ENGINEERING PROPERTIES OF BEDROCK AT THE LIANYUNGANG NPP SITE IN CHINA

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SUMMARY

The site of Lianyungang Nuclear Power Plant has capacity for six units of 1000 MWe each. The first 2 units are planed Russian Type PWRs (WWER 1000). The site geology is a granitic outcrop with the height around 80 m. The outcrop is planed to level to 8 m above sea level to reveal good quality rock for the reactor building foundations. Coring of the rock were conducted and many good quality samples were extracted. Laboratory tests some of the rock samples were performed to obtain engineering properties of the granite in Kajima Technical Research Institute. Tests included cyclic triaxial compression, monotone triaxial compression, and unconfined compression tests. From the Mohr's circle at failure in the monotone triaxial and unconfined compression tests, the internal friction angle was 63.5 degree and the shear strength was 41.8 MPa were obtained. Relationships of Young's modulus and normal strain, shear modulus and shear strain, and damping ratios and shear strain were obtained from the cyclic triaxial compression test. Poisson's ratios were obtained 0.163 and 0.284 by the cyclic triaxial compression test and the unconfined compression test, respectively. The shear modulus showed very slow decrease rate to the shear strain ratio 0.05 % and then showed clearly a tendency for strain hardening along with increasing shear strain. Damping ratios 0 - 1 % was obtained in the shear strain ratios 0.0006 % - 0.005 %. Shear wave velocity was obtained from the cyclic triaxial compression test and unconfined compression test; both tests showed almost the same results about Vs = 3000 m/s. The earthquake observed at the site will contain source and path effects only and will not be affected by the local soil condition. Future earthquake observations at the site will produce valuable data for the evaluation of seismic design earthquakes on NPP.

INTRODUCTION

The site of Lianyungang Nuclear Power Plant (LNPP) is located at Pashantou, 29 km northeast of Lianyungang City at the base of Shandong peninsula along the coast of Huang Hai (Yellow Sea) between Qingdao and Shanghai. According to the preliminary assessment, the site has capacity for six units of 1000 MWe each. The first 2 units are planed Russian Type PWRs (WWER 1000). Seismological and geological investigations were conducted according to the requirements of Nuclear Safety Guides HAF0101-1, "Earthquake Topics In Relation to Nuclear Power Plant Siting" in China. Existing geological and seismological data for the region were compiled and then intense investigations of geological and seismological conditions for the local area were performed. The evaluation of the historical earthquakes, seismotectonics, and probabilistic seismic hazard analysis were performed for the estimation of the design basis earthquake of the site. The site is on a granitic outcrop with the height around 80 m. The outcrop is planed to level to 8 m above sea level to reveal good quality rock for the reactor building foundations. Rock samples were obtained by coring from the granite outcrop to below the ground level intended and many good quality samples were extracted. Laboratory tests some of the rock samples were performed to obtain engineering properties of the granite at the Kajima Technical Research Institute using high performance cyclic triaxial compression test apparatus in 1998. Tests included cyclic triaxial compression, monotone triaxial compression, and unconfined compression tests. Relationships of Young's modulus and normal strain, shear modulus and shear strain, and damping ratios and shear strain were obtained from the cyclic triaxial compression test. Poisson's ratios were evaluated both of the cyclic triaxial

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compression test and the unconfined compression test, respectively. The internal friction angle and the shear strength were obtained from the Mohr's circle at failure in the monotone triaxial and unconfined compression tests. Figure 1 shows the elevation view of the LNPP.

