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COUPLED THERMO - HYDRO - MECHANICAL
EXPERIMENT AT KAMAISHI MINE

TECHNICAL NOTE 02-95-02

INSTRUMENTATION

M. Chijimatsu, T. Fujita, Y. Sugita and H. Ishikawa
Power Reactor and Nuclear Fuel Development Corporation (PNC)

Y. Moro
Hazama Corporation

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釜石原位置試験場における粘土充填・熱負荷試験
テクニカルノート　02-95-02
計測機器

千々松正和*[1]・藤田朝雄*[1]・杉田裕*[1]・茂呂吉司*[2]・石川博久*[1]

要　旨

地層処分における技術開発の観点からは、工学規模での試験によるニアフィールド環境である周辺岩盤の挙動が人工バリアに与える影響の把握および周辺岩盤を含むニアフィールド性能の定量的評価と室内および原位置における大型試験による人工バリアの品質性能の確認を行い、地層処分技術の信頼性向上を図ることが重要となっている。そのため、動力炉・核燃料開発事業団東海事業所の地層処分基盤研究施設等における工学規模の試験と並行して、原位置試験場において、人工バリアの品質性能の確認およびその実岩盤条件下でのニアフィールド連成挙動を評価することが必要となっている。

そこで、実条件でのニアフィールド環境を把握するため釜石原位置試験場において粘土充填・熱負荷試験を実施している。

本論では、粘土充填・熱負荷試験を実施するに先駆けて岩盤内に設置された計測機器の仕様について示す。岩盤内の温度変化を測定するために熱電対が、水圧の変化を測定するために間隙水圧計が試錐孔内に設置された。また、岩盤変位を測定するために孔径ひずみ計、ボアホールひずみ径および亀裂変位計が試錐孔内に、πゲージ、軸変位計が坑道表面に設置された。また、本論においては、これら各計測機器の設置位置及びその座標も示す。

*[1] 東海事業所　環境技術開発部　地層処分開発室
*[2] ハザマ　技術研究所

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ABSTRACT

It is an important part of the near field performance assessment of nuclear waste disposal to evaluate coupled thermo-hydro-mechanical (T-H-M) phenomena, e.g., thermal effects on groundwater flow through rock matrix and water seepage into the buffer material, and generation of the swelling pressure of the buffer material, and thermal stresses potentially affecting porosity and fracture aperture of the rock. An in-situ T-H-M experiment, which is named 'Engineered Barrier Experiment', has been conducted at the Kamaishi Mine, of which host rock is granodiorite, in order to establish conceptual models of coupled T-H-M processes and to build confidence to the mathematical models and computer codes.

This note describes the specifications of sensor installed in the rock mass for T-H-M experiment. Thermocouples were installed in the boreholes to measure the change of temperature and Pore pressure transducers were installed in the boreholes to measure the change of pore pressure. To measure the displacement of rock, Strain gauges, Borehole strain meters and Joint deformeters were installed in the boreholes and Surface displacement transducers (Pi gauge) and Joint transducers (Axial strain gauge) were installed on the surface of rock. And this note shows the location and coordinates of all sensors.

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1. LAYOUT OF SENSORS INSTALLED IN ROCK MASS

In order to measure the changes of temperature, pore pressure and stress in the rock mass, various sensors are installed. These sensors are installed according to Figure 1. These sensors are connected to the data logger system, so it is possible to acquire the data automatically.

