The late Prof. Toshihisa Adachi, my memory and his contribution in geomechanics - characterization of softening of soft rock -

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ABSTRACT

Professor T.Adachi has passed away on February 10, 2019 in Osaka. The author got acquainted with him when he had enrolled at the Graduate School of University of California in August, 1969. Since then, we had been working together to promote geotechnical engineering at the Kyoto University and Geo Research Institute. He contributed to study soft sedimentary rock based upon the constitutive equation of soil material. He was also specializing tunnel engineering. This paper describes the short summary of the life of Professor T.Adachi and introduces one of the major results of his study of soft tuff rock. One of the key finding is characterization of strain softening of soft rock. The paper describes also the effects of strain softening upon tunnel excavation.

Keywords: Toshihisa Adachi; soft rock, softening,

1 INTRODUCTION

Professor Toshihisa ADACHI was born in Pyongyang, Korea in 1938 and returned to Japan after the end of the Second World War. He describes his young days of student of Iwakuni high school, Yamaguchi Prefecture as follows,

He had to walk a bridge of long arch span to across a river after riding off a bus. He always used to be late at the high school.

Total span of 193.3m with 5 wooden arches was constructed in October 1673 supported by 6 stone masonry foundations with 5m in width. The bridge is very unique structure of wooden beam arch with stone masonry foundation named “Kintai-kyo bridge.”

Figure 1 Kintaikyo Bridge, Iwakuni-city

The bridge had been flown away by a heavy flood in the next year because of high rise of the river flow caused by heavy rain. The reason of the failure was scouring of the foundation. The bridge was reconstructed as the same structure within the next year except the river bed condition surrounding the foundation. To prevent the scouring, the river bed was strengthened by placing large and heavy stones not only near the foundation but also all over the river width as shown in Figure 1.

Since then, the bridge was never collapsed for 276 years before 1950 when a strong typhoon of September 14 by over flooding one of the foundation, which had caused washing away the wooden bridges.

2 STUDENT AND THE WAY TO TUNNELING

To study the basic principles of these mechanical phenomena, he wanted to study mechanical rather than geotechnical engineering when he graduated the high school. However, when he applied Kyoto University, he was only accepted by the department of civil engineering as submitted his second choice.

After graduation of the Department of Civil Engineering of Kyoto University, he entered the Department of Mechanical Engineering at Michigan State University and worked under Professor Shosei SERATA, who established his Laboratory at Berkeley and moved from Michigan to California in 1967. Mr.Adachi moved to the Department of Mechanical Engineering and studied theory of plasticity. Mr.Adachi developed laboratory tests of salt rock to obtain plastic behavior of hollow sample under high cell pressure at the SERATA Geo Mechanics and submitted Ph.D. dissertation to the University of California, Berkeley.

Professor T.Adachi had returned to the Department

of Civil Engineering of Kyoto University in 1970 and started to study soft rock for characterization of geotechnical properties.

Professor Sakuro MURAYAMA, who established Osaka Soil Test Lab in 1961, which has changed it's name as Geo Research Institute in 2001, had designed the undersea tunnel of Kanmon Tunnel between Kyushu and main Islands in 1937 before the Second World War. As Professor of Kyoto University, Dr. Murayama had been developed such various fields in soil mechanics as soil compaction, seepage, electro osmosis, and tunneling, and educated his students to become professors in each fields except tunneling. He had been providing his students tunneling problems at Disaster Prevention Research Institute of Kyoto University but never educate as to become professor.

We, Adachi, and me, had often spent with Prof.MURAYAMA drinking in a small pub-house in Kyoto to break the barrier of the tunneling field. One evening at the pub, Professor MURAYAMA asked us a question "What does mean the word 'constitutive equation '?"

Prof.ADACHI responded as " Prof. MURAYAMA, You better resign Professor of Soil Mechanics at the Kyoto University" and left the pub. At the same night, I called him and told "Adachi-san, you made the mistake that shall result in serious problem between Murayama sensei."

However, amazingly, Professor MURAYAMA invited Adachi as a member of JSCE committee of Earth Pressure for Seikan undersea tunnel.

Figure 2 at Seikan Undersea Tunnel
(Serata, Iwasaski, Murayama, and Adachi)

Dr.Serata has developed Creepmeter to monitor tunnel behavior for salt rock excavation site and was invited to Seikan Tunnel to study creep during tunneling. I measured creep at the tunnel face and sidewall.

