a wave S in the depth scale by the analysis of the Rayleigh's surface waves, is a very useful tool.

3. Result of Seismic research in the area of GRSS seismological sites.

3.1 Seismic measurements in Żarki (Janina station).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.1 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

Fig. 3.1. Location of the measuring site in Żarki.

3.1.1 Measurements by the method of a shallow refraction.

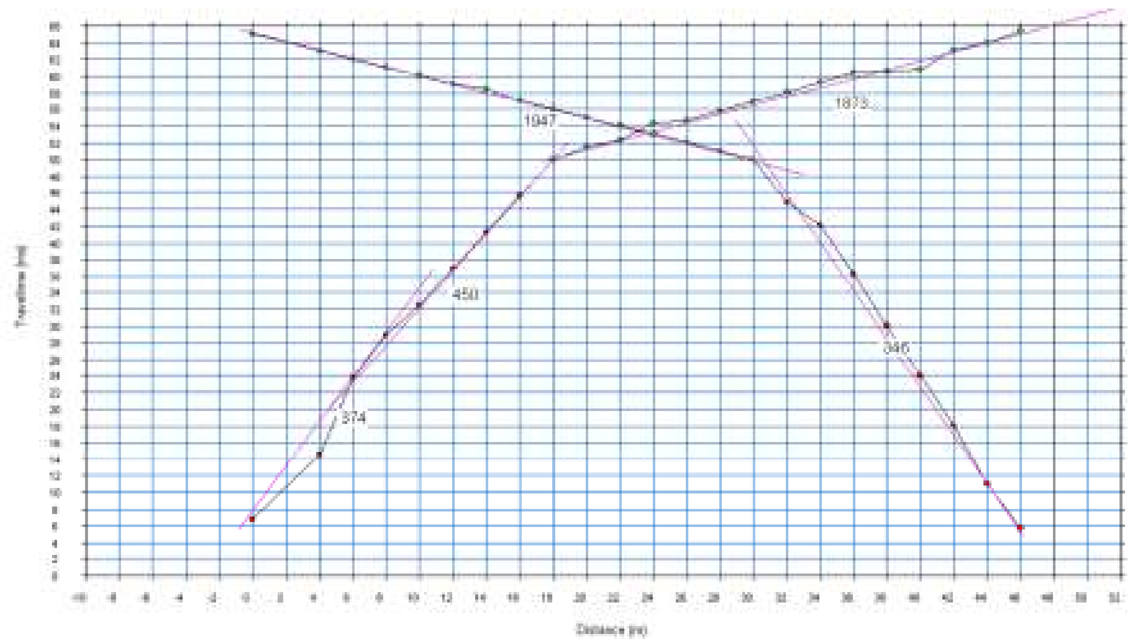


Fig. 3.2. Configuration of convergent hodographs obtained through a seismic profile.

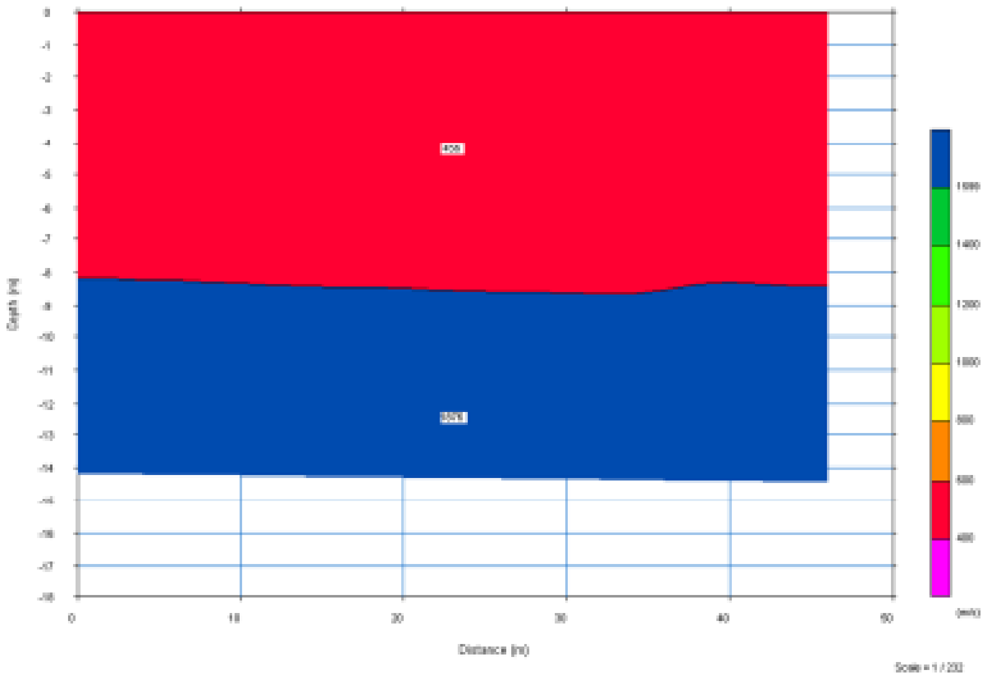


Fig. 3.3. Interpretation of hodographs from the fig. 3.2.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth 8-8.5m. The average velocity of P seismic wave over this boundary amounts to 456 m/s, on the boundary – 1876 m/s.

3.1.2 Measurements by the MASW method.

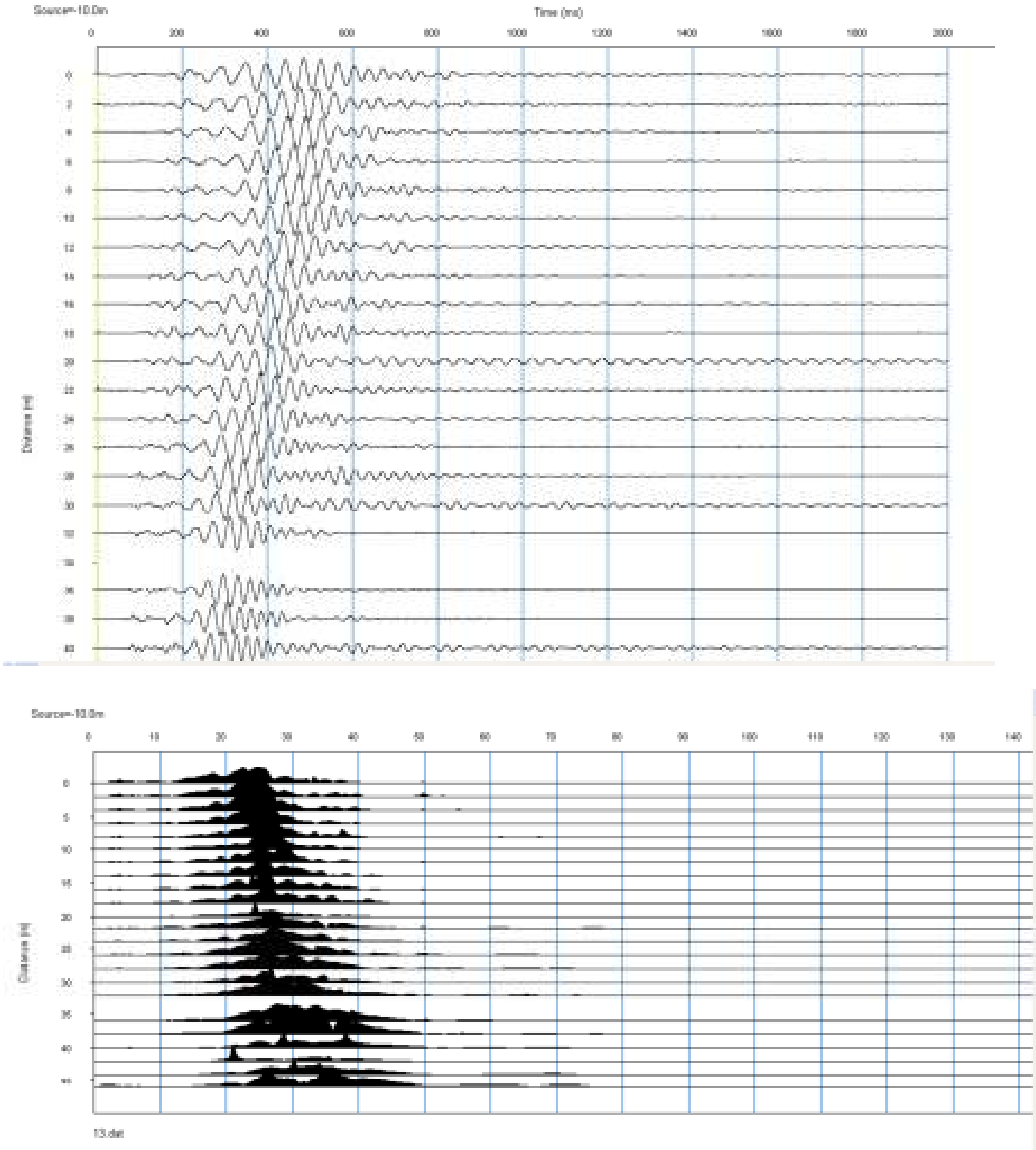


Fig. 3.4. An example seismic recording from the measurements and a corresponding amplitude spectrum.

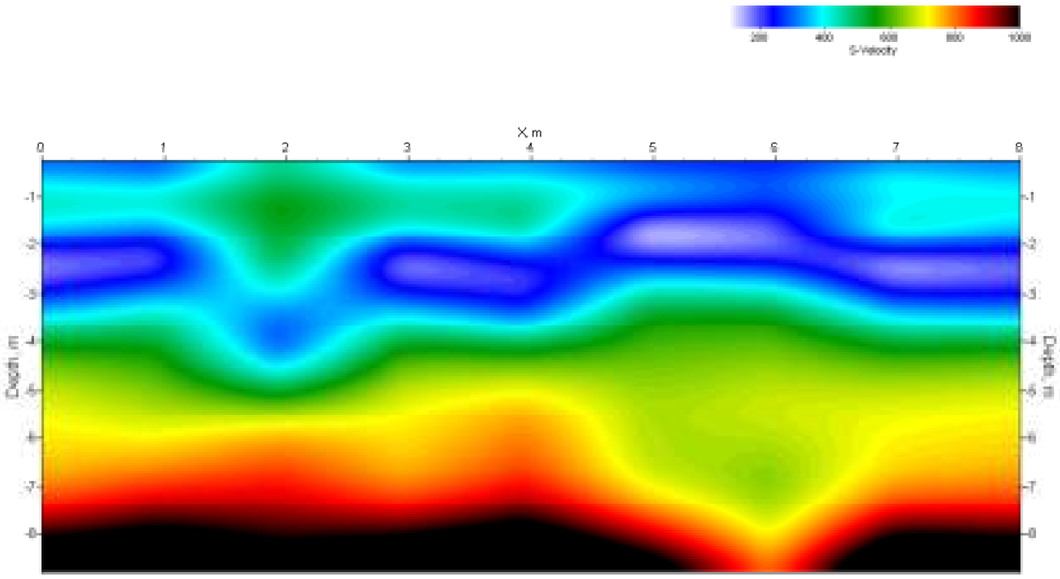


Fig. 3.5. Map of a velocity of a shear wave obtained through the MASW method measurements.

Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 145m/s, maximum 1242m/s, average 591m/s. Depth: about 9m. V_{s30}=821 m/s.
This velocity describes A-class grounds, according to the European norm Eurocode 8.

3.2 Seismic measurements in Wola (Czeczott site).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.6 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

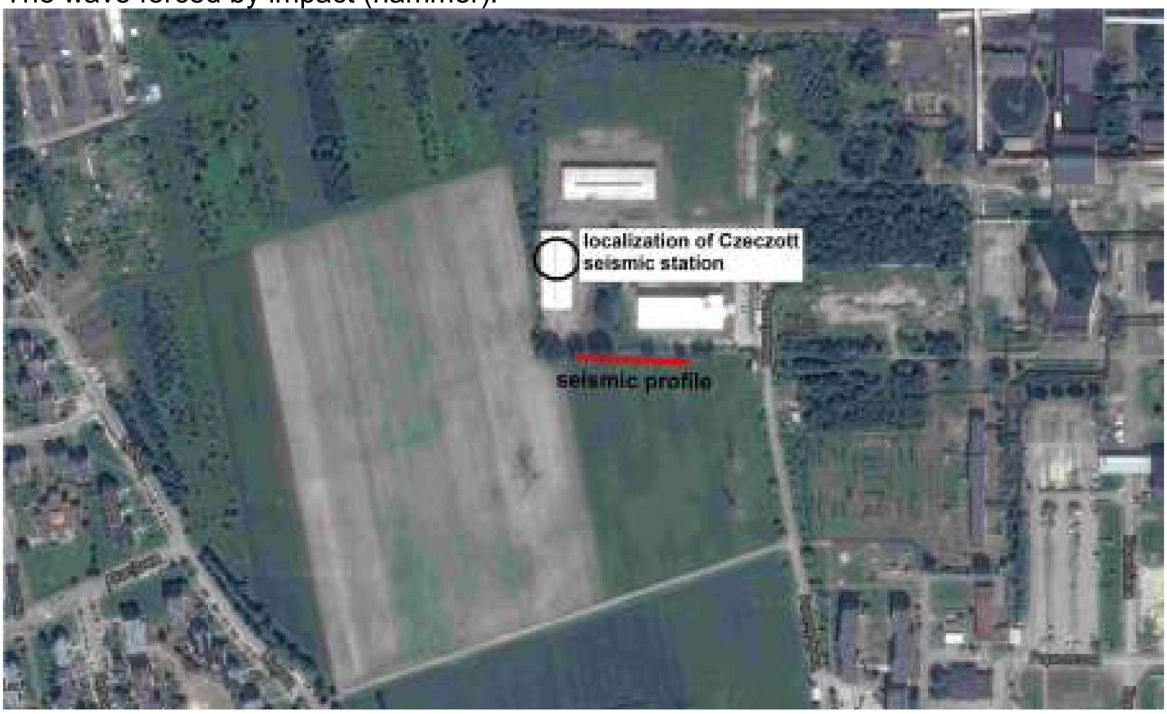


Fig. 3.6. Location of the measuring site in Wola.

3.2.1 Measurements by the method of a shallow refraction.

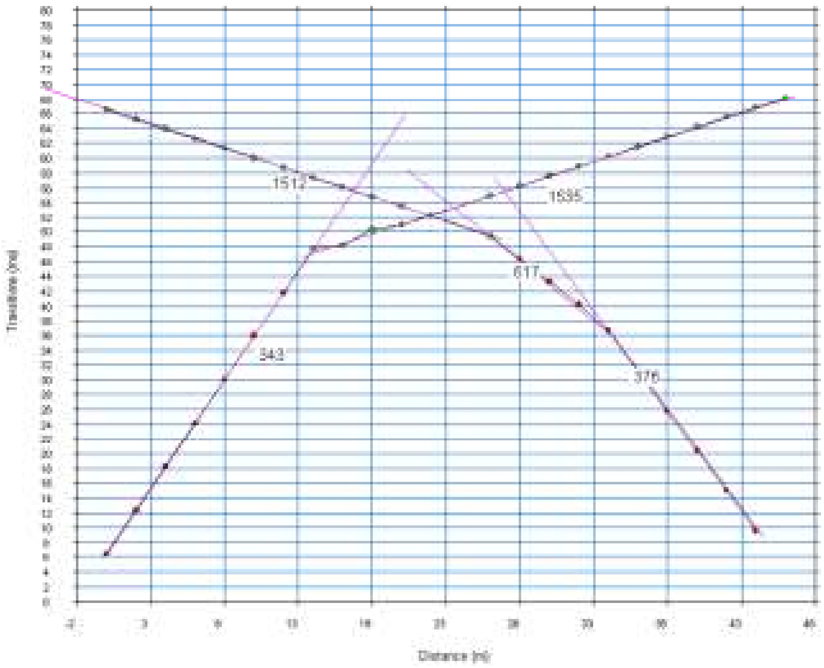


Fig. 3.7. Configuration of convergent hodographs obtained through a seismic profile.

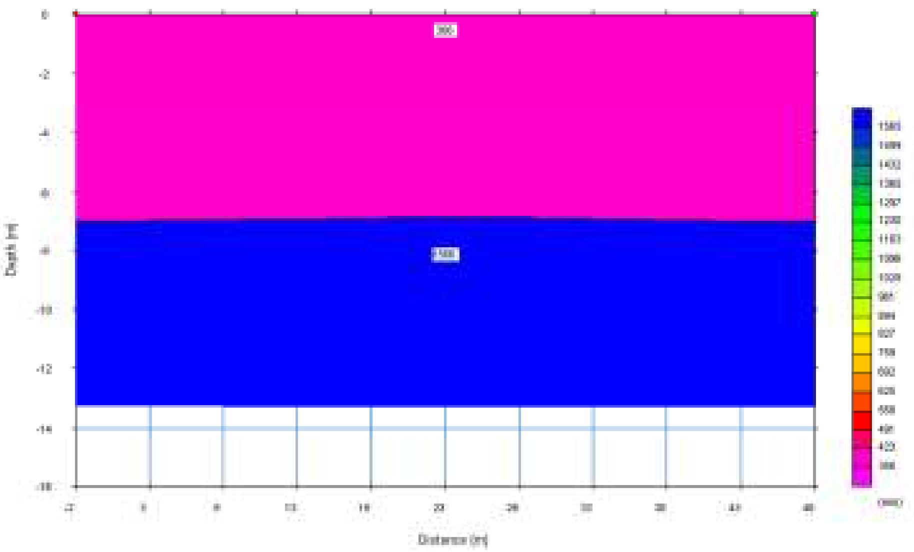


Fig. 3.8. Interpretation of hodographs from the fig. 3.7.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth 7.0m. The average velocity of P seismic wave over this boundary amounts to 366 m/s, on the boundary – 1566 m/s.