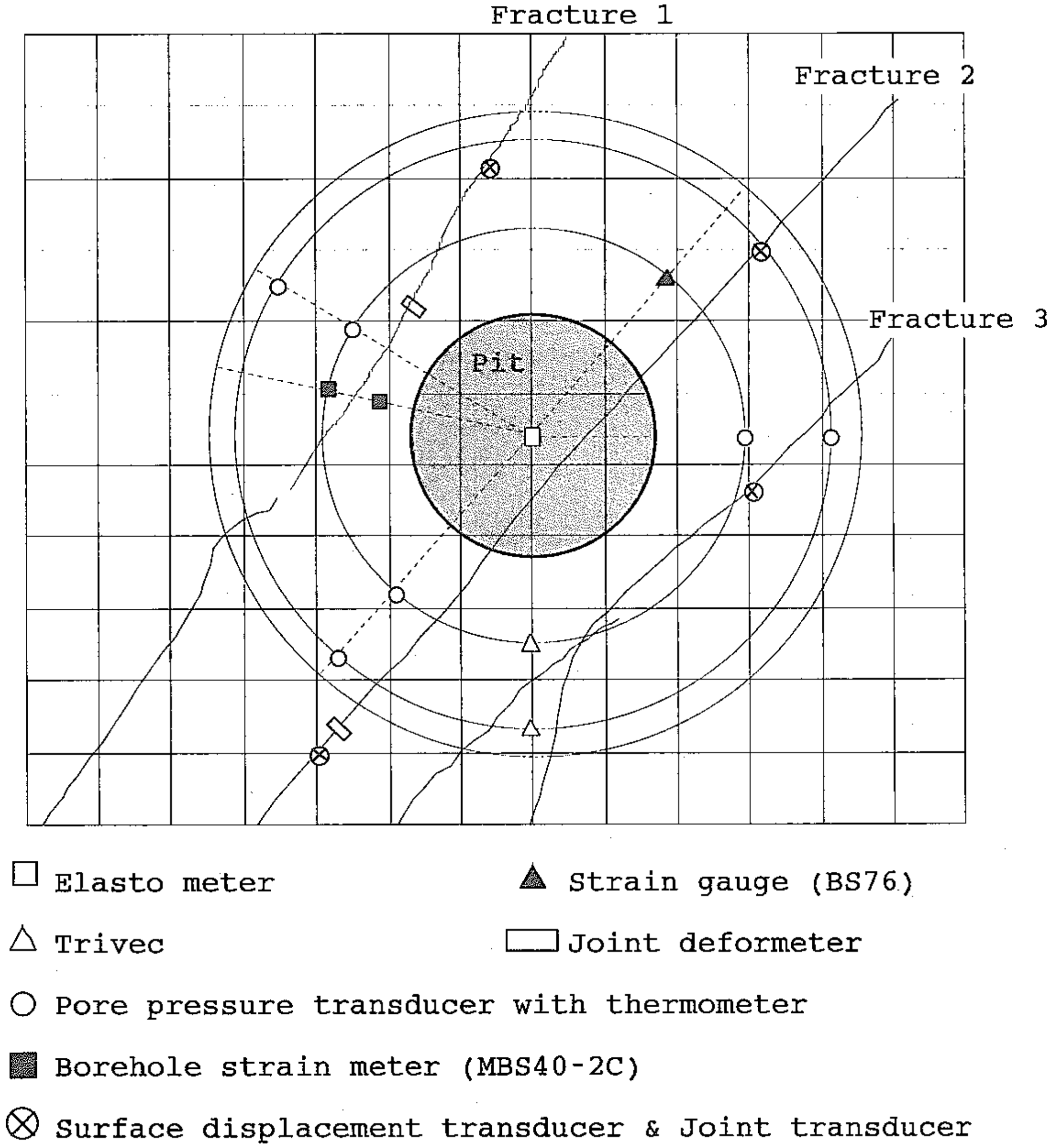

Figure 1 Layout of sensors installed in rock mass

2 SPECIFICATIONS

2.1 PORE PRESSURE TRANSDUCER WITH THERMOMETER (BP-2KBT)

Usually these pore pressure transducers are used for measuring infiltration pressure and uplift pressure in a dam body, etc. They have a flat filter at their head and are embedded in concrete or installed at the bottom of a borehole. This sensor can measure the pore pressures and the temperatures at the same time.

This time, they are fixed at the surface of stainless rod with rubber packers and are installed in the borehole, so it is possible to measure the pore pressure and the temperature of water between packers in the borehole.

In Table 1, specifications of pore pressure transducer are shown.

Table 1. Specifications of pore pressure transducer

Maker	Kyowa (Japan)
Capacity	0 to 0.196 MPa
Accuracy	98×10^{-5} MPa
Rated output voltage	0.75 mV/V or more
Non-linearity	2 %RO
Recommended excitation	2 to 10 V
Input/Output resistance	350 Ω
Safe temperature range	-30 to +80°C
Resistance to water pressure	150 %
Outside diameter	30 mm
Weight	0.320 kg
Amount	29

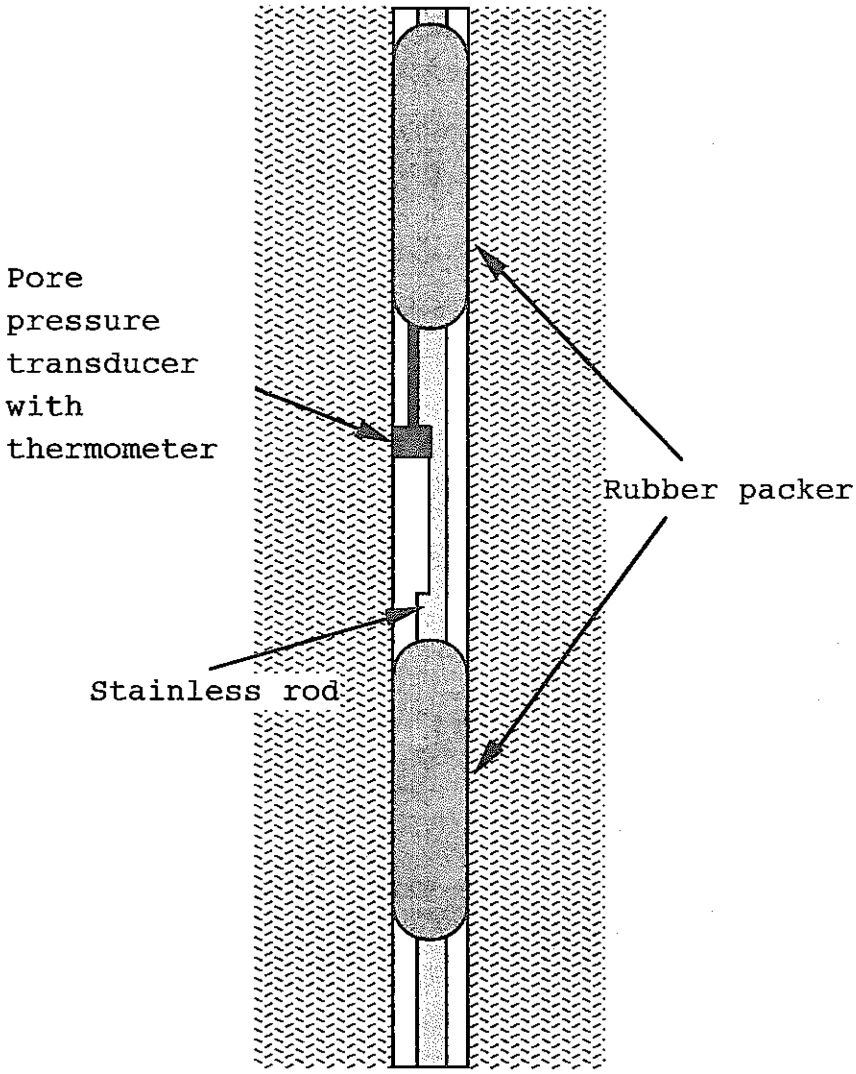

Figure 2 Installation of pore pressure transducer with packer system

2.2 JOINT DEFORMETER (JH-600)

This Joint deformeter consists of three LVDTs (Linear Variable Displacement Transducer) and two bodies which make it possible to adjust the wall surface of the borehole with the expanded contact pins (Figure 3). Three LVDTs are set to measure three orthogonal directions, and these Joint deformeters are installed at the point where the borehole cut the fracture, so it is possible to measure three orthogonal directions of the displacement between two region of the rock mass divided by the fracture.

In Table 2, specifications of Joint deformeter are shown.