In 1975, Unesco invited Professor Sakuro Murayama to have his technical advice on the safety of the Borobudor of cultural heritage for preservation against earthquakes and heavy rain. Professor Murayama appointed us of Adachi and me to visit Indonesia, which was the opening door for me to go the way of geotechnical engineering for cultural heritage in Angkor, Cambodia.

Figure 3 Borobudur (Murayama, Adachi, Iwasaki)

3 SOFTROCK CHARACTERIZATION

Professor Adachi had selected a tuff stone of "Ohya-ishi, " which is produced in north of Tokyo (Figure 4) and has been used as masonry wall surrounding homes in Tokyo area due to easy to cut and shape.

Figure 4 Ohya Ishi stone

A special triaxial device was developed for high cell pressure as well as to measure pore water and volume change during the test.

Table-1 Ohya-Ishi soft rock

Item			unit
Dry Density	γ_d	14.4	(kN/m3)
Saturated Density	γ_s	18.6	(kN/m3)
Water Contents	W/C	29.2	(%)
Void Ratio	e	0.72	
Particle Specific Gravity Gs		2.48	

As shown in Table-1, the Ohya-ishi is quite unique characteristics compared to what is considered as "soft rock." The density is smaller than common soil, however, it is rock, which means shear strength is much higher than soils.

Triaxial test results are shown in Figures 5A, 5B, 6A, and 6B for stress-strain, stress-volumetric, and stress-pore pressure during shear to their failure.

Two types of stress and strain are easily recognizable for CD and CU test series of Figures 5A and 6A.

In every figure, the left hand sides are for only lower confining pressure and show the strain softening behavior, which are quite different from those of high confining pressures of black lines in right hand sides. The boundary of the hardening and softening is around 2-3MPa.

Figure 5B shows volumetric expansions are recognized for the lower confining pressure compared to compression for the larger confining pressures.

Figure 6B shows water pressure change under undrained shear process. The pore pressure generated for the lower confining pressure in the final stage is negative pressure, which gives additional effective confining stress to the sample, and increased strength compared to CD condition.