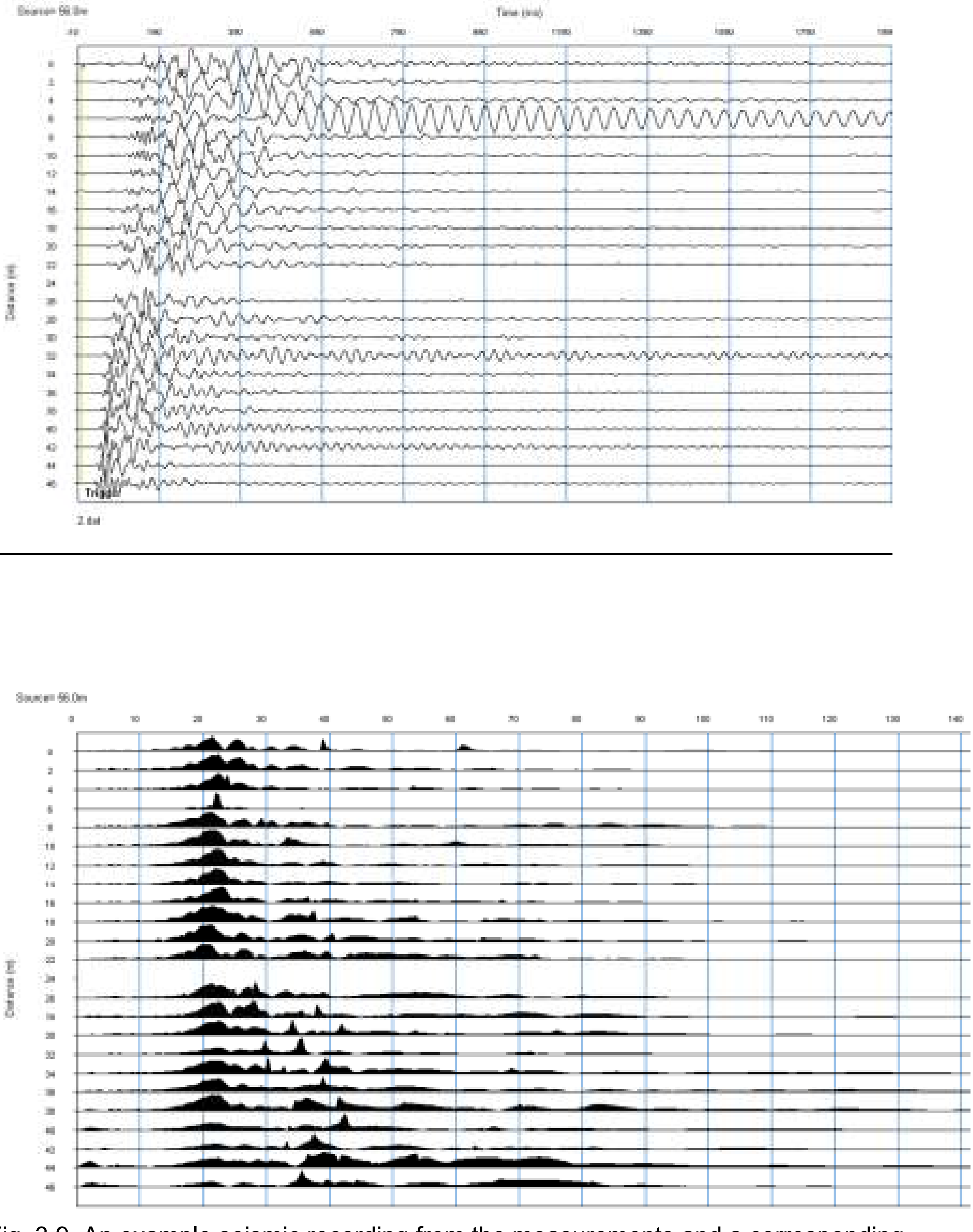


Fig. 3.9. An example seismic recording from the measurements and a corresponding amplitude spectrum.

3.2.2 Measurements by the MASW method.

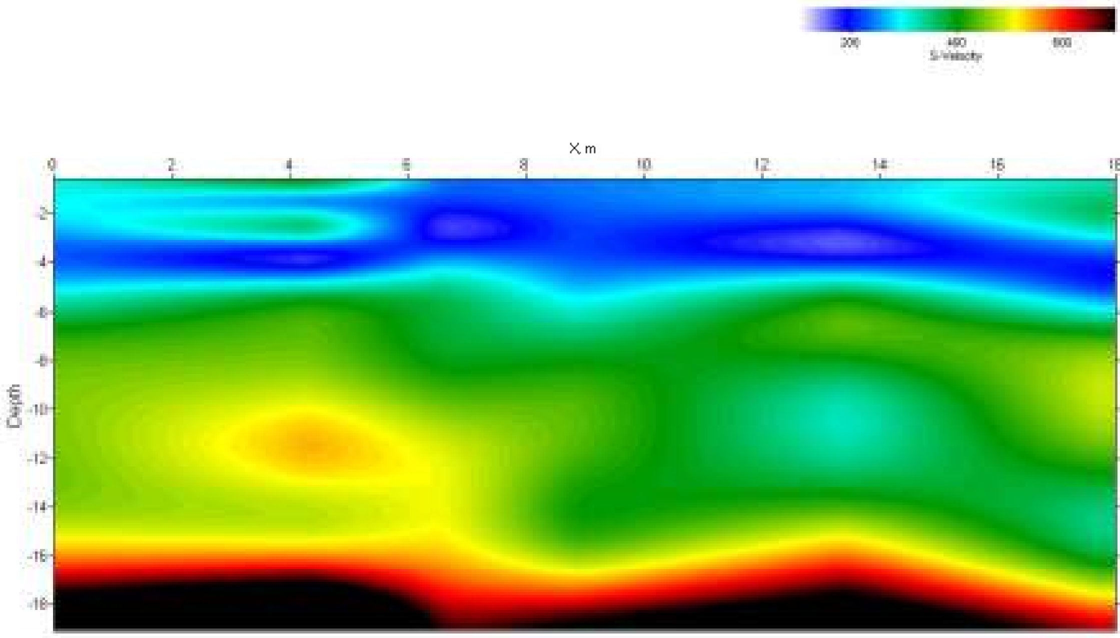


Fig. 3.10. Map of a velocity of a shear wave obtained through the MASW method measurements.

Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 161m/s, maximum 845m/s, average 415m/s. Depth: about 19m. V_{s30}=418 m/s.
This velocity describes B-class grounds, according to the European norm Eurocode 8.

3.3 Seismic measurements in Gliwice (Gliwice site).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.11 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

Fig. 3.11. Location of the measuring site in Gliwice.

3.3.1 Measurements by the method of a shallow refraction.

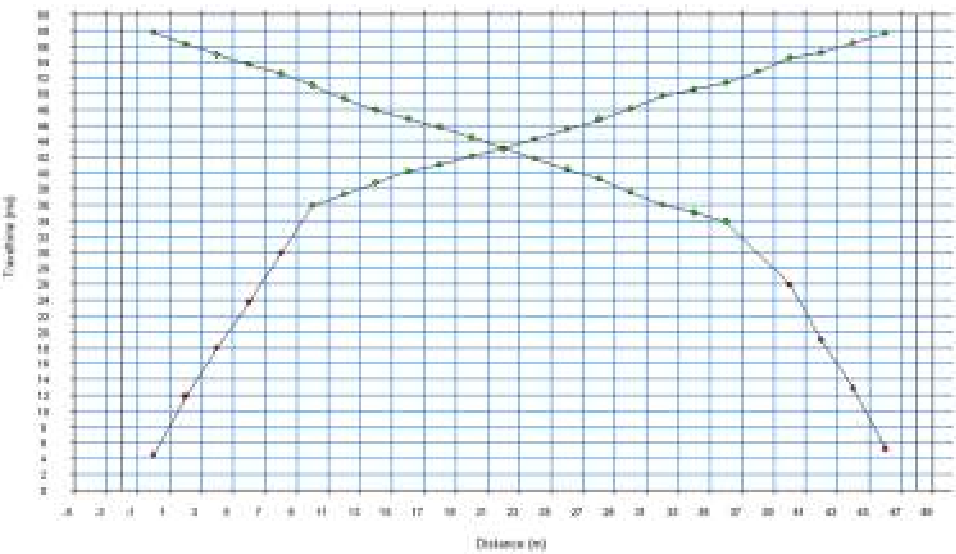


Fig. 3.12. Configuration of convergent hodographs obtained through a seismic profile.

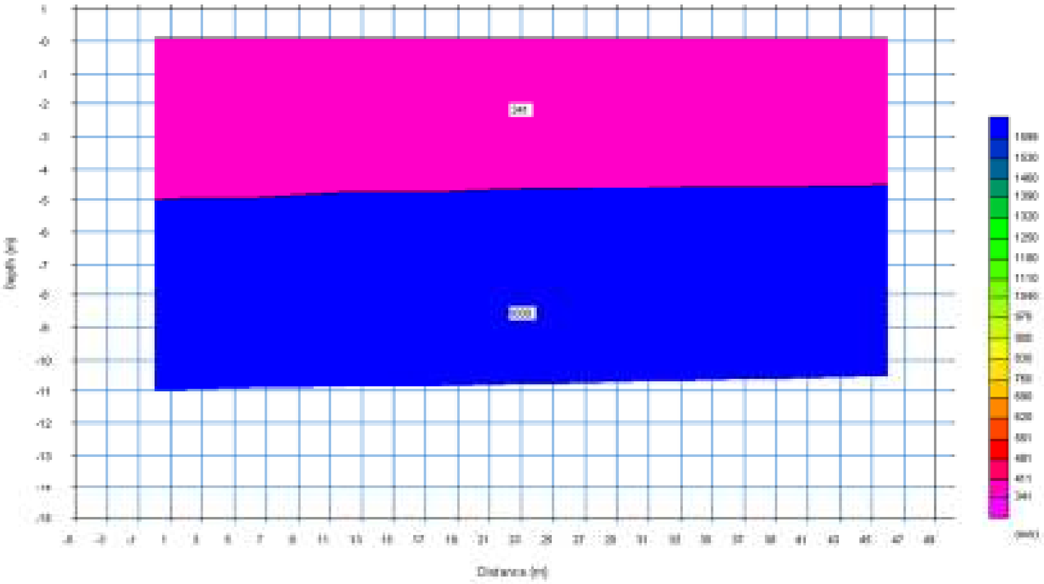
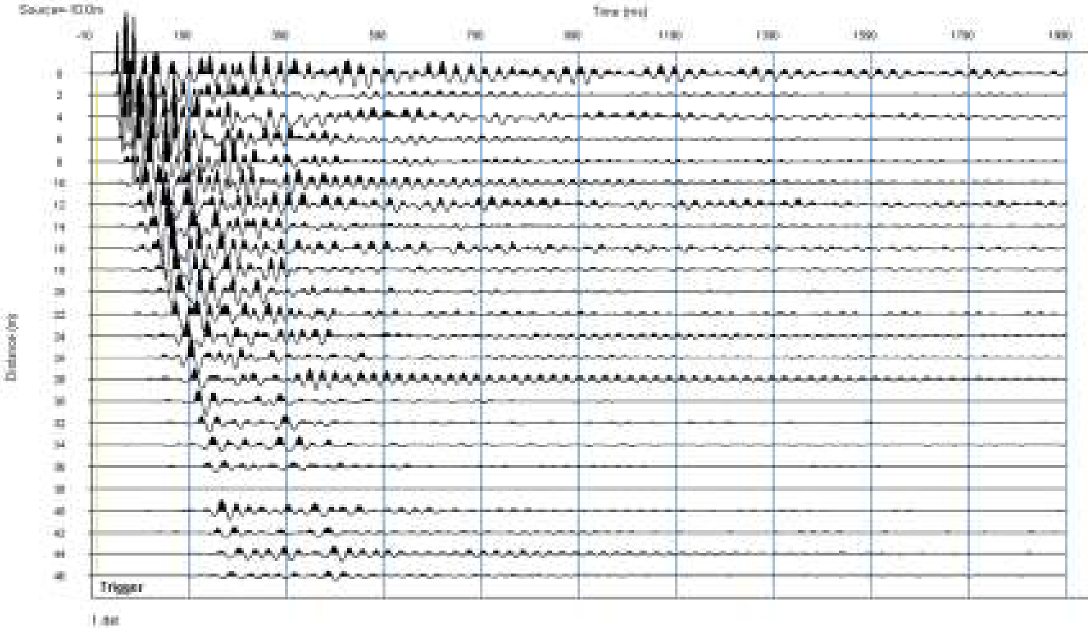


Fig. 3.13. Interpretation of hodographs from the fig. 3.12.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth 4.5-5m. The average velocity of P seismic wave over this boundary amounts to 341 m/s, on the boundary – 1600 m/s.



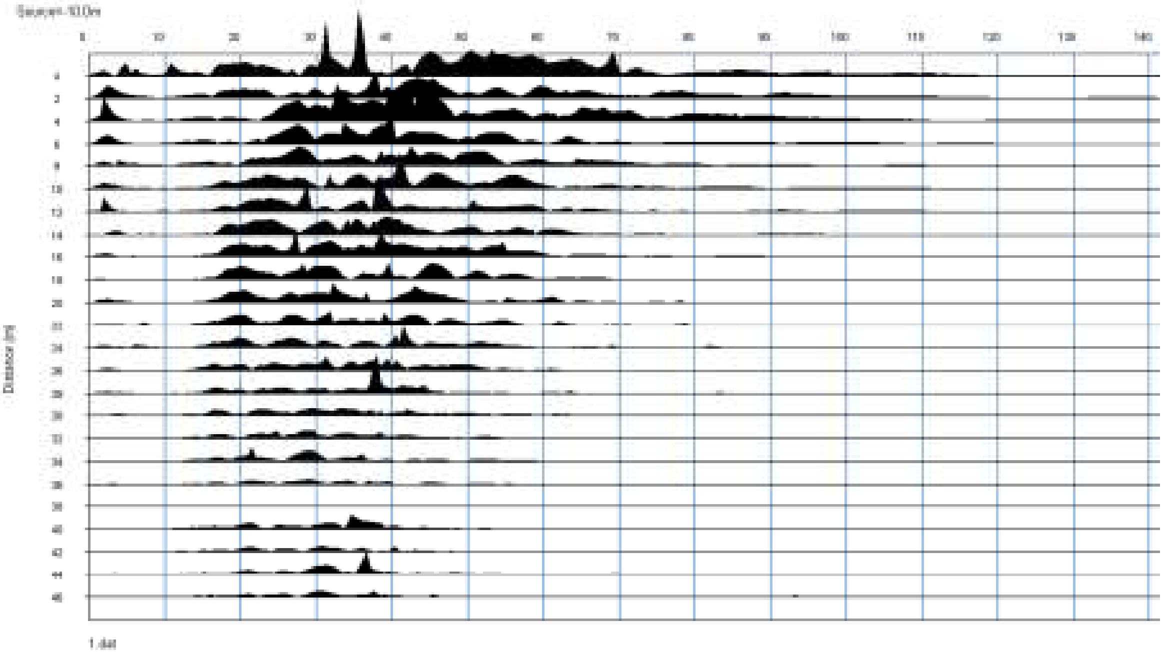


Fig. 3.14. An example seismic recording from the measurements and a corresponding amplitude spectrum.

3.3.1 Measurements by the MASW method.

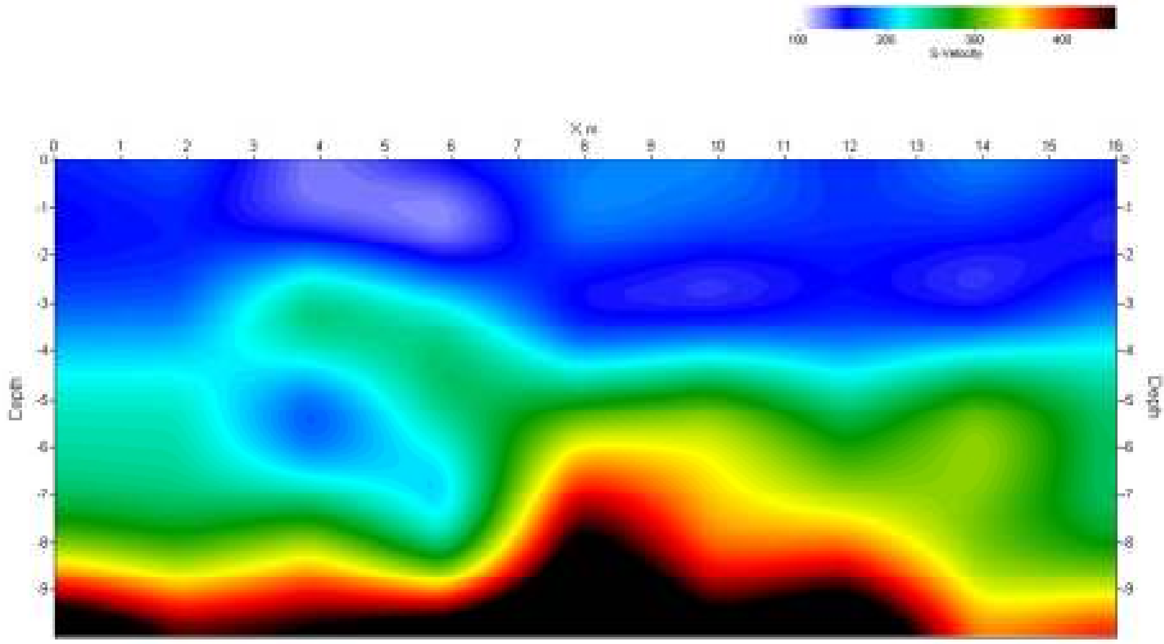


Fig. 3.15. Map of a velocity of a shear wave obtained through the MASW method measurements.

Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 126m/s, maximum 582m/s, average 261m/s. Depth: about 10m. V_{s30}=330 m/s.
This velocity describes C-class grounds, according to the European norm Eurocode 8.

3.4 Seismic measurements in Imielin (Imielin site).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.6 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

Rys 3.16. Location of the measuring site in Imielin.

