Site response and vulnerability index estimation for King Saud University Compound, Riyadh, Saudi Arabia.

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ABSTRACT

Microtremors measurement at King Saud University compound were performed at 45 sites using Taurus digital seismograph equipped by 3-component trillium compact seismometer with measurement spacing of 400 meters. The recording time continued for 61 minutes at each site with sampling rate of 100 Hz. Then these data were processed and analyzed to estimate the fundamental frequency and the average amplification factor and the vulnerability index as well for all measurements sites.

The results showed that the range of Fundamental frequency in the study area is between 0.64 and 1.94 Hz with average below of 1 Hz. Spectral ratio of H/V ranges from 1.19 to 17.22. Moreover, the seismic vulnerability index at each measurement site was estimated. The seismic vulnerability index ranges from 0.7 to 150. The northern zone is highly vulnerable due to the great thickness of the soft sediments. These results correlate well with the geotechnical borehole data. Based on these results it is concluded that King Saud University compound has low to moderate potential of seismic risk.

ACKNOWLEDGMENTS

I would like to express my deepest appreciation and my grateful thanks to my advisor Dr. Sattam Abdulkareem Madani and Prof. Kamal Hassanein, for the guidance and helpful orientation that given to me during field excursion data processing and writing this report.

I would like also to thank the department of Geology, College of Science - King Saud University for allowing me this opportunity.

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1. Introduction

Microtremor is a ground vibration (Susilo and Wiyono, 2012) caused by natural or artificial events, such as wind, waves, or vibrations of a vehicle that can reflect the geological conditions near the surface. The study aims to assist the site response effect by calculating the Microtremor measurements to identify the vulnerable sites within the King Saud University compound, Riyadh, Saudi Arabia (Fig.4).

The methods applied in this study are microtremor data which carried out including analysis of H/V amplification ratio, dominant frequency and seismic vulnerability index. The results after proccing matched with the geotechnical reports about four boreholes that were drilled to depths varying from 8 to 12 m below the existing ground surface (Soil & Foundation Co. Ltd., 2014; Fig. 1).

1.1 Literature Review

Ventura et al. (2006) Site Period Estimations Using Microtremor Measurements-Experimental and Analytical Studies in British Columbia, this paper presents site period investigations at nodes on a 1-km grid within a 6-km by 8-km area in Vancouver and Richmond, BC. The area includes a range of site conditions, and is selected as the pilot application area for an urban seismic instrumentation project (Canadian Urban Seismology Program - CUSP) undertaken by the Geological Survey of Canada (GSC).

Noor and Daud (2016) Determination of Soil Thickness Based on Natural Frequency Using Microtremor Measurement ambient vibrations from microtremor measurement were carried out in the Universiti Tun Hussein Onn Malaysia (UTHM) using Lennartz 1Hz tri-axial seismometer sensor. Microtremor measurements have been conducted on 5 boreholes at UTHM, to study the correlation between the natural frequency (Fo) and depth of borehole.

Fnais et al. (2010) Microtremor measurements in Yanbu city of Western Saudi Arabia: A tool for seismic microzonation, Microtremor measurements are one of the most popular world-wide tool for estimation of site response especially within the urban area. This technique has been applied over 85 sites distributed regularly through Yanbu metropolitan area with an aim of seismic hazard microzonation for ground shaking site effects.

2. Geological Setting

The study is conducted in King Saud University compound, Riyadh, most of the compound lay on Arab Formation Member C and D, also there near the study site the Late Jurassic Jubaila Limestone (Arkell, 1952), divided by Manivit et al. (1985) into informal units J1 and J2, with alluvium and sheet gravel also nearby.

Map of the study sites in (Fiq.1). The Arab Formation (Veslet et al., 1991), formally defined by Steineke et al. (1958), was revised by Powers et al. (1966) and Powers (1968), who described a subsurface alternation, 127.5 m thick (Dammam well7), of limestone and anhydrite, subdivided into four formal members from Arab-D at the bottom to Arab-A at the top. Each member corresponds to a sedimentologic sequence that evolves from shallow-water marine limestone at the base to anhydrite at the top. The anhydritic part of the Arab-A Member, however, is more than 90 m thick, and Powers et al. (1966) therefore assigned it formation status.

Rocks assigned to the Arab-D Member in the Riyadh quadrangle are predominantly carbonate. Collapse breccias overlying this first carbonate unit of the formation are also regarded as part of the member; however, as they usually constitute the foot of the cuesta of Arab-C carbonates, they are mapped together with Arab-C Member carbonates. Outcrop thicknesses of the Arab-D Member (including carbonates and breccia) range from 27 m in the central part of the quadrangle to 20.50 m in the northwest, and 17 m in the south.

The carbonate facies of the Arab-D Member, 12m thick east of A1 Ha‘ir, comprises an alternation of gray to bluish laminated calcareous mudstone and bioclastic, in- traclastic, and locally oolitic calcarenite that channels the muddy facies. Beige micropelletoidal laminated limestone and gypsiferous laminae showing secondary calcitization occur in the upper part of the sequence.

The evaporitic part of the Arab-D Member is not known in outcrop. Solution breccias enveloping components of the Arab-D and Arab-C members are assigned to a lower breccia complex which is 25 m thick east of Al Ha‘ir, and 13 m thick at Manffihah in the south of the city of Riyadh. The lower breccia complex is composed of angular fragments of various types of limestone and bioclastic calcarenite, the size of the fragments increasing from the base (a few centimeters) to the top (several decimeters). The breccia cement is entirely calcitized from a former gypsiferous matrix. Locally, in the Awsat graben area, fine-grained sandstone in channels 10 to 50 m wide and 2 to 10 m thick, showing secondary silicification, has been disaggregated

and occurs in the lower breccia complex over about 100 m: the di- rection of the channel flow is generally northeasterly.

In the Abfi Jifan oil field, the evaporitic facies of the Arab-D Member comprise 35.66m of gray to white massive anhydrite.

The subsurface geologic information is based on the geotechnical reports about four boreholes that were drilled to depths varying from 6 to 15 m below the existing ground surface (Soil & Foundation Co. Ltd., 2014; Fig. 1). The subsurface geologic setting at the site consists of three layers that extend from the ground surface to the maximum depths investigated:

- Silty sand with gravel: A top layer of brown medium dense and dry to damp silty sand with gravel. This layer has an average thickness of ~5.5 m.
- Completely weathered limestone: Below the top layer of the very dense sand; dry to damp and creamy; completely weathered limestone in four boreholes. The thickness of this layer varies from 2.5 to 13.5 m.
- Limestone: Below the top layer in the BH-3borehole. It is interbedded with thin layers of silty sand; creamy, moderately weathered, and very highly to highly fractured limestone rock.

