Feasibility Study on Base Mat Uplift of Nuclear Power Plants Using Large-Scale Blast Excitations (Part 1: Measurement and Investigation of Ground Motion)

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ABSTRACT

It is important to estimate the base mat uplift for the design of nuclear power plants against severe earthquakes in Japan. JNES (Japan Nuclear Energy Safety Organization) is conducting a test project focused on base mat uplift behavior using blast-induced ground motion. After research to find an appropriate test site location, Black Thunder Mine (BTM) was chosen. BTM is one of the largest coalmines in North America and is located in northeast Wyoming, U.S.A. Also vibration tests of pile structure [1][2] were conducted in BTM.

We investigated the site characteristics and measured the blast-induced ground motions at BTM [3] in order to confirm that the mine site and ground motions are appropriate for the base mat uplift test.

INTRODUCTION

Figure 1 shows the location of BTM. At the mine, there is an overburden over the coal layers. The overburden is dislodged by large blasts called "cast blasts" and the rubble is removed by huge earthmoving equipment. The ground motion caused by cast blasts could be used for the base mat uplift test in order to understand the non-linear interaction responses between soil and building structure.

We investigated the site characteristics using P-S logging and elastic wave exploration. And we measured the blast-induced ground motion at BTM in order to confirm that the mine site and ground motion are appropriate for the base mat uplift test.

Fig. 1 Location of Black Thunder Mine in the U.S.A.

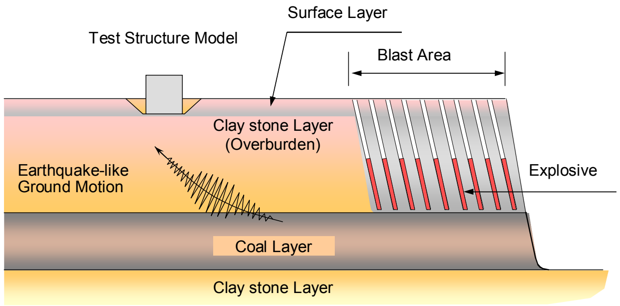


Fig. 2 Outline of uplift test at mining site

SITE CHARACTERISTICS

The surface layers at the mining site were measured using P-S logging, core logging and elastic wave exploration. Table 1 shows the results of the P-S logging. We measured four bore holes at 20m intervals for core logging. Figure 3 shows the results of the core logging. We can see most of the site surface constructed with clay layer and clay stone layer. Figure 4 shows the results of elastic wave exploration. The ground surface of the test site is has almost parallel stratification.

Table 1 Result of P-S logging

Level GL (m)	Thickness of Layer (m)	Layer	P-wave Velocity (m／s)	S-wave Velocity (m／s)
0-2	2	Clay	520	240
2-8	6	Silty Sand ～Clay Stone	980	240
8-12	4	Clay Stone	980	340
12-21	9	Clay Stone ～ Silt Stone	1750	510
21-30	9	Clay Stone	1750	630

