

A TEST TO EVALUATE NON-LINEAR SOIL STRUCTURE INTERACTION

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ABSTRACT

JNES is planning a new project to study non-linear soil-structure interaction (SSI) effect under large earthquake ground motions equivalent to and/or over a design earthquake ground motion of S2.

Concerning the SSI test, it is pointed out that handling of the scale effect of the specimen taking into account the surrounding soil on the earthquake response evaluation to the actual structure is essential issue for the scaled model test. Thus, for the test, the largest specimen possible and the biggest input motion possible are necessary. Taking into account the above issues, new test methodology, which utilizes artificial earthquake ground motion, is considered desirable if it can be performed at a realistic cost.

With this motivation, we have studied the test methodology which applying blasting power as for a big earthquake ground motion. The information from a coalmine company in the U.S.A. indicates that the works performed in the surface coalmine to blast a rock covering a coal layer generates a big artificial ground motion, which is similar to earthquake ground motion.

Application of this artificial earthquake ground motion for the SSI test is considered very promising because the blasting work is carried out periodically for mining coal so that we can apply artificial motions generated by the work if we construct a building model at a closed point to the blasting work area.

The major purposes of the test are to understand (a) basic earthquake response characteristics of a Nuclear Power Plant (NPP) reactor building when a large earthquake strikes the NPP site and (b) nonlinear characteristics of SSI phenomenon during a big earthquake.

In the paper of ICONE-13, we will introduce the test method and basic characteristics of measured artificial ground motions generated by the blasting works on an actual site.

Keywords: SSI test, blast excitation, non-linear, basemat uplift

1. INTRODUCTION

Recently some large earthquake records are reported which have maximum acceleration of nearly equal to 1.0g. In order to confirm the seismic safety of NPPs, we have to study the behaviour of NPP reactor building under such large earthquake ground motions.

The paper proposes new test methodology to evaluate ultimate behaviour of NPP structures against a strong earthquake ground motion. Currently we are planning the vibration tests using large scale model structures by applying artificial ground motions generated by a large scale blast work in the surface coal mine.

As for the preparation works for the test, we have observed ground motion generated in the coal mine to

evaluate the basic ground motion characteristics and have conducted soil survey of the coal mine site to comprehend the soil properties. In this test project, we are paying particular attention on the basemat uplift.

2. TEST METHODOLOGY

Figure 1 shows a photo of the coal mining site. As it can be seen in the photo, sand-rock, coal and mud-rock form strata, and a sand-rock stratum covers the coal stratum. The blasting power has been applied to remove the sand-rock stratum before mining coal.

A typical blast is being conducted using an underground explosive array (typically, width is about 80meters, length is about 500meters).

Figure 2 shows a schematic drawing of the field test. We construct a structure model beside an explosive array area taking into account the coal-mining plan and wait for some major blastings conducted for mining. Under this plan we can expose artificial earthquake ground motions of various loads to the model generated by mining blasts.

The advantages of the test method using the blast excitation are;

- a) Large-scale structures can be tested
- b) Ground motions of various amplitudes can be applied.
- c) The SSI in actual ground and three-dimensional effects can be taken into account.



Fig. 1 A picture of a surface coal mine

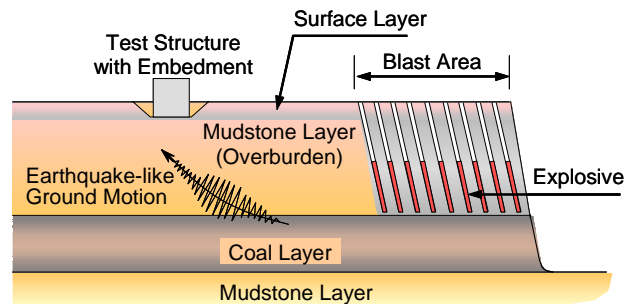


Fig. 2 Vibration test method at mining site

3.1 Soil survey of the test site

The underground structure of the portion near a surface layer is surveyed by the elastic wave surface exploration technique.

We conduct the boring investigation by four borings with a depth of about 30m. Stratum structure and soil properties are examined in detail. The PS logging is carried out using the boreholes.

