

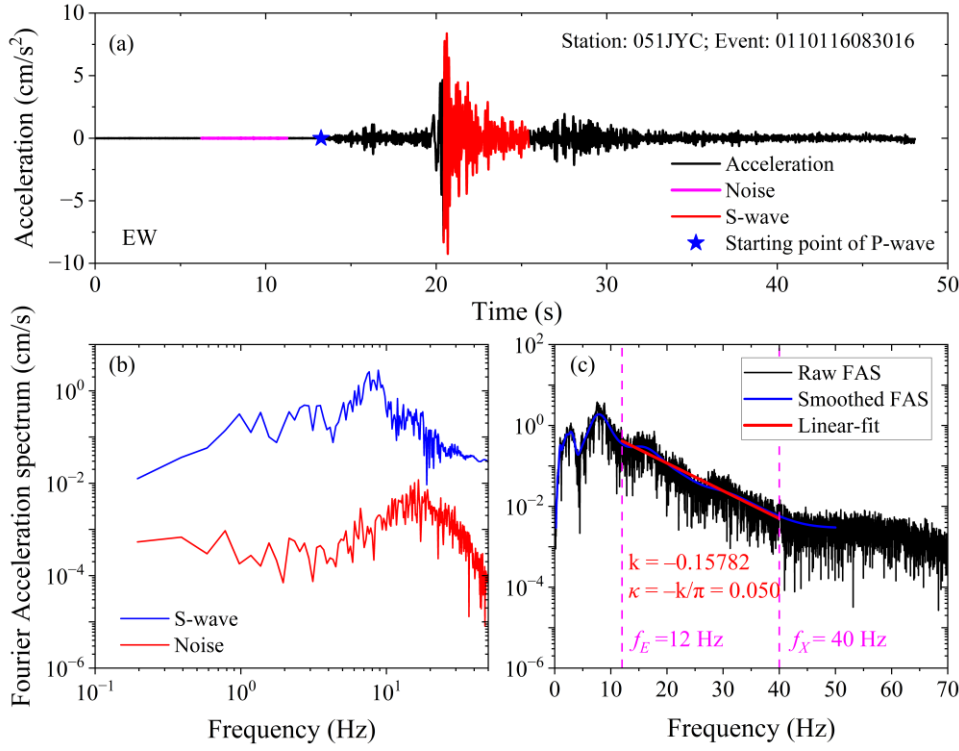


Figure S1. An example of spectral decay kappa estimation. (a) Examples of extracted S-waves (red), background noise (pink), and P-wave starting points (red pentagram). (b) Fourier amplitude spectrum obtained from background noise (red) and S-waves (blue) and (c) an example of the process of estimating the kappa parameter.

