Jour of the KGS Vol 16, No 3, June 2000, pp 119~129

SPT Rod Energy Ratios for Three Types of SPT Hammers

표준관입시험 해머의 종류에 따른 롯드 에너지 전달률

An, Shin-Whan*1 안 신 환
Lee, Won-Je*2 이 원 제
Lee, Woo-Jin*3 이 우 진

요 지

국내에서 가장 많이 사용되는 현장조사방법인 표준관입시험의 결과로 얻어지는 N값에 대해 가장 큰 영향을 미치는 롯드 에너지 전달률(Rod Energy Ratio)을 지반조건이 상이한 3개 현장에서 항타분석기(Pile Driving Analyzer)를 이용하여 실측하였다. 에너지전달률에 영향을 미치는 요인들 중에서 해머의 종류, 로프의 상태, 자아틀에 감은 횟수 등의 조건을 달리하여 롯드 에너지 전달률에 미치는 영향을 측정/분석하였다. 실험결과에 의하면 도넛해머, 안전해머, 개량형 도넛해머(Modified Automatic Donut Hammer)는 롯드에너지 전달률이 각각 42%, 66%, 57% 정도로 측정되었으며 로프의 상태와 자아틀에 감은 횟수는 상대적으로 영향이 적은 것으로 측정되었다. 실험결과를 바탕으로 실측된 N값을 해머의 이론적 위치에너지의 60%에 해당하는 에너지가 롯드에 전달되었을 때의 N값(N_{60})으로 변환하기 위한 식을 제안하였다.

Abstract

Standard Penetration Test has been the most widely used technique for a site investigation. N value from SPT is directly influenced by the energy transferred to rod stem as well as the ground condition and the state of stress. For three sites of different ground conditions, rod energy ratio is measured with Pile Driving Analyzer. The donut, safety, and modified automatic donut hammer were measured to deliver the 42%, 66%, and 57% of the theoretical potential energy of the hammer, respectively. Rope condition and number of rope turns around cathead in rope-pulley system have slight influences on rod energy ratio. Based on test results, a series of equations were proposed to convert measured N-value to N_{60}, that is the expected blow count when 60% of theoretical potential hammer energy delivered to the rod.

Keywords : Standard penetration test, N value, N_{60}, Rod energy ratio

1. Introduction

SPT(Standard Penetration Test) is the in-situ testing technique which has been widely used for decades to investigate the soil profiles and to obtain the basic soil properties. In spite of its advantages, such as inexpensive and simple test procedure, easy sampling, and many useful correlations with various soil parameters, the reliability of N-value has been questioned by many practitioners and researchers. Since the main purpose of SPT is to evaluate the design parameters, N-value should be converted to desired parameters by empirical correlations and the error in evaluated parameters is likely to be reduced by measuring more reliable N-values. For identical soil conditions, level of energy transmitted to the split spoon sampler is influenced by many factors related to the detailed testing procedure and equipments, and, therefore, measured N-values would not be identical if different

*1 Member, Researcher, Korea Institute of Construction Technology
*2 Member, Graduate Student, Dept of Civil Engrg, Korea Univ
*3 Member, Associate Professor, Dept of Civil Engrg, Korea Univ

types of hammer, release mechanism, and anvil were used. The equipments and practices used for SPT at different parts of the world are also different, and the measured N-value can not be directly comparable.

Empirical correlations to estimate the strength parameters and soil properties from measured N-value have been developed by many researchers during 1950 ~ 1970's, without realizing the effect of impact energy on N-value. It was just after 1980's that researchers (Skempton, 1986; Kovacs and Salomone, 1981; Robertson et al., 1983) began to be concerned about the energy transmitted to SPT rod. It was concluded that the transferred energy during typical SPT of early days was about 50 ~ 60% of the theoretical potential energy of hammer and that many different test systems used around the world deliver a wide range of impact energy. Skempton(1986) suggested to use the N-value corresponding to the 60% of the theoretical energy (N_{60}) and provided the correction factors for various SPT testing system and procedure. Therefore, the N-value measured should be corrected to N_{60} by estimating the transferred energy with Skempton's procedure or by directly measuring the rod energy during the test.

In Korea, the efforts to evaluate the impact energy during SPT were initiated early 1990's by several researchers (Lee et al., 1992; Park et al, 1993; Park et al, 1994; Lee et al., 1996; Lee et al., 1997). However, most of the studies were mainly concentrated to the estimation of velocity energy ratio, which is defined as the ratio of velocity energy of hammer immediately before impact on anvil to theoretical energy. Therefore, the energy loss during impact on anvil should have been estimated from the data base accumulated by experiences in foreign countries.

In this study, a series of standard penetration tests were performed at three construction sites for different combinations of hammer, rope condition, and number of rope turns. Energy transferred to drilling rod due to the impact of SPT hammer is evaluated using PDA(Pile Driving Analyzer) with an instrumented rod. PDA measures the time histories of strain and acceleration from two sets of strain gages and accelerometers on instrumented rod located under an anvil, and converts them to force and particle velocity. By integrating these variables with respect to time, the energy transferred to drilling rod is calculated. The data were analyzed to evaluate the effects of test conditions on N-value and the correction values for each factors were suggested.