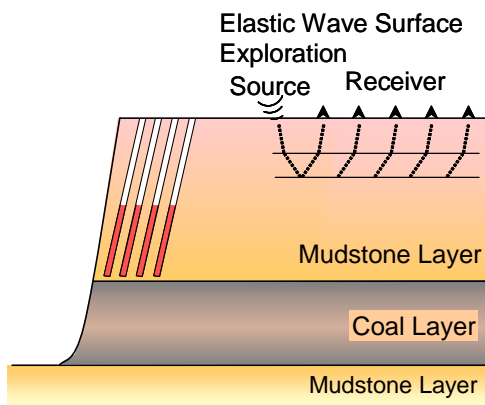


Fig. 3 Elastic wave surface

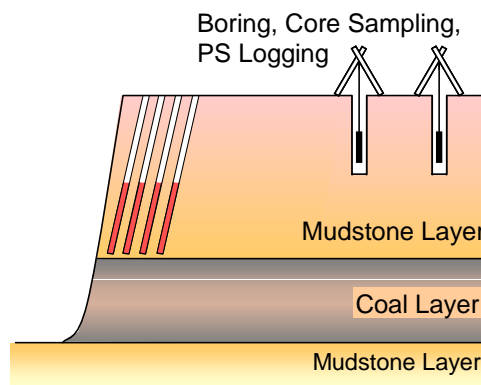


Fig. 4 Boring, PS logging exploration

3.2 Measurement of artificial ground motions

We have measured artificial ground motions using the horizontal and vertical arrays. In order to grasp the motion in an area, we place a concrete slab on the ground and measure the slab motion. The wave propagation characteristics of horizontal and vertical motions are studied using these measured records.

3.2.1 Horizontal motion

Artificial ground motions are observed with a horizontal array of accelerometers and the observed horizontal motions are analyzed to study the wave propagation characteristics in the horizontal direction. The analyses are carried out regarding the distances between blasting area and the measuring points and the influence of directivity of the blasting. Figure 6 shows on outline of the measurement, we deploy ten measurements, T01-T10, together with on RC slab

3.2.2 Vertical motion

Artificial ground motions are observed with three vertical arrays T03, T07, and T08 of accelerometers to analyze the wave propagation characteristics of the artificial ground motions in the vertical direction.

The relevance of the acceleration components in the horizontal and the vertical directions of the artificial ground motions are analyzed and evaluated regarding the scale of blasting and acceleration level of the ground motions.

Arrays of accelerometers are installed in three boreholes (see Fig.6).

3.2.3 Reinforced concrete slab

In Fig. 6, an outline of the reinforced concrete (RC) slab installed to comprehend the artificial ground motion. The size of the RC slab has 8 meters square in plan and 0.5 meters in thickness. Seven accelerometers are arranged on the slab as shown in Fig.6.