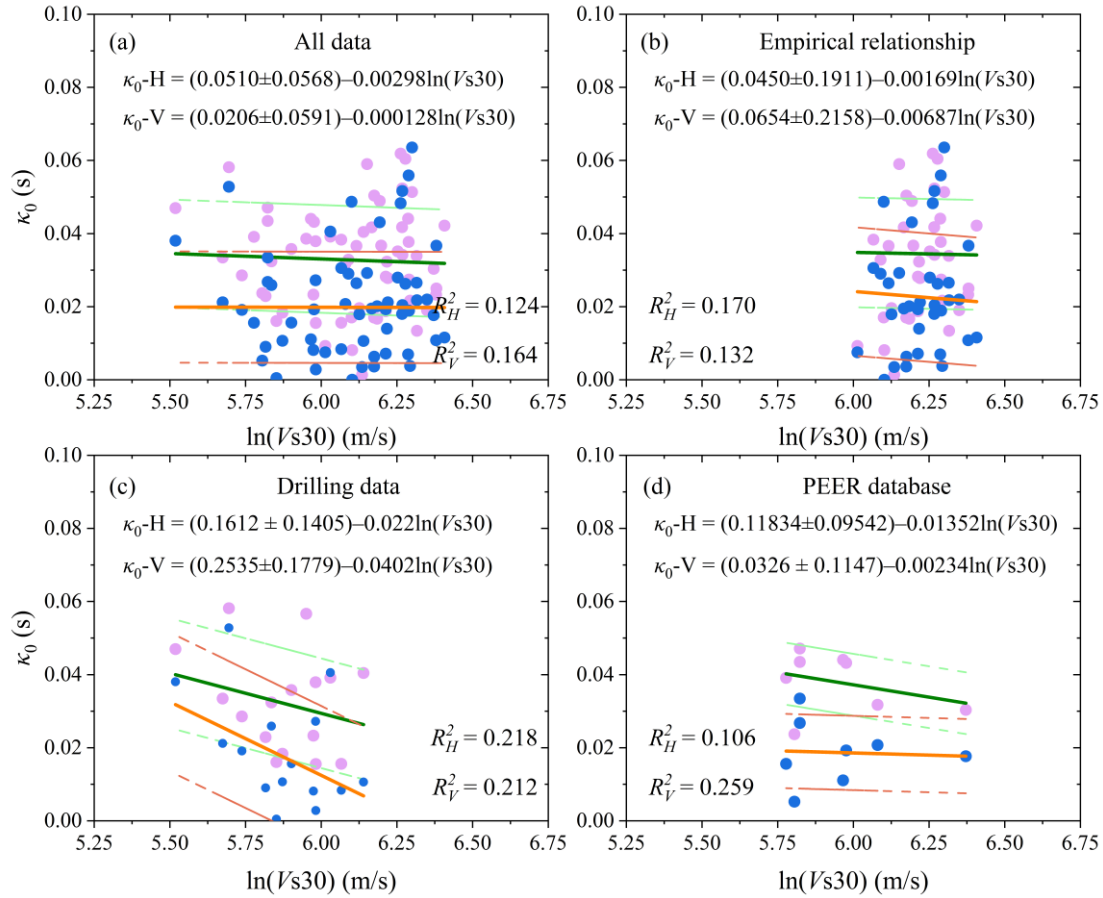


Figure S2. Relationship between zero-distance κ_0 and $Vs30$. The solid lines in green and orange represent the robust

regression results for the horizontal and vertical components, respectively. The corresponding thin dashed lines are the $\pm\sigma$ range. (a) V_s30 values are sourced from empirical relationships, drilling data, and the PEER database. (b) V_s30 values are sourced from an empirical relationship. (c) V_s30 values are sourced from drilling data, and (d) V_s30 values are sourced from the PEER database.

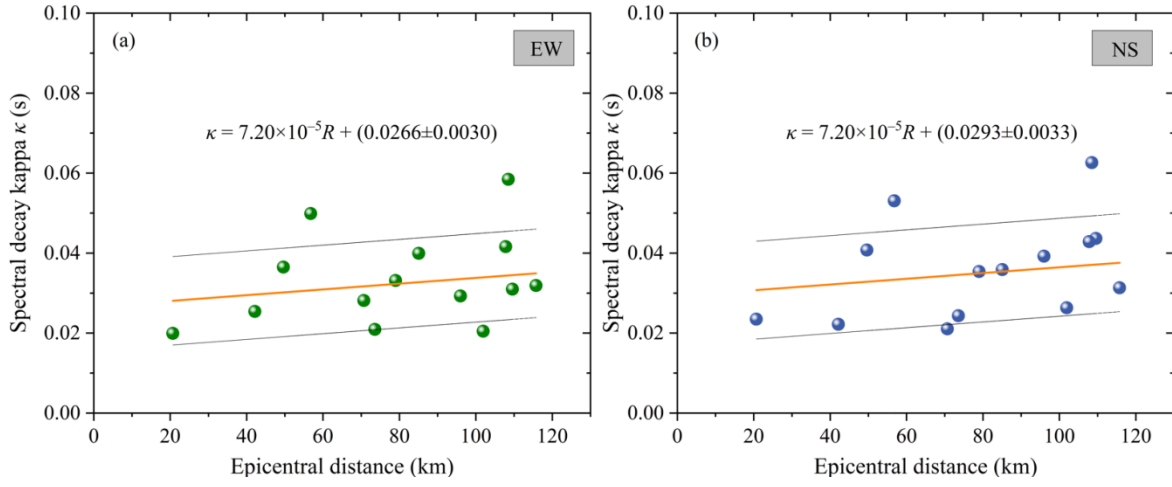


Figure S3. Distribution of spectral decay kappa versus epicentral distance for (a) EW and (b) NS components. The solid circles in these two figures indicate the individual kappa values calculated from the ground motion records of the Changning earthquake in China. The orange solid line indicates the fitted model, and the thin dashed line represents the $\pm\sigma$ range.