2. Testing Programs

In Korea, most of the SPT have been performed by donut hammer with rope-pulley system while safety hammer became popular recently. Some specialty contractors have used the donut hammer system modified to lift and drop automatically at a constant height. Effect of three types of hammer, such as donut, safety, and MAD (modified automatic donut), on the energy transferred to rod is studied, with the variation of rope condition and rope turns around cathead during the tests. Since most of SPT equipments in Korea use similar size of anvil, cathead, and split spoon sampler without liner, their effects were not investigated in this study. Descriptions on the sites and testing programs performed are as follows.

Sang-Moon Dong (S-Site)

S-Site is in Sang Moon-Dong, northern part of metropolitan Seoul, and the test was a part of subsurface investigation 5 story residential building. The site is mainly consisted of weathered soil and weathered rock. The system for SPT is consisted of 63.5kg donut hammer with an anvil of 8.5cm diameter and 10.5cm height. A 20mm diameter manila rope was employed with the 2¼ rope turns around the cathead and appeared to be used more than 6 months. Diameter of cathead was 11.1cm when tests were performed, and it was suspected to be worn out due to the long-time use.

Rotary boring was performed down to the depth of 15m and the N value were measured every 1.5m up to the depth of 12.0m. Diameter of drilled hole was 73mm and steel casing to support borehole wall was installed to 4.5m down from ground level.

PaJu City (P-Site)

P-site is located at PaJu city, northern Kyunggido. The site is a construction field for 15 story apartment complex. Boreholes were excavated down to 7.5~9m with a large size boring machine and steel casing was installed throughout the depth to support the borehole wall. The SPT were carried out at two groups of boreholes(P1, P2), which were located at 200m distance.

At P1-site, soft clay, clay, clayey sand, and weathered soil exist along the depth. The MAD hammer was used for the first borehole in order to figure out the strata and variation of N-value to a depth of 7.5m. Ground water level was found at depth between 4.5~6.0m from ground level and was believed to be related to the stream nearby. As a matter of fact, N-value of this site increases remarkably between 4.5~6m.

At P2-site, soft clay, sand, sand-gravel, weathered soil, and weathered rock exist from the top of ground. The first borehole at this site was drilled and tested with the MAD hammer for the investigation of subsoil to a depth of 9m. Instruments and procedures were changed several times during the test to investigate the effects of influencing factors on rod energy. The tests for each items were carried out at the same depths of different boreholes nearby so as to remove the effect of ground condition.

Young-Jong Do (Y-Site)

Y-site is located at YoungJong-do where new airport is under construction. The site is mainly consisted of soft to medium clay. Borehole was drilled to a depth of 15.3m and a steel casing was employed for whole depth. Sea mud clay of which N-value is in a range of 3~25 is deeply distributed down to 13.5m, and soft rock appears abruptly of which N-value is even more than 300. Similar set of SPT system with that used in S-site was employed in this site, with slightly larger cathead. The donut hammer was tested with only new rope for the investigation of the strata and N-value. And finally donut and safety hammer were tested alternately to compare energy level.

The combination of the equipments used at each sites are summarized in Table 1.

3. Instrumentation

3.1 Measuring Systems

Pile Driving Analyzer

Pile Driving Analyzer, which has been used as an effective tool for the construction control of pile foundation, measures force and particle velocity in pile due to driving, and calculates several control parameters based on the 1-D wave propagation theory. The SPT involves stress wave propagation in a slender rod due to hammer impact, like pile driving, and, thus, the principles of wave mechanics is applicable to this dynamic penetration test.

PDA acquires the time histories of force and particle velocity due to driving of sampler, and also calculate the transferred energy through both square force and force-velocity integration method. The force and velocity measurements during SPT are similar to the routine measurements performed during dynamic testing of piles. Rod energy ratio(ER_r) is defined as the ratio of the calculated energy to theoretical energy, and is in turn expressed by multiplication of velocity energy ratio(ER_v)

Table 1. Test conditions for each sites

	S-site	P-site			Y-site
Boring Technique	Rotary Wash Boring				
Borehole Depth (m)	15	7.5~10.5			15.3
Casing Depth (m)	4.5	to the bottom			to the bottom
Hammer	Donut	Donut	Safety	MAD	Donut, Safety
Rope Condition	used	used, new		–	new
Anvil Size Dia (cm)×Height(cm)	8.5×10.5	8.5×10.5	–	–	8.5×10.5
Rope Turns	2¼	1¼, 2¼, 3¼		–	2¼, 3¼
Cathead dia (cm)	11.1	10.9		–	12.5

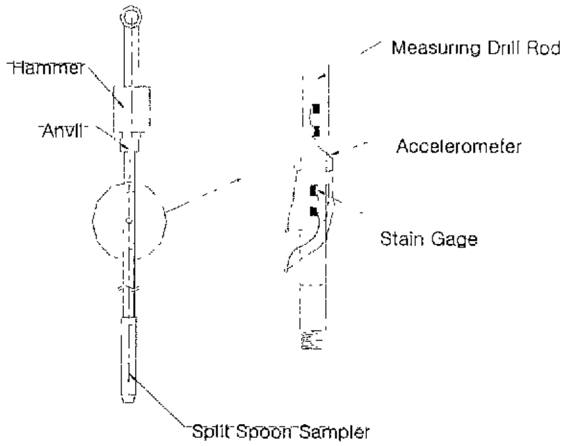

Fig. 1 Schematics of instrumented drill rod

and dynamic efficiency(η). Selecting the measuring location below anvil removes the inconvenience to consider velocity energy ratio and dynamic efficiency separately.