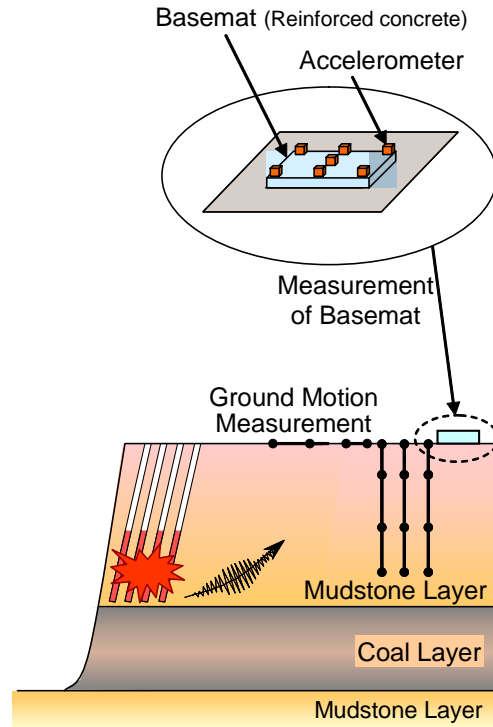


Fig. 5 Measurement of ground motion

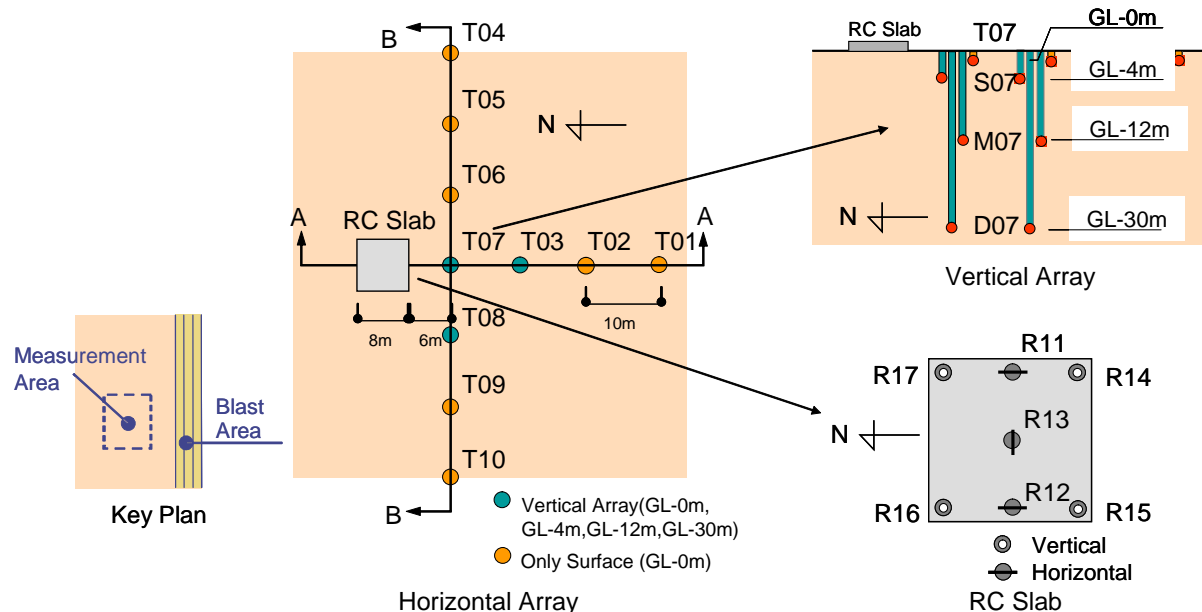


Fig. 6 Outline of arrangement of accelerometers

4. MESUAREMENT RESULT

4.1 Result of soil survey

Table 1 shows the physical properties of the soil layers evaluated using the results of PS logging and boring data. The shear wave velocity at the ground surface is about 240 meters/second (m/s) and is increasing with the increment in depth up to about 630 m/s.

Table. 1 Soil properties

Stratum GL.(m)		P-wave velocity (m/s)	S-wave velocity (m/s)
0-2	Clay	520	240
2-8	Silty Sand - Clay	980	240
8-12	Clay Stone	980	340
12-21	Clay Stone - Silt Stone	1750	570
21-30	Clay Stone	1750	630

4.2 Observation result

Three cases of ground motions were measured three times using the observation arrays. The locations of the blast areas for each case are shown in Fig. 7.

The observation results of maximum accelerations are shown in Table 2. The maximum acceleration measured on the ground surface was nearly 1g on December 30 (04/12/30). The 04/12/30 blast was about 300m from the test site.

Acceleration time history records of the horizontal array of T01 to T10 are shown in Fig. 8. The maximum accelerations of the records are almost the same except for the point of T07, which locates the closest to the blasting area.

Figure 9 shows the acceleration time histories of vertical array of T07-D07 together with their response spectra. The record in the deepest point contains the frequency components higher than 40Hz and the components raise the maximum acceleration twice. It can be confirmed excepting the phenomenon that the wave propagation characteristics in the vertical direction was similar to a usual earthquake movement. The high frequency components were considerably decreased with the wave propagation process.

The acceleration time histories on the RC slab are shown in Fig. 10 for comparison. The shape of the records in the same direction (NS and EW) can be found nearly the same. Also when we compare the records with the records on the ground surface, the motions can be found nearly the same. The fact indicates that no particular extraordinary motions are observed in the ground motion observation array and on the RC slab.

