EXPERIMENTS ONTO RENEWAL OF STRONG MOTION OBSERVATION INSTRUMENTS

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SUMMARY

In this study for renewal of strong motion seismometry, an algorithm to evaluate the recording performance of a seismograph is first introduced. Based upon this algorithm the typical conventional strong motion seismograph in Japan, SMAC type accelerograph, was examined and found insufficient at several points. For improving such insufficiency and further for approaching the ideal strong motion seismograph, the authors propose two different graded strong motion seismographs, the popular and the advanced types, capable of covering wide amplitude-and-frequency range.

INTRODUCTION

The SMAC type accelerograph was developed in 1953 in Japan for aiming at obtaining basic data for response analysis of structures during large earthquakes. Table 1 lists briefly specifications of several accelerographs in SMAC group. The total number of SMAC is, today, beyond 1000 throughout the country and therefore it has been recognized as the standard strong motion seismograph in Japan in the last 30 years. However, it is not doubtless whether the SMAC is well responsible even now as a seismograph in earthquake engineering and related fields, because much information about ground motions in wider period range has been demanded for aseismic consideration of recent very large buildings both in hight and width and for current strong motion seismology. It is true that digital type accelerographs have been developed (Ref. 1, 2, 3),

Table 1 Specifications of SMAC type seismographs

	SMAC-B(BII)	SMAC-E(EII)	SMAC-M
Sensor			
type	mechanical	mechanical	force balance
natural freq	10 Hz	20 Hz	400 Hz
Recorder			
medium	stylus paper	scrachy film	analog cassette tape
recording range	40 db 10-1000(5-500) gal	40 db 10-1000(5-500) gal	46 db, 5-1000 gal
recording speed	10 mm/sec	2.5 mm/sec	4.75 cm/sec
recording duration	3 min	1.5 min	3 min
Total number (1977)	650	250	50

Note: The performance of SMAC-B and -E, and SMAC-M are almost equivalent to those of SMA-1 and SMA-2 respectively, except for a few differences that SMA types have additional devices for a Master/Slave operation and for absolute time recording.

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however no definite examination about their observation capability is considered in view of answering to such higher demands.

For improvement the authors began a study from the recognition that fundamental surveys of disclosing inadequacy of the conventional accelerographs and of exploring ideal specifications to be installed in a forth-coming seismograph should precede. Along this way of thinking the authors first describe a systematic algorithm to evaluate the performance of a strong motion seismograph, and then explore better specifications and finally propose new strong motion seismographs.

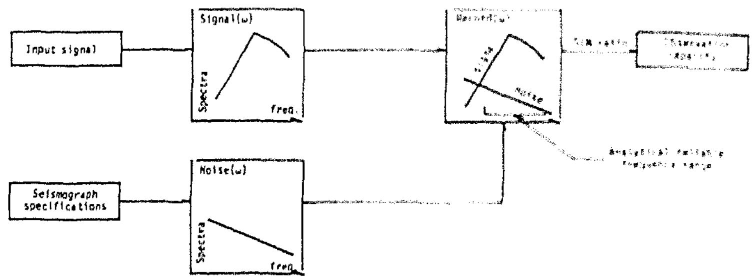


Fig. 1 Conceptual explanation of seismograph observation capacity.

