***inter.noise 2000***
***The 29th International Congress and Exhibition on Noise Control Engineering***
***27-30 August 2000, Nice, FRANCE***

---

**I-INCE Classification:** 2.4

# CHARACTERISTICS OF IMPULSIVE LOW FREQUENCY SOUNDS BY BLAST DENSIFICATION METHOD

**H. Imaizumi*, S. Kunimatsu*, T. Isei*, M. Jinguuji*, S. Tsujino**, S. Maeda**, T. Nakashima****

* National Institute for Resources and Environment, 16-3 Onogawa, 305-8569, Tsukuba, Japan

** Sato Kogyo Co. Ltd., 4-12-20 Nihonbashi honmachi, Chuo-ku, 103-8639, Tokyo, Japan

Tel.: +81-298-58-8775 / Fax: +81-298-58-8758 / Email: hiro@nire.go.jp

**Keywords:**
LOW FREQUENCY SOUND, BLAST DENSIFICATION METHOD, G-WEIGHTING, NOISE PROPAGATION

## ABSTRACT

Experimental results of the generation, propagation and attenuation of impulsive low frequency sounds by blast densification method (BDM), which is one of the countermeasures to prevent generation of ground liquefaction by underground detonation of explosives, were described as well as their evaluation by several weighting characteristics for environmental noises. Human responses to the blast sounds were also examined by comparison with the result of responses in published studies concerning low frequency noises.

## 1 - INTRODUCTION

When water−saturated layers or grounds, which are consisted mainly of sands, are forced on a strong motion by an earthquake, the grounds frequently behave like a liquid (liquefaction of ground). Underground structures such as foundation piles of buildings or industrial facilities and lifelines of gas or water were destroyed and serious damages occurred by occurrence of the liquefaction of ground.

Recently, several countermeasures have been proposed to effectively prevent generation of the ground liquefaction [1]. Blast densification method (BDM) is one of the countermeasures, in which the explosives are detonated underground and their impulsive energy makes the weak ground densification. This method has advantages with respect to the cost, duration of the operation and others. On the other hand, generation of impulsive low frequency noises and vibrations due to blasting will be sometimes disadvantage as compared to other methods [2].

Then, characteristics of blast sounds and vibrations generated by the method were studied in order to make the BDM more effective and minimize the impacts to the surrounding environments. We reported experimental results of the generation, propagation and attenuation of impulsive low frequency sounds obtained from a preliminary field measurement of the BDM.

## 2 - EXPERIMENTS

Field experiments on propagation attenuation of the blast sounds generated by the BDM were carried out on a flat sandy ground. Experimental conditions were shown in Table 1. One explosive was installed in a borehole in a preliminary experiment (Ex−1). In another experiment (Ex−2), there were 6 boreholes, with two explosives each, in the blasting area. The blast sounds were measured at 5 receivers, which were 25, 50, 75, 100, and 175 m distant from the blasting point, by low frequency sound level meters (frequency weighting: flat, time weighting: FAST). Vibration meters were used to measure blast vibrations at the same receivers. The blast sounds and vibrations observed at the receivers were recorded on a DAT recorder.

| Experiment | Ex-1 | Ex-2 |
|---|---|---|
| No. of boreholes | 1 | 6 |
| No. of explosives | 1 | 12 |
| Weight of explosives (kg/unit) | 3 | 3 |
| Depth of explosives (m) | 12 | 10 and 14 |
| Time delays of blasting (s) | | 0.15 |
| Temperature (°C) | 23 | 23 |
| Wind condition | weak | downwind |