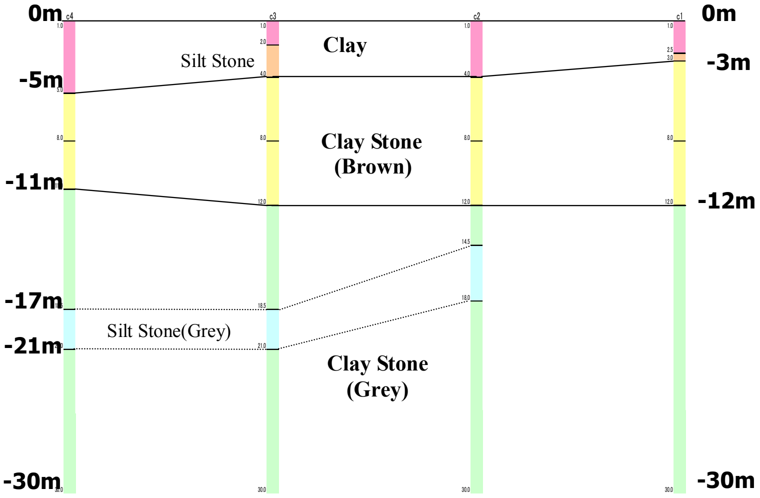


Fig. 3 Results of core logging

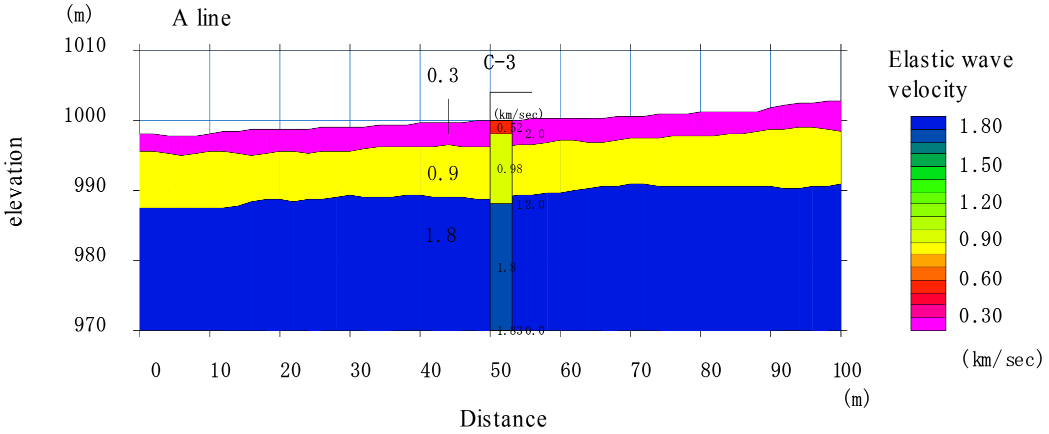


Fig. 4 Surface exploration results

MEASURMENT OF GROUND MOTION

Measurement Plan

In order to measure the blast-induced ground motion, 10 tri-axial accelerometers were installed on the surface and 6 tri-axial accelerometers were installed underground at the BTM test site. Figures 5, 6 and 7 show the location of the accelerometers. We also built the reinforced-concrete (RC) slab, as shown in Figure 8. The size of the RC slab was 8 meters square in plan and 0.5 meters in thickness. Seven 1-direction accelerometers were installed on the RC slab to measure 3-dimensional input motion of the base mat. We measured the ground motion from November 2004 to December 2005 in the same area.