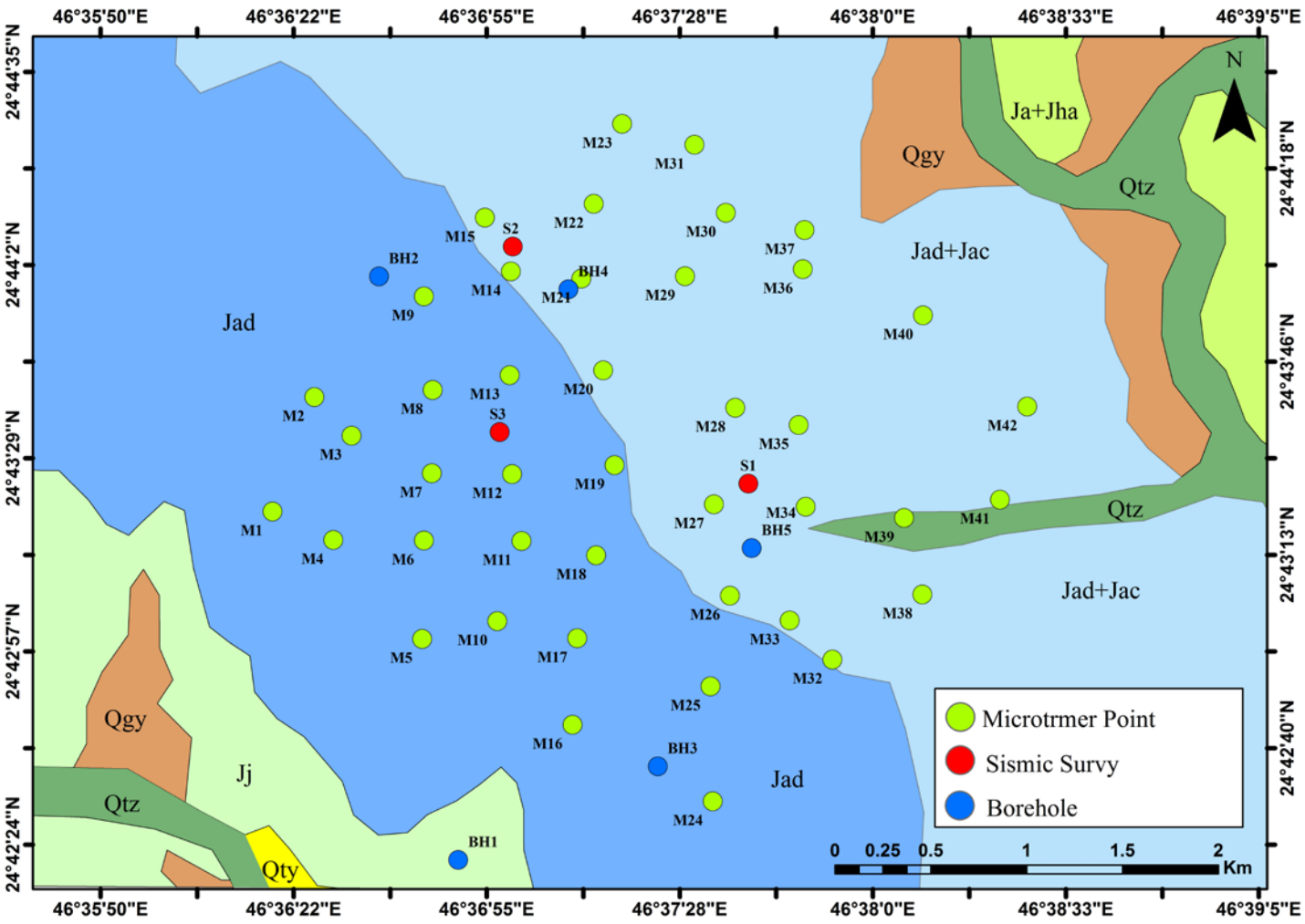


Figure (1) Geological of the study area (ArcMap).

3. Methodology

The methods applied on this study are evaluation on geological and seismological secondary data. Evaluations on microtremor data is also carried out including analysis of H/V amplification ratio, dominant frequency and seismic vulnerability index.

Microtremor is a ground vibration (Susilo and Wiyono, 2012) caused by natural or artificial events, such as wind, waves, or vibrations of a vehicle that can reflect the geological conditions near the surface. Microtremor is used in seismic techniques to estimate the shear wave velocity profile (Vs). Microtremor also dominated by surface waves that can be used to determine the Rayleigh wave dispersion curve without the need for an artificial source. Microtremor analysis can be performed using HVSR method (Horizontal to Vertical Spectral Ratio). This method is one of the easiest and most inexpensive ways to understand the properties of the subsurface layer structure without causing disruption to the structure.

HVSR method is a method that is used as an indicator of subsurface structure, which shows the relationship between the ratio of the spectrum of H/V with the ellipticity curve of Rayleigh waves. The H/V is the ratio between the amplitude of Fourier spectral of horizontal and vertical components of microtremor. Many urban areas with large populations are erected on soft-sediment, the soil structure tends to amplify the seismic waves. The soft lithology tends to respond a long period of vibration (low frequency), and vice versa.

4. Data Acquisition

4.1 Microtremor Measurement

Microtremor data acquisition has been collected using Taurus digital seismograph (Nanometrics Company) equipped with three-component Trillium compact seismometer. These data acquired during from the period of 2 -15 February 2017. The total sites of measurements are 45 distributed all over the study area (Table 2) with spacing 400 meters (Fig. 1). The continuous recording period was extended up to 60 minutes with 100 Hz sampling rate at each recording site (360000 samples at each site) following the recommendations of the SESAME project (SESAME, 2004; Bard, 2007).

Figure (3) Taurus the digital seismograph.

Figure (2) Trillium sensor directed to the north pole.

Station	Latitude (North)	Longitude (East)	Start Time	End Time	Duration (Hour)
M1	24.72233	46.60523	13:43	14:44	1:01
M2	24.72769	46.60719	15:39	16:40	1:01
M3	24.72589	46.60894	18:19	19:20	1:01
M4	24.721	46.60809	7:10	8:11	1:01
M5	24.71636	46.61225	14:20	15:21	1:01
M6	24.72097	46.61233	17:24	18:25	1:01
M7	24.72412	46.61271	19:25	20:26	1:01
M8	24.72803	46.61275	8:44	9:45	1:01
M9	24.73242	46.61233	10:56	11:57	1:01
M10	24.71719	46.61578	13:16	14:17	1:01
M11	24.72094	46.61692	15:47	16:48	1:01
M12	24.72408	46.61647	13:20	14:21	1:01
M13	24.72872	46.61636	14:58	15:59	1:01
M14	24.73358	46.61642	17:58	18:59	1:01
M15	24.73611	46.61519	10:30	11:31	1:01
M16	24.71233	46.60264	12:43	13:44	1:01
M17	24.71639	46.61953	14:52	15:53	1:01
M18	24.72028	46.62042	9:12	10:13	1:01
M19	24.7245	46.62128	11:59	13:00	1:01
M20	24.72894	46.62075	13:55	14:56	1:01
M21	24.73325	46.61972	16:09	17:10	1:01
M22	24.73675	46.62031	18:14	19:15	1:01

M23	24.7405	46.62164	12:15	13:16	1:01
M24	24.70875	46.62589	14:02	15:03	1:01
M25	24.71414	46.62578	16:24	17:25	1:01
M26	24.71839	46.62669	7:51	8:52	1:01
M27	24.72267	46.62594	12:21	13:22	1:01
M28	24.72719	46.62694	13:50	14:51	1:01
M29	24.73336	46.62458	15:31	16:32	1:01
M30	24.73633	46.6265	17:08	18:09	1:01
M31	24.73953	46.62503	18:35	19:36	1:01
M32	24.71539	46.6315	6:09	7:10	1:01
M33	24.71722	46.6295	7:28	8:29	1:01
M34	24.72256	46.63025	8:49	9:50	1:01
M35	24.72639	46.62992	10:46	11:47	1:01
M36	24.73369	46.63011	12:15	13:16	1:01
M37	24.73553	46.63019	13:50	14:51	1:01
M38	24.71844	46.63572	13:20	14:21	1:01
M39	24.72203	46.63486	14:39	15:40	1:01
M40	24.73153	46.63575	9:10	10:11	1:01
M41	24.72289	46.63936	10:45	11:46	1:01
M42	24.72725	46.64064	12:07	13:08	1:01
S1	24.72364	46.62756	13:37	14:38	1:01
S2	24.73475	46.6165	15:09	16:10	1:01
S3	24.72606	46.61589	17:26	18:27	1:01

Table (1) Location and duration time of the measuring points.

