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STIEGLER'S GORGE SEISMIC NETWORK

A Proposal for Monitoring Seismic Activity in the Stiegler's Gorge Area, Tanzania

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ABSTRACT

For artificial reservoirs as large as the one proposed for the Stiegler's Gorge area in Tanzania, there are strong general recommendations for installation of seismic networks for monitoring of earthquake activity before, during and after water impounding. An investigation of the conditions for induced activity has furthermore revealed that the Stiegler's Gorge area is one which has a definite potential for such induction. The various requirements on microearthquake monitoring networks are discussed, followed by a detailed proposal for the configuration as well as the instrumentation of an array called the Stiegler's Gorge Seismic Network (SGSN). The proposed array, which has 7 elements distributed over an area of about 50 km in diameter, should be able to detect events down to a magnitude of at least one, with a location accuracy of about 1-2 km. The proposed instrumentation is based on radio telemetry and digital recording, and provides great opportunities for a sophisticated and flexible data analysis. An outline of the requirements on and the purpose of such analysis is also given. The costs of the proposed solution are about N.kr. 533 000, excluding the subsequent data analysis.

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1. INTRODUCTION

It is well known that the building of large dams, with the subsequent accumulation of large water reservoirs, in many cases has induced seismic activity in the immediate vicinity of the dams. In six of these cases (possibly seven) earthquakes of magnitude (m_b) greater than 5 have been induced, accompanied by both foreshock and aftershock activity (Simpson, 1976; Gupta and Rastogi, 1976; Rothé, 1970, 1973; Bozović, 1974; Bufe et al, 1976; Gough and Gough, 1970; Carder, 1945). These cases are:

1.	Koyna, India	$m_b = 6.5$	(1967)
2.	Kremasta, Greece	$m_b = 6.3$	(1966)
3.	Hsinfengkiang, China	$m_b = 6.1$	(1962)
4.	Kariba, Rhodesia	$m_b = 5.8$	(1963)
5.	Hoover, U.S.A.	$m_b = 5.0$	(1939)
6.	Marathon, Greece	$m_b = 5.0$	(1938)

Table 1.1

Two of these earthquakes (Kremasta and Koyna) caused loss of life and severe property damage, and considerable damage of the dam structures themselves were inflicted both for the Koyna and the Hsinfengkiang dams. In none of these cases had the pre-impounding seismicity been studied, so that large difficulties arose in determining the exact nature of the seismicity induction.

All of these now well-known examples of large induced earthquakes had occurred by the end of the sixties, and they resulted in a considerable activity directed towards a mitigation of such earthquake risks. The following four points describe some of this activity:

1. A UNESCO Working Group on "Seismic Phenomena Associated with Large Reservoirs" was appointed, and recommended during its first meeting in 1970 that instrumental studies and surveys at the sites of large reservoirs be planned in the following two phases. Phase 1 should coincide with the feasibility stage of the project and include (1) a study of historical seismicity, (2) a preliminary geological and geomorphological survey, and (3) a preliminary investigation of pre-impounding seismicity. Phase 2 should depend on the results from phase 1; it should commence one to two years before impounding, and include (1) a more detailed geological and neotectonic survey, (2) installation of permanent seismological instrumentation, and (3) possible other work.

At a later stage, the Working Group specifically stressed that the permanent seismological stations be installed well in advance of reservoir impounding, and that these stations should continue to operate for a few years after impounding even when a particular reservoir does not show any seismic effect. Upon the invitation from the Working Group, a report was published which included detailed recommendations for suitably instrumenting the artificial reservoirs (Adams et al, 1973).

2. A UNESCO "Intergovernmental Conference on the Assessment and Mitigation of Earthquake Risk" was held in Paris in February 1976. The adopted Resolution 8.41 reads as follows (UNESCO, 1976):

> "In order to ensure the greatest possible protection of dams and downstream populations from risks associated with induced seismicity, the Conference recommends to Member States in which large reservoirs are planned that detailed seismic surveillance be carried out to obtain good hypocentral control and source parameters of the earthquakes in the reservoir area from two years or more prior to the beginning of construction. Furthermore, it is recommended that measurements of initial stress near the deepest points of the future reservoir be carried out by the available techniques such as hydraulic fracturing and overcoring strain rosettes, as a means of understanding the mechanism of induced seismicity after filling.
>
> For the purpose of this resolution a 'large reservoir' is one which will have a maximum depth exceeding 100 m and a maximum volume exceeding $10^9 m^3$ at operational level."

3. The International Committee on Large Dams (ICOLD) appointed in 1970 a "Committee on Earthquakes", with the purpose of studying the influence of earthquakes on dams, and to review current practice and recommendations in this respect. In their report the Committee states (ICOLD, 1975):

> "Earthquakes of appreciable intensity are experienced even in low seismicity areas. Accordingly, all large dams should be designed with due consideration for earthquake load."

It follows that a prerequisite for this is a sufficiently reliable assessment of the earthquake risk.

4. In a personal communication, geophysicist A.K. Viksne from the U.S. Bureau of Reclamation (responsible for all large dam projects in the United States) states that seismic networks are now generally implemented in the U.S. for dams with height 100 m and/or reservoir volume $10^9 m^3$, and he continues:

> "As a general guideline, the Bureau [of Reclamation] seismic monitoring programs to determine activity of geologic faults are operated for at least two years, and in the case of large reservoirs, seismic monitoring is advisable at least two years prior to construction of the reservoir and then should be continued through the construction phase, and subsequently at least through two cycles of filling of the reservoir. This of course is the minimum time span for a microseismic monitoring program before some degree of confidence can be assigned to the results, and whenever possible, a longer time period of monitoring should be recommended."

The large dam which is presently under consideration for the Stiegler's Gorge area in the Rufiji basin of Tanzania will possibly raise the water level more than 100 m, with a water volume of more than $10^{10} m^3$. Considering these large dimensions, and the strong recommendations quoted above, this all adds considerable weight to the proposal of implementing a Stiegler's Gorge Seismic Network.

The purpose of this report is to propose, in details, such a microearthquake monitoring network for the Stiegler's Gorge area. The investigation includes necessary background information on induced seismicity in general and the seismicity of Tanzania in particular. This is followed by a detailed proposal for the configuration of the network, including a recommendation for type of instruments, data transmission and recording facilities. An evaluation of the network capability in terms of expected detection and location performance is then included, followed by a proposal for the analysis of the recorded seismic data. Finally, a cost estimate for the project is given.

2. DAMS AND SEISMICITY

More than 30 cases of reservoir-induced seismicity are now known, six of which are listed in Table 1.1. An extensive review of these cases is given by Simpson (1976), and other reviews have been published by Carder (1970), Rothé (1970, 1973), Gupta et al (1972a,b, 1973), National Academy of Sciences (1972), Bozović (1974), Lomnitz (1974) and Gupta and Rastogi (1976). In most of the cases when induced seismicity was found, the following characteristics could be extracted (Gupta et al, 1972a):

1. The seismicity increased considerably after water impounding, and epicenters are confined to the vicinity of the reservoir.
2. The seismicity increased or decreased with water level, the largest earthquakes following a rapid rate of loading.

We will now discuss these and some other factors in more detail.

2.1 Seismicity and water impounding

Between the two characterstics mentioned above, this is the one which is most difficult to establish, because the pre-impounding seismicity in most cases has not been sufficiently well known. Typically, seismic instrumentation with sufficient sensitivity and location capability has been installed only after the first induced earthquakes have been felt, a factor which naturally tends to over-emphasize the seismicity increase. Only in more recent years have pre-impounding seismicity surveys become more common.

One of the best and most recent examples of induced seismicity can be taken from the Manic 3 dam in Canada, as reported by Leblanc and Anglin (1976). Some of their results are reproduced in Fig. 2.1, which shows a very close connection between seismicity and rate of change of water level. Based on the rapid seismicity increase during September and October 1975, a written warning was issued on October 20 from the Earth Physics Branch of the Department of Energy, Mines and Resources (responsible for the seismic investigations) to the Hydro Quebec (responsible for the dam). The warning was based on data from only one station (MNQ, see Fig. 2.1),

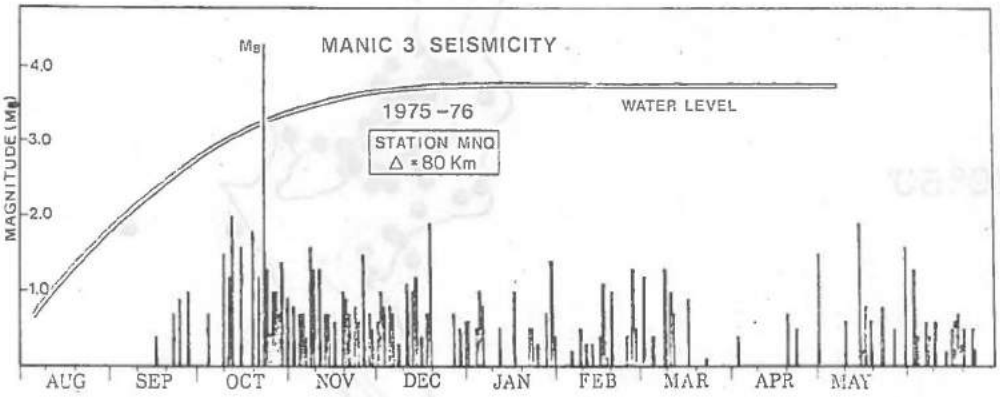

Fig. 2.1 Earthquake activity associated with the initial filling of the Manic 3 reservoir, Canada, as recorded at station MNQ, 80 km from the dam. The main shock ($m_b = 4.3$) occurred on October 23, 1975. The relative water level is also given. (After Leblanc and Anglin, 1976.)

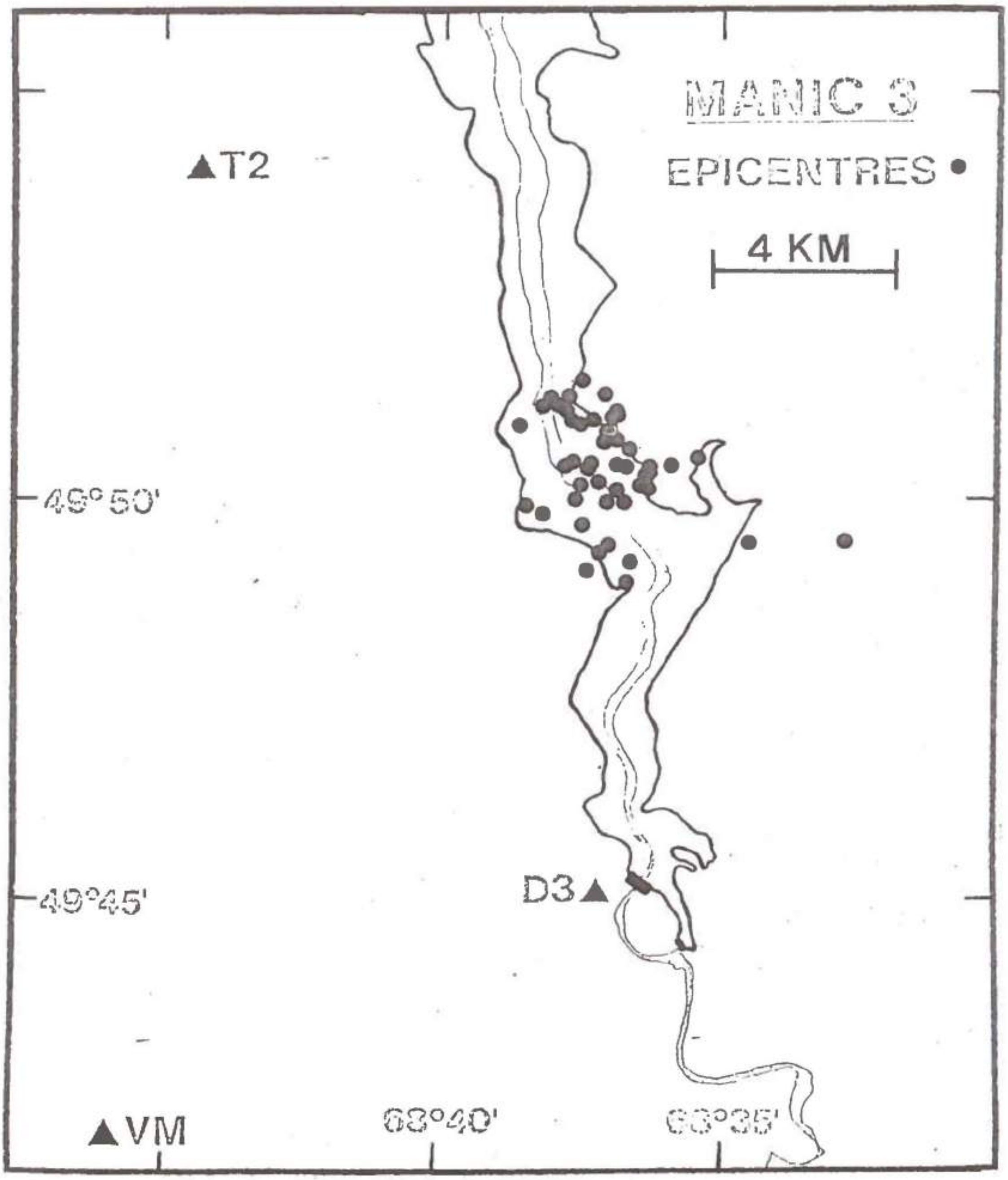

Fig. 2.2 Earthquake activity associated with the initial filling of the Manic 3 reservoir, Canada, as recorded by a temporal threepartite station (VM, D3, T2). The figure shows the location of about 50 aftershocks following the main shock ($m_b = 4.3$) on October 23, 1975. (After Leblanc and Anglin, 1976.)

and it said (1) that the activity was most likely induced, (2) that a larger shock could occur, (3) that the responsibility to slow down the rate of filling was Hydro's own, and (4) that three portable seismometers should be installed in order to locate the source. Three days later, on October 23, a shock of magnitude 4.3 occurred, and nobody, of course, could know whether this was the main shock or just another foreshock. Hundreds of workers were immediately evacuated from the powerhouse and the tunnels, and portable seismometers were installed the same night. The location of the main shock had been about 10 km behind the dam, and in the next 5 months more than 1000 small events were located in the same general area. About 50 of these epicenters are shown in Fig. 2.2, and it was found that about 80% of the solutions were contained within a volume of 4 x 4 x 4 km. No temporal change was found in the occurrence of the aftershocks; it seemed that they were occurring at random within a certain fractured volume. Leblanc and Anglin (1976) have indicated that the activity could be explained by the infiltration of water into an area of some inhomogeneity of the local basement.

There are many more examples of this kind, one of which is reproduced in Fig. 2.3, referring to the Kremasta dam in Greece, where the main shock had a damaging magnitude of 6.3 (Galanopoulis, 1967).

2.2 Seismicity and changes in water level

This is the second typical characteristic of reservoir-induced seismicity, and one naturally needs several cycles of filling to establish the connection. One of the best examples is from the oldest known case of induced seismicity, at the Lake Mead (Hoover dam) in the United States. Fig. 2.4 shows that there was for a number of years a clear positive correlation between seasonal lake load and local seismicity (Carder, 1968, 1970; Mickey, 1973). Little instrumental data were available during the initial filling of the reservoir, while the earthquake activity for the following years (1938-44) was found to be tied to existing faults and confined to an area within 25 km from the lake (Carder, 1945; Rogers and Gallanthine, 1974).

Another and more recent example is shown in Fig. 2.5, referring to the Vajont reservoir in Italy (Galanopoulis, 1967). About 250 small earthquakes

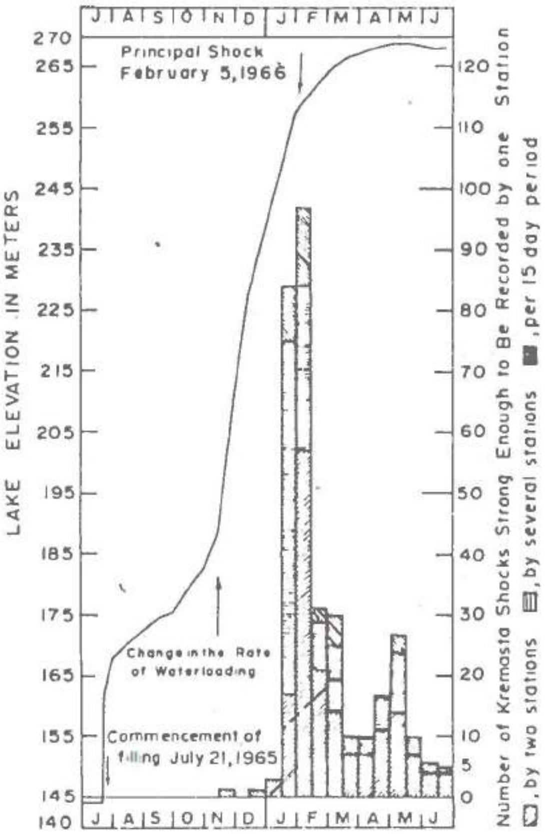

Fig. 2.3 Kremasta Lake elevations and earthquake frequency in the region. (After Gupta et al, 1972a.)

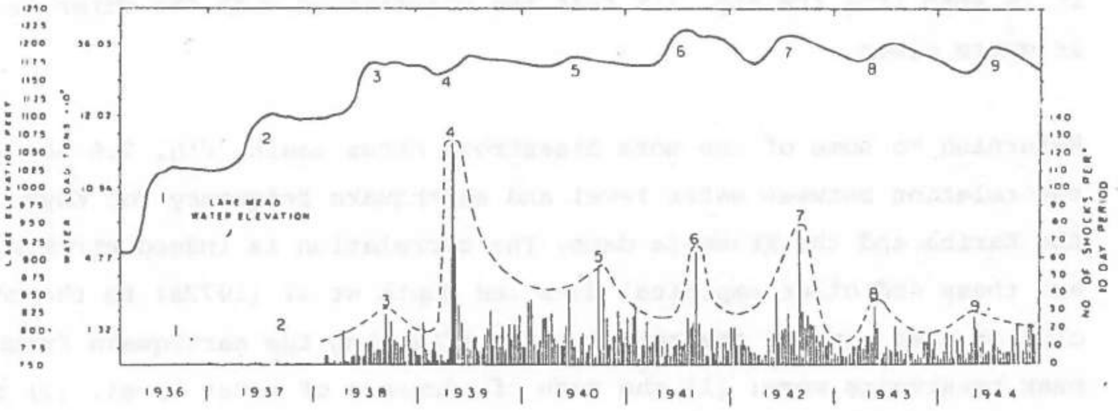

Fig. 2.4 Lake Mead (Hoover Dam) water levels and local seismicity. For the years 1936 and 1937, only felt shocks are plotted (Carder, 1945). General trend of tremor frequency variation is shown by dotted lines. (After Gupta et al, 1972a.)

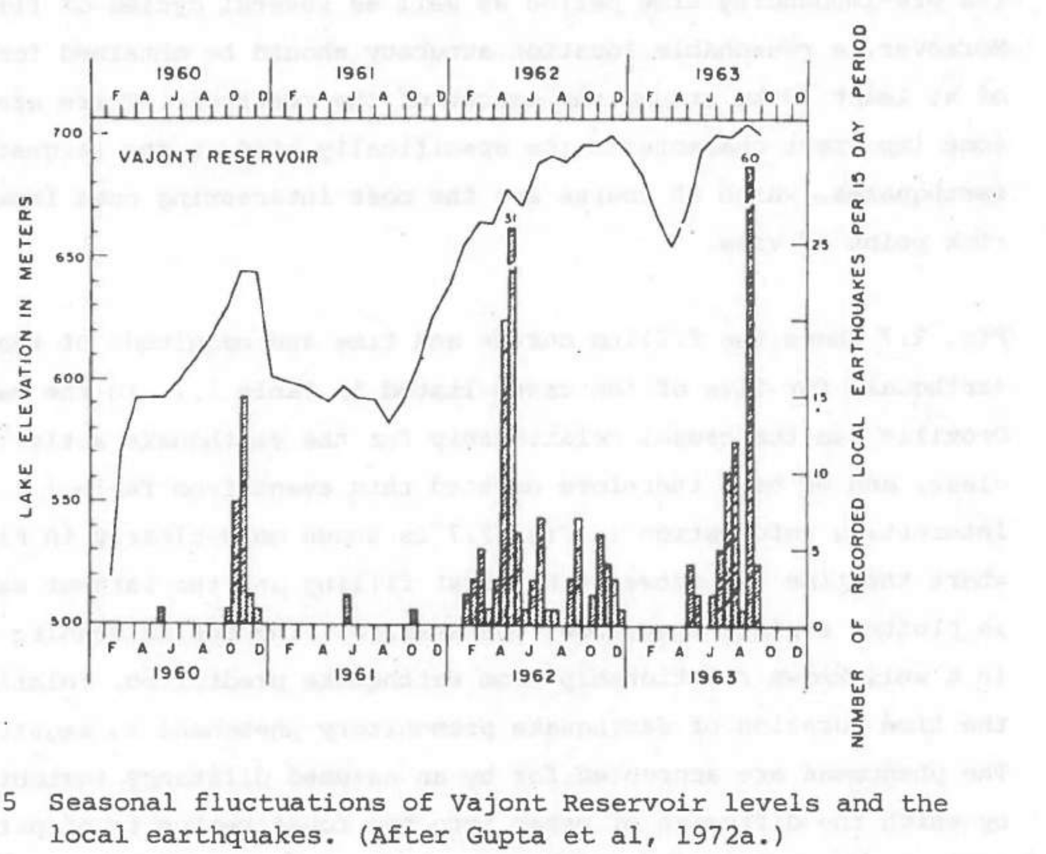

Fig. 2.5 Seasonal fluctuations of Vajont Reservoir levels and the local earthquakes. (After Gupta et al, 1972a.)

were located during the years 1960-63, all within 2.5 km from the dam. It is seen from the Fig. 2.5 that the correlation with the water level is quite clear.

Returning to some of the more disastrous cases again, Fig. 2.6 now shows the relation between water level and earthquake frequency for Koyna, the Kariba and the Kremasta dams. The correlation is indeed striking, and these and other empirical data led Gupta et al (1972a) to the conclusion that some of the main factors affecting the earthquake frequency near reservoirs were: (1) the rate of increase of water level, (2) the duration of loading, (3) the maximum load reached, and (4) the period for which the levels are retained.

2.3 The largest induced earthquakes

The typical reservoir-induced earthquake characteristics presented above have demonstrated the importance of local seismic surveillance covering the pre-impounding time period as well as several cycles of filling. Moreover, a reasonable location accuracy should be obtained for an area of at least 30 km around the center of the reservoir. There are, however, some important characteristics specifically tied to the largest induced earthquakes, which of course are the most interesting ones from a seismic risk point of view.

Fig. 2.7 shows the filling curves and time and magnitude of the largest earthquake for five of the cases listed in Table 1.1. In the case of the Oroville dam the causal relationship for the earthquake activity is not clear, and we have therefore omitted this event from Table 1.1. The most interesting information in Fig. 2.7 is shown more clearly in Fig. 2.8, where the time lag between the first filling and the largest earthquake is plotted against magnitude. The straight line due to Scholtz et al (1973) is a well-known relationship from earthquake prediction, relating the time duration of earthquake premonitory phenomena to magnitude. The phenomena are accounted for by an assumed dilatancy instability by which the diffusion of water into the focal region is of prime importance (Nur, 1972). According to this theory (which is not universally accepted), the dilatancy mechanism is an instability from which there is no other return than through an earthquake. Regardless of theory,

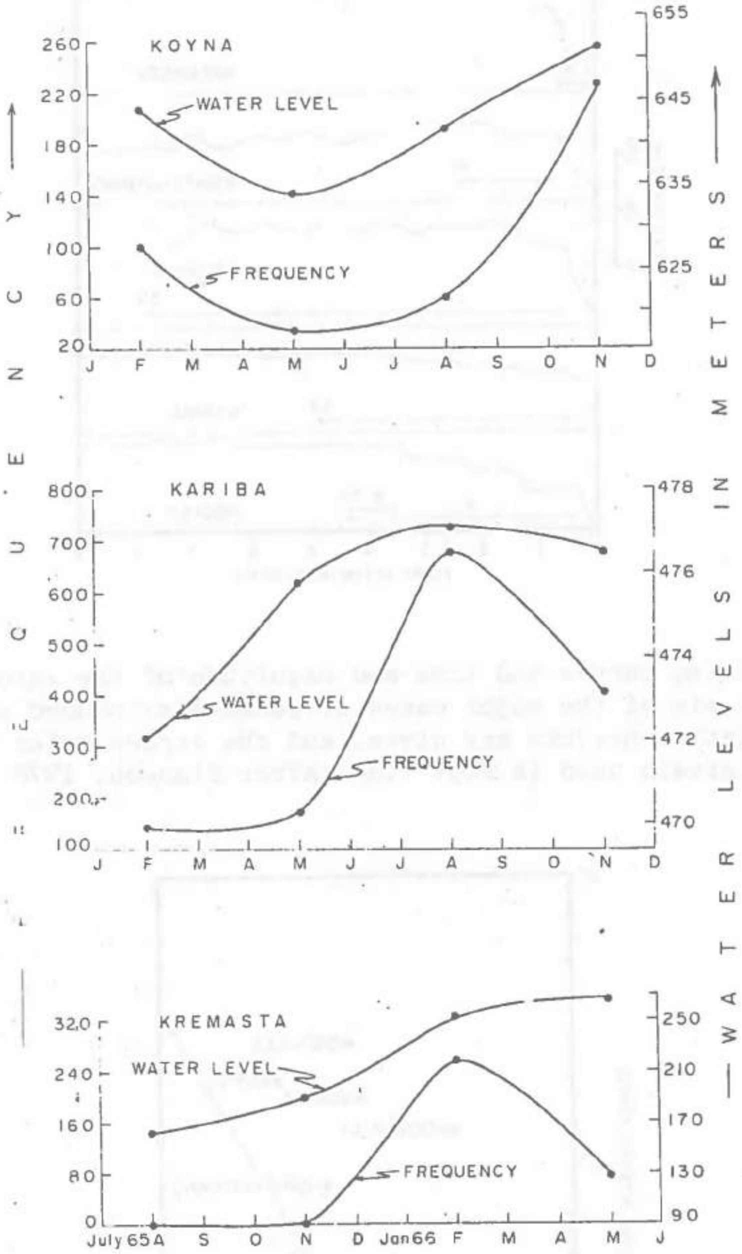

Fig. 2.6 Three monthly average of water levels and totals of earthquake frequency for the same months at Koyna, Kariba and Kremasta; the correlation coefficients are found to be +0.93, +0.74 and +0.69, respectively. The periods include 1964-1968 for Koyna, 1959-1968 for Kariba and July 1965 to June 1966 for Kremasta. (After Gupta and Rastogi, 1976.)