Measuring Drill Rod

The force and velocity measurements were accomplished with strain gages (foil type) and accelerometers (piezo-resistive type), mounted at the midpoint of a 60cm long SPT drill rod section as shown in Fig. 1. The measuring rod used for the tests was designed to have the same size with AW-rod for direct connection to rod stem. Due to high frequency signals generated by the steel to steel impact between the hammer and anvil, piezo-resistive type of accelerometers were used, and a high sampling rate of 20kHz was required when converting the analog signals to digital form.

3.2 Hammers and Release System

Hammers and Hammer Drop Systems

Designations on SPT in ASTM and Korean Industrial Standards(ASTM D1586-84, KSF-2318) specify the weight of hammer(140 ± 2lb, 63.5 ± 1kg) and the drop height(30 ± 1.0in, 0.76m±25mm), but do not describe the specific hammer type or the hammer drop system allowable for the test. Several types of hammers (such as old standard, pin weight, donut, and safety hammer) and different hammer drop systems (such as rope-cathead, trip, semi-automatic, automatic) are referred in the manuals. However, it was found by many researchers that hammer type and hammer drop system are the most influencing factors on the velocity energy ratio and dynamic efficiency of SPT.

Donut hammer has been predominantly used for SPT in domestic sites. Safety hammer released by rope-pulley system have been used occasionally and is expected to be used more because of the safety reason. Though it uses same release system with the donut hammer, energy transferred to the drilling rod is known to be larger than that of the donut hammer. Recently, some of the practicing engineers modified the donut hammer, as shown in Fig. 2,

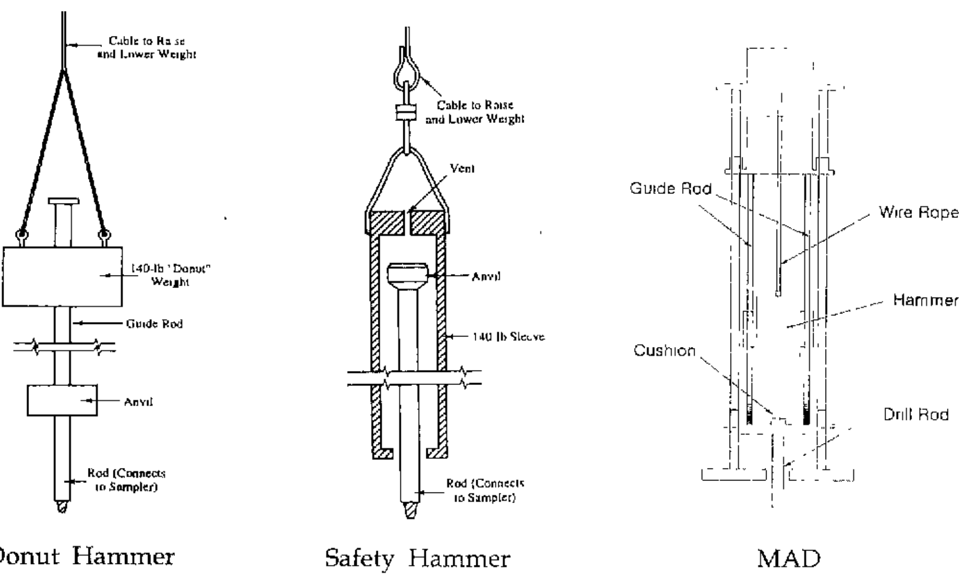

Fig. 2 Types of SPT hammers tested

for mechanical lift and accurate release height, and this system is also expected to gain popularity in Korea. Rope and pulley is removed from the system and the donut hammer is designed to be lifted by wire rope connected to winch. Once the hammer is dropped along two guide rods, it impacts the cushion connected to drill rod.

Rope and Others

When a rope and pulley system is used to lift and drop the hammer, the number of rope turns around cathead and the condition of rope are the most significant influencing factors on the driving energy, since they are related to the

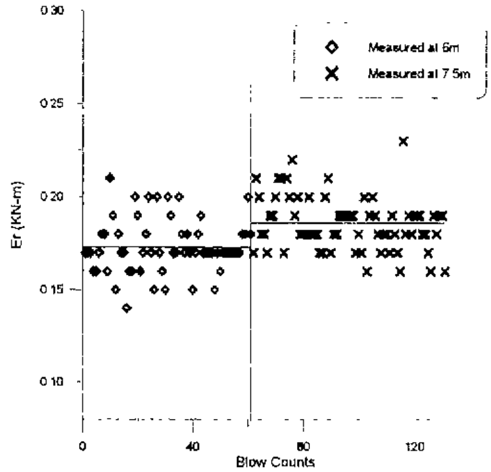

Fig. 5 Variation of ER_r (donut, used, $2\frac{1}{4}$)

