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KIGAM Quake: An open platform for seismological data and earthquake research information

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Abstract. The "Korea Institute of Geoscience and Mineral (KIGAM) Quake" is a web-based open platform developed for publicly serving seismological data from 61 stations operated by KIGAM in Korea. The service provides meta-information related to observatory sites, sensors, and recorders necessary for utilizing the seismological data, as well as mainly observed continuous and strong-motion waveforms. The data is available through both the web and International Federation of Digital Seismograph Networks (FDSN) web services (open API), a unified data-providing interface in seismology. The platform aims to strengthen its open nature by offering a signal processing function for strong ground motions that can be controlled by user requests. The processed results can be downloaded in ASCII format, designed to meet the increased demands and accessibility in the earthquake engineering field. The platform also offers earthquake research information produced by KIGAM, such as recent major earthquake source information and academic annual report of earthquakes. Additionally, a site flat file was constructed for the geotechnical characteristics of 61 KIGAM station (KGNET) sites based on direct investigations and estimations.

Keywords: earthquake research information; engineering strong-motion; FDSN web services; KIGAM Quake; seismological data; site flat file; web-based open platform

1. Introduction

Seismological data plays a fundamental role in earthquake-related research and is essential for developing earthquake hazard assessments. Many relevant agencies around the world, such as Incorporated Research Institutions for Seismology (IRIS, Ahern 2003, Ahern *et al.* 2015), Engineering Strong-Motion database (ESM, Luzi *et al.* 2016), Consortium of Strong-Motion Observation Systems (COSMOS, Archuleta *et al.* 2006), ITalian ACcelerometric Archive (ITACA, Luzi *et al.* 2008, Pacor *et al.* 2011a, Pacor *et al.* 2011b), National Research Institute for Earth Science and Disaster Resilience (NIED, Okada *et al.* 2004), Center for Engineering Strong-Motion Data (CESMD, Haddadi *et al.* 2008), and others, share their data with the community without any conditions, to make it broadly available for a variety of purposes (Ahern *et al.* 2015).

In Korea, there was a significant increase in investment in earthquake-related fields following strong earthquakes that caused actual damages, such as the 2016 Gyeongju Earthquake (M_L 5.8) (Kim *et al*. 2016, Son *et al*. 2018, Lee *at al.* 2022) and the 2017 Pohang Earthquake (M_W 5.4) (Kim *et al.* 2018, Son *et al.* 2020, Lee *at al.* 2022). In terms of quantity, the number of seismic stations operated by the Korea Meteorological Administration (KMA) rapidly increased from 156 (KMA 2017) to 265 (KMA 2021). Those operated by the Korea Institute of Geoscience and Mineral Resources (KIGAM) also increased significantly from 40 to 61 stations during the same period. The KMA is responsible for national earthquake-related tasks and operates real-time seismic monitoring (Cho *et al.* 2022), so many stations were installed evenly across the country. The KIGAM stations are also distributed throughout the country. However, those are relatively concentrated in the southeast region and fault areas of interest for research-oriented purposes.

This paper introduces the "KIGAM Quake," a web-based open platform developed to share seismological data produced by 61 KIGAM permanent seismic stations in Korea. In addition to meeting the data requirements of seismology, we aimed to satisfy the demand for data in earthquake engineering, such as strong ground motions.

2. KIGAM Quake

2.1 KIGAM KERC

KIGAM is a government-funded research institute, and

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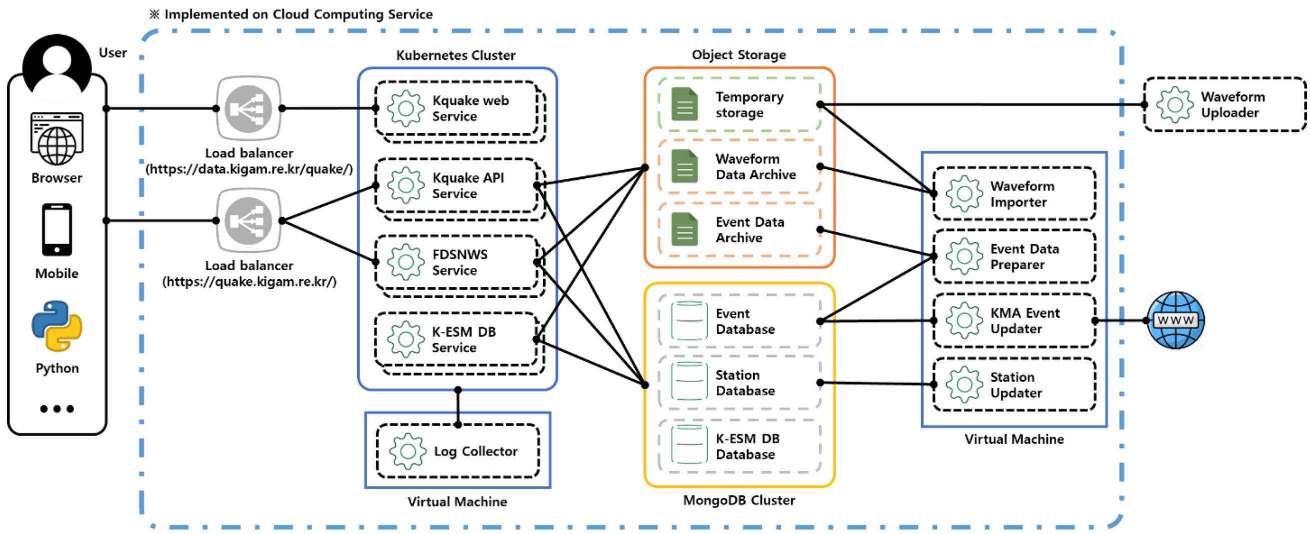


Fig. 1 The composition diagram of the cloud-based seismological data service platform

its sub-organization, KIGAM Earthquake Research Center (KERC), has focused on expanding seismic monitoring infrastructures and conducting research and development in the field of earthquakes since its establishment in 1999. Since 2002, Korea Integrated Seismic System (KISS), developed by KERC, has played a major role in real-time seismic data exchange among different seismic networks operated by four earthquake monitoring institutes (Park et al. 2009). KIGAM/KERC has been designated as the National Data Center (NDC) in Korea by the UN. The NDC is the national technical organization that advises governments on verifying the Comprehensive Nuclear-Test-Ban Treaty (www.ctbto.org). KERC quickly responded to the detection and analysis of the main and aftershocks of the two earthquakes that occurred in Gyeongju in 2016 and Pohang in 2017. Currently, sixty-one domestic seismic stations (KGNET) included in the national seismic network are operated by KIGAM KERC.

2.2 "KIGAM Quake" web-based open platform

KIGAM KERC is responsible for sharing seismological data with the public. Academia and industry require earthquake-related information that is highly useful for engineering research and seismic design (e.g., instrumental corrected waveforms, response spectra, observation metadata, etc.) in addition to basic information such as earthquake source parameters and raw observational records. Therefore, a platform called "KIGAM Quake" (https://data.kigam.re.kr/quake/) was developed to provide raw and processed seismological data produced by KGNET through the web, making it easily accessible to the public. The service was launched at the end of 2022 and currently provides seismological data from January 1st, 2016, as a pilot service period. The service will be expanded to include past observational data soon.

2.3 Cloud-based web data sharing system

The KIGAM Quake platform has been built on public cloud computing services and is configured using various cloud services. Raw observational data is stored in cloud storage, which is faster to read and easier to expand than traditional local physical storage. Metadata of the raw data and event analysis results are stored in a clustered, managed database. All services, including the web server, are modularized, containerized, and run on a Kubernetes cluster (https://kubernetes.io/). Kubernetes is a container orchestration tool allowing modularized services to scale up or down based on usage. Fig. 1 illustrates the configuration of the cloud-based seismological data service platform.

The system construction using cloud computing services reduces the initial cost of introducing the system and allows for the gradual expansion of services. Additionally, the environment, which is separate from the KERC's internal network, has the advantage of protecting the internal network from potential security threats or loads caused by external services. Furthermore, this cloud-native architecture enables the creation of a stable service in a short period of time.