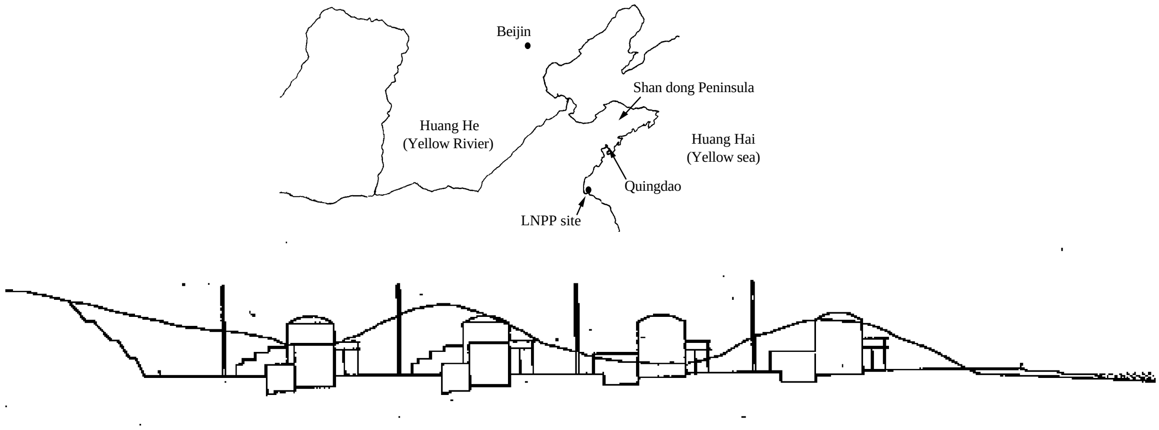
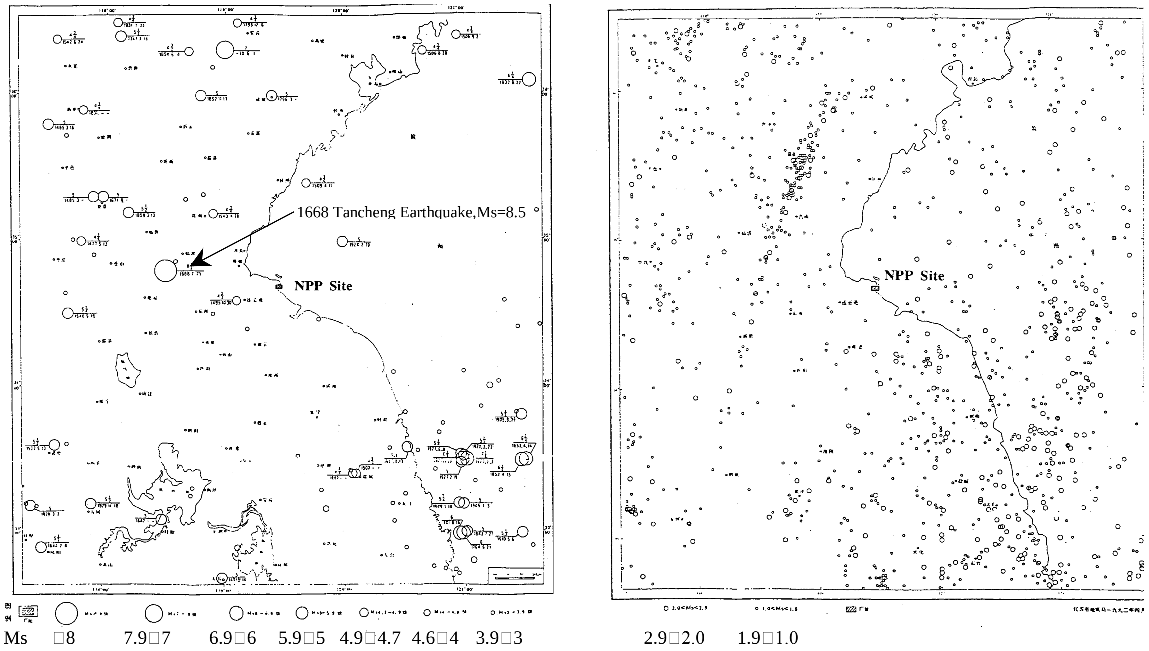


Figure 1. Elevation view of the plant

HISTORICAL EARTHQUAKES AND GEOLOGY IN THE SITE REGION

The LNPP site region belongs to the Sino-Korea crustal block in the east part of China. Shino-Korea crustal plate is formed by Precambrian craton and Shandong peninsula is formed by Archean craton [1]. The site geology is based very old hard rock. Based on the comprehensive studies in the radial extents 200 km in the region, 5 seismogenic structures are identified: Tanlu fault zone, Cangni fault, Mengshangian fault, Laiwu fault, Shanwujing fault. There were 47 earthquakes with $Ms \geq 4.7$ from B.C. 70 to the end of 1990 in the region. The largest earthquake among them was 1668 Tancheng Earthquake, Ms=8.5 occurred at the Tanlu fault on 25. 7. 1668. The distance of the fault is about 85 km west from the site. Tanlu fault zone can be divided into Tancheng-Anqiu segment and Sihong segment, which are coincided with the division of Tancheng-Anqiu seismotectonic province and Fengyang-Lingbi seismotectonic province. The maximum earthquake potential and the distances for the site associated with the five seismotectonic structures were determined as follows, Tancheng-Anqiu segment Ms=8.5, r=85 km, Cangni fault Ms=6.5, r=115 km, Mengshanqian fault Ms=6.0, r=117 km, Laiwu fault Ms=6.0, r=120 km, and Shanwujing fault Ms=6.5, r=185 km.