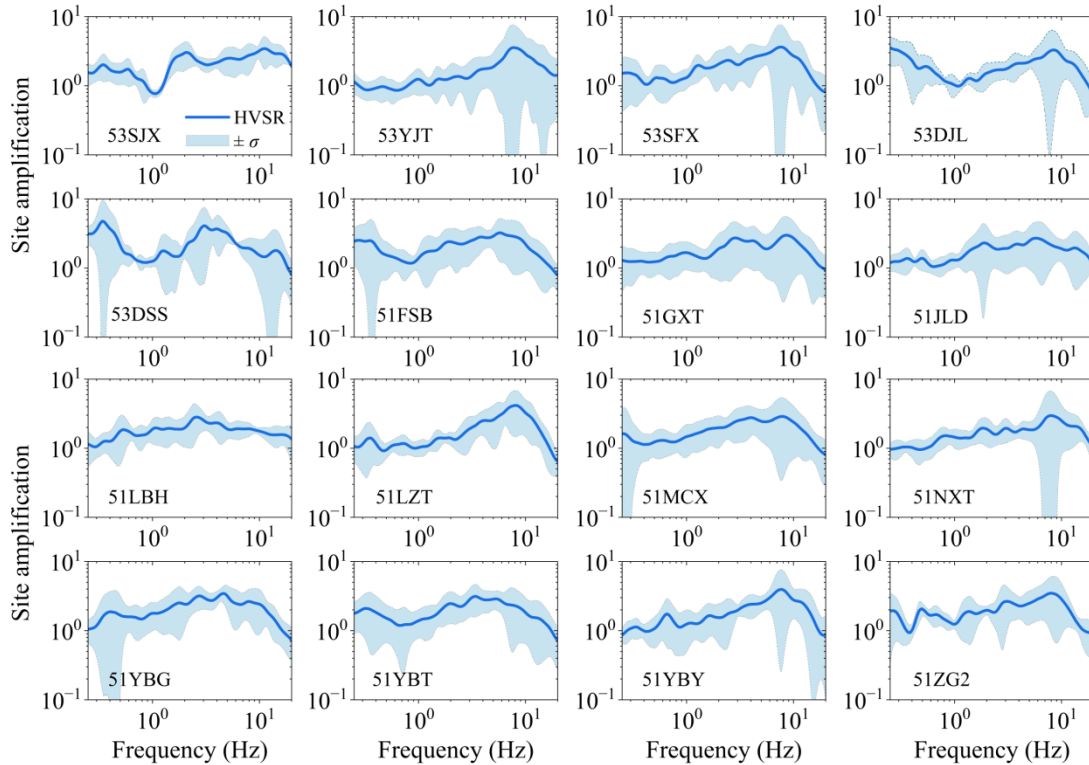


Figure S4. Site effects obtained from the H/V spectral ratio method. The blue solid line indicates the mean result, and the shaded area indicates the $\pm\sigma$ range.