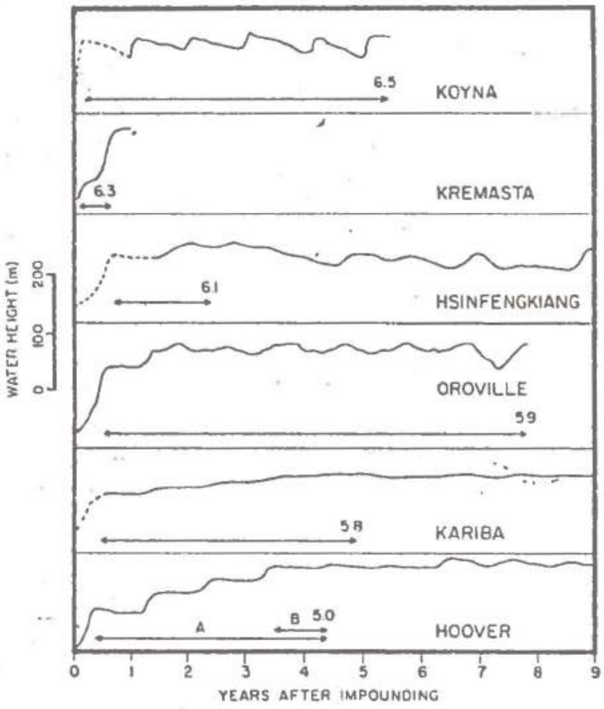

Fig. 2.7 Filling curves and time and magnitude of the largest earthquakes for six of the major cases of reservoir-induced seismicity. Only relative heights are given, and the arrows refer to the time intervals used in Fig. 2.8. (After Simpson, 1976.)

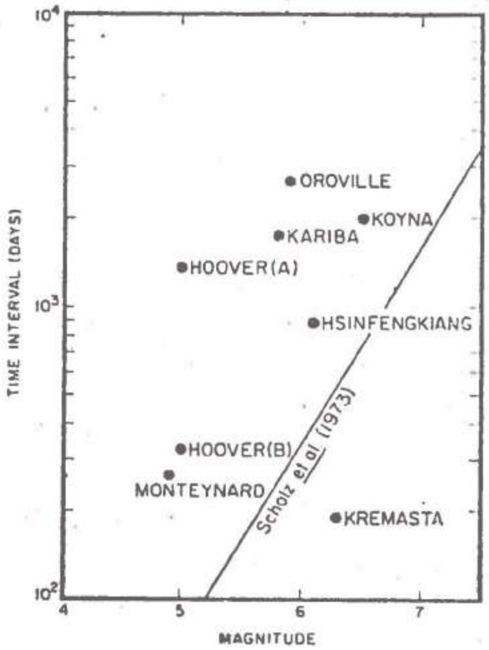

Fig. 2.8 Time delay between the completion of the first stage of filling of the reservoir and the largest earthquake, plotted against magnitude. (After Simpson, 1976.)

however, the straight line in Fig. 2.8 holds as an empirical relationship, and it is interesting to note that a similar relationship seems to hold (with the exception of Kremasta) for reservoir-induced earthquakes. What it means, in other words, is the following:

If the potential for a large reservoir-induced earthquake is present, the potential magnitude will increase with time.

From Fig. 2.8 we find the following guiding relationship for the magnitude of the event:

$$m_b = 1.0 \pm 0.5 + 1.5 \log_{10} T$$

where T is elapsed time in days since the completion of the first stage of filling of the reservoir. One practical implication of this is the need to continue the local seismic surveillance for a sufficiently long time, in the hope of detecting possible precursors (such as changes in the local seismic regime).

2.4 Possible mechanisms of induction

The mechanisms of induced seismicity are still subject to considerable discussion. It should be noted, however, that for a majority of the dams, the impounding of water does not lead to any noticeable change in the seismicity of the area. In one case, when the reservoir was located in an area of considerable natural seismicity, it was found that the activity in fact decreased during the initial stages of filling (Jacob et al, 1976). It is therefore evident that local geological conditions (in the wide sense) are more instrumental for induced earthquakes than the reservoir itself. The former define the pre-impounding stress regime and the latter creates added stresses, and a change in the seismicity regime is the result of an interaction between the two (Simpson, 1976).

There are primarily two ways in which the reservoir can affect the stress environment; first, through the stress increase due to added load, and secondly, through an increase in pore pressure which decreases the effective stress. In their discussion of the Kariba earthquakes, Gough and Gough (1970) consider the stress-triggering effect to be the most important one, i.e., the effect of the added stress in triggering large initial stress. However, the importance of the pore-pressure effect (increased fluid pressure) is actually better demonstrated, in experiments where seismicity changes are caused by injection of fluid under high pressure (Healy et al, 1968; Raleigh et al, 1976; Fletcher and Sykes, 1977). Simpson (1976) found that the factors controlling reservoir seismicity could be grouped in three main areas: (1) *pre-existing stress* (orientation, magnitude of stress, rate of stress accumulation), (2) *geological and hydrological conditions* (faults, hydro-mechanical rock properties, hydrological conditions), and (3) the *reservoir* (size, temporal changes in water level).

Even though the different factors of importance for induced seismicity are now known, much less is known about their relative importance and their interaction in any particular case. One important unanswered question for example, is whether only the time for the stress release changes (triggering effect), or if the magnitudes of potential earthquakes also can be modified. Some patterns are emerging, however, which can assist in assessing the *potential* for seismicity induction in a new area (Simpson, 1976):

1) The potential for induced activity seems to be highest in areas of strike-slip or normal faulting.
2) Most induced activity is confined to areas of high to moderate strain accumulation, the latter areas being most susceptible to *major* seismicity changes.
3) Little induced activity has been found in areas of low strain accumulation.

These three points are the most important ones to be kept in mind when we now look somewhat closer at the seismicity of Tanzania in general and the Stiegler's Gorge area in particular.

3. SEISMICITY OF TANZANIA

Reports on the seismicity of Tanzania have been published by Ambraseys (1972) and Båth (1975), and brief discussions have also been given by Anderson (1976) and by Ringdal (1977). In the present report, we will review the topic only to the extent which is considered necessary as background information for the proposal of a seismic network in the Stiegler's Gorge area. In this respect, a consideration of the potential for seismicity induction is one of the most important problems.

3.1 Major seismotectonic features

The seismicity of Africa south of 10°N is dominated by the seismicity of the East African Rift system, an outline of which is given in Fig. 3.1. (Gutenberg and Richter, 1949, 1954; Rothé, 1954; Sutton and Berg, 1958; De Bremaecker, 1959; Sykes and Landisman, 1964; Wohlenberg, 1968; Fairhead and Girdler, 1971). It is seen in this figure that the rift system, in dividing the Somalia plate from the Nubia plate, branches into two sections south of 5°N, one on each side of Lake Victoria. The Western Rift is the one which is most extensively studied and also the one which is most active seismically, whereas the Eastern (Gregory) Rift is the one which is of particular interest to us because it extends all the way into the Rufiji Basin of Tanzania (Maguire and Long, 1976).

The East African Rift System is one of the few areas on land where one can study the effects of major extensional tectonics. It differs also from oceanic rift zones in that the associated seismicity is much more dispersed, as demonstrated in Fig. 3.2 and also in Fig. 3.3. This has been interpreted by Oxburgh and Turcotte (1974) as characteristic of a propagating fracture system caused by membrane stresses in the lithosphere, being due to the northward movement of the African plate on a non-spherical earth. In fact, there is clear geological evidence of crustal extension over a relatively wide area (Searle, 1970). While the seismicity of Kenya is only moderate, Fig. 3.3 shows that more activity is associated with the rifting in northern Tanzania, where the rift fans out in a number of east-facing fault scarps (Fairhead and Girdler, 1971). It is seen from the fault map in Fig. 3.3 that the faulting pattern is quite complex, although with a general orientation in the direction of the rifting axes. Earthquake focal mechanisms from the

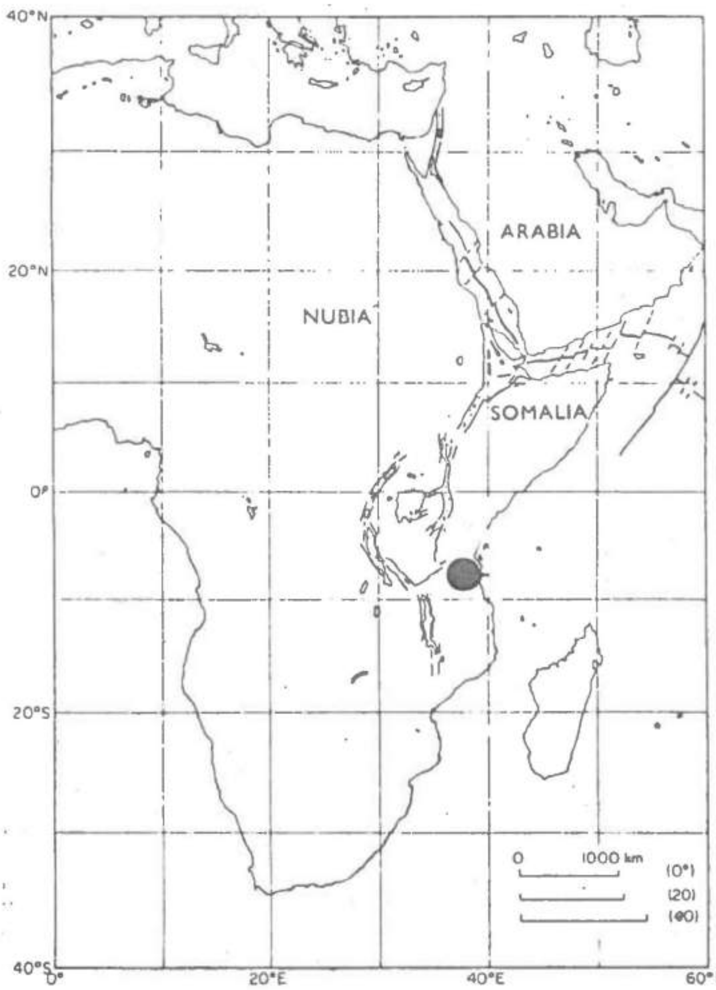

Fig. 3.1 Outline of the East African Rift System. (After Darracott et al, 1973.) Black dot indicates location of Stiegler's Gorge.

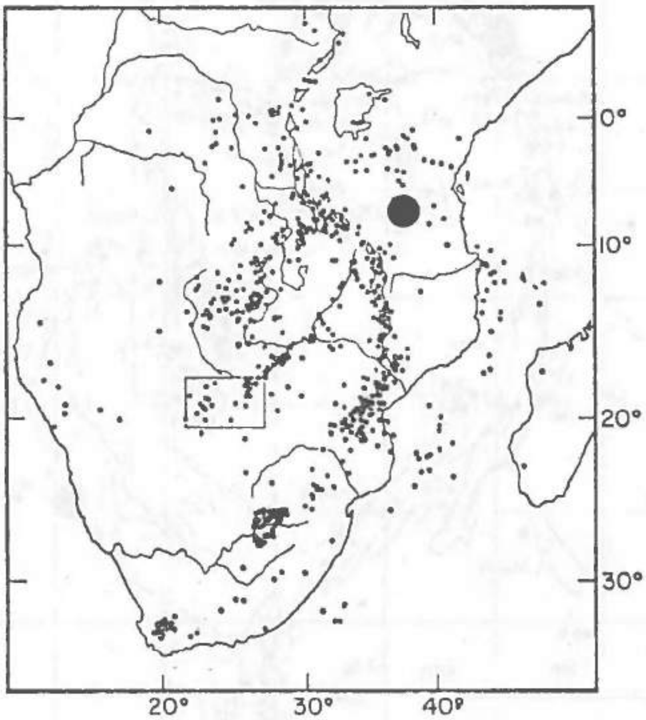

Fig. 3.2 Seismicity of central and southern Africa for the years 1969-1973. Data from Seismological Bulletins, Rhodesia Meteorological Services. (After Scholtz et al, 1976.) Black dot indicates location of Stiegler's Gorge.

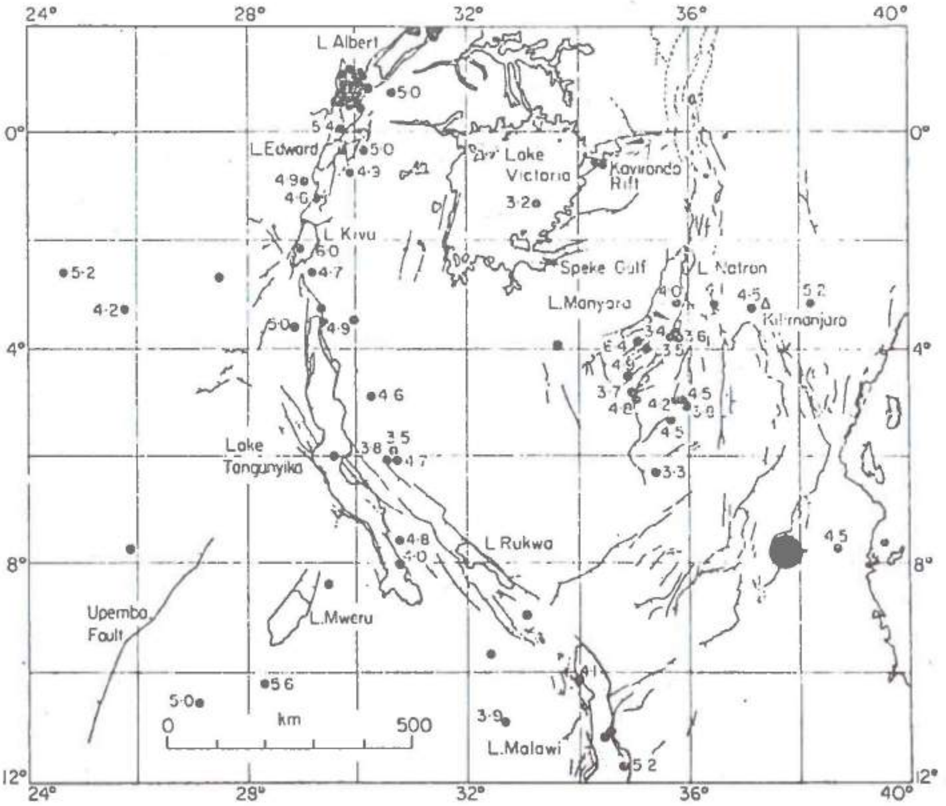

Fig. 3.3 Fault map of the East African Rift System between 2°N and 12°S showing the seismicity for the period January 1963 to December 1970. (After Fairhead and Girdler, 1971.) Black dot indicates location of Stiegler's Gorge.

area (Sykes, 1967; Fairhead, 1968; Baughar and Sykes, 1969; McKenzie et al, 1970; Fairhead and Girdler, 1971) are presented in Fig. 3.4, showing only strike-slip and normal faulting. Of particular interest here are the three events around Lake Victoria, where the two in the Western Rift are associated with normal faults with maximum tension perpendicular to the rift. The strike-slip solution for the earthquake in Tanzania, on the other hand, is more difficult to reconcile with the local geology, because the strike of the faulting in the area (N50°E) does not coincide with any of the nodal plane directions. Guided by the more regional pattern of solutions for eastern and southern Africa, however, Fairhead and Girdler (1971) have suggested that the fault plane is the one striking NW-SE.

We can conclude from this that the seismotectonic patterns in the Tanzania region, being located in the southern end of the Gregory Rift, are quite complicated and dispersed. This is supported by geologic information as well as earthquake distribution and focal mechanisms.

3.2 Seismicity of the Rufiji Basin

The studies of Ambraseys (1972) and Båth (1975) are the two most extensive ones covering the seismicity of Tanzania. However, the coverage of the seismic stations has been generally poor and not very stable in time, resulting in relatively inhomogeneous earthquake catalogues. The main event here was the installation of the African network IRSAC in 1956, from which time the quality of the earthquake reports increased considerably.

Båth's (1975) seismicity map for Tanzania is reproduced in Fig. 3.5 (see also Fig. 3.3), where it is seen that the main activity is concentrated in the northern and western parts of the country, outside the Stiegler's Gorge area. The map covers only the larger events, however, and Fig. 3.6 shows, based on the data of Ambraseys (1972), that the Rufiji Basin is far from seismically inactive. That map (Fig. 3.6) covers only the time since the installation of IRSAC (1956), which explains the increased detectability. However, there is still a considerable inhomogeneity in the catalogue, which we can see simply from the fact that most of the events in Fig. 3.6 are from one single year (1966). We can therefore safely assume that the occurrence of small and intermediate

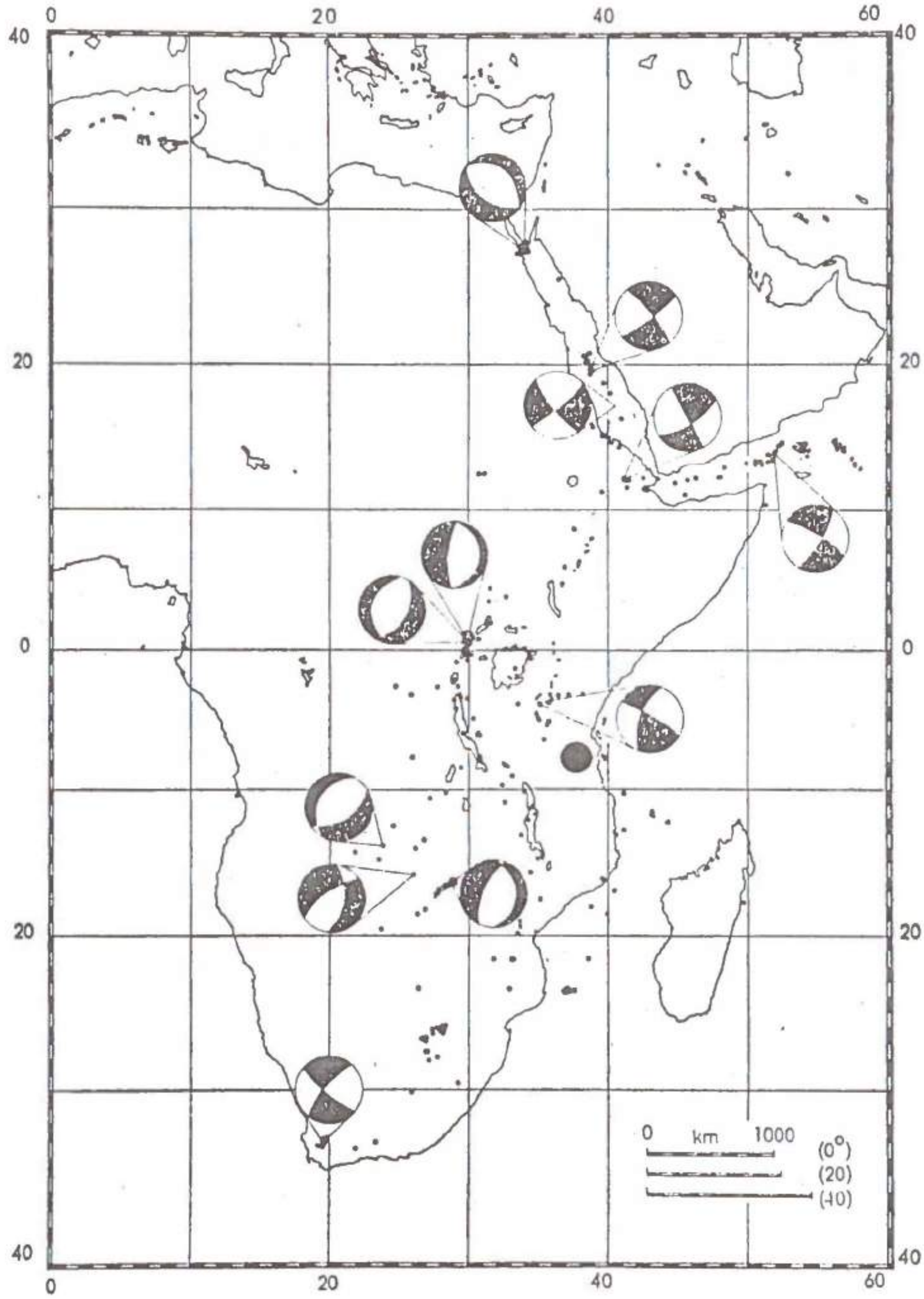

Fig. 3.4 Map showing seismicity of Africa (1963-1970) and fault plane solutions available for Africa at the end of 1970. (After Fairhead and Girdler, 1971.) Large black dot indicates location of Stiegler's Gorge.

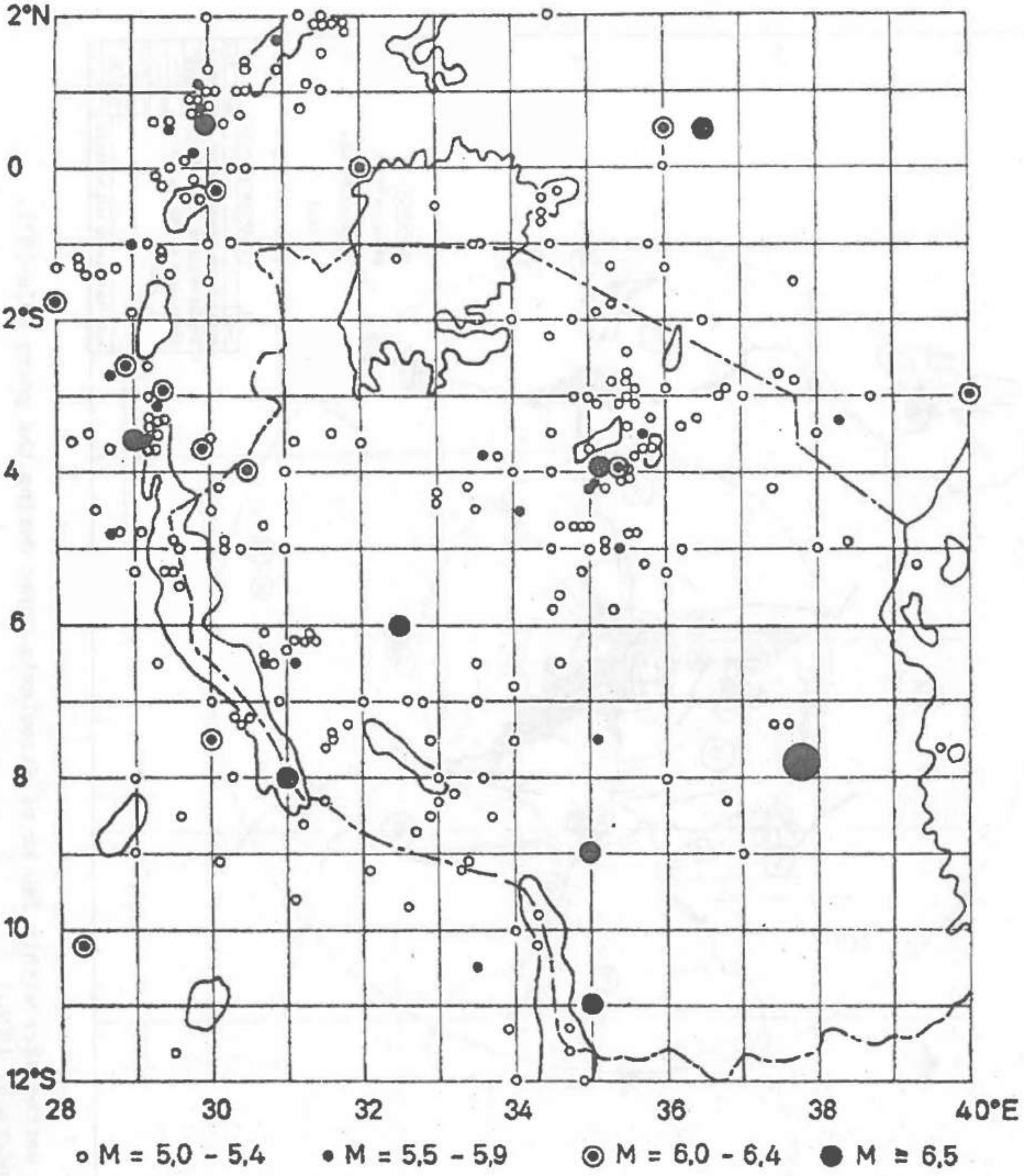

Fig. 3.5 Seismicity of Tanzania 1910-1974. (After Båth, 1975.)
Large black dot indicates location of Stiegler's Gorge.