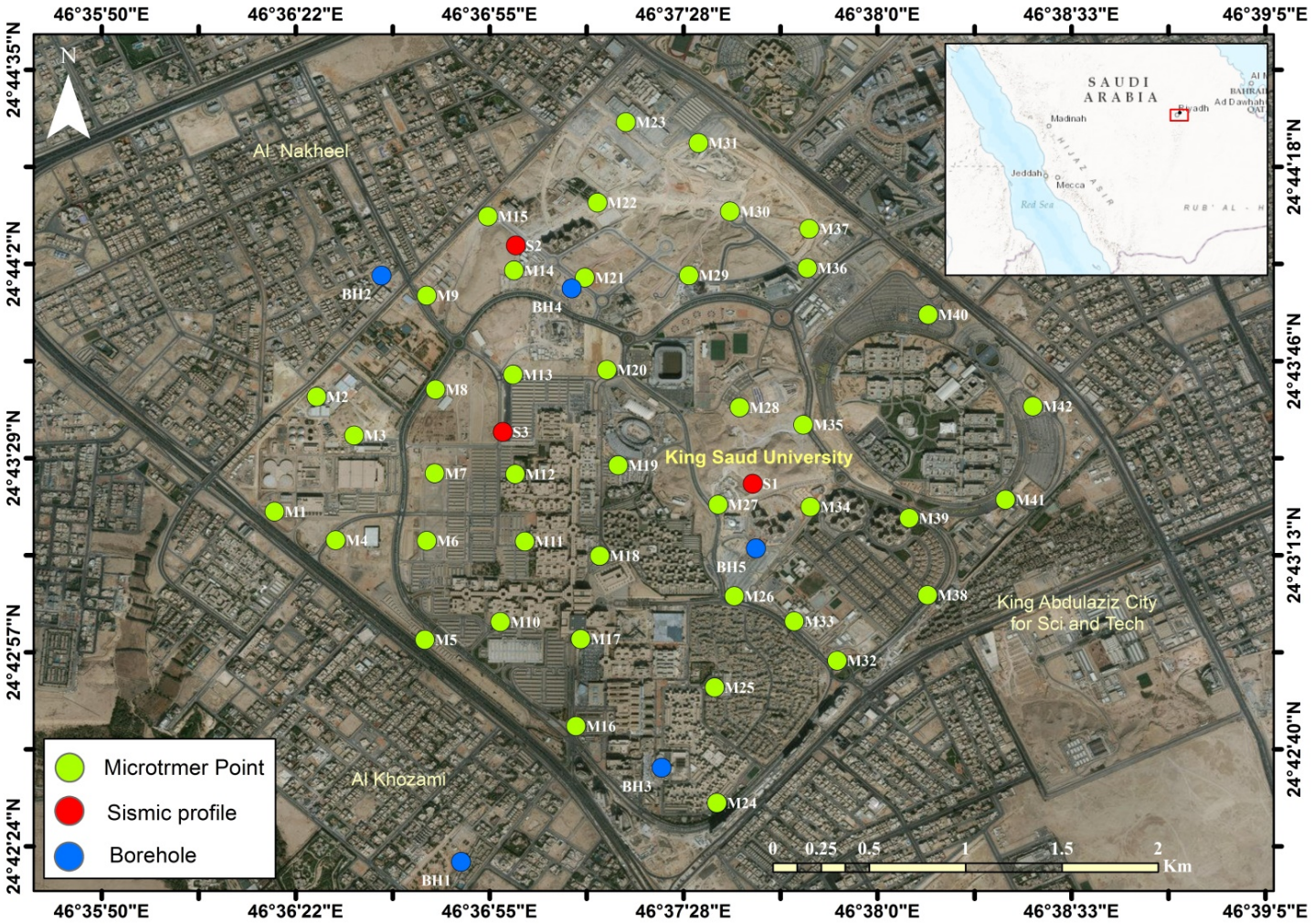


Figure (4) Location of the study area (ArcMap).

4.2 Borehole Collection

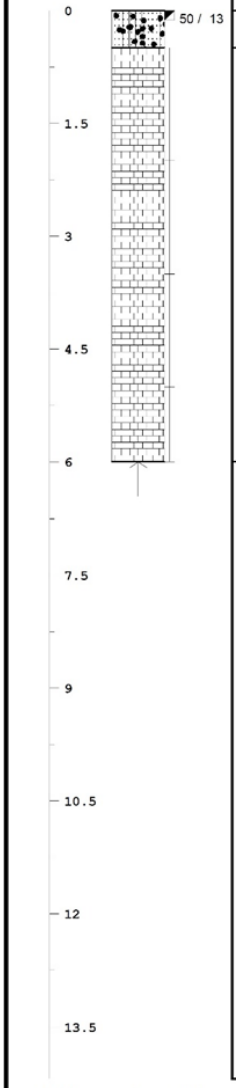
The report from Soil & Foundation Co. Ltd. (2014) presents the results of geotechnical investigation carried out by Geotechnical and Material Testing Division of The Saudi Engineer.

The purpose of the geotechnical investigation was to determine the subsurface formation and ground water conditions to evaluate the allowable bearing capacity of the subsurface formation encountered at the site and to recommend the most feasible type of foundation for the proposed structure. Four Boreholes were performed at the site. The boreholes 2 and 3 were drilled to 6 m depth while the borehole 4 to 7.5 m depth and the borehole 5 to 15 m depth, the subsurface geologic setting at the site consists of three layers.

TEST BORING LOG

BORING NO.: BH-1

PROJECT	:GIRLS SCHOOL			**DATE STARTED**	20/8/2009
CLIENT	:M.O.E			**DATE FINISHED**	20/8/2009
LOCATION	:AL-NAKHEEL DIST, RIYADH, K.S.A			**DRILL RIG**	B-53
PROJECT NO.	:RSM 9575-35	**ELEVATION :**		**DRILLER**	:JAMAL
GWD ▽	: -	**NORTH**	:24° 44' 00.6"	**GEOLOGIST**	S.S
GWL	:	**EAST**	:46° 36' 36.8"	**TOTAL DEPTH**	6.0M



ELEV/ DEPTH	USCS	Description	SPT (N)	W.C. (%)	L L (%)	P I (%)	REC. (%)	RQD (%)	SAMPLE NO.	CURVE (SPT) 20 40 60 80
0	SM	SILTY SAND WITH GRAVEL, brown, very dense, dry	100	1.7	-	NP			BH-1-1	
		LIMESTONE INTERBEDDED WITH THIN LAYERS OF SILTY SAND, creamy, highly weathered, very highly fractured					53	12	BH-1-2	
							49	16	BH-1-3	
							55	19	BH-1-4	
							63	21	BH-1-5	
6		END OF BORE HOLE								

Drilling performed by using tricone bit and casing & Coring in rock performed by using double tube core barrel

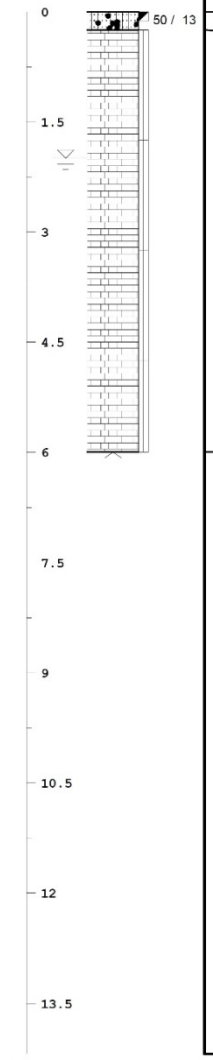
Figure 2 PAGE 1 of 1 **Soil and Foundation Co., Ltd.**

Table (2) Test boring for Borehole 2 (Soil & Foundation Co. Ltd., 2014).

TEST BORING LOG

BORING NO.: BH-1

PROJECT	: UNIVERSITY HOUSING MAINTENANCE UNIT			**DATE STARTED**	: 12/7/2010
CLIENT	: SAM KABBANI & PARTNERS			**DATE FINISHED**	: 12/7/2010
LOCATION	: KING SAOUD UNIVERSITY, RIYAD			**DRILL RIG**	B-53
PROJECT NO.	: RSM 10496	**ELEVATION**	:	**DRILLER**	SAEED
GWD ▽	: 2.0M	**NORTH**	: 24° 42' 37.4"	**GEOLOGIST**	MAHDI
GWL	:	**EAST**	: 46° 37' 23.9"	**TOTAL DEPTH**	6.0M