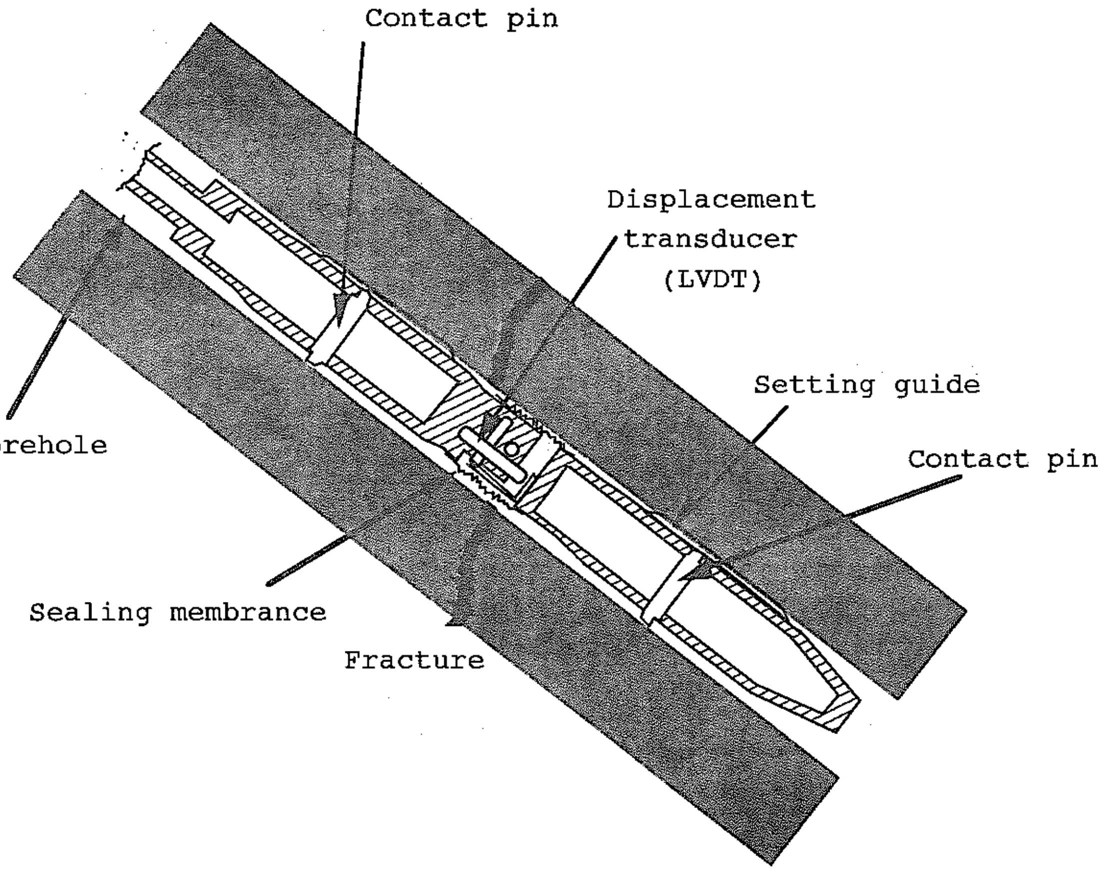

Figure 3 Installation of Joint deformeter in the borehole

Table 2 Specifications of Joint deformeter

Maker		MEC (Japan)
Measuring range		$\pm 2.5 \times 10^{-3}$ m
Accuracy		5×10^{-6} m
Direction		x-direction y-direction z-direction
Applicable borehole size		0.076 m
Output		±10V (0.25 mm/V) (Amplified)
Size	Outside diameter	56 mm(without contact pin)
	Length	450 mm(without contact pin)
Weight		1.0 kg
Amount		2

2.3 STRAIN GAUGE (BS-75)

This strain gauge can measure the strain of one direction of borehole diameter (Figure 4), so two strain gauges are installed in the almost same depth of the borehole, and it is possible to measure the changes of strain of the orthogonal two directions in the same plane normal to the borehole axis (Figure 5).

In Table 3, specifications of Strain gauge (BS-75) are shown.

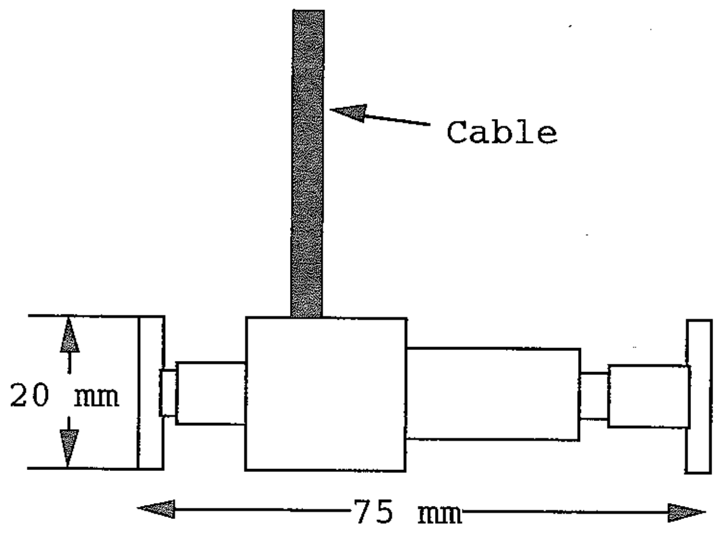

Figure 4 Schematic view of Strain gauge (BS-75)