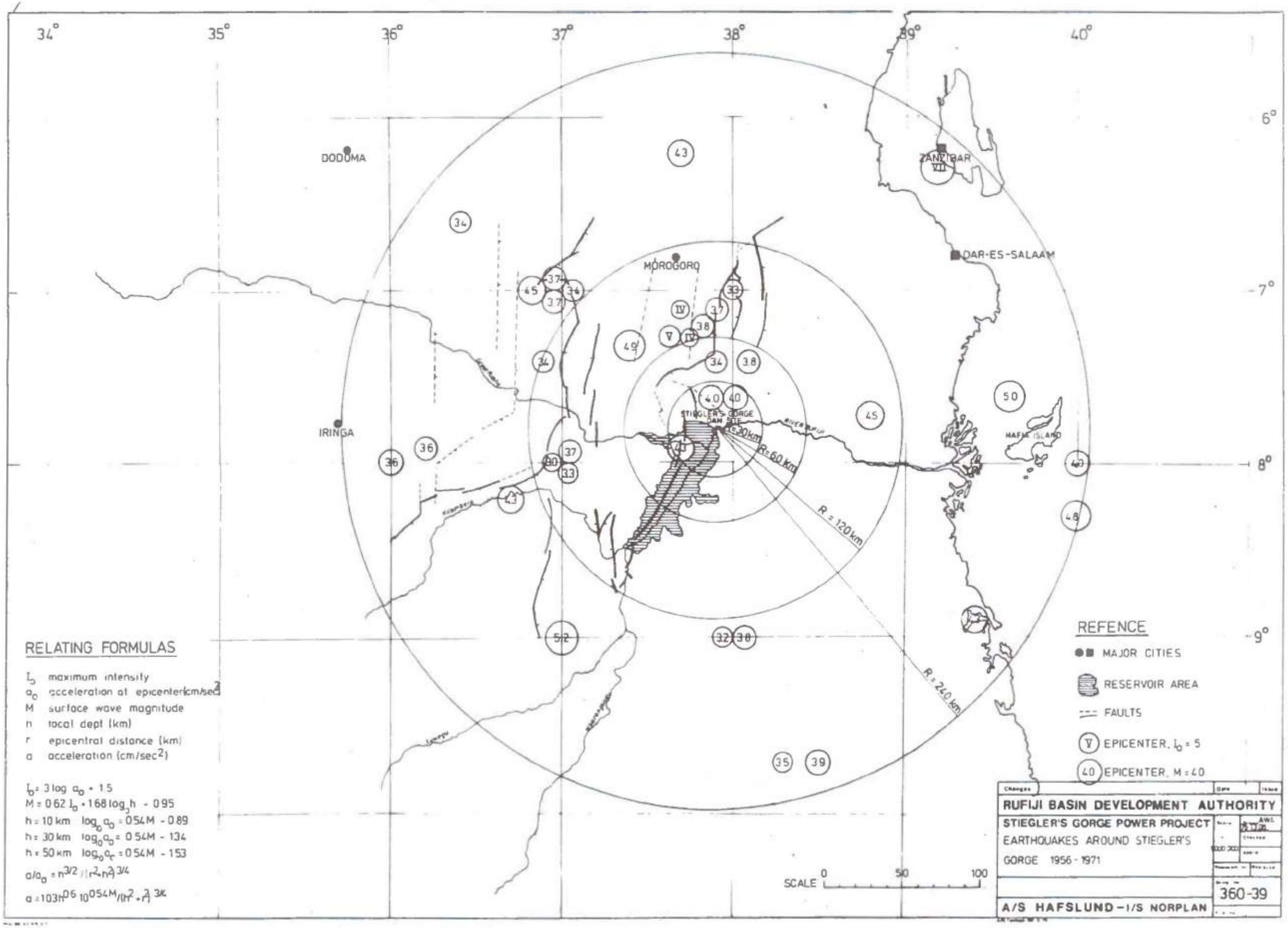

Fig. 3.6 Reported earthquakes within 240 km of Stiegler's Gorge during the years 1956-1971.
(After Anderson, 1976.)

earthquakes is much larger than indicated by available catalogues. A confirmation of this is the fact that a hitherto unreported earthquake in 1976 was clearly felt by Geoteam A/S personell (W. Hoffman, personal communication) in Stiegler's Gorge.

Besides the problems with inhomogeneity and time-varying detectability, there are also considerable uncertainties in the locations of the earthquakes in the available catalogues. We consider that the location accuracy is not better than 10-30 km in most of the cases, and probably even worse in many cases.

We conclude that the seismicity in the Rufiji Basin area is moderate, located as it is in the immediate vicinity of the southern extension of the Gregory Rift. As such, the area is probably one of moderate strain accumulation, which in Chapter 2.4 was identified as areas most susceptible to major reservoir-induced seismicity changes. Moreover, the general area is one of strike-slip and normal faulting, which fulfills another of the criteria for an area with potential for induced activity. A Stiegler's Gorge Seismic Network, a proposal for which the rest of this report will be devoted to, could therefore become of vital importance for the safety of the people and the installations associated with the Stiegler's Gorge Power Project, as well as for the areas of the lower Rufiji Basin.

4. STIEGLER'S GORGE SEISMIC NETWORK

The previous chapters have been used for the dual purpose of (1) investigating the possible need for a seismic network around Stiegler's Gorge, and (2) obtaining information needed for the design of such a network. In the following chapters, we will present a detailed proposal for a Stiegler's Gorge Seismic Network, hereafter also called SGSN.

4.1 Purpose of network

There are two main purposes for a SGSN, the first and dominating one being the need to monitor the local seismicity before, during and after the impounding of water in the reservoir. Since the natural seismicity of the area is poorly known, it is especially important to conduct a thorough pre-impounding seismicity study. This would help in two ways, (1) in order to provide seismicity parameters of importance for the construction (dimensioning) of the dam, such as earthquake time-space distribution (possibilities of active faults), seismicity levels (magnitude, acceleration), signal duration, attenuation, and other parameters, and (2) in order to provide the necessary background for the monitoring of possible induced seismicity (the need for which is documented in the previous chapters).

The second purpose of the network is tied to the way in which it would provide important supplementary data for the general risk analysis for the area. Such an analysis would have to be based on all available earthquake catalogues and reports from the whole general area of eastern and southern Africa, and the local data would enter basically for calibration purposes. The need here is evident especially with respect to seismic magnitudes, where available catalogues appear to be inconsistent, and where a local network could be used to establish a local magnitude scale which should be calibrated against teleseismically recorded magnitudes.

4.2 Requirements on configuration

The map in Fig. 3.6 gives a rough idea of the river system in the Rufiji Basin, the location of the dam and the possible size and location of the resulting aritificial lake. Although this has not yet been finally determined, we understand from Hafslund A/S (R.J. Strand, personal communication) that the water level will probably be increased from about 75 to at most 185 m, resulting in a lake with a volume of $25 \cdot 10^9 m^3$, covering an area of 1100 km^2 (roughly 10 x 100 km, see Fig. 3.6). Estimates of the minimum numbers are 160 m, $10 \cdot 10^9 m^3$, and 600 km^2, respectively. This is a very large reservoir, the definition of which was given in Chapter 1 as at least 100 m in water depth and/or $10^9 m^3$ in volume.

Two of the purposes of the network lead to partially conflicting requirements on the configuration:

1) Monitoring of the seismotectonic activity in the immediate vicinity of the dam would require a network of 5-10 stations within an area with radius about 1 km around the dam. A manufacturer's proposal for such a system is included in Appendix D. The detectability of such an array would normally be below zero in magnitude, and events within the array could probably (after calibration of the area using explosions) be located with an accuracy of around 100 m. It is obvious that this would give an excellent coverage of the microearthquake activity at the dam site.

2) Monitoring of the earthquake activity in the immediate vicinity of the reservoir would require a network of 5-10 stations within an area with radius about 30 km around the center of the reservoir. A manufacturer's proposal for a similar system is included in Appendix E. It will be demonstrated below that the location accuracy of this array would be in the order of 1 km (Chapter 6).

Between these two purposes we have to give priority to the second one, because of the importance of monitoring possible induced seismic activity. In order to simultaneously serve the first purpose, however, we should make this configuration such that a better coverage is obtained in the dam end of the reservoir.

In addition to these ideal requirements the practical solution depends also heavily on the physical solution for instrumentation and data recording and transmission. We understand from Hafslund A/S that with distances from the main camp in Stiegler's Gorge in the order of 30 km one should not expect access to each site more than about once every month (because of costs and availability of helicopter transport). With that restriction it would be very difficult to find a solution based on individual recording at each site, because (1) data storage problems would give poor time resolution and/or poor detectability, (2) there could be problems with power supply, (3) long time intervals of non-operation would be likely to occur (possibly requiring more sites), and (4) very long delays would occur in the data analysis. This leaves us with a requirement for data transmission using telemetry, and for simple practical reasons it would have to be radio telemetry. What this means for the configuration of the array is that as many as possible of the sites should have a direct sight to the Central Recording Station (CRS), in order to avoid the expenses and the practical and logistical problems with repeater radio stations. In the Stiegler's Gorge area, the obvious choice for the CRS is the main camp, and it is with all these requirements in mind that we have arrived at the solution to be presented below.

4.3 Siting considerations

The selection of the site for each sensor must necessarily be a compromise between several partially conflicting requirements. Some of these, regarding the configuration, have been discussed above. Some other site criteria are:

Accessibility. For SGSN we assume that helicopter transport must be used for all sites. We understand that landing spots are expected to be available within a very short distance of practically every point on the map, with the exception of the very limited forested areas. Another important restriction here is that no site should be located in an area to be flooded later, even if several years of operation during the pre-impounding period is be planned. This is because of the desired stability and consistency of the data analysis (one should not be faced with the problems of a changing configuration) as well as the practical problems with the moving of sites. Finally, the distance from the Central Recording Station is important, both with regard to helicopter access and to the data transmissions.

Power supply. Generally, one should select sites where commerical power is available. For the Stiegler's Gorge area, batteries (or preferably solar cells) are needed regardless of site.

Geological requirements. These are as follows: (1) Bedrock should be as competent and homogeneous as possible, (2) Igneous bedrock is preferable to sedimentary or metamorphic bedrock, (3) Geologic structure of the region should be as simple as possible, (4) The amount of desired overburden is 1 to 3 m for surface seismometer vaults.

Seismic noise. These effects should be minimized by (1) avoiding cultural activities (such as roads, blasting, machines, etc.), (2) avoiding trees within 100 m from the site, (3) avoiding large rivers, waterfalls, etc., (4) preferring flat topography over mountains, (5) preferring the leeward side of hills and mountains.

Radio telemetry. If such is needed, free sight should be obtained between each site and the Central Recording Station. Repeater stations could be used, but avoided if possible.

Equipment security. Due consideration should be given to such possibilities as theft and vandalism.

Environmental effects. Due consideration should also be given to the effect that construction, installation and operation will have on the environment and ecology of the site.

4.4 A suggested solution

Our proposal for the configuration of the Stiegler's Gorge Seismic Network is presented in Fig. 4.1. As a basis for our solution we have used seven topographical maps (provided by Hafslund A/S) scaled 1:50000. In Fig. 4.1 we have mounted these maps together and scaled them down a factor of 10, besides drawing contours with a heavier line for each 300 ft. The maps are not of high quality, and especially so for the two in the upper left corner, where elevation contours are not provided. Consequently, stations 01 and 07 are the most uncertain ones with respect to location.

In Fig. 4.2, which also shows the proposed configuration, we have blackened the area which would be covered by the reservoir with a water level of 600 ft or 183 m, which we understand is the highest of the alternatives now being considered. The geographic and UTM cartesian coordinates for

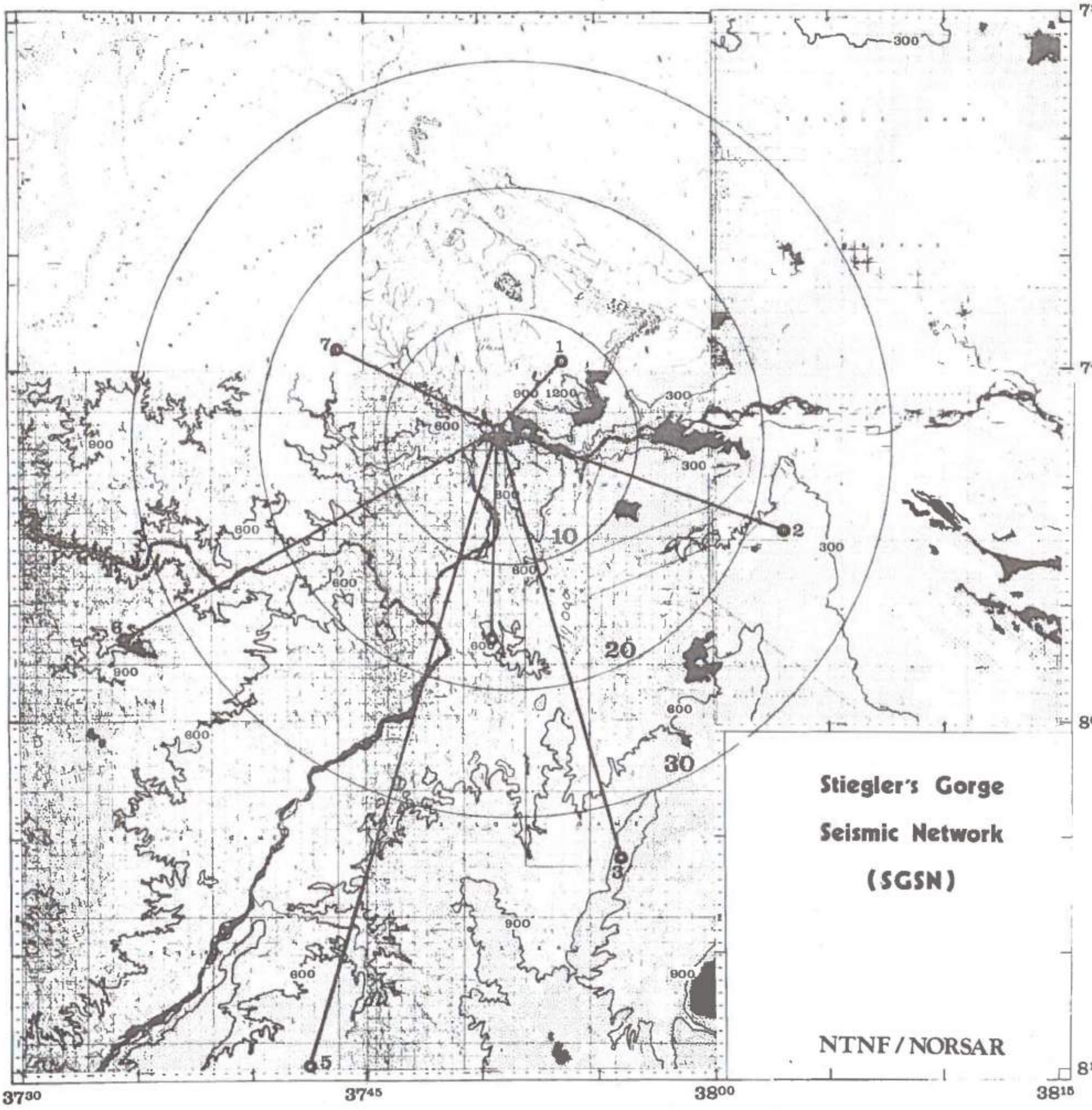

Fig. 4.1 Proposed configuration for the Stiegler's Gorge Seismic Network (SGSN). Circles are drawn at distances of 10, 20 and 30 km around the dam site at Stiegler's Gorge. The central point to which straight lines from each site are drawn, is the suggested Central Recording Station at the main camp. Map scale 1:500000.

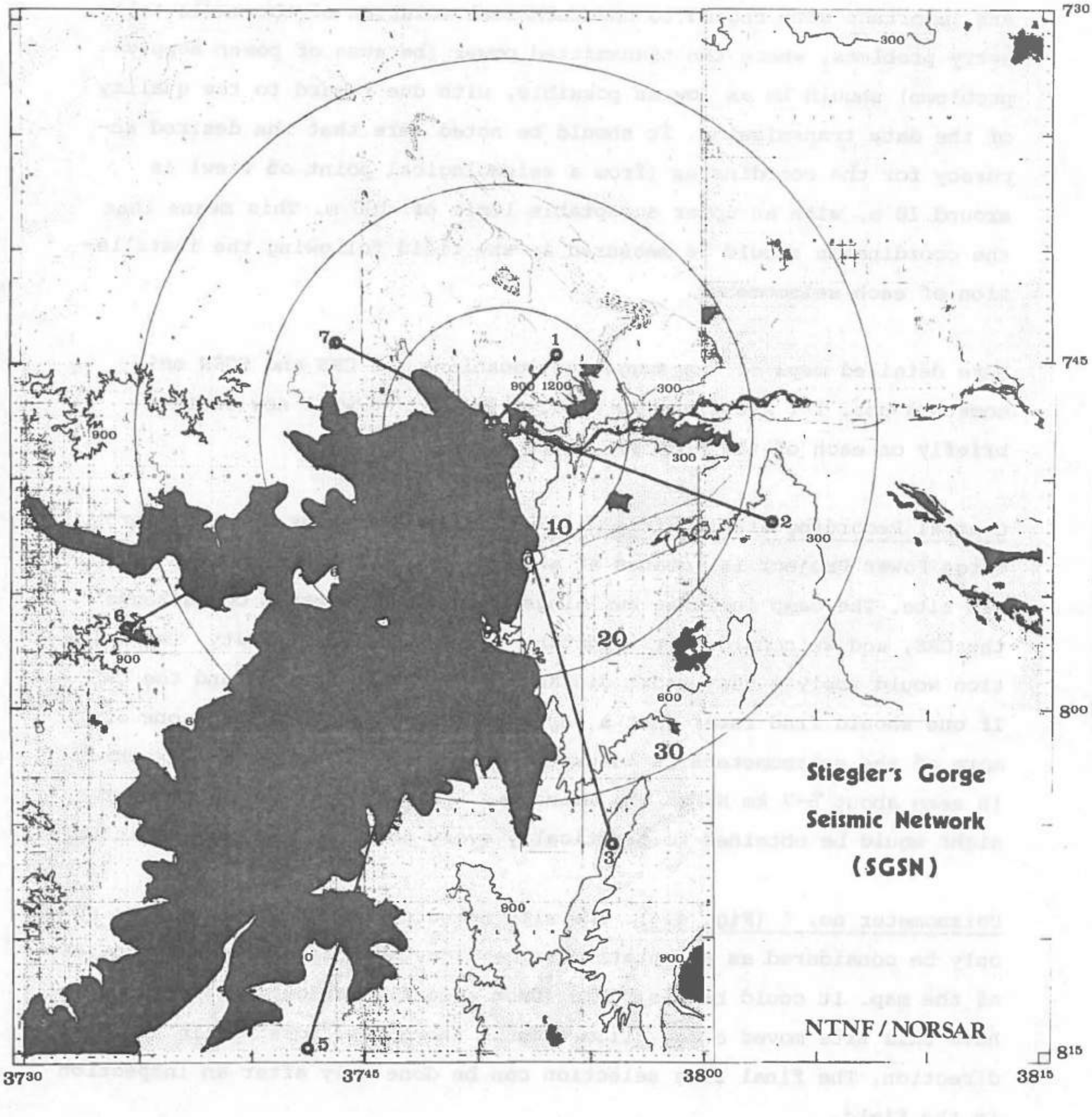

Fig. 4.2 Proposed configuration for the Stiegler's Gorge Seismic Network (SGSN) together with an outline of the water level if reaching an elevation of 600 ft or 183 m. Map scale 1:500000.

suggested sites are given in Table 4.1, read directly from the map. The cartesian coordinates relative to CRS at main camp are given in Table 4.2, where also the distances from each site to CRS are given. These distances are important with regard to the technical solution of the radio telemetry problems, where the transmitted power (because of power supply problems) should be as low as possible, with due regard to the quality of the data transmission. It should be noted here that the desired accuracy for the coordinates (from a seismological point of view) is around 10 m, with an upper acceptable limit of 100 m. This means that the coordinates should be measured in the field following the installation of each seismometer.

More detailed maps of the suggested locations for CRS and SGSN seismometers nos. 1-7 are given in Figs. 4.3-4.10. We will now comment briefly on each of the proposed sites.

Central Recording Station (Fig. 4.3). The main camp for the Stiegler's Gorge Power Project is located at a small hill immediately north of the dam site. The camp includes buildings which we understand could house the CRS, and we consider it important to use this possibility. The solution would imply a very short distance between the antenna and the CRS. If one should find later that a repeater station is needed for one or more of the seismometers, a natural choice would be the high peak which is seen about 6-7 km NE of the main camp. From that hilltop, a direct sight would be obtained to practically every point in the area of interest.

Seismometer no. 1 (Fig. 4.4). The site selected for this seismometer should only be considered as a tentative suggestion, because of the poor quality of the map. It could be desirable (from a configuration point of view) to have this site moved a few kilometers to the north, possibly in the NNW direction. The final site selection can be done only after an inspection in the field.

Seismometer no. 2 (Fig. 4.5). This site is located down the gorge, and there should not be any telemetry problems. One should consider moving the site to a place with less exposure topographically than the present hilltop location.

Station	Lat (S)	Long (E)	NS (km)	EW (km)	Elev (m)
01	7°44.59'	37°53.57'	9144.1	377.9	300
02	7°51.85'	38°03.04'	9130.8	395.4	190
03	8°05.91'	37°56.00'	9104.7	382.4	310
04	7°56.59'	37°50.49'	9122.0	372.3	200
05	8°14.85'	37°42.43'	9088.2	357.6	230
06	7°56.46'	37°34.48'	9122.0	343.0	300
07	7°44.02'	37°43.86'	9145.1	360.1	300
CRS	7°47.47'	37°50.85'	9138.7	372.9	250

Table 4.1 Geographic and UTM cartesian coordinates for the proposed Stiegler's Gorge Seismic Network, as read from topographic maps. The network is located within UTM zone 37.

Station	NS (km)	EW (km)	Distance (km)
01	5.4	5.0	7.4
02	-7.9	22.0	23.4
03	-34.0	9.5	35.3
04	-16.7	-0.6	16.7
05	-50.5	-15.3	52.8
06	-16.7	-29.9	34.3
07	6.4	-12.8	14.3

Table 4.2 Cartesian coordinates for the proposed Stiegler's Gorge Seismic Network, relative to the Central Recording Station (CRS). The distances are also relative to CRS.

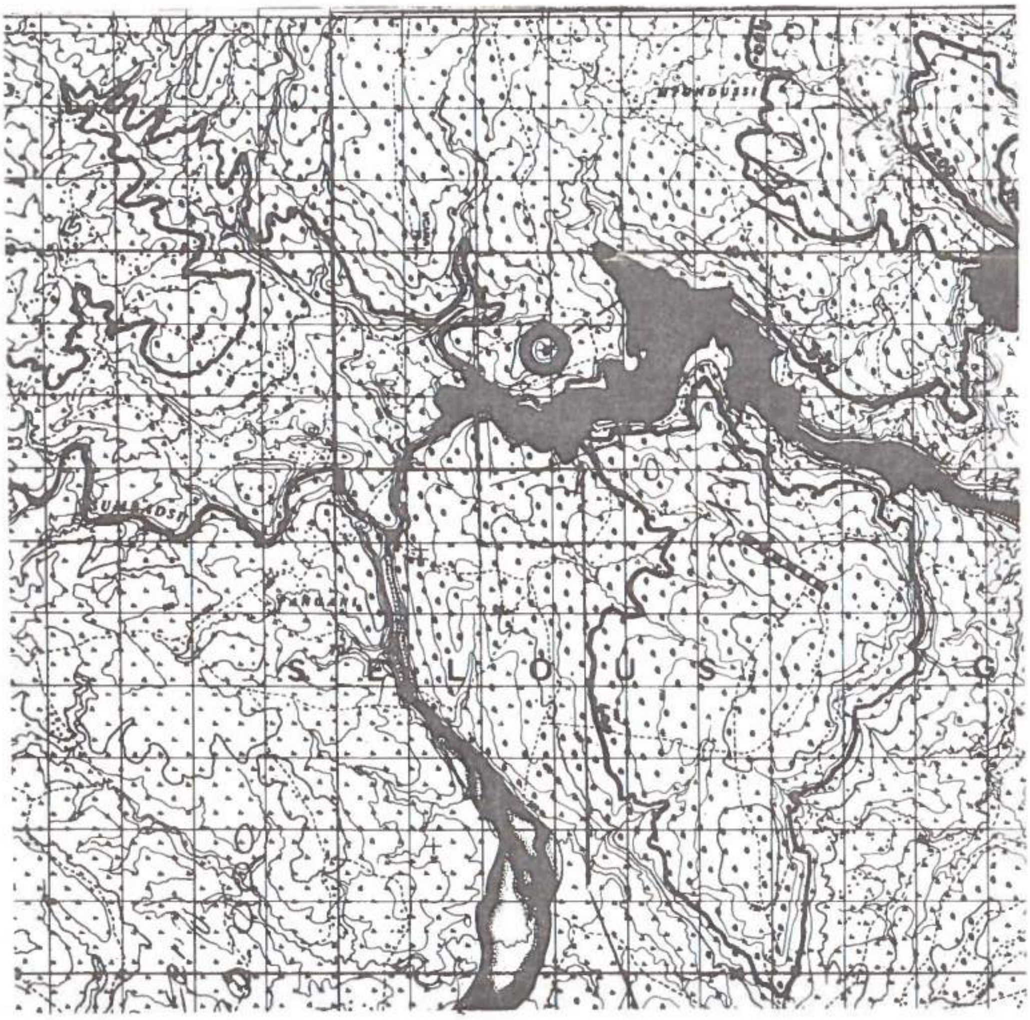

Fig. 4.3 Suggested location for the Central Recording Station (CRS) near the main camp at Stiegler's Gorge. The black area is green on the original map, indicating forested land. Map scale 1:100000.

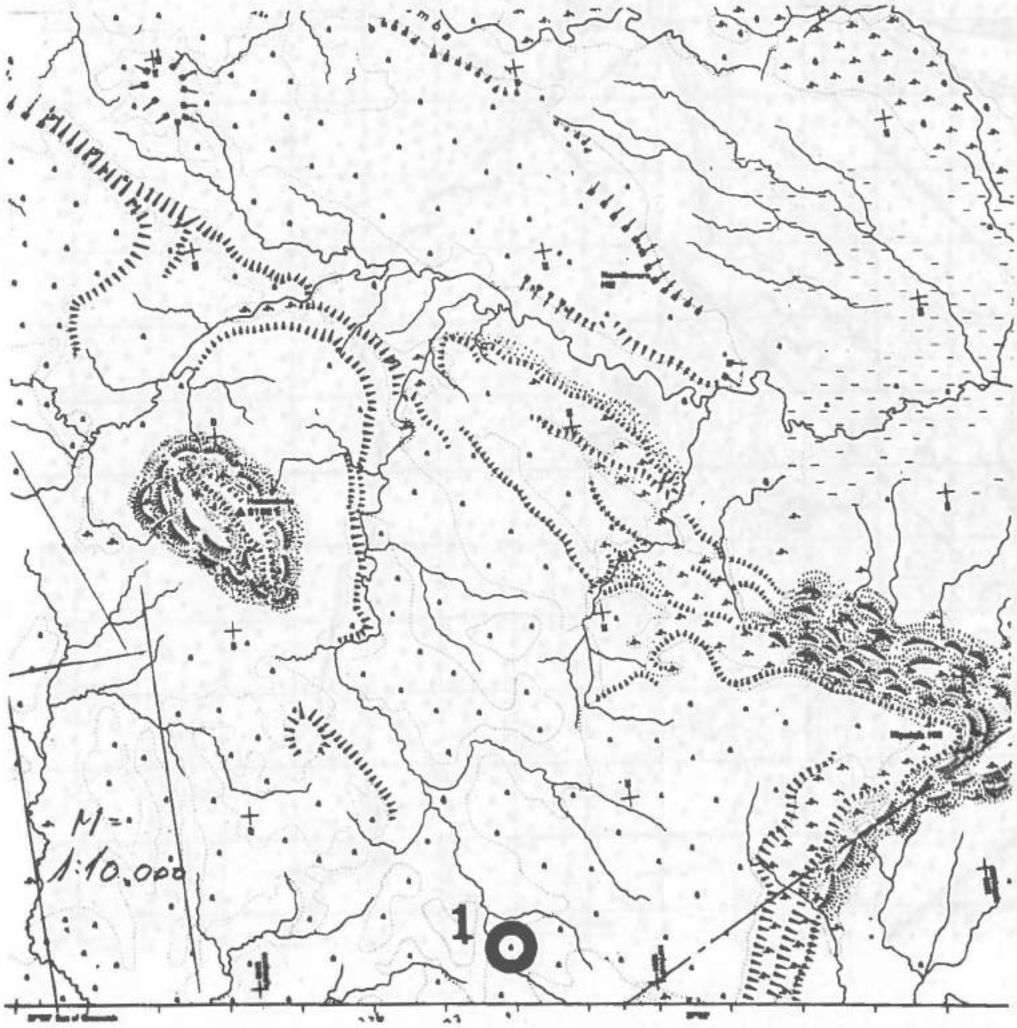

Fig. 4.4 Suggested location for SGSN seismometer no. 1. Map scale 1:100000.