3.4.1 Measurements by the method of a shallow refraction.

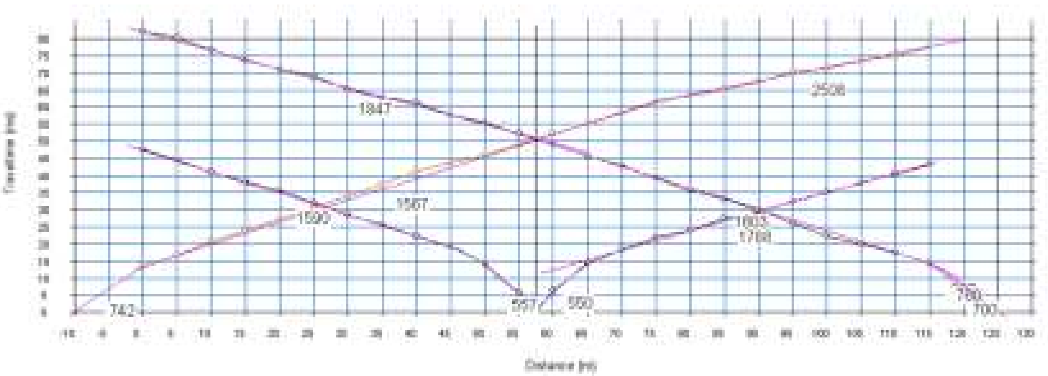


Fig. 3.17. Configuration of convergent hodographs obtained through a seismic profile.

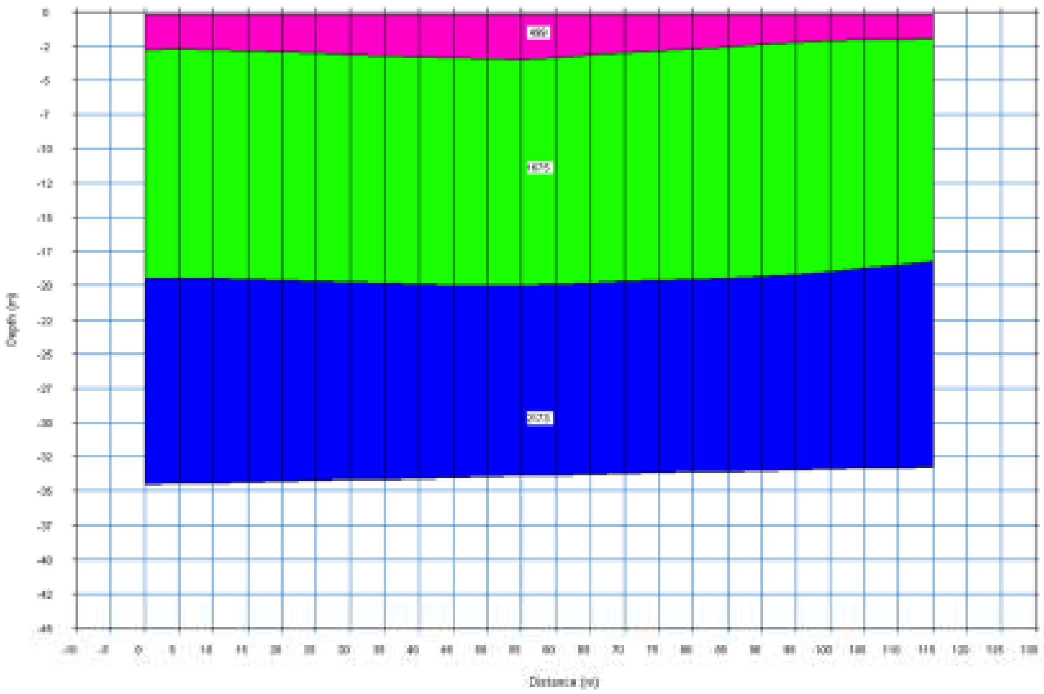
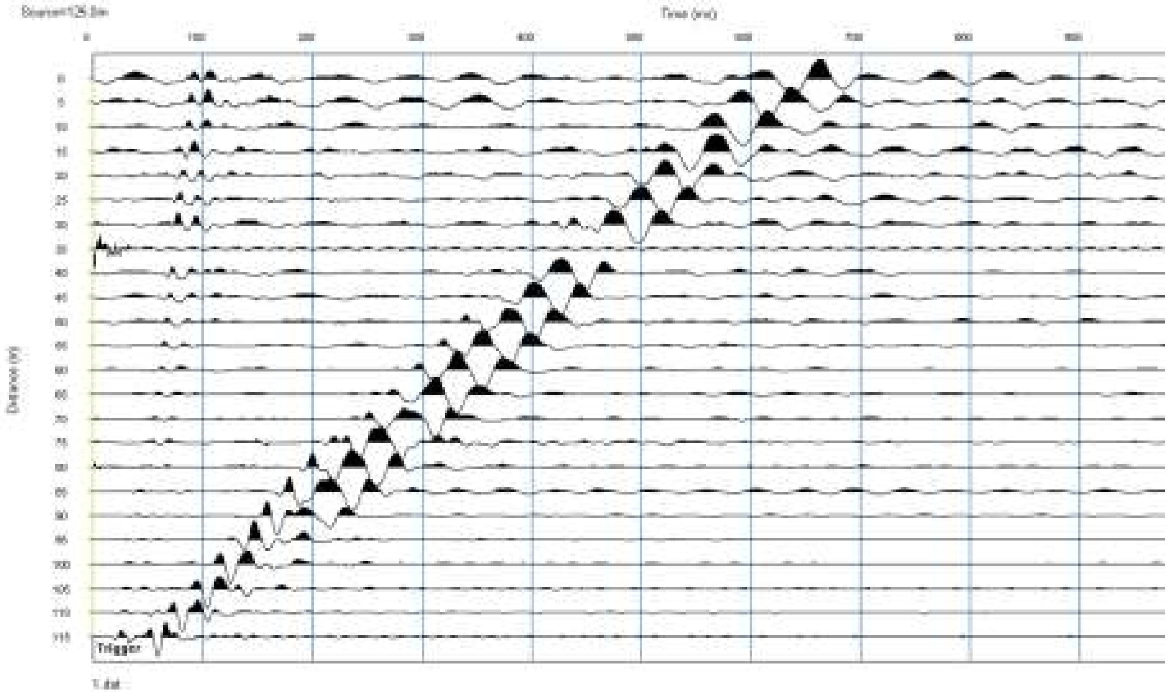


Fig. 3.18. Interpretation of hodographs from the fig. 3.17.

As a result of interpretation of convergent hodographs, two refractions boundary was obtained on the depth 2m and 19-20m. The average velocity of P seismic wave over the first boundary amounts to 499 m/s, over the secend boundary 1675 m/s, on the secend boundary - 2173 m/s.



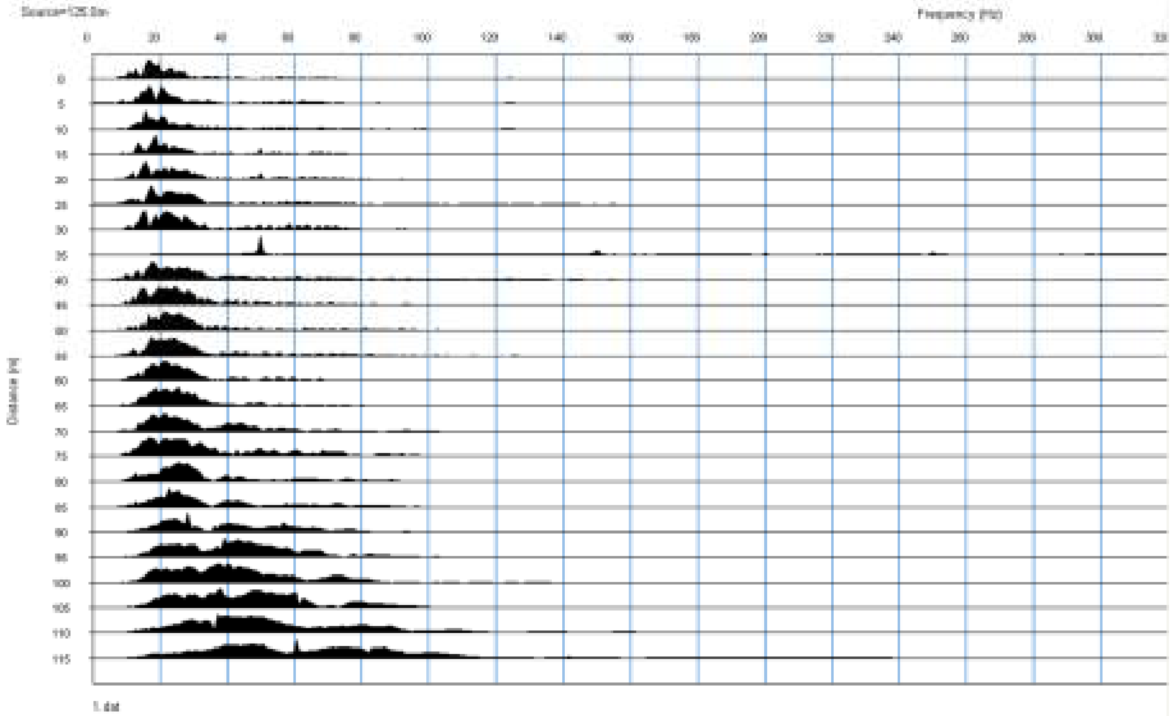


Fig. 3.19. An example seismic recording from the measurements and a corresponding amplitude spectrum.

3.4.2 Measurements by the MASW method.

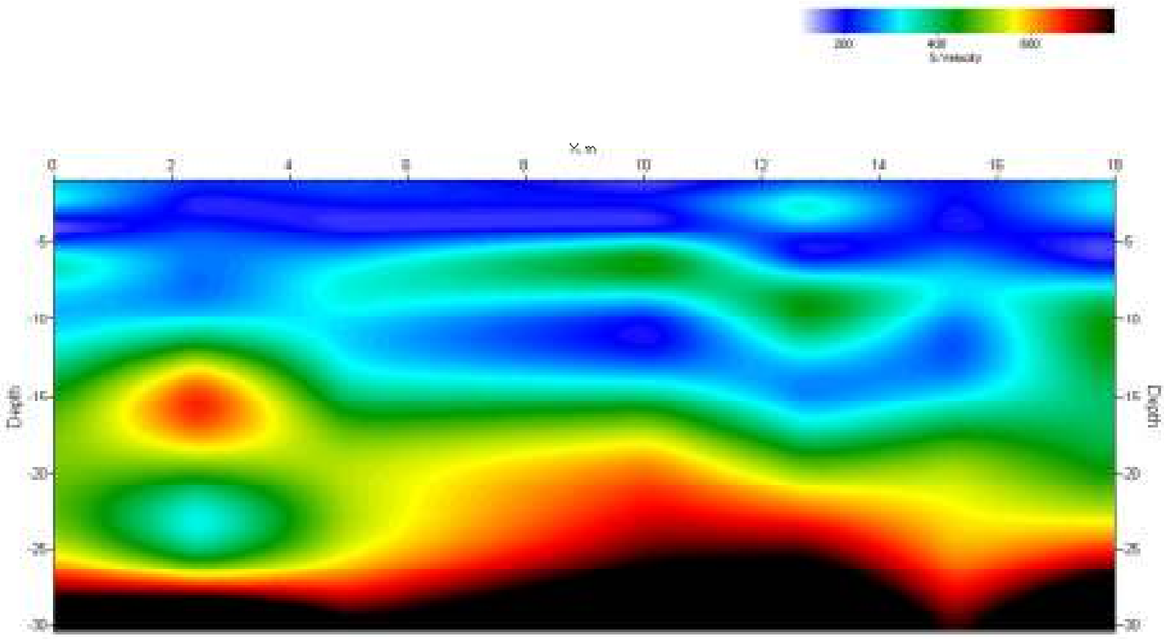


Fig. 3.20. Map of a velocity of a shear wave obtained through the MASW method measurements.

Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 139m/s, maximum 673m/s, average 308m/s. Depth: about 30m. V_{s30}=423 m/s.
This velocity describes B-class grounds, according to the European norm Eurocode 8.

3.5 Seismic measurements in Broszkowice (Broszkowice station).

Seismic measurements were carried in the area of a site of a regional network, by the MASW method. The location of a seismic profile was presented on the fig. 3.21 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

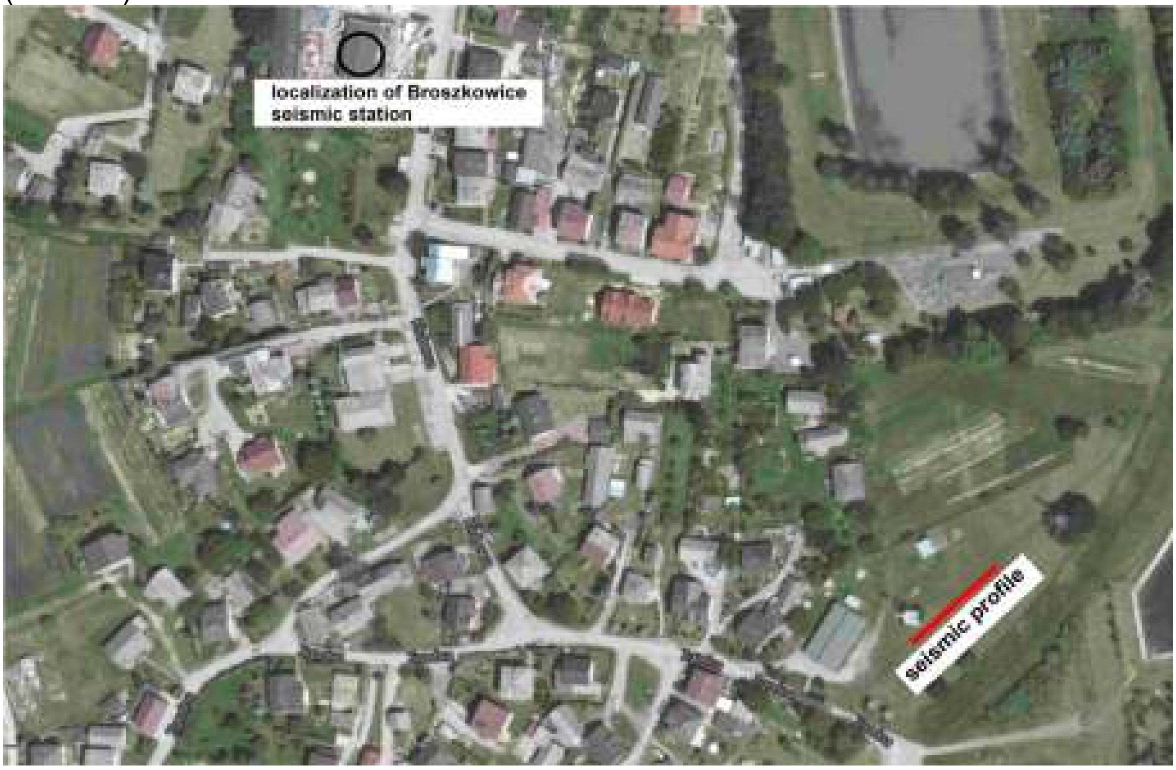


Fig. 3.21. Location of the measuring site in Broszkowice.

3.5.1 Measurements by the MASW method.

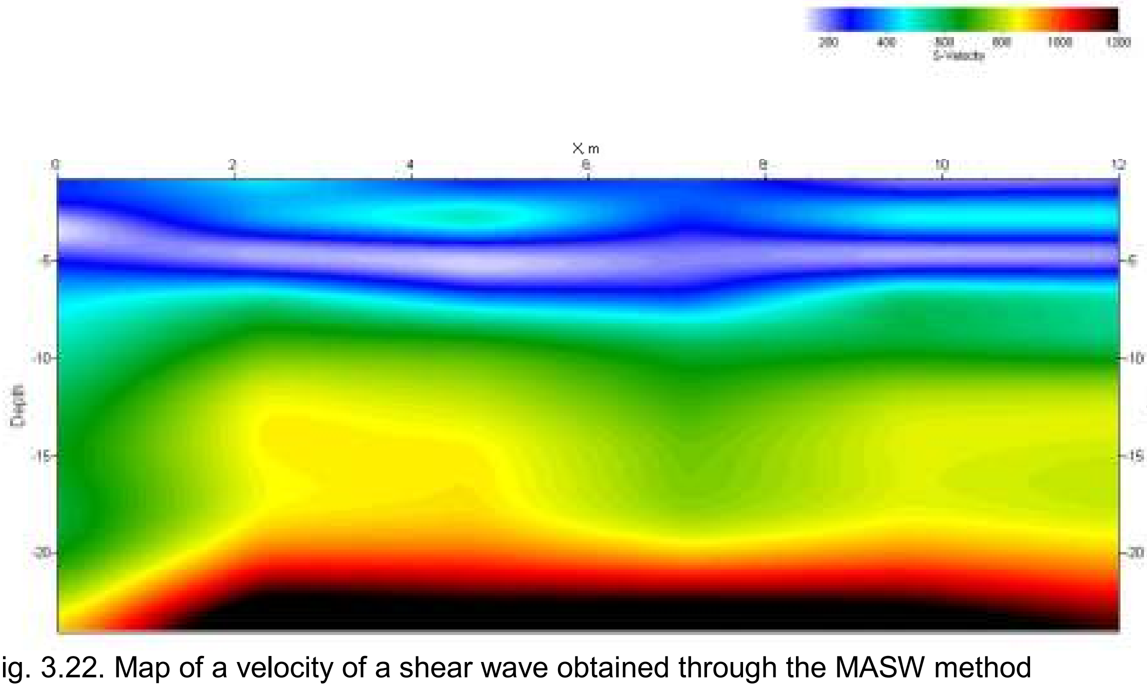


Fig. 3.22. Map of a velocity of a shear wave obtained through the MASW method measurements.

Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 145m/s, maximum 1400m/s, average 761m/s. Depth: about 25m. V_{s30}=515 m/s.
This velocity describes B-class grounds, according to the European norm Eurocode 8.