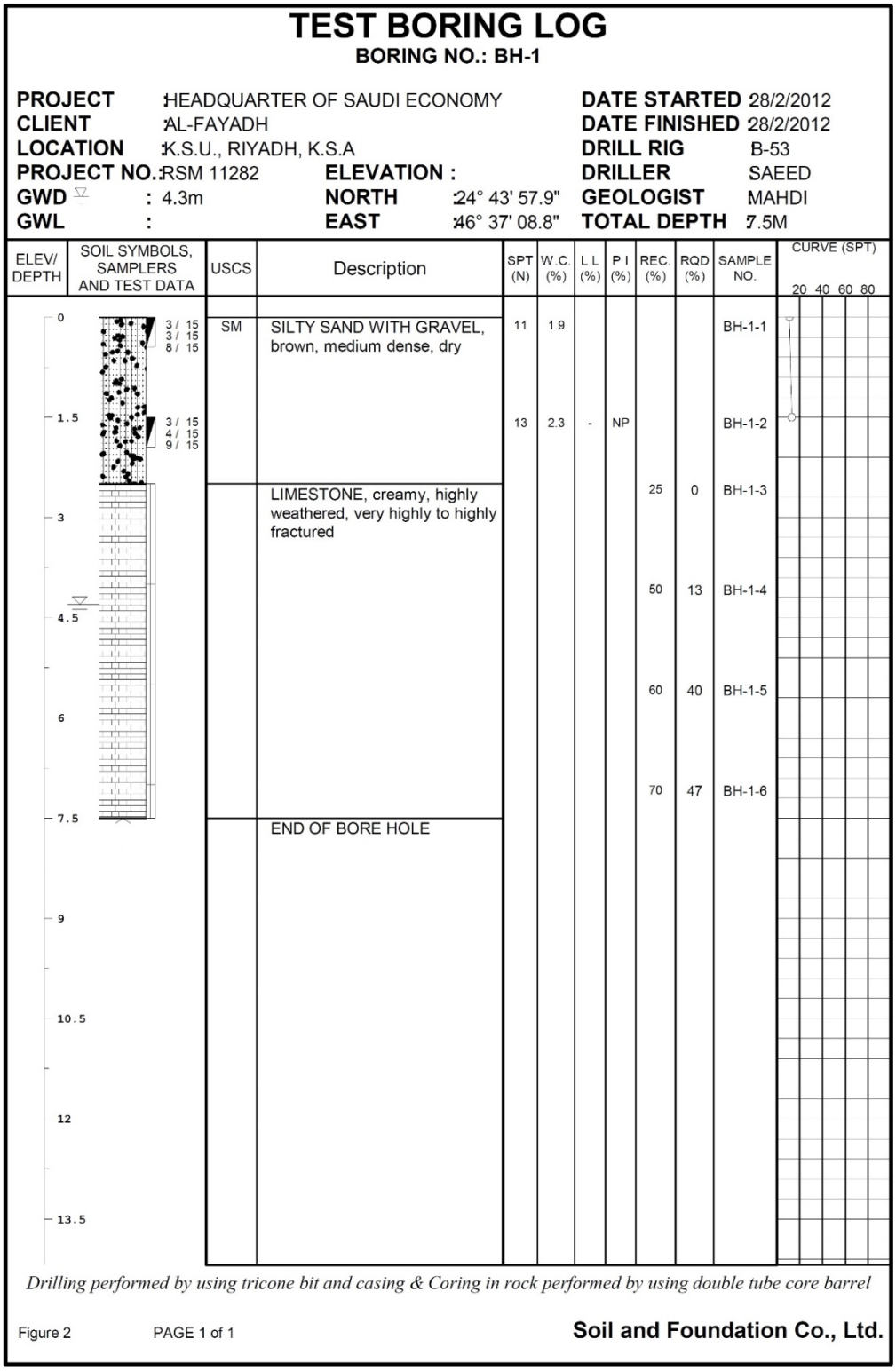
ELEV/ DEPTH	USCS	Description	SPT (N)	W.C. (%)	L L (%)	P I (%)	REC. (%)	RQD (%)	SAMPLE NO.
	SM	SILTY SAND WITH GRAVEL, light brown, very dense, dry	100	2.8	-	NP	55	26	BH-1-1 BH-1-2
		LIMESTONE INTERBEDDED WITH THIN LAYERS OF SILTY SAND, moderately weathered, highly to slightly fractured					78	39	BH-1-3
							100	67	BH-1-4
							100	85	BH-1-5
		END OF BORE HOLE							

CURVE (SPT): 20 40 60 80

Drilling performed by using Tricone Bit and Casing & Coring in rock performed by using Double Tube Core Barrel

Figure 2 PAGE 1 of 1 **Soil and Foundation Co., Ltd.**

Table (3) Test boring for Borehole 3 (Soil & Foundation Co. Ltd., 2014).



TEST BORING LOG

BORING NO.: BH-1

PROJECT	HEADQUARTER OF SAUDI ECONOMY			**DATE STARTED**	28/2/2012
CLIENT	AL-FAYADH			**DATE FINISHED**	28/2/2012
LOCATION	K.S.U., RIYADH, K.S.A			**DRILL RIG**	B-53
PROJECT NO.	RSM 11282	**ELEVATION :**		**DRILLER**	SAEED
GWD ▽	: 4.3m	**NORTH**	24° 43' 57.9"	**GEOLOGIST**	MAHDI
GWL	:	**EAST**	46° 37' 08.8"	**TOTAL DEPTH**	7.5M

ELEV/ DEPTH	SOIL SYMBOLS, SAMPLERS AND TEST DATA	USCS	Description	SPT (N)	W.C. (%)	L L (%)	P I (%)	REC. (%)	RQD (%)	SAMPLE NO.	CURVE (SPT) 20 40 60 80
0	3 / 15 3 / 15 8 / 15	SM	SILTY SAND WITH GRAVEL, brown, medium dense, dry	11	1.9					BH-1-1	
1.5	3 / 15 4 / 15 9 / 15			13	2.3	-	NP			BH-1-2	
3			LIMESTONE, creamy, highly weathered, very highly to highly fractured					25	0	BH-1-3	
4.5 ▽								50	13	BH-1-4	
6								60	40	BH-1-5	
7.5								70	47	BH-1-6	
			END OF BORE HOLE								
9											
10.5											
12											
13.5											

Drilling performed by using tricone bit and casing & Coring in rock performed by using double tube core barrel

Figure 2 PAGE 1 of 1 **Soil and Foundation Co., Ltd.**

Table (4) Test boring for Borehole 4 (Soil & Foundation Co. Ltd., 2014).

TEST BORING LOG

BORING NO.: BH-1

PROJECT	:PREVENTION OF FLOODS			**DATE STARTED**	2/4/2012
CLIENT	:SAM KABBANI CO.			**DATE FINISHED**	2/4/2012
LOCATION	:KING SAUD UNIVERESITY, RIYADH, K.S.A			**DRILL RIG**	B-53
PROJECT NO.	:RSM 11797	**ELEVATION :**		**DRILLER**	SAEED
GWD ⏚	: -	**NORTH**	:24.72062	**GEOLOGIST**	ZAMRAWI
GWL	:	**EAST**	:46.62771	**TOTAL DEPTH**	:15.0M

ELEV/ DEPTH	SOIL SYMBOLS, SAMPLERS AND TEST DATA	USCS	Description	SPT (N)	W.C. (%)	L L (%)	P I (%)	REC. (%)	RQD (%)	SAMPLE NO.	CURVE (SPT) 20 40 60 80
0	33 / 15 50 / 10	FILL	CLEAN FILL MATERIALS	100						BH-1-1	
1.5	8 / 15 9 / 15 7 / 15	GM	SILTY GRAVEL WITH SAND	16		-	NP			BH-1-2	
	4 / 15 5 / 15 7 / 15	SC-SM	SILTY CLAYEY SAND WITH GRAVEL	12		21	5			BH-1-3	
3	5 / 15 9 / 15 11 / 15	GM	SILTY GRAVEL WITH SAND	20		-	NP			BH-1-4	
4.5	9 / 15 11 / 15 13 / 15	GM	SILTY GRAVEL WITH SAND	24		-	NP			BH-1-5	
	10 / 15 11 / 15 16 / 15	GM	SILTY GRAVEL WITH SAND	27		-	NP			BH-1-6	
6	8 / 15 13 / 15 17 / 15	GM	SILTY GRAVEL WITH SAND	30		-	NP			BH-1-7	
7.5	7 / 15 8 / 15 10 / 15			18						BH-1-8	
	10 / 15 12 / 15 13 / 15			25						BH-1-9	
9	7 / 15 11 / 15 14 / 15			25						BH-1-10	
10.5	11 / 15 13 / 15 19 / 15			32						BH-1-11	
	11 / 15 15 / 15 19 / 15	GM	SILTY GRAVEL WITH SAND	34		-	NP			BH-1-12	
12	44 / 15 50 / 9	GM	SILTY GRAVEL WITH SAND	100		-	NP			BH-1-13	
	50 / 8			100						BH-1-14	
13.5			LIMESTONE, creamy, moderately weathered,					90	70	BH-1-15	

Drilling performed by using tricone bit and casing & Coring in rock performed by using double tube core barrel

Figure 2 PAGE 1 of 2 **Soil and Foundation Co., Ltd.**

Table (5) Test boring for Borehole 5 page 1 (Soil & Foundation Co. Ltd., 2014).