The detailed menu of KIGAM Quake, implemented on the web (https://data.kigam.re.kr/quake/), is detailed in sections 3 to 5.

2.4 Authentication system

The public can access KIGAM Quake, but only users registered as members of the KIGAM Geo BigData Open Platform (https://data.kigam.re.kr/), the parent service of KIGAM Quake, are authorized to download any data. The collection of user login information will provide better future service based on platform usage statistics.

3. Seismic station

This section provides an overview of the "Seismic Station" menu on the KIGAM Quake website, which includes both "Station Information" and "Metadata" sub-menus.

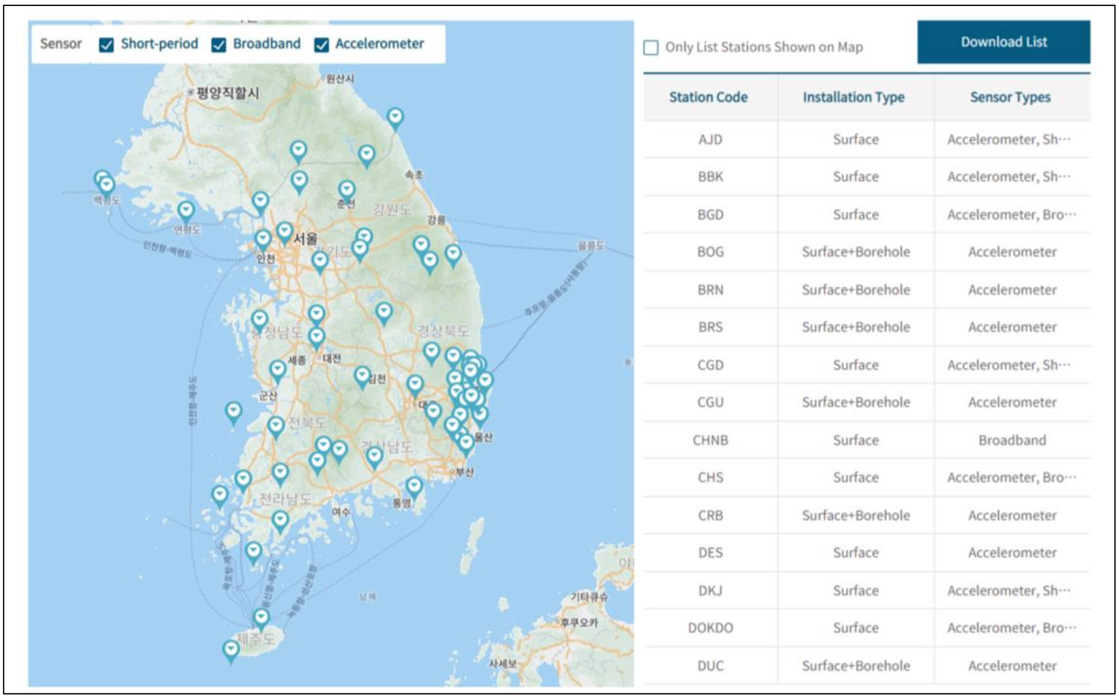


Fig. 2 The web page for station information (https://data.kigam.re.kr/quake/observatory/stations)

Fig. 3 The pop-up page for BOG seismic station details

3.1 Station information

Detailed information about 61 seismic stations of KGNET is provided in the "Station Information" menu, as shown in Fig. 2. Icons represent the stations' location on the map on the left side of the figure, and related information is arranged in ascending order by station code on the right side in the table. Clicking an icon on the map or a row in the table brings up a detailed information page for the station, as shown in Fig. 3.

The detailed information includes the monitoring start date, coordinates (latitude, longitude, and altitude), installation type (surface, borehole, and surface/borehole types), sensor type, and engineering site classification by $V_{S,30}$-based NEHRP site classes (BSSC, 1997; 2020) and/or H- and $V_{S,Soil}$-based site classes in Korea (MOLIT 2018).

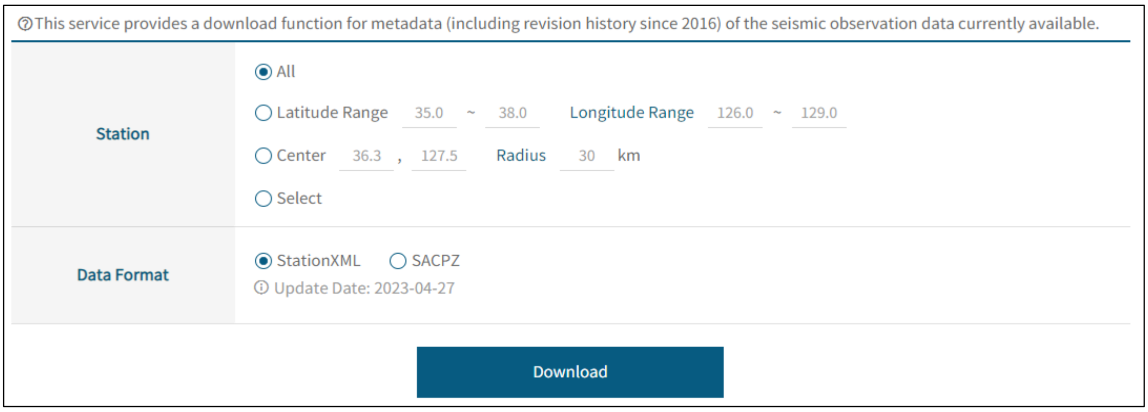


Fig. 4 The web page for station metadata (https://data.kigam.re.kr/quake/observatory/metadata)

$V_{S,30}$ refers to the average shear wave velocity (V_S) from the surface to a depth of 30 m. H and $V_{S,Soil}$ represent the depth of the engineering bedrock and the mean V_S of soils above the H, respectively. The three geotechnical seismic response parameters are covered in more detail in Section 3.3, in the form of a site flat file for all KGNET observatory sites. The V_S-profile is additionally provided as an image for some observatory sites where site investigation was performed, along with information on sensor installation depth. Photos of the observatories are also available, as shown in Fig. 3

3.2 Metadata

Ground motions observed by seismographs are typically stored, managed, and distributed as a series of integer values rather than physical values. Instrument response information from sensors and recorders is required to convert this series of integers into physical ground motions. This information is commonly referred to as "metadata" in seismology, describing the characteristics and properties of seismic data. KERC creates and manages a total of 97 items of metadata, including 16, 52, and 24 items related to the observatory site, seismograph, and recorder, respectively, in Standard for the Exchange of Earthquake Data (SEED) format (IRIS 2012). On the other hand, it has recently become common to distribute metadata in StationXML format (http://www.fdsn. org/xml/station/). The International Federation of Digital Seismograph Networks (FDSN) Working Group II, responsible for seismic data exchange-related topics, is leading the standardization by defining the StationXML schema. As a result, a system was established to convert and provide KERC's SEED format station meta-information in StationXML and SAC ASCII format (SACPZ, https://ds.iris. edu/files/sac-manual/commands/tran sfer.html), as shown in Fig. 4. Users can download data for all or selected stations.

3.3 Site flat file of KGNET

This subsection reports detailed information on the geotechnical seismic response parameters of 61 KGNET seismic stations separately from the web service. It followed the method of Cho *et al.* (2022) and the form, which wrote a site flat file for all KMA observatory sites. Site investigations and explorations were conducted directly, or some estimated results were cited from literature sources (Kim *et al*. 2020, Ahn *et al*. 2021)..As summarized in Table 1, the three seismic response parameters of $V_{S,30}$, H, and $V_{S,Soil}$ are listed for each individual station according to the acquisition techniques used. According to the parameters, the observatory sites were divided into $V_{S,30}$-based (BSSC 1997; BSSC 2020) and/or H- and $V_{S,Soil}$-based (MOLIT 2018) site classes. When multiple results exist due to differences in acquisition methods for one parameter, measurements were prioritized over estimations (Seyhan *et al.* 2014, Felicetta *et al*. 2017) in the site classifications. The most reliable acquisition methods are listed in order from left to right.