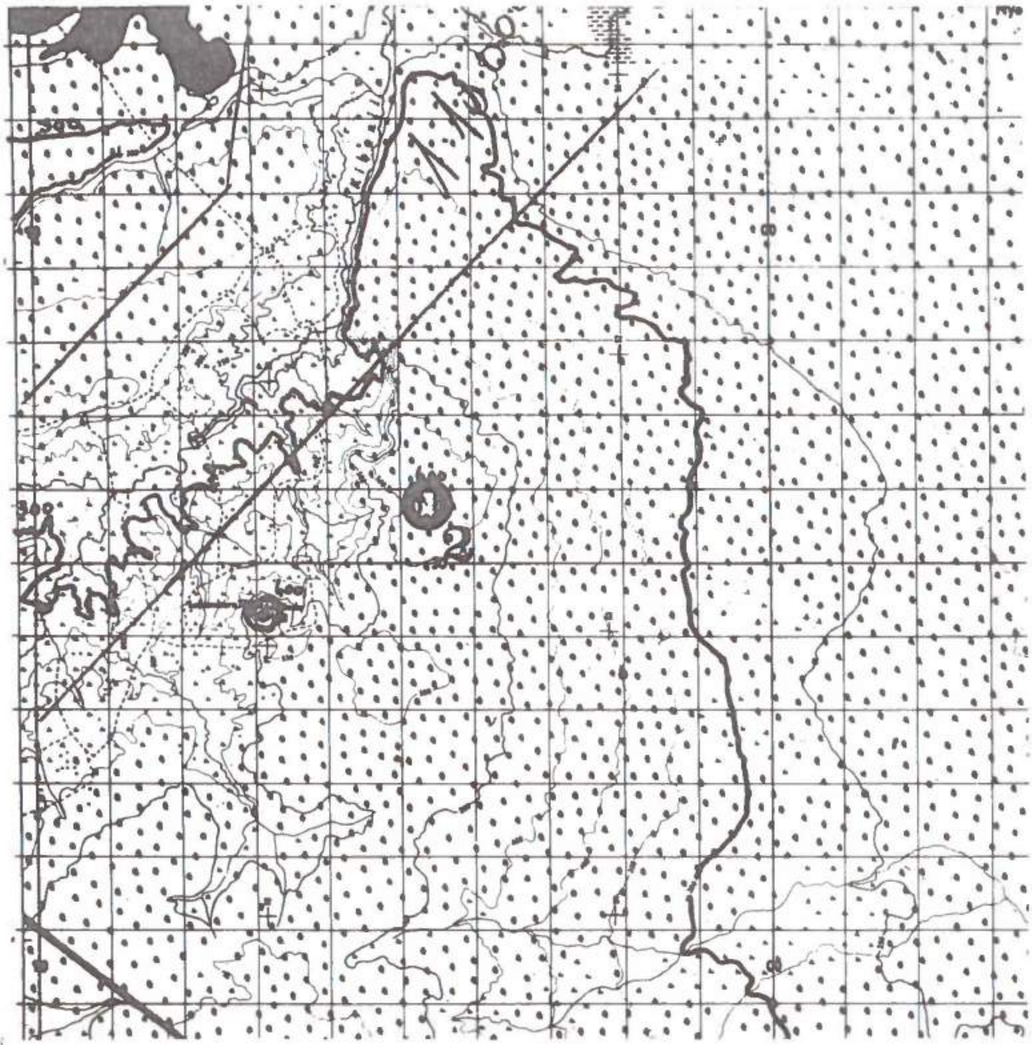

Fig. 4.5 Suggested location for SGSN seismometer no. 2. Map scale 1:100000.

Seismometer no. 3 (Fig. 4.6). The only problem we can see with this site is the possibility of being shadowed by the hilltop 5-7 km from CRS. In that case, the site could be moved in the SSW direction.

Seismometer no. 4 (Fig. 4.7). This is the most problematic of the sites. There will be no telemetry problems, but with a water level of 600 ft the site will be practically flooded. Moreover, a water level that high will require saddle dams and consequently construction activities in the immediate vicinity of the sensor. The reason why we then still propose a site there is its essential location with respect to the reservoir and the dam, being the center instrument of the array. Moreover, if we plan for, say, several years of both pre- and post-impounding data recording, the site will be of limited use (during the construction period) only for a relatively small part of its lifetime.

Seismometer no. 5 (Fig. 4.8). It is seen from Table 4.2 that this site is proposed at a distance of 53 km from the CRS, and it could therefore require more power than the others. Moreover, there could be problems with the line of sight. However, since the southern part of the reservoir is not as well covered in our proposal, this is also an important site.

Seismometer no. 6 (Fig. 4.9). We do not see any problems with this site, except that a somewhat less exposed location possibly should be found.

Seismometer no. 7 (Fig. 4.10). The location of this site is as uncertain as no. 1, and for the same reason. It does not seem, however, as if there should be many problems with the line of sight. A location somewhat farther away could be of interest, and especially if no. 1 is moved NW.

4.5 Concluding remarks

It should be kept in mind when the sites are finally selected that various seismological capabilities of the array will not be significantly affected if any one of the seismometers is moved within a radius of, say, 4-6 km from the suggested location. That should give some capabilities to make allowance for factors which we at this stage have not been able to consider.

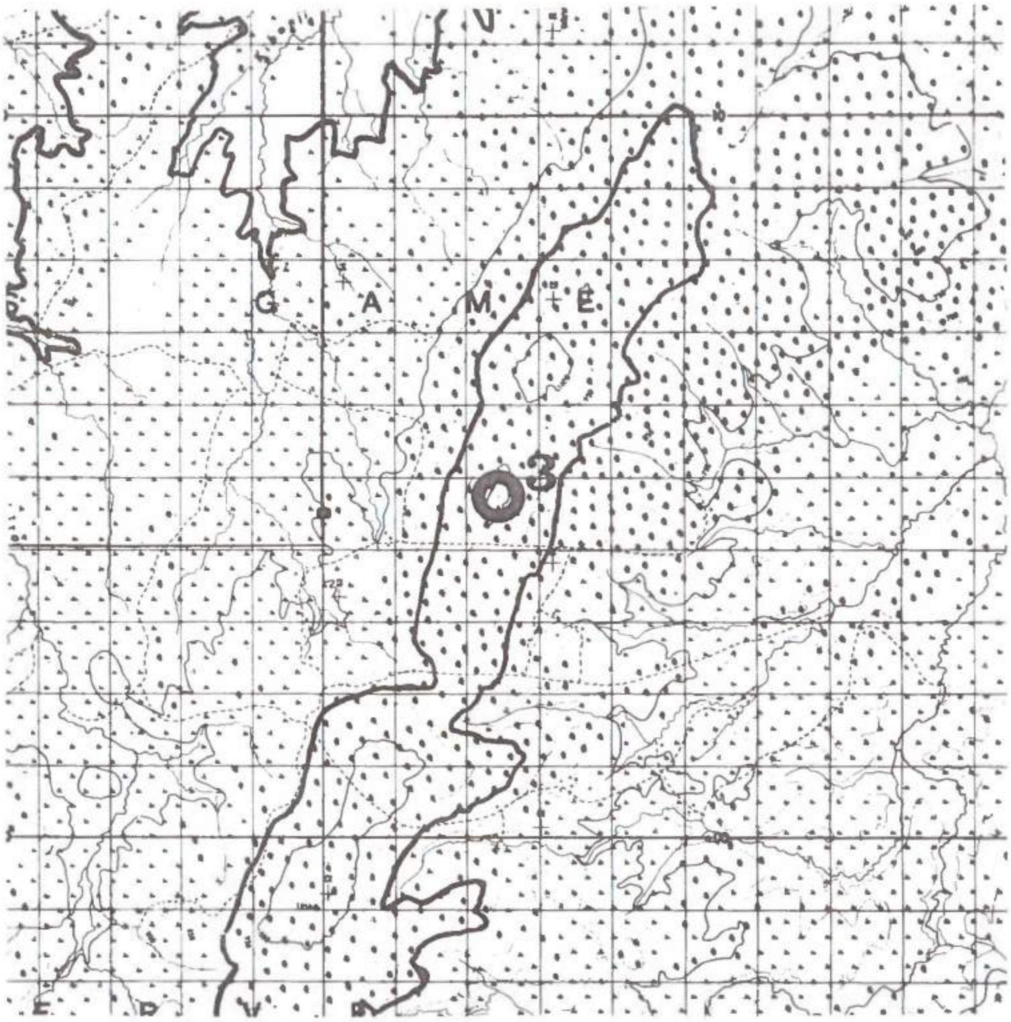

Fig. 4.6 Suggested location for SGSN seismometer no. 3. Map scale 1:100000.

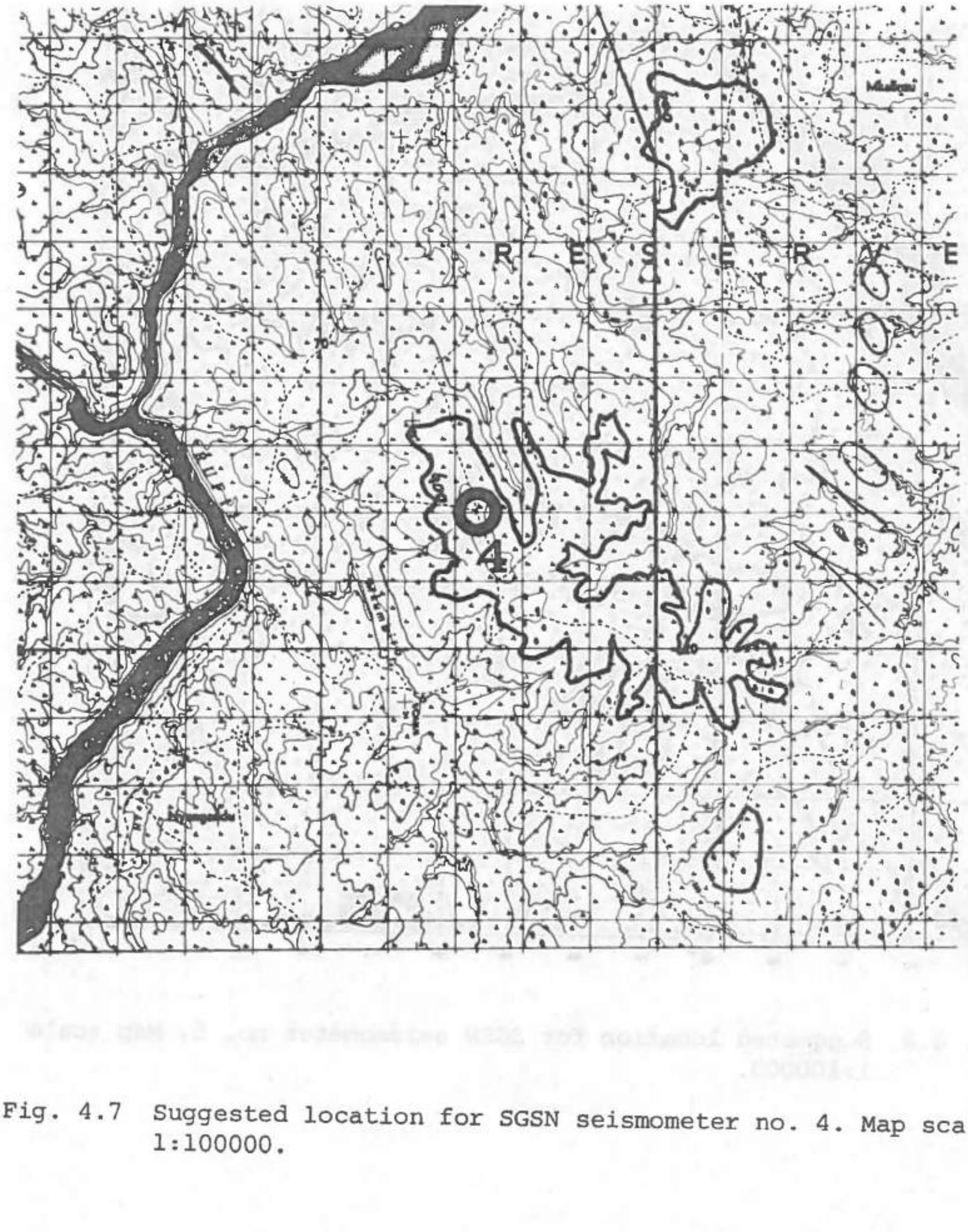

Fig. 4.7 Suggested location for SGSN seismometer no. 4. Map scale 1:100000.

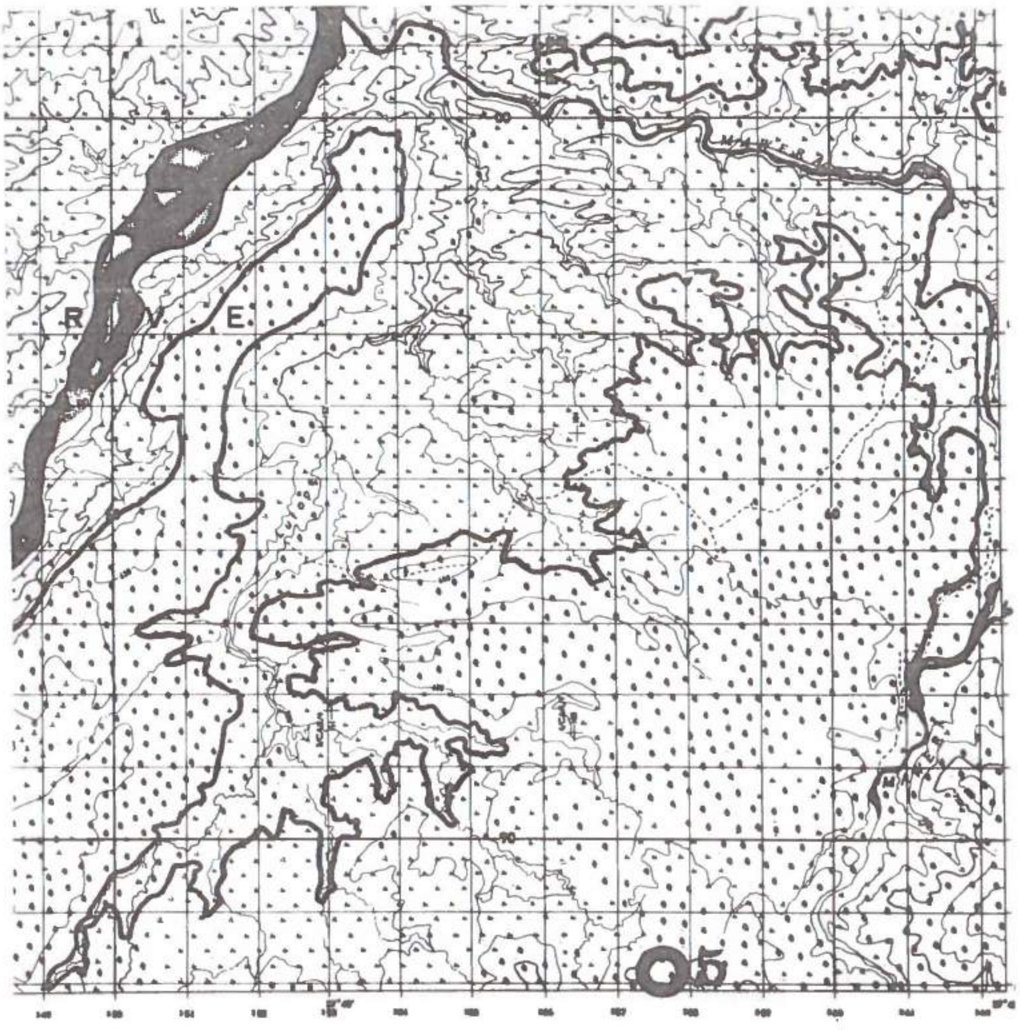

Fig. 4.8 Suggested location for SGSN seismometer no. 5. Map scale 1:100000.

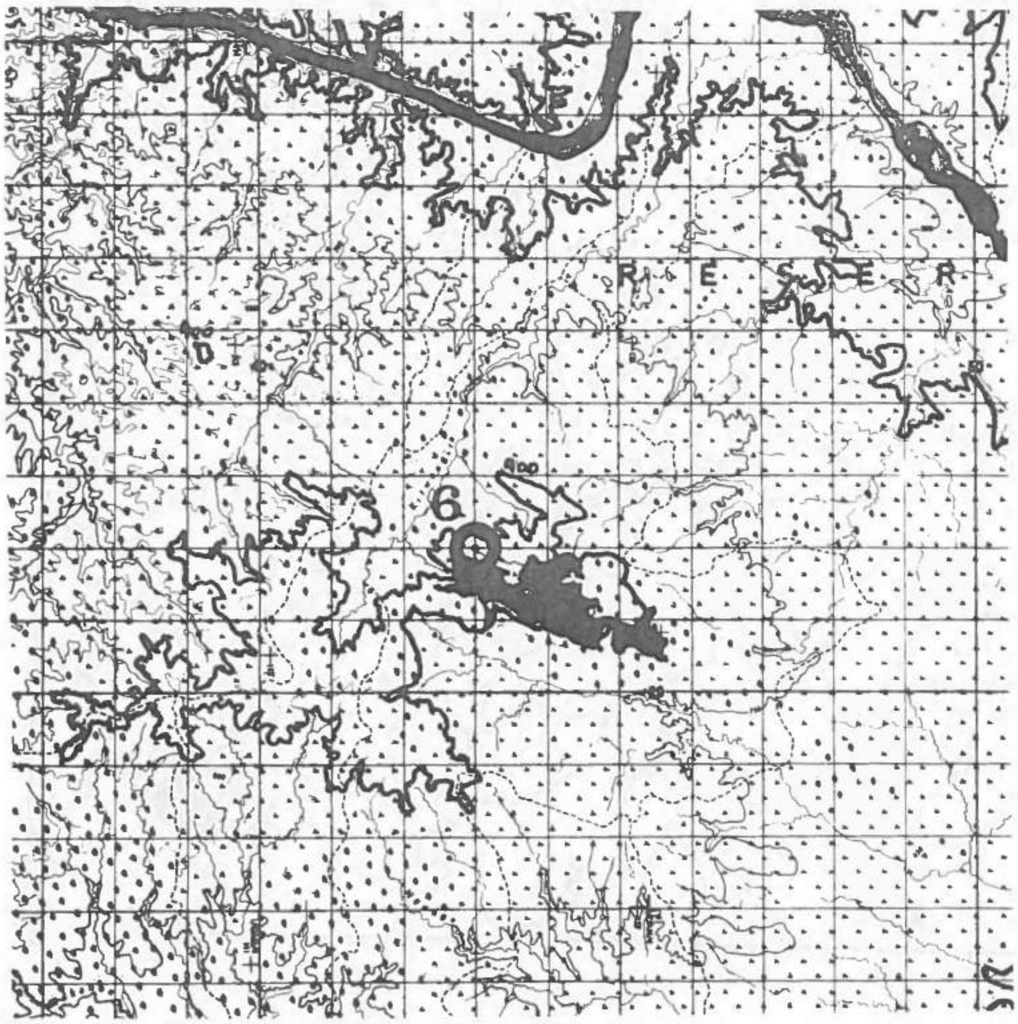

Fig. 4.9 Suggested location for SGSN seismomter no. 6. Map scale 1:100000.

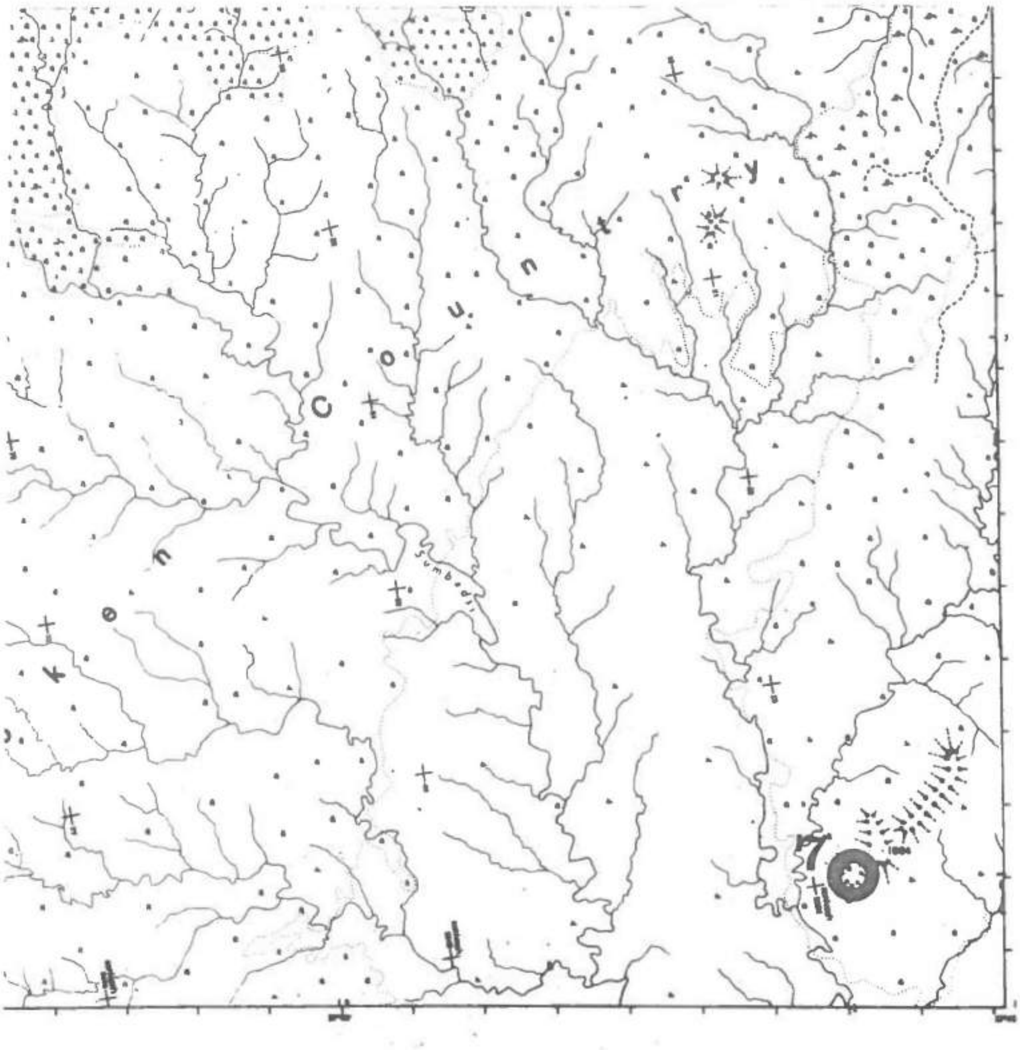

Fig. 4.10 Suggested location for SGSN seismometer no. 7. Map scale 1:100000.

A more important possible modification is tied to the solution chosen for the recording at CRS. The seven channel array proposed here has been designed primarily from seismological considerations, i.e., to obtain a sufficiently reliable seismic surveillance of the area with a minimum number of sensors. However, if the suggested (see Chapter 5) 8-channel recording unit is chosen for the CRS, one should consider installing one more seismometer. A natural re-distribution of sites will then be to move no. 6 SW (see Fig. 4.2) to somewhere around $8^{\circ}04'$S, $37^{\circ}31'$E, and to install a new seismometer somewhere around $7^{\circ}49'$S, $37^{\circ}34'$E. The resulting 8-sensor array is then more balanced with respect to coverage of the reservoir, having 3 sites on each side of the lake, one in a central position, and one beyond the dam. This solution is presented in Fig. 4.11.

Another possible and maybe more important alternative for the exploitation of an 8-channel recording system is to record one of the seismometers also at low gain. This is to prevent overloading by the larger events, and is indeed quite an important option. Any one of the seven seismometers could be used here, since the purpose is only to provide a means of measuring magnitudes also for larger events.