**Table 1:** Description of blast conditions.

## 3 - RESULTS AND DISCUSSION

We observed impulsive sound pressure by detonation of an explosive, and low frequency sounds followed to the impulsive sound at the receiver of 25 m distant from the blasting point in the preliminary experiment ( Fig. 1, top). It can be considered primary peak of the sound pressure was due to the detonation of explosive and second was generated by rapid gas expansion of the explosion [3]. When propagation distance increased, amplitude of the sound pressure rapidly decreased and sounds with higher frequencies from 16 to 150 Hz were primarily measured at more distant receiver before low frequency sounds below 10 Hz (Fig. 1, bottom). The propagation speed of blast vibration in the ground, which was calculated from the delay of arrival time to each receiver relative to the nearest receiver, was around 1700 m/s. The arrival time of the blast vibration at the receiver of 100 m agreed well to the beginning of fluctuation of the sound pressure (bottom of Fig. 1, upward arrow). Therefore, the initial part of sound pressure−time waveform was due to vibration of the air excited by the blast vibration at the receiver. We also showed arrival time of the blast sound to the receiver by propagation speed in the air calculated from the atmospheric temperature (bottom of Fig. 1, downward arrow). The amplitude of the propagated blast sound was smaller than that of the sounds generated by the gas expansion and low frequency components were more predominant at the distant receivers. Very low frequency sounds at around 4 Hz, which followed to the gas expansion sounds, may be acoustic surface waves [4].

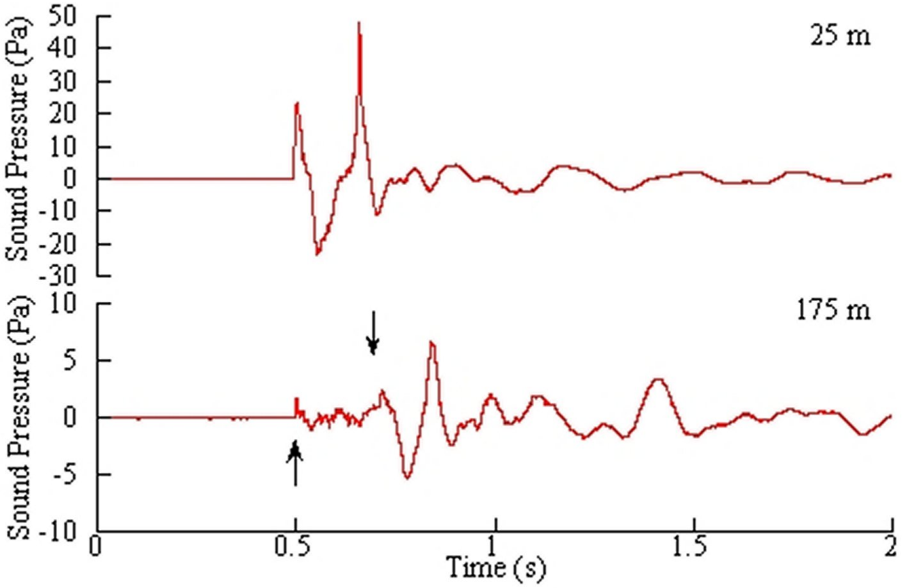

**Figure 1:** Sound pressure−time waveforms at each receiver in Ex−1.

We examined sound pressure−time waveforms measured at both receivers of 25 and 175 m in case of sequential detonation of the explosives in the 6 boreholes in Ex−2 (Fig. 2). The impulsive sound pressure was observed at the receiver close to the blasting point, while air−borne sound by the blast vibration arrived prior to the low frequency sound propagating to the distant receivers.

We compared to the results of frequency analyses in one-third octave bands of the blast sounds (Fig. 3). The blast sounds consisted of frequencies below 100 Hz predominantly. The sound pressure levels at frequencies from 3 to 20 Hz were over 100 dB at the receiver of 25 m and about 90 dB even at the