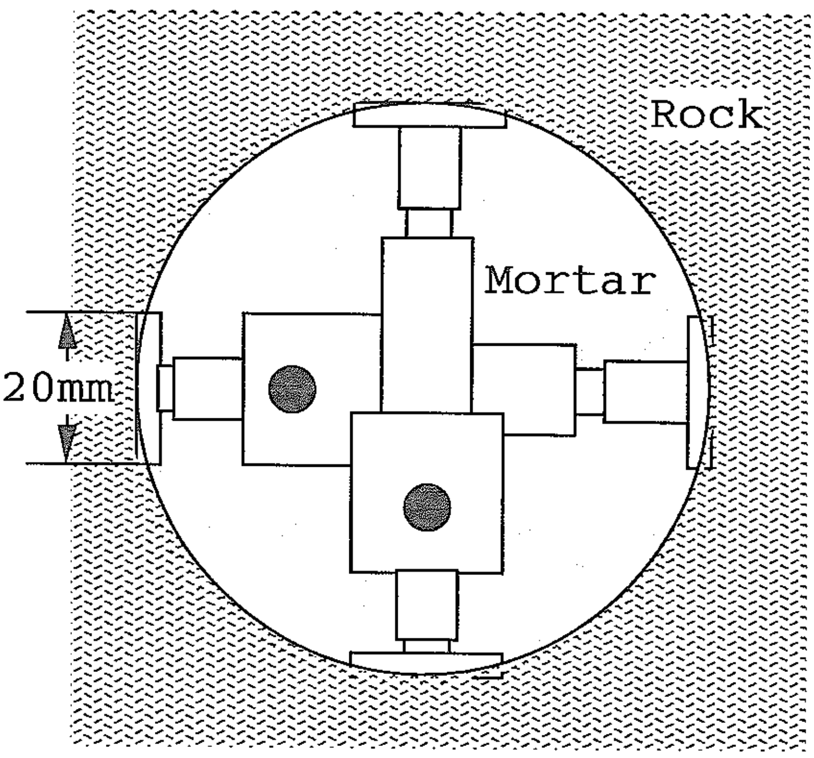

Figure 5 Installation of Strain gauge (BS-75)

Table 3 Specifications of BS-75

Maker	Kyowa (Japan)
Measuring range	$\pm 10^{-3}$
Accuracy	10^{-5}
Rated output voltage	1 mV/V or more
Non-linearity	2 %RO or less
Recommended excitation	10 V
Input/Output resistance	350 Ω
Safe temperature range	-10 to +60 °C
Resistance to water pressure	0.098 MPa
Weight	0.120 kg
Amount	6

2.4 BOREHOLE STRAIN METER (MBS40-2C)

This borehole strain meter consists of two set of the strain meters and the quantities measured directly are the strains of borehole diameter in orthogonal two directions in the same plane normal to the borehole axis.

In Table 4, specifications of Borehole strain meter (MBS 40) are shown.

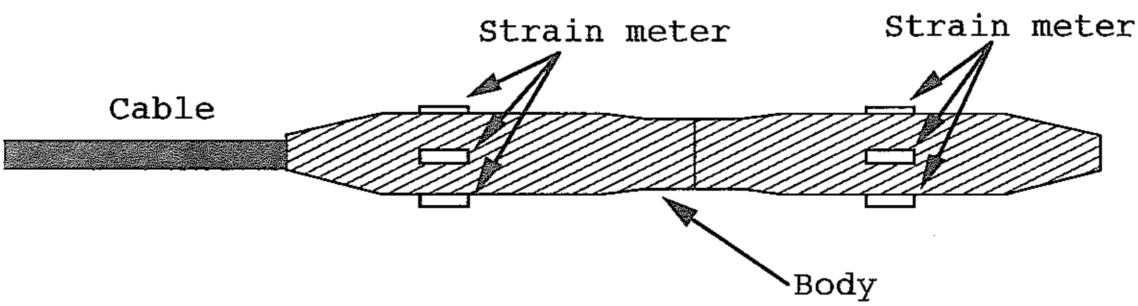

Figure 6 Schematic view of structure of Borehole strain meter (MBS40-2C)

Table 4 Specifications of Borehole strain meter (MBS 40)

Maker		Techno Sugaya (Japan)
Measuring range		10^{-7} to 10^{-3}
Accuracy		10^{-6} (0.0030 V)
Direction		2 directions (an orthogonal axis)
Safe temperature range		-5 to +50 °C
Type		Water proof
Size	Outside diameter	40 mm
	Length	248 mm
Weight		1.5 kg
Amount		2

2.5 TRIVEC

In order to measure the distribution of all three displacement vector components along a borehole, the Trivec probe is applicable. The quantities measured directly are the axial strain and the inclinations s_{xz} and s_{yz} in two vertical planes normal to each other through the borehole axis. The instrument represents a further development of the Sliding Micrometer which is a device to measure the distribution of the axial strain along boreholes of arbitrary direction. Thus the Trivec is basically a Sliding Micrometer provided with an inclinometer sensor (servo accelerometer) which is rotated by means of two micro-motors to stop fittings in the subsequent positions 90 degrees apart from one another. In contrast to the common borehole inclinometer technique with a smooth casing the Trivec casing is provided with a chain of reference points having the form of ring-shaped measuring marks at intervals of 1.00 m (Figure 7).

In Table 5, specifications of Trivec are shown.

Table 5 Specifications of Trivec

Maker		SOL EXPERTS LTD. (Switzerland)
Base length		1.0 m
Micrometer	Measuring range	±0.010 m
	Sensitivity	10^{-6} m
	Accuracy	$\pm 3\times 10^{-6}$ m
Inclinometer	Measuring range	±14.5° to the vertical
	Sensitivity	5×10^{-6} m/m(1″)
	Accuracy	$\pm 5\times 10^{-5}$ m/m(10″)
Working temperature		0 to +40 °C
Amount		2