4. Continuous waveforms

This section introduces a sub-menu for downloading continuous waveform data for an arbitrary time interval.

4.1 Download through the WEB interface

Through a sub-menu of seismic observation data called "continuous waveform data," continuous waveform data can be provided for an arbitrary time interval set by the user. Users can retrieve data by setting search conditions such as seismic stations, channels, and time intervals. Depending on the selected channels, acceleration and velocity with different sampling rates can be downloaded in miniSEED (http://ds.iris.edu/ds/nodes/dmc/data/formats/miniseed/), SAC (http://www.adc1.iris.edu/files/sac-manual/manual/file _format.html), and GeoCSV ASCII (Stults *et al.* 2015) formats (Fig. 5(a)). Data can be downloaded for up to 72 hours per request.

The continuous waveform data provided through the web interface undergoes basic quality control (QC) assessment and its index (QC-Index) is provided to the user for the requested data period as a 100-point scale. This approach enhances both data management and user comprehension. The QC-Index calculation is based on three variables: 1) Data availability (50%), 2) Mass position

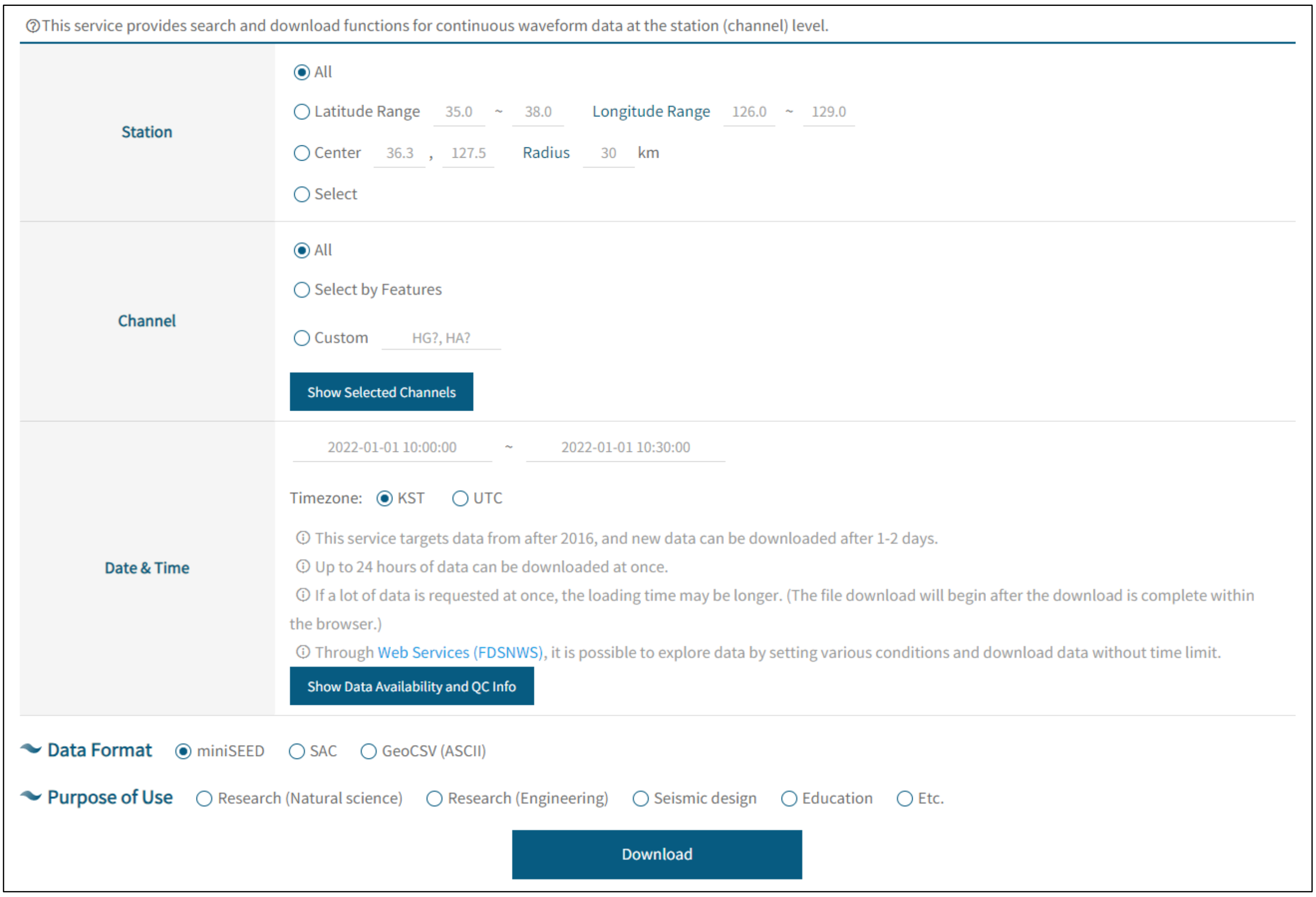
Table 1 Site conditions of KGNET total 61 seismic stations