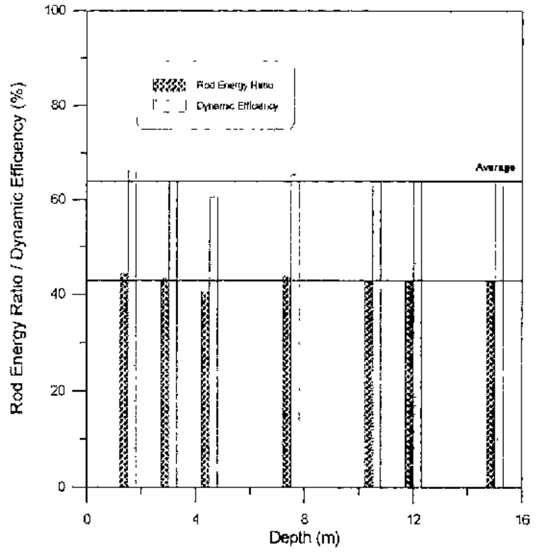

Fig. 3 Rod energy ratio at S-site (Donut)

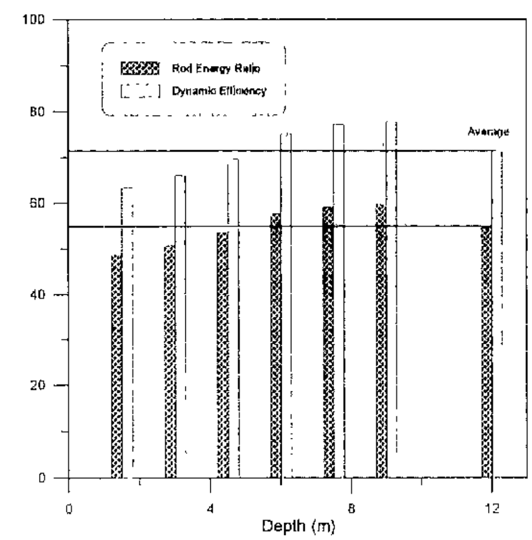

Fig. 4 Rod energy ratio at P-site (MAD)

friction between rope and cathead remained after the release of rope. ASTM Designation D1586-84 describes the number of rope turns around the cathead as "the total contact angle between the rope and the cathead at the beginning of the operator's rope slackening to drop the hammer, divided by 360° ", and recommends not to wrap a cathead more than $2\frac{1}{4}$ turns.

The diameter of cathead used in this study varies slightly for each equipment, but it is between 100 to 130mm, which is typically considered as small one. The dimension of the anvil used with the donut is 85mm diameter and 105mm height, and the weight is approximately 4.5kg. Compared with the anvils used in Japan, U.S.A., and U.K., the anvil weight of 4.7kg is slightly heavier than the small anvil of 2 to 3kg and it is significantly lighter than large one of 12 to 19kg. Since the anvil of the safety hammer locates inside the hammer, its dimensions and weight could not be identified.

4. Observed Performance

4.1 S-Site

The variation of rod energy ratio measured through the depth is illustrated in Fig. 3, and average rod energy ratio for total 371 blows is 42.89%. Accepting the results by Park et al. (1993, 1994) and Lee et al. (1996) that velocity energy ratio of donut hammer is around 63 to 71% in

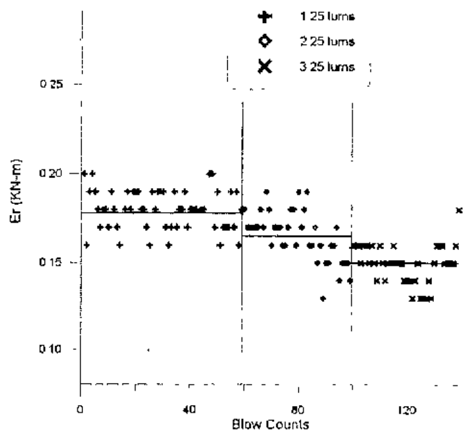

Fig. 6 Variation of ER_r (donut, new)

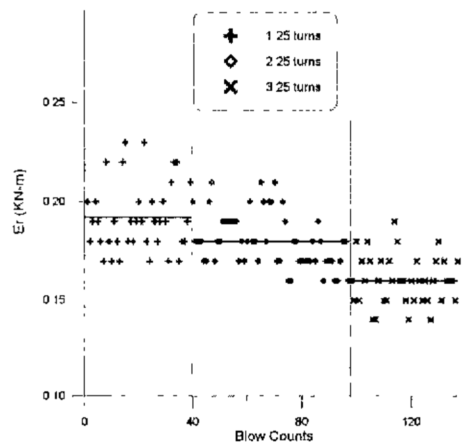

Fig 7 Variation of ER_r (donut, used)

Korea, average dynamic efficiency is estimated with a weighting factor of number of blows to be around 64%.

4.2 P-Site

MAD Hammer

The variation of measured rod energy ratio with depth is shown in Fig. 4 and the average value was 54.91%. The velocity energy ratio of the MAD hammer are assumed to be 75 to 78% by accepting the previous research results by Park et al. (1994) and Lee et al. (1996), and, therefore, the dynamic efficiency estimated is about 72%. It was observed that the MAD hammer showed the most reliable waveforms and the smallest blow-by-blow variation of rod energy ratio among three hammers.