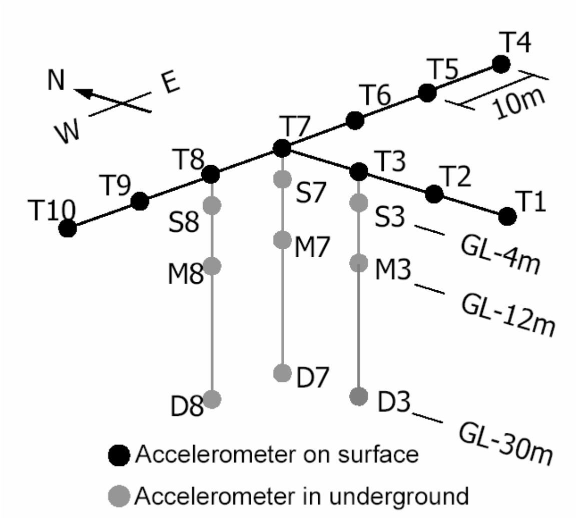


Fig. 5 Location of the accelerometers

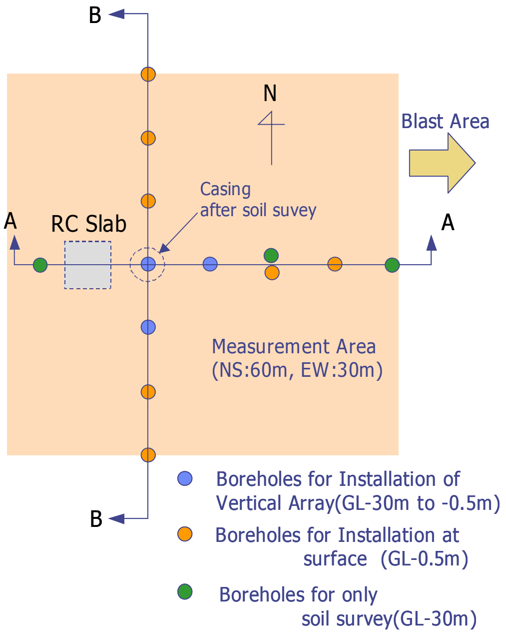
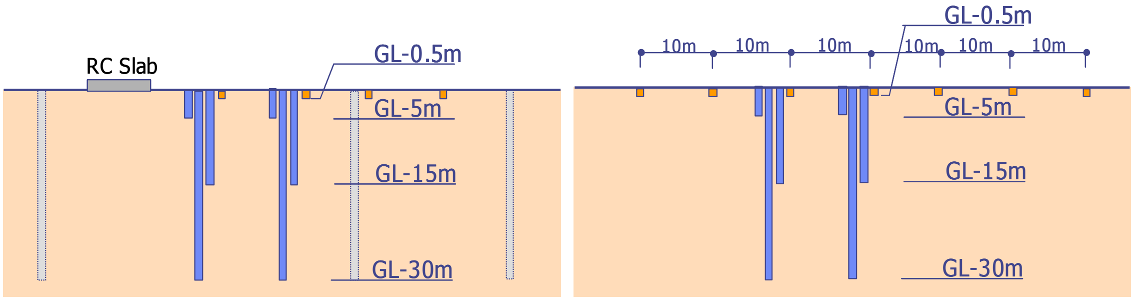


Fig. 6 Top view of bore hole locations



A-A section B-B section

Fig. 7 Sectional view of A-A section and B-B section

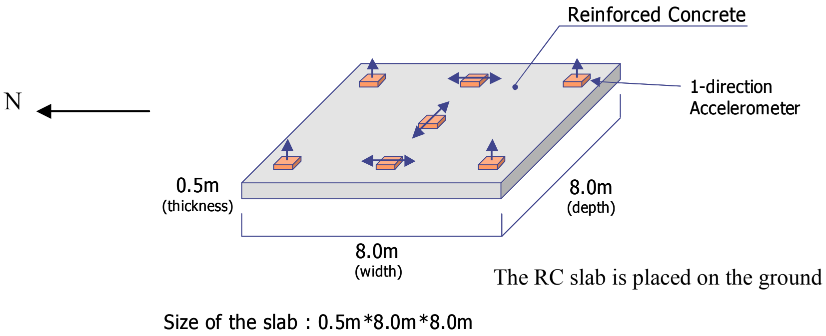


Fig. 8 RC slab and arrangement of accelerometers

Ground Motion

Table 2 shows the summaries of the blast-induced ground motion observed for a year. Figure 9 shows the location of the blast area. The different distances between the test site and the blast areas produced different levels of ground motion. As the maximum acceleration at ground surface is over 1000cm/s^2, the blast-induced ground motion would be enough acceleration for the base mat uplift tests. Figure 9 shows the relationship between the distance from the blast area and the maximum acceleration. As a result, we were able to estimate input level.

Table 2 Summary of measurement results

Date Year/month/day	Blast data*1				Maximum acceleration at ground surface *3		
	Blast Area width (m)	Blast Area length (m)	Amount of explosive (ton)	Distance to Test site*2 (m)	NS (cm/s^2)	EW (cm/s^2)	UD (cm/s^2)
04/12/17	60	670	700	780	93.1	88.5	51.0
04/12/31	60	500	980	350	333	342	385
04/12/30	60	400	910	270	941	804	678
05/04/30	60	360	710	210	567	854	660
05/07/17	60	660	970	690	172	178	140
05/08/07	60	470	830	250	629	512	227
05/08/19	60	190	350	150	960	1,167	888
05/09/05	60	340	170	370	279	338	183
05/11/22	60	270	430	550	285	277	102
05/11/27	60	450	700	180	1,329	1,530	487