3.6 Seismic measurements in Chorzów (Planetarium station).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.23 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

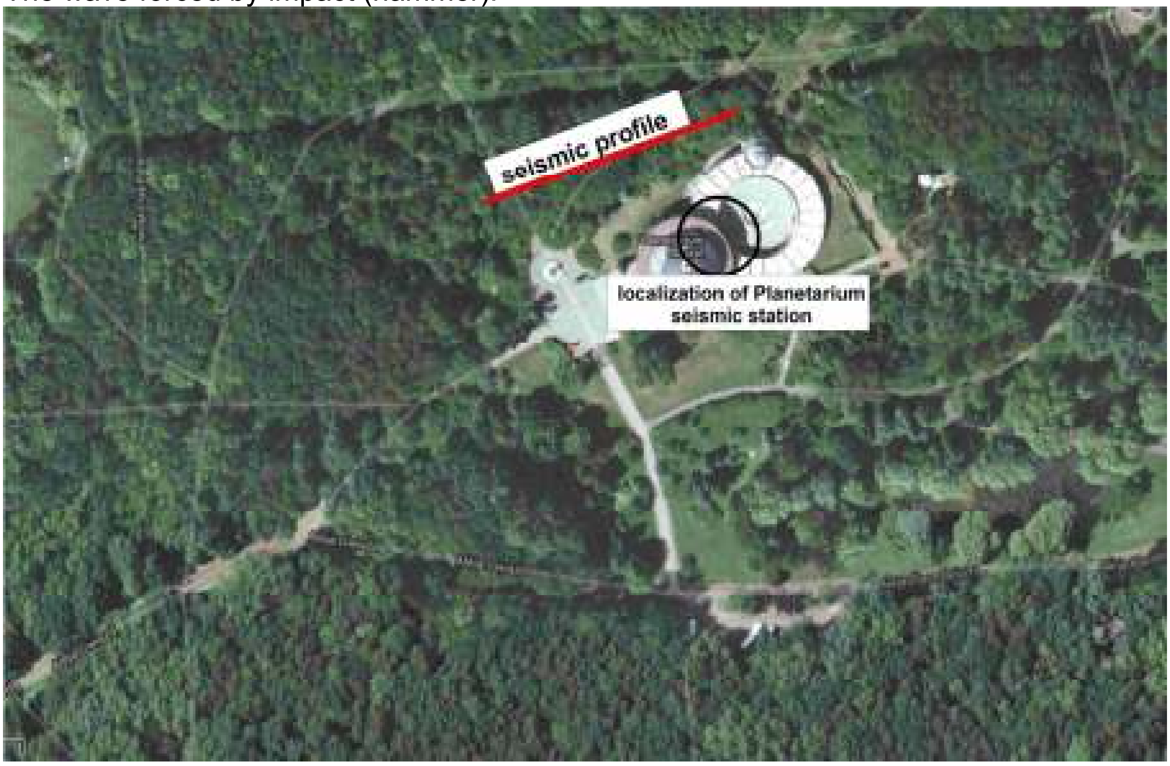


Fig. 3.23. Location of the measuring site in Chorzów.

3.1.1 Measurements by the method of a shallow refraction.

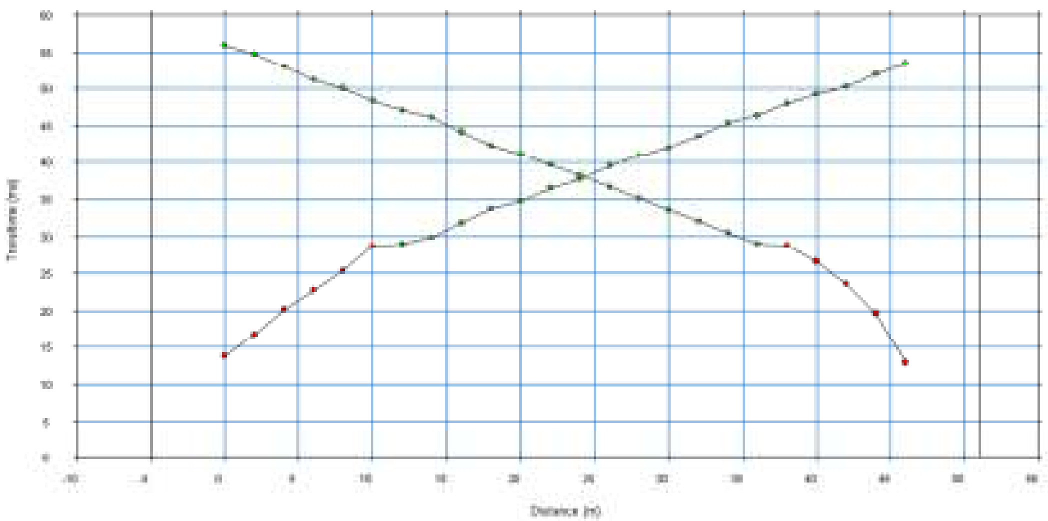


Fig. 3.24. Configuration of convergent hodographs obtained through a seismic profile.

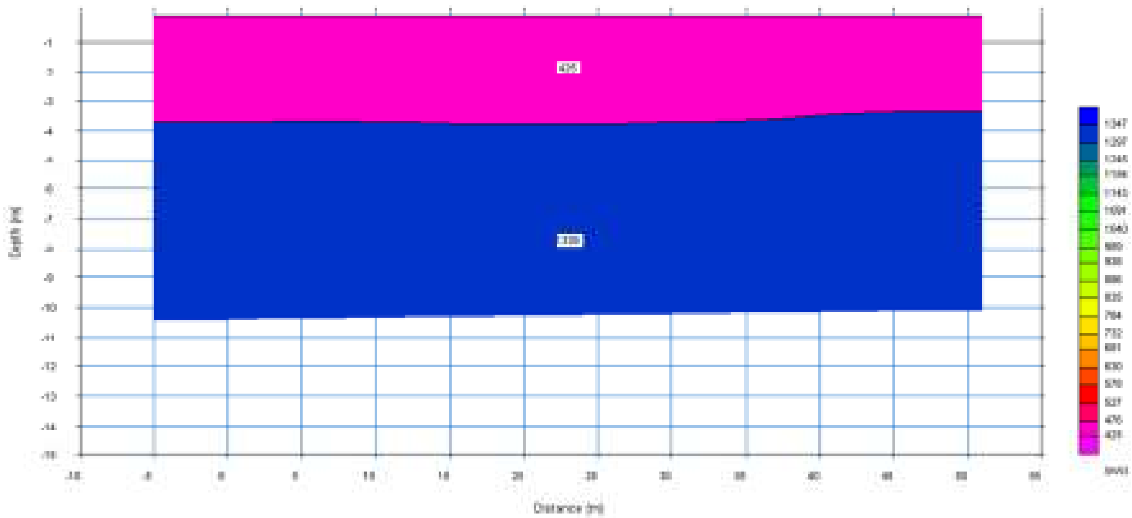
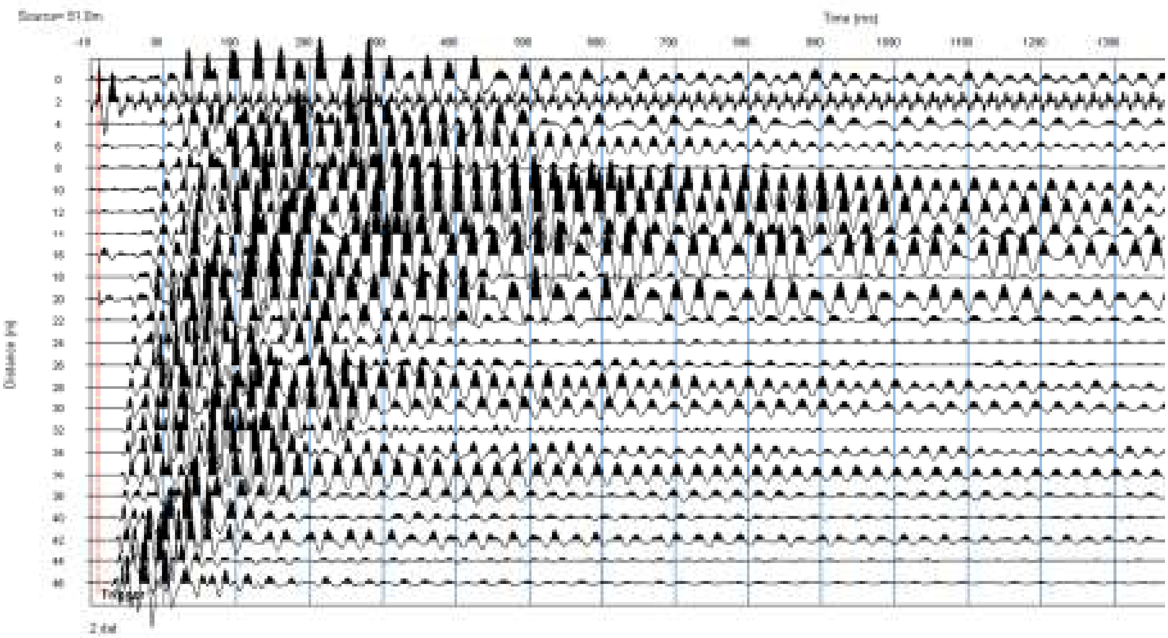


Fig. 3.25. Interpretation of hodographs from the fig. 3.24.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth 3.5-4m. The average velocity of P seismic wave over this boundary amounts to 425 m/s, on the boundary – 1338 m/s.



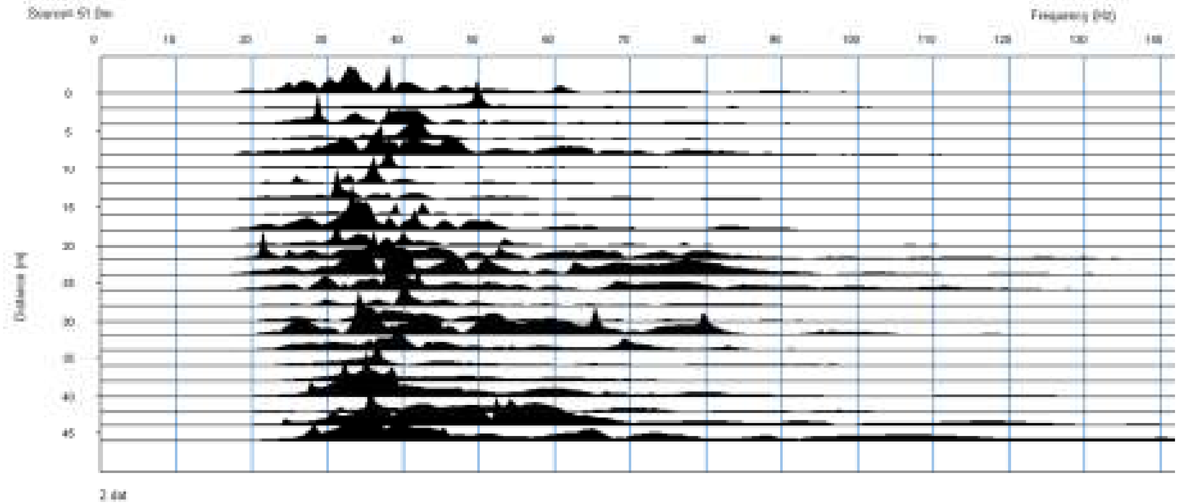


Fig. 3.26. An example seismic recording from the measurements and a corresponding amplitude spectrum.

3.6.2 Measurements by the MASW method.

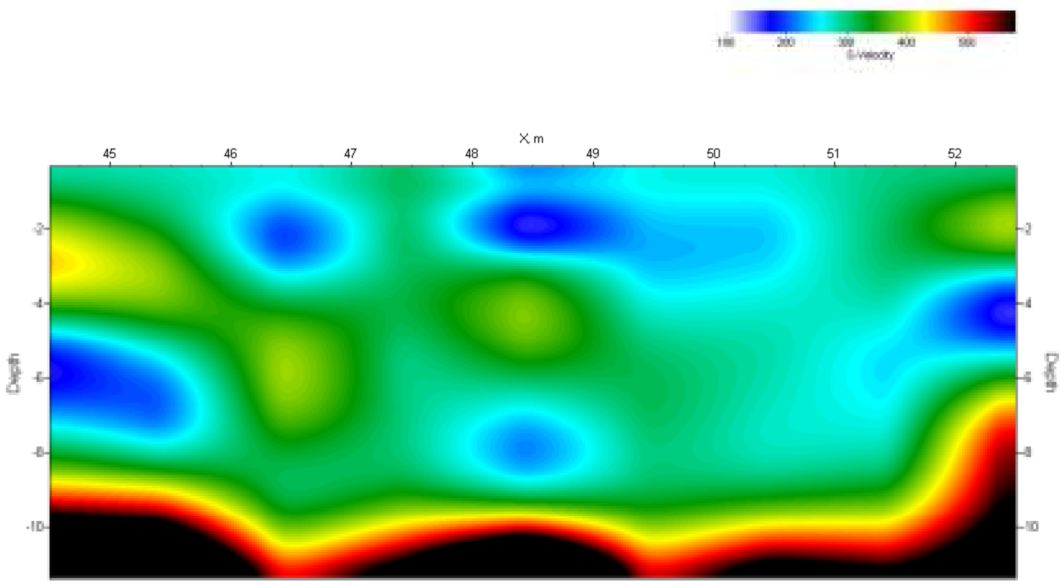


Fig. 3.27. Map of a velocity of a shear wave obtained through the MASW method measurements.

Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 161m/s, maximum 957m/s, average 345m/s. Depth: about 11m. V_{s30}=513 m/s.
This velocity describes B-class grounds, according to the European norm Eurocode 8.

3.7 Seismic measurements in Katowice (Jesionowa station).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.28 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

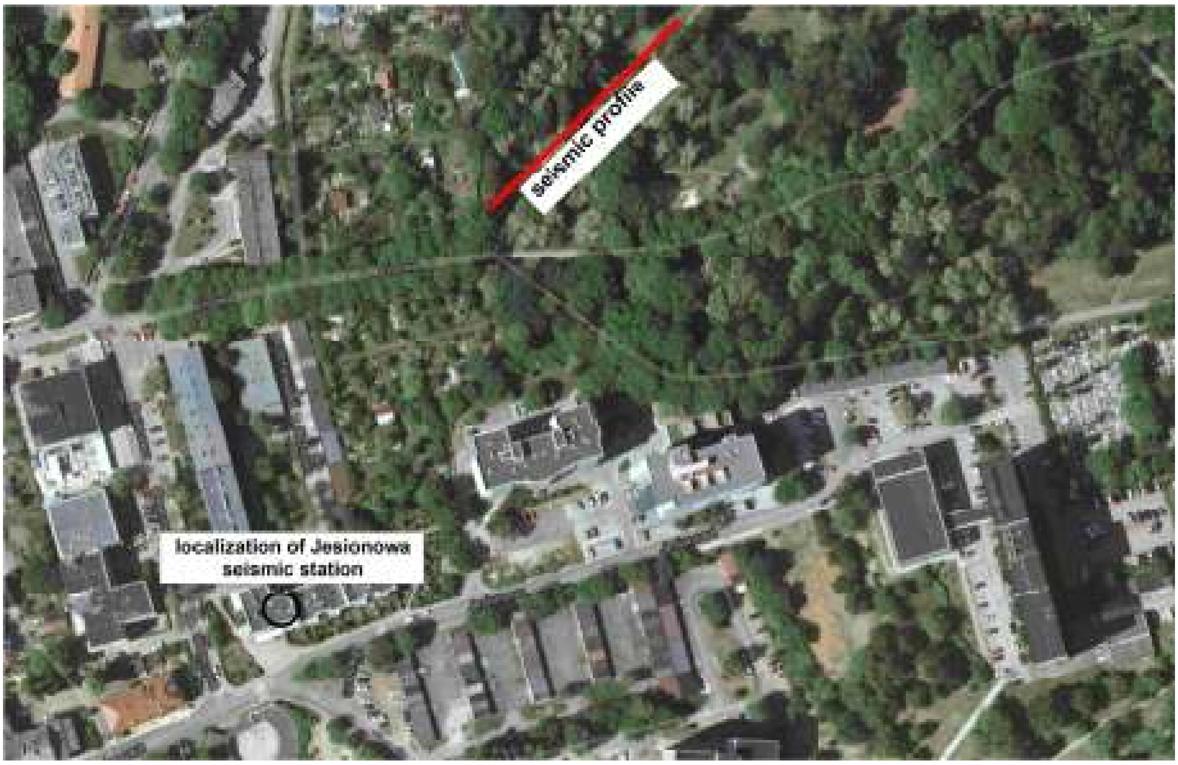
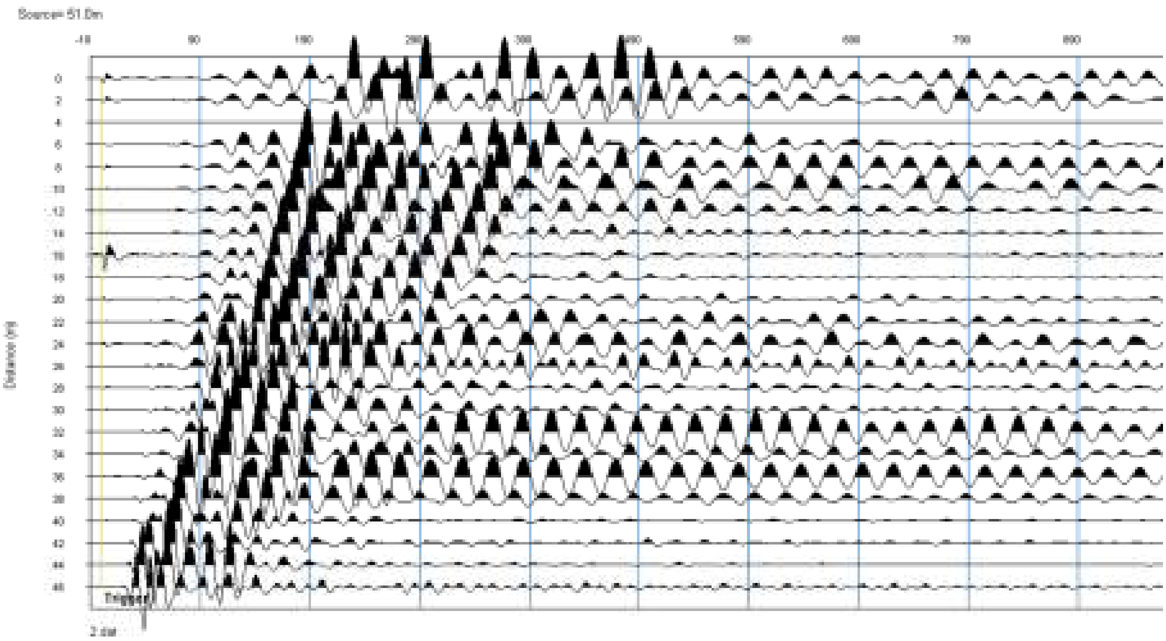


Fig. 3.28. Location of the measuring site in Katowice.