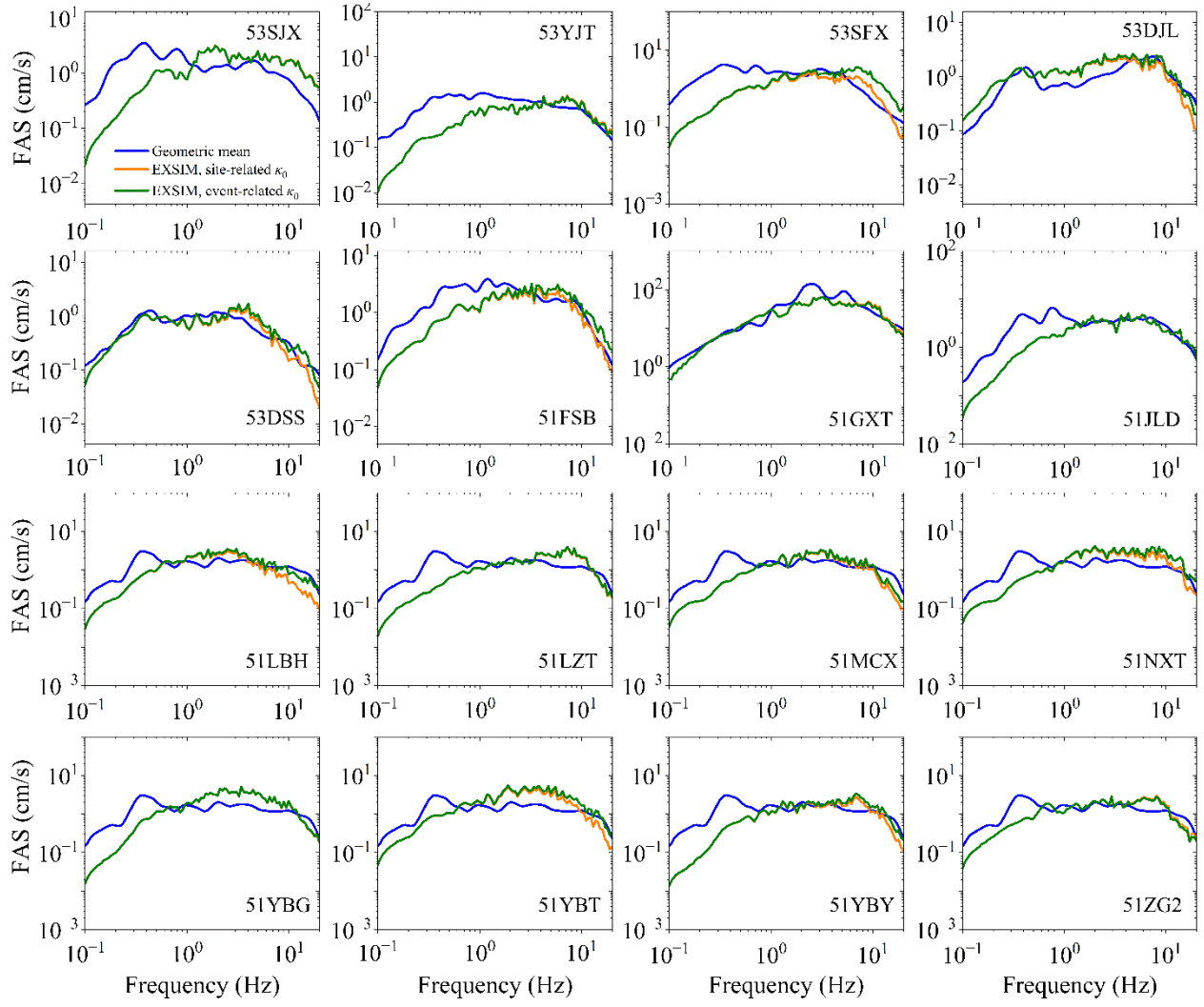


Figure S5. Comparison between the simulated and observed FAS values at 16 selected ground motion stations. The red and blue solid lines indicate the PSA obtained from the EW and NS components, respectively, and the orange and green solid lines represent the simulated PSA obtained from site-related κ_0 and event-related κ_0 , respectively.

Table S1 Strong motion stations selected in this study for the western-central Sichuan region, China

No.	Station name	κ_0 -EW (s)	κ_0 -NS (s)	κ_0 -UD (s)	# of records	Latitude (°N)	Longitude (°E)	f_{peak} (Hz)	A_{peak}	V_{s30} (m/s)	Site condition
1	51LXT	0.022884	0.022892	0.009026	42	31.6	103.4	3.56	2.77	335.69 #	SOIL
2	51BCB	0.033573	0.039988	0.026436	41	31.799	104.199	2.86	2.61	453.31	SOIL
3	51LXK	0.012456	0.023210	0.003622	37	31.6	103.3	5.07	3.00	480.42	SOIL
4	51MXN	0.011699	0.020642	0.002814	35	31.6	103.699	7.60	2.95	396.25 #	SOIL
5	51SFB	0.058786	0.057497	0.052800	33	31.3	104	3.30	2.60	297.43 #	SOIL
6	51MXF	0.026103	0.041362	0.029000	33	31.799	104	2.80	2.73	441.48	SOIL
7	51GXT	0.019404	0.024145	0.003741	31	28.4	104.8	8.61	2.98	541.17	SOIL
8	51EMS	0.031528	0.036483	0.026548	26	29.6	103.5	7.40	2.66	552.96	SOIL
9	51DJZ	0.045345	0.052718	0.043087	25	31	103.599	4.63	2.77	489.41	SOIL
10	51WCD	0.001416	0.001240	0.003474	25	31.5	103.599	3.00	2.57	461.74	SOIL
11	51MXB	0.013482	0.006328	0.007501	24	31.899	103.599	3.03	3.31	408.86	SOIL