*1 Based on data provided by Black Thunder Mine
*2 Distance between blast area edge and the location of accelerometer (T3)
*3 Maximum acceleration at T 7 : Low pass filter treatment with 30Hz
*4 Measurement results for the cast blast at adjacent mine（used for horizontal propagation analysis）

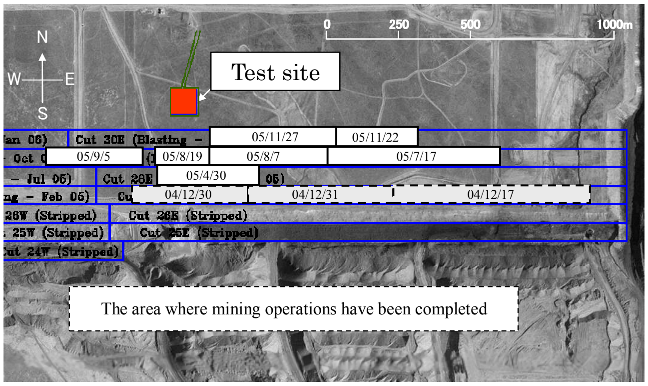


Fig. 9 Location of blast area

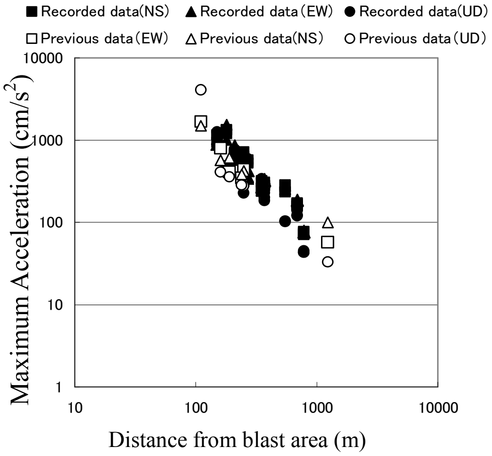


Fig. 10 Distance from blast area and maximum acceleration

Figure 12 shows acceleration records of ground motion observed by the vertical array in the NS direction. Figure 13 shows acceleration response spectra of the vertical array records in Figure 12. The duration of motion is 2 seconds or more. Amplitude of the motion increased as the motions traveled upward.

Figure 13 shows horizontal accelerations on the RC slab with rocking-induced or torsion-induced component. Rocking-induced horizontal acceleration and torsion-induced horizontal acceleration are much smaller than the horizontal response of the RC slab. The ground vibrations do not include the rotation component of the RC slab behavior.

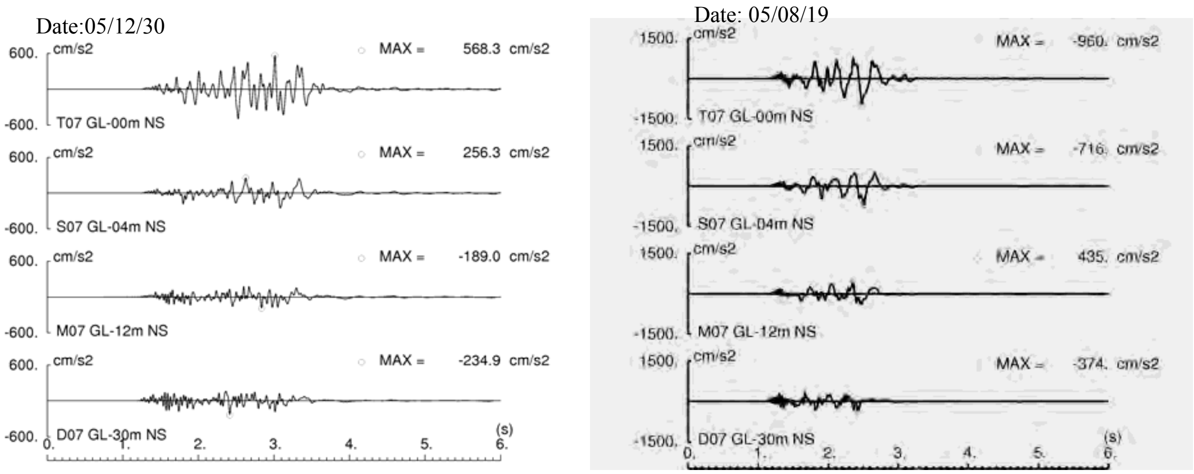


Fig. 11 Acceleration records of vertical array (T7,S7,M7,D7)