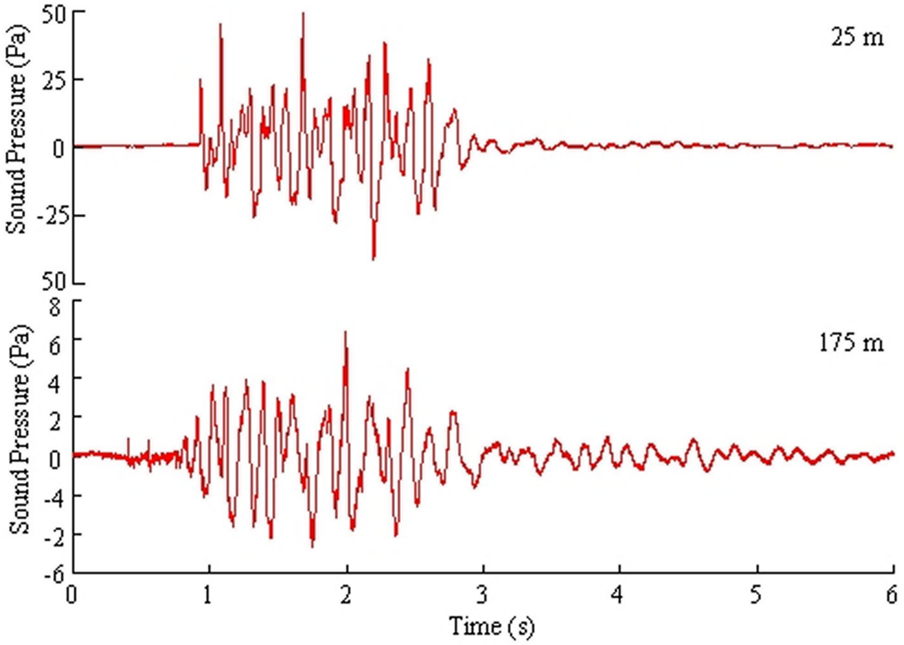

**Figure 2:** Sound pressure−time waveforms at each receiver in Ex−2.

receiver of 175 m. In addition, we could find a predominant frequency at 6.3 Hz caused by time delay of the blasting of 0.15 s.

Complaints against low frequency sounds were made by direct human perception as well as rattling of building fittings. We compared the results of frequency analyses to both thresholds of sensation level of human beings ( Fig. 3, curve A) and the rattling of Japanese building fittings for incident low−frequency sine waves (Fig. 3, curve B) [5]. These two curves divided domain of frequency and sound pressure level into four areas:

- There may be any complaints at all.
- There is no any rattling, but some human sense such as sounds of a driven motor.
- Sometimes the sound by the rattling is detected and complaints are made as weird feeling.
- Due to both human sense and the rattling, strong complaints are frequently made.

If sound feature located in the areas of (3) or (4), complains often occur in Japan. In case of the blast sound measured at the receiver close to the blasting area, the sound pressure levels at around predominant frequencies were much larger than those two threshold curves, and then the blast sound probably made complaints by both human sensation and the rattling. At more distant receiver, the sound pressure levels were above the curve of the rattling at around predominant frequencies but less than human sensation. In this case, we could estimate that the sounds made complaints of the rattling of building fittings.

Distance attenuation of several evaluation indices of the low frequency noises such as G−weighted sound pressure level [6] and sound pressure level with time constant, SLOW [7], obtained from digital simulation [8] using the blast sounds was shown in Fig. 4.

Both sound pressure levels were very high at the receiver close to the blasting point and the values were about 115 dB. Sound attenuation with distance of both evaluation values was similar, and the gradients were almost the same as the curve of −6 dB per doubling of distance. It is considered the property depended on relationship between frequency distribution of the blast sounds and frequency characteristic of the G−weighting (Fig. 5). Namely, negative correction values at frequencies below 10 Hz and above 25 Hz were consequently cancelled by positive correlation from 10 to 25 Hz.