12	51YBT	0.036360	0.040401	0.030572	22	28.7	104.599	3.41	3.13	431.07	SOIL
13	51SWH	0.020388	0.026618	0.010800	22	29.299	103.599	7.70	2.38	589.55	SOIL
14	51WCW	0.036445	0.035125	0.015617	21	31	103.199	7.52	2.79	365.54 #	SOIL
15	51MCL	0.035186	0.029830	0.025899	21	29	103.699	3.03	4.92	342.23 #	SOIL
16	51DJH	0.064552	0.056565	0.026252	21	31.1	103.699	7.55	2.90	532.81	SOIL
17	51LXS	0.020349	0.017243	0.007145	20	31.5	102.9	4.73	2.69	499.25	SOIL
18	51LSL	0.028968	0.025972	0.018918	19	29.5	103.8	7.25	2.78	539.16	SOIL
19	51HSS	0.008610	0.007638	0	18	31.899	103.4	3.36	2.89	446.86	SOIL
20	51BXD	0.033283	0.027673	0.017658	17	30.399	102.8	6.85	3.37	585.00 &	ROCK
21	51AXD	0.026418	0.023625	0.036691	17	31.6	104.4	8.86	2.53	590.26	SOIL
22	51JYC	0.041730	0.039176	0.010604	16	31.9	105	8.42	3.35	463.99 #	SOIL
23	51PJW	0.046928	0.047274	0.026762	16	30.299	103.699	3.52	3.08	338.00 &	ROCK
24	51MZX	0.055681	0.049141	0.051615	16	31.399	104.199	3.60	2.12	527.36	SOIL
25	51AXH	0.040585	0.042965	0.018009	16	31.5	104.599	5.87	2.65	527.03	SOIL
26	51BCQ	0.029516	0.035342	0.013965	16	31.799	104.5	7.70	3.31	501.21	ROCK
27	51PJD	0.039458	0.049096	0.011054	15	30.3	103.4	7.38	3.11	390.00 &	SOIL
28	51LSJ	0.012121	0.020044	0.008375	15	30.2	102.9	2.79	2.82	431.05 #	SOIL
29	51JYH	0.039594	0.038629	0.015587	15	31.8	104.6	5.90	3.81	323.00 &	SOIL
30	51MCX	0.038393	0.037052	0.055882	15	28.9	103.9	7.82	2.88	538.51	SOIL
31	51LXM	0.039828	0.020488	0.019120	14	31.7	102.8	3.53	2.73	310.47 #	SOIL
32	51HYP	0.061726	0.056354	0.029222	14	29.2	102.8	3.86	2.78	469.35	SOIL
33	51YAM	0.010101	0.017774	0.021746	14	30.1	103.099	7.81	2.72	553.52	SOIL
34	51LDJ	0.040307	0.046879	0.033435	13	29.7	102.199	3.58	2.91	338.00 &	SOIL
35	51MXD	0.031339	0.035681	0.021184	13	32	103.699	3.65	3.61	291.30 #	ROCK
36	51FSB	0.043760	0.039736	0.019486	13	29.1	104.8	5.76	3.22	476.57	ROCK
37	51BXZ	0.048445	0.038538	0.019262	12	30.5	102.9	3.12	2.99	394.00 &	ROCK
38	51YAS	0.038407	0.037408	0.027208	12	29.899	103	7.49	2.21	395.98 #	SOIL
39	51HYT	0.027926	0.036095	0.020740	12	29.899	103.4	7.04	3.00	437.00 &	SOIL
40	51QLY	0.021715	0.025001	0.008137	12	30.399	103.3	0.22	3.52	393.17 #	SOIL
41	51JKH	0.015014	0.017222	0.000452	12	29.2	103.099	3.32	3.64	347.93 #	SOIL
42	51HSD	0.014305	0.023538	0.010670	12	32.099	103	3.20	3.36	354.88 #	SOIL
43	51BCY	0.066601	0.057451	0.048299	12	31.7	104.5	4.38	2.35	524.45	SOIL
44	51YAL	0.057615	0.045725	0.063528	12	29.899	102.8	8.16	2.87	544.66	SOIL
45	51PWP	0.052065	0.037303	0.006935	12	32.099	104.699	8.06	2.93	537.51	SOIL
46	51ZGS	0.044731	0.027561	0.027945	12	29.399	104.599	7.11	2.97	519.36	ROCK
47	51BCZ	0.029686	0.026831	0.019291	12	31.899	104.3	5.27	2.82	499.25	SOIL
48	51YAD	0.046510	0.047381	0.038048	11	30	103	5.67	3.37	249.23 #	SOIL
49	51BXY	0.020359	0.027538	0.005244	11	30.5	102.9	5.66	2.37	332.00 &	SOIL
50	51MZQ	0.036210	0.032271	0.020419	11	31.5	104.099	7.46	2.94	527.57	SOIL
51	51MBD	0.031700	0.024431	0.021177	11	28.799	103.5	8.81	3.50	502.68	SOIL
52	51CNT	0.026409	0.051039	0.115415	11	28.6	104.9	2.97	2.25	491.80	ROCK
53	51PWN	0.016145	0.017972	0.048704	11	32.2	104.8	3.40	2.91	446.04	SOIL
54	51JYW	0.015693	0.023093	0.021947	11	31.899	104.8	9.77	2.81	572.35	SOIL
55	51SML	0.057247	0.026029	0.122043	10	29	102.3	7.38	2.59	383.92 #	SOIL
56	51TQL	0.038586	0.039747	0.040571	10	29.899	102.4	4.09	2.40	415.75 #	ROCK