TEST BORING LOG

BORING NO.: BH-1

PROJECT	:PREVENTION OF FLOODS			**DATE STARTED**	2/4/2012
CLIENT	:ESAM KABBANI CO.			**DATE FINISHED**	2/4/2012
LOCATION	:KING SAUD UNIVERESITY, RIYADH, K.S.A			**DRILL RIG**	B-53
PROJECT NO.	:RSM 11797	**ELEVATION :**		**DRILLIER**	SAEED
GWD	:	**NORTH**	:24.72062	**GEOLOGIST**	ZAMRAWI
GWL	:	**EAST**	:46.62771	**TOTAL DEPTH**	:15.0M

ELEV/ DEPTH	SOIL SYMBOLS, SAMPLERS AND TEST DATA	USCS	Description	SPT (N)	W.C. (%)	L L (%)	P I (%)	REC. (%)	RQD (%)	SAMPLE NO.	CURVE (SPT) 20 40 60 80
15			moderately fractured								
16.5			END OF BORE HOLE								
18											
19.5											
21											
22.5											
24											
25.5											
27											

Figure 2 PAGE 2 of 2 **Soil and Foundation Co., Ltd.**

Table (6) Test boring for Borehole 5 Page 2 (Soil & Foundation Co. Ltd., 2014).

5. Data Processing

The next step is the processing that is composed of the FFT process by Geopsy program, involving the smoothing process. Smoothing process is done by using algorithms Konno and Ohmachi (1998) with bandwidth b coefficient of 25 second. It is also made the process of cosine taper to minimize the effects of borders or boundaries due to window selection process. Konno-Ohmachi algorithm is stated in the following equation:

$$W_B(f,\ f_c) = \frac{\sin(log_{10}\left(\frac{f}{fc}\right)^b)}{(log_{10}\left(\frac{f}{fc}\right)4)}$$

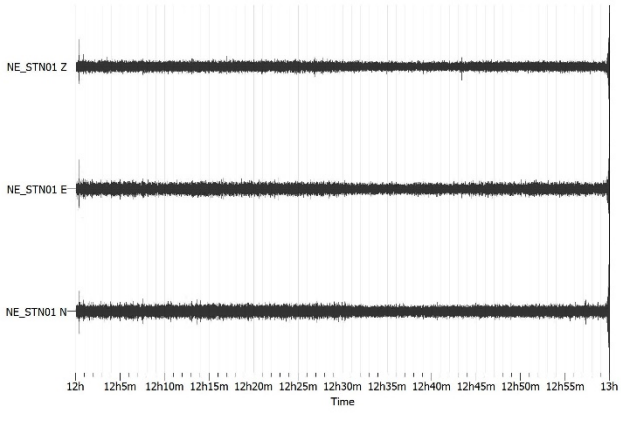
where:

f = frequency

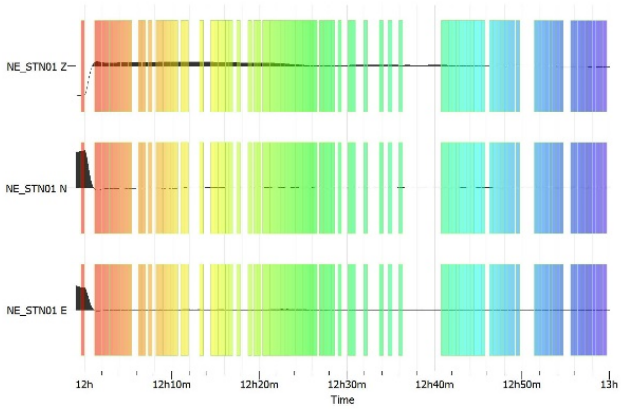
fc = the central frequency where the smoothing is done

b = bandwidth coefficient

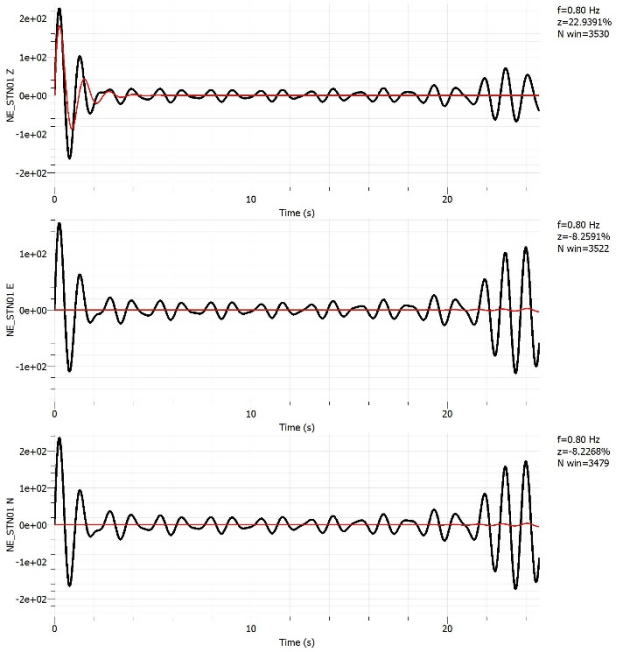
To obtain the spectral ratio of horizontal and vertical components, then the two horizontal components must be one value, using the average of the square, before divided by the horizontal component. This process is performed for every window that is selected. Spectral ratio value of H/V is obtained from the average ratio of H/V of all the selected window. To obtain a low standard deviation, then the value of H/V must be either a value of more than 0.4 because values below 0.4 will have a very high standard deviation.



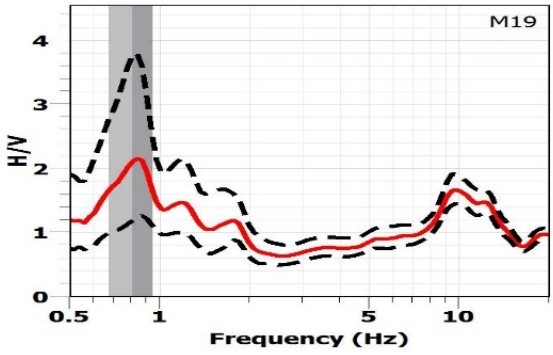
(A)


NE_STN01 Z
NE_STN01 N
NE_STN01 E
12h
12h10m
12h20m
12h30m
12h40m
12h50m
13h
Time

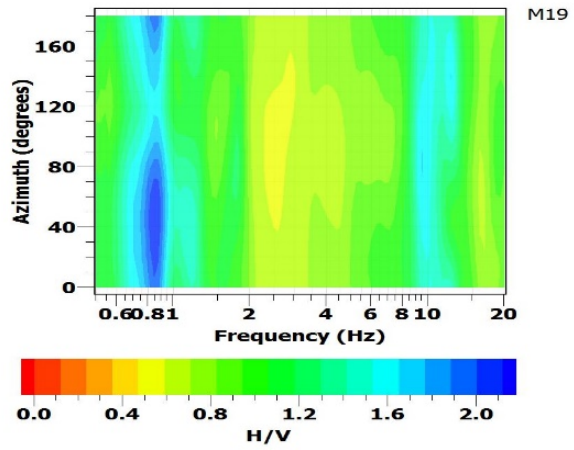
(B)


f=0.80 Hz
z=22.9391%
N win=3530
NE_STN01 Z
Time (s)
f=0.80 Hz
z=-8.2591%
N win=3522
NE_STN01 E
Time (s)
f=0.80 Hz
z=-8.2268%
N win=3479
NE_STN01 N
Time (s)

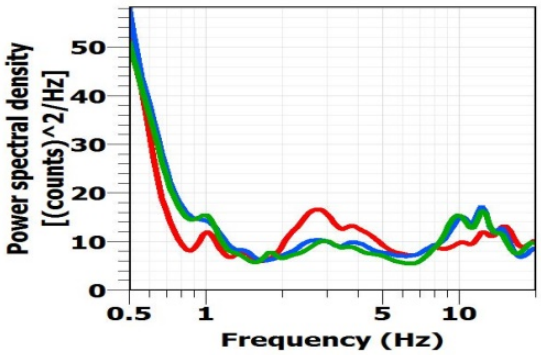
(C)


M19
H/V
Frequency (Hz)

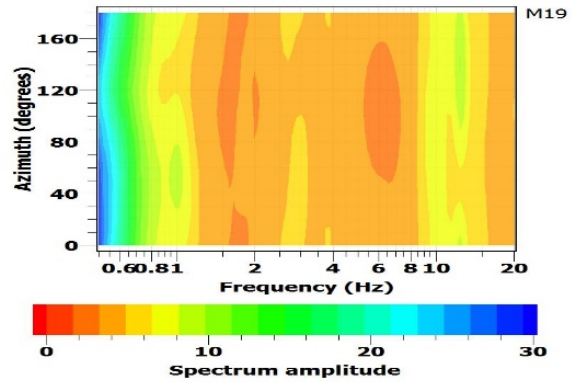
(D)



(E)



(F)



(G)

Figure (5) sequence of the H/V spectral ratio of point M19 (A) show the microtremer record (waveform), (B) show selected windows model, (C) show the damping test of a peek of natural origin 0.81 Hz, (D) H/V ratio curve, (E) show H/V rotate ratio, (F) show the spectrum curve, (G) Spectrum rotate ratio.