Currently we are performing earthquakes response analyses using the observation records and an analytical structure model to estimate non-linear SSI phenomena expected in the test in this site. The results will be applied to the planning of the testing in the next stage.

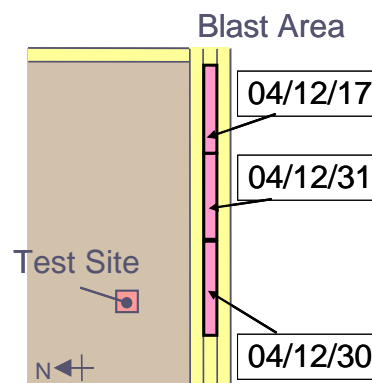


Fig. 7 Locations of blasts and test site

Table. 2 Observed maximum acceleration

Date	On the RC Slab			Ground Surface *		
	NS	EW	UD	NS	EW	UD
04.12.17	75	84	51	93	88	52
04.12.30	546	401	699	971	833	882
04.12.31	252	225	376	337	342	447

* The maximum value

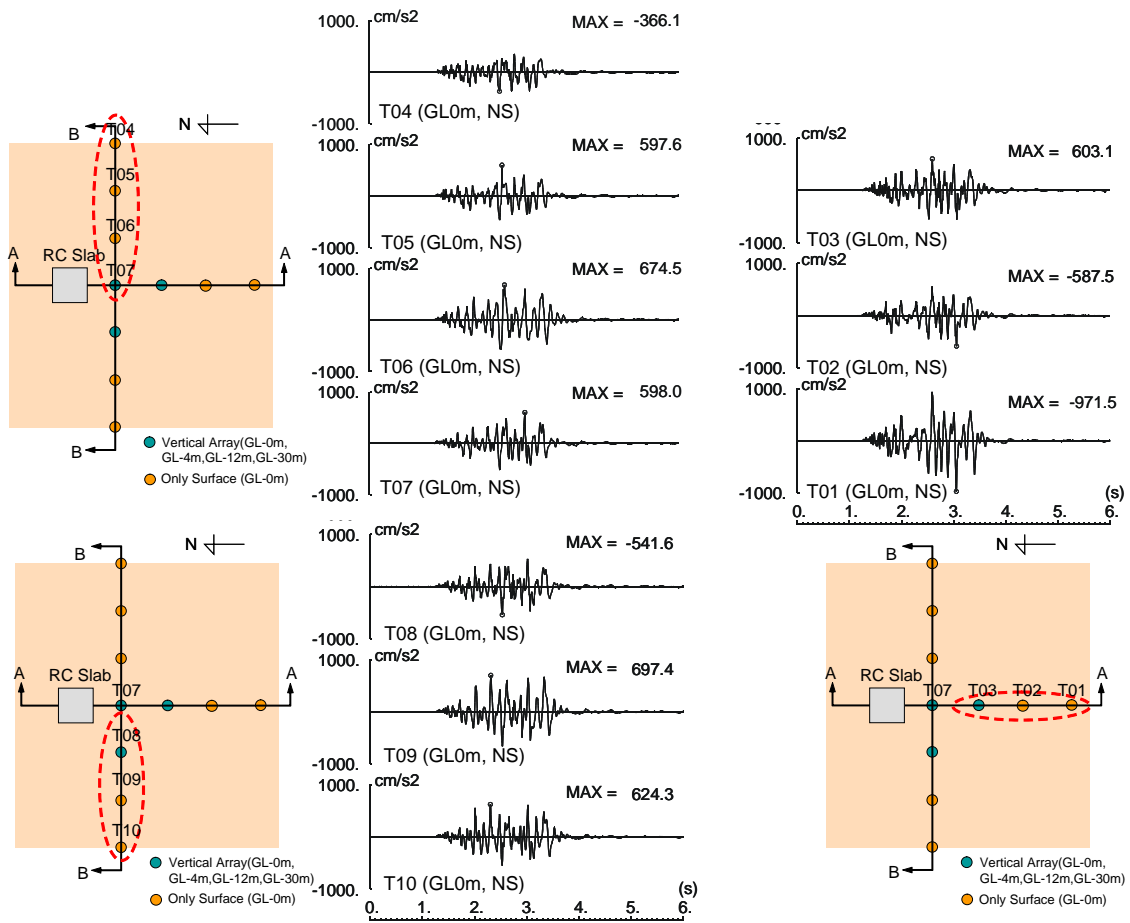


Fig. 8 Acceleration records in horizontal array (04/12/30, NS-dir.)