Tanlu fault zone is a prominent seismogenic structure, crossing Tanlu-Anqiu seismotectonic province and Fengyang-Lingbi seismotectonic province in the region. It is a lithospheric fault with great dimension and boundary of dividing the geological and tectonic framework units. A study of historical data for 1668 Tancheng Earthquake, Ms=8.5, including the collection of all-available data and field surveys were performed. A citizen-house with the brick-wood structure, built in Ming Dynasty, still exist in Haizhou and looks fine, in spite of the major earthquake experienced. An antique tower, called as Haiqing-Temple Tower or Ayu-King Tower, is deserved well in Dacun. The tower was built in Song Dynasty (AD 1023) and has lasted for 900 years. Vertical fissures can be found in the tower body and the caves were slightly protruded. As considering the damage were caused by the 1668 Tancheng Earthquake, Ms=8.5, the intensity can be defined as 8. According to the historical records, the intensity in Haizhou and Funing are defined 8 and 7, respectively. There are no earthquake records in Suchengying, Xugouying and Nancheng, that distances are 10-30 km from the LNPP site. Based on the above data of the earthquake experience, the intensity in LNPP, caused by the 1668 Tancheng Earthquake, Ms=8.5, is defined as 8. The magnitude and focus distribution of historical earthquakes and recorded earthquakes in this region are shown in Figure 2.



B.C.70 – 1990 (Ms>3.0)
(a) Historical earthquakes

1970 – 1990 (2.9>Ms>1.0)
(b) Recorded earthquakes

Figure 2. Magnitude and focus distribution of the earthquakes in the site region

LABORATORY TEST OF THE BEDROCK

The test specimens of the granite used in the laboratory test were obtained by coring the foundation ground of the reactor building construction area in the LNPP site. The foundation ground will be leveled at 8 m high from the sea level by cut off the granite outcrop height around 60 m. Core borings were performed from the outcrop surface to below the ground level intended. Laboratory tests were performed cyclic triaxial compression test to clarify the dynamic characteristics, and monotone triaxial compression test and unconfined compression test to clarify the static strength characteristics of the site bedrock granite.

The granite sample were shaped to three test specimens in the diameter 50 mm and the length 120 mm each to be used in three kind of tests. Physical properties of the test specimens are shown in Table 1.

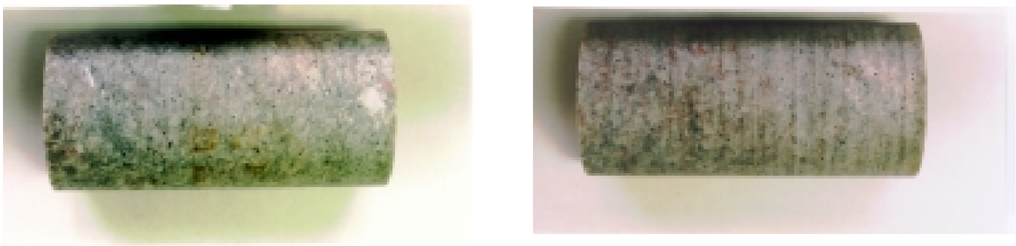
Sample	Sampling depth (m)	Test case	Height H (cm)	Diameter ϕ (cm)	Volume V(cm^3)	Weight m(N)	Bulk density γ_t (kN/m^3)	Confining stress σ_3 (MPa)
granite	GL±0 ~-60m	CTC※1	12.042	4.84	221.25	5.72	25.83	1.6※4
		MTC※2	10.010	4.83	183.41	4.74	25.82	9.8
		UCT※3	10.035	4.84	184.63	4.77	25.85	0.0

※ 1 Cyclic triaxial compression test ※ 4 Stress equivalent at depth 60.7m
※ 2 Monotone triaxial compression test
※ 3 Unconfined compression test

Table 1. Physical properties of the specimen

The loading rates both in the unconfined compression test and the monotone triaxial compression test were conducted by the strain rate 0.2% per minute till the failure. The motone triaxial compression test was performed in undrained test condition after confirmed the consolidation by loading confining pressure 9.8 MPa. The test specimens before and after the test are shown in Figure 3.