Ochiai et al. investigated the evaluation methods of low frequency noises obtained in field measurements and laboratory experiments, and reported relationship between complaints and G−weighted sound pressure levels [9]. From their investigation, the complaints tend to occur by G−weighted sound pressure levels of 90±10 dB for the fluctuated or impulsive noises. As compared their investigation to our current

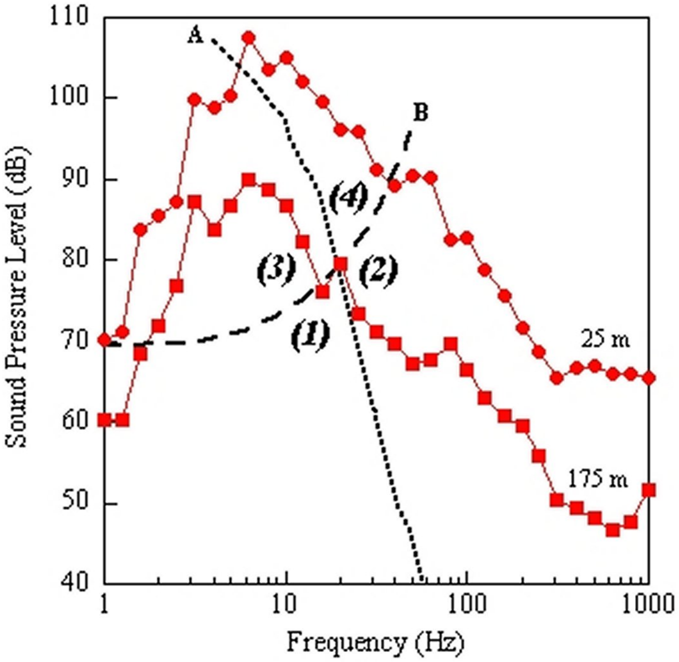

**Figure 3:** 1/3 octave band frequency analyses of the blast sounds and comparison to both thresholds of human sensation and rattling of the building fittings.

study, it may indicate complaint occur by the blast sounds even at the most distant receiver. In comparison with another published study concerning influence on sleep by low frequency noises, the G−weighted sound pressure levels obtained in the experiments were within range of disturbing sleep seriously [10].

## 4 - CONCLUSION

Summary of the study is as follows:

- Impulsive sound pressure by detonation of the explosives were observed primarily in sound pressure−time waveforms of the blast sounds, and low frequency sounds by rapid gas expansion followed to the impulsive sound. Frequency components of several Hz by the gas expansion were predominant after long−range propagation of the blast sounds.
- At distant receivers, air−borne sounds excited by the blast vibration, which arrived prior to the blast sounds, were measured. Frequency components of the blast sounds by sequential detonation were below 100 Hz and the sound pressure levels at frequencies from 3 to 20 Hz were about 90 dB even at the receiver of 175 m.
- The sound pressure levels at the receiver close to the blasting point exceeded both thresholds of human sensation and the rattling of the building fittings. Even at most distant receiver, the sound pressure levels indicated the occurrence of the rattling.
- Both sound pressure levels of G−weighting and with time constant of SLOW attenuated by 6 dB per doubling of distance, and their values were about 115 dB at the receiver close to the blasting point. These sound pressure levels may indicate high possibility of complaints against the blast sounds as well as serious influence on sleep.

The blast densification method is still developing technique for ground liquefaction and it will be necessary to examine and control the blasting for decreasing impact to surrounding environments.

## REFERENCES

1. **T. Ishiguro and H. Shimizu** , Better countermeasure against liquefaction, *Journal of Japan Society of Civil Engineering*, Vol. 83, pp. 17-19, 1998