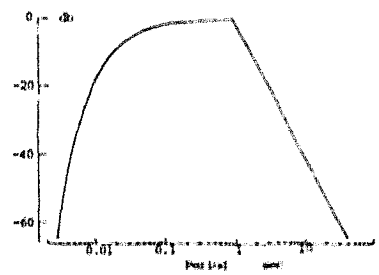
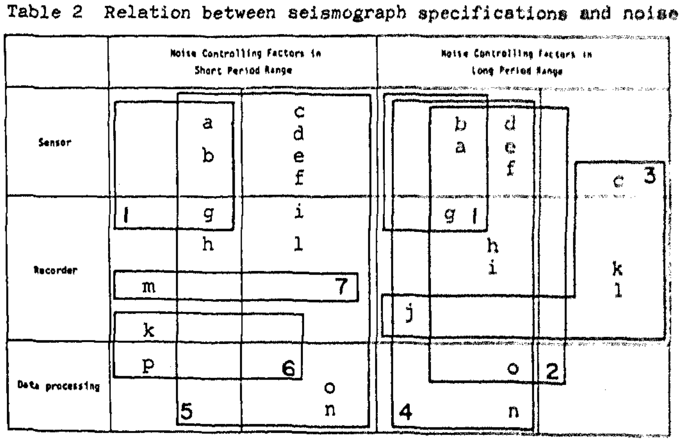


Fig. 2 Spectrum of idealized input acceleration used to calculate the seismograph observation capacity. Hence, ω-square model of which corner frequency is 1 cps is adopted as source spectrum. The effect of the attenuation due to wave propagation upon input signal is also considered as $\exp(r\omega/2Q\beta)$, where $r/Q\beta$ is simply fixed as 1/150.

Table 2 Relation between seismograph specifications and noise controlling factors



Sensor specifications
- a. full scale range
- b. linearity
- c. frequency response
- d. resolution errors
- e. operating temperature
- f. cross-axis sensitivity

Recorder specifications
- g. peak recording amplitude
- h. digital resolution
- i. binary gain amplifier
- j. low cut filter characteristics
- k. sampling rate
- l. alias filter characteristics
- m. timing accuracy

Data processing
- n. seismograph characteristics correction
- o. manual A/D conversion errors
- p. interpolation of time historical data

1.Peak recording amplitude, 2.Recording resolution, 3.Aliasing,
4.Low cut filter characteristics, 5.Sensor characteristics,
6.Sampling effect, 7.Timing inaccuracy

ALGORITHM FOR EVALUATING THE PERFORMANCE OF A SEISMOGRAPH

For evaluating quantitatively the performance of a seismograph the authors pay attention to the frequency (or period) range in which the recorded amplitude by a seismograph is above a certain threshold. This range is termed as observation capacity of a seismograph, and is derived as follows (see Figure 1). In frequency domain the record by a seismograph is generally given as

$$\text{Record}(\omega) = \text{Signal}(\omega) + \text{Noise}(\omega),$$

where Signal is the strong motion to be accurately recorded, and Noise, caused by the inadequate specifications of an instrument, is counterfeit information by which the Record is distorted. It is proper that the records make securer in analytical reliability in accordance with the higher signal to noise ratio. The authors give a definition of observation capacity of a seismograph as the frequency range in which the signal to noise ratio of spectral amplitudes is above 20 db. At a calculation of the observation capacity, simplified seismic motions, illustrated in Figure 2, are adopted as input signal. In this case any seismograph under consideration is examined as an accelerometer.

On the other hand, property of noise, such as amplitude level and frequency characteristics, is uniquely determined accompanied by the equipment specifications. Factors controlling noise are investigated by the following seven items of (1)peak recording amplitude, (2)recording resolution, (3)aliasing, (4)low cut filter characteristics, (5)sensor characteristics, (6)sampling effect, and (7)timing inaccuracy. Table 2 summerizes the relation between these items and seismograph specifications in case of using an accelerometer as sensor.

INSUFFICIENCY OF CONVENTIONAL SEISMOGRAPH AND WAY OF DEVELOPMENT

The observation capacity of SMAC type accelerograph is calculated as shown in Figure 3 based upon the above algorithm. This figure tells us that the insufficient amplitude coverage of SMAC is caused in the period range over 1 sec by the ill-conditioned manual digitization with the rough round-off errors and is also caused in the period range below 0.1 sec by the lowering of the accelerometer sensitivity. Multiplication of new style in structural designing from year to year results in broadening in the natural period range. For example, the natural period of nuclear power station is beneath 0.1 sec and the period of sloshing of liquid in a large-scale storage reaches 10 sec or more. This new situation suggests that the strong motion seismogram is preferable to be recorded with the high precision in the period range from 0.01 to 20 sec as data for the profound study in earthquake engineering. It emphasizes the necessity of developing the new instrument with much wider amplitude-and-frequency range than that of conventional seismograph (see solid arrows in Figure 4).