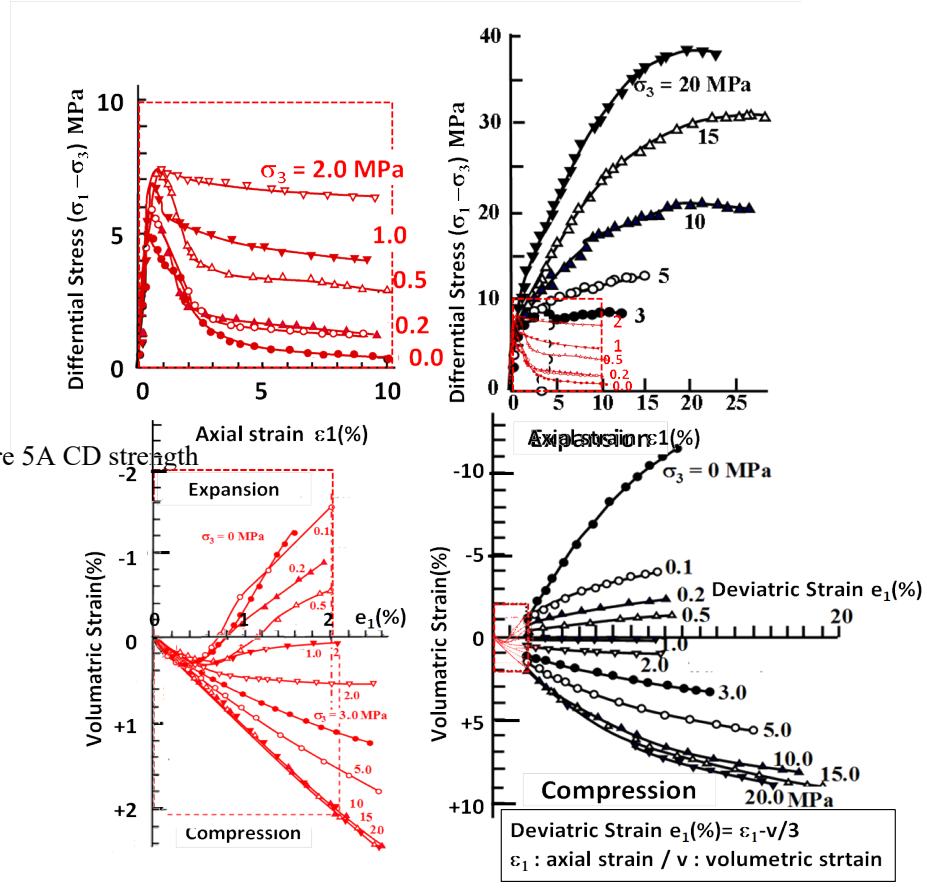


Figure 5A CD strength

Figure 5B CD Volume

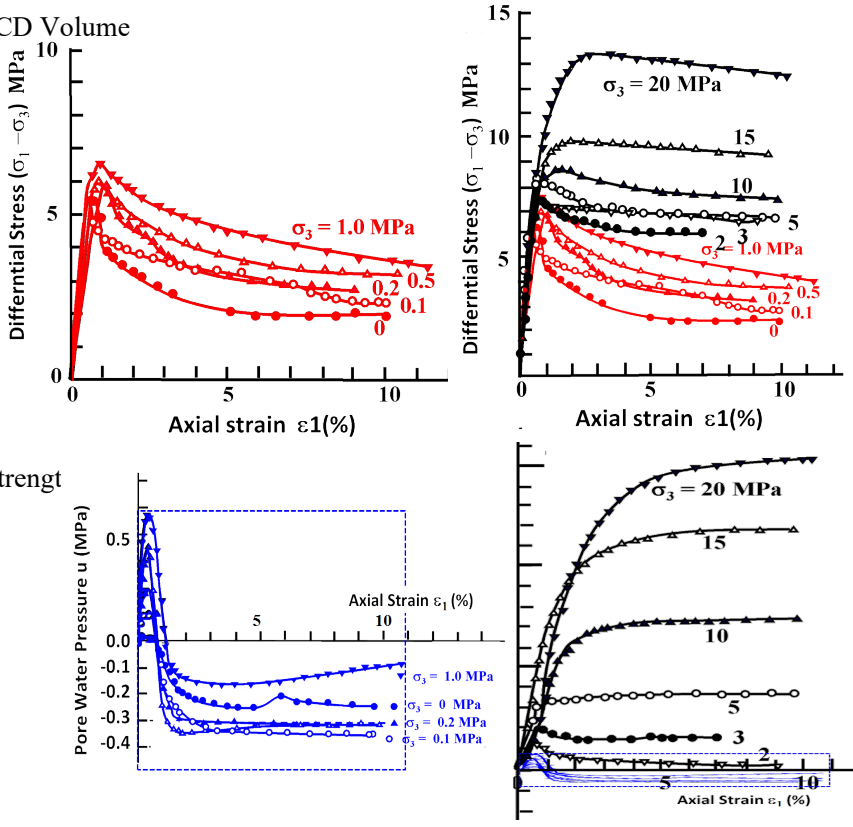


Figure 6A Strengt

Figure6-B Volume

4 SOFTENING OF SOFTROCK

One of the character defining factors of the soft rock that was developed by Professor ADACHI is softening. The softening is the phenomena of decrease of the shear resistance after reaching the peak resistance of the maximum strength as shown in Figure 7. The final resistance is called as the residual strength.

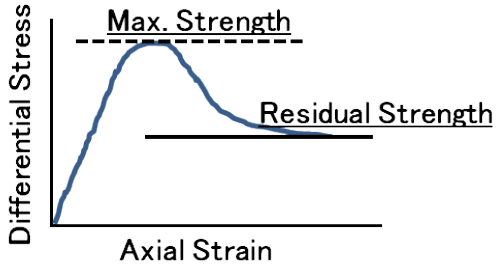


Figure 7 Softening of Stress Strain relationships

Figure 8 shows stress paths for consolidated drained (in blue) and undrained (in red) tests for lower confining pressures for right hand sides. After reaching the peak strength, the resistances come down to the residual resistance and the final plots of the mean effective stress σ'_m and the differential stress $(\sigma_1-\sigma_3)$ falls upon the unique line of the Residual Strength as in Figure 8.

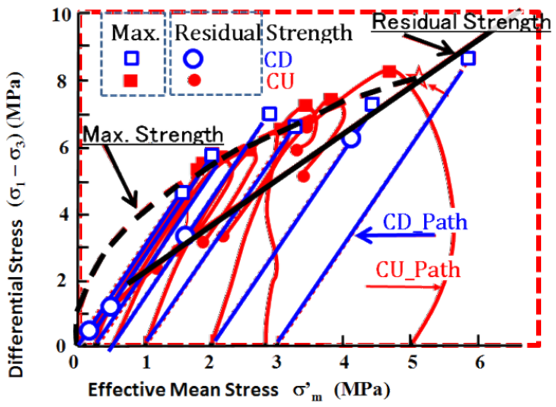


Figure 8 Stress Path

When the test results for the higher confining stress are included, the relationship is shown in the right hand side of Figure 8. The line of the residual strength is rather curved.