57	51BXM	0.035356	0.050311	0.011555	10	30.399	102.699	11.2	2.66	606.14	SOIL
58	51LSQ	0.045153	0.056213	0.006322	10	29.2	103.9	3.90	2.66	480.57	SOIL
59	53YJT	0.015343	0.018136	0.020098	10	28.1	104.2	7.78	3.56	485.23	ROCK
60	51PWD	0.015875	0.024214	0.017930	10	32.4	104.5	6.88	3.79	457.65	SOIL
61	51SMX	0.069506	0.066544	0.044927	9	29.299	102.3	2.71	4.78	332.65	SOIL
62	51HSL	0.013990	0.016114	0.011023	9	32.099	103.3	4.33	2.37	520.26	SOIL
63	53YST	0.034468	0.036902	0.010487	9	28.2	103.599	7.55	3.04	520.47	ROCK
64	51YBG	0.028155	0.021067	0.025686	9	28.8	104.4	4.63	3.45	439.41	SOIL
65	51LSF	0.032170	0.037491	0.037077	8	30	102.9	1.97	2.64	414.79	SOIL
66	53YSZ	0.059347	0.039795	0	8	27.899	103.699	4.84	2.79	492.65	SOIL
67	53YML	0.033233	0.025027	0.018584	8	27.6	103.599	8.22	2.95	538.18	SOIL
68	51SFS	0.021511	0.024753	0.040050	8	31.2	104.199	7.30	2.86	532.46	SOIL
69	51HYY	0.049666	0.042091	0.005197	7	29.6	102.4	1.78	3.70	344.46	SOIL
70	51LBH	0.041603	0.042868	0.015318	7	28.399	103.8	2.56	2.82	425.96	SOIL
71	51LDL	0.058723	0.044186	0.025082	7	29.799	102.199	6.66	3.40	479.41	SOIL
72	51ZG3	0.065035	0.066183	0.044233	7	29.3	104.7	7.91	2.69	558.63	ROCK
73	51ZG1	0.058714	0.062002	0.050371	7	29.3	104.7	8.16	3.17	518.85	ROCK
74	53SFX	0.049874	0.053072	0.010596	7	28.6	104.4	7.64	3.63	478.67	ROCK
75	51NXT	0.037768	0	0.002702	7	28.8	105	7.98	2.96	533.77	SOIL
76	51JLD	0.025416	0.022199	0.017445	7	28.2	104.5	5.75	2.70	519.66	ROCK
77	51QCS	0.020918	0.031238	0.036654	7	32.4	105.099	4.06	2.46	503.70	SOIL
78	51YBY	0.033147	0.035378	0.029999	6	29	104.599	7.66	3.95	459.46	ROCK
79	51AXT	0.062756	0.049382	0.034401	6	31.5	104.4	1.86	2.39	430.15	SOIL
80	51MNW	0.055500	0.034654	0.021181	6	28.799	102.3	7.22	3.85	459.47	SOIL
81	51PWM	0.042840	0.044989	0.012152	6	32.599	104.5	2.95	3.53	393.36	SOIL
82	51CDZ	0.026560	0.022910	0.019372	6	30.6	104.099	5.70	5.01	383.32	ROCK
83	51SMW	0.016116	0	0.036769	6	29.399	102.199	3.64	3.09	440.00	SOIL
84	51TQD	0.066778	0.049114	0.044502	6	30.1	102.8	9.67	3.36	523.66	SOIL
85	51JGS	0.053674	0.039581	0.027664	6	32.299	105.5	7.37	3.32	496.40	SOIL
86	51JYT	0.035371	0.026868	0.025449	6	31.799	104.699	8.11	3.61	486.07	SOIL
87	51JYZ	0.030387	0.020250	0.017875	6	31.8	104.7	8.11	3.89	468.42	SOIL
88	53DJL	0.029266	0.039236	0.024658	6	28	104	0.20	4.16	–	SOIL
89	51JGD	0.020845	0.037721	0.030058	6	32	105.5	0.48	2.49	–	SOIL
90	51DYB	0.057773	0.057579	0.040233	5	31.3	104.5	3.07	5.55	318.21	ROCK
91	51HYQ	0.053142	0.052156	0.016041	5	29.6	102.599	3.27	2.82	448.90	SOIL
92	51SPA	0.035627	0.041423	0.043516	5	32.5	103.6	3.42	3.16	429.25	SOIL
93	51ZG2	0.058453	0.062631	0.026456	5	29.3	104.7	7.99	3.48	493.06	ROCK
94	51ZG4	0.047634	0.049120	0.032522	5	29.299	104.699	2.91	2.77	441.50	ROCK
95	51MBQ	0.032897	0.027789	0.010955	5	28.799	103.699	0.26	4.03	–	SOIL
96	M1002	0.032741	0.046446	0.027197	5	30.2	102.9	5.87	2.92	502.21	SOIL
97	51LZT	0.025202	0	0.006549	5	28.9	105.4	8.11	4.16	453.78	ROCK
98	53SJX	0.020465	0.026308	0.002806	5	28.6	103.9	11.17	3.45	533.65	ROCK
99	51MNC	0.040285	0.069856	0.056212	4	28.6	102.199	2.70	3.81	371.57	SOIL
100	51SMC	0.067824	0.063876	0.051498	4	29.1	102.3	2.97	3.06	422.45	SOIL
101	51ZG6	0.070211	0.061071	0.038311	4	29.3	104.7	5.67	3.03	489.33	ROCK