Application of the new seismological knowledge, such as of the seismic source process theory and of the seismic wave attenuation law to

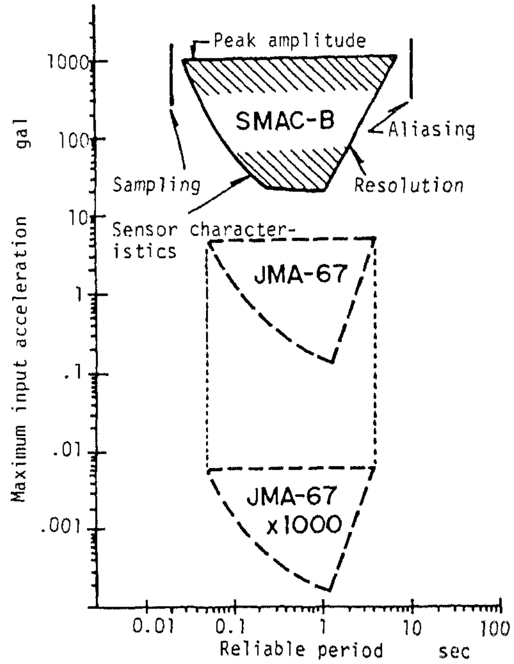


Fig. 3 Observation capacities of SMAC type for engineering use and of JMA-67 type for seismological use. JMA-67 type, operated by JMA as for routine observation of seismic activity, belongs to an analog type electromagnetic seismograph (1Hz natural frequency, 50% critical damping, 0.8 kine full scale).

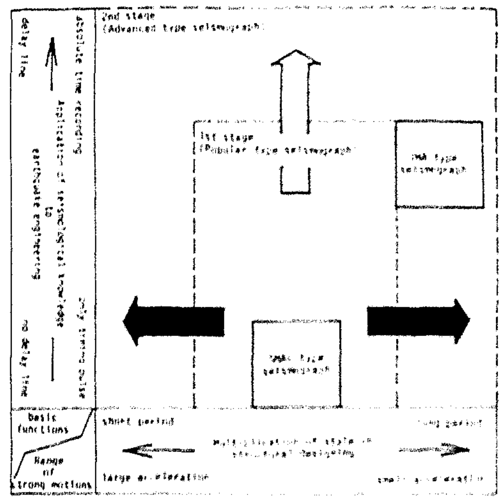


Fig. 4 Required approaches for renewal of SMAC.

Table 3 Main specifications of popular and advanced type seismographs

	Popular type	Advanced type
Sensor	SMAC pendulum	force balance type accelerometer
Recorder		
dynamic range	66 db(12bit)	78 db(14bit) + 36 db(AGA)
sampling rate	120 point/sec	200 point/sec
alias filter	30 Hz high cut 18 db/oct	30 Hz high cut 18 db/oct
event trigger	0.01-10 % F.S.	start/stop logic circuit*
delay time	5-10 sec	40 sec
recording length	1,2,4,8 min	variable
recording medium	digital cassette tape (770BPI)	digital cartridge tape (6400BPI)
crystal clock	10^{-9} accuracy	10^{-9} accuracy
power supply	12 VDC (floating)	100 VAC (floating)

Note: A circuit with a mark(*) opens the gate for the starting (or stopping) signal to the system only when the average input acceleration is holded higher (or lower) than a predetermined reference level among 1, 3, and 6 (or 0.5, 1.5, and 3) gals. Averaging duration is also selectable for 2, 3, and 4 (or 30, 60, and 120) sec.

engineering seismology, requires much more delicate information about seismic ground motions. SMAC type accelerograph is far insufficient for responding those demands because of its lacking of absolute or common time consideration and of delay line by which recordings of infinitesimal initial ground motions is made possible. It emphasizes the necessity for grading functionally up of the SMAC (see open arrow in Figure 4).