If the relationship between strength and mean stress is drawn in the log-log scale, the relationship becomes much simpler as shown in Figure 9.

The peak strength vs the mean stress and the residual strength vs the mean stress are shown linear relationship with different gradients..

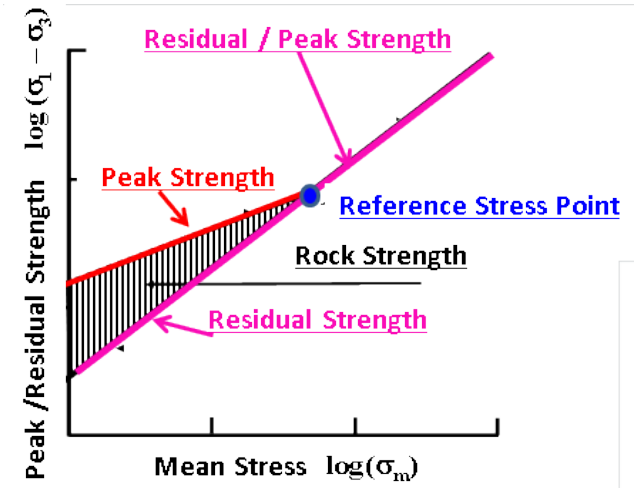
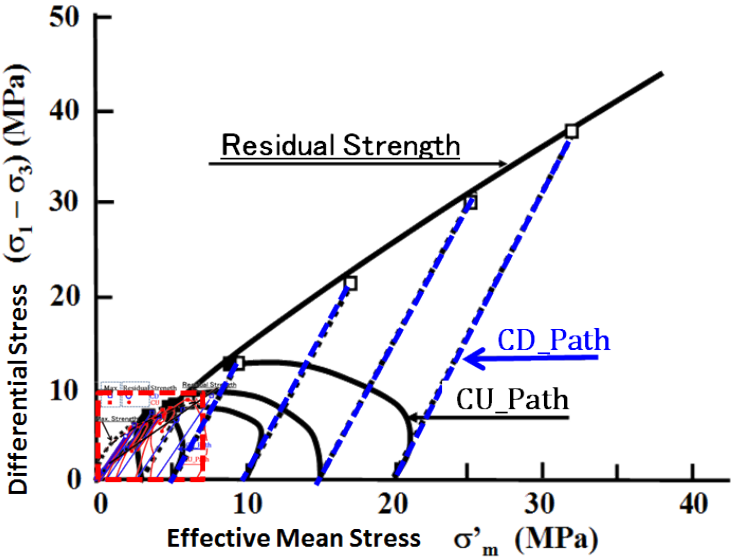


Figure 9 Peak/Residual Strength

4 FAILURE OF SOFTROCK

In soft rock, two types of the strength of peak and residual are recognized. These strengths and effective stress are more or less linear relashionship in log-log scale as shown in Fig.9. The ratio of the resdual strength to the mean effective stress is genenrally considered as to internal friction and not constant as expected for common soils. The peak strength is generally higher than the residual one but the difference decreases and become equal at the reference stress point.



Since the nonlinear relashionship between the strength and mean stress,the Mohr-Coulomb criteria is not applicable for soft rock.

However, the Mohr Coulomb may be applicable if the range of the stress level is limited with appropriate values of c and ϕ to be adapted.

3 DEFORMATION PARAMETER

Deformation parameter that is reprenseted by Young's modlud were obtained by series of triaxial tests for

Ohya-Ishi soft stone.