Before



(a) Unconfined compression test   (b) Monotone triaxial compression test

After

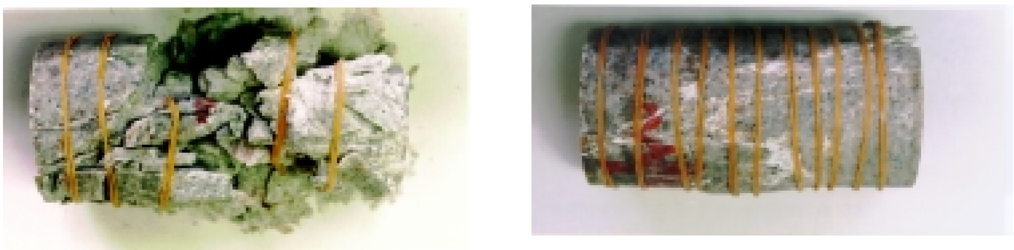
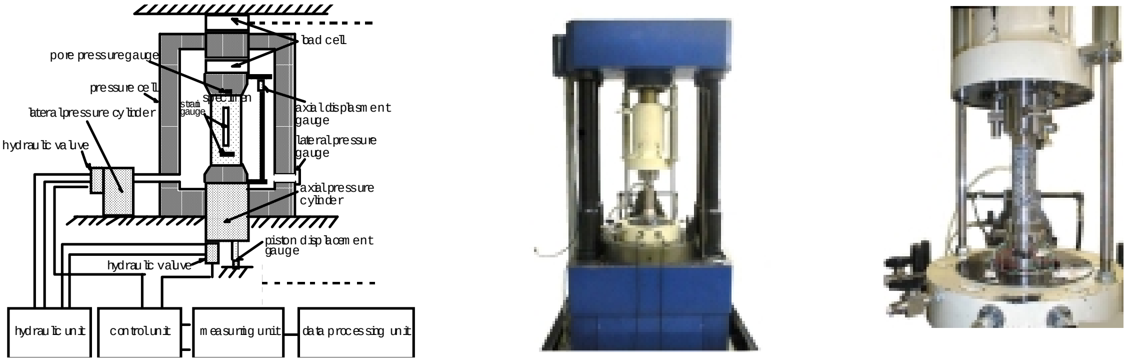


Figure 3. Specimens before and after the test

Cyclic triaxial compression tests were performed in undrained test condition after confirmed the consolidation by loading the confining pressure 1.6 MPa. The loading conditions were determined considering the maximum deviator stress, (σ1-σ3)max of the monotone triaxial compression test result that is, 6 steps of double amplitude triangular wave loading, 10 cycles for each step with loading rate 1.0 Hz in low amplitude region, and 10 steps of single amplitude triangular wave loading, half cycle for each step with loading rate 0.8(σ1-σ3) max/sec in high amplitude region. The confining pressure 1.6 MPa was applied to represent the confining stress at the depth 60.7 m. The test equipment used is shown in Figure 4..