6. Results

Based on the results of data processing for 45 measuring points (Table 3) , f_0 values span between 0.64 and 1.94 while A_0 ranges from 1.19 to 17.22 (Fig. 7) . The contour map of f_0 (Fig. 5) illustrates the higher value of the fundamental frequency close to Preparatory Year building which indicates to harder bedrock compared to other areas, also there are another area with moderate f_0 at the old faculty housing.

Station	f_0	f_0 Std.	A_0	A0 Std.	No. of Windows	No. of Cycles
M1	0.83	0.1564	2.12	1.92	100	915000000
M2	0.91	0.158	1.4193	1.44	102	933300000
M3	1.25	0.3	1.33	1.86	68	622200000
M4	0.84	0.165	2.747	3.00	68	622200000
M5	0.867	0.172	1.199	1.38	111	1015650000
M6	0.83	0.1487	3.27	2.80	61	558150000
M7	0.709	0.123	1.7	1.64	135	1235250000
M8	0.759	0.118	12.8729	1.83	44	402600000
M9	0.84	0.149	13.11	3.07	65	594750000
M10	0.642	0.102	2.259	2.56	46	420900000
M11	0.7	0.122	1.862	1.94	77	704550000
M12	0.822	0.128	1.665	1.53	115	1052250000
M13	0.8	0.15	13.52	1.73	64	585600000
M14	0.675	0.1	5.38	1.86	65	594750000
M15	0.845	0.15	5.68	2.00	55	503250000
M16	0.785	0.1	2.7	1.73	74	677100000
M17	0.98	0.17	1.92	1.99	121	1107150000
M18	0.944	0.158	2.03	1.71	88	805200000
M19	0.811	0.13	2.1	1.79	97	887550000
M20	1.252	0.18	4.81	1.39	90	823500000
M21	0.92	0.17	5.55	2.26	49	448350000
M22	0.92	0.198	2.53	2.37	82	750300000
M23	1.946	0.285	2.729	2.21	97	887550000
M24	0.77	0.127	2.72	1.79	114	1043100000
M25	1.4	1	1.3	1.27	118	1079700000
M26	0.81	0.15	4.14	1.71	82	750300000
M27	0.88	0.198	10	1.92	69	631350000
M28	0.8	0.12	11.29	1.83	71	649650000
M29	0.8	0.13	11.55	1.71	44	402600000
M30	0.87	0.145	8.51	2.19	33	301950000
M31	0.78	0.129	12.88	1.88	40	366000000
M32	0.776	0.144	4.36	1.92	75	686250000
M33	0.75	0.009	3.06	1.79	79	722850000

M34	0.82	0.154	3.83	1.83	58	530700000
M35	0.84	0.14	2.95	1.99	87	796050000
M36	0.84	0.14	6.37	2.18	79	722850000
M37	0.77	0.009	17.22	1.80	38	347700000
M38	0.829	1.14	2.48	1.27	64	585600000
M39	0.8	0.86	3.66	1.31	108	988200000
M40	0.8	0.16	3.84	1.95	77	704550000
M41	0.758	0.125	5.4	2.11	72	658800000
M42	0.827	0.14	6.12	1.83	98	896700000
S1	0.735	0.11	6.33	2.17	79	722850000
S2	0.72	0.119	11.71	1.75	57	521550000
S3	0.75	0.077	6.94	1.99	72	658800000

Table (2) Data processing parameters of measuring points.

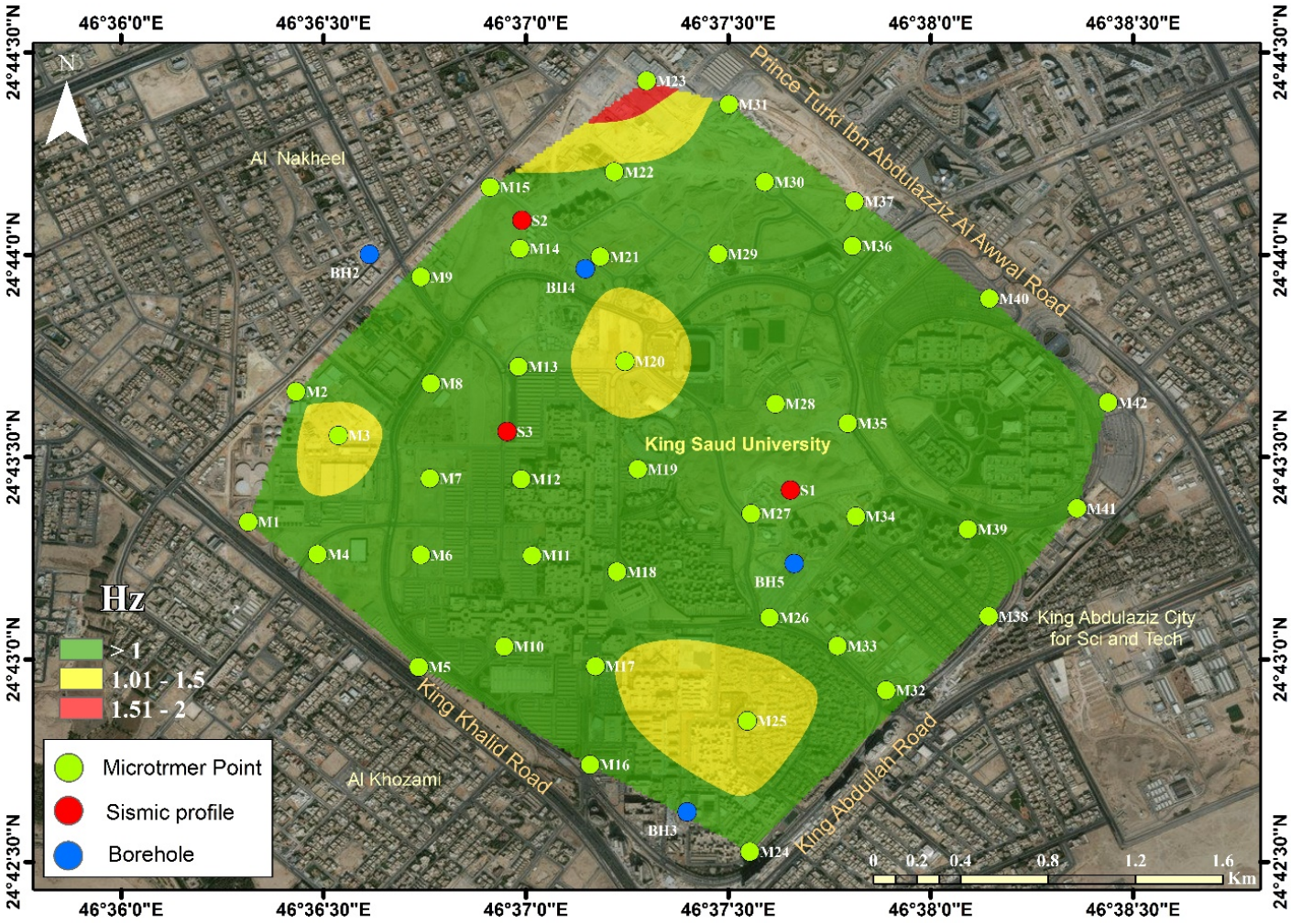


Figure (6) Fundamental frequency (f_0) contour map.