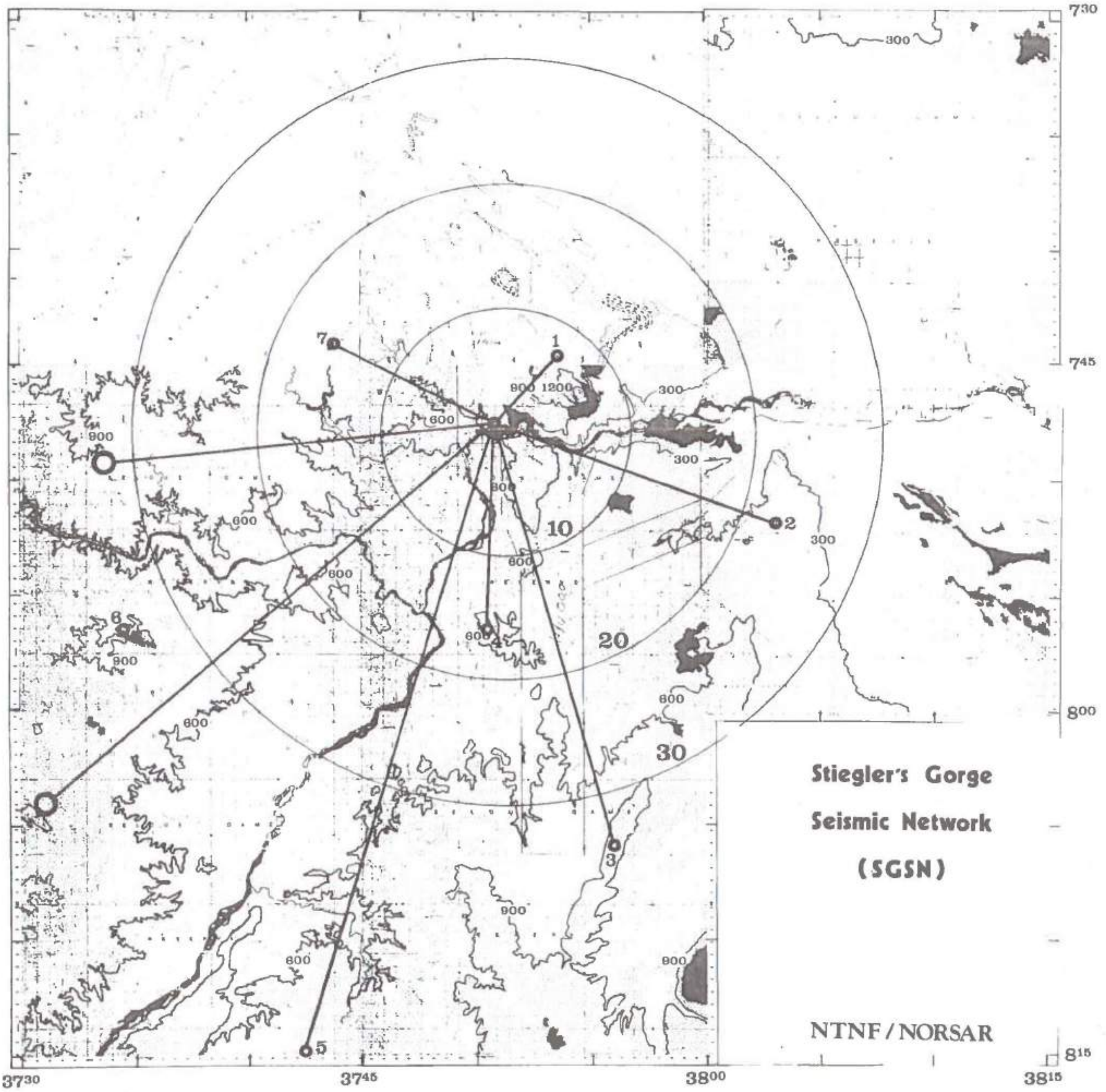

Fig. 4.11 An alternative solution for the configuration of SGSN, based on 8 seismometers. Map scale 1:500000.

5. NETWORK INSTRUMENTATION

For the purpose of this report, a number of manufacturers of seismological equipment were approached in order to find out what could be available for the instrumentation of the Stiegler's Gorge Seismic Network. Also, seismologists with personal experience in microearthquake surveys were contacted (and reports were studied, of course) in order to obtain independent opinions on the feasibility and the reliability of the various systems.

5.1 General considerations

Two of the most essential requirements on instrumentation are as follows (see, e.g., Bolt and Hudson, 1975; Adams et al, 1973):

1. The instrumentation should be as physically reliable as possible, and one should be able to keep it operational for 5-10 years.
2. The instrumentation should be of high quality, and give as good data analysis flexibility as possible.

These two requirements are partially conflicting because a system with the highest level of operational stability quite often is not the one with the highest level of sophistication, and a tradeoff between these factors is therefore normally required. With respect to operational stability and reliability, it is always a point to look for systems with a satisfactory field performance, and which already have been tested under different physical (environmental) conditions. Moreover, the level of sophistication one can choose is clearly dependent on the technical competence of the operational staff. It is in this respect essential that the purchaser is willing to pay for, and the manufacturer is able to offer, both a supervision of the installation and a training program for the personell in charge of the daily operations.

We stress at this point that the microearthquake systems discussed in this section are not claimed to constitute a complete survey of available instrumentation. Rather, we have attempted to cover solutions which are logistically different, and then select the one alternative within each category which appears to us to be most appropriate for the SGSN. The corresponding cost estimates are those given by the manufacturer for that particular system.

5.2 Self-contained units

Analog systems

The traditional and most widely used solution for earthquake monitoring systems is based on independent units with analog recording on paper. This is clearly the system with the best operational stability, and it is usually also the least expensive one. An instrument which may be recommended here is the Sprengnether MEQ-800, which seems to have several superior qualities. It is (relative to similar analog units) a light-weight, compact unit with high data quality and modest power consumption; it has good timing and calibration capabilities; and it can, with a low drum speed, record for up to one week on the same piece of paper (giving very poor time resolution, of course). Moreover, the MEQ-800 has been successfully used in micro-earthquake studies in many parts of the world. The manufacturer's presentation of the system is included in Appendix A, and prices are given in Chapter 8.2.1.

Digital systems

We have been able to find only one commercially available system of this type, namely, the Sprengnether DR-100, a system based on event triggering and recording on casettes. One of the critical factors here is again the data storage capacity. Even if recording is done only upon triggering, the capacity of each digital casette is quite limited, and the system can only be recommended if relatively frequent visits can be made to each site. The manufacturer's presentation of the system is included in Appendix B, and prices are given in Chapter 8.2.2.

5.3 Telemetry systems

Systems based on data transmission using (radio) telemetry and central data recording can also be divided into analog and digital systems, although analog paper recording in this case is usually no longer a viable approach. However, the field system (including data transmission) would not have to be different in the two cases, and the main line would have to be drawn between solutions where (1) all data are recorded centrally on analog tape, or (2) selected time intervals (from an event triggering system) are digitized and recorded automatically on digital tapes or casettes.

In each case one has to acquire a suitable number of radio frequencies from the telegraph authorities in Tanzania. According to discussions with Hafslund A/S, the lowest frequency should be 160.25 MHZ, and the other frequencies should be higher in steps of 50 KHz (160.75 MHz, 161,25 MHz,... etc.). The manufacturer must know these frequencies before radio transmitters and receivers are built.

We have found that the following three systems each satisfy our general requirements:

(1) A complete system from Racal-Thermionic, based on data recording using their analog Geostore tape recorder (Appendix C).

(2) A complete system from Kinemetrics, based on selected data recording using their digital DDS-1105 Data Acquisition System (Appendices D, E and F).

(3) The same field system from Kinemetrics, but based on data recording using the analog Geostore tape recorder (Appendices D, E and F).

Price information for these systems is given in Chapter 8.2.3, where the price for alternative (3) is obtained by the proper combination of subtotals. It is noteworthy here that (3) is a complete solution offered by Kinemetrics, only that they use the Geostore recorder (see Appendix E). Our recommendation (see below) is for alternatives (2), (3) and (1), and in that order.

5.4 Strong-motion instrumentation

Strong-motion accelerographs are also available both with analog and digital recording, always with a triggering system. We see no reason for recommending a digital solution in this case, and moreover, the analog systems are presumably more stable operationally. Our recommendation is for the Kinemetrics SMA-1. A manufacturer's presentation of the system is included at the end of Appendix F, with price information in Chapter 8.2.4.

5.5 A suggested solution

We will now present and discuss our alternatives in some more detail.

Alternative 1

Our recommendation for the instrumentation of the Stiegler's Gorge Seismic Network is to go for a package solution of the type offered by Kinemetrics, using their digital DDS-1105 Data Acquisition System. Of primary importance for our choice is that a digital solution is very much desired, because of the much greater flexibility in the subsequent analysis of the data (see Chapter 7). A prerequisite for this, of course, is that the analysis is done in an institution with the proper competence and experience within processing and analysis of digital seismic data.

One of the problems in suggesting a digital system is that it will imply a delay of probably at least 2-4 weeks in the basic analysis of the data. This could create difficulties because (1) a possible rapid increase in seismicity during the period of impounding will be detected only with a delay of at least one month, and because (2) there will be a similar delay in the feedback of information regarding the quality of the recorded data. However, the same problem will be present if a solution with analog tape recording is chosen, as long as the data analysis is not done locally.

It is because of this problem that we have suggested (see Chapter 8.2.3) buying a Direct Write Recorder to be installed at the Central Recording Station. One should have the option of plugging any one of the channels (in parallel with the tape recording) to this recorder, in order to (1) regularly control that sound seismic data is received from the seismometers, and (2) to have a rough means of checking the earthquake activity with no delay in time. It would, for partly the same reason, be of considerable advantage to have independently a portable seismometer such as the Sprengnether MEQ-800 in the area. If that unit arrived at the scene some time before the main system, it could also be used in the final survey of the sites in order to check out possible noise level differences.

Another problem in suggesting a digital system is that it is, being the one with the highest level of sophistication, presumably more susceptible to operational problems and failures than the simpler solutions. It is therefore important to find out if the basic environmental conditions for the DDS-1105 can be fulfilled in the Stiegler's Gorge area, and the manufacturers should be asked independently of their opinion in this respect. If this solution is chosen, we recommend the installation of 7 seismometers as suggested in Fig. 4.1, with the 8th channel used for parallel low gain recording from one of the sensors.

Alternative 2

If the suggested digital solution for some reason could not be used, we recommend replacing the digital unit with an analog tape recorder, e.g., of the Geostore type, as suggested by Kinemetrics. It should not be assumed, however, that the restrictions on the environmental conditions are less in this case. With the Geostore recorder there would be 14 channels available for seismic data, in which case we recommend an 8-seismometer array as suggested in Fig. 4.11, with a 9th channel used for parallel low gain recording from one of the sensors.

Alternative 3

Only as a third alternative do we suggest a package solution similar to that offered by Racal-Thermionic.

Both of the analog alternatives are based on the Geostore recorder, in which case fairly expensive equipment for signal analysis would be needed (see Chapter 8.2.3). Even with that, one would be nowhere near the data analysis flexibility of a digital system.

Strong-motion accelerographs

We recommend four strong-motion accelerographs of the Kinemetrics type SMA-1 to be installed at various points in the dam itself. Two of these should be located to record earthquake motions at the foundation, and two to monitor dam response (Bolt and Hudson, 1975). Since these instruments cannot become operational before the dam is completed, we recommend that one strong-motion instrument be installed as soon as possible near the main camp, in order to record possible large events up to the time of construction. It is evident that this could give important data with implications on the design and the dimensioning of the dam.

Conclusion

In short, we recommend:

(1) acquisition of one portable seismograph (e.g., Sprengnether MEQ-800-B) as soon as possible (autumn 1977). Cost about N.kr. 27 000 (see Chapter 8.2.1).

(2) installation of one strong-motion accelerograph (e.g., Kinemetrics SMA-1) as soon as possible (autumn 1977). Cost about N.kr. 11000 (see Chapter 8.2.4).

(3) installation of a Kinemetrics Seismic Monitoring System (or equivalent system) with digital data recording (spring 1978). Cost about N.kr. 495000 (see Chapter 8.2.3).

The costs for these and other alternatives are given in Chapter 8, where also the operational costs are discussed.

6. NETWORK EVALUATION

Many recent studies have successfully demonstrated the capabilities and the potentials of small-scale seismic networks in investigating microearthquake activity and various structural properties of the area in the immediate vicinity of the stations (Seeber et al, 1970; Hadley and Combs, 1974; Pennington et al, 1974; Menke and Jacob, 1976; Rogers, 1976; Stauder et al, 1976; Armbruster et al, 1977; Combs and Hadley, 1977). We will now briefly discuss the expected potentials of the Stiegler's Gorge Seismic Network as it has been proposed in the previous chapters of this report.

6.1 Simulation of events

In order to get some idea about the kind of data one could expect to record within the SGSN, a simulation experiment has been conducted. We have found a subset of the NORSAR arrray with (after translation and rotation of coordinates) approximately the same configuration as SGSN. The NORSAR seismometers used are identified in Table 6.1 and plotted together with the SGSN seismometers in Fig. 6.1. Local events within the NORSAR area (see Bungum et al, 1971a; Bungum and Husebye, 1974) are quite scarce, but we have found the three given in Table 6.2. The seismograms from Event 1, which is an explosion within the array, are reproduced in Fig. 6.2 It is seen that the travel distances are between 6 and 58 km. Event 2 (Fig. 6.3) and Event 3 (Fig. 6.4) are local earthquakes outside the array, with travel distances between 40 and 94 km, and between 110 and 161 km, respectively. Our examples consequently cover 21 travel distances ranging from 6 to 161 km, and should therefore be a good illustration also of what one should expect to record with the proposed array in the Stiegler's Gorge area. The differences between crustal structures in the two areas will of course lead to certain differences between the seismic records (such as in frequency content). However, the basic composition of the seismograms will be as shown in Figs. 6.2-6.4, dominated by the arrival of the P and S waves.

The examples given here can serve as good illustrations of two basic problems in the analysis of such local data:

SGSN No.	NORSAR Seismometer No.	Name	NS (km)	EW (km)
01	23	03B05	11.4	20.4
02	2	01A02	-2.0	3.5
03	47	07B05	14.4	-20.2
04	10	01B04	21.0	-4.4
05	132	14C00	40.5	-30.2
06	57	02C03	46.8	-0.1
07	13	02B01	25.3	24.9

Table 6.1 Correspondence between the Stiegler's Gorge Seismic Network and a subset of the NORSAR array with about the same relative configuration. A translation as well as a rotation was needed in order to obtain the match.

Event	Date	NORSAR location NS	EW	SGSN location NS	EW	Source
1	18 Sep 75	-1.0	10.0	-13	9	Explosion
2	23 Nov 76	-28.6	33.4	26	41	Earthquake
3	01 Oct 73	-108.6	31.2	38	120	Earthquake

Table 6.2. Date and relative location of the three NORSAR recorded events used for simulating real seismic data recorded at the Stiegler's Gorge Seismic Network.

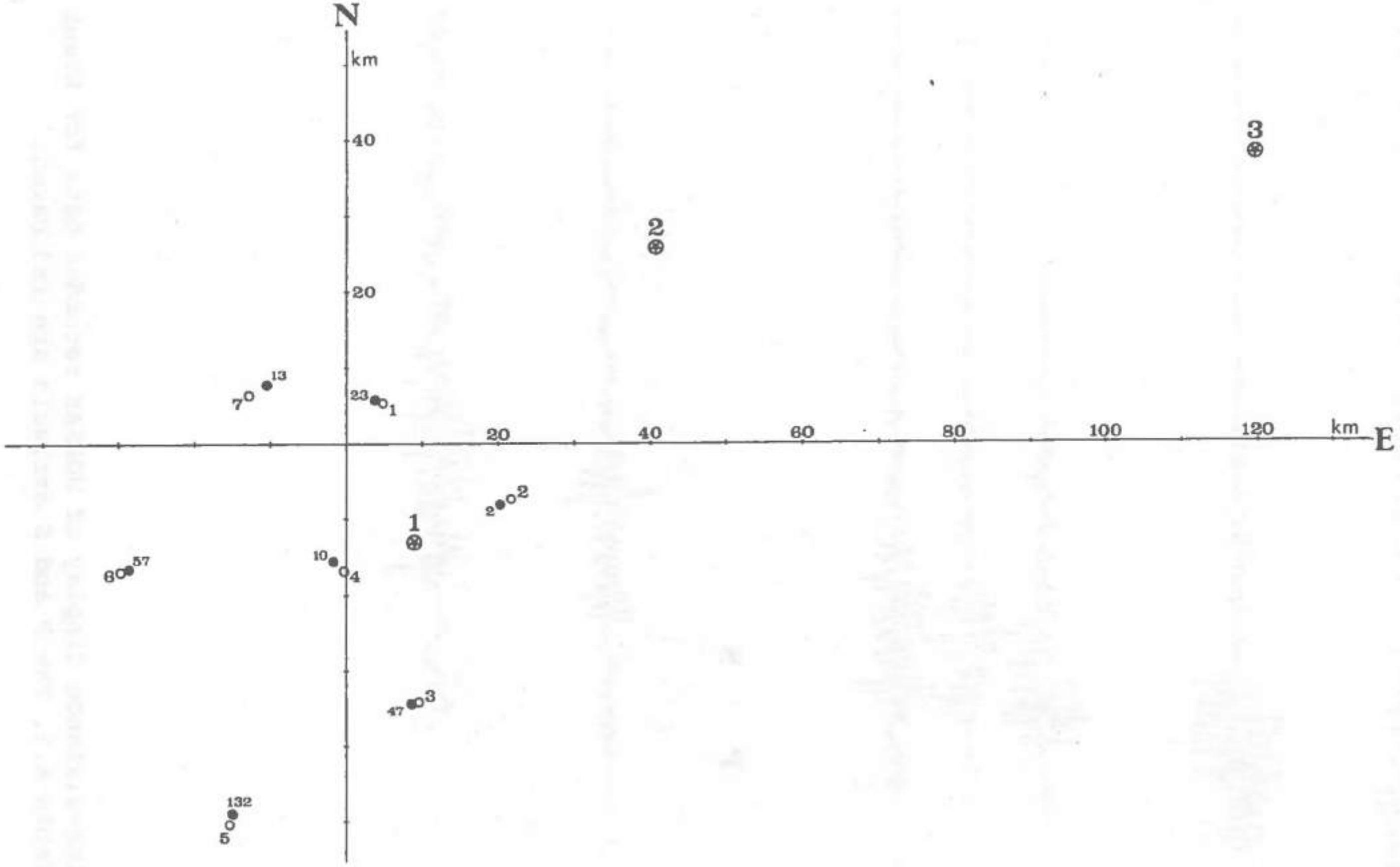

Fig. 6.1 Locations of the SGSN seismometers (open circles) and NORSAR seismometers (closed circles) used for the simulation of events. The epicenters of the 3 events displayed in Figs. 6.2-6.4 are also given.

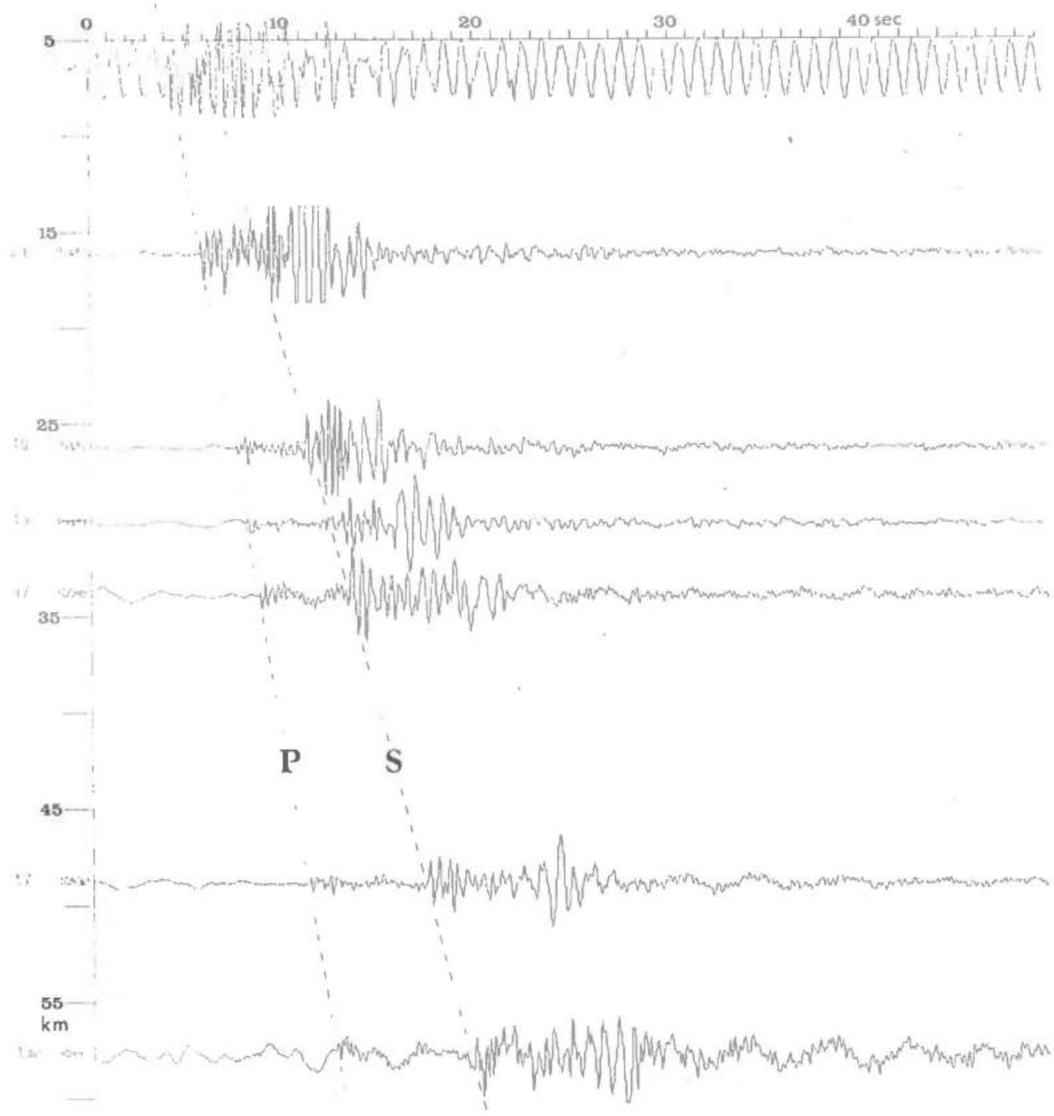

Fig. 6.2 A time-distance display of NORSAR recorded data for Event 1 in Table 6.2. The P and S arrivals are indicated.

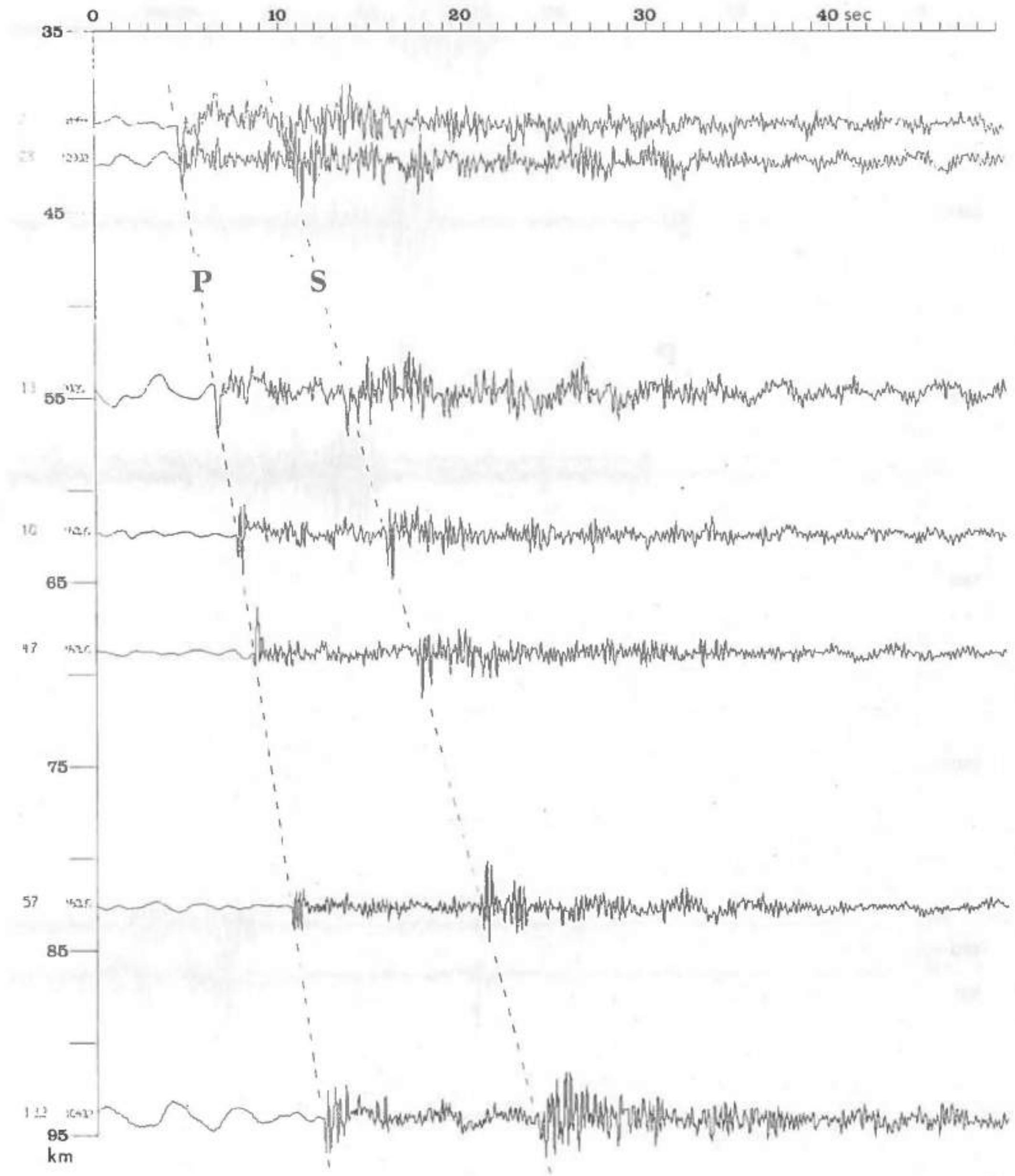

Fig. 6.3 A time-distance display of NORSAR recorded data for Event 2 in Table 6.2. The P and S arrivals are indicated.