Station code	$V_{S,30}$ (m/s)								H (m)					$V_{S,Soil}$ (m/s)					Site class		
	Measurements					Estimations			Measurements					Measurements							
	Exploration			Boring		Seismic records		Proxy	Exploration			Boring		Exploration			Boring				
	CHT	DHT	MASW	SPT	Geo layers*	HVSR (Ahn *et al.* 2021)	P-wave (Kim *et al.* 2020)	Slope ($^1/_6$ arc-second)	CHT	DHT	MASW	SPT	Geo layers	CHT	DHT	MASW	SPT	Geo layers	NEHRP 1997	NEHRP 2020	MOLIT 2018
AJD	-	-	-	-	-	-	-	836	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
BBK	-	-	-	-	-	923	784	836	-	-	-	-	-	-	-	-	-	-	*B*	*B*	NA
BGD	-	-	-	-	-	288	432	836	-	-	-	-	-	-	-	-	-	-	*D*	*D*	NA
BOG	-	633	710	624	762	1,115	708	480	-	6.0	6.0	21.0	4.2	-	396	359	564	264	*C*	*C*	S_2
BRN	-	-	-	-	899	-	582	-**	-	-	-	-	2.8	-	-	-	-	325	*B*	*BC*	S_2
BRS	-	-	-	-	1,019	-	352	-**	-	-	-	-	0.5	-	-	-	-	190	*B*	*B*	S_1
CGD	-	-	-	-	-	-	521	836	-	-	-	-	-	-	-	-	-	-	*C*	*C*	NA
CGU	-	779	546	619	498	674	683	570	-	12.0	18.0	10.0	16.5	-	493	371	308	344	*B*	*BC*	S_2
CHNB	-	-	-	-	-	-	360	162	-	-	-	-	-	-	-	-	-	-	*D*	*CD*	NA
CHS	-	-	-	-	-	-	-	836	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
CRB	1,616	1,059	666	651	910	576	729	836	4.0	7.0	4.0	17.0	3.2	272	315	232	546	371	*A*	*A*	S_2
DES	-	502	438	378	272	-	-	836	-	34.0	-	24.0	37.0	-	488	-	356	317	*C*	*C*	S_4
DKJ	-	-	-	-	-	-	-	836	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
DOKDO	-	-	-	-	-	-	603	836	-	-	-	-	-	-	-	-	-	-	*C*	*C*	NA
DUC	-	755	576	828	643	407	-	690	-	9.0	-	7.0	8.3	-	395	-	384	308	*C*	*BC*	S_2
GCN	-	808	429	-	566	-	731	570	-	-	-	-	11.0	-	-	-	-	308	*B*	*BC*	S_2
GHR	-	612	-	-	530	-	696	836	-	-	-	-	17.0	-	-	-	-	380	*C*	*C*	S_2
GKP2	-	925	-	-	949	-	-	836	-	-	-	-	1.0	-	-	-	-	190	*B*	*B*	S_3
GRE	-	-	-	-	-	-	-	836	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
GSU	-	1,497	-	-	-	1151	720	836	-	-	-	-	-	-	-	-	-	-	*B*	*B*	NA
HAK	-	-	-	-	-	-	-	836	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
HCH	-	494	511	376	338	-	402	836	-	22.0	-	23.0	26.0	-	386	-	344	306	*C*	*C*	S_4
HDB	-	433	391	334	405	-	197	690	-	-	-	>30	32.8	-	-	-	NA	429	*C*	*CD*	S_4
HKU	-	554	-	-	-	-	-	690	-	-	-	-	-	-	-	-	-	-	*C*	*C*	NA
HSB	1,701	1,059	540	574	763	382	744	836	5.0	9.0	9.0	4.0	8.2	447	434	274	345	420	*A*	*A*	S_2
HWSB	1,623	1,427	1,030	1,031	901	-	-	570	3.0	2.0	4.0	2.0	2.5	437	505	391	448	301	*A*	*A*	S_2
IBA	836	646	790	382	549	-	-	836	10.0	10.0	8.0	>30	9.5	324	266	345	NA	264	*B*	*BC*	S_2
JJB	-	-	-	-	-	-	691	480	-	-	-	-	-	-	-	-	-	-	*C*	*BC*	NA
JRB	867	724	655	723	606.5	-	-	690	7.0	12.0	9.0	4.0	7.7	364	414	321	277	264	*B*	*BC*	S_2
JSB	-	-	-	-	-	-	-	480	-	-	-	-	-	-	-	-	-	-	*C*	*C*	NA
JUC	-	450	445	440	723	-	-	836	-	-	-	>30	9.3	-	-	-	NA	410	*C*	*C*	S_2
KIP	-	-	-	-	-	-	-	162	-	-	-	-	-	-	-	-	-	-	*E*	*DE*	NA
KJM	-	-	-	-	-	-	727	836	-	-	-	-	-	-	-	-	-	-	*C*	*BC*	NA
KMC	-	760	608	491	698	840	607	836	-	7.0	18.0	9.0	14.6	-	342	384	255	504	*C*	*BC*	S_2
KNUC	349	381	305	391	391	524	743	400	-	-	-	8.0	59.3	-	-	-	208	574	*D*	*CD*	S_3
KNUD	-	-	-	-	-	-	-	836	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
KSA	-	-	-	-	-	250	-	-**	-	-	-	-	-	-	-	-	-	-	*D*	*D*	NA
MAK	-	-	-	-	-	594	870	836	-	-	-	-	-	-	-	-	-	-	*C*	*C*	NA
MGB	-	817	-	-	-	1,481	594	836	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
MKL	-	-	-	-	-	-	-	836	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
MRD	-	-	-	-	-	-	860	690	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
MUN	-	-	-	-	-	370	-	836	-	-	-	-	-	-	-	-	-	-	*C*	*CD*	NA
NPR	-	-	-	-	-	-	606	836	-	-	-	-	-	-	-	-	-	-	*C*	*C*	NA
OJR	-	1,235	-	-	834	327	853	836	-	-	-	-	2.0	-	-	-	-	190	*B*	*B*	S_3
PCH	-	-	-	-	-	-	-	836	-	-	-	-	-	-	-	-	-	-	*B*	*BC*	NA
PKNU	-	748	524	691	736	-	787	400	-	11.0	-	16.0	11.0	-	378	-	588	468	*C*	*BC*	S_2
POHB	-	751	509	561	601	-	814	690	-	6.0	-	10.0	5.2	-	303	-	310	190	*C*	*BC*	S_2
POSB	-	-	-	-	571	-	-	690	-	-	-	-	9.5	-	-	-	-	280	*C*	*C*	S_2
SIG	-	404	324	445	211	-	-	690	-	36.0	-	4.0	56.1	-	404	-	671	338	*C*	*CD*	S_4
SND	-	-	-	-	-	-	245	836	-	-	-	-	-	-	-	-	-	-	*D*	*D*	NA
SNU	-	-	-	-	-	-	613	836	-	-	-	-	-	-	-	-	-	-	*C*	*C*	NA
TJN	-	-	-	-	-	447	685	836	-	-	-	-	-	-	-	-	-	-	*C*	*C*	NA
UNI	681	570	461	402	569	653	778	836	10.0	12.0	11.0	>30	9.3	305	289	232	NA	274	*C*	*BC*	S_2
WDL	444	332	614	291	431	-	-	836	21.0	24.0	21.0	20.0	21.2	317	261	493	242	344	*C*	*C*	S_4
WID	-	-	-	-	-	-	560	836	-	-	-	-	-	-	-	-	-	-	*C*	*C*	NA
YIN	-	-	-	-	-	-	716	690	-	-	-	-	-	-	-	-	-	-	*C*	*BC*	NA
YKB	-	-	-	-	-	653	783	162	-	-	-	-	-	-	-	-	-	-	*C*	*BC*	NA
YPD	-	-	-	-	-	-	-	162	-	-	-	-	-	-	-	-	-	-	*E*	*DE*	NA
YSB	-	507	410	1,046	535	-	567	836	-	-	-	9.0	14.4	-	-	-	657	343	*C*	*C*	S_2
YSUK	164	175	176	194	289	-	-	340	41.0	44.0	-	46.0	42.7	194	212	-	244	371	*E*	*DE*	S_4
YSUM	1,953	1,109	633	779	928	-	-	836	3.0	7.0	-	2.0	2.1	352	361	-	123	302	*A*	*A*	S_2

* Soil layers with assumed representative V_S values for each soil layer (Sun *et al.* 2012)

** No data near the Military Demarcation Line on the Korean Peninsula

- DHT: DownHole Test, CHT: CrossHole Test, MASW: Multi-channel Analysis of Surface Waves, SPT: Standard Penetration Test, HVSR: Horizontal-to-Vertical Spectral Ratio
- A detailed description of the methodology used to derive each seismic response parameter can be found in Cho *et al.* (2022)



(a) the search page and a button for the QC-Index

(b) the QC-Index pop-up screen

Fig. 5 The web page for continuous data (https://data.kigam.re.kr/quake/data/continuous-data)

(20%), and 3) Time quality (30%). In cases where a broadband velocimeter is not involved, the mass position component is omitted, with time quality carrying a 50% weightage. The QC-Index represents the average score for the user's requested period (Fig. 5(b)). Each variable is computed by accounting for the presence or absence of pertinent data and deviations from the reference data recommended by individual equipment manufacturers. In the future, the calculation of the QC-Index is planned to be more advanced, potentially incorporating factors such as the outlier level of Power Spectral Density (PSD).

4.2 Download through FDSN web services

Open API (Application Programming Interface) is now widely used to provide information in various fields. It is a computer program-friendly interface for data access rather than for web users. Users can easily find and download data that meets complex conditions using open API and can be linked to automatic analysis. FDSN has defined specifications for a unified data-providing interface in seismology, and the open API is known as FDSN web services. The services are considered the de facto international standards for providing seismic data, and 24 organizations, including IRIS in the US and ORFEUS in Europe, provide data according to the specifications (https://www.fdsn.org/datacenters /).

KIGAM Quake also provides continuous waveform data and station metadata through FDSN web services. Users must have an open API authentication key to use the services. The key can be issued by signing up for the Geo BigData Open Platform of KIGAM and making a separate request on the open API page (https://data.kigam.re.kr/my-openapi /request/). The web services allow users to download up to 72 hours of data at once, while FDSN web services, instead of a time limit, have a data limit of 2 GB per request. These restrictions may change in the future. The FDSN web services segment continuous waveform data according to user requests and primarily provide it in miniSEED format. By storing continuous waveform data in a distributed file system in miniSEED format and managing meta-information on miniSEED records as separate files, a fast and efficient system was established for delivering miniSEED data. Data is also provided in SAC and GeoCSV ASCII formats; however, data conversion takes additional time.

The KIGAM Quake's website (https://data.kigam.re.kr/ quake/data/web-services) introduces the functions of the FDSN web services and provides sample codes on how to use the open API using the Python ObsPy library (Beyreuther *et al*. 2010).