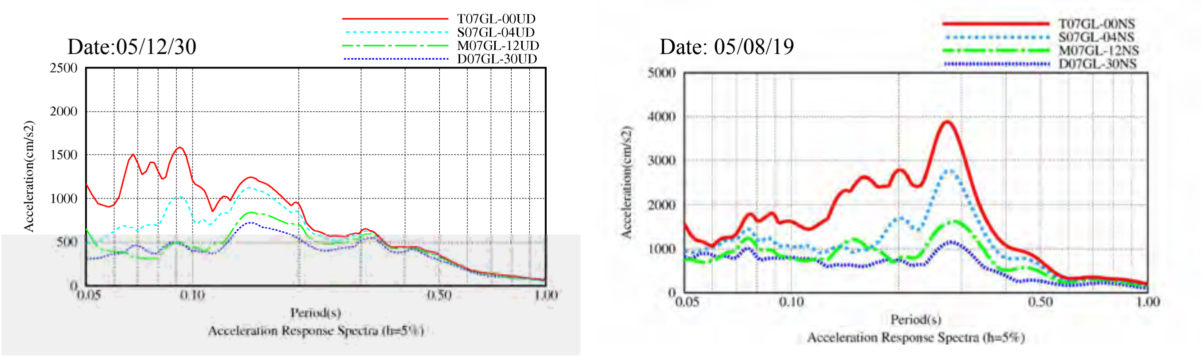
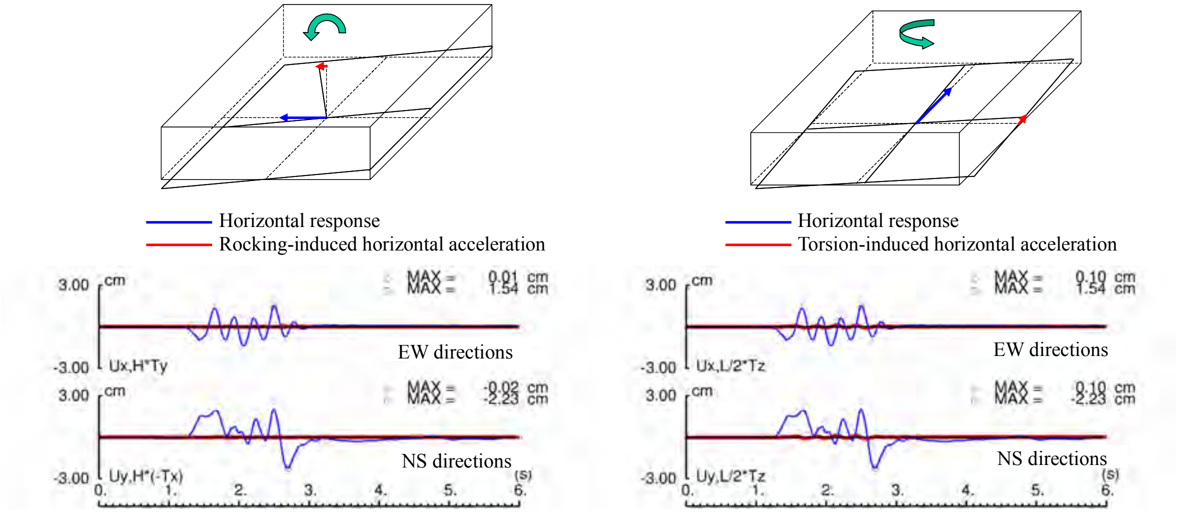


Fig. 12. Acceleration response spectra of vertical array (T7,S7,M7,D7)