Contour map of A0 (Fig. 5) shows the higher value of the peak ratio is in the area between M31 and M37 near Prince Turki Ibn Abdulaziz Al Awwal road, while the area from M29 to M27 has moderate A0 values.

The seismic vulnerability index distribution in the area of study has values ranges from 0.7 to 148 (Fig. 6). There are areas which have high susceptibility values (the area between M31 and M37) near Prince Turki Ibn Abdulaziz Al Awwal road.

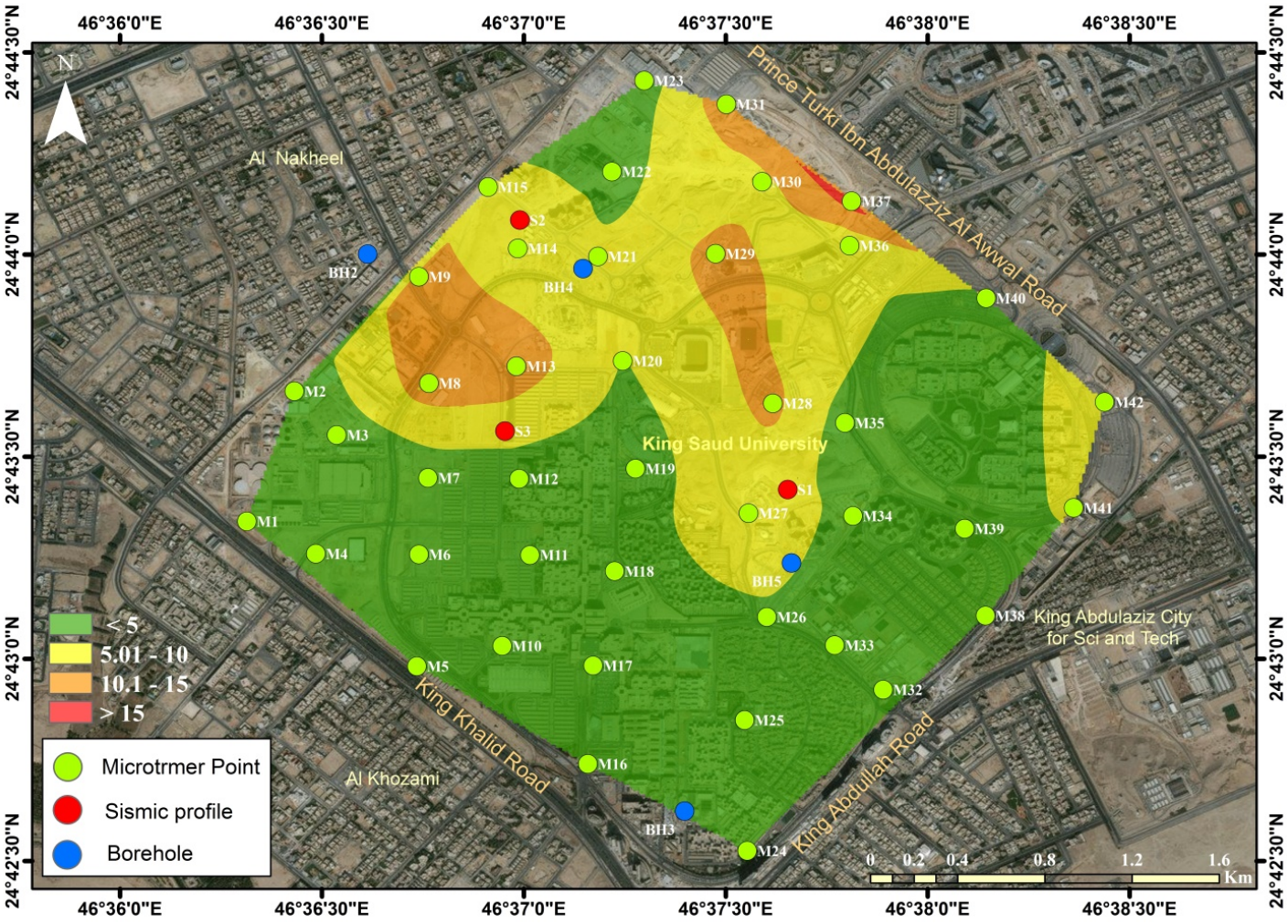


Figure (7) Amplification factor (A_0) contour map.

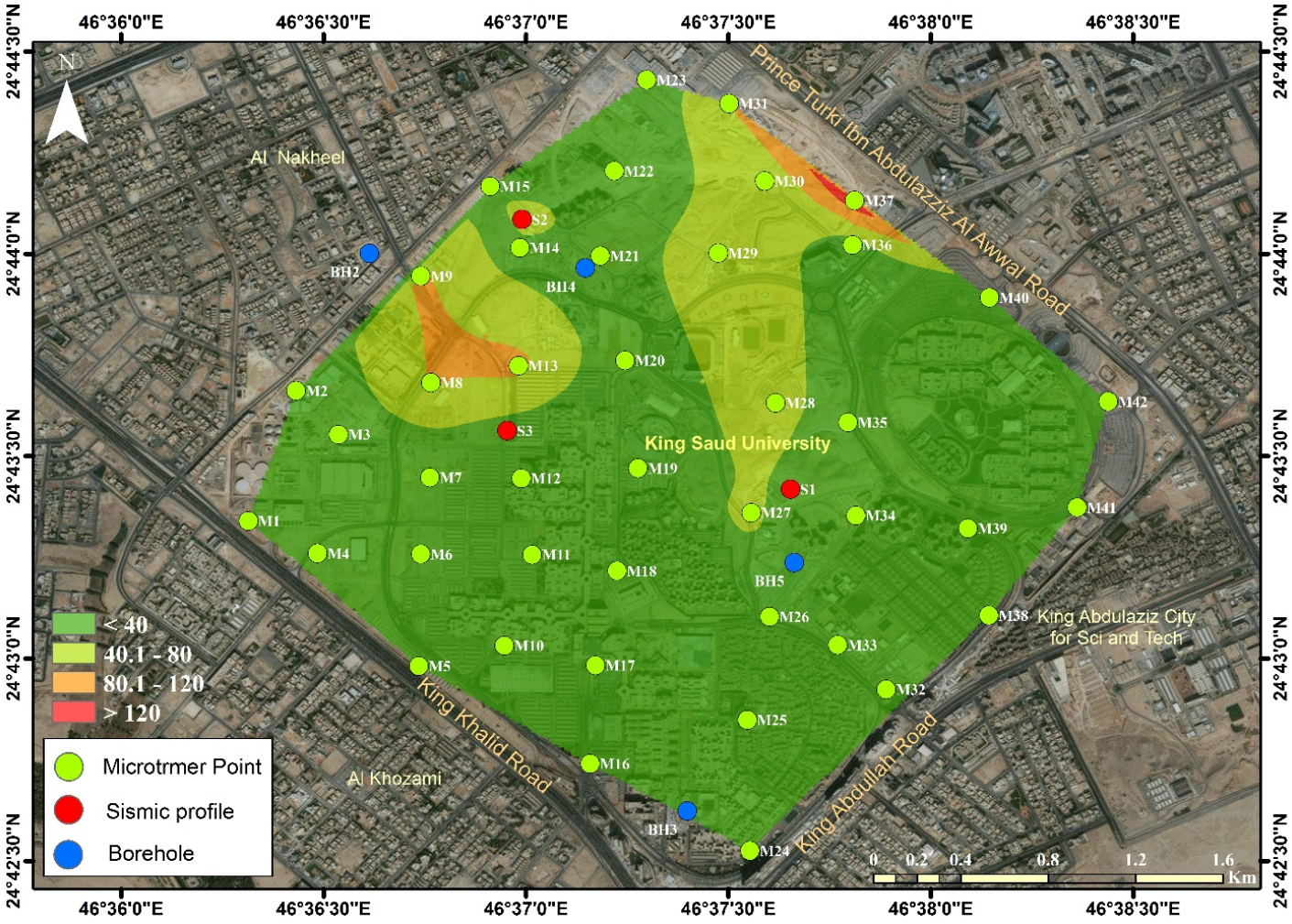
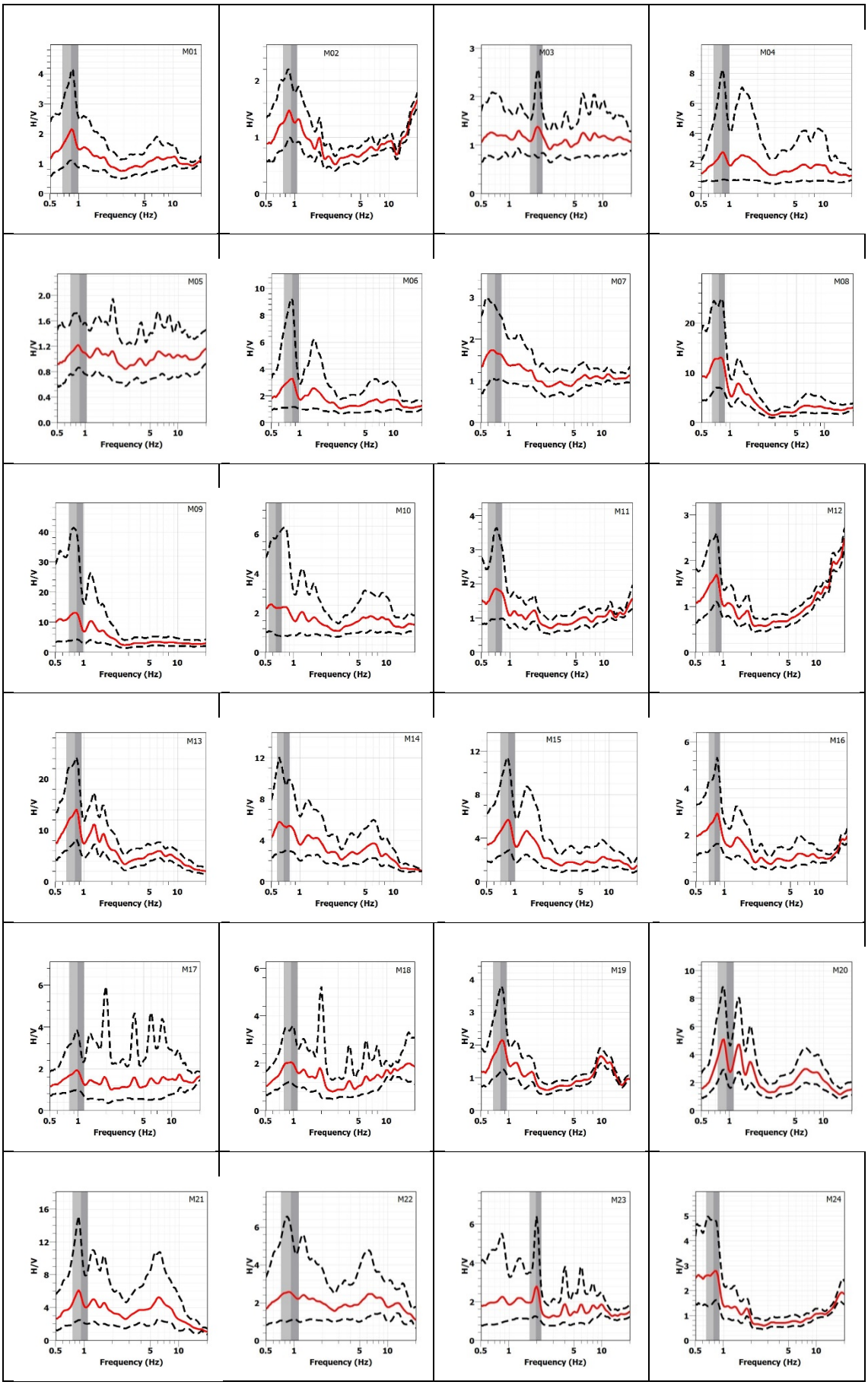