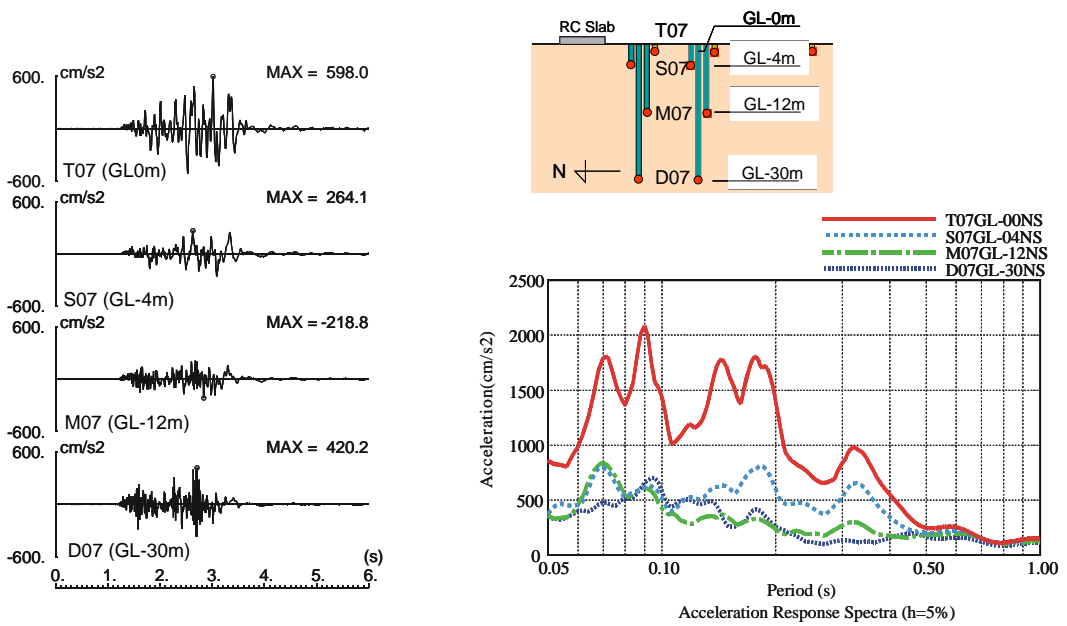


Fig. 9 Acceleration records in vertical array (04/12/30, NS-dir.)

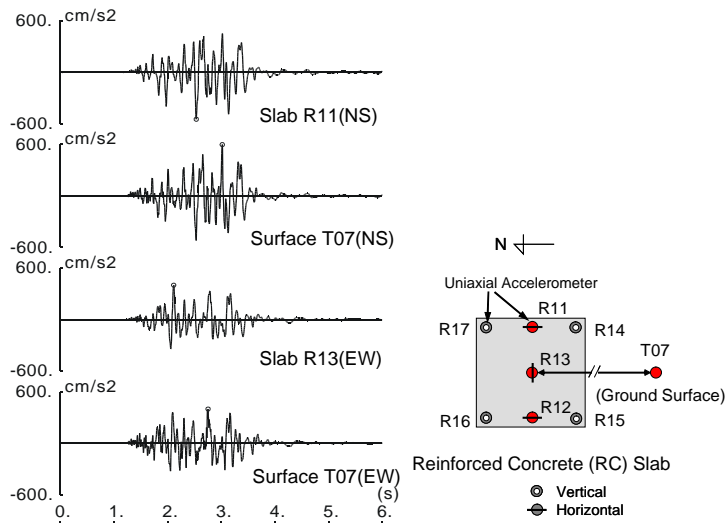


Fig. 10 Acceleration records of ground surface and RC slab (04/12/30, NS-dir.)

5. ANALYSIS RESULT

5.1 Analytical model

The response analysis of the assumed building model was carried out using the 3D FEM model. The parameters of the assumed building model are shown in Fig. 11. Nonlinearity due to the basemat uplift was modeled by the contact elements between the basemat and the foundation soil. The 3D FEM model is shown in fig. 12. The nonlinearity of the soil was modeled by taking into account equivalent physical properties.