5. Strong ground motions

This section introduces two sub-menus for downloading strong ground motions.

5.1 Raw data bundle

A database of earthquake lists with local magnitudes larger than 2.5 is created from the KMA domestic earthquake catalogue (https://www.weather.go.kr/) and periodically updated using web crawling techniques. The event waveforms' entire raw data observed in KGNET is provided as a bundle for a specific unit time (300 seconds) after the origin time using the database. For each earthquake event, the target is acceleration and velocity time series data of 20 and 100 samples per second (sps), respectively. It is possible to search for data based on conditions such as earthquake magnitude, occurrence period, and epicenter. Fig. 6(a) shows the sub-menu web page and a result from an example search with magnitudes larger than 4.0 that occurred in 2023. The user can preview the event waveform for all stations as an image through the preview icon on the right side of the search result, as shown in Fig. 6(b). Selected data can be downloaded in miniSEED format.

5.2 K-ESM DB

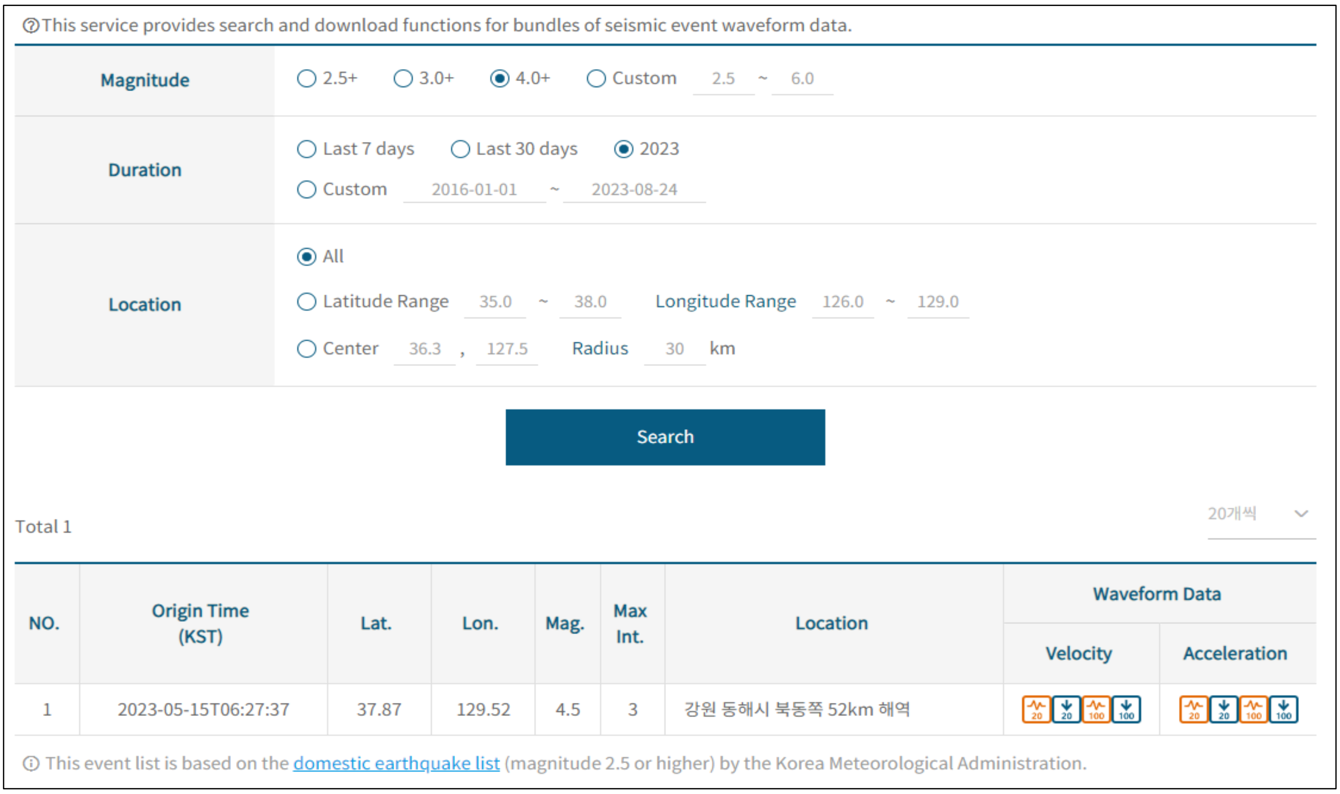
The sub-menu of "K-ESM DB (KIGAM Engineering Strong-Motion Data Base)" provides processing and download services for accelerometric records observed at 61 KGNET seismic stations. It is designed to increase usability and accessibility for engineering research. The K-ESM DB segments the time interval with concentrated ground motion energy at each station based on normalized Arias intensity (Arias 1970). Users can choose between [processed data], which has undergone pre-processing, and [raw data]. Users can also set techniques and variables to directly process a selected ground motion and download the processed data. This feature is designed and developed by referring to the strong-motion data processing service (Puglia *et al*. 2018) of the engineering strong-motion database for accelerometric data recorded in Europe and the Middle East (ESM DB, Luzi et al. 2016). The K-ESM DB is limited to 100 sps records with local magnitudes larger than 3.0.

5.2.1 Processing

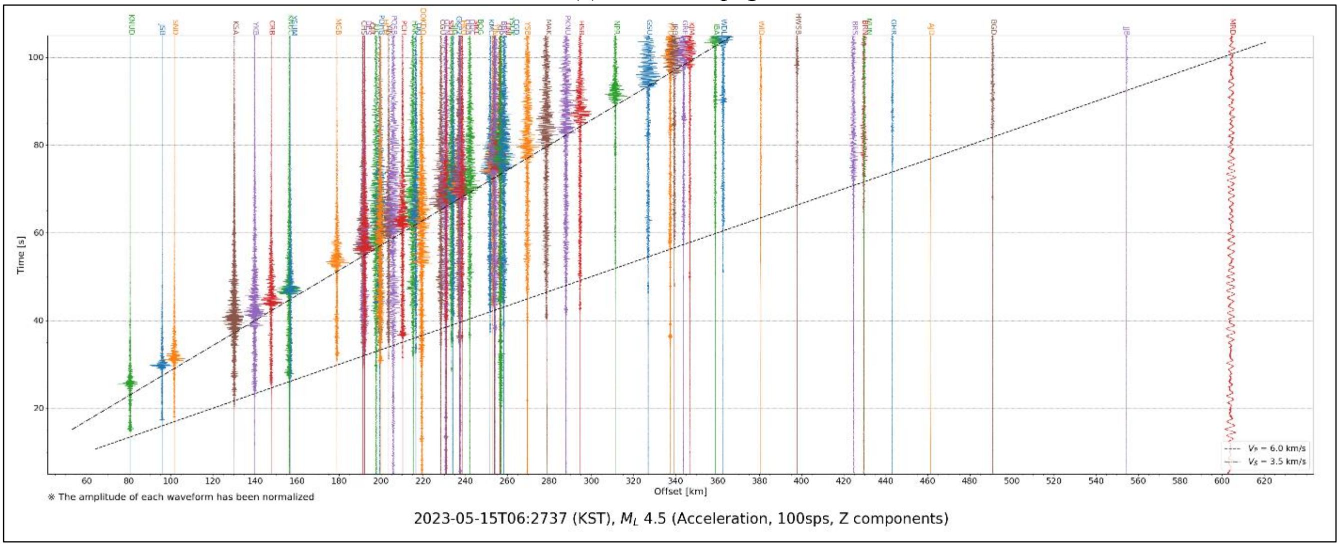
First, the extracting process of the event waveform [raw data] from continuous waveform data was described. Accelerometric records for all KGNET seismic stations were extracted from the raw data of continuous waveforms for 600 seconds after the origin time of KMA's domestic earthquake catalogue (https://www.weather.go.kr/). The 1%–99% level of normalized Arias intensity (Arias 1970) of the individual accelerometric record was set as the earthquake event's signal interval. Then, the event waveform [raw data] was extracted by adding 15 seconds of noise before and after the signal interval. It was considered to sufficiently include P and coda waves. The three components of the ground motion were aligned with the same time axis, and records with an epicentral distance greater than 500 km and an average Signal-to-Noise Ratio (SNR) of less than 2.7 were excluded. The SNR was defined as the root mean square ratio in the noise section to that in the signal section (Noh *et al.* 2003), and the value was set somewhat conservatively to ensure the exclusion of seismograms recording small, consecutive earthquakes within a few tens of seconds.