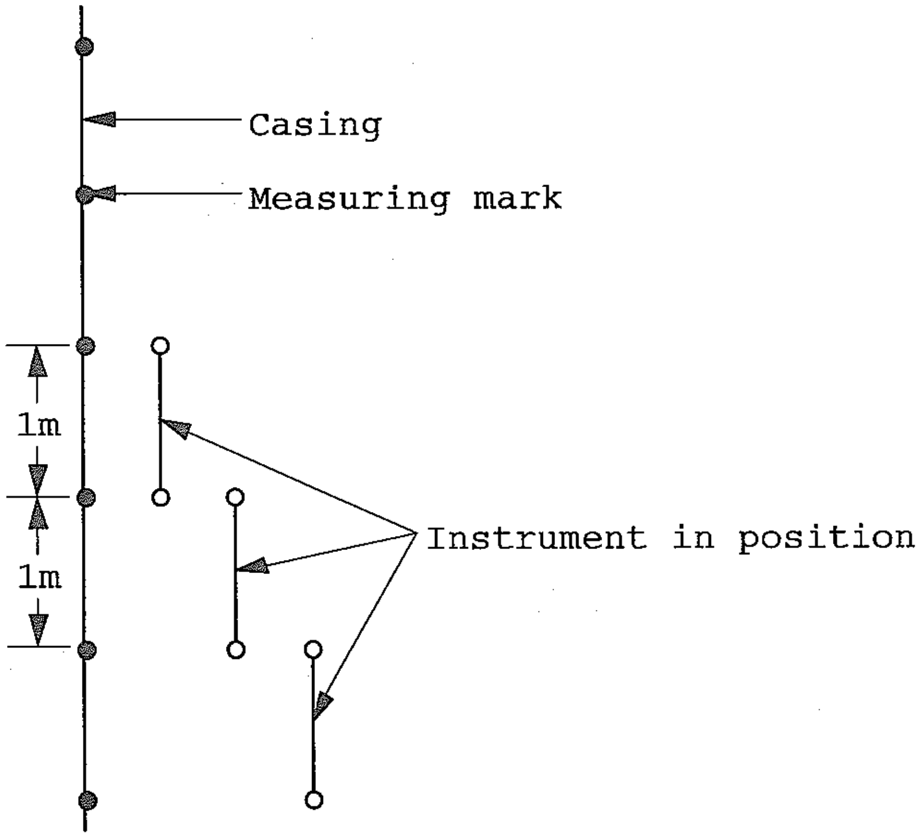

Figure 7 The measuring principle of Trivec using a chain of reference points along a vertical borehole

2.6 ELASTO METER

This system can measure the loading pressure against the wall surface of borehole by packer expansion and the change of the diameter of borehole, so the stress-strain curves is obtained.

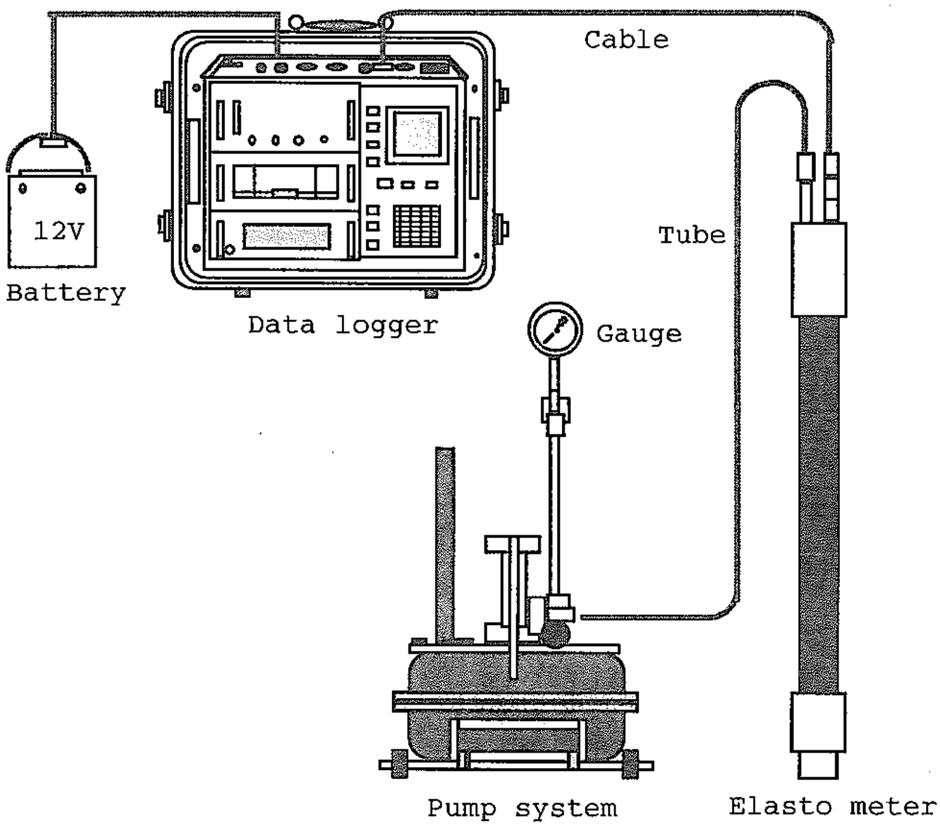

Figure 8 Schematic view of Elasto meter measuring system

Table 6 Specifications of Elasto meter

Maker		DIA Consultant (Japan)
Measuring item		pressure, displacement
Measuring range	Pressure	0.098 to 19.6 MPa
	Displacement	0.0001 m to 0.0999 m
Output		Stress-Strain Curve
Amount		1

2.7 SURFACE DISPLACEMENT TRANSDUCER (PI GAUGE)

This surface displacement transducer can measure the change of aperture of the fracture by strain gauge. Two surface displacement transducer are set, shown in Figure 9, so it is possible to monitor the shear movement along to the surface of rock mass. And this surface displacement transducer is removable and repeatedly usable.