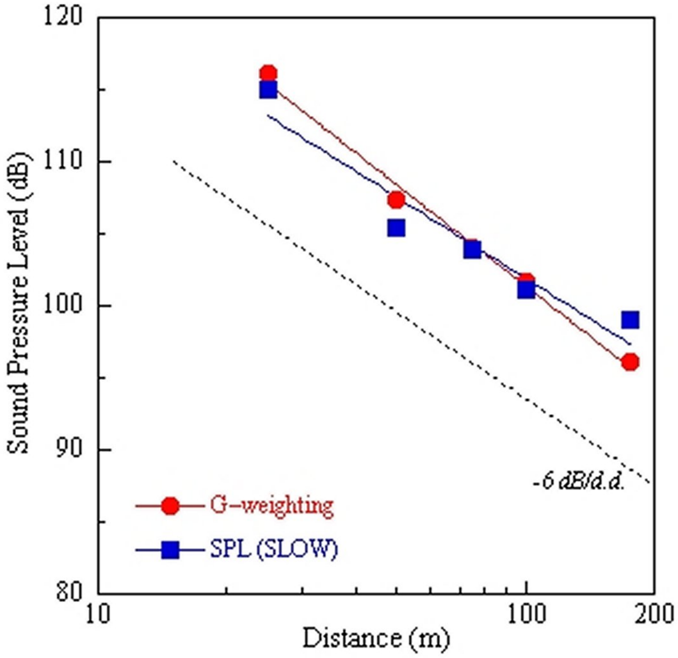

**Figure 4:** Sound attenuation with distance of several noise evaluation indices using the blast sounds.

2. **S. Kunimatsu and al.**, Ground vibration characteristics by blast densification method, In *Annual meeting of Japan Society of Civil Engineering*, pp. 656-657, 1999
3. **E. Kuroda and al.**, Air vibration from underground explosions, *Kogyo Kayaku*, Vol. 46, pp. 229-236, 1985
4. **G. A. Daigle and al.**, Experiments on surface waves over a model impedance plane using acoustical pulses, *Journal of Acoustical Society of America*, Vol. 99, pp. 1993-2005, 1996
5. **S. Yamada and al.**, *Sound and Vibration due to Blasting*, Sankaido, 1996
6. **ISO 7196-1995**, *Acoustics-Frequency-weighting characteristics for infrasound measurements*, 1995
7. **Sub-committee of low frequency noise of INCE/Japan** , Proposal of measurement method of low frequency noise, *Journal of INCE/J*, Vol. 16, pp. 198-203, 1992
8. **S. Kunimatsu and al.**, Multi-evaluation of blast sound propagation attenuation by using digital simulation for both frequency and time weighting, *Journal of INCE/J*, Vol. 17, pp. 261-267, 1993
9. **H. Ochiai and A. Yokota**, Evaluation of low frequency sound by G-weighted sound pressure level, In *Annual meeting of INCE/J*, pp. 191-194, 1998
10. **Environmental Agency of Japan**, *Report of low frequency air vibration*, 1984

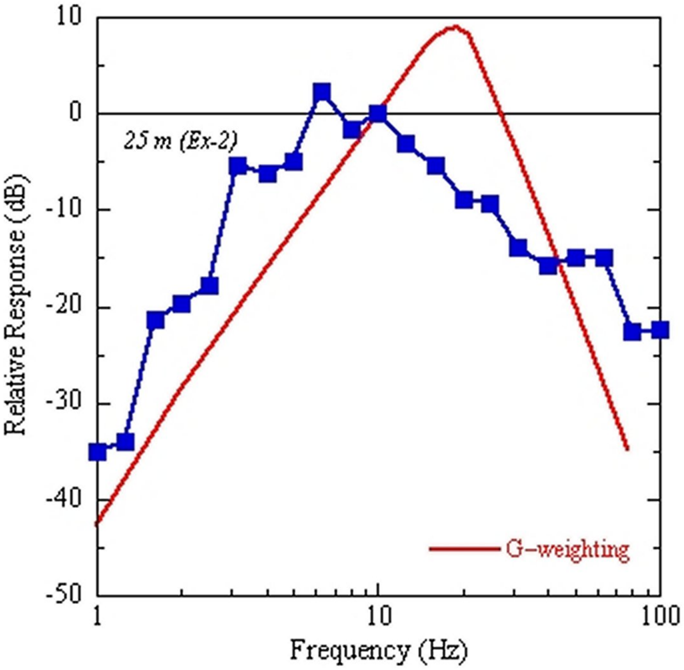

**Figure 5:** Frequency distribution of the blast sound and relative response of G−weighting network.