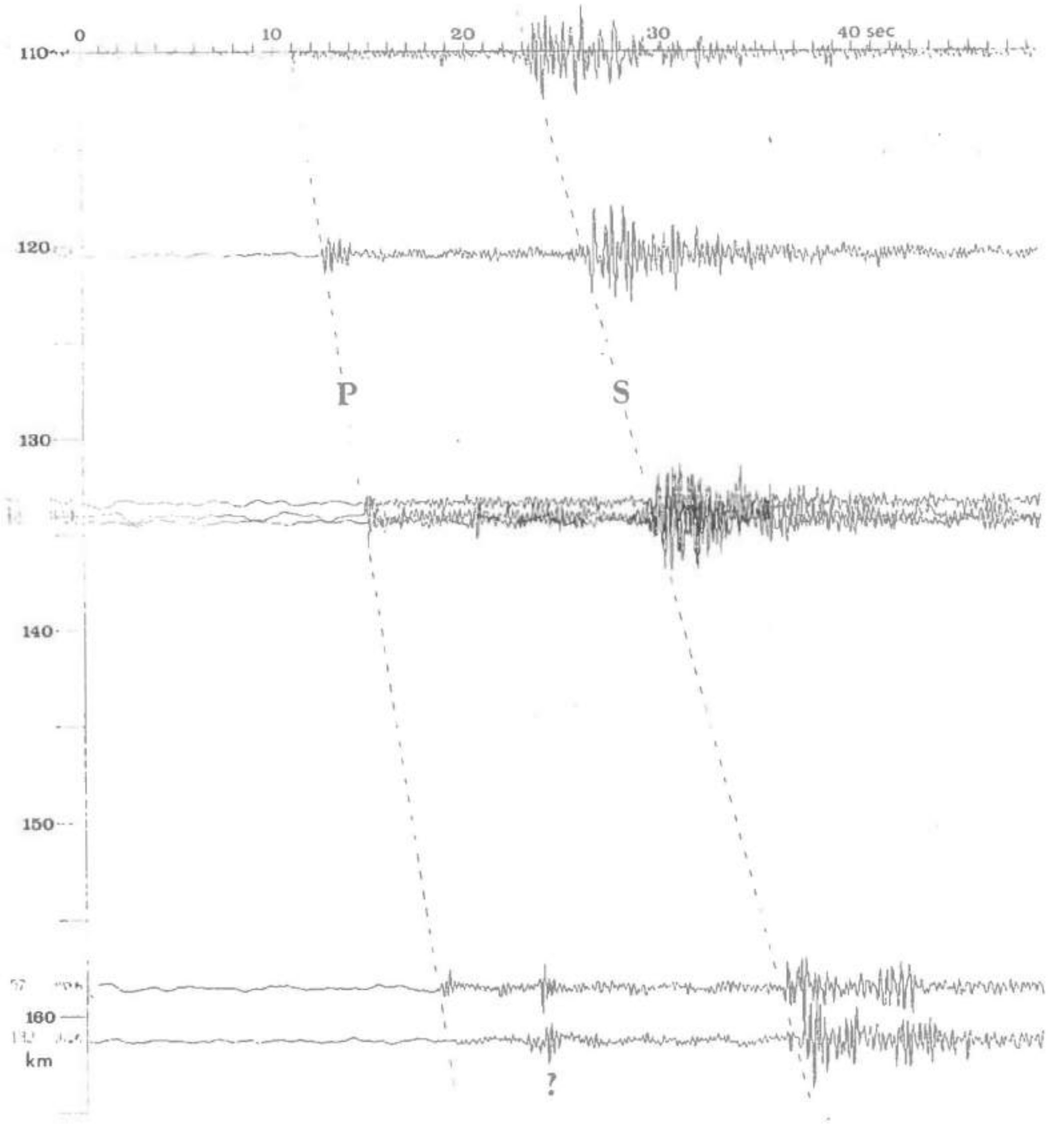

Fig. 6.4 A time-distance display of NORSAR recorded data for Event 3 in Table 6.2. The P and S arrivals are indicated.

The first problem is that there is (practically) no way in which a local explosion (Fig. 6.2) can be discriminated from a local earthquake (Figs. 6.3-6.4). This means that it is absolutely necessary that reliable records are kept of all blasting in the area after the seismic instrumentation is installed, and that this information is available at the time the data are analyzed. This will serve not only as a source of event identification, but it will also be important for a proper calibration of the area, i.e., for the derivation of crustal models important for the precision with which earthquakes can be located.

The second problem is tied to the difficulties in identifying phases (P and S) properly, and to determine their times of arrival. This problem is complex and has not only to do with the quality (time resolution, signal-to-noise ratio, etc.) of the seismic records (see, e.g., Bungum and Husebye, 1971), but it is also involved with the effects caused by structural deviations from the usually assumed homogeneous and isotropic, horizontally stratified crust (see, e.g., Ringdal and Husebye, 1977). We will return briefly to this problem in Chapter 6.3.

6.2 Detectability

The detectability of a seismic network such as the one proposed for Stiegler's Gorge is very difficult to estimate because there are many unknown factors of great influence in this respect. Some of these are:

Noise level

This factor is practically unknown at present. It is known that the average seismic background noise of the earth normally is in the range of 1 to 10 nanometers at 1 Hz, a variation which means one whole magnitude unit expressed in detectability. Moreover, considerable temporal variations in the noise level should be expected (Ringdal and Bungum, 1977), especially on account of the proximity of the array to noise sources in the Indian Ocean (see, e.g., Bungum et al, 1971b).

Signal enhancement/noise suppression capabilities

With high quality digital recording simple methods are available by which a signal-to-noise ratio of 10-20 dB above that of a paper seismogram can be obtained. However, an automatic digital detection system (such as the proposed Kinemetrics system) would have to operate with fairly high thresholds in order to avoid too many false alarms. For NORSAR, these thresholds are in the range 10-12 dB, corresponding to signal-to-noise ratios in the range 3-4. There is consequently a notable difference between the operational level of detectability and the optimal capability of signal enhancement provided prior knowledge about the event (Bungum and Husebye, 1974). In the case of analog tape recording some sort of detection system would have to be developed using the playback system, with the detectability depending on the amount of work put down in this process.

Local magnitudes

A given claim on detectability may depend significantly both on method of measurement (Ringdal, 1975; Berteussen et al, 1976) and on method of magnitude estimation (Ringdal, 1976). The latter point is especially important for local studies (Lee et al, 1972; Thatcher, 1973; Stewart, 1975), and it is therefore quite important that a local magnitude scale be derived for the Stiegler's Gorge area.

It is because of the complications just discussed that we want to be careful in estimating an expected detectability for SGSN with regard to local events. However, if we expect a performance similar to what has been claimed under roughly similar conditions (Menke and Jacob, 1976; Stauder et al, 1976; Combs and Hadley, 1977), we should be able to detect most of the events within the area of the network having a magnitude above zero. A detectability down to $M_L=1$ could safely be assumed.

6.3 Location capability

The location capability is easier to estimate than the detectability, even though it depends also here on several factors:

Timing

Since seismic velocities are in the range 3-6 km/s, significant location errors are introduced with timing errors in excess of 0.1 s. If daily calibrations against radio time signals are possible, a crystal clock with a stability of $1:10^7$ would be sufficient.

Network coordinates

For similar reasons, station coordinates should be known with an accuracy better than 100 m.

Network geometry

This source of error (Sato and Skoko, 1965; Peters and Crosson, 1972; Adams et al, 1973) arises when changes in hypocenter location have little effect on the relative onset times at some or all of the receiving stations. A uniform and symmetric distribution of stations is normally to be recommended.

Reading accuracy

This is one of the main sources of location errors. The problem is quite complex because it cannot (as sometimes assumed) be removed simply by improving the signal-to-noise ratio of the recordings. The arrival time of a clear onset can easily be measured with an accuracy better than 0.1 s, the problem is only that other onsets are not so clear, and that the picked arrival times are not consistent with a plane wavefront. Such wave scattering effects are caused by local structural irregularities in the crust (Dahle et al, 1974; Aki and Chouet, 1975; Berteussen et al, 1975; Aki and Lee, 1976), and they have a significant impact on the precision with which the hypocenter of a local event can be determined. Even though a more dense distribution of stations would give better examples, there are some clear ones to be found also in Figs. 6.2-6.4: (1) relative differences between S-arrival times between channels 3 and 4 (from top) in Fig. 6.2; (2) the poor P-wave onset for channel 4 in Fig. 6.2; (3) the difficult S-wave onset for channel 3 in Fig. 6.3; and (4) the differences between the P-wave onsets for channels 6 and 7 in Fig. 6.4, with a secondary P-arrival emerging. This problem of reading accuracy is mixed up with the next point.

Velocity (crustal) models

In the absence of any detailed knowledge about crustal structure, this would be the most severe source of error. Even with such knowledge it would be a significant source of error because of the scattering effects and the inhomogeneities mentioned above. It is therefore necessary that a local crustal study be conducted after installation of the array, using explosions for which both time and location are accurately known. Some of the explosions used in the construction could also be used for this purpose, provided a timing system is set up.

For the purpose of this report, we have tested by simulations the location accuracy of the SGSN, given certain assumptions about the factors discussed above. The process has been the following:

(1) Assume a certain velocity model for the area

(2) Determine a grid of simulated hypocenters both inside and outside of the array

(3) Compute P and S theoretical travel times from each of the hypocenters to each of the stations

(4) Perturb each of the computed travel times by adding random errors with zero mean and a certain standard deviation. To be realistic, these errors must incorporate both timing errors, reading errors and errors in the velocity model

(5) Locate the simulated events using the same velocity model and the computed P and S travel times with errors, and compute standard errors

(6) Plot the standard errors on a map of the area and draw contour lines for equal location accuracy.

Little information is available on the crustal structure in the area of the Rufiji Basin. For the purpose of these simulations, however, that is not a critical point, and we have therefore used a model derived for the rift zone in northern Tanzania (Rykounov et al, 1972; Maguire and Long, 1976). The model assumes a Moho depth of 36 km, the average P velocity in the upper 18 km is 5.8 km/s, in the next 18 km it is 6.5 km/s, and the upper mantle velocity is 8.0 km/s. The S velocities are derived from the P velocities using a ratio of 1.78. For the locations, the computer program HYPO71 has been used (Lee and Lahr, 1976).

We have used a grid of 25 epicenters as shown in Figs. 6.5 and 6.6, where also the stations are indicated. The grid size is 10' or 18.5 km. We have assumed zero depth for all the simulated events, and for each epicenter 5 sets of timing errors have been generated in order to obtain a sufficient statistical stability. The resulting standard errors are averaged over the 5 'events' in each epicenter.

The simulations have been conducted using standard deviations in the arrival time errors of 0.5 and 1.0 s (both in P and S), with results shown in Figs. 6.5 and 6.6, respectively. It has been checked that the plotted standard errors in the locations (computed from the residuals) correspond reasonably well to the real errors (how much the epicenter has been moved). The results show that the SGSN can locate events within the array to an accuracy of about 1 km, assuming timing errors in the order of 0.5 s, with errors between 2 and 2.5 km if the timing errors are increased to 1.0 s. One may argue that timing errors of 0.5-1.0 s are very large, however, since these errors include uncertainties in the velocity model they are certainly realistic at least during the initial stage of the program. Later, as the area gets better calibrated, there should be a chance of reducing the location error inside the array to maybe less than 1 km. A factor pulling in the other direction is, however, that the simulations are performed assuming a known (zero) hypocentral depth. We have reasons to assume that the inclusion of a depth calculation could increase the location error by a factor of two inside the array, and even more outside, where in particular large distance errors could occur.

It is seen in Figs. 6.5 and 6.6 that there is a reasonably azimuth-independent decrease in location accuracy, which means that there are no 'weak spots' caused by the configuration. Since we have only 7 sensors, we should expect, however, that such effects would occur if one or more of the sensors are lost. The results of an investigation of this effect are given in Table 6.1, where two of the epicenters have been recalculated using a decreasing number of sensors. Epicenter 1 is the central point in Fig. 6.5 and epicenter 2 is the one in the lower left corner. It should be noted that we each time have dropped out the sensor which supposedly should have the least adverse effect on the location accuracy, so that Table 6.1 really reflects a best-case experiment.

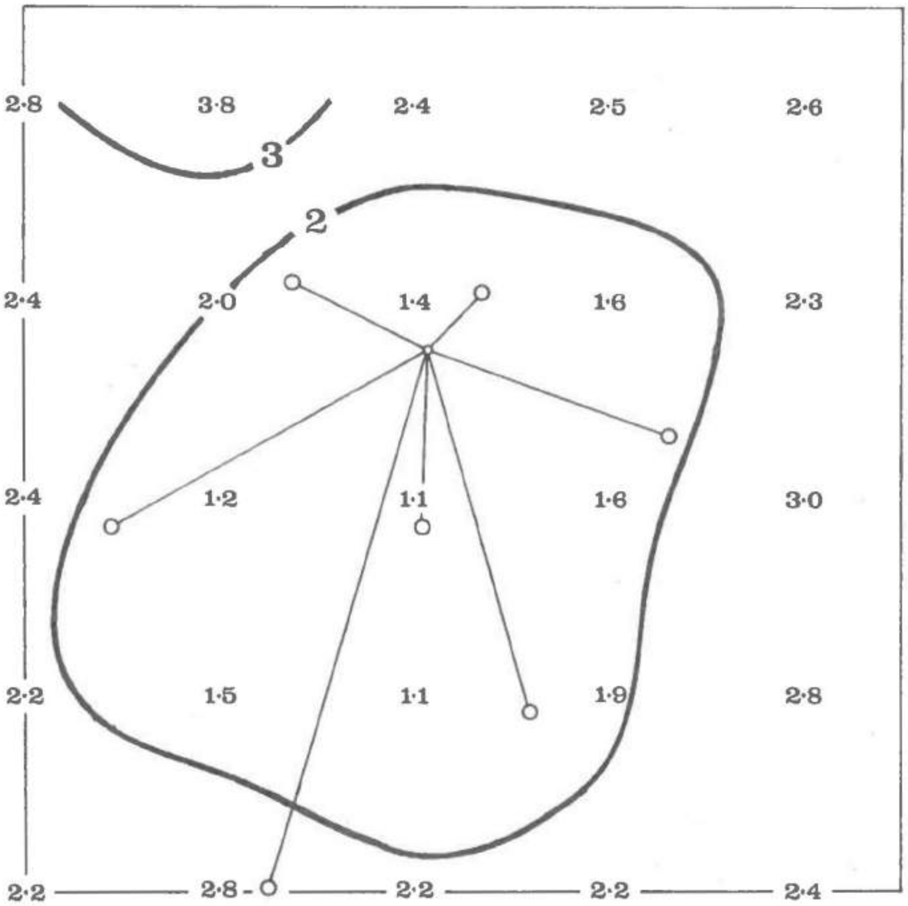

Fig. 6.5 Location accuracy simulation results, with standard errors in km plotted at each epicenter. The results are based on P and S arrival time errors with zero mean and a standard deviation of 0.5 s. The area within the frame is that covered in Fig. 4.1.

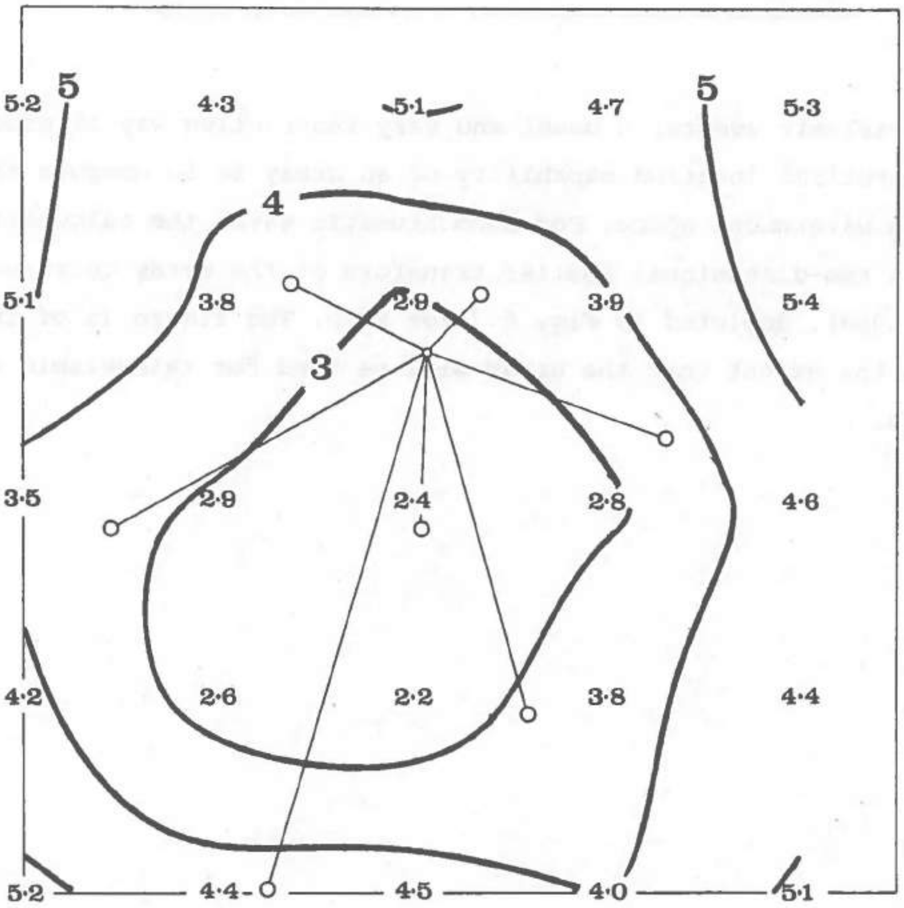

Fig. 6.6 Location accuracy simulation results, with standard errors in km plotted at each epicenter. The results are based on P and S arrival time errors with zero mean and a standard deviation of 1.0 s. The area within the frame is that covered in Fig. 4.1.

Sensors	Location Errors (km)	
	Epicenter 1	Epicenter 2
All 7	1.1	2.2
1,2,3,5,6,7	1.1	2.4
2,3,5,6,7	1.2	2.7
2,3,6,7	1.4	3.3
2,3,6	2.3	4.1

Table 6.1

For teleseismic events, a usual and very instructive way of studying the theoretical location capability of an array is to compute the resolving power in wavenumber space. For monochromatic waves the calculation is simply a two-dimensional Fourier transform of the array coordinates (Burg, 1968), depicted in Fig. 6.7 for SGSN. The figure is of interest only to the extent that the array will be used for teleseismic event analysis.

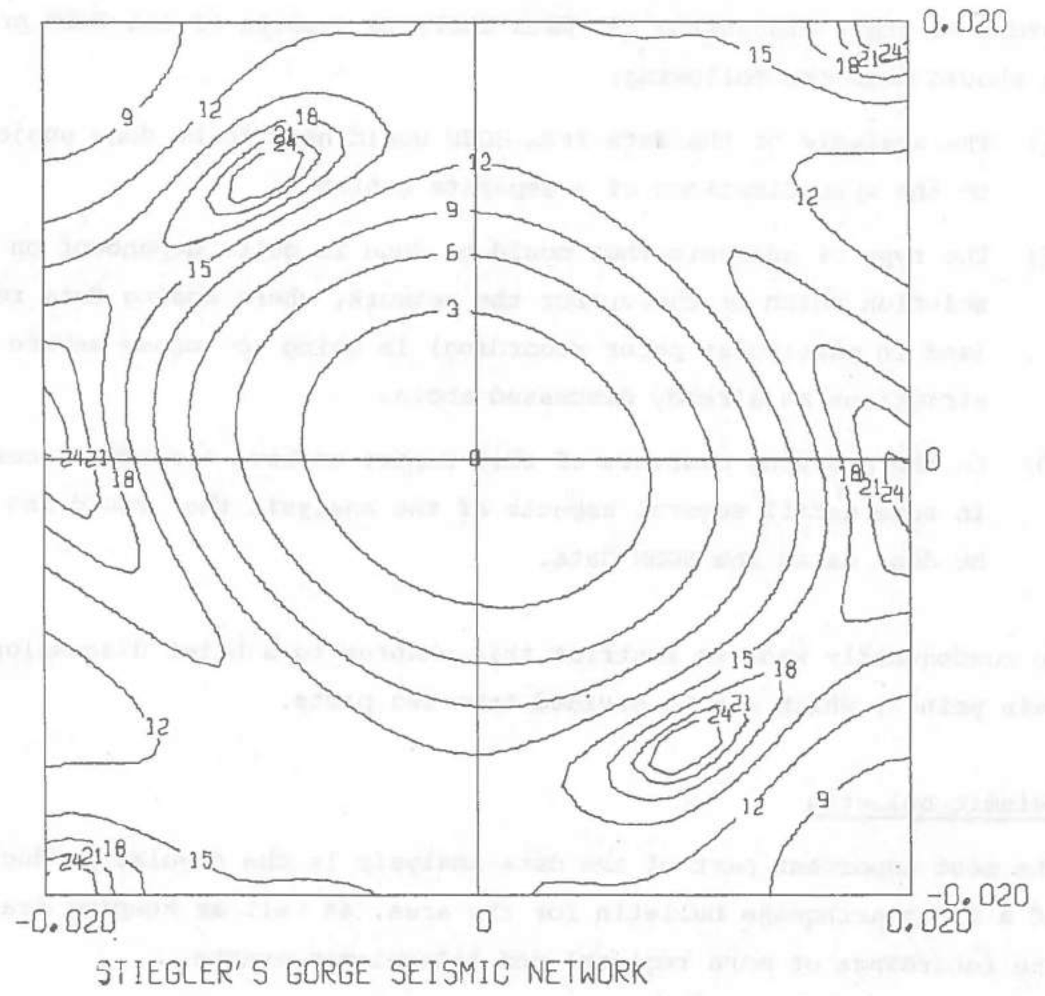

Fig. 6.7 Single frequency array response in wavenumber space for SGSN. The contours are in dB down from origin, and the axes are wavenumber difference in c/km.

7. DATA ANALYSIS

Before we start discussing the data analysis aspects of the SGSN proposal, we should note the following:

(1) The analysis of the data from SGSN would have to be done subject to the specifications of a separate contract.

(2) The type of analysis that could be done is quite dependent on the solution which is chosen for the network, where analog data recording (and in particular paper recording) is going to impose severe restrictions as already discussed above.

(3) In the previous chapters of this report we have already discussed in some detail several aspects of the analysis that could and should be done using the SGSN data.

We consequently want to restrict this chapter to a brief discussion of the main points, which can be divided into two parts.

7.1 Seismic bulletin

The most important part of the data analysis is the regular production of a microearthquake bulletin for the area, as well as keeping track of the recordings of more regional and teleseismic events.

With a digital triggering system much of the work is done already in real time. However, each of the recorded time intervals can only be considered to contain a potential event, and the following subsequent analysis at the data center will be necessary:

(1) Plot a filtered section of the data covering each detection

(2) Determine whether it is a false alarm, a teleseismic event or a local event

(3) If it is a teleseismic event, measure arrival time, period and amplitude of the P waves for one sensor, punch the results and save them for subsequent analysis

(4) If it is a local event, check with the blasting records to see if it is an explosion. Only a few of those would be subjected to further analysis.

(5) If it is not a known explosion, assume it to be a local earthquake and measure arrival time, period, amplitude, first motion, quality and duration of the P waves for all sensors

(6) Identify possible later phases (such as S) and measure arrival times and quality for all sensors

(7) Punch the results from (5) and (6), compute hypocenter and include the event in the earthquake data base

(8) At regular time intervals (such as monthly), prepare a seismic bulletin for internal distribution to interested parties.

Many of the points above (i.e., not only (1) and (2)) are well suited for automatic computer analysis, such as the determination of (1) relative delay (arrival) times for each channel and each arrival; (2) absolute arrival time for one (reference) channel; (3) signal amplitude (first cycle) and maximum amplitude; (4) signal period; and (5) signal duration. However, it is absolutely necessary that an analyzing procedure be developed in which all automatic results are controlled and (if needed) corrected by analysts, in order to obtain the highest possible quality of the results. In all these respects, the job is very similar to the NORSAR detection and event analysis, for which purpose a number of sophisticated computer programs and analyzing routines have been developed and thoroughly tested (Bungum et al, 1971a; Bungum and Husebye, 1974). This experience and these programs would be an ideal basis for the development of an analyzing procedure for the SGSN seismic data.

Another point which has been mentioned several times before in this report is the need for developing reliable velocity (crustal) models for the Stiegler's Gorge area. Controlled explosions are needed for this purpose, and most likely one would have to conduct a separate shooting program as well. The refinement of the model would take place in parallel with the data analysis, and it could for this reason be necessary to recompute the hypocenters of all events in the area perhaps several times. A flexible computer-based analyzing procedure would be needed for this purpose.

It should also be mentioned that the computer program HYPO71 (Lee and Lahr, 1975), which was used testing the SGSN location capability, in our view is the best one available for hypocenter and magnitude determination of local events. The program has been developed for the U.S. Geological Survey, and is now also in operation at NORSAR.

7.2 Seismotectonic interpretations

This is an important part of the SGSN data analysis, and one of the main jobs here would be to analyze the events from the microearthquake bulletin in time and space. For the time before impounding, the work would be directed towards a better understanding of the tectonic processes in the area, especially with respect to the identification of possible active faults. It would also be important to establish the level of seismicity precisely, and to study other parameters of importance for the seismic risk in the area, such as spectral properties (frequency contents) and signal attenuation. More detailed analysis of the larger events would also be needed, in particular with respect to the calibration of local signal parameters against those measured teleseismically.

For the time during and after impounding, the analysis should be directed towards possible changes in the earthquake regime of the area, based on a detailed knowledge of the pre-impounding activity. If a large increase in the seismicity should take place, and especially if indications of a strong earthquake in the area are found, it would be necessary to discuss various precautionary measures, the nature of which would depend on the situation.

8. COST ESTIMATES

8.1 General

Cost estimates are based on the following:

- Kinemetrics Proforma invoice dated 10 January 1977
- R-data A.S. (Racal-Thermionic) price list dated 6 January 1977
- Sprengnether Instrument Co., Inc., price list 1976A, added 15%. (According to info received from Dr. Sacks, Carnegie Institute, Washington).

Conversion from US dollars to N.kr. according to 1 US$ = N.kr. 5.30. No taxes are included in the estimates.

The costs for the Stiegler's Gorge Seismic Network are based on 7 remote seismometer sites and one complete spare field station, i.e., a total of 8 units.

Costs for preparation of 7 seismometer sites (Remove 2-3 m^3 overburden, build seismometer and equipment housing, cement floor in seismometer pit, helicopter transport of personnel and materiel) are not included in the following estimates.