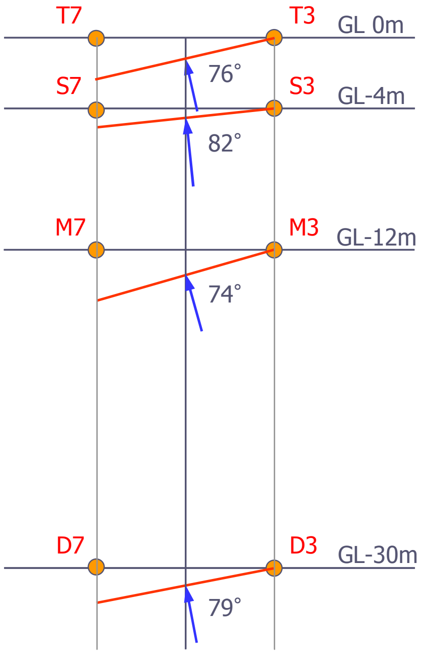
Rocking-induced horizontal acceleration and horizontal response

Torsion-induced horizontal accelerations and horizontal response

Fig. 13 Comparison between horizontal acceleration due to rocking and torsional response and horizontal response (Date:05/8/19)

Input Angle

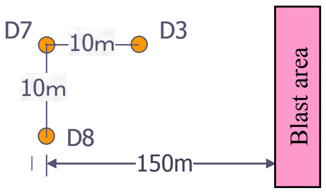
Figure 12 shows input angles that were estimated by the time differences of the arrival waves. The time differences were calculated by cross correlation of each acceleration record with each observation points. As the input angles are approximately 80 degrees, we thought that the ground vibrations propagate almost vertically upward.



Input angle(D7-D3 section)

Ob.point		Coeff. of correlation	Time difference(s)	Vs (m/s)	Distance (m)	Input Angle(deg.)
A	B					
T3	T7	0.97	0.011	220	10.0	76
S3	S7	0.99	0.008	180	10.0	82
M3	M7	0.97	0.005	555	10.0	74
D3	D7	0.97	0.003	664	10.0	79
T3	T8	0.94	0.018	220	14.1	74
S3	S8	0.97	0.015	180	14.1	79
M3	M8	0.95	0.011	555	14.1	64
D3	D8	0.94	0.006	664	14.1	74
T7	T8	0.97	0.007	220	10.0	81
S7	S8	0.97	0.007	180	10.0	83
M7	M8	0.98	0.005	555	10.0	74
D7	D8	0.98	0.003	664	10.0	79

Input angle=$90-\mathrm{ArcSin}(dt \times Vs/L)$
where dt:Time difference(s) L: Distance(m)



Location

Fig.14 Input angle（Date:05/08/19, EW direction）

SIMULATION ANALYSIS

The ground motion was simulated by the equivalent linear analysis using one-dimensional wave propagation theory (SHAKE). Figure 15 and Figure 16 show comparisons of the analysis and the observations. In figure 15, the analysis results of August 8, 2005 are in good agreement with the observations. But in figure 16 the analysis results of August 19, 2005 did not agree with the observations because of strong input motion.

In order to simulate the strong input motion, the ground motion of August 19, 2005 was simulated by time domain non-linear analysis using 3-dimentional multi spring model, as shown in figure 17. Figure 18 shows comparisons of the analyses using a multi-spring model [4] and the observations. The analysis results matched the observations much better than before.

As these analysis are based on the vertical propagate, these results show that the ground vibration propagates vertically upward.