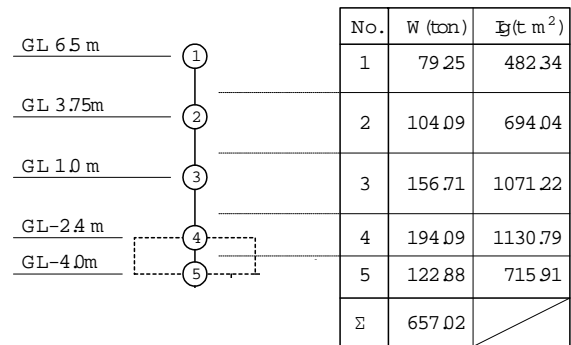


Fig. 11 Parameters of building model

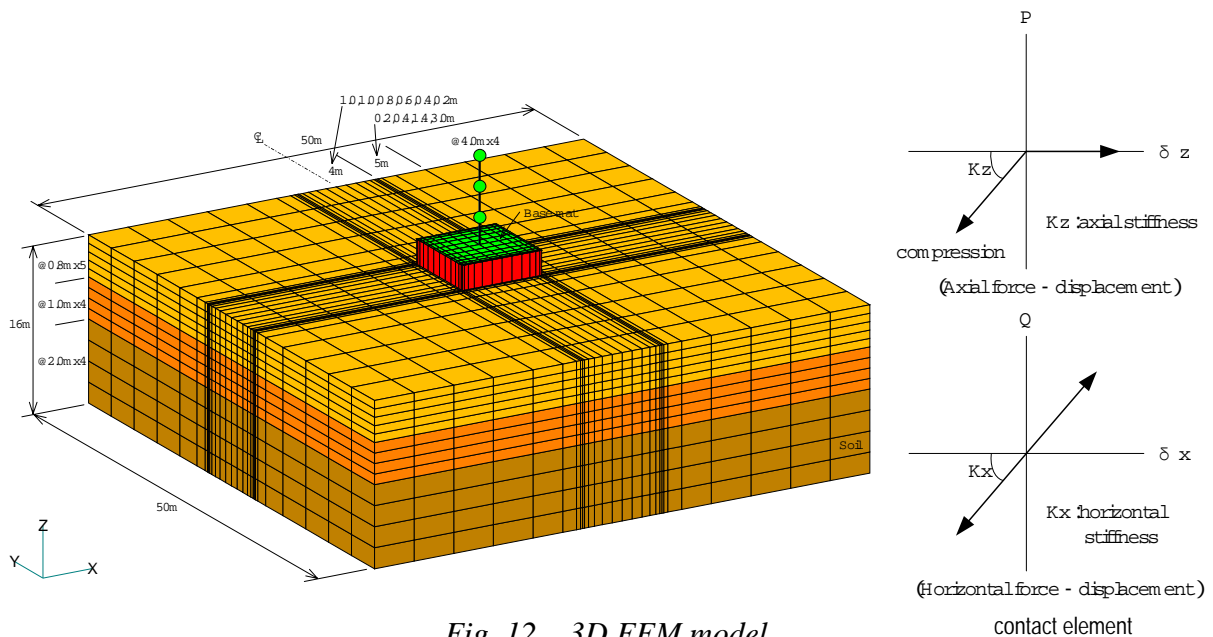


Fig. 12 3D FEM model

5.2 Response analysis result

The input motion used for the response analysis was the motion observed at M07 (GL-12m) point during the blast work on Dec. 30, 2004. Tri-axes recorded motions were applied to the model simultaneously.

The ground contact ratio is shown in Fig. 13. The vertical displacement distribution of the basemat at the time of the minimum ground contact ratio is shown in Fig. 14. The minimum ground contact ratio is at a 38.7%. Thus one of the nonlinear phenomena was confirmed theoretically by this analysis.

The result indicate the feasibility of the nonlinear soil-structure interaction examination to study the basemat uplift phenomenon, one of the current big issues, using the artificial ground motions generated by the blasting works on an actual site.