Second, by applying the following signal processing techniques to the extracted event waveform [raw data], the event waveform [processed data] was obtained. In general, the Python ObsPy library (Beyreuther *et al.* 2010) was used for processing. 1) Removing DC offset and applying cosine taper: The DC offset was removed using the "detrend" function (with "linear" option), and a cosine taper (half cosine shape) was applied to both ends corresponding to 1% of the [raw data]'s total length. 2) Applying an acausal Butterworth bandpass filter: The data was zero-padded at both ends so that the total number of data was matched to a power of two (Boore 2005). After the fast Fourier transform (FFT) of the entire signal, an acausal (zero-phase) Butterworth (Boore and Akkar 2003) bandpass filter was applied. The high-pass (low-cut), low-pass (high-cut) corner frequencies, and filter order were set as 0.1 Hz, 25 Hz, and second-order (Boore 2005), respectively. No separate frequency-domain noise removal was performed based on the SNR level.

Finally, baseline correction was performed to ensure that the displacement obtained by integrating acceleration twice converges to zero. The zero-padded portions to both ends were stripped off (Pacor *et al*. 2011b, Boore *et al.*



(a) the search page



(b) the event preview pop-up screen

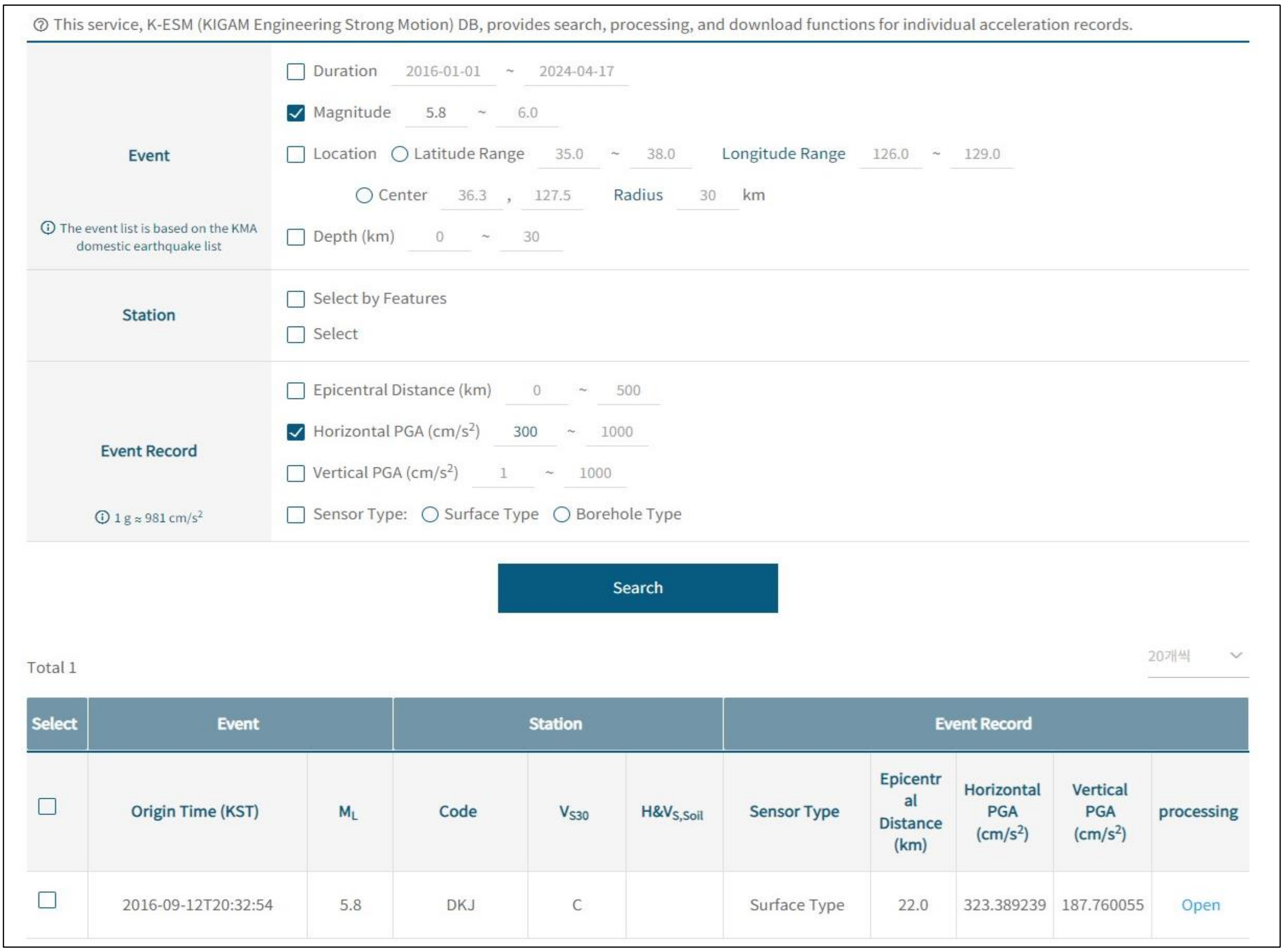
Fig. 6 The web page for strong-motion raw data bundle (https://data.kigam.re.kr/quake/data/events)

2012, Puglia *et al*. 2018), and a cosine taper was applied to each 1% of the length before and after the pad-stripped (Boore *et al*. 2012) acceleration time history. A fourth-order polynomial was determined to match the velocity time series obtained by integrating the data once. Then, the baseline-corrected acceleration time history (i.e., the event waveform [processed data]) was generated by recursive differentiating the modified velocity time history, in which the velocity with time by the fourth-order polynomial was removed from the velocity time history.

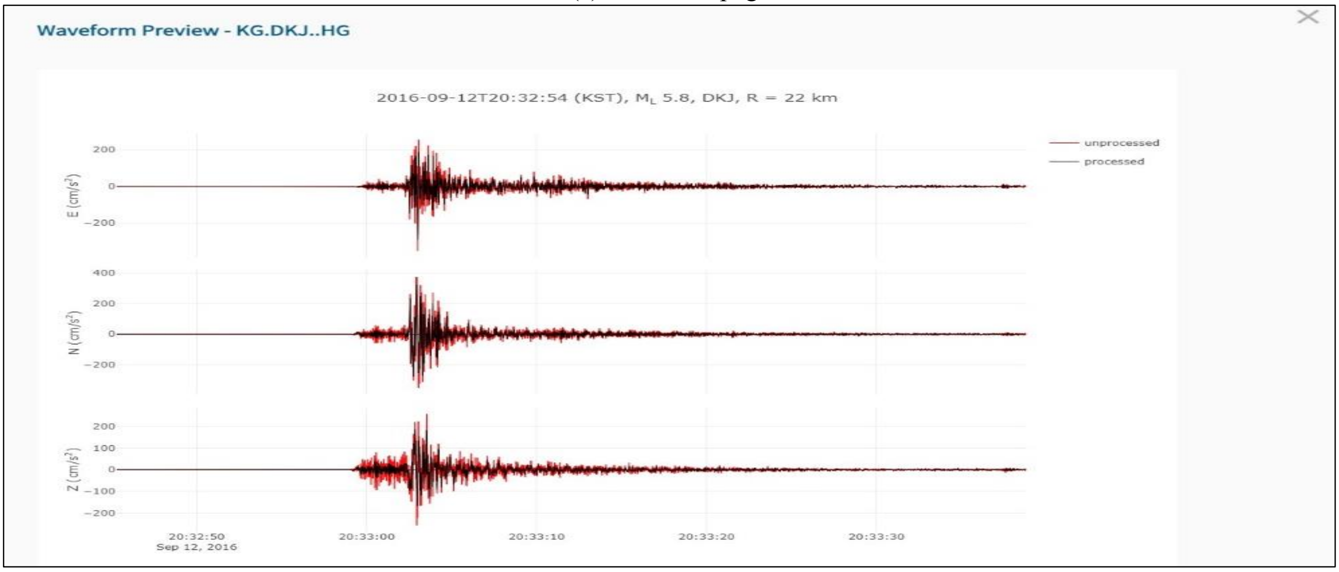
A total of 2,363 KGNET strong-motion records (one record means three components of the ground motion) have been processed and made available through the sub-menu of K-ESM DB for the period from 2016 to the end of 2022 that satisfy the above conditions.