Table 7 Specifications of Surface displacement transducer

Maker	Kyowa (Japan)
Tension strain	2.0%(0.00140 m) max
Compression strain	0.3%(0.00021 m) max
Rated output voltage	±1 mV/V
Non-linearity	2 %RO
Recommended excitation	2 to 10 V
Input/Output resistance	350 Ω
Safe temperature range	-10 to +60°C
Distance between marks	70 mm
Weight	0.450 kg
Amount	8

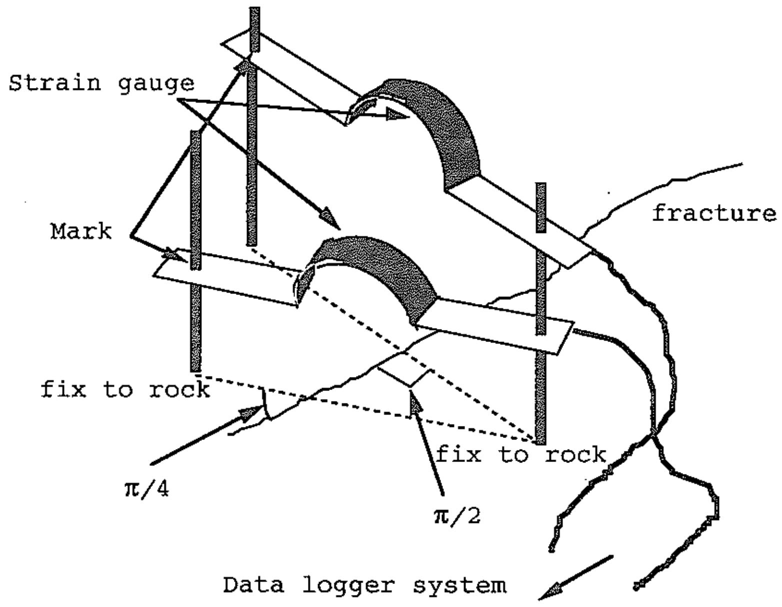

Figure 9 Schematic view of installation of Surface displacement transducer

2.8 JOINT TRANSDUCER (AXIAL STRAIN GAUGE)

This joint transducer can measure displacement normal to the surface of rock mass. This is installed as shown in Figure 10. In Table 8, specifications of Joint transducer are shown.

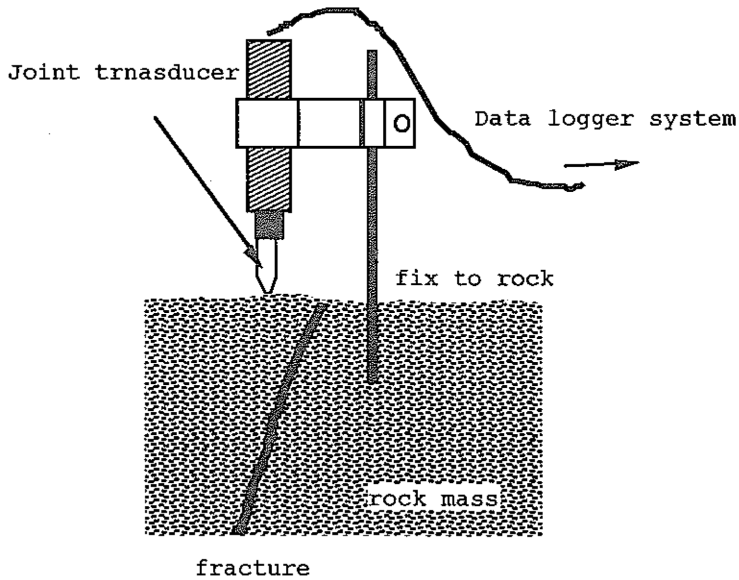

Figure 10 Schematic view of Installation of Joint transducer at the surface of rock mass

Table 8 Specifications of Joint transducer

Maker	Tokyo Sokki (Japan)
Measuring range	0.0100 m
Accuracy	0.1 %
Rated output voltage	0.005 V/V or more
Non-linearity	0.1 %RO
Recommended excitation	2 V or less
Input/Output resistance	350 Ω
Safe temperature range	0 to +60 °C
Length	123 mm
Outside diameter	20 mm
Weight	0.090 kg
Amount	4

2.9 STRESS PROPERTY METER (S200)

This system is developed by Serata Geomechanics, Inc., USA, to measure the principal stresses and properties of in situ rock mass. This system is applicable to both soft and hard rock because maximum loading is high(68.6Mpa). Principal stresses are measured by Double Fracturing Method which is based that the directions of primary fractures produced by loading are in agreement with the direction of principal stresses. The diameter displacements of four directions in the same plane normal to the axis is measurable by eight LVDTs.

In Table 9, specifications of Stress property meter are shown.

Table 9　Specifications of Stress property meter

Maker		Serata Geomechanics, Inc.(USA)
Maximum Pressure		68.6 MPa
Borehole size		76 mm
Length of loading		Oil pressure
Sensitivity	Pressure	9.8×10^{-4} MPa
	Displacement	0.001 mm
Measuring direction		4 directions at angles of 45° in horizontal plane (by LVDT)
Size of Probe	Length	219 mm
	Outside diameter	71 mm
Weight		22 kg
Water proof		< 9.8 MPa
Output		Maximum principal stress Minimum principal stress Unconfined compressive strength Young's modulus
Amount		1

3 COORDINATES OF SENSORS

Figure 11 shows the location of boreholes and sensors. A series of KBH and KBM are the location of boreholes and a series of PI are the location of sensors installed on the rock surface. Boreholes KBH3, KBH4, KBM6 and KBM7 are oblique.

In Table 10, sensor numbers, measurement numbers and coordinates of all sensors installed in the rock are shown.