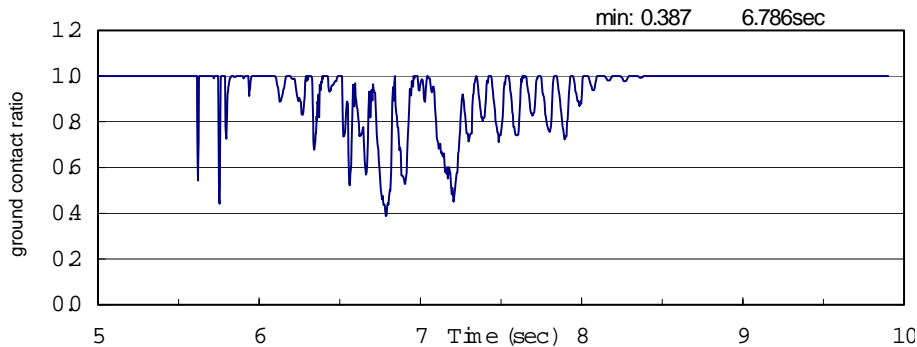
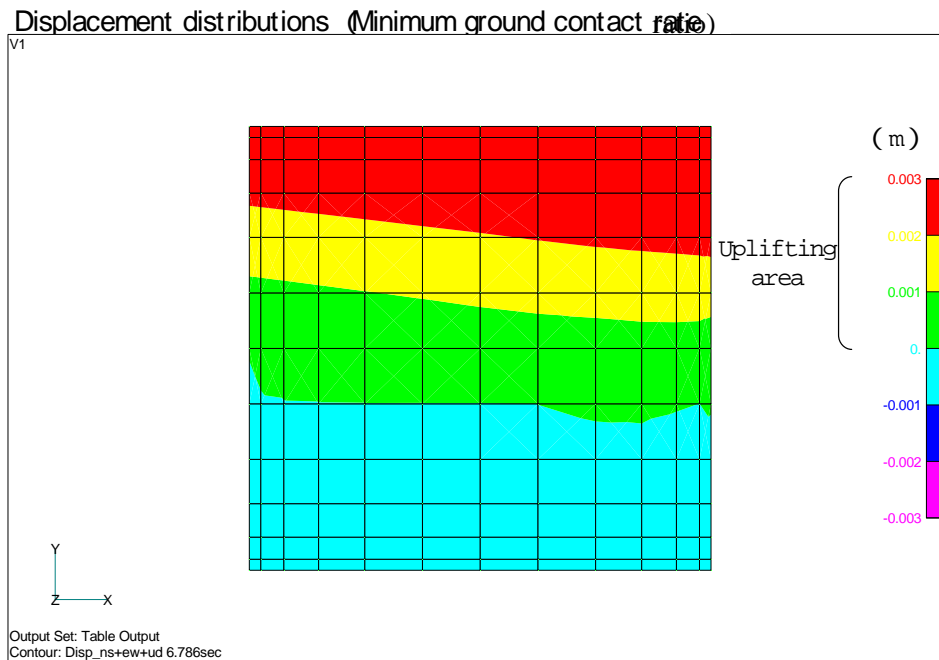


Fig. 13 Ground contact ratio



(Relative vertical displacement. Positive number shows the uplifting.)

Fig. 14 Displacement distribution

6. CONCLUSION

JNES is planning a new test project to study non-linear SSI effect on the earthquake response of the safety related important structure, e.g. reactor building, under a big ground motion generated by the blasting works in a surface coal mine regarding the motion as a big earthquake ground motion. In order to confirm a feasibility of using the ground motion as to be an earthquake motion, we have observed ground motions generated in the coal

mine and evaluated their basic characteristics.

It was confirmed that the artificial ground motions generated by blasting works were enough acceleration level for the non-linear SSI tests. The observed motions have similar characteristics (horizontal and vertical wave propagation) to the earthquake ground motions.

The feasibility study is still on going, but we have piled up many promising data which indicate the feasibility of performing the non-linear SSI test.

We will continue the observations to confirm the characteristics of the artificial ground motions exceeding the maximum acceleration of 1g. Using these data, we will make detailed plan for the non-linear SSI test.

REFERENCES

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