Donut Hammer

Donut hammer was used in this site to investigate the average rod energy ratio and the effect of assembly of the rope pulley system. Most tests were performed at a depth of 6～7.5m where N-value was large enough to have a consistent energy level.

Fig. 5 shows the variation of rod energy of donut hammer, measured with a used rope wrapping the cathead 2¼ turns, for each blows at depths of 6m and 7.5m. The average values of rod energy were 0.173 KN-m at 6m and 0.186 KN-m at 7.5m. The average rod energy weighted to number of blows was 0.180 KN-m, which is 38.06% of theoretical potential energy of the hammer, and average dynamic efficiency was estimated to be 56.74%.

Fig. 6 and Fig. 7 show the efffects of rope condition and number of rope turns around cathead. It can be seen that hammer release system with used rope delivers slightly larger energy on the average than that with new rope. It is also shown that the energy level decreases as the number of rope turns around cathead increases.

Safety Hammer

The tests were performed with the safety hammer in the same manner with the donut hammer. Generally, safety hammer is known to transfer more energy than donut hammer does, and it was confirmed by the results of this test. Fig. 8 shows the distribution of rod energy for each blow by safety hammer with a used rope wrapping cathead 2¼ turns. The tests were performed at the depths of 6m and 7.5m. The average rod energy measured at 6m is 0.310 KN-m, and at 7.5m is 0.319 KN-m. Weight average for all the blows is 0.312 KN-m, which is about 65.98% of the theoretical potential energy of the hammer. Dynamic efficiency calculated is 94.25%, using the velocity energy ratio of 70% as proposed by Skempton (1986). Fig. 9 and Fig. 10 show the distributions of the rod energy with new and used rope wrapping the cathead 1¼, 2¼, and 3¼ turns.

4.3 Y-Site

Donut Hammer

The test was performed using donut hammer with a new rope wrapping the cathead 2¼ turns down to depth of

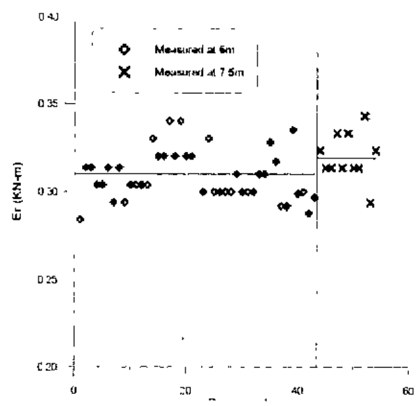

Fig. 8 Variation of ER_r (safety. used, 2¼)

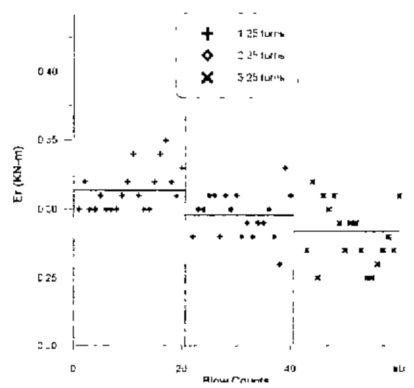

Fig. 9. Variation of ER_r (safety, new)

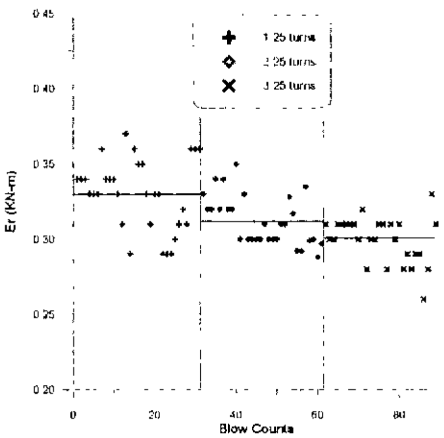

Fig. 10 Variation of ER_r (safety, used)

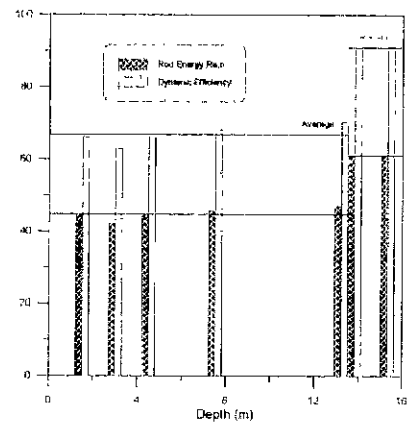

Fig. 11. Rod energy ratio (Y-site)

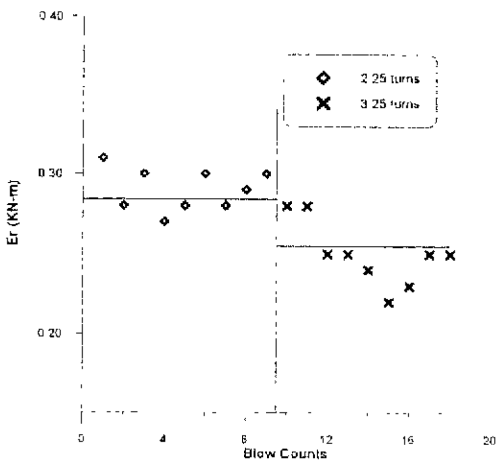

Fig. 12 Variation of ER_r(Dount, new)