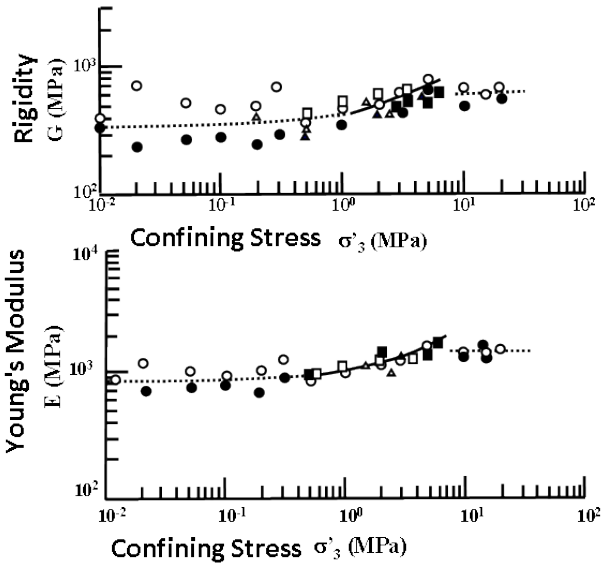


Figure 10 Shear Moduli vs Confining Stress

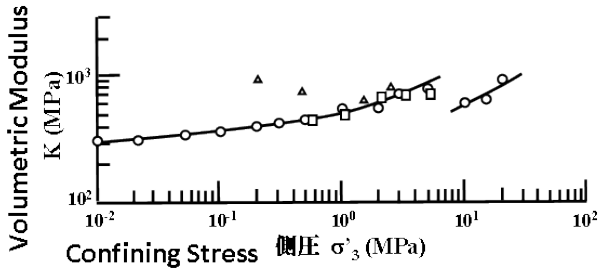


Figure 11 Volumetric Moduli vs Confining Stress

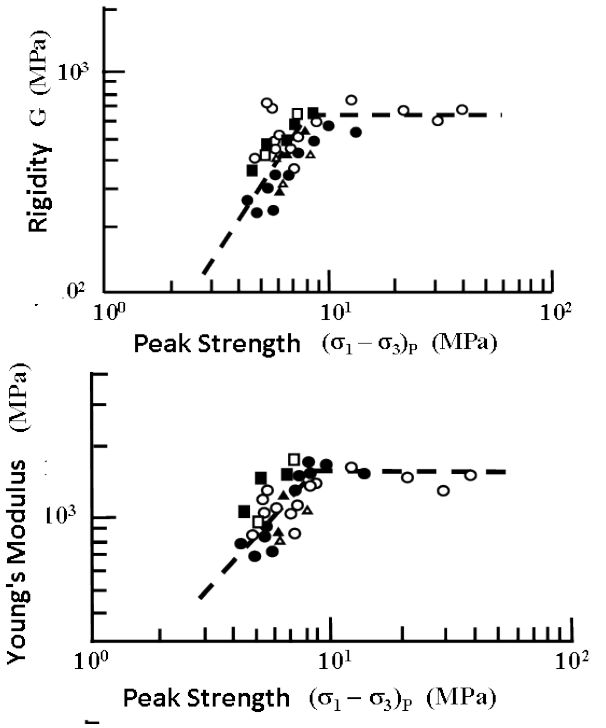


Figure 12 Shear Moduli vs Peak Strength

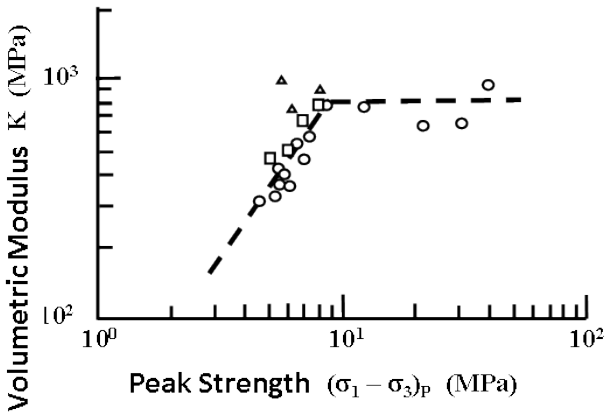


Figure 13 Volumetric Moduli vs Peak Stregnth

The modulus of deformation as shown in Figures 10 and 11 depend upon the confining stres, however, keep rather constant up to the reference stress point, which is 2-5MPa for Ohya-Ishi soft stone.

These modulus are also shown in Figures 13 and 14 as the function of the peak strength. The Young's modulus may be expressed as

Young's modulus $E=200\ (\sigma_1 - \sigma_3)$, peak

Based upon the laboratory tests, Adachi and his group found that the so called soft rock shows basic similar characteristics applicalbe of effective stress concept as to general soil mechanics.

The strain softening is another character that was clarified by Adachi. After the peak strength, the stress decreases to stable level as the residual strength, which is considered as caused by internal friction of the soft rock. Since the in situ soft rock contains shear cracks, the shear strength as a block is considred weaker than the sampled soft rock. The shear strength in the field is considered to be distributed between the peak strength of the sample and the strength that was caused by only friction.