102	53LDX	0.056839	0.058887	0.036720	4	27.2	103.6	8.24	3.25	513.53	SOIL
103	53DSS	0.030971	0.043651	0.023985	4	27.899	103.9	0.34	4.74	—	SOIL
104	51BCD	—	—	—	3	31.6	104.5	—	—	—	SOIL
105	51LDS	—	—	—	3	29.899	102.199	—	—	—	SOIL
106	51HYW	—	—	—	3	29.2	102.9	—	—	—	SOIL
107	51KDT	—	—	—	3	30	102	—	—	—	SOIL
108	51GYZ	—	—	—	3	32.599	106.099	—	—	—	SOIL
109	51LDG	—	—	—	3	29.799	102.199	—	—	—	SOIL
110	51QCQ	—	—	—	3	32.5	104.9	—	—	—	ROCK
111	53DGX	—	—	—	3	27.7	103.9	—	—	—	ROCK
112	M1001	—	—	—	3	30.2	103.099	—	—	—	SOIL
113	53YHX	—	—	—	3	28.299	103.9	—	—	—	SOIL
114	53YPE	—	—	—	3	28.2	104.199	—	—	—	ROCK
115	51MES	—	—	—	3	31.899	102.5	—	—	—	SOIL
116	51MXX	—	—	—	3	32	103.699	—	—	—	SOIL
117	51MXJ	—	—	—	3	31.7	103.9	—	—	—	ROCK
118	51AXY	—	—	—	3	31.7	104.5	—	—	—	SOIL
119	51CXQ	—	—	—	2	31.7	105.9	—	—	—	SOIL
120	51GLQ	—	—	—	2	29	102.8	—	—	—	SOIL
121	51HYJ	—	—	—	2	29.5	102.599	—	—	—	SOIL
122	51JZW	—	—	—	2	33	104.199	—	—	—	SOIL
123	51LSH	—	—	—	2	30.1	102.9	—	—	—	SOIL
124	51MNH	—	—	—	2	28.5	102.099	—	—	—	SOIL
125	51MNT	—	—	—	2	28.5	102.199	—	—	—	SOIL
126	51LBD	—	—	—	2	28.299	103.599	—	—	—	SOIL
127	51XDM	—	—	—	2	28.399	102.3	—	—	—	SOIL
128	51DXY	—	—	—	2	30.6	103.5	—	—	—	SOIL
129	51JZG	—	—	—	2	33.099	104.3	—	—	—	SOIL
130	51MXT	—	—	—	2	31.7	103.9	—	—	—	ROCK
131	51QCD	—	—	—	2	32.599	105.199	—	—	—	SOIL
132	51ZG7	—	—	—	2	29.3	104.7	—	—	—	ROCK
133	61YZB	—	—	—	2	32.9	105.9	—	—	—	SOIL
134	M2001	—	—	—	2	30.299	103.099	—	—	—	SOIL
135	51MNA	—	—	—	1	28.6	102.199	—	—	—	SOIL
136	51MNJ	—	—	—	1	28.5	102.199	—	—	—	SOIL
137	51PXZ	—	—	—	1	30.9	103.8	—	—	—	ROCK
138	51ZJJ	—	—	—	1	27.9	102.6	—	—	—	SOIL
139	51JLT	—	—	—	1	29	101.5	—	—	—	SOIL
140	51MNL	—	—	—	1	28.299	102.199	—	—	—	SOIL
141	51SMK	—	—	—	1	29.399	102.099	—	—	—	SOIL
142	51XJD	—	—	—	1	31	102.4	—	—	—	SOIL
143	51ZJQ	—	—	—	1	28	102.8	—	—	—	SOIL
144	51CST	—	—	—	1	29.5	104.2	—	—	—	SOIL
145	51DJA	—	—	—	1	30.799	103.599	—	—	—	SOIL
146	51DST	—	—	—	1	29.2	105.1	—	—	—	SOIL