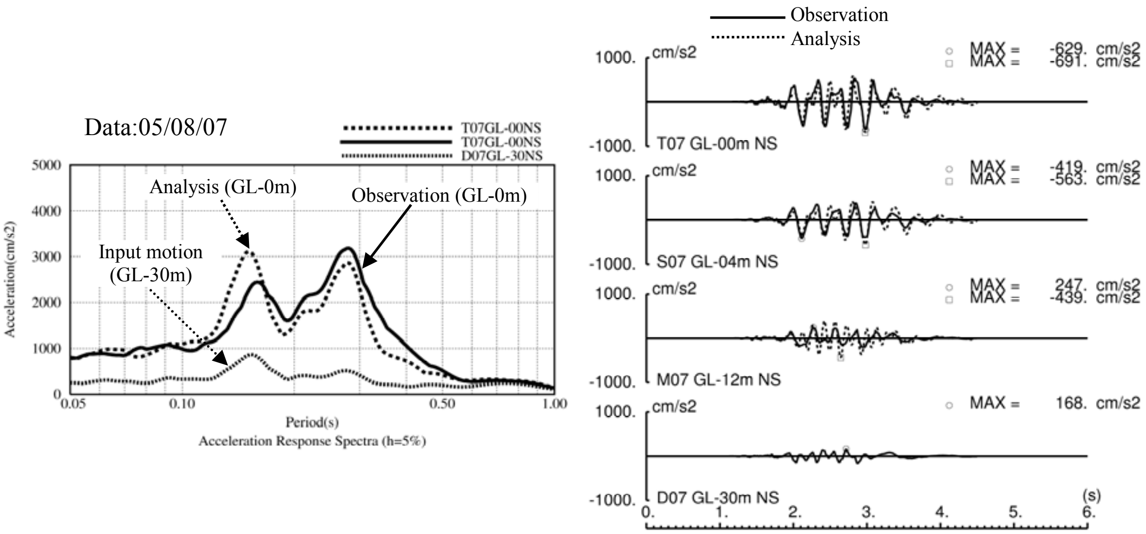


Fig. 15 Saturation analysis using one-dimensional wave propagation theory
(Date:05/08/07, NS direction)

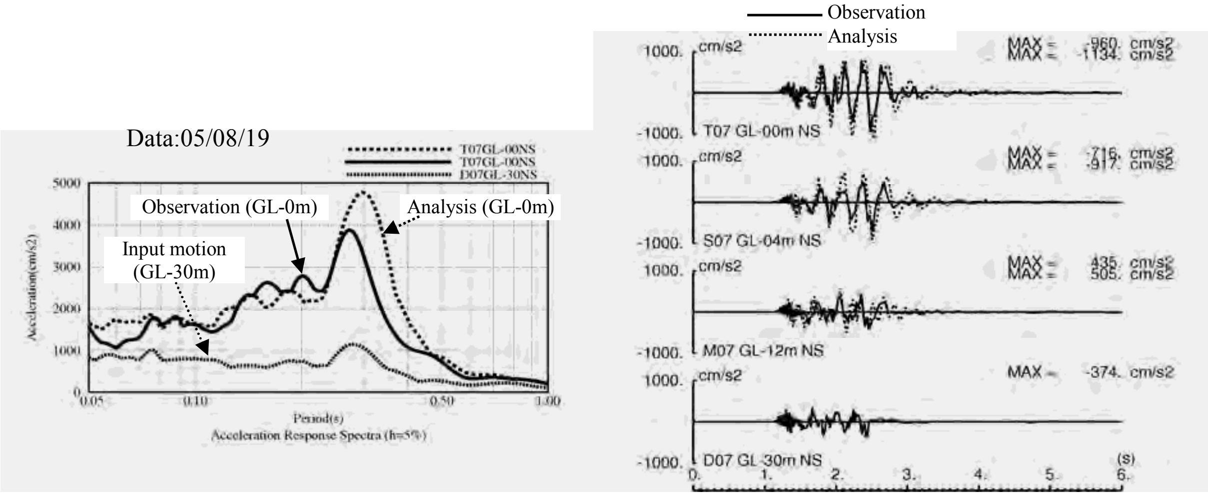


Fig. 16 Saturation analysis using one-dimensional wave propagation theory
(Date:05/08/19, NS direction)