4 THE WORDS HE LOVED AND THE MESSAGE HE LEFT FOR US

Professor T.ADACHI liked to visit construction and sites to find out the real situation and try to understand the problem.

He love to speak the words by Immanuel Kant, a German phylosopher, (1724 -1804),
"Intuitiion without concept is blind, The concept without intuition is Empty."
He always insists that "Civil engineers need to go and look the construction sites and have to cultivate his intuition."

"Let's be a best friend with Soil and Ground" is the spirit of Professor ADACHI.
Most of the engieers say we are fignting agasint soft ground and difficult ground. The late Professor ADACHI

usually refferred “You never fight against the mountains during tunneling, instead, be a good friend with them and ask them whart you need and help them to be stable.”

4 CONCLUSIONS

The author just introduced only one of the basic studys among various aspects of soft rock that Professor ADACHI made research at Kyoto University.

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Professor Toshihisa ADACHI (1938-2019)

Personal History of Professor Toshihisa ADACHI

Life and death
Born on December 5, 1938 in Pyongyang, Korea
Passed away on February 10, 2019 in Osaka, Japan

Education
1958 graduated at Iwakuni High School, Yamaguchi Pref.
1962 graduated at Dep. of Civil Engineering, Kyoto Univ.
1962 entered at Graduate School of Engineering, Kyoto Univ.
1964 transferred to Graduate School of Engineering, Michigan State University, U.S.A.
1967 transferred to Graduate School of Engineering, University of California, Berkeley, U.S.A.
1969 graduated from Graduate School of Engineering, University of California, Berkeley, with Ph.D.
(He worked for Prof.Shosei SERATA, at Michigan State University from 1964 to 1967 and at SERATA GEOMECHANICS from 1967 to 1969. He performed laboratory test on cylindrical sample of salt rock and studied safety of tunnel of salt mining.)

Teaching profession
1970 Associate Professor, Dep. of Eng., Kyoto Univ.
1983 Professor, Dep. of Eng., Kyoto Univ.
2002 Professor Emeritus, Kyoto University

2002 Principal Director, Geo Research Institute, Osaka

Academic Society
1995-1996 Chair, Research Committee of Kobe Earthquake of 1995, Geotechnical Society of Japan,
1998-1999 Branch President, Kansai Brach, Japanese Society of Civil Engineer
2002-2004 President, Geotechnical Society of Japan
2006-2007 President, Japanese Society of Dam Engineering

Academic Prize
1986 Best paper award, Geotechnical Society of Japan
1993 Best paper award, Japanese Society of Civil Engineers
1997 Award for Significant Paper （International Association for Computer Methods and Advances in Geomechanics）“An Elasto-plastic Constitutive Model for Soft Rock with Strain Softening”
1999 Contribution award, Geotechnical Society of Japan
2005 Best paper award, Geotechnical Society of Japan
2006 Contribution award, Japanese Society of Civil Engineers
2009 Special Contribution award, Society of Dam Engineering
2017 Distinguished Contribution award for River Engineering from Japan River Association

2018 The Order of the Sacred Treasure, Gold Rays with Neck Ribbon, The cabinet of Japanese Government

Medical History
In 2001, the author was asked by my friend in Tokyo, who was a member of a technical committee with Professor Adachi as the chair, “The committee just stopped its activity of meeting, what happened to ADACHI ? ”
A few days later, I found him being in bed at the Hospital of Kyoto University.
He told me “A large bowel cancer had been found when I visited at a local hospital and I was told to stay in the hospital for operation. However, I moved to the Hospital of Kyoto University and asked the second diagnosis. The result was they identified not only the large bowel cancer but also a pharyngeal cancer”.
He accepted the cutoff operation of these cancers in the same day. The operation was successful and he successfully continued to survive more than 10 years.
In 2018, he was found to suffer the recurrent cancer of the pharyngeal cancer and hospitalized for a few months. He received the Order of the Sacred Treasure by Japanese Government at the Imperial Palace in the presence of the Emperor.
The celebration party of Receiving the Order of the Sacred Treasure was hold with attendances of more than 500 persons on Saturday, February 2, 2019. On the next Monday, he appeared to his office of Geo Research Institute and told, “I shall return soon after some treatment.” On the early morning of AM 3 O’clock on February, 10, he vomited blood and passed away after one hour.