5.2.2 Advanced search for strong-motion

An advanced search function is available for both the event waveform [raw data] and [processed data]. Detailed searching will be possible by using individual or combinations of the following conditions; events (origin time, magnitude, epicenter location by latitude and



(a) the search page



(b) the event preview pop-up screen

Fig. 7 The web page for K-ESM DB (https://data.kigam.re.kr/quake/analysis/kesmdb)

longitude, and focal depth in km), stations (location by latitude and longitude, and direct selection), and records (epicentral distance in km, horizontal and vertical peak ground acceleration [PGA] in cm/s^2 based on the [processed data], and sensor installation types, such as surface or borehole).

For example, one result is retrieved by setting and searching conditions for earthquake events of magnitude

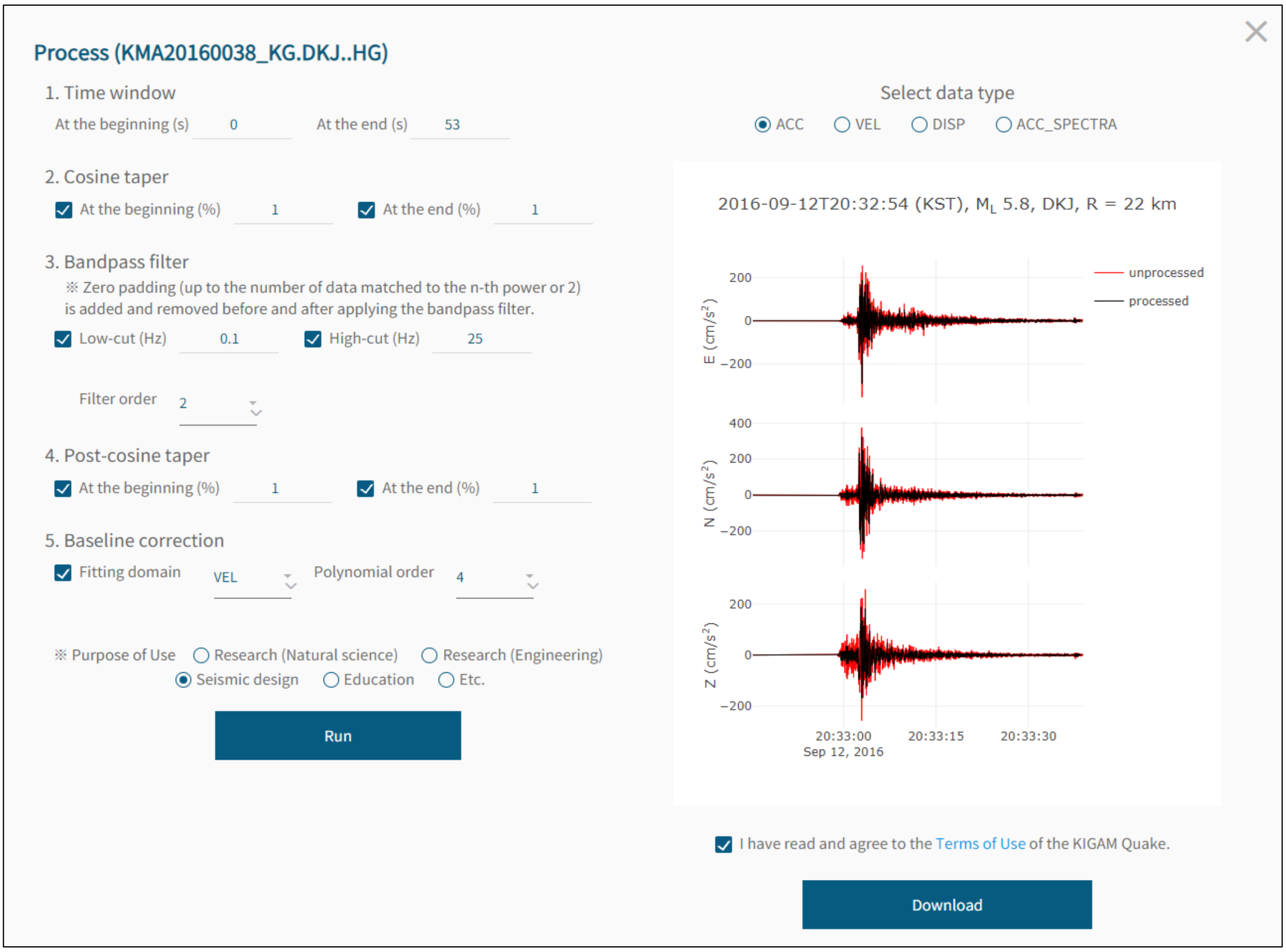


Fig. 8 The pop-up page of signal processing for individual accelerometric records

greater than 5.8 and PGAs greater than 300 cm/s^2 in the horizontal direction, as shown in Fig. 7(a). It also provides a waveform preview function for the search result. By clicking on a search result row, both [raw data] and [processed data] waveforms can be previewed on a pop-up page before downloading, as shown in Fig. 7(b). The [raw data] is displayed with linear detrending applied on the preview page.

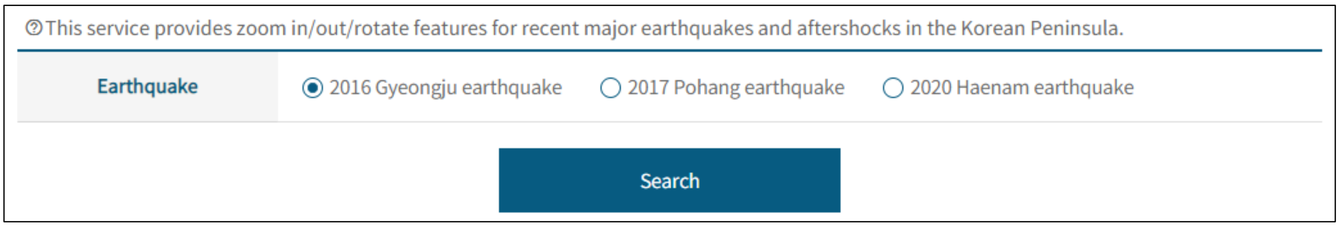
5.2.3 User-defined processing tools

As shown in Fig. 7(a), a signal processing 'open' button is provided for each individual accelerometric ground motion on the right side of the search result. When clicked, a new page pops up, allowing users to perform signal processing, as illustrated in Fig. 8. The first signal processing procedure on the page is to adjust the records' start and end time within the event waveform [raw data] length range. The second to fifth signal processing procedures are identical to those described in Section 5.2.1, and basic variables used for generating [processed data] are displayed as placeholders. If a specific signal processing is deactivated, its corresponding procedure will not be applied. After answering the questionnaire on the usage purpose, users can click the 'Run' button and view the processed data (displayed in black) on the right graph alongside the unprocessed red data (i.e., [raw data] with applying linear detrend) for comparison. The graphs are interactive so that users can zoom in and out. Users can also view graphs of the velocity, displacement time series, and acceleration response spectra generated from processed acceleration records and simultaneously download all three components of each ground motion.