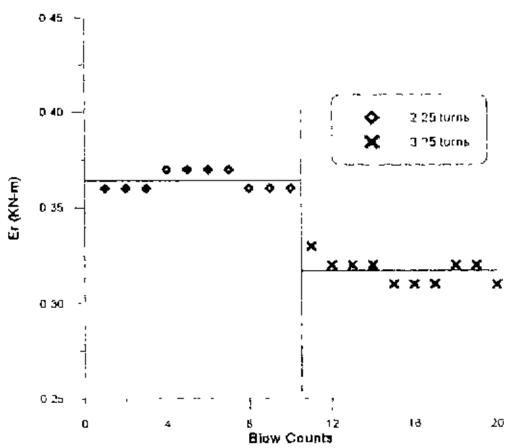

Fig. 13 Variation of ER_r (safety, new)

15.3m. The values of rod energy obtained in clay layer are used and the average rod energy ratio of donut hammer obtained is 45.58%. The data obtained in weathered rock layer are excluded from the calculation because of the significantly different level of energy measured. The variations of rod energy ratio and dynamic efficiency are shown in Fig. 11. At 15.3m, the tests were performed with rope turns of 2¼ and 3¼, and the results are shown in Fig. 12. The average rod energies are 0.284 KN-m with 2¼ turns and 0.255 KN-m with 3¼ turns.

Safety Hammer

The safety hammer was tested at 15.3m, with a new rope of 2¼ and 3¼ rope turns. As shown in Fig. 13, the average rod energies are 0.364 KN-m with 2¼ turns and 0.317 KN-m with 3¼ turns. Also, significant difference in rod energy ratio due to the change in rope turns were observed.

5. Discussion of Results

5.1 Type of Hammer

The data of rod energy ratio measured, following standard test procedure, at three sites for different types of SPT hammers are plotted together in Fig. 14. The average rod energy ratios by donut, safety, and MAD hammers for all the sites are 42.1%, 66.0%, and 57.3%, respectively. As shown by other researchers, safety hammer delivers significantly larger rod energy than donut hammer does. The rod energy ratio by MAD hammer, which is only available in Korea, is larger than that of donut hammer but is slightly smaller than that of safety hammer. Since the MAD hammer is lifted by the wire rope of small diameter and is dropped by releasing the wire rope when the top of the hammer contacts the trigger, there is no energy loss due to friction at cathead and pulley, and the energy delivered to drilling rod is larger than that of donut hammer. Rod energy ratio of donut hammer is slightly lower than the typical values in the range of 43% to 50%, suggested by Skempton (1986), Robertson et al. (1982), and Clayton (1990). It is surprising that the rod energy ratio of 42.1% measured in domestic sites is significantly smaller than that of 60% reported by Skempton (1986) for Japanese case, even though the SPT hammer system and release mechanism are similar with those of Japan.

For the safety hammer with rope-pulley system, Clayton (1990), Skempton (1986), and Robertson et al. (1993) gave the rod energy ratio ranging from 55% to 65%. The average rod energy ratio of 66% acquired in this study agrees well with the previous results.

The MAD hammer is designed to maintain the constant drop height of hammer and, therefore, it is expected to show almost constant velocity energy ratio. Lee et al. (1997) measured the velocity energy ratio of 75% for a similar type of hammer system and reported rod energy ratio of 54% by adopting dynamic efficiency of 0.72. Measured rod energy ratio, 57.3%, for the MAD hammer in this study agrees well with that of Lee et al. (1997).

To standardize the SPT results from different hammer types, N-value measured must be corrected to the 60% level of theoretical energy. Based on Schmertmann and Palacios (1979) showing that penetration resistance varies inversely with transferred energy, the correlation converting measured N-value to N60 is suggested in Eq. (1).

$$N_{60} = 0.70\ N_{donut} = 1.10\ N_{safety} = 0.96\ N_{MAD} \quad (1)$$

5.2 Number of Rope Turns

Since more energy is needed to lift a hammer up to 76cm height as the number of rope turns, rope diameter, and

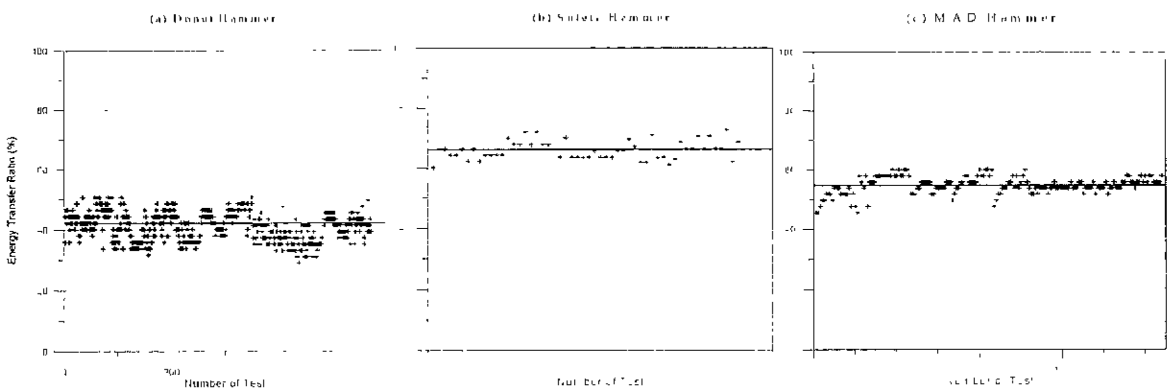

Fig. 14 Distribution of rod energy ratio (hammer)