For aiming at an achievement of the above demands, the authors developed two different graded strong motion seismographs.

DEVELOPMENT OF NEW DIGITAL RECORDING INSTRUMENTS

Popular type seismograph A popular type seismograph is made in anticipation of a renewal of SMAC type accelerograph by introducing a digital recording system and a high sensitive crystal clock. First it was ascertained that the pendulum of SMAC itself is accurately responsible from 1000 gals even to as small amplitude of several 10 mgals as ambient microtremors. A displacement-voltage transducer, so-called magnetic sensor, is attached to the SMAC pendulum and the electric output is led to the new digital recording instrument. The specifications are listed in Table 3. It seems that these specifications are similar to those of American made digital recorders, such as DSA-1. The block diagram and the exterior of this recorder are shown in Figures 5 and 6 respectively. In Figure 7 there is an example of records obtained by this new seismograph. As is obviously seen in this figure, the popular type seismograph has an appropriate response to the very small acceleration which is far unappreciable to the conventional SMAC type acceleragraph. The observation capacity of this popular type seismograph is shown in Figure 11. It is certain that this seismograph covers the large part of amplitude range necessary in the study of earthquake engineering.

Advanced type seismograph In order to provide available data to the profound studies in seismology as well as in earthquake engineering, it is desired to develop the seismograph of which observation capacity extends so as to cover both of capacities of SMAC type for earthquake engineering use and, for example, of JMA-67 type for seismological use (see Figure 3). The previously proposed popular type is still insufficient to cover such a wide observation capacity. An advanced type seismograph is specially designed in the desire of covering the above capacities. This system is composed of three force balance type accelerometers and a four channel digital recorder of which dynamic range is adjustable from 78 db up to 114 db by Auto Gain Amplifier of 12 db/bit. The main specifications are also listed in Table 3. The block diagram and the exterior of the recorder are shown in Figures 8 and 9 respectively. Figure 10 shows an example of records obtained in a field test of this advanced type seismograph. Supported by the built-in delay line with the sufficient allowance of 40 sec and the 14 bit A/D converter capable of converting even the micro-motions into high quality proportional digital values, the whole aspect of the seismic waves can be completely obtained including the initial and codar parts, of which amplitudes are too small to be recorded by SMAC. The seismograph observation capacities of this and conventional types are compared in

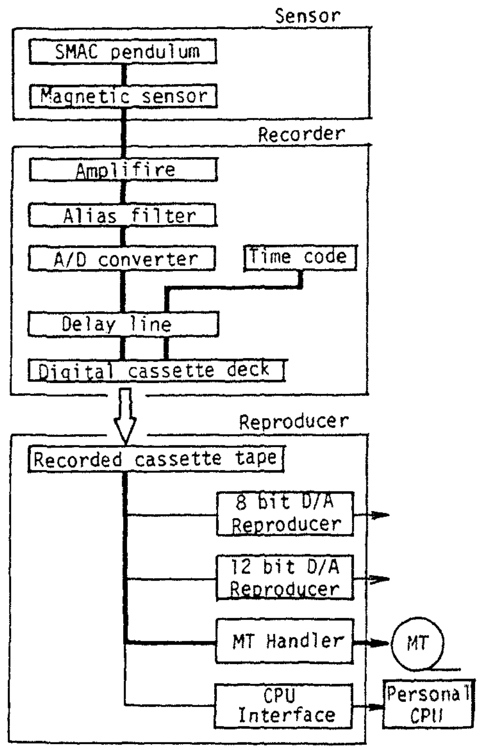


Fig. 5 Block diagram of popular type.