3.7.1 Measurements by the method of a shallow refraction.



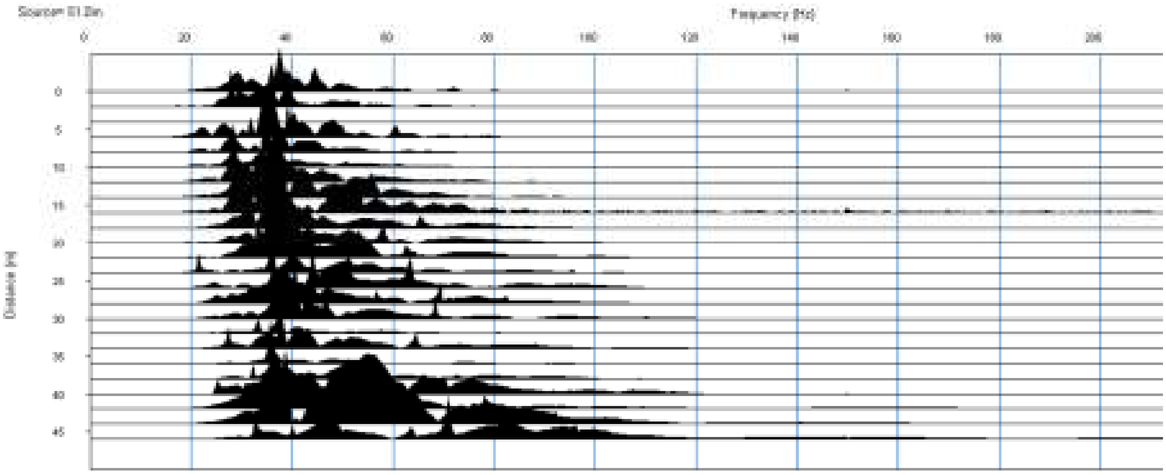


Fig. 3.29. An example seismic recording from the measurements and a corresponding amplitude spectrum.

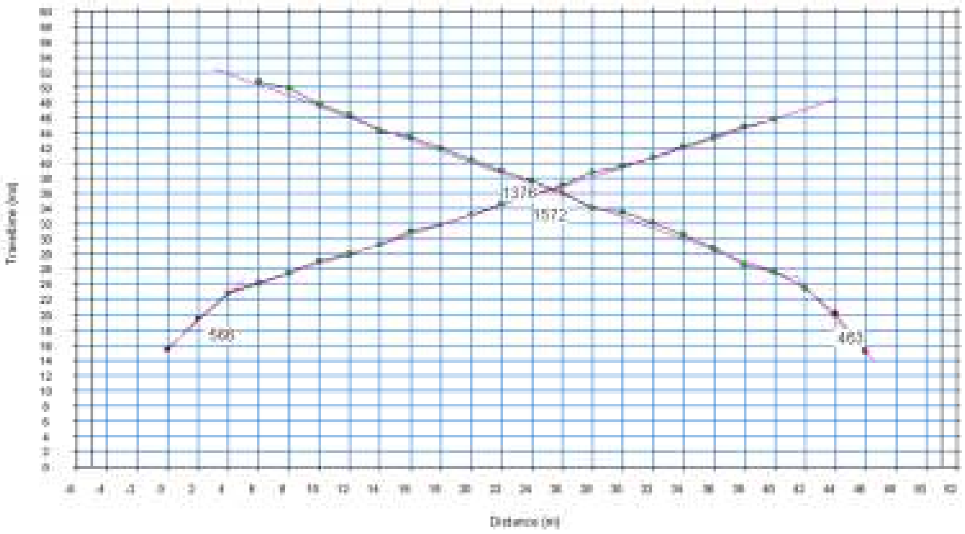


Fig. 3.30. Configuration of convergent hodographs obtained through a seismic profile.

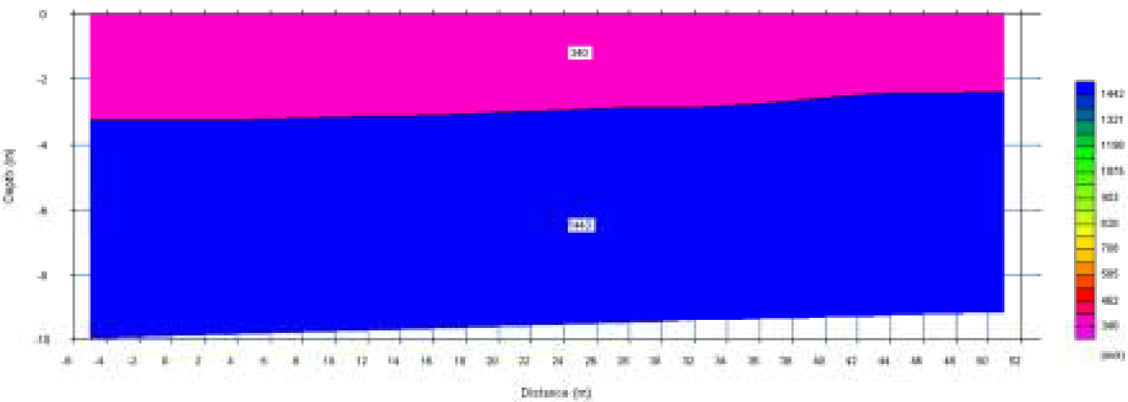


Fig. 3.31. Interpretation of hodographs from the fig. 3.30.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth 3m. The average velocity of P seismic wave over this boundary amounts to 340 m/s, on the boundary – 1443 m/s.

3.7.2 Measurements by the MASW method.

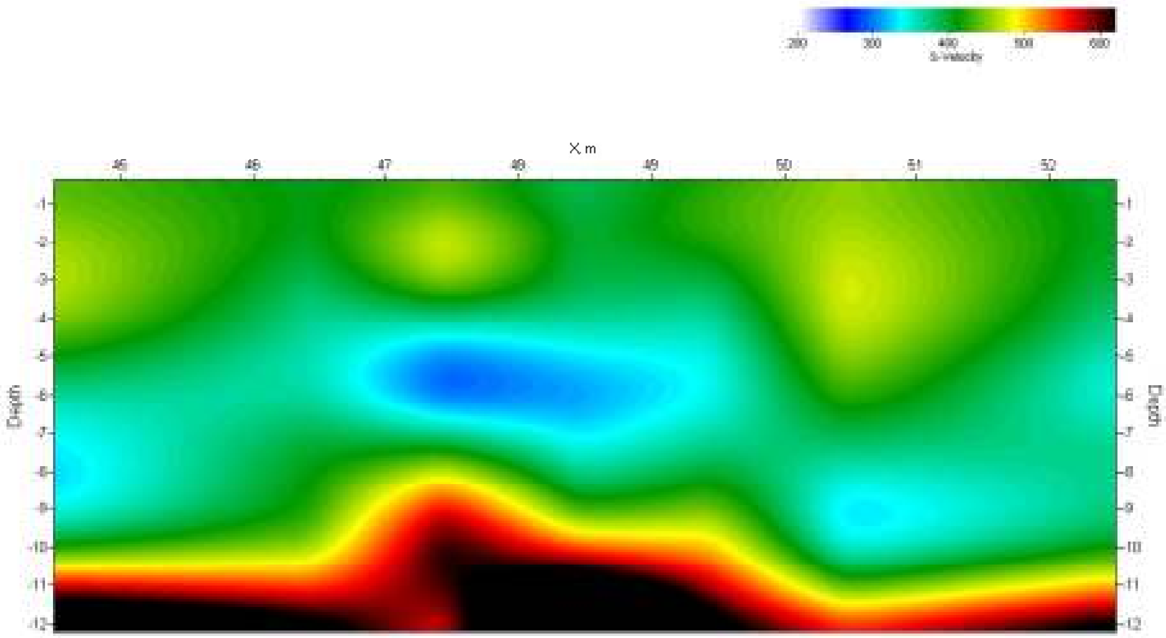


Fig. 3.32. Map of a velocity of a shear wave obtained through the MASW method measurements.

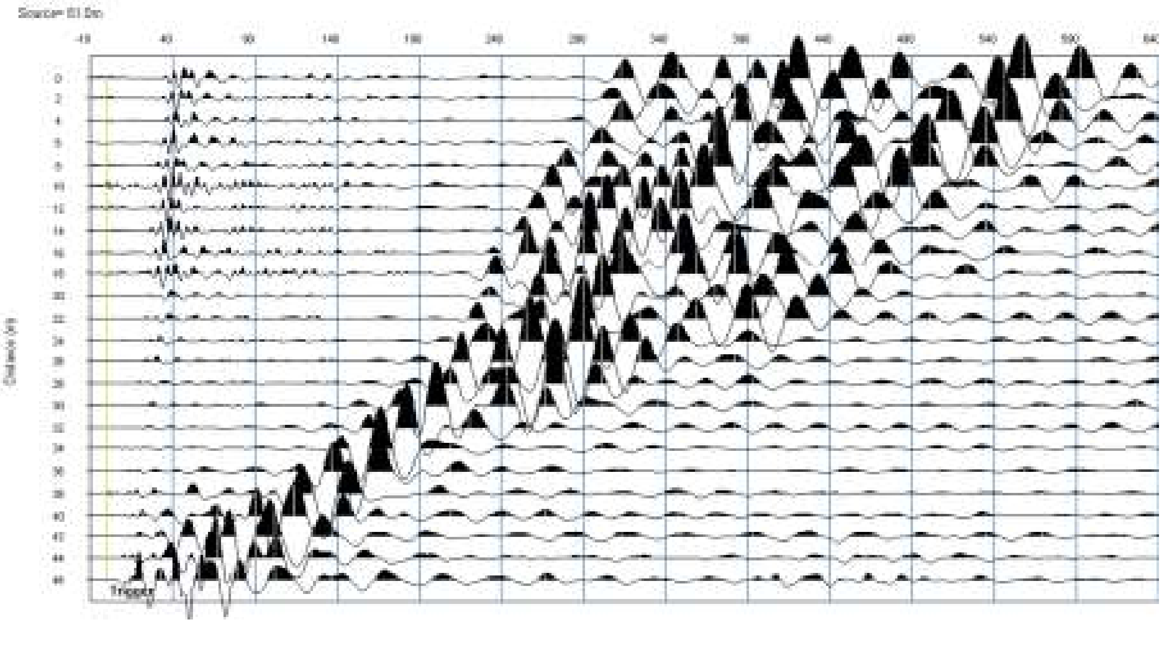
Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 295m/s, maximum 881m/s, average 431m/s. Depth: about 12m. V_{s30}=560 m/s.
This velocity describes B-class grounds, according to the European norm Eurocode 8.

3.8 Seismic measurements in Zabrze (Makoszowy station).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.33 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

Fig. 3.33. Location of the measuring site in Zabrze.

3.8.1 Measurements by the method of a shallow refraction.



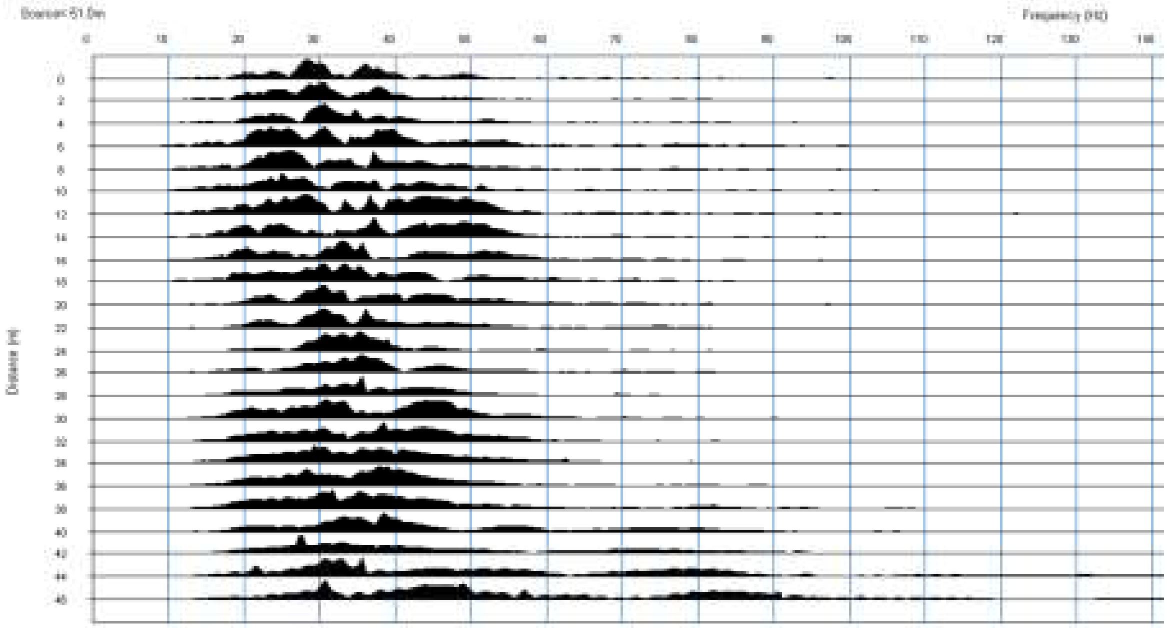


Fig. 3.34. An example seismic recording from the measurements and a corresponding amplitude spectrum.

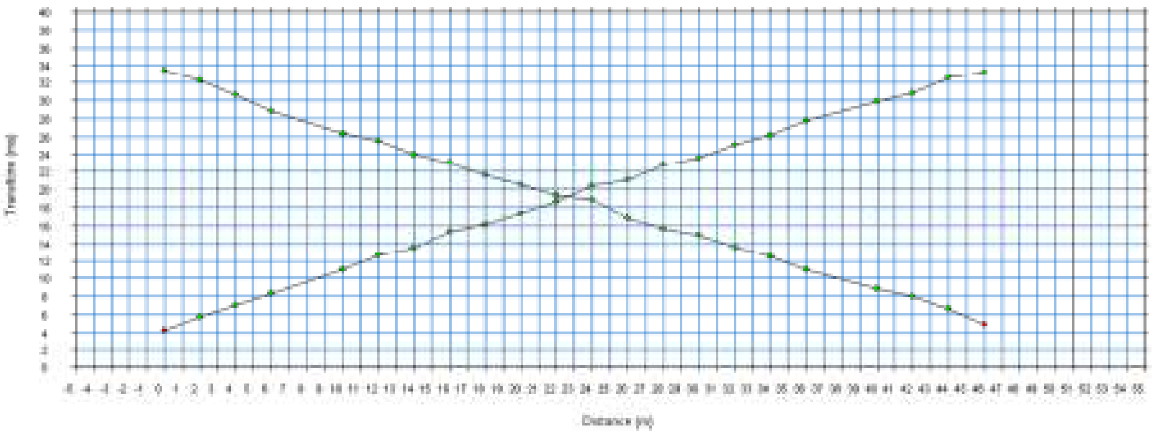


Fig. 3.35. Configuration of convergent hodographs obtained through a seismic profile..

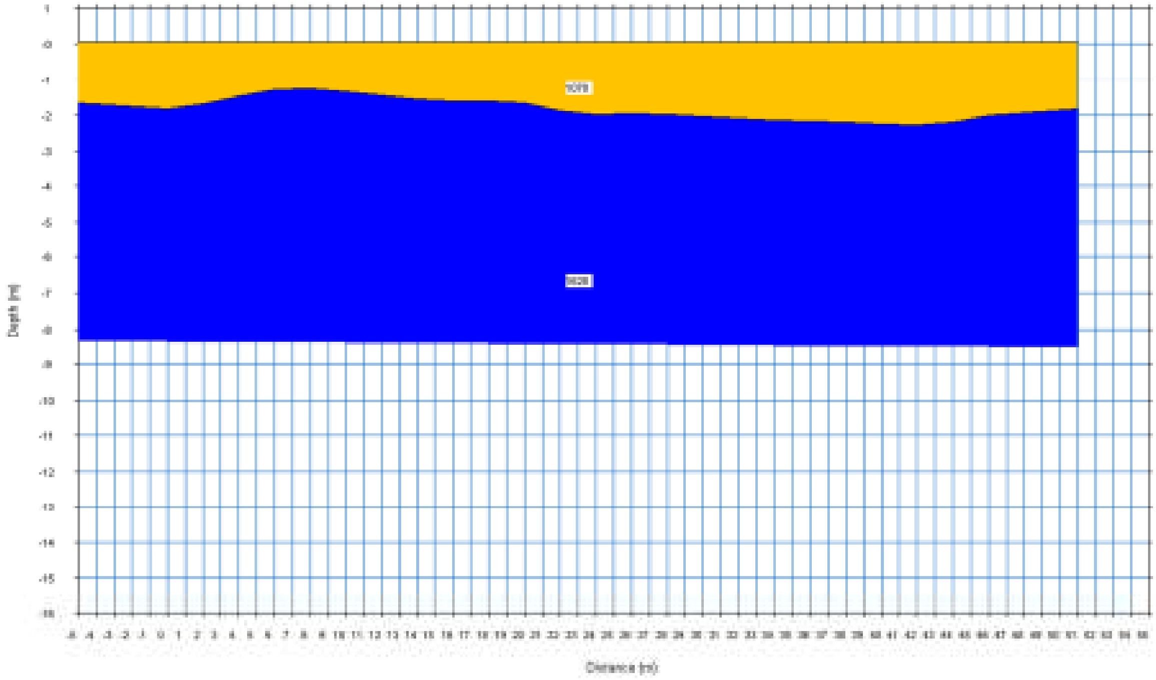


Fig. 3.36. Interpretation of hodographs from the fig. 3.35.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth 2m. The average velocity of P seismic wave over this boundary amounts to 1078 m/s, on the boundary 1628 m/s.