Cyclic triaxial compression test apparatus (front face)   Sample's capping

Figure 4. Cyclic triaxial compression test apparatus and the block diagram

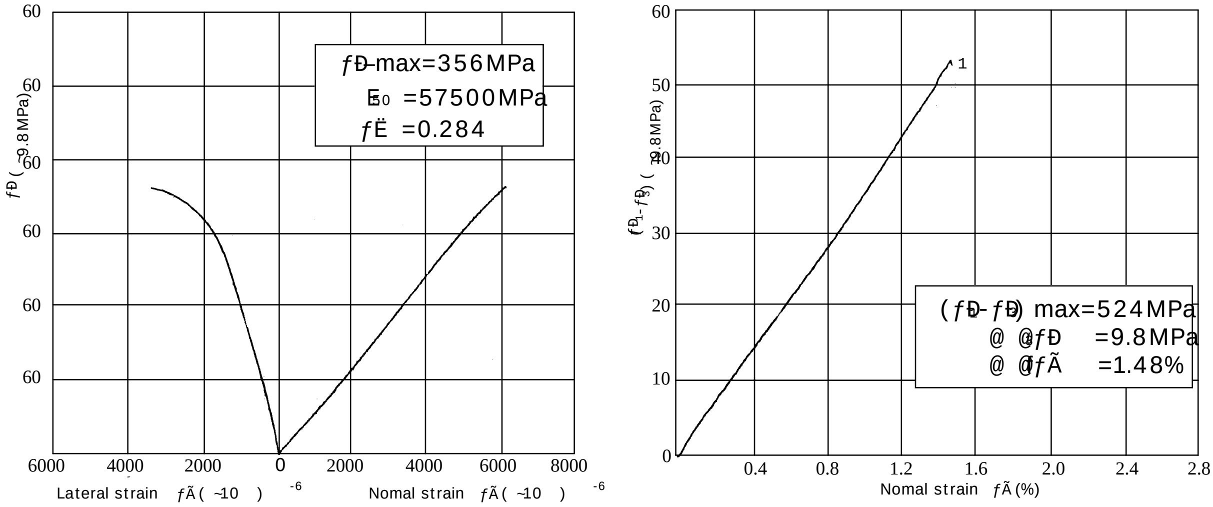
RESULTS OF THE LABORATORY TEST

Static strength characteristics of the granite

Static strength characteristics of the bedrock granite were obtained from the monotone triaxial test and the unconfined compression test. The stress-strain curves are shown in Figure 5. The test results are compression shown as the Mohr's circle at failure in Figure 6. From the Mohr's circle at failure, the internal friction angle was 63.5 degree and the shear stress was 41.8 MPa were obtained. Compressive strength in unconfined compression test showed 356 MPa. From the unconfined compression test, the initial Young's modulus, E_0, was 57500 MPa, the Poisson's ratio, ν, was 0.284, the initial shear modulus, G_0, was 22400 MPa and the shear wave velocity, Vs, 2915 m/s were obtained. The initial Young's modulus was represented by E_{50} at the point of half strength of unconfined compression test. Then the initial shear modulus and the shear wave velocity were calculated by the following equations.

$$G = \frac{E}{2(1+\nu)} \tag{1}$$

$$Vs = \sqrt{\frac{G \cdot g}{\gamma_t}} \qquad \text{g=gravity acceleration} \tag{2}$$



Unconfined compression test

Monotone triaxial compression test

Figure 5. Stress-strain curves

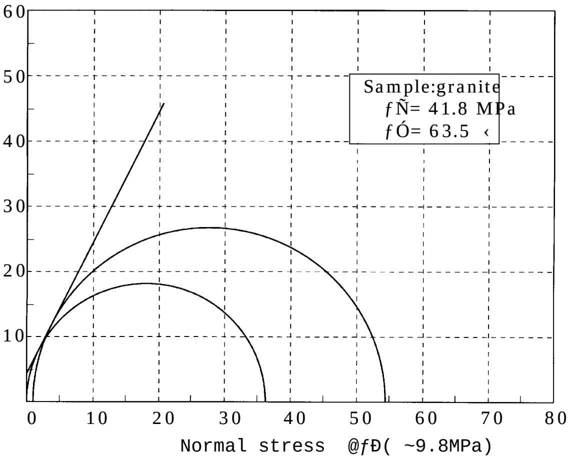


Figure 6. Mohr's circle at failure

Dynamic characteristics of the granite

Cyclic deformation characteristics of the bedrock granite were obtained from the cyclic triaxial compression test. The hysteresis curves of deviator stress and normal strain are shown in Figure 7. Relationships of Young's modulus vs. normal strain (E - ε) and Poisson's ratios vs. normal strain (ν - ε) are shown in Figure 8. Relationships of shear modulus vs. shear strain (G - γ) and damping ratios vs. shear strain (h - γ) are shown in Figure 9. The shear modulus showed very slow decrease rate from the initial to shear strain ratio 0.05 % and showed clearly a tendency for strain hardening along with increasing shear strain ratio above 0.05 %. The damping ratios from 0 to 1 % were obtained in the shear strain ratios 0.0006 % to 0.005 %. The initial Young's modulus, E_0, Shear modulus, G_0, and Poisson's ratio, ν, were evaluated by the average of the results of first 3 steps loading as follows, 57700 MPa, 24800 MPa, and 0.163, respectively.

