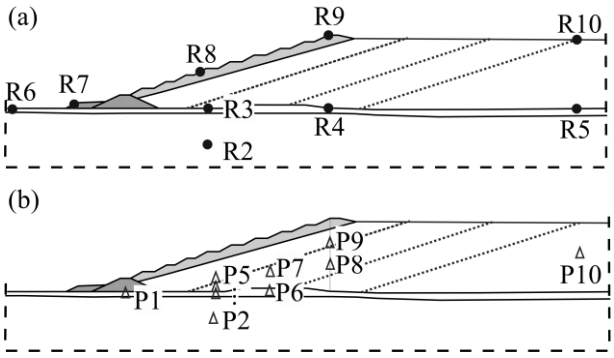


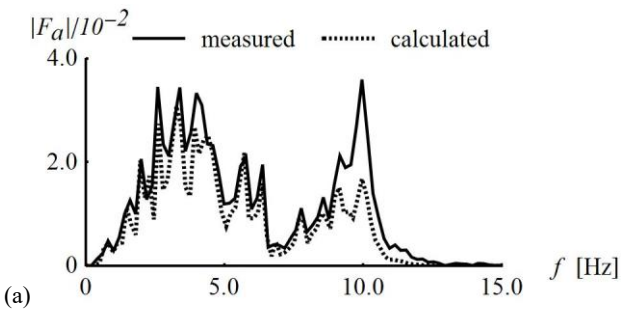
Fig. 7. Selected points for an assessment of the dynamic response of dam.

6 Results

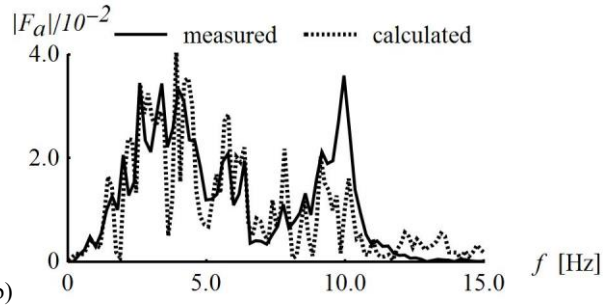
The dynamic response of the tailings dam was successfully reproduced for both material models. Fit has been confirmed by comparison of calculated and measured spectrum of acceleration amplitudes at points corresponding to the location of both seismic stations, Fig. 8. Good agreement was achieved for equivalent linear model while using *chirp* signal as test signal. However, mean value of relative error of amplitude spectrum is 50% higher than for target signal. In the case of HSs material model quite good fit was achieved by incorporating recorded signal. In both cases appropriate selection of *PHA* turned out to be very important. The *PHA* of test signals was reduced by 40% with respect to the measured one.

Errors of the reproduced acceleration and displacement time-series at the seismic station located at the dam toe for both seismic events calculated in *GEOSTUDIO* were shown in Table 2. Relative error of calculated and measured peak horizontal acceleration δpa_x for March seismic event was equal to 1.2%. Mean value of relative errors $\delta|F_a|$ calculated for every frequency was equal to 0.31. L^2-norm $||\Delta F_a||$ of absolute errors vector was equal to 0.023. Relative error of horizontal displacement δpd_x was not larger than 2.2%.

As it was mentioned above, the signals in *PLAXIS* were reproduced with larger error, e.g. relative error of pa_x was equal to 4.46%, and mean value of relative errors $\delta|F_a|$ calculated for every frequencies was equal to 4,6.



(a)



(b)

Fig. 8. Fourier transform of horizontal acceleration time-history measured in March by seismic station K compared with calculated one using (a) EQ, (b) HSs material model.

Table 2. Errors of reproduced acceleration and displacement time-history at the seismic station located at the dam toe.

Error / Signal	δpa_x [%]	$\mu(\delta\|F_a\|)$ [-]	$\|\|\Delta F_a\|\|$ [m/s^2]	δpd_x [%]
March	1.2	0.31	0.023	2.2
November	1.9	0.47	0.062	3.0

Calculated maximum horizontal displacement of the dam crest, assuming equivalent linear material model, was equal to 2.41 mm during March seismic event and 5.89 mm during November seismic event.

The stability analysis carried out for five independent accelerograms scaled to design peak acceleration did not result in any permanent displacements *D* calculated by simplified approach, Table 3. Maximum value of peak horizontal displacement pu_x of the dam crest caused by analyzed dynamic loading was equal to 12.9 mm.

Stability analysis with *full dynamic approach* has been carried out based on the assessment of the resulting variables calculated at selected points. In the article selected results are presented only, Table 3. Maximum value of permanent horizontal displacement due to dynamic loading applied was equal 9.3 mm. Maximum value of peak shear strains $p\gamma$ calculated at selected location P1-P10 were in range $2.1\cdot10^{-5}$ to $9.1\cdot10^{-5}$. The highest additional shear stress with reference to static shear stress $\max\tau_d/\tau_s$ was calculated at point P3 and it was equal to 10.1%.

Table 3. Parameters that describe dynamic response of the dam for selected signals with PGA_x scaled to $0.13g$.

Signal	*#1*	*#2*	*#3*	*#4*	*#5*
D [mm]	0	0	0	0	0
pu_x^{R9} [mm]	12.2	12.9	4.5	4.0	12.1
pu_x^{R9} [mm]	11.0	11.4	3.5	4.1	10.3
pu_x^{R9R7} [mm]	-2.7	-3.1	-1.0	-1.1	-2.4
$p\gamma^{P6}\cdot10^{-5}$ [–]	8.7	9.1	3.9	3.1	7.8
$\max\tau_d/\tau_s^{P3}$ [%]	9.8	10.1	4.5	4.3	8.5

7 Conclusions

The dynamic response of the tailings dam was successfully reproduced. Both simplified and full