3.8.2 Measurements by the MASW method.

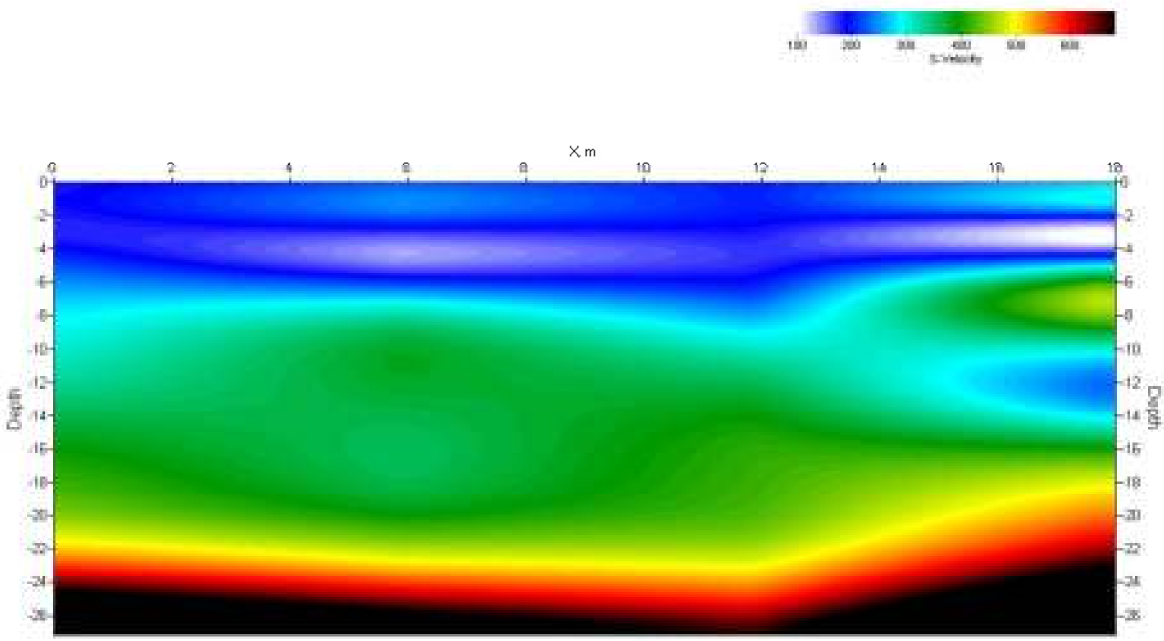


Fig. 3.37. Map of a velocity of a shear wave obtained through the MASW method measurements.

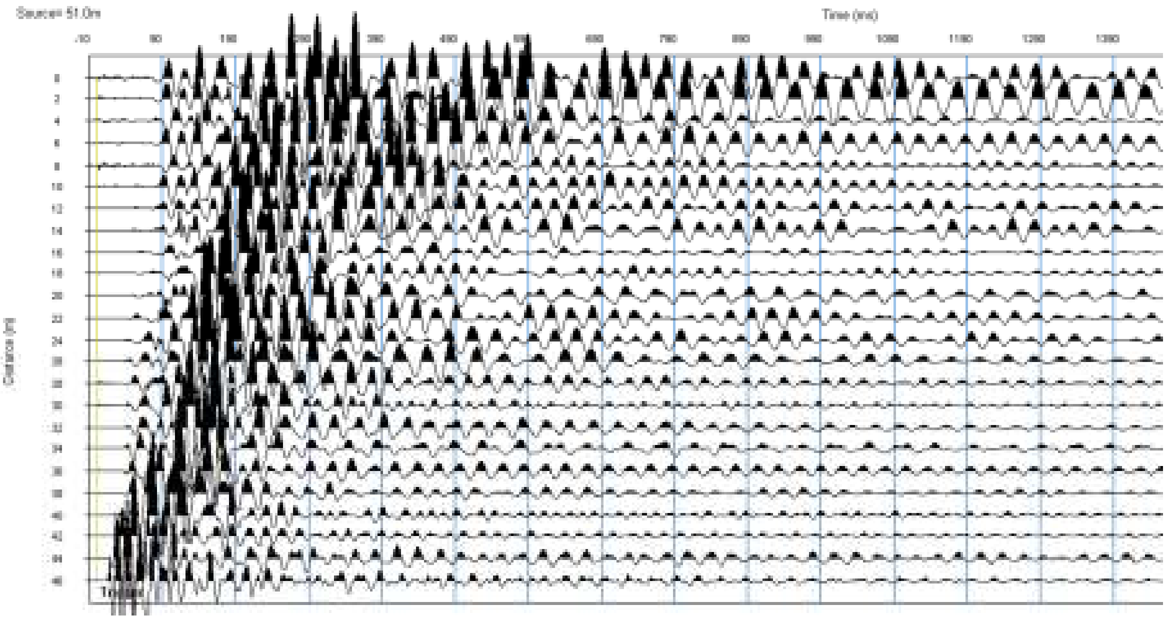
Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 95m/s, maximum 925m/s, average 382m/s. Depth: about 26m. V_{s30}=382 m/s.
This velocity describes B-class grounds, according to the European norm Eurocode 8.

3.9 Seismic measurements in Katowice (Murcki station).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.38 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

Fig. 3.38. Location of the measuring site in Katowice.

3.9.1 Measurements by the method of a shallow refraction.



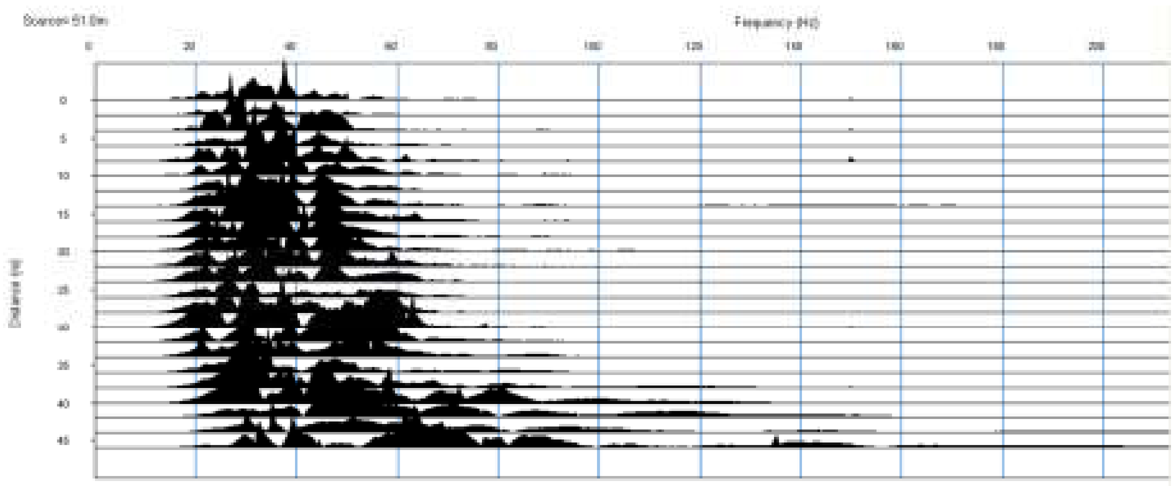


Fig. 3.39. An example seismic recording from the measurements and a corresponding amplitude spectrum.

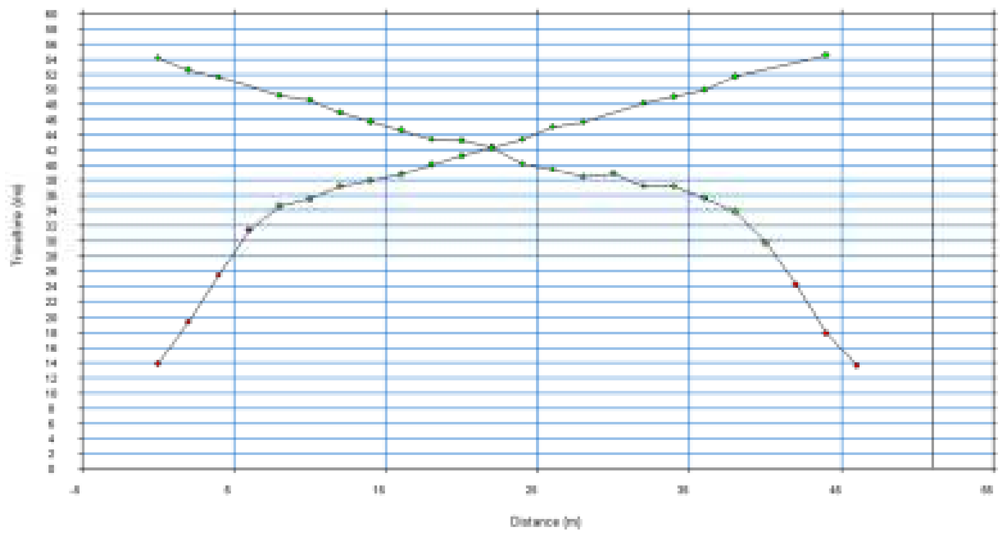


Fig. 3.40. Configuration of convergent hodographs obtained through a seismic profile.

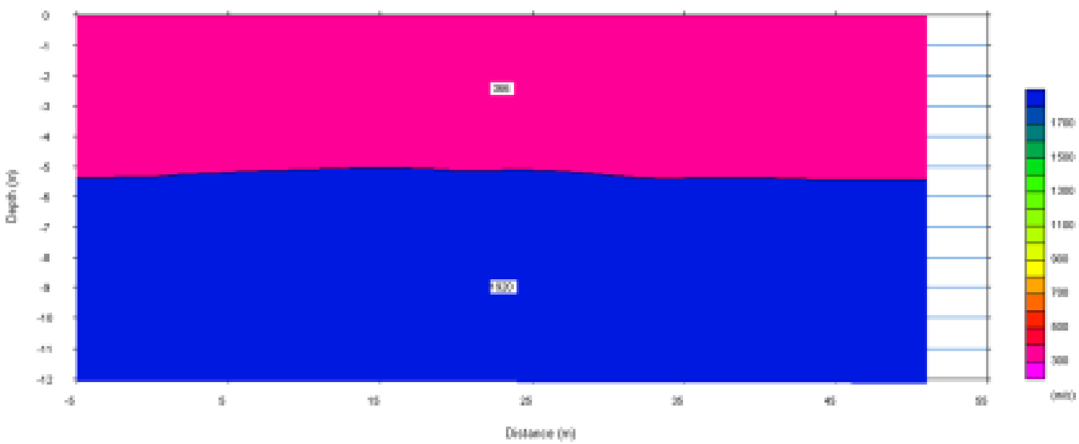


Fig. 3.41. Interpretation of hodographs from the fig. 3.40.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth about 5m. The average velocity of P seismic wave over this boundary amounts to 366 m/s, on the boundary – 1920 m/s.

3.9.2 Measurements by the MASW method.

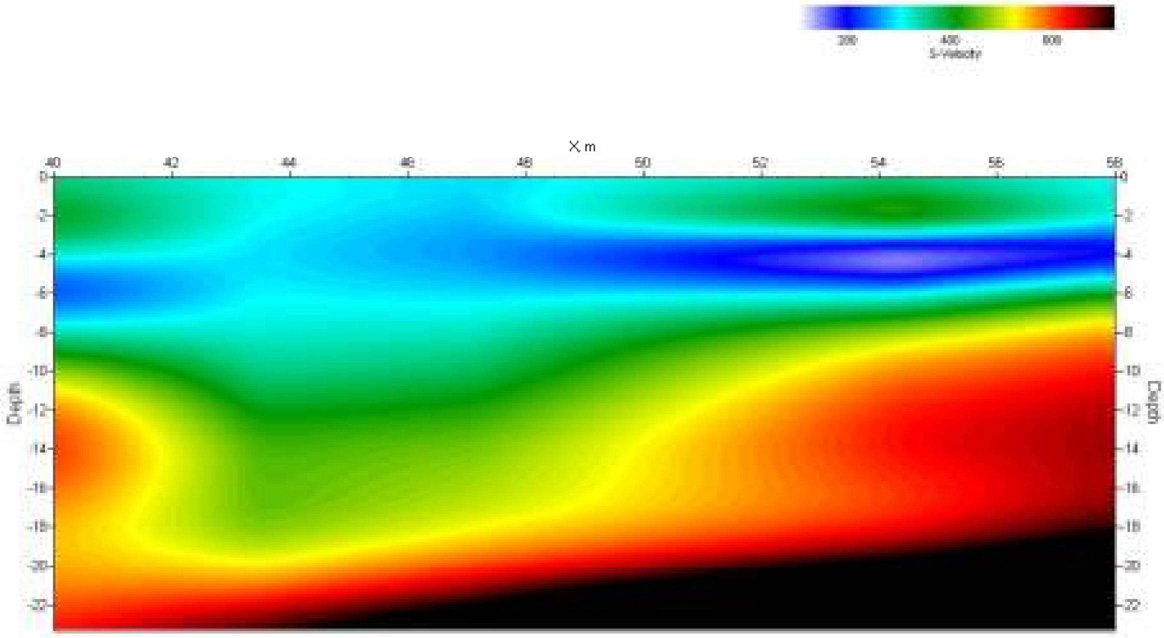


Fig. 3.42. Map of a velocity of a shear wave obtained through the MASW method measurements.

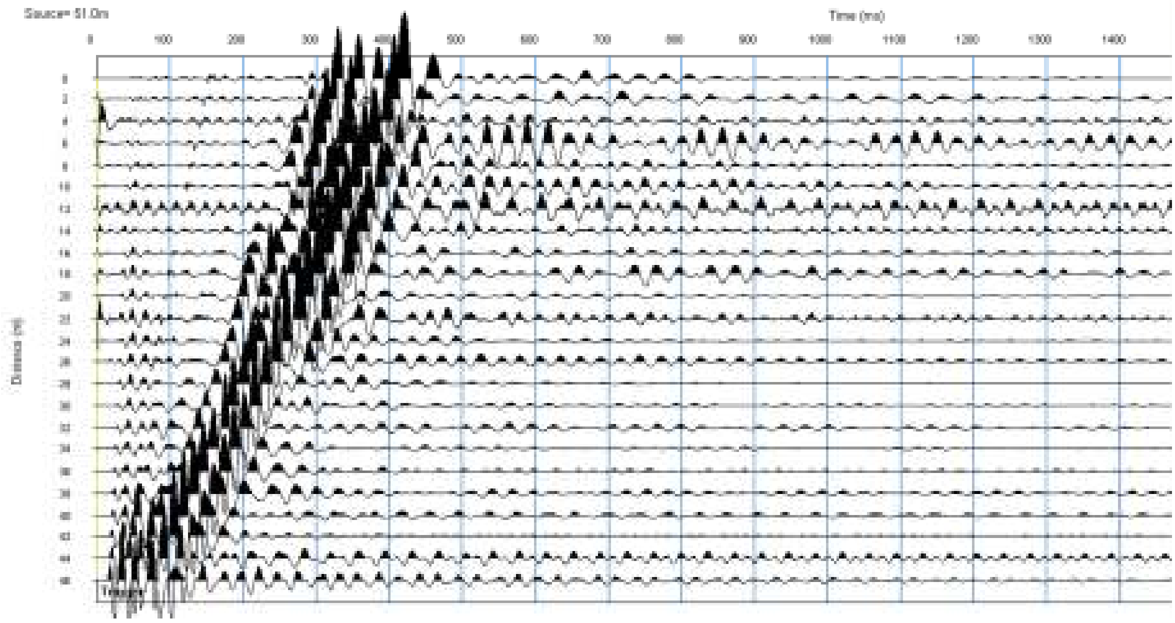
Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 150m/s, maximum 885m/s, average 465m/s. Depth: about 23m. V_{s30}=514 m/s.
This velocity describes B-class grounds, according to the European norm Eurocode 8.

3.10 Seismic measurements in Łaziska Górne (Wyry station).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.43 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

Fig. 3.43. Location of the measuring site in Łaziska Górne.

3.10.1 Measurements by the method of a shallow refraction.



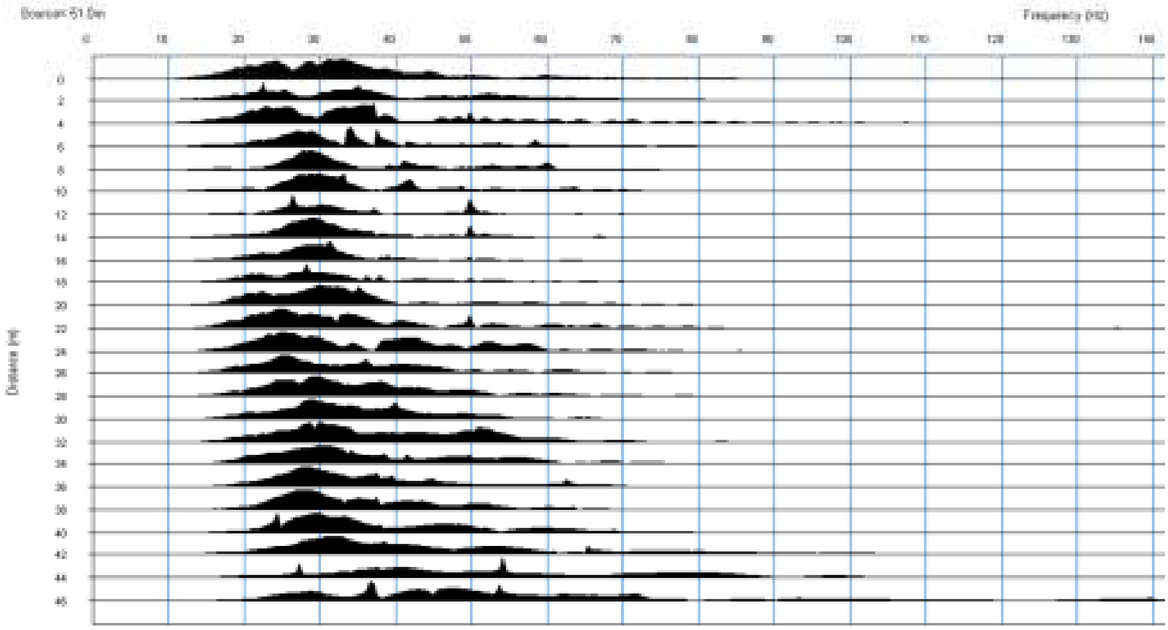


Fig. 3.44. An example seismic recording from the measurements and a corresponding amplitude spectrum.