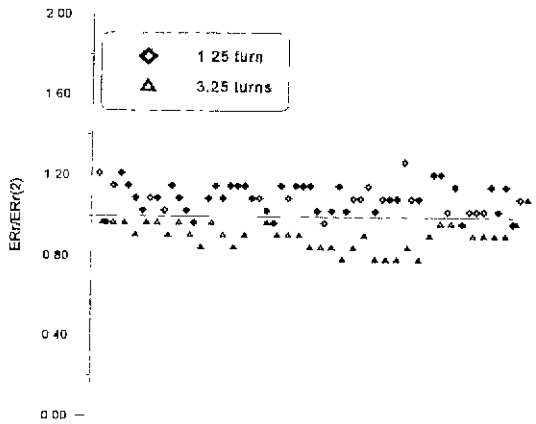

Fig. 15 $ER_r/ER_{r(2\frac{1}{4})}$ of donut hammer

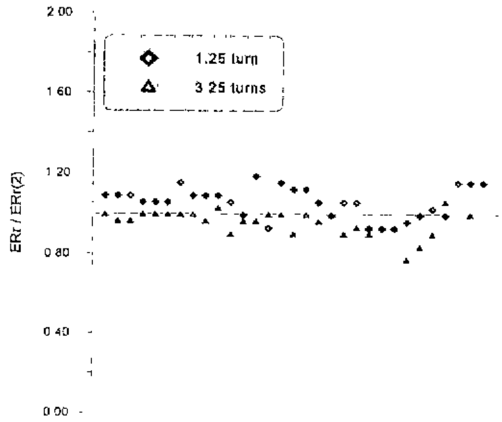

Fig. 16 $ER_r/ER_{r(2\frac{1}{4})}$ of safety hammer

Table 3. Rod energy ratio for new and used rope

Hammer / rope turn		$ER_{r(now)}$	$ER_{r(used)}$	$ER_{r(now)}/ER_{r(used)}$
Donut	1¼	37.6	40.6	0.93
	2¼	34.9	38.1	0.92
	3¼	31.8	33.8	0.94
Average ER_r				0.93
Safety	1¼	66.4	69.8	0.95
	2¼	62.6	66.0	0.95
	3¼	60.1	63.6	0.94
Average ER_r				0.95

cathead diameter decrease, operator favors larger number of rope turns during SPT. As frictional area becomes larger, the larger friction would be remained after the release of the rope. The increase of rope turns would cause the more friction between rope and cathead, and results in less velocity energy, less rod energy, and larger N-value. Therefore, it is necessary to estimate the variation of rod energy and the effect on N-value due to the change of rope turns around cathead.

To investigate the influence of number of rope turns, rod energy ratio was measured at 2 sites using donut and safety hammers. Measured rod energy ratio is divided by energy ratio of 2¼ rope turns to normalize the effect of number of rope turns. Fig. 15 and Fig. 16 show the distribution of the rod energy ratio divided by that with 2¼ rope turns tested with both new and used rope. It is clearly shown that more turns of rope around cathead provide less rod energy. It can be concluded that the number of rope turns around cathead affects N-value as much as about ±10%.

To correct the measured N-value to N-value with 2¼ rope turns, following equations are suggested for donut and safety hammers. The difference between Eq. (1) and Eq. (2) appears due to the different impact mechanism of hammer on anvil. For donut hammer,

$$N_{(2\frac{1}{4})} = 1.08\ N_{(1\frac{1}{4})} = 0.90\ N_{(3\frac{1}{4})} \qquad (2)$$

For safety hammer,

$$N_{(2\frac{1}{4})} = 1.06\ N_{(1\frac{1}{4})} = 0.96\ N_{(3\frac{1}{4})} \qquad (3)$$

5.3 Condition of Rope

Compared with used rope, new rope mobilizes larger friction between rope and cathead after the release of rope. Since the friction interfere the free fall of the hammer, the condition of rope is expected to affect the velocity energy. To investigate the effect of rope condition on N-value, rod energy ratio was measured for donut and safety hammers, with a rope used more than a year and a new rope, at P-site. Results of tests are summarized in Table 3.