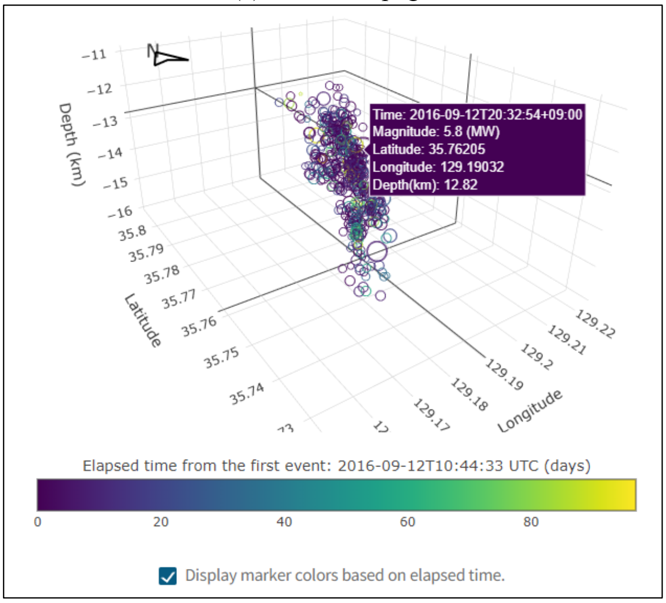
5.2.4 Download and data format

The raw data bundle in Section 5.1 and the event waveform [raw data] in Section 5.2.1 are provided as count values in miniSEED format without converting to physical values using station metadata. This is because they have not undergone any signal processing techniques.

The event waveforms [processed data] in Section 5.2.1, which have undergone a series of signal processing, and the ground motion processed by the user in Section 5.2.3 are converted to physical values from count values; this can be downloaded as an ASCII data format file. The file has a header and data section to enhance user readability and compatibility with programming. The header, as tabulated in Table 2, contains information on the earthquake event, station and sensor, record, and processing. The three components of the ground motion in two horizontal



(a) the search page



(b) 3D display of hypocenter information of major continuous earthquakes on the Korean Peninsula (2016 Gyeongju earthquake, Son *et al.* 2018)

Fig. 9 The web page for recent major earthquakes on the Korean Peninsula (https://data.kigam.re.kr/quake/analysis/major-earthquake)

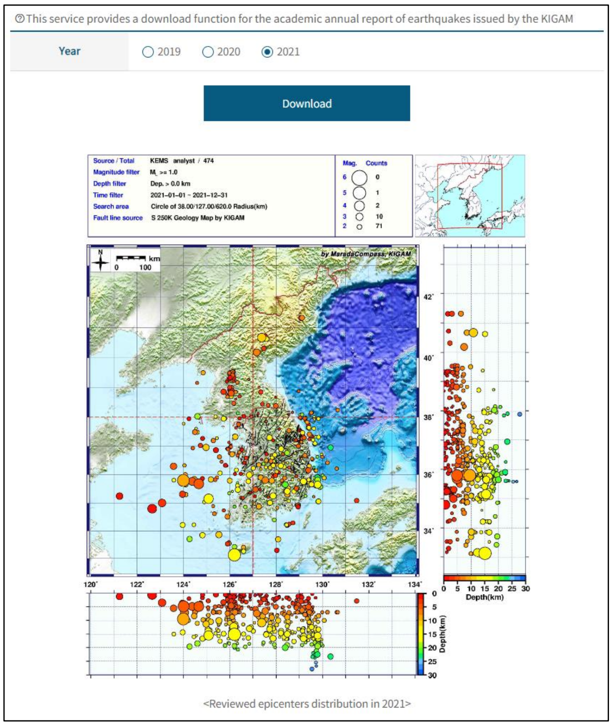


Fig. 10 The web page for academic annual report of earthquakes (https://data.kigam.re.kr/quake/analysis/annual-report)

directions and one vertical direction can be simultaneously downloaded as separate files.

6. Other earthquake research information

In addition to seismological data, a separate menu titled "earthquake analysis information" provides the earthquake analysis results conducted by the KIGAM KERC as research information in related fields through sub-menus.

The sub-menu "Major earthquakes on the Korean Peninsula" offers information on the earthquake source parameters of major earthquakes that have occurred on the Korean Peninsula since 2016. This information includes the 2016 Gyeongju (Son *et al*. 2018), the 2017 Pohang (Son *et al.* 2020), and the 2020 Haenam earthquakes (Son *et al.* 2021) (Fig. 9(a)). The sub-menu also features 3D interactive functions such as zooming and rotating for the major earthquakes' forward, main, and aftershock sequences, as shown in Fig. 9(b).

The sub-menu "Academic annual report of earthquakes" enables searching and downloading services for the academic annual report of earthquakes published annually since 2019 (Fig. 10). The report includes a review by analysts for earthquake events with local magnitudes greater than 2.0 that occurred in and around the

Table 2 The header information of event waveform processed data in ASCII format

EARTHQUAKE EVENT INFO (KMA)
EVENT_DATE_TIME:
EVENT_LATITUDE_DEGREE:
EVENT_LONGITUDE_DEGREE:
EVENT_DEPTH_KM:
EVENT_MAGNITUDE_L:
STATION & SENSOR INFO
NETWORK_CODE:
STATION_CODE:
STATION_LATITUDE_DEGREE:
STATION_LONGITUDE_DEGREE:
STATION_ELEVATION_M:
PREFERRED_SITE_VS30_M/S:
PREFERRED_SITE_CLASSIFICATION_NEHRP:
SENSOR_DEPTH_M:
SENSOR_MODEL_NAME:
RECORD INFO
STREAM_ID:
EPICENTRAL_DISTANCE_KM:
EARTHQUAKE_BACKAZIMUTH_DEGREE:
MEASURED_DATA_TYPE:
SAMPLING_INTERVAL_S:
NUMBER_OF_SAMPLES:
DATE_TIME_FIRST_SAMPLE:
DATE_TIME_LAST_SAMPLE:
DURATION_S:
PROCESSING INFO
REMOVE_DC_OFFSET:
PRE_COSINE_TAPER_AT_THE_BEGINNING_%:
PRE_COSINE_TAPER_AT_THE_END_%:
ZERO_PADDING:
FILTER_TYPE:
FILTER_ORDER:
LOW_CUT_FREQUENCY_HZ:
HIGH_CUT_FREQUENCY_HZ:
REMOVE_ZERO_PADDING:
POST_COSINE_TAPER_AT_THE_BEGINNING_%:
POST_COSINE_TAPER_AT_THE_END_%:
BASELINE_CORRECTION_TYPE:
BASELINE_CORRECTION_FITTING_DOMAIN:
BASELINE_CORRECTION_POLINOMIAL_ORDER:
OUTPUT_DATA_TYPE:
OUTPUT_UNITS:

KoreanPeninsula in the given year. Each earthquake event includes the following information: earthquake occurrence information (origin time, epicenter, local and moment magnitudes, focal depth, occurrence region, etc.), seismic wave arrival information, earthquake occurrence status around the epicenter, event waveforms, PGA distribution map, and fault plane solutions for earthquakes with magnitudes larger than 2.5.

The earthquake research results produced by KIGAM will continuously be updated and added to the KIGAM Quake open platform.

7. Conclusions

We introduced KIGAM Quake (https://data.kigam.re.kr/quake/), an open platform to share seismological data and earthquake research information. KIGAM Quake offers seismic data from all 61 KGNET seismic stations, a nationwide seismic monitoring network operated by KIGAM, through highly accessible web and FDSN web services. It provides station metadata necessary for analyzing seismic data. Moreover, the geotechnical seismic response parameters of the observatory sites are summarized in a table. Unprocessed continuous waveforms and strong-motion records can be downloaded in various data formats, and processed strong-motion records can be downloaded in ASCII format. The platform also has a user-controlled signal processing tool for individual strong-motion records. In addition to seismological data, a separate menu is dedicated to earthquake research information produced by KIGAM, such as information on recent major earthquake sources and the academic annual report of earthquakes. With KIGAM Quake, we aim to increase the accessibility of seismological data and related research information to not only seismologists but also engineering seismologists and earthquake engineers.

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