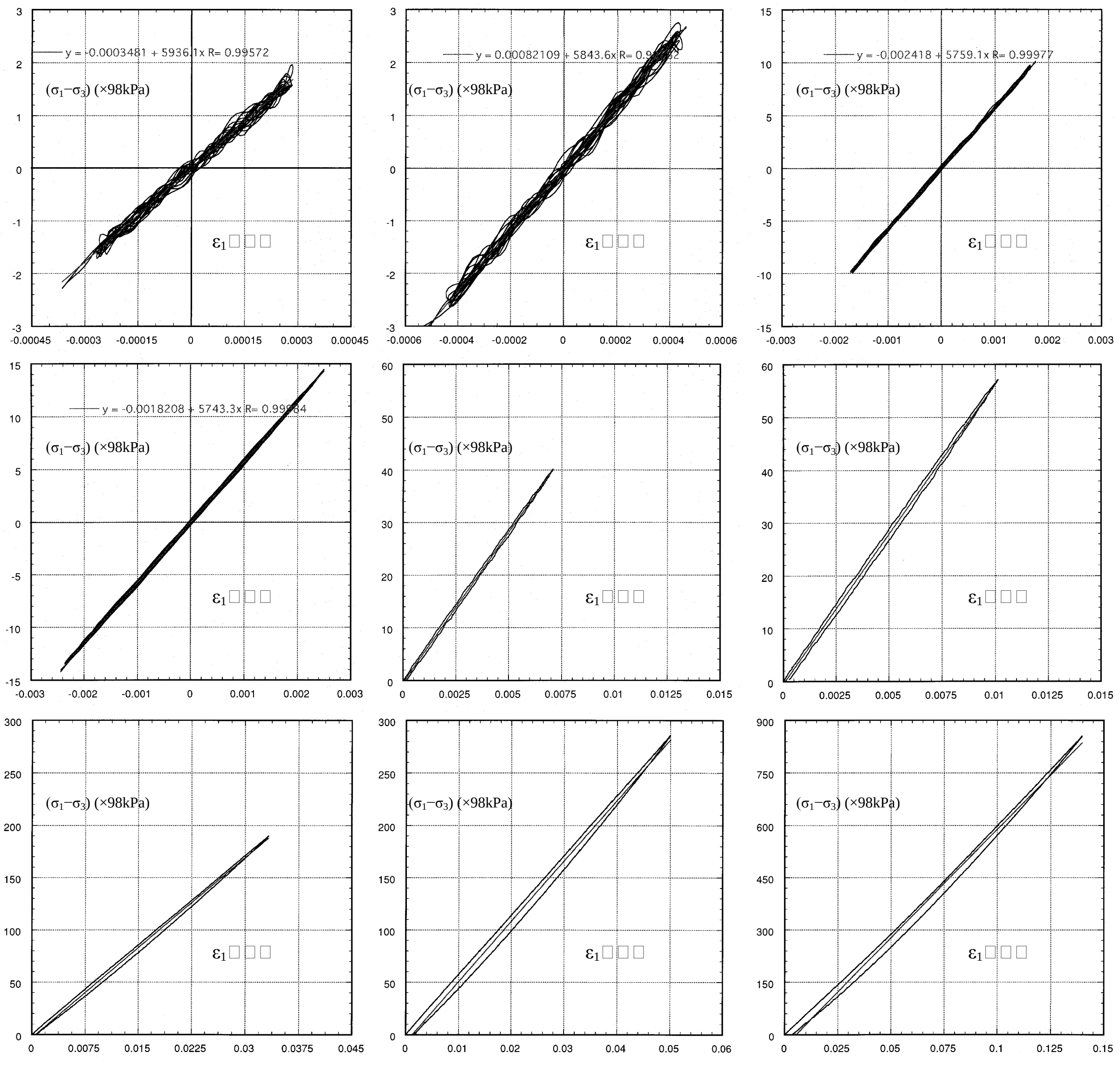


Figure 7. Hysteresis curves of deviator stress and normal strain in cyclic triaxial compression test