Table 4. Rod energy ratio and correction factors

Factors	Condition		ER_r (%)	Correction Factors	
Hammer	Donut		42.1	α_1	0.70
	Safety		66.0		1.10
	MAD		57.3		0.96
Rope Condition	Donut	New	34.8	α_2	0.93
		Used	37.5		1.0
	Safety	New	63.0		0.95
		Used	66.5		1.0
No. of Rope Turns	Donut	1¼	39.1	α_3	1.08
		2¼	36.6		1.00
		3¼	32.8		0.90
	Safety	1¼	68.5		1.06
		2¼	64.7		1.00
		3¼	62.2		0.96

On the average, new rope would give about 6% reduction of rod energy, compared with used rope. When new rope is used for SPT, following equation could be used for the correction of the N-value.

$$N_{used} = 0.94\ N_{new} \tag{4}$$

5.4 Correction of N value

The N-value measured by SPT can be influenced by several factors. The energy transferred to the rod in the field was directly measured by PDA without any experimental assumption. The equation to correct measured N-value to N_{60} is proposed as Eq. (5) for different type of hammers, condition of rope, and number of rope turns around cathead. And the rod energy ratio and correction factors are shown in Table 4.

$$N_{60} = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot N_{measured} \tag{5}$$

where α_1, α_2, and α_3 are correction factors.

6. Conclusions

A series of SPT was performed at three sites, measuring the energy transferred to drilling rod using PDA. Through the investigations on rod energy ratio for various test conditions, following conclusions are drawn.

1) The average rod energy ratio of donut, safety, and MAD hammer are calculated as 42.1%, 66.0%, and 57.3% of the theoretical potential energy, respectively.

2) Rope condition in rope-pulley system has slight influence on transferred energy. It was found that, on the average, new rope would have about 6% reduction of rod energy, compared with used one.

3) The rod energy were measured with number of rope turns of 1¼, 2¼, and 3¼, and it was found that transferred energy is 6~8% larger with 1¼ rope turns and 4~10% smaller with 3¼ rope turns.

4) The equation to correct N-value, measured by different test conditions, to 60% of theoretical potential energy was proposed.

References

1. ASTM Standard D1586-84. Standard Method for Penetration Test and Split-Barrel Sampling of Soils, ASTM Designation D1586-84, Vol. 04.08, pp 232-236.
2. An, Shin-Whan (1998), The Measurement of SPT Rod Energy Transfer Ratio using PDA. M.S.C.E. Thesis, Korea University.
3. Clayton, C R I. (1990), SPT energy transmission : theory, measurement and significance, Ground Engineering, Vol 12, pp 35-43.
4. Fletcher, G F. A. (1965). Standard Penetration Test its uses and abuses, Journal of the Soil Mechanics and Foundations Divisions, ASCE, Vol 91, pp 67-75.
5. Kovacs, W. D. (1979). Velocity Measurement of Free-Fall SPT Hammer, Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No GT1, pp 1-10.
6. Kovacs, W. D (1982), SPT Hammer Energy Measurement, Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, No

GT4, pp. 599-620.

7. Kovacs, W. D., Evans, J C., and Griffith, A. H. (1977), Towards a more standardized SPT, Proceedings 9th ICSMFE, Vol. 2, pp. 269-276

8 Kovacs, W D., Salomone, L A., and Yokel, F Y. (1981), Energy Measurements in the Standard Penetration Test, U.S. National Bureau of Standards, Building Science Series 135

9. Lee, Myung-Whan, Kang, In-Tak, Lee, Won-Je, Kim, Young-Jin (1992), Evaluation of the Falling Velocity of SPT Hammer via Actual Measurement, Journal of the Korean Geotechnical Society, Vol 8, No. 1, pp 59-69

10. Lee, Ho-Choon, Kim, Byoung-Il, Park, Yong-Won (1996), Rod Energy Ratio Measurement of SPT, Journal of the Korean Geotechnical Society, Vol 12, No. 5, pp. 117-125

11 Lee, Ho-Choon, Park, Yong-Won (1997), Hammer Energy Level of SPT in Korea Journal of the Korean Geotechnical Society, Vol. 13, No. 1, pp. 169-180

12 Lee, Woo-Jin Lee, Won-Je, An, Shin-Whan (1998), The Measurement of SPT Rod Energy Transfer Ratio using PDA Proceedings of the KGS Spring 1998 National Conference, pp 75-84.

13. Matsumoto, T., Sekiguchi, H , Yoshida, H., and Kita, K. (1992), Significance of Two-Point Strain Measurement In SPT, Soils and Foundations, Vol. 32, No. 2, pp. 67-82.

14. Park, Yong-Won, Lee, Ho-Choon, Park, Jong-Ho, Kim, Seok-Hoon (1993), The Measurement of SPT Hammer Energy, Proceedings of the KSCE '93 National Conference, KSCE, pp. 573-576.

15. Park, Yong-Won, Lee, Ho-Choon, Park, Jong-Ho (1994), A Comparison of SPT Hammer Energy, Proceedings of the KSCE '94 National Conference, KSCE, pp. 821-824.

16. Schmertmann, J. H. and Palacios, A. (1979), Energy Dynamics of SPT, Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No 8, pp. 909-926

17. Skepmton, A. W. (1986), Standard penetration test procedures and the effects in sands of overburden pressure, relative density, particle size, ageing and overconsolidation, Geotechnique, Vol 36, No. 3, pp 425-447.

18. Robertson, P. K. and Campanella, R G., M. ASCE, and A. Wightman (1983). "SPT-CPT Correlations", Journal of Geotechnical Engineering, ASCE, Vol. 109, No 11, pp.1449-1459

(received on May., 17, 2000)