8.2 The network

8.2.1 Sprengnether MEQ-800 Portable microearthquake system

Seismometer L-4C	N.kr.	3 505
MEQ-800-B	"	20 800
Spare parts, supplies	"	2 600
Total	N.kr.	26 905

8.2.2 Sprengnether self-contained system

A.	Seismometer site				
	- 1 ea L-4C seismometer	N.kr.	3505		
	- 1 ea AS-110 Amplifier	"	3687		
	- 1 ea DR-100 Digital Event Recorder	"	23160		
	- Solar Cell	"	5300		
	- 5 ea cassettes C-120 a kr 50	"	250		
	Subtotal one site	N.kr.	35902		
	Subtotal 8 units			N.kr.	287 216
B.	Timing System TS-400			"	5 730
C.	Radio WWV receiver			"	3 975
D.	Battery Charger ELTECO-PSF 24/5			"	1 725
E.	Replay system (to be located at NORSAR), DP-100			"	23 160
F.	Supervision from manufacturer (time and travel, 20 days), estimate			"	30 000
G.	Supervision, NORSAR, 10 days			"	20 000
H.	Shipping costs, estimate			"	10 000
	Total			N.kr.	381 806

Operational costs

Two visits per site per month to calibrate the timing system and change cassettes. Estimated time 30 minutes per site, i.e., 7 hours helicopter transport per month plus cost for one technician in that time.

8.2.3 Field stations transmitting data to a central recording system

Item \ Producer	Kinemetrics		Racal-Thermionic	
	Product	Price N.kr.	Product	Price N.kr.
A. Remote Site				
- Seismometer	SS-1	3896	Willmore Mark III	5200
- Amplifier	Monitron Mod 2000	4744	Mark II	4070
- Solar Cell estimate		5300		5300
- Antenna + mast	CA 5-150 Scala	1960	PYE AE 12U Yagi	1240 + 530
- Radio transmitter	T15F23 Monitron	2995	OS 04	4210
Subtotal one site		18895		20550
Subtotal 8 units		151160		164400
B. Central Recording System				
- Recording System	DDS-1105	111141	Geostore	57020
- Radio receivers (8 units)	R15F Monitron	37312	OS 05	46080
- 4 batteries (estimate)	12V, 100ah	1600	12V, 100ah	1600
- Antenna + mast	VCA-150 Scala	1431	PYE AE 12U Yagi	1770
- Discriminators (8 ea)	I-Disc Interproducts	10176		-
- Cabinets for discriminators		2862		-
- Cabling & testing		4770		(estimate) 1500
- Std time and frequency receiver	WVTR Radio	4425	Not in this firm's price list	4425
- Battery charger	ELTECO-PSF 24/5	1725	ELTECO-PSF 24/5	1725
- Direct write recorder, rack mount adaption & amplifier w/ amplifier filter	VRlB, Rack mount adaption	14416	Field test box	19010
- Cabinet		3180		-
Subtotal B		193038		133130

Producer / Item	Kinemetrics		Racal-Thermionics	
	Product	Price N.kr.	Product	Price N.kr.
C. Various costs				
- Installation supervision by manufacturer	Field technician, one	32000 +12000	Field technician, one	32000 +12000
- Supervision by NORSAR	1 Seismologist, 10 days	20000	1 seismologist, 10 days	20000
- Shipping charges	estimate	20000	estimate	20000
- System engineering	"	26500	"	10000
- Spare parts	"	20000	"	20000
- Education of operator at manufacturer	"	20000	"	20000
Subtotal C		150500		125000
D. Equipment for signal analysis (to be located at NORSAR)				
- Base reproducer		-		68670
- Adjustable low pass filter		-		5770
- Chart recorder		-	estimate	50000
Subtotal D		-		124440
TOTAL		494698		546970

Operational costs for systems under 8.2.3.

Personnel costs for one technician in connection with changing of magnetic tapes approximately once a week and checking the central recording equipment once a day (½ hour). An occasional visit to the remote sites when trouble is indicated on the data channels at the central site.

8.2.4 Strong motion instrumentation

- Kinemetrics Strong-Motion Accelerograph	N.kr.	9 275
- Batteries	"	800
- Spares, etc.	"	700
Total one system	N.kr.	10 775
Total four systems	N.kr.	43 100

8.3 Data analysis

8.3.1 Develop software package for complete analysis of the digital seismic data recovered by the various systems, including a special event processor special signal analysis and evaluation techniques, hypocenter location routines, local magnitude estimates and various kinds of statistical routines for a comprehensive description of the seismic activity in the area in question.

Estimate: N.kr. 100 000.

8.3.2 Yearly costs for data analysis, production of seismic bulletin and seismotectonic analysis of collected data.

Estimate: N.kr. 150 000.

8.3.3 Further special studies to be conducted upon separate agreements with A/S Hafslund.

9. CONCLUSIONS

1. Several cases of damaging earthquakes induced by the impounding of large water reservoirs are known.

2. An investigation of the conditions under which reservoir-induced earthquakes occur, and a review of the seismicity and tectonics of the Rufiji Basin lead us to the conclusion that the Stiegler's Gorge area has the potential for reservoir-induced seismicity.

3. Because of this possibility for damaging earthquakes, it is strongly recommended to install a Stiegler's Gorge Seismic Network. The network should monitor the local seismicity before, during and after water impounding.

4. The configuration of such a network is discussed, and it is recommended to install an array of 7 sensors distributed over an area with a diameter of about 50 km. A detailed location of each site is proposed.

5. We recommend the installation of a seismic monitoring system of the type delivered by Kinemetrics, based on radio telemetry to the main camp at Stiegler's Gorge, where the data are recorded digitally after passing an event triggering system.

6. We furthermore recommend the acquisition of one portable seismograph and one strong-motion accelerograph, and that later four accelerographs be installed in the dam.

7. It is expected that the proposed array should be able to detect local events down to at least magnitude one, with a location accuracy of 1-2 km. Subsequent refinements of the velocity models for the area could improve the locations.

8. The costs of the recommended installations will be about N.kr. 533 000, with 495 000 for the main seismic monitoring system, 11 000 for the portable seismograph, and 27 000 for the strong-motion accelerograph. In addition there would be costs associated with the installation of the remote sites and with the subsequent data analysis.

9. The analysis of the data from the network should result in a seismic bulletin as well as more general seismotectonic interpretations.

10. The specific technical solutions which are recommended should at this stage primarily be considered as examples of the type of instrumentation which would satisfy the various requirements discussed in this report.

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APPENDIX A

SPRENGNETHER MICROEARTHQUAKE SYSTEM MEQ-800

MANUFACTURERS OF
SEISMOLOGICAL·GEOPHYSICAL·AND·ENGINEERING·INSTRUMENTS···4567·SWAN·AVE·

W. F. SPRENGNETHER
INSTRUMENT CO. INC.

·SAINT·LOUIS·MO·63110·U·S·A·
Telephone: 314-535-1682
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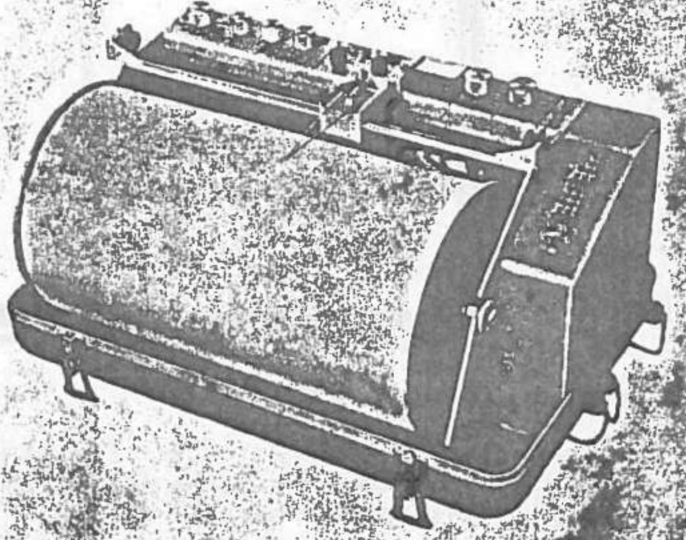
NEW

- COMPLETELY REDESIGNED
- SINGLE CASE – CARRY ON SIZE
- 80 Hz RESPONSE
- NEW AMPLIFIER
- NEW CLOCK
- ½ WATT
- OVER 4 DAYS ON INTERNAL BATTERIES
- LARGER RECORD SIZE FOR 2 DAYS AT 60 MM/MIN



SPRENGNETHER

MICROEARTHQUAKE SYSTEM MEQ-800

The MEQ-800 is a completely new, state-of-the-art seismic system that capitalizes on Sprengnether's years experience in the fabrication of ultra-portable, high sensitivity systems featuring smoked-paper recording. The recorder system has been redesigned. A new low-noise seismic amplifier and a new ultra low power precision timer are introduced. Dependability and flexibility have been improved throughout the system. Compactness and component size have been developed to put everything but the seismometer and it's cable into one aluminum transit case weighing only 32 pounds. Drum size has been increased fo greater resolution and/or recording durations.

The truly exceptional flexibility designed into the MEQ-800 is illustrated by the following standard features

COMPACT TRANSIT CASE

2 Rotation rates per Motor Selection at a 2:1 ratio (From 24 to 7.5 MM/Min.)

3 Translation rates at 4, 2 and 1 MM/Revolution Amplifier gai variable from 60 to 120 dB in 6 dB steps.

High-Pass Filter variable at out, 5, 10 Hz.

Low-Pass Filter variable at 5, 10, 30 Hz, out.

Variable pen-clipping amplitude at 5, 10, 25 mm, peak-to-zero.

Second marks selectable by panel control.

Adjustable Calibration current monitored on Panel Meter.

Provision for use of external function generator for calibration.

Input Plug provisions for external battery operation.

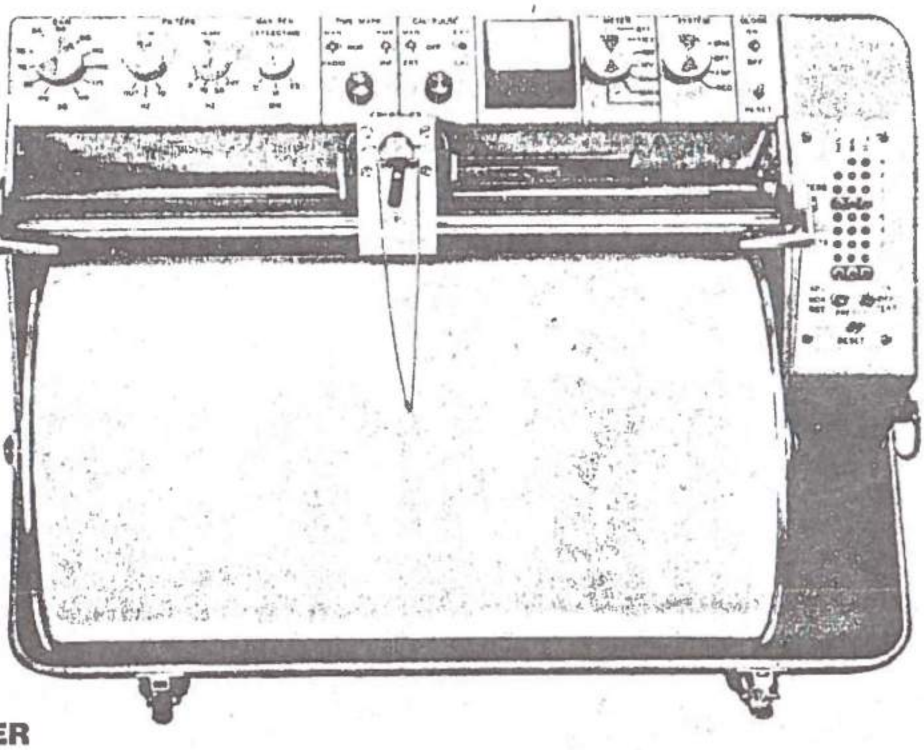
Input Plug provisions for charging internal batteries.

Input Plug for Radio time signals.

Battery Voltage Monitor on Panel Meter.

Output Signal for Tape Recording, Telemetering, etc.

These features provide remarkable versatility in an instrument useful in applications from remote microearthquake monitoring to a low cost visual station. Any seismometer may be used with the system, th response determined by this selection plus filter settings.



RECORDER

A *new Peripheral Friction* drum drive that is far superior to standard gear drives has been designed for the Recorder. The rotation error is now less than 0.1 sec. per revolution and temperature effects have been markedly reduced over a wide environmental range.

A *new drum size,* for records 13.5 x 24 inches, allows recording for 26 hours at 60 mm/min. with a 2mm line spacing. (Observatory records are 12 x 36 inches, 60 mm/min, 2.5mm line-spacing).

By means of simple drive changes, each recorder has *2 rotation rates* at a ratio of 2:1 (standard is 120 and 60 mm/min) and *3 line spacings,* also in 2:1 ratios (standard is 1, 2, 4 mm). Optional motors will yield from 24 mm/min. to 7.5 mm/min. rotation rates for maximum resolution or recording duration.

Improved drum construction ensures concentricity by placing ball bearings in the drum ends. For transport, a "quicklatch" feature gives positive locking of the drum into the recorder side frames. A spare drum is standard equipment.

Precision screw-driven translation system for the pen-motor assures an especially uniform translation rate that is independent of the rotation rate. A positive locking mechanism holds the pen unit in transit.

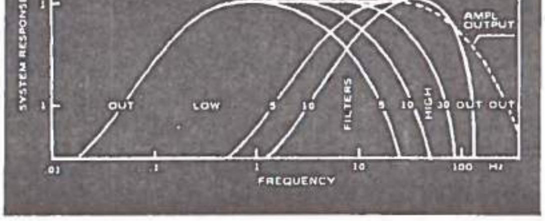
A unique pen-lift feature at the edge of the drum provides pen protection at the limits of excursion, i. e., against the drum edge at the end of the recording interval.

The pen-motor system is also new with extended frequency response to 80 Hz (6dB). The stylus has a 1 mil spherical radius sapphire tip for durability and fine tracings.

A weatherproof aluminum transit case houses the recorder, total battery supply, amplifier, clock and system control circuitry at a total weight of only 32 pounds. The recorder size will fit under a plane seat, i. e., will pass as carry-on luggage. Everything but the seismometer and it's cable is contained within the transit case. The batteries will provide over 100 hours continuous recording without recharge. Charging can be accomplished without removing batteries from the case or stopping the click. External power can also be used if desirable.

AMPLIFIER

A new low noise, high gain amplifier has been developed specifically for the MEQ-800. The amplifier features variable gain from 60 to 120 dB in 6 dB steps. Variable low and high-cut filters allow shaping of system response as desired. The amplified signal is available at an external connector for tape recorder, telemetry, or other peripheral data monitoring system. This signal, with the high cut filter in the out position is somewhat more broad band than the actual record, since the pen response is not involved.



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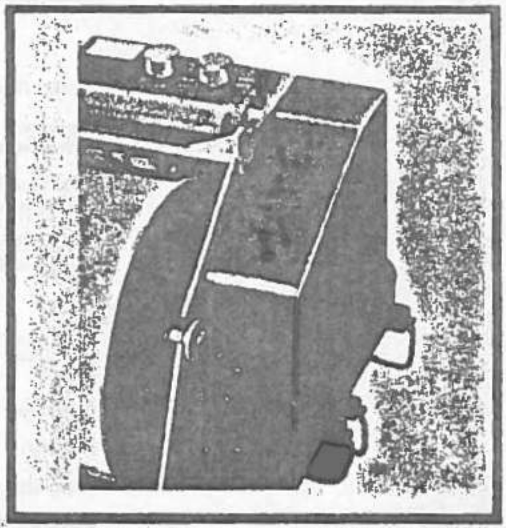
TIMING SYSTEM TS-300



TS-300-10

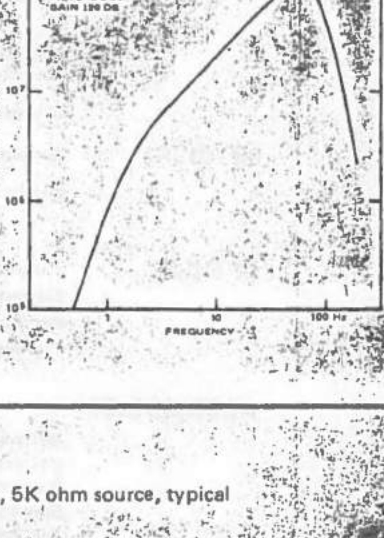
Two options are available as timing systems for the MEQ-800, both with the same long term stability of 5×10^{-8} and utilizing a temperature compensated crystal oscillator. The simpler and less costly approach does not feature preset capability to selected time nor variable readout. It can, however, be reset to zero hours, zero minutes, zero seconds by a switch on the control panel. The alternate clock features visible readout and complete preset capabilities as well as advance/retard in precise synchronization to absolute time. This provides convenience of maintaining near zero time corrections in multi-station field installations.

CONTROL PANEL

The control panel contains gain and filter switches in the amplifier. Time mark controls and adjustments as well as calibration controls are present. A multi-purpose meter monitors system voltage and calibration current. The master operation switch allows battery charging or amplifier and recorder control. The timing system remains on during all master switch positions and can only be turned off by the separate clock switch. This allows the timing system to operate in transit or on the shelf, expediting field setup. The battery system can power the clock alone (display off) for about 20 days. When the MEQ-800 is operated without the timing system display, the right end clock panel is absent.

SYSTEM RESPONSE

Selection of a specific seismometer will determine the overall system response. The wide range of available filter settings allows use of a single low frequency detector for many applications. The magnification curve shown will result if a 1 Hz geophone having a generator constant of 100 V/m/s is used. Eleven gain levels, in steps of 6 dB, are provided. For extremely high magnification, i. e. 10^7 or more at 10 Hz, caution must be exercised in selecting a seismometer that is free of parasitic spring resonances, such as the Sprengnether S-7000 magnetic suspension variable period seismometer.



SPECIFICATIONS

AMPLIFIER

Voltage Gain: 60 to 120 dB in 6 dB steps.

Noise: 0.2 μv peak referred to input, 5K ohm source, typical

Filters: Approx. 6 dB points.
Low Cut: Out (0.2 Hz), 5, 10 Hz.
High Cut: 5, 10, 30 Hz, Out (approx. 80 Hz on record, approx. 100 Hz amplifier signal output).

External Output: 1 volt

SPECIFICATIONS
(Cont'd.)

RECORDER

Record Size:	13-½ x 23.5 inches (600 x 340 mm).
Drive:	Peripheral friction, less than 0.1 sec/revolution error.
Rotation Rates:	2 provided in ratio 2:1, 60 and 120 mm/min. standard-available 7.5 to 240 mm/min.
Translation Rates:	3 provided in ratio 4:2:1, 1,2,4 mm/rev at 60 mm/min, 0.5, 1, 2 mm/rev at 120 mm/min standard-others available as special options.
Record Duration:	52 Hours at 60 mm/min., 1 mm/rev.
Frequency Response:	6 dB down at 80 Hz.
Maximum Pen Deflection:	5, 10, 25 mm, by panel switch, peak-to-zero.
Overall Pen Sensitivity:	3mm/µv, mid-band, 120 dB gain.

TIMING SYSTEM

TS-300-1

Type:	TCXO
Stability:	5×10^{-8} at constant temperature.
Display:	None
Setability:	To Zero only.
Advance/Retard:	No
Time Marks:	Hours (2 sec.) Minutes (1 sec.) Seconds (.05 sec.) Selectable by Panel Switch

TS-300-10

Type:	TCXO
Stability:	5×10^{-8} at constant temperature.
Display:	BCD format LED's.
Setability:	To any desired time.
Advance/Retard:	By panel switch
Time Marks:	Hours (2 sec.) Minutes (1 sec.) Seconds (.05 sec.) Selectable by Panel Switch.

POWER

Internal Supply:	4 Sealed Rechargeable lead dioxide, 12 volt – 1.5 amp. hrs. each; can be charged in place.
Operating Power:	40 ma (½ watt) quiescent, clock display off, 6 ma timing system only.
Operating Time on Full Charge:	100 Hours, Minimum.
External Supply:	± 12VDC (not furnished)

PHYSICAL

Dimensions:	18 x 12 x 9 inches.
Weight:	32 Pounds with Batteries. 25 Pounds without Batteries.

OPTIONS

Timing System Choice
Seismometer Choice
Rotation Rates
Translation Rates

ACCESSORIES

Battery Charger
Battery Cable with large Alligator Clips
Record Smoking/Fixing Kit
Spare Drum (Two Drums furnished standard)
Ink Recording Kit

APPENDIX B

SPRENGNETHER DIGITAL EVENT RECORDER DR-100

MANUFACTURERS·OF
SEISMOLOGICAL·GEOPHYSICAL·AND ENGINEERING·INSTRUMENTS·4567·SWAN·AVE
W. F. SPRENGNETHER
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Cable: SPRENCO

FEATURES

- 1-3 CHANNELS
- 12 BIT DATA WORD
- 25 TO 500 SPS
- TIME-AVERAGE RATIO TRIGGERING
- DIGITAL MEMORY
- INTERNAL TIMING SYSTEM
- 20 MA AT 12 VDC

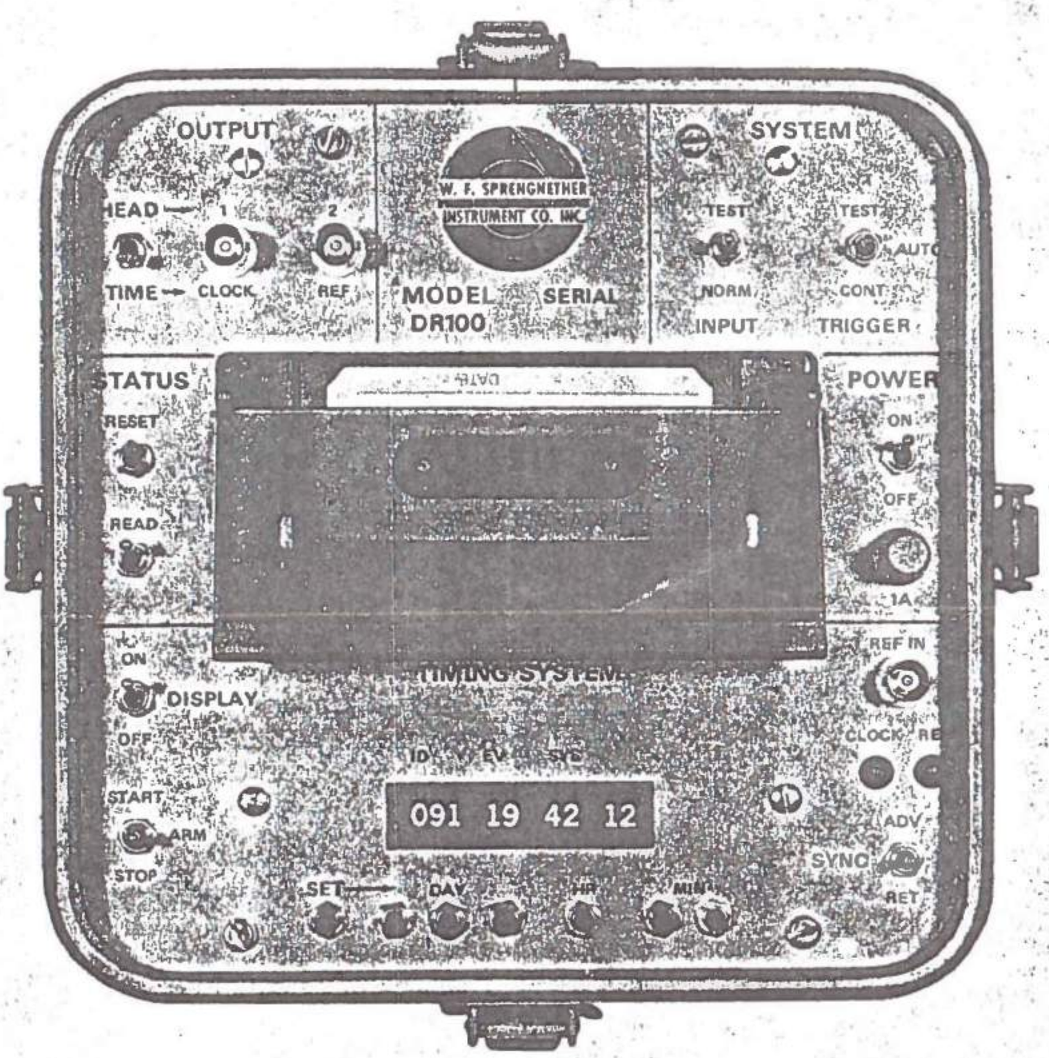
SPRENGNETHER

DIGITAL EVENT RECORDER DR-100

The DR-100 is the basic model in a newly-developed line of low-power, portable digital recording systems for seismological applications at frequencies up to 200 Hz. Using magnetic tape cassette recording with a complete timing system, a digital data delay memory, and a versatile triggering circuit, the DR-100 is an optimum digital event recorder for single-or three-channel field recording systems. Micropower circuitry with a wide range of simply adjustable sample rates, trigger parameters, and record lengths, results in an extremely useful digital data acquisition system for transient events typical in strong-motion and microearthquake seismology or blast vibration monitoring. A companion playback system, the DP-100, provides analog and parallel digital outputs for data analysis using either visible records or direct computer input.

Input signals in the range of 1V to 10V full-scale, typically from a short-period seismometer or accelerometer, are digitized to 12 bit words at the selected clock-controlled sample rate, nominally 50 to 500 samples per second in single-component or 25 to 200 samples per second in 3-component mode, and stored continuously in a 551 word (standard, up to 1969 word capacity available) memory. Simultaneously, the trigger circuitry computes short-term (0.1 to 5 sec) and long-term (5 to 200 sec) averages of the incoming signal, and their ratio STA/LTA. The system is triggered ON when the STA/LTA ratio reaches a preset level (3 to 24dB), and a digital record is written from the memory onto the cassette. Recording will continue for a preset time (2 to 50 sec) after the last trigger, thus retaining all the information of interest, at 66dB dynamic range, including data before the onset of the event. At 50 samples per second, 30 or 60 minutes of data may be recorded on C-60 or C-120 type cassettes, respectively.

A precision timing system provides the digital system clock as well as real time (day, hr, min, sec) to the display and the data stream. Provision is made for synchronization of the clock to absolute time (by radio or auxilliary portable clock such as the TS-400), with automatic or manual start and advance/retard slewing. The timing system is stable to 5×10^{-8} per day. Time is recorded in digital format with the data, and decoded and displayed by the DP-100 playback unit.



The display serves a dual purpose. In the normal operating mode it indicates absolute time. In the STATUS mode the readout is the 3-digit serial number of the unit (hard-wired), the 2-digit number of the last-recorded event (resettable to zero by front-panel switch), and a 2-digit configuration identification (number of channels) number. This feature facilitates subsequent identification of the recordings. The time and status information is written at the beginning and end of each event record, and sampling times are locked to the real time clock.