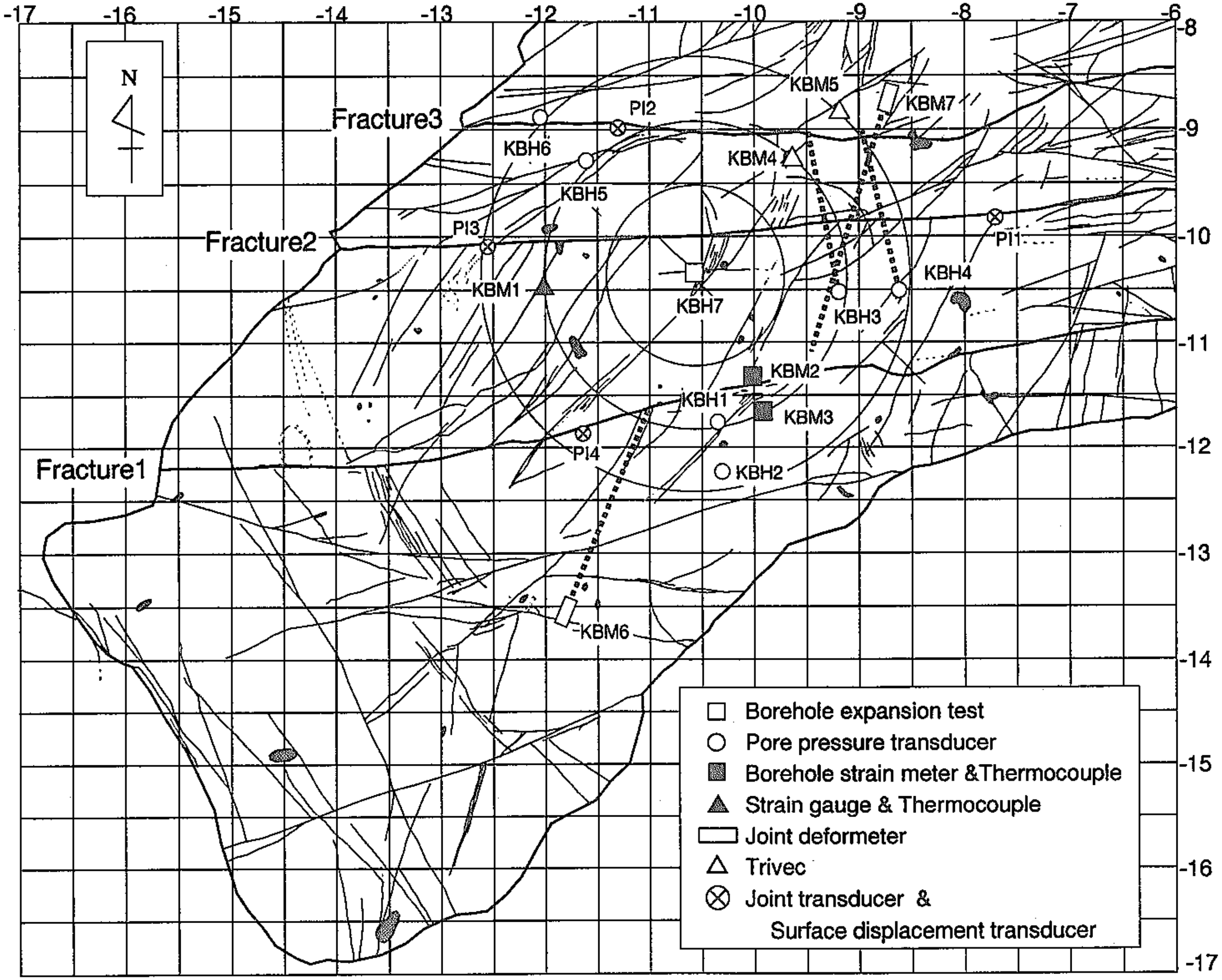

Figure 11 Location of boreholes and sensors

Table 10(1) Sensors installed in rock mass

Sensor	Sensor Number	Measurement	Measurement Number	Coordinate(m) x	y	z	Borehole or place	Section
Pore pressure transducer with thermometer	PT-1	Pore pressure	H-1	-10.338	-11.764	-3.598	KBH1	KBH1-1
	2	Pore pressure	H-2	-10.338	-11.764	-4.948	KBH1	KBH1-2
	3	Pore pressure	H-3	-10.338	-11.764	-6.523	KBH1	KBH1-3
	4	Pore pressure	H-4	-10.338	-11.764	-8.323	KBH1	KBH1-4
	5	Pore pressure	H-5	-10.338	-11.764	-10.023	KBH1	KBH1-5
	6	Pore pressure	H-6	-10.301	-12.237	-3.667	KBH2	KBH2-1
	7	Pore pressure	H-7	-10.301	-12.237	-5.567	KBH2	KBH2-2
	8	Pore pressure	H-8	-10.301	-12.237	-7.517	KBH2	KBH2-3
	9	Pore pressure	H-9	-10.301	-12.237	-9.567	KBH2	KBH2-4
	10	Pore pressure	H-10	-9.226	-10.342	-3.525	KBH3	KBH3-1
	11	Pore pressure	H-11	-9.277	-10.080	-4.899	KBH3	KBH3-2
	12	Pore pressure	H-12	-9.335	-9.785	-6.446	KBH3	KBH3-3
	13	Pore pressure	H-13	-9.397	-9.466	-8.114	KBH3	KBH3-4
	14	Pore pressure	H-14	-9.462	-9.129	-9.881	KBH3	KBH3-5
	15	Pore pressure	H-15	-8.656	-10.314	-3.530	KBH4	KBH4-1
	16	Pore pressure	H-16	-8.723	-10.026	-5.051	KBH4	KBH4-2
	17	Pore pressure	H-17	-8.806	-9.663	-6.965	KBH4	KBH4-3
	18	Pore pressure	H-18	-8.884	-9.328	-8.732	KBH4	KBH4-4
	19	Pore pressure	H-19	-8.944	-9.068	-10.107	KBH4	KBH4-5
	20	Pore pressure	H-20	-11.603	-9.306	-3.633	KBH5	KBH5-1
	21	Pore pressure	H-21	-11.603	-9.306	-5.183	KBH5	KBH5-2
	22	Pore pressure	H-22	-11.603	-9.306	-6.783	KBH5	KBH5-3
	23	Pore pressure	H-23	-11.603	-9.306	-8.333	KBH5	KBH5-4
	24	Pore pressure	H-24	-11.603	-9.306	-9.883	KBH5	KBH5-5
	25	Pore pressure	H-25	-12.035	-8.896	-3.532	KBH6	KBH6-1
	26	Pore pressure	H-26	-12.035	-8.896	-5.282	KBH6	KBH6-2
	27	Pore pressure	H-27	-12.035	-8.896	-7.082	KBH6	KBH6-3
	28	Pore pressure	H-28	-12.035	-8.896	-8.582	KBH6	KBH6-4
	29	Pore pressure	H-29	-12.035	-8.896	-10.032	KBH6	KBH6-5