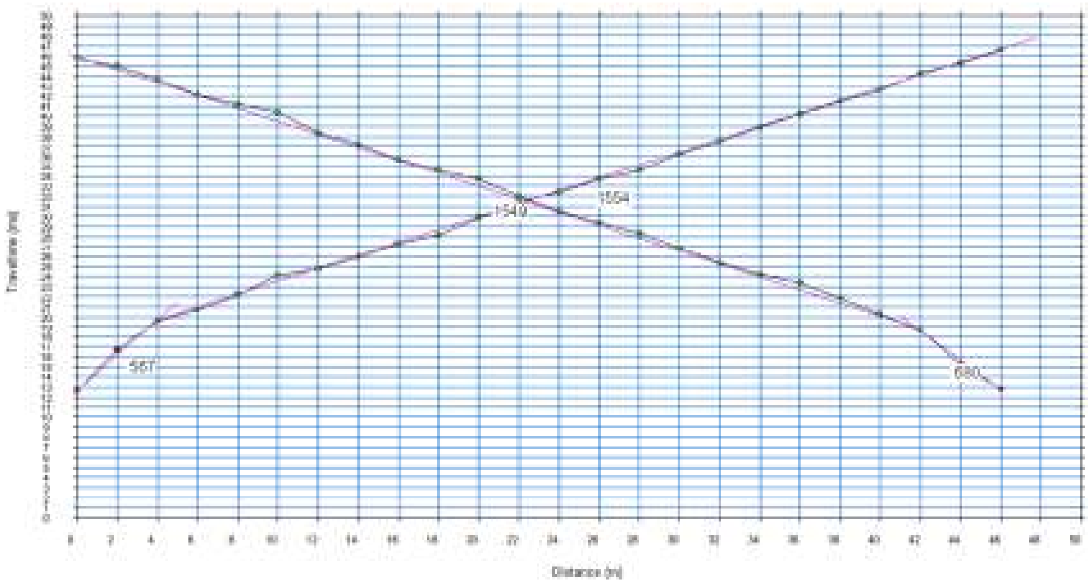


Fig. 3.45. Configuration of convergent hodographs obtained through a seismic profile.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth 3m. The average velocity of P seismic wave over this boundary amounts to 340 m/s, on the boundary – 1443 m/s.

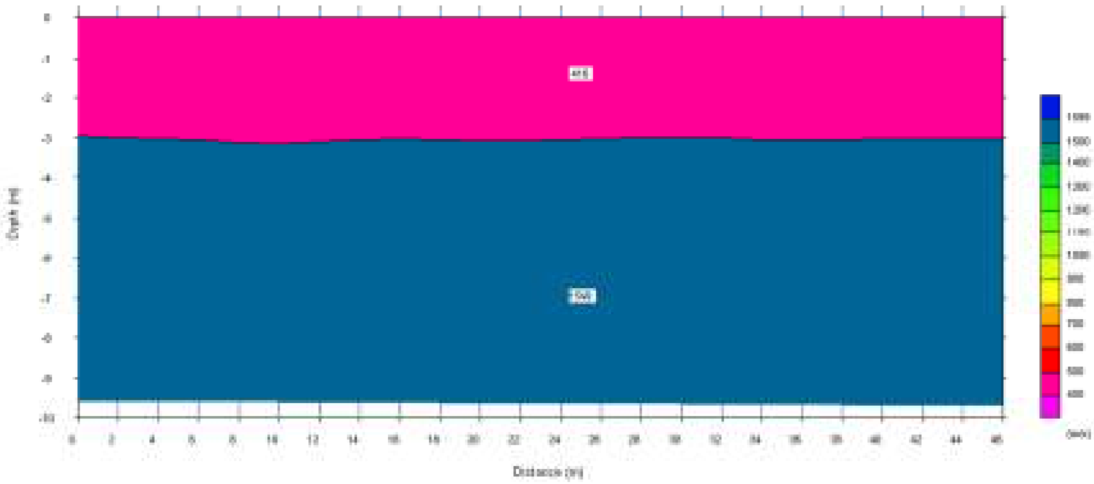


Fig. 3.46. Interpretation of hodographs from the fig. 3.44.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth about 3m. The average velocity of P seismic wave over this boundary amounts to 416 m/s, on the boundary – 1549 m/s.

3.10.2 Measurements by the MASW method.

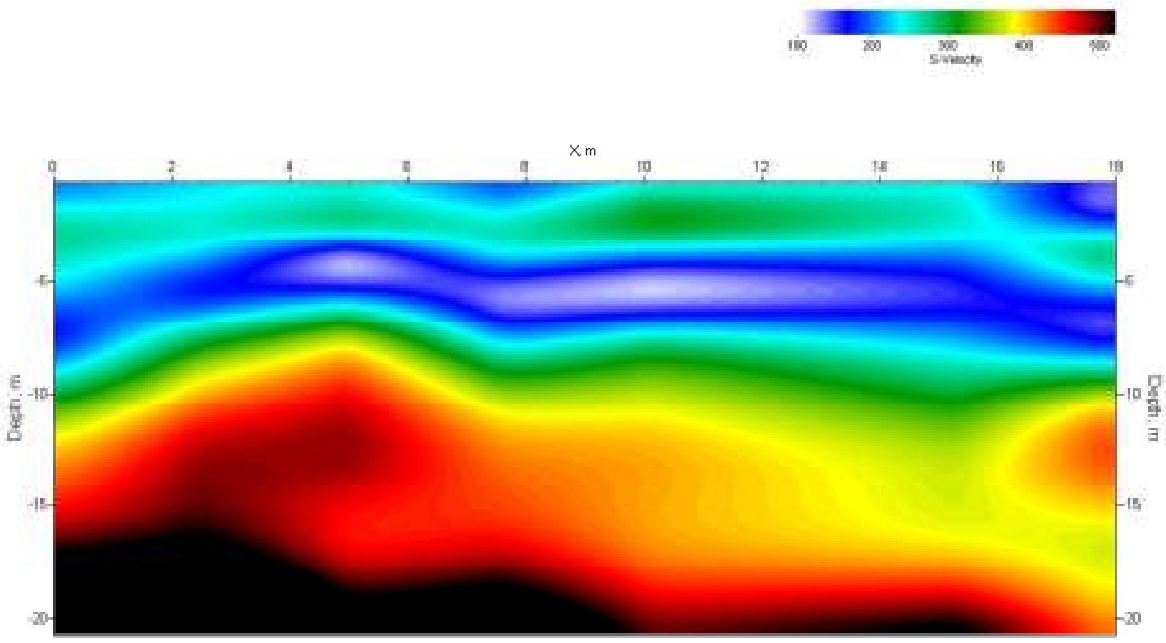


Fig. 3.47. Map of a velocity of a shear wave obtained through the MASW method measurements.

Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 115m/s, maximum 802m/s, average 353m/s. Depth: about 20m. V_{s30}=514 m/s.
This velocity describes B-class grounds, according to the European norm Eurocode 8.

3.11 Seismic measurements in Jaworzno (Jaworzno station).

Seismic measurements were carried in the area of a site of a regional network, by the MASW method. The location of a seismic profile was presented on the fig. 3.48 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

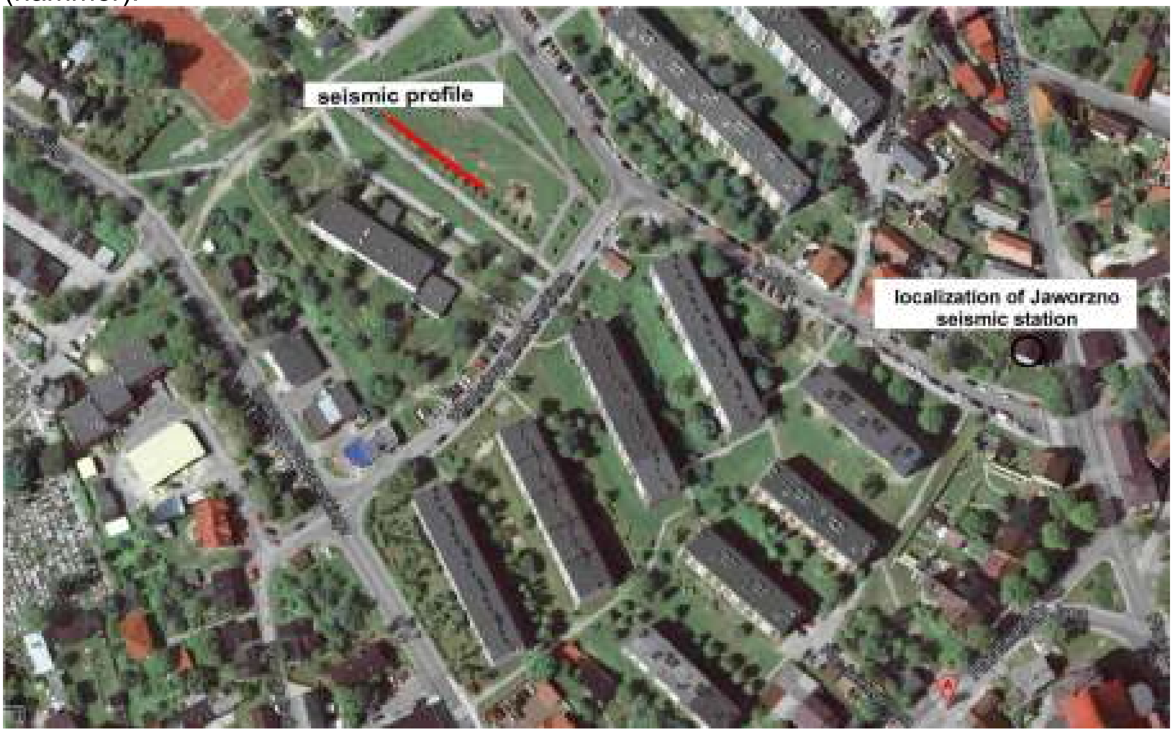


Fig. 3.48. Location of the measuring site in Jaworzno.

Measurements by the MASW method.

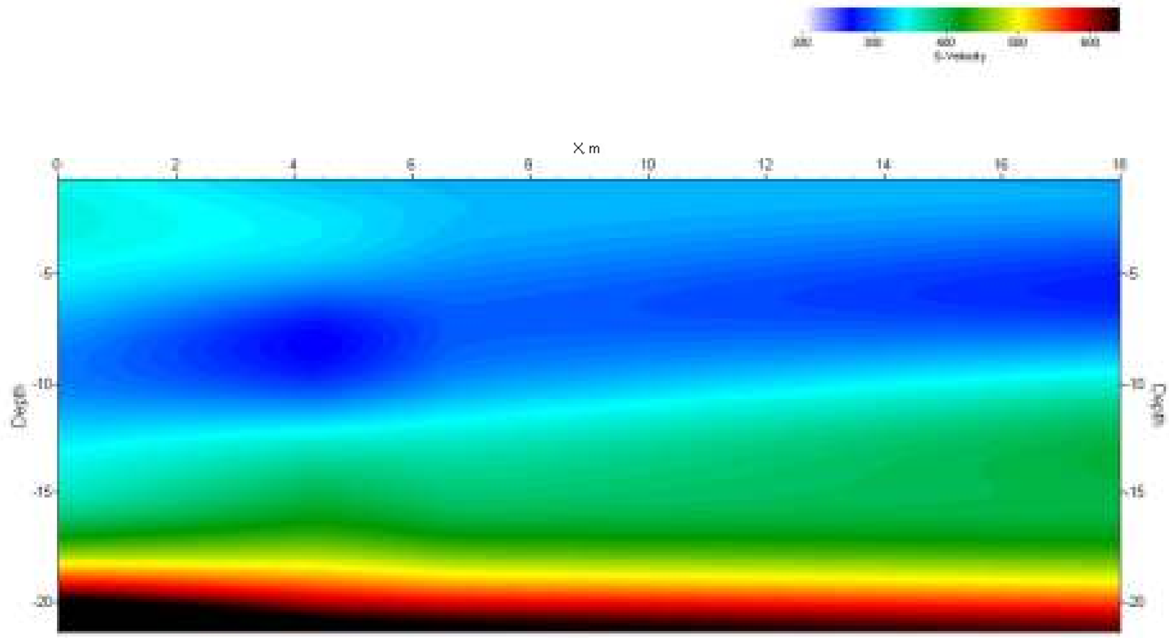


Fig. 3.49. Map of a velocity of a shear wave obtained through the MASW method measurements.

Results of measurements obtained through the MASW method:

Velocity of a wave S: minimum 267m/s, maximum 767m/s, average 379m/s. Depth: about 20m. V_{s30}=380 m/s.
This velocity describes B-class grounds, according to the European norm Eurocode 8.

3.12 Seismic measurements in Balin (Balin station).

Seismic measurements were carried in the area of a site of a regional network, by the method of a shallow refraction and a MASW method. The location of a seismic profile was presented on the fig. 3.50 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

Fig. 3.50. Location of the measuring site Balin.

3.12.1 Measurements by the method of a shallow refraction.

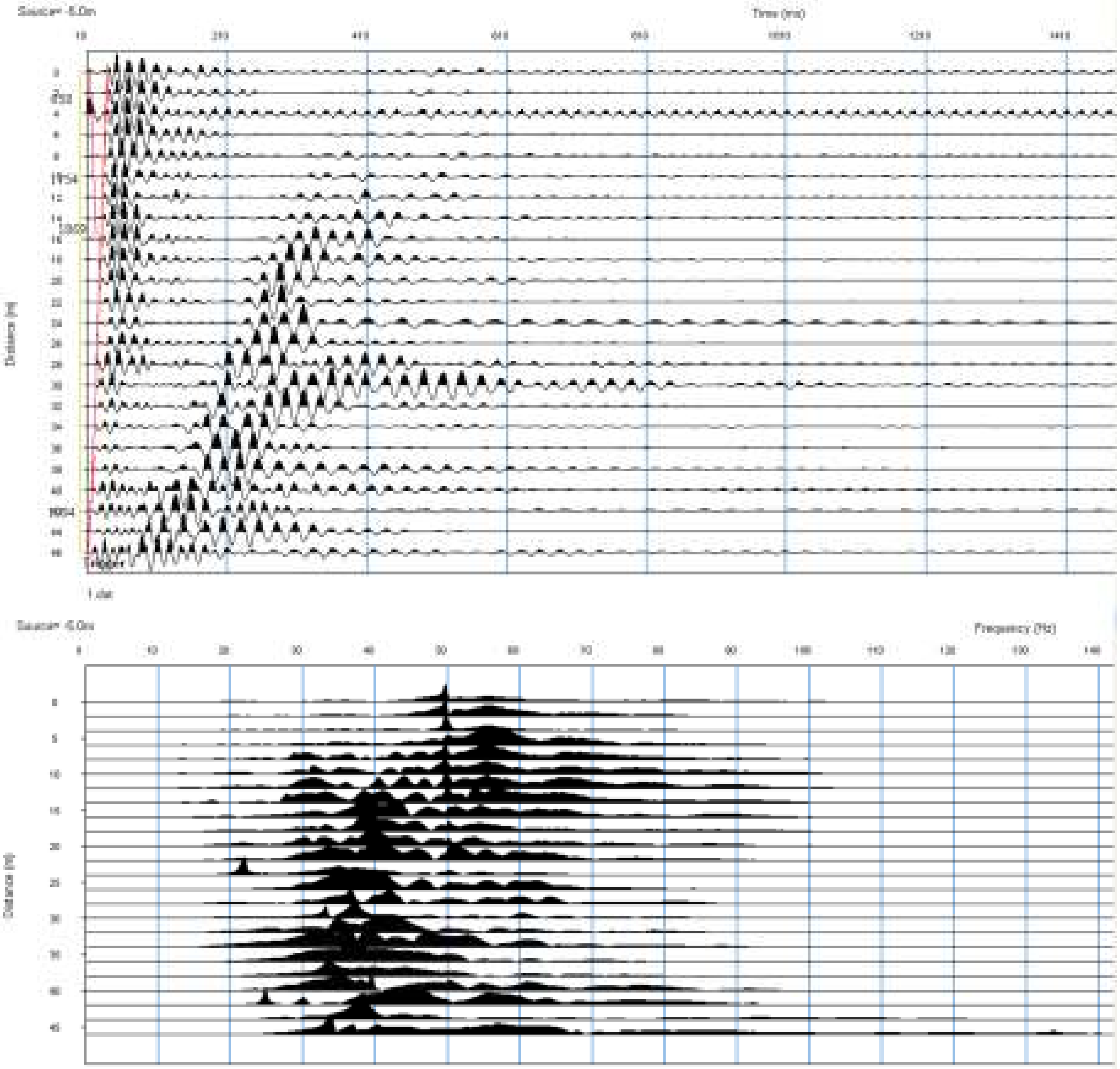


Fig. 3.51. An example seismic recording from the measurements and a corresponding amplitude spectrum.

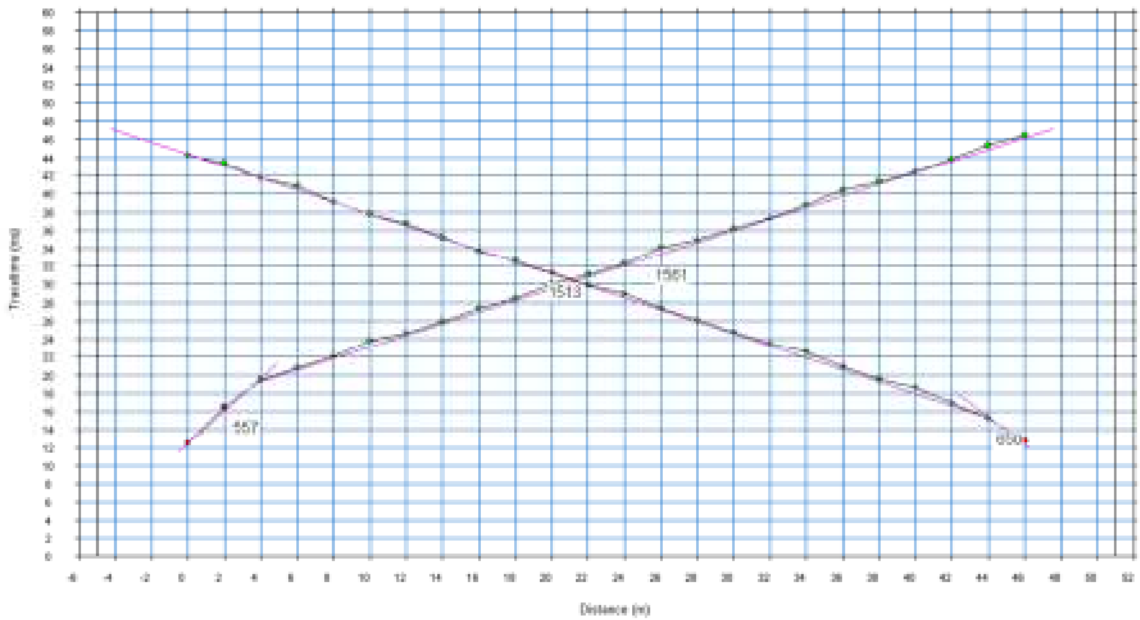


Fig. 3.52. Configuration of convergent hodographs obtained through a seismic profile.