147	51DYJ	–	–	–	1	31.1	104.3	–	–	–	SOIL
148	51GYD	–	–	–	1	32.099	106.199	–	–	–	SOIL
149	51GYT	–	–	–	1	29.1	104.4	–	–	–	ROCK
150	51HYS	–	–	–	1	32	102.599	–	–	–	SOIL
151	51JGZ	–	–	–	1	32	105.5	–	–	–	SOIL
152	51LD5	–	–	–	1	28.4	105	–	–	–	SOIL
153	51MNF	–	–	–	1	28.399	102.199	–	–	–	SOIL
154	51MNS	–	–	–	1	28.4	102.2	–	–	–	SOIL
155	51PGQ	–	–	–	1	27.5	102.5	–	–	–	SOIL
156	51SMM	–	–	–	1	29.299	102.4	–	–	–	SOIL
157	51SPT	–	–	–	1	32.7	103.599	–	–	–	ROCK
158	51XJW	–	–	–	1	31	102.599	–	–	–	SOIL
159	51YAH	–	–	–	1	29.7	102.699	–	–	–	SOIL
160	51ZG5	–	–	–	1	29.3	104.7	–	–	–	ROCK
161	53JLT	–	–	–	1	28	104	–	–	–	SOIL
162	53MLT	–	–	–	1	27.6	103.599	–	–	–	SOIL
163	53SSX	–	–	–	1	27.899	103.9	–	–	–	SOIL
164	53YJP	–	–	–	1	28.2	104.199	–	–	–	ROCK
165	53ZJA	–	–	–	1	27.5	103.8	–	–	–	SOIL
166	M1004	–	–	–	1	30	102.8	–	–	–	SOIL
167	M1005	–	–	–	1	30.1	102.8	–	–	–	SOIL
168	M2002	–	–	–	1	30.299	103.199	–	–	–	SOIL

Note: The symbol “–” in the table indicates that the related value was not obtained. # indicates that the V_{s30} value was obtained from the drilling data, * indicates that the V_{s30} value was obtained from the PEER database, and the remaining characters in Column 11 indicate that the V_{s30} values were obtained from the empirical relationship given by Ghofrani and Atkinson (2014). The zero value in Columns 3 to 5 indicates that the fitted zero-distance kappa (κ_0) is negative.

Table S2 Model input parameters of the simulated earthquake events.

Input parameters	Values	References
Rupture fault strike and dip	131° (12°), 59° (50°)	Guo <i>et al.</i> (2022)
Rupture fault size (km)	21×12	Guo <i>et al.</i> (2022)
Subfault size (km)	3×3	This study
κ_0 (s)	Single station κ_0 values	This study
Slip distribution	Inverted source model	Guo <i>et al.</i>
	$1/R$, $R < 70.5$ km	Dang <i>et al.</i> (2023)
Geometric spreading function	$1/70.5$, $70.5 \leq R \leq 117.5$ km	
	$1/R^{0.5}$, $R > 117.5$ km	
	0, $R < 10$ km	Atkinson and Boore (1995)
Path duration	$0.16(R-1)$, $10 \leq R < 70$ km	
	$9.6-0.03(R-70)$, $70 \text{ km} \leq R < 130$ km	
	$7.8+0.04(R-130)$, $R \geq 130$ km	
Rise time	$1/f_0$	Boore (2003)
Crustal amplification	NEHRP Class C and D	Boore and Joyner (1997)
Pulsing area percentage	50%	Motazedian and Atkinson (2005)
Frequency-related Quality factor	$327.8 f^{0.591}$	Dang <i>et al.</i> (2023)
Local site amplifications	H/V spectral ratio methods	This study
Stress drop (MPa)	0.8	Dang <i>et al.</i> (2025a)

Table S3 Strong motion stations with epicentral distances less than 120 km triggered by the Changning earthquake.

Station			Epicentral	Site	κ_0	Geometric	Simulated	(Obs.-Sim.)/Obs.
name	Latitude	Longitude	distance	condition	value	mean of	PGA	
	(°N)	(°E)	(km)		(s)	PGA	(cm/s ²)	
						(cm/s ²)		
51GXT	28.4	104.7	20.67	Soil	0.0217	599.37	535.37	0.02
51JLD	28.2	104.5	42.14	Rock	0.0238	22.52	28.594	-0.12
51YBT	28.7	104.6	49.60	Soil	0.0386	55.44	58.885	-0.03
51NXT	28.8	105.0	52.06	Soil	0.0378	50.35	57.93	-0.25
53SFX	28.6	104.4	56.77	Rock	0.0515	11.09	10.699	-0.03
51YBG	28.8	104.4	70.70	Soil	0.0246	25.41	24.908	-0.12
53YJT	28.1	104.2	73.58	Rock	0.0226	4.48	5.176	-0.12
51YBY	29.0	104.6	78.99	Rock	0.0343	16.94	19.264	-0.41
51LZT	28.9	105.4	79.10	Rock	0.0252	7.75	6.152	0.20
51FSB	29.1	104.8	85.05	Rock	0.0379	8.67	11.575	-0.24
53DJL	28.0	104.0	95.96	Soil	0.0343	8.29	8.0164	0.03
53SJX	28.6	103.9	101.92	Rock	0.0234	6.38	7.987	-0.41
51LBH	28.4	103.8	107.81	Soil	0.0422	7.45	7.3704	-0.02
51ZG2	29.3	104.7	108.49	Rock	0.0200	4.82	5.341	-0.20
53DSS	27.9	103.9	109.57	Soil	0.0373	2.60	3.038	-0.17
51MCX	28.9	103.9	115.75	Soil	0.0316	14.05	12.773	0.29