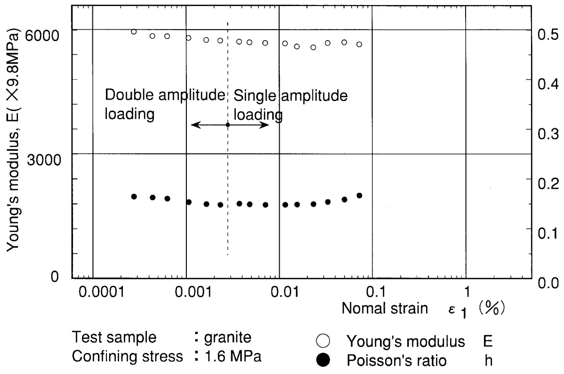


Figure 8. E - ε and ν - ε relationships

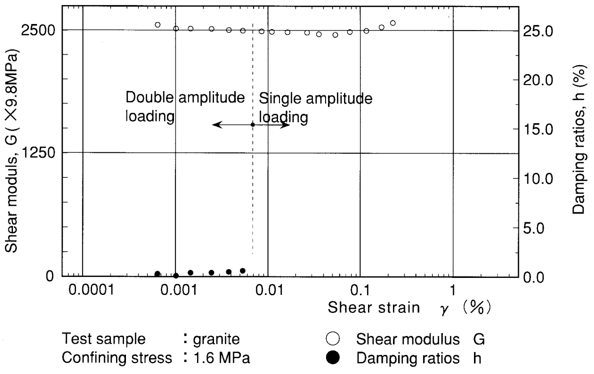


Figure 9. G - γ and h - γ relationships

Shear wave velocities were obtained 3069 m/s and 2915 m/s from the cyclic triaxial compression test and the unconfined compression test, respectively. Both tests showed almost the same results about Vs = 3000 m/s. Table 3 shows test results of both static and dynamic characteristics.

Test case	Confining stress σ_3(MPa)	Young's modulus E_0 (MPa)	Poisson's ratio ν	Shear modulus G_0 (MPa)	Shear wave velocity Vs (m/sec)
CTC*1	1.6	57,700	0.163	24,800	3069
UCT*2	—	57,500	0.284	22,400	2915

Table 3. Test results of the static and dynamic characteristics

＊1 Cyclic triaxial compression test
＊2 Unconfind compression test

5. CONCLUSION

The engineering properties of the foundation rock on the Lyangungang NPP site is obtained by the laboratory tests of the granite rock samples extracted by core boring in the site. The test results are summarized as follows.

Static strength characteristics of the granite obtained by the monotone triaxial compression test and unconfined compression test showed the internal friction angle 63.5 degree and the shear stress 41.8 MPa. The initial Young’s modulus, Eo, was 57500 MPa, the Poisson’s ratio, ν, was 0.284, the initial shear modulus, Go, was 22400 MPa and the shear wave velocity, Vs, 2915 m/s were obtained.

Dynamic characteristics of the granite obtained by the cyclic triaxial compression test showed the decrease rate of the Youmg’s modulus is very slow along with the normal strain increased in the test range to the normal strain ratio 0.1 %. The decrease rate of the shear modulus showed more slow than Young’s modulus and showed clearly a tendency for strain hardening along with increasing shear strain ratio above 0.05 %. The damping ratios from 0 to 1 % were obtained in the shear strain ratios 0.0006 % to 0.005 %. The initial Young’s modulus, Eo, Shear modulus, Go, and Poisson’s ratio, ν, were evaluated by the average of the results of first 3 steps loading as follows, 57700 MPa, 24800 MPa, and 0.163, respectively.

The shear wave velocity obtained from both of the cyclic triaxial compression test and the unconfined compression test showed almost same results of about Vs = 3000 m/s.

The static strength of the LNPP site granite showed very strong in compressive strength and in shear strength compared with the granite extracted from 1600 m deep stratum in Kobe, Japan that showed compressive strength and shear strength 100 MPa and 16 MPa, respectively [2]. On the other hand, the dynamic characteristics of the granite both in LNPP and Kobe showed almost same values in shear modulus,Go,and shear wave velocity,Vs.

Such a hard rock outcrop (Vs =3000 m/s) is a very rare case for NPP sites and provide good opportunity to study earthquake engineering. The earthquake observed at the site will contain source and path effects only and will not be affected by the local soil condition. Future earthquake observations at the site will produce valuable data for the evaluation of seismic design earthquakes on NPP..

ACKNOWLEDGEMENT

The granite samples were produced to the author when I visited the Lianyungang NPP site as a member of IAEA Workshop on Seismic Safety of WWER 1000 NPPs on March 1998 in China. At that time, we also visited the Haiqing-Temple Tower in Haizhou and Tanlufault in the vicinity of Tancheng. It was a very exciting and precious visit. I wish to express my sincerely gratitude for the valuable experience given by the National Nuclear Safety Administration, People’s Republic of China.

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