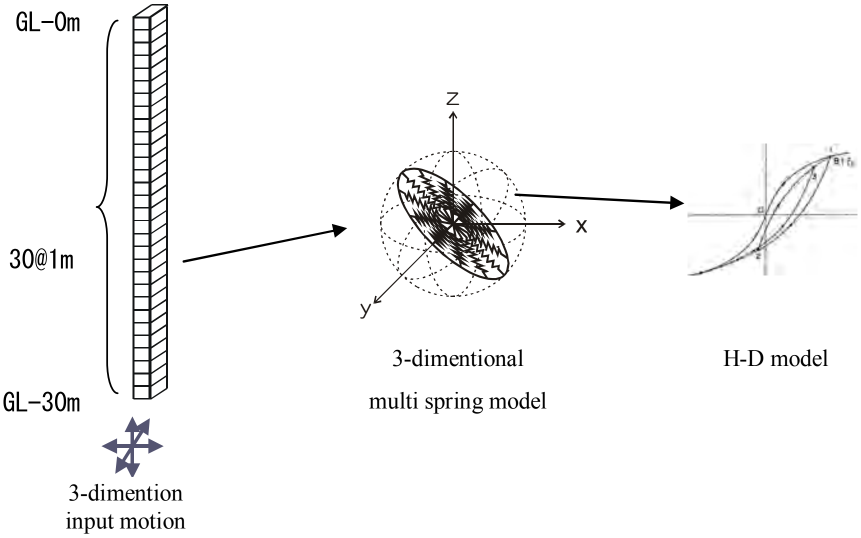


Fig. 17 Outline of 3-dimentional multi-spring model[4]

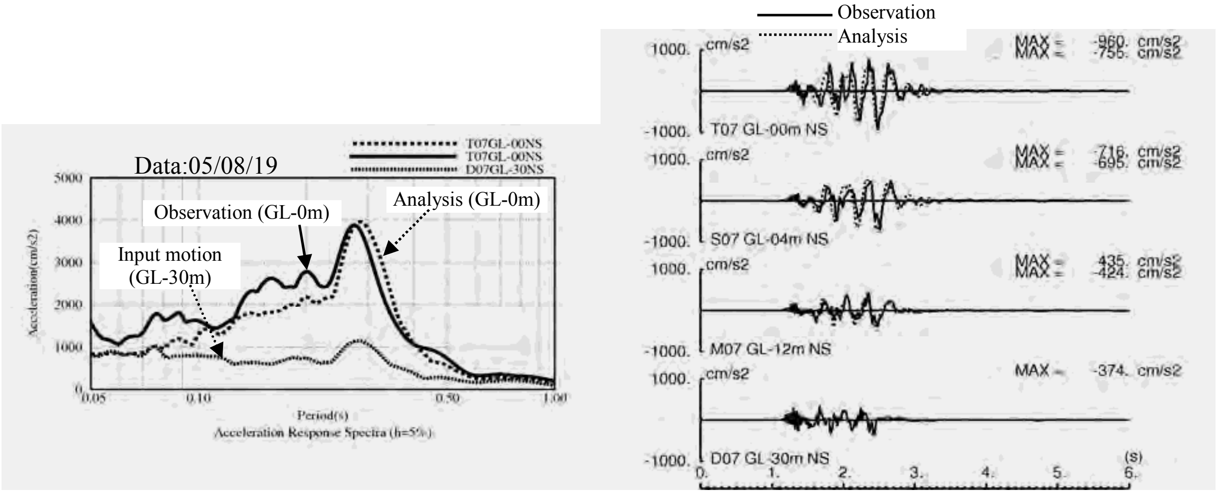


Fig. 18 Simulation analysis using 3-D multi-spring model
(Date:05/08/19, NS direction)

CONCLUSIONS

(1) The ground surface of the test site was constructed with parallel stratification.
(2) We confirmed that we could have ground motion having a maximum acceleration of 5-10m/s^2 and durations of 2 seconds or more as input motion to the test structure.
(3) We could estimate input levels with the distance from the blast area.
(4) The ground vibrations propagate almost vertically upward as the result of the examination in input angle and simulation analysis.
(5) The ground vibrations did NOT include a rotation component as the observations of the RC slab behavior.

ACKNOWLEDGEMENTS

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