Table 10(2) Sensors installed in rock mass

Sensor	Sensor Number	Measurement	Measurement Number	Coordinate(m) x	y	z	Borehole or place	Section
Pore pressure transducer with thermometer	PT-1	Temperature	T-1	-10.338	-11.764	-3.598	KBH1	KBH1-1
	2	Temperature	T-2	-10.338	-11.764	-4.948	KBH1	KBH1-2
	3	Temperature	T-3	-10.338	-11.764	-6.523	KBH1	KBH1-3
	4	Temperature	T-4	-10.338	-11.764	-8.323	KBH1	KBH1-4
	5	Temperature	T-5	-10.338	-11.764	-10.023	KBH1	KBH1-5
	6	Temperature	T-6	-10.301	-12.237	-3.667	KBH2	KBH2-1
	7	Temperature	T-7	-10.301	-12.237	-5.567	KBH2	KBH2-2
	8	Temperature	T-8	-10.301	-12.237	-7.517	KBH2	KBH2-3
	9	Temperature	T-9	-10.301	-12.237	-9.567	KBH2	KBH2-4
	10	Temperature	T-10	-9.226	-10.342	-3.525	KBH3	KBH3-1
	11	Temperature	T-11	-9.277	-10.080	-4.899	KBH3	KBH3-2
	12	Temperature	T-12	-9.335	-9.785	-6.446	KBH3	KBH3-3
	13	Temperature	T-13	-9.397	-9.466	-8.114	KBH3	KBH3-4
	14	Temperature	T-14	-9.462	-9.129	-9.881	KBH3	KBH3-5
	15	Temperature	T-15	-8.656	-10.314	-3.530	KBH4	KBH4-1
	16	Temperature	T-16	-8.723	-10.026	-5.051	KBH4	KBH4-2
	17	Temperature	T-17	-8.806	-9.663	-6.965	KBH4	KBH4-3
	18	Temperature	T-18	-8.884	-9.328	-8.732	KBH4	KBH4-4
	19	Temperature	T-19	-8.944	-9.068	-10.107	KBH4	KBH4-5
	20	Temperature	T-20	-11.603	-9.306	-3.633	KBH5	KBH5-1
	21	Temperature	T-21	-11.603	-9.306	-5.183	KBH5	KBH5-2
	22	Temperature	T-22	-11.603	-9.306	-6.783	KBH5	KBH5-3
	23	Temperature	T-23	-11.603	-9.306	-8.333	KBH5	KBH5-4
	24	Temperature	T-24	-11.603	-9.306	-9.883	KBH5	KBH5-5
	25	Temperature	T-25	-12.035	-8.896	-3.532	KBH6	KBH6-1
	26	Temperature	T-26	-12.035	-8.896	-5.282	KBH6	KBH6-2
	27	Temperature	T-27	-12.035	-8.896	-7.082	KBH6	KBH6-3
	28	Temperature	T-28	-12.035	-8.896	-8.582	KBH6	KBH6-4
	29	Temperature	T-29	-12.035	-8.896	-10.032	KBH6	KBH6-5

Table 10(3) Sensors installed in rock mass

Sensor	Sensor Number	Measurement	Measurement Number	Coordinate(m) x	y	z	Borehole or place
Strain gauge	SD-1	Strain(r)	M-1	-12.042	-10.453	-4.408	KBM1
	2	Strain(θ)	M-2	-12.042	-10.453	-4.408	KBM1
	3	Strain(r)	M-3	-12.042	-10.453	-7.408	KBM1
	4	Strain(θ)	M-4	-12.042	-10.453	-7.408	KBM1
	5	Strain(r)	M-5	-12.042	-10.453	-10.408	KBM1
	6	Strain(θ)	M-6	-12.042	-10.453	-10.408	KBM1
Borehole strain meter	SB-1	Strain(r)	M-7	-10.013	-11.342	-5.360	KBM2
	1	Strain(θ)	M-8	-10.013	-11.342	-5.360	KBM2
	SB-2	Strain(r)	M-9	-9.913	-11.672	-5.480	KBM3
	2	Strain(θ)	M-10	-9.913	-11.672	-5.480	KBM3
Thermocouple	TC-1	Temperature	T-30	-12.042	-10.453	-4.408	KBM1
	2	Temperature	T-31	-12.042	-10.453	-7.408	KBM1
	3	Temperature	T-32	-12.042	-10.453	-10.408	KBM1
	4	Temperature	T-33	-10.013	-11.342	-5.360	KBM2
	5	Temperature	T-34	-9.913	-11.672	-5.480	KBM3
Joint deformeter	JM-1	Displacement	M-11	-11.107	-11.871	-6.359	KBM6
	1	Displacement	M-12	-11.107	-11.871	-6.359	KBM6
	1	Displacement	M-13	-11.107	-11.871	-6.359	KBM6
	JM-2	Displacement	M-14	-9.087	-9.902	-4.821	KBM7
	2	Displacement	M-15	-9.087	-9.902	-4.821	KBM7
	2	Displacement	M-16	-9.087	-9.902	-4.821	KBM7
Joint transducer	T-1	Displacement	M-17	-7.699	-9.819	-2.542	PI1
	2	Displacement	M-18	-11.304	-8.995	-2.436	PI2
	3	Displacement	M-19	-12.570	-10.078	-2.196	PI3
	4	Displacement	M-20	-11.635	-11.869	-2.340	PI4
Surface displacement transducer	P-1	Displacement(45)	M-21	-7.699	-9.819	-2.542	PI1
	2	Displacement(90)	M-22	-7.699	-9.819	-2.542	PI1
	3	Displacement(45)	M-23	-11.304	-8.995	-2.436	PI2
	4	Displacement(90)	M-24	-11.304	-8.995	-2.436	PI2
	5	Displacement(45)	M-25	-12.570	-10.078	-2.196	PI3
	6	Displacement(90)	M-26	-12.570	-10.078	-2.196	PI3
	7	Displacement(45)	M-27	-11.635	-11.869	-2.340	PI4
	8	Displacement(90)	M-28	-11.635	-11.869	-2.340	PI4