Figure (8) Vulnerability index (Vi) contour map.


M01
M02
M03
M04
M05
M06
M07
M08
M09
M10
M11
M12
M13
M14
M15
M16
M17
M18
M19
M20
M21
M22
M23
M24
H/V
Frequency (Hz)

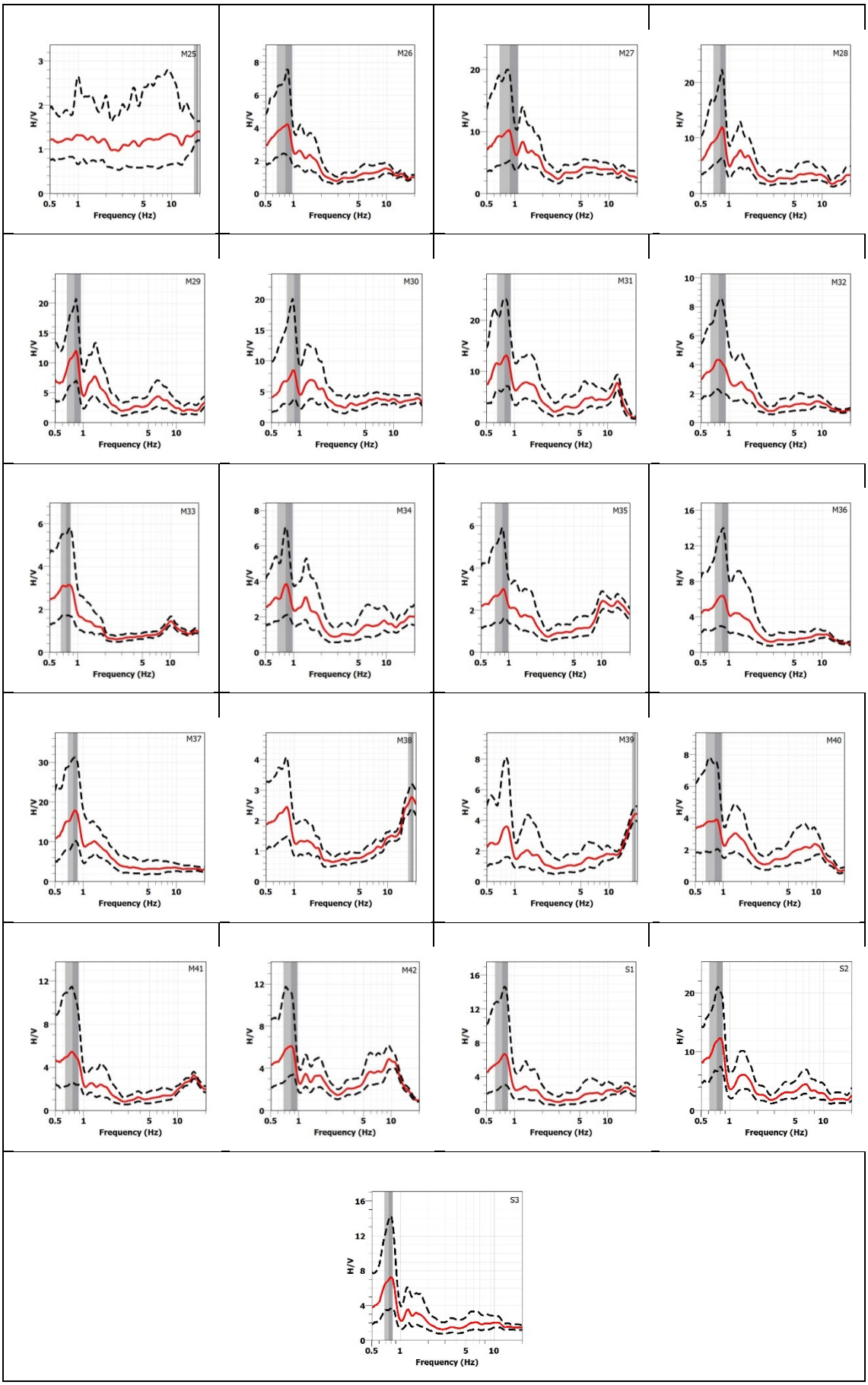


Figure (9) H/V ratio curve for all measuring points.

7. Conclusions

Based on research results, some conclusions can be outlined as follows:

Fundamental frequency value for KSU compound ranges between 0.64 and 1.94 Hz., while HVSR or amplification factor value varies from 1.19 to 17.22. This corresponds to the value of the seismic vulnerability index (Kg) ranges from 0.7 to 148. The geotechnical reports and the results identify the existence of a completely weathered limestone (Soil & Foundation Co. Ltd., 2014). From analysis of these three parameters, it is illustrated that the highest potential will be near the Preparatory Year Building. From the consideration between f_0 and A_0 it is indicated that, the potential damage is quite low.

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