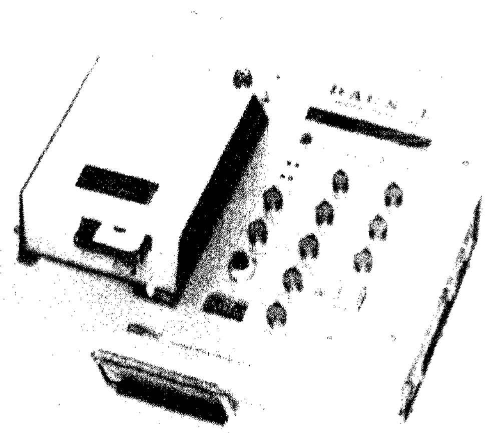


Fig. 6 Recorder of popular type seismograph. Outsize dimensions are 17cm high, 38cm wide, and 37cm long, respectively. Weight is approximately 10kg. This system is protected by water-and-dust proof tight case.

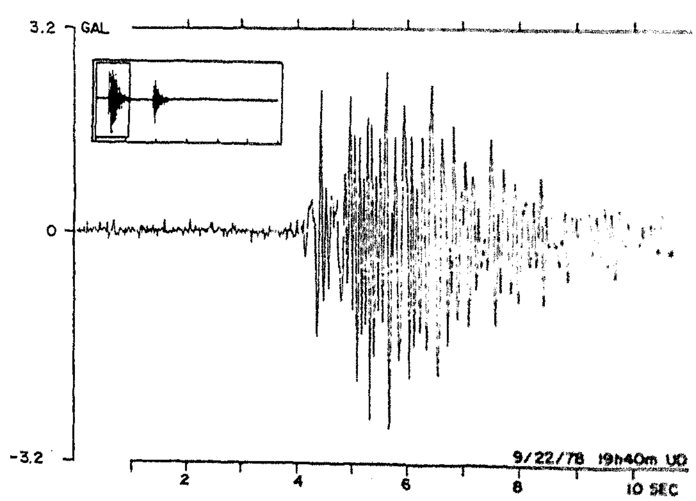


Fig. 7 Example of seismic records obtained by popular type seismograph. Pre-amplifier is set as x10.

Figure 11. It is concluded that the advanced type is almost sufficient to cover the amplitude and frequency ranges which should be treated at least as strong motions to human society.

CONCLUSION

In the first, the recording performance of the conventional strong motion seismograph, SMAC type, was evaluated on the basis of a new algorithm for calculating the seismograph observation capacity. As a result of this analysis, it was clarified that the recording accuracy of this instrument deteriorates in the period range over 1 sec and below 0.1 sec mainly owing to rough round-off errors, and better specifications were explored in account of current demands from earthquake engineering and neighbouring fields. As a logical continuation the authors proposed two different graded acceleration seismographs as a first step to renew strong motion seismometry.

The equipments in this study were designed and manufactured with the powerful assistance from MARKRAND DENSHI KOGYO Co., Ltd., Japan.

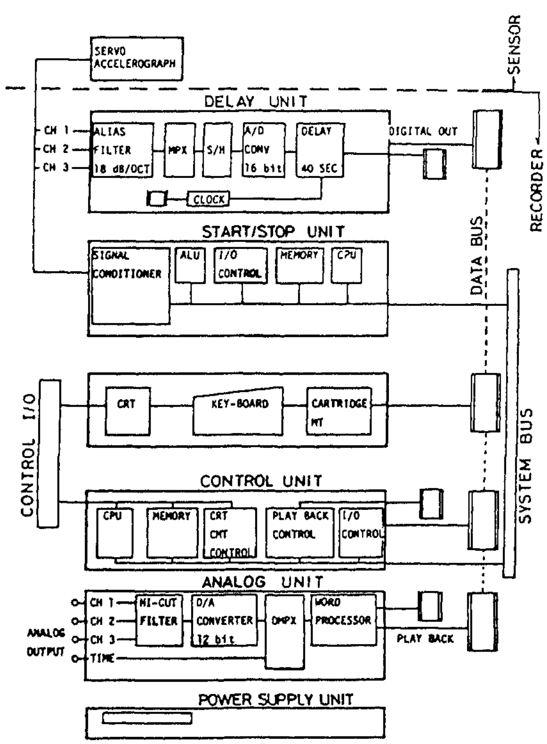


Fig. 8 Block diagram of advanced type.