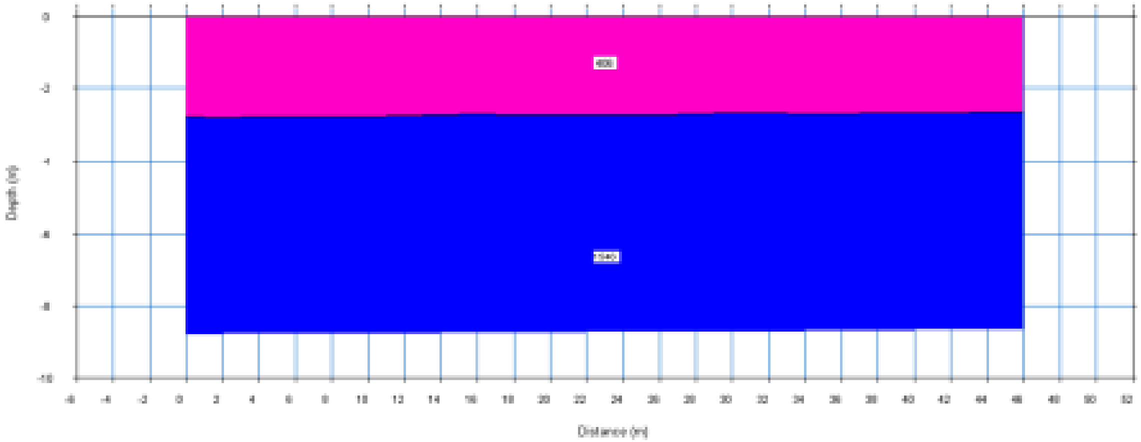
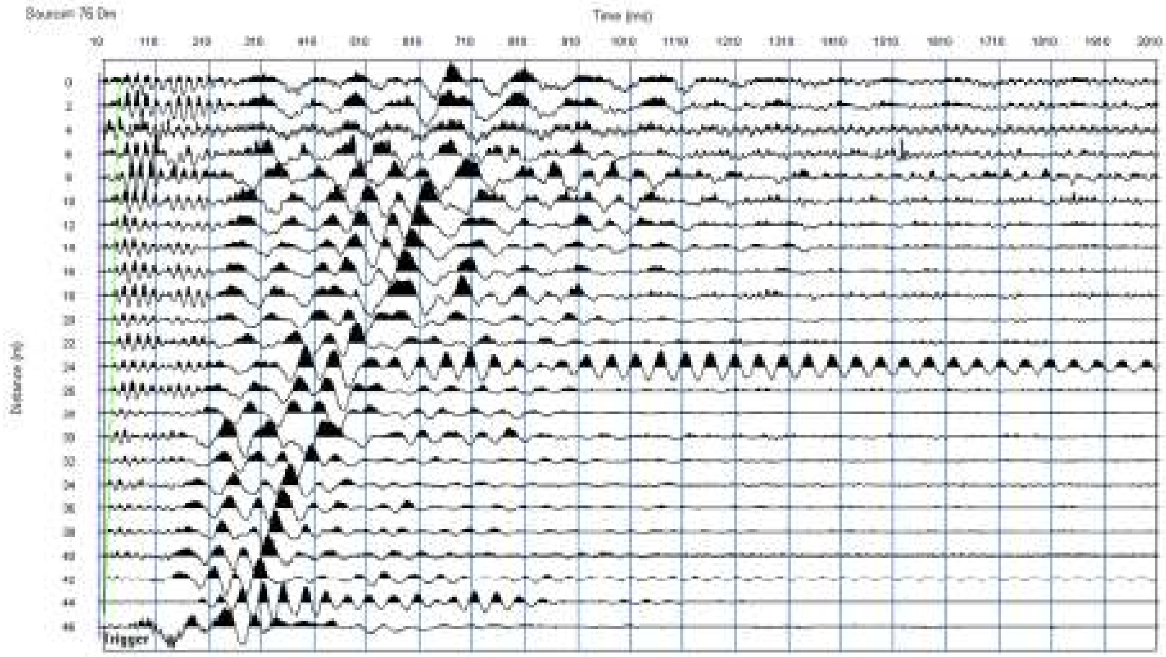


Fig. 3.53. Interpretation of hodographs from the fig. 3.52.

As a result of interpretation of convergent hodographs, one refraction boundary was obtained on the depth 3m. The average velocity of P seismic wave over this boundary amounts to 406 m/s, on the boundary – 1546 m/s.

3.12.2 Measurements by the MASW method.



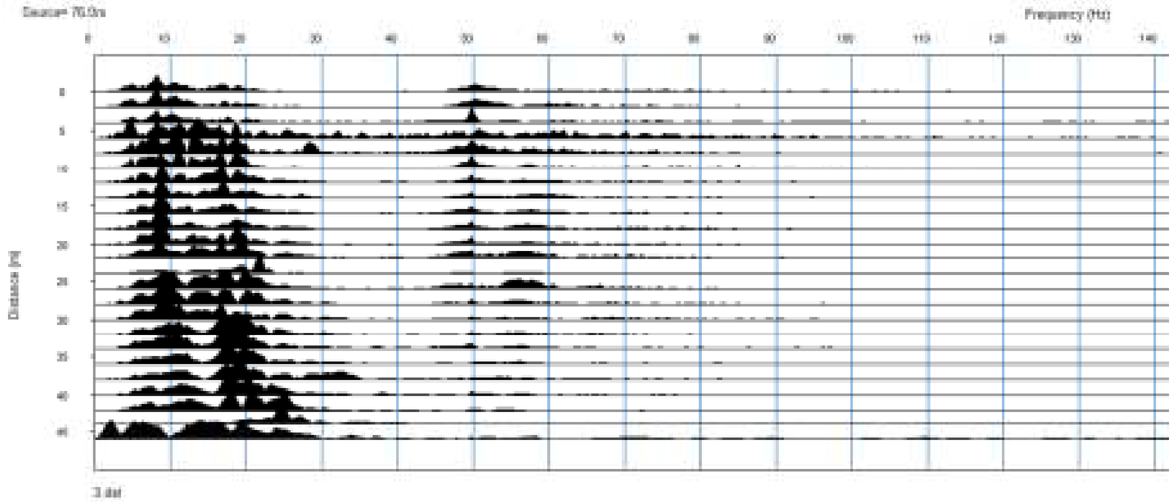


Fig. 3.54. An example seismic recording from the measurements by the MASW method and a corresponding amplitude spectrum.

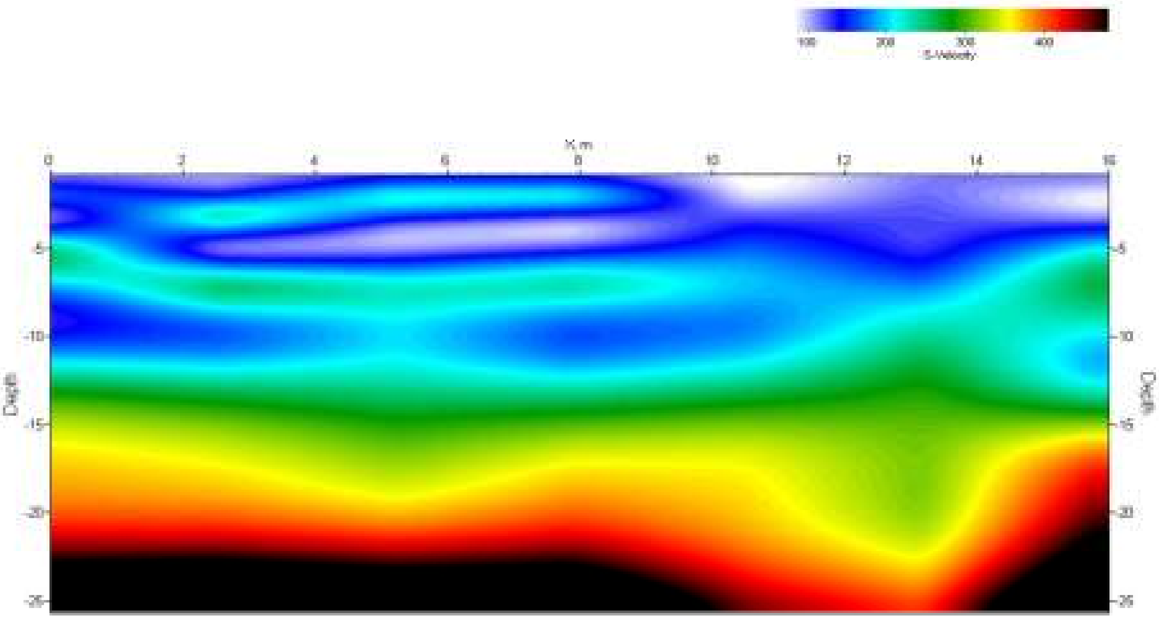


Fig. 3.55. Map of a velocity of a shear wave obtained through the MASW method measurements.

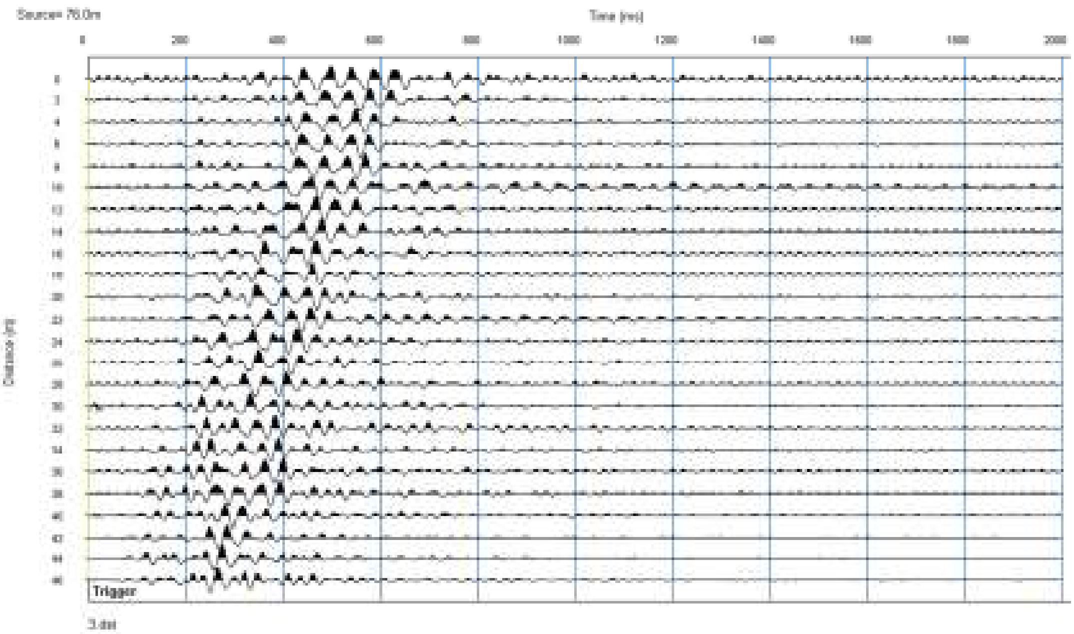
Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 79m/s, maximum 615m/s, average 285m/s. Depth: about 25m. V_{s30}=272 m/s.
This velocity describes C-class grounds, according to the European norm Eurocode 8.

3.13 Seismic measurements in Radzionków (Hubert station).

Seismic measurements were carried in the area of a site of a regional network, by the MASW method. The location of a seismic profile was presented on the fig. 3.56 below. Parameters of the registration: sampling frequency: 1kHz, time of recording: 2 s. Amount of the geophones: 24, distance between the geophones: 2 m. The wave forced by impact (hammer).

Fig. 3.56. Location of the measuring site in Radzionków.

Measurements by the MASW method.



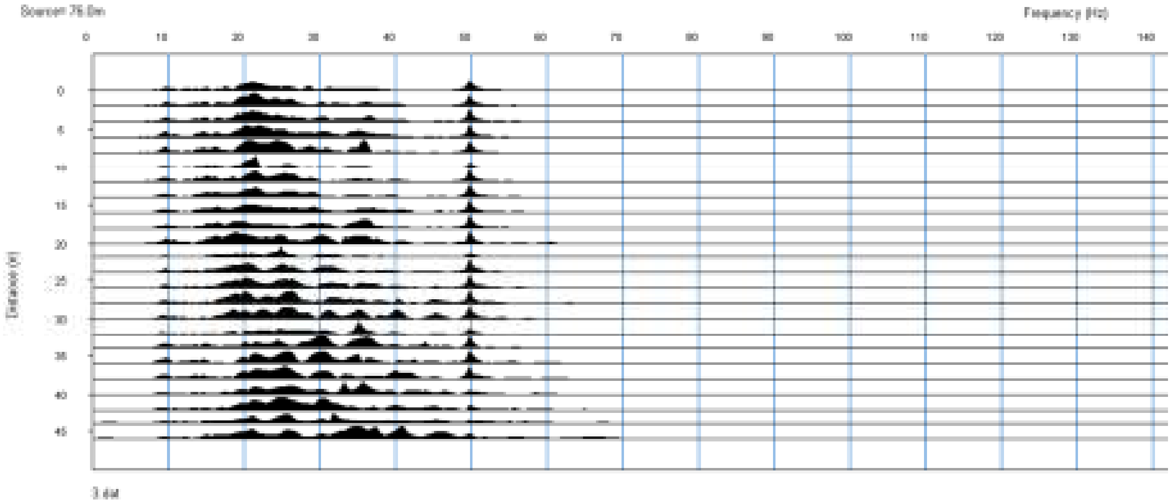


Fig. 3.57. An example seismic recording from the measurements by the MASW method and a corresponding amplitude spectrum.

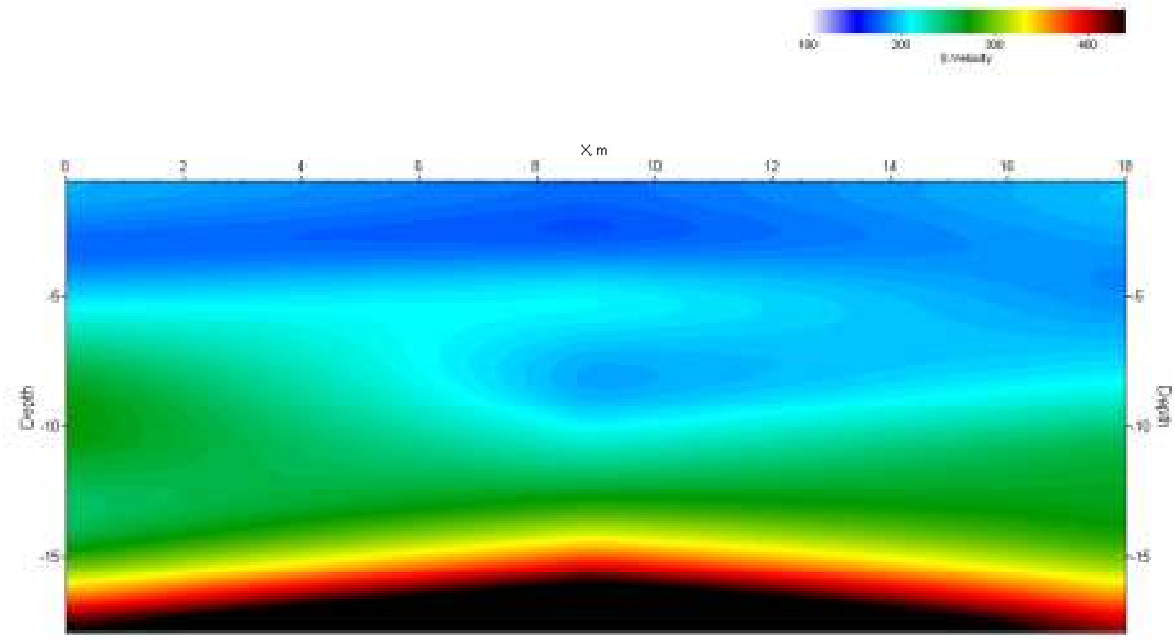


Fig. 3.58. Map of a velocity of a shear wave obtained through the MASW method measurements.

Results of measurements obtained through the MASW method:
Velocity of a wave S: minimum 171m/s, maximum 575m/s, average 256m/s. Depth: about 18m. V_{s30}=312 m/s.
This velocity describes C-class grounds, according to the European norm Eurocode 8.

4. Summary

Tabela 1. Summary of the positions of the Silesian Regional Seismological Network and V_{s30} values.

Station's name	**Coordinates** **the ellipsoidal system GRS80, degrees** **altitude above sea level, m**	**V_{s30}, m/s**

	LAT	LON	Z, m	
Czeczott (CZE)	**50.0171**	**19.1091**	**243**	**418**
Gliwice (GLI)	**50.3038**	**18.6916**	**242**	**330**
Janina (JAN)	**50.0854**	**19.3465**	**266**	**821**
Jesionowa (JES)	**50.2768**	**19.0249**	**291**	**560**
Hubert (HUB)	**50.3903**	**18.8946**	**290**	**312**
Makoszowy (MAK)	**50.2663**	**18.7663**	**227**	**382**
Marcel (MAR)	**50.0411**	**18.4890**	**285**	
Murcki (MUR)	**50.1907**	**19.0444**	**351**	**514**
Planerarium (PLA)	**50.2894**	**18.9938**	**319**	**513**
Łaziska (LAZ)	**50.1397**	**18.8775**	**308**	**514**
Bobrek (BOB)	**50.3532**	**18.8625**	**291**	
Broszkowice (BRO)	**50.0568**	**19.2330**	**229**	**515**
Imielin (I-g, I-d)	**50.1453**	**19.2036**	**267**	**423**
Balin (BAL)	**50.1654**	**19.3924**	**300**	**272**