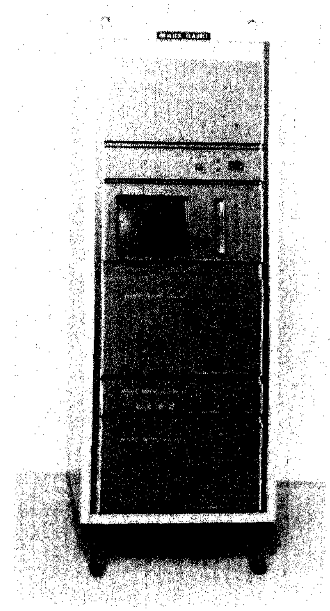


Fig. 9 Recorder of advanced type seismograph. Outsize dimensions are 149cm high, 53.5cm wide, and 60cm long, respectively. Weight is approximately 120 kg. This system is composed of 6 subsystems of delay line, start/stop, operational, control, analog output, and power supply units.

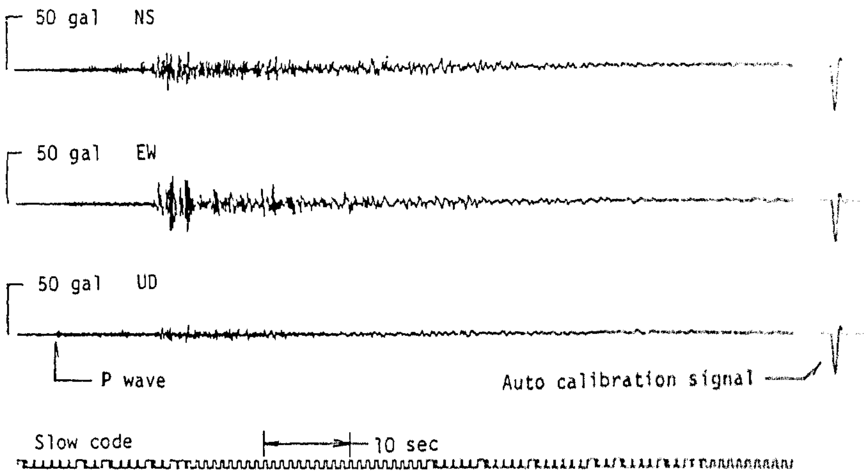


Fig. 10 Seismic records obtained by advanced type seismograph at Tokyo area with an epicentral distance of around 90km (M 5.8).

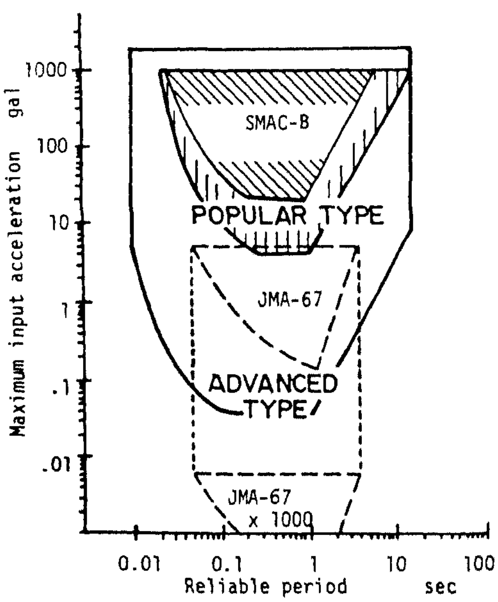


Fig. 11 Comparison of observation capacities of popular, advanced, and conventional type seismographs.

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