Two front-panel outputs present the recording head signals for monitoring. Alternately, they provide access to the internal 1PPS and the external reference time signals. System-check switches on the front panel allow application of a DC offset voltage to the analog input circuits or manual activation of the trigger. Three connectors on the case accept analog data, system power, and external trigger commands, as well as providing a trigger signal for controlling peripheral devices or interconnecting several units (e.g., in multi-site strong-motion recording).

PC card controls, readily accessable by lifting the unit from its field case, select the three trigger parameters, the record duration, the sample rate with associated tape speeds, the full-scale sensitivity, single-vs 3-channel operation, and adjust the TCXO frequency. Modular construction, relating principal functions to independent plug-in circuit boards, facilitates servicing and modifications. The entire system, exclusive of battery, sensor(s) and signal conditioning, is housed in a 8 x 8 x 14 in (20 x 20 x 36cm) field case and weighs only 14 lbs (6.4 kg).

Low-power circuit design has resulted in a remarkable quiescent power requirement of only 180 mw (15 ma at 12 VDC, nominal). During the recording cycle, the unit draws approximately 400 ma. This low-power performance permits remote operation for an indefinite period from a small solar panel and 1 amp-hr battery or, alternately, up to 5 months from a single 60 amp-hr 12 VDC car battery, exclusive of external signal conditioning requirements.

Applications for the DR-100 range widely over requirements for transient event recording where low-power, remote, unattended operation is necessary and the signal characteristics are:

Event(s) duration, ...	0.1 sec to 1 hr
Maximum frequency content, ...	up to 200 Hz
Dynamic range, ...	66dB (12 bits)

Strong-motion recording with force-balance accelerometers as sensors, is an ideal usage of the DR-100. Microearthquake or aftershock recording are other typical applications. Even without subsequent digital computer processing, the DR-100, with the companion DP-100, provides the full 66dB range for analog processing via strip-chart, filters, spectrum analyzers, etc., in the laboratory. The system represents state-of-the-art in wide dynamic range recording, with the versatility of analog or digital analysis capabilities.

SPECIFICATIONS

INPUT:	1-10 V Full Scale
DIGITAL WORD:	Data — 12 Bits Sync — 1 Bit
MEMORY:	7168 bits standard (551 words) expandable to 25600 bits (1969 words)
SAMPLE RATES:	50, 100, 200, 500 sps, 1 channel, selectable 25, 50, 100, 200 sps per channel, 3 channels, selectable
TAPE:	C-60 or C-120 digital-grade cassette
TAPE SPEED:	1-10 ips, nominal, depending on sampling
FORMAT:	complementary NRZ 2-tracks (zeros-ones)
DENSITY:	800 bpi, nominal
TRIGGER:	selectable ratio $\frac{STA}{LTA}$, 3, 6, 9, 12, 18, 24dB STA selectable average, 0.1, 0.2, 0.5, 1, 2, 5 sec LTA selectable average, 5, 10, 20, 50, 100, 200 sec
RECORD DURATION:	2, 5, 10, 20, 30, 50 sec after last trigger, selectable
RECORD FORMAT:	213 bits time/identification information, data, 213 bits time/identification information, each record. In data stream odd numbered seconds are marked by fixed offset in data word between trigger ON and trigger OFF. Times of first and last time marks are times written in header and tailer, respectively.
TIMING SYSTEM:	± 5 x 10^{-8} per day TCXO to system clock and day (365/366 by switch), hr, min, sec code
CLOCK START PULSE:	+1V or greater
CLOCK SLEW RATE:	± 20 ms/sec
POWER:	10-15 VDC, 20 ma quiescent, 400 ma recording
DIMENSIONS:	8 x 8 x 14 in (20x20x36 cm)
WEIGHT:	14 lbs (6.4 kg)
TEMPERATURE:	0 — 70°C

APPENDIX C

GEOSTORE FIELD RECORDING SYSTEM FOR SEISMIC DATA

GEOSTORE

Field Recording System for Seismic Data

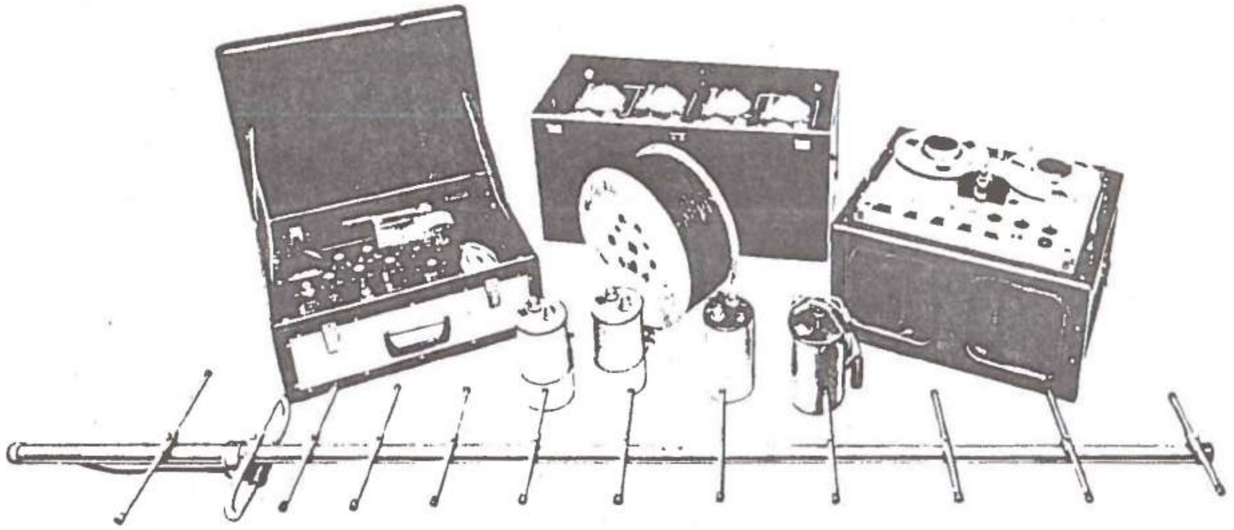
Racal-Thermionic Limited

GEOSTORE

- * Long period seismic data collection
- * 680 hours unattended operation
- * Exceptionally low power consumption
- * Economic and easy system build-up
- * Proven field reliability

INTRODUCTION

Designed for the collection of long period seismic data, the Geostore Recording System is a development of the successful Racal-Thermionic T.8100 Seismic System which was produced in conjunction with Dr. P.L. Willmore of the Institute of Geological Sciences at Edinburgh. Intended for use in remote areas, the Geostore will enable a small field party to lay down a complete network of seismograph stations within a week or two, with a total recording power superior to that which a few years ago would have seemed adequate for the permanent observatory network of an entire country.



COMPONENTS OF THE GEOSTORE FIELD SYSTEM

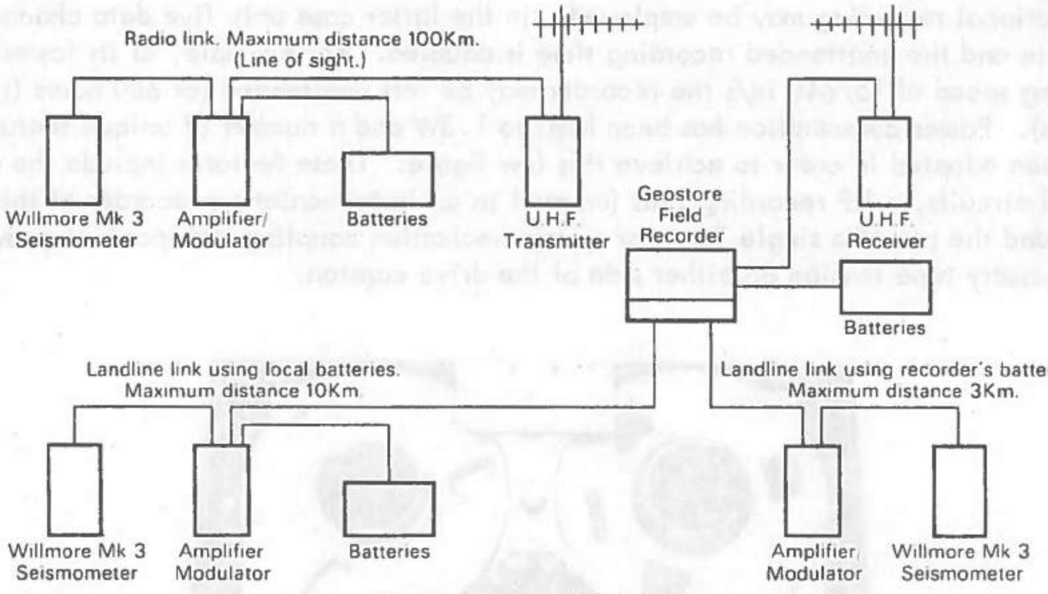
Suitable for temporary or permanent stations all Geostore components are lightweight, designed for easy installation, and are fully protected against the ingress of dirt or water and each is easily accessible for routine checks and maintenance.

Racal Seismic Systems are in world-wide use. Not only are they collecting geophysical data for the study of natural earth movements, but they will also be found in mining areas where a knowledge of microseisms and rock burst data is vital for the protection of life and machinery. The systems may also be used with other transducers to record low frequency data such as water flow rate of rivers, micropulsations in geo-magnetism, long-term settling of buildings due to traffic vibrations etc. Wherever long term recordings are required Racal-Thermionic will be pleased to advise on the use of suitable recording systems.

THE FIELD NETWORK

Detection, Amplification & Transmission of Data

A maximum of eleven seismic detecting positions can be laid down over a given area the outputs from which are fed into a central recording site by landlines or radio. Where landlines are in use the necessary power required at the seismometer positions can be carried over the data lines from the field recorder position. Using this method would limit the line distance to 3km but if independent batteries are used at each seismometer pit the line distance may be extended to 10km. Where even greater distances are required a line-of-sight U.H.F. radio link is included in the system, and this will work effectively up to 100km. Alternatively signals may be fed into the public telephone lines which would enable a national network to be set up.



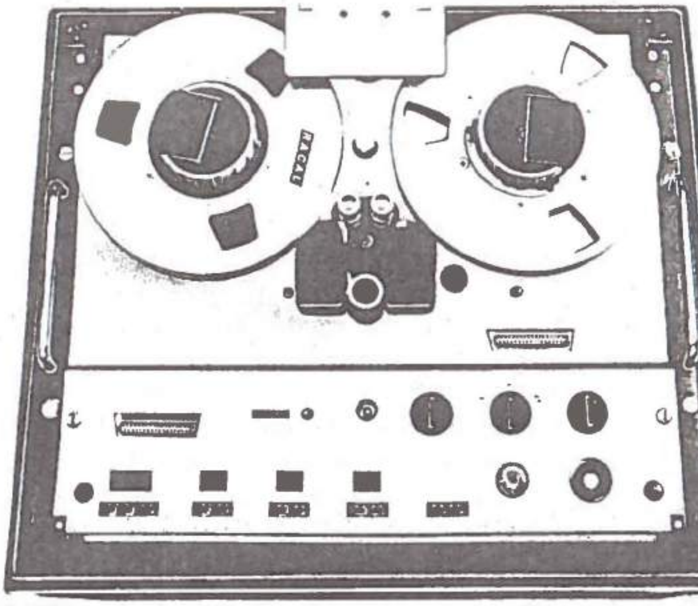
The Geostore Seismic Data Field Recording System

The output from a seismometer is immediately fed into an amplifier/modulator the output of which is a frequency modulated signal centred on 676 Hz. This simple audio frequency signal is not only suitable for transmission by line or radio but also for direct recording onto magnetic tape. Therefore, when line transmission is used the line (such as Army Type D10) literally connects the output terminals of the amplifier/modulator to the input terminals of the field recorder. When a radio link is employed the output from the amplifier/modulator is taken to the input of a miniature U.H.F. transmitter housed in a metal can strapped to the aerial mast above ground level; the coaxial output from the transmitter is connected directly to a multi-element Yagi array. A similar arrangement with a U.H.F. receiver is used at the field recorder site.

Batteries for use at the remote seismometer pits are of the depolarised-cell variety and such is the extremely low power consumption of the equipment at these locations that a single set will last for approximately two years. The field recorder is powered from a standard car-type battery of 12V and to operate for the maximum recording time of 680 hours a capacity of at least 85Ah would be needed.

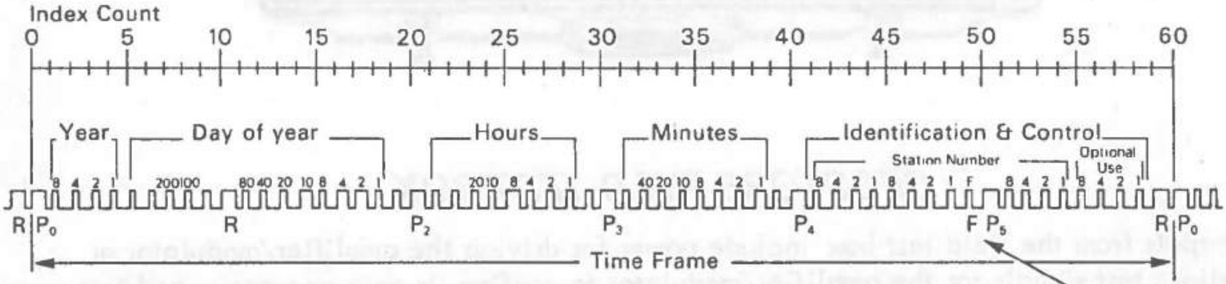
The Field Recorder

Because the output of the amplifier/modulator at the seismometer site is a frequency modulated signal, the field record unit of the Geostore system differs from other FM recorders in that it contains no provision for frequency modulating a signal within itself; thus all inputs to this unit intended for the data channels must be FM signals; this, however, does not apply to an external Standard Radio Time Signal. Housed together with a time encoder in a completely weatherproof aluminium cabinet, the field record unit uses a ½" tape which will accommodate a total of 14 tracks: eleven of which are used for data, one for time, and the other two for flutter compensation to improve the signal to noise ratio. Two seven-track interleaved heads are fitted and either uni- or bi-directional recording may be employed. In the latter case only five data channels are available and the unattended recording time is doubled. For example, at its lowest recording speed of 15/640 in/s the recorder may be left unattended for 680 hours (i.e. 4 weeks). Power consumption has been kept to 1.5W and a number of unique features have been adopted in order to achieve this low figure. These features include the use of MOS circuits, a HF recording bias (unusual in an instrumentation recorder of this type), and the use of a single Tensator spring mechanism coupling the spools to provide the necessary tape tension on either side of the drive capstan.



THE GEOSTORE FIELD RECORDER

The time encoder is an integral part of the recorder and provides time code data, an accurate flutter compensation signal, and a capstan servo reference frequency. The timing signals from the encoder are accurate to one part in 10^6 over the full operating temperature range, and recording is in accordance with Vela Uniform Code for one minute time frames. Timing is in days, hours, minutes, and seconds which can be read numerically. When the key-operated security switch is turned; a push button associated with each digit enables the date/time to be updated. An external check facility has also been included whereby a Standard Radio Time Signal can be recorded on one channel. This may be done automatically once every hour on the hour to conserve data recording space or the time may be recorded continuously.



P_0-P_5 = 0·8 sec. duration - '10 sec. marks' - Position Identifiers
R = 0·8 sec. duration - 'End of frame marks' - Rererence
R & P_0 denote '1 minute mark'
Binary coded decimal bits - 'One' = 0·5 sec.
'Zero' = 0·2 sec.

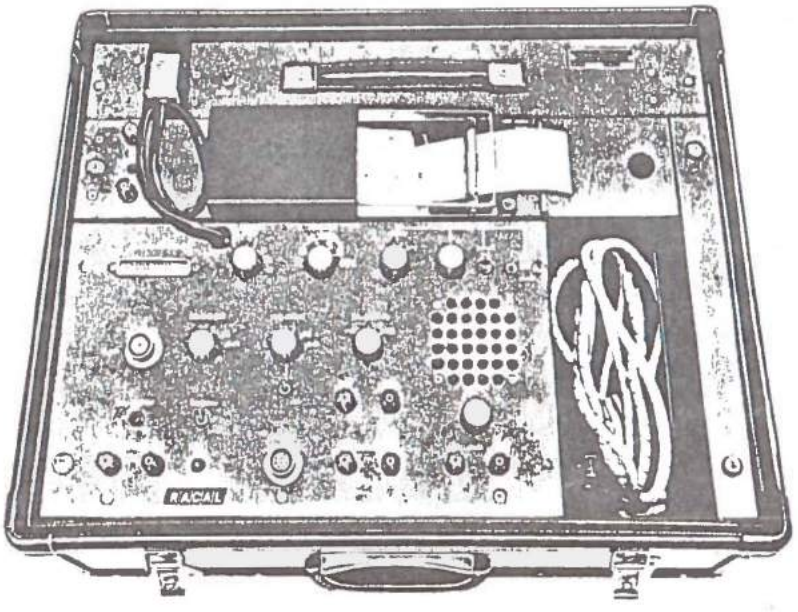
Unused bits = 0·2 sec.
Clock rate (Bit rate) = 1 PPS
Clock interval = 1 sec.
Time frame interval = 1 min.
Flag bit 'F' denotes abnormal recording format when value is 'One'. (See index count 49)

Time decoded reads:
Year = Zero
Day of year = 16
Hours = 8
Minutes = 1

Vela standard time code for use with Magnetic Tape Recording

The Field Test Box

In order that a field network may be brought to its fully operational state in the shortest possible time, the Geostore system includes a self-contained and very compact field test box. In its own right this test box can be used as a "short-run" seismograph station, or it may be used to monitor any channel whilst the Geostore system is in use.



GEOSTORE FIELD TEST BOX

Outputs from the field test box include power for driving the amplifier/modulator or radios, test signals for the amplifier/modulator to confirm its gain accuracy, and test signals for setting up radios and the field recorder.

Inputs include the seismometer signals which can be checked on the field test box pen recorder, and the field recorder head currents which can be monitored in both frequency and amplitude on each of the 14 channels.

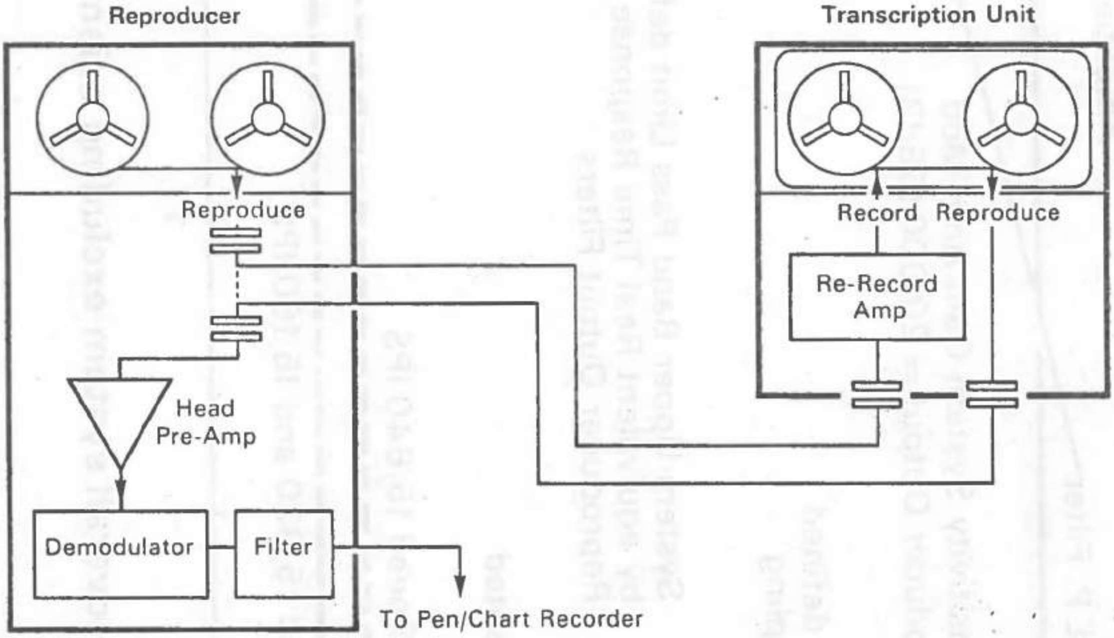
BASE REPRODUCTION AND ANALYSIS

Base Reproducer

The base reproducer comprises a mains operated tape deck and an electronics unit housed in separate cabinets. Two different head assemblies are offered with the tape deck the choice of which depends on whether uni- or bi-directional recording is employed in the field. For uni-directional recordings a full 14-track head assembly is used and the tape replayed in one pass. In the case of bi-directional recording the first replay run would reproduce half the tracks only; the take-up spool would then be transferred to the left hand side of the reproducer and a second run made for the remaining tracks.

A subtractive flutter compensation system is used to reduce the base line noise and thereby improve the signal to noise ratio on all data channels. The compensated data outputs and the time code output are fed to a 15-way cannon socket in the front of the electronics unit; additionally a monitor switch enables any one channel to be switched independently to a BNC socket at the rear of the unit. From either of these outputs the final signals may be fed to a chart recorder, computer, or other analysing equipment.

Racal-Thermionic Ltd., supply jet-pen recorders, filters and a patch panel in order to complete the base reproducing station.



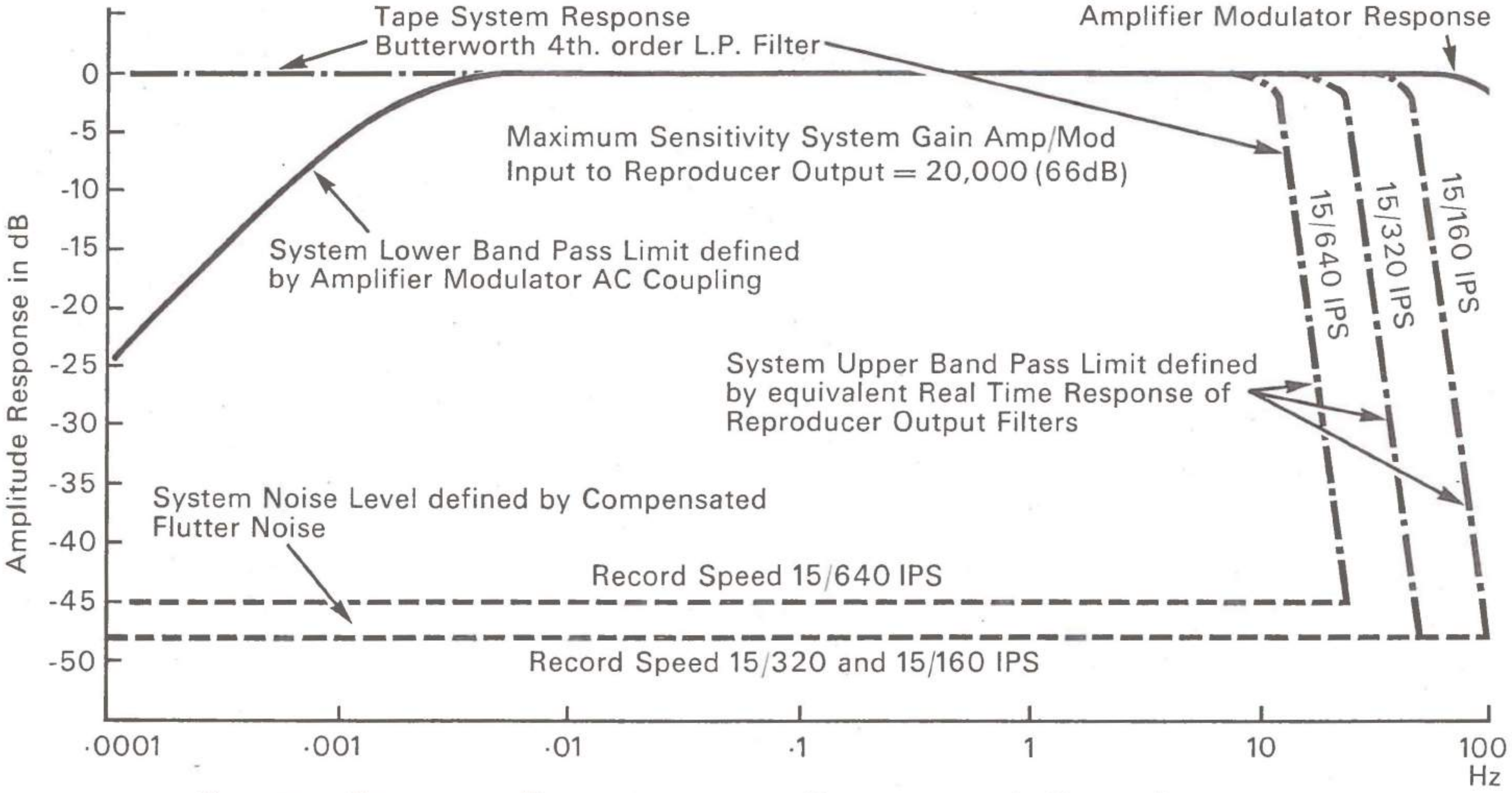
INTERCONNECTION OF REPRODUCER UNITS

Transcription Unit

In appearance the transcription unit is very similar to the base reproducer but it cannot function as an independent unit - it can only be used in conjunction with a base reproducer. The transcription tape deck is fitted with record heads and an erase head in addition to the normal replay heads. The electronics unit contains only interface amplifiers to transfer data in its frequency modulated form between the field and library tapes.

The transcription unit has two main uses. First, in the reel-to-reel mode it is used for the production of library tapes from the field recordings, and secondly, used with a closed loop of tape it can continuously replay a given incident for close analysis.

Using the transcription unit an incident can typically be located in about one minute, so that a complete year's field recordings can be reduced to a library tape in a few weeks.



Geostore Frequency Response – overall system excluding seismometer

EFFECTIVE SYSTEM SENSITIVITY

The sensitivity of three separate elements must be summed to obtain the overall sensitivity of the Geostore system.

(a) The Seismometer or Transducer
(b) The Geostore Recording System
(c) The Output Display Device.

In the Geostore Recording System the maximum permitted carrier deviation of ± 40% is obtained with an input signal of ± 0.25 millivolts into the amplifier modulator at maximum gain. Regardless of recording or replay speeds the output for full deviation carrier is ± 5 Volts. The midband gain of the recording system is therefore:-

$$\frac{5 \times 10^3}{0.25} = 20000$$

The frequency and phase response within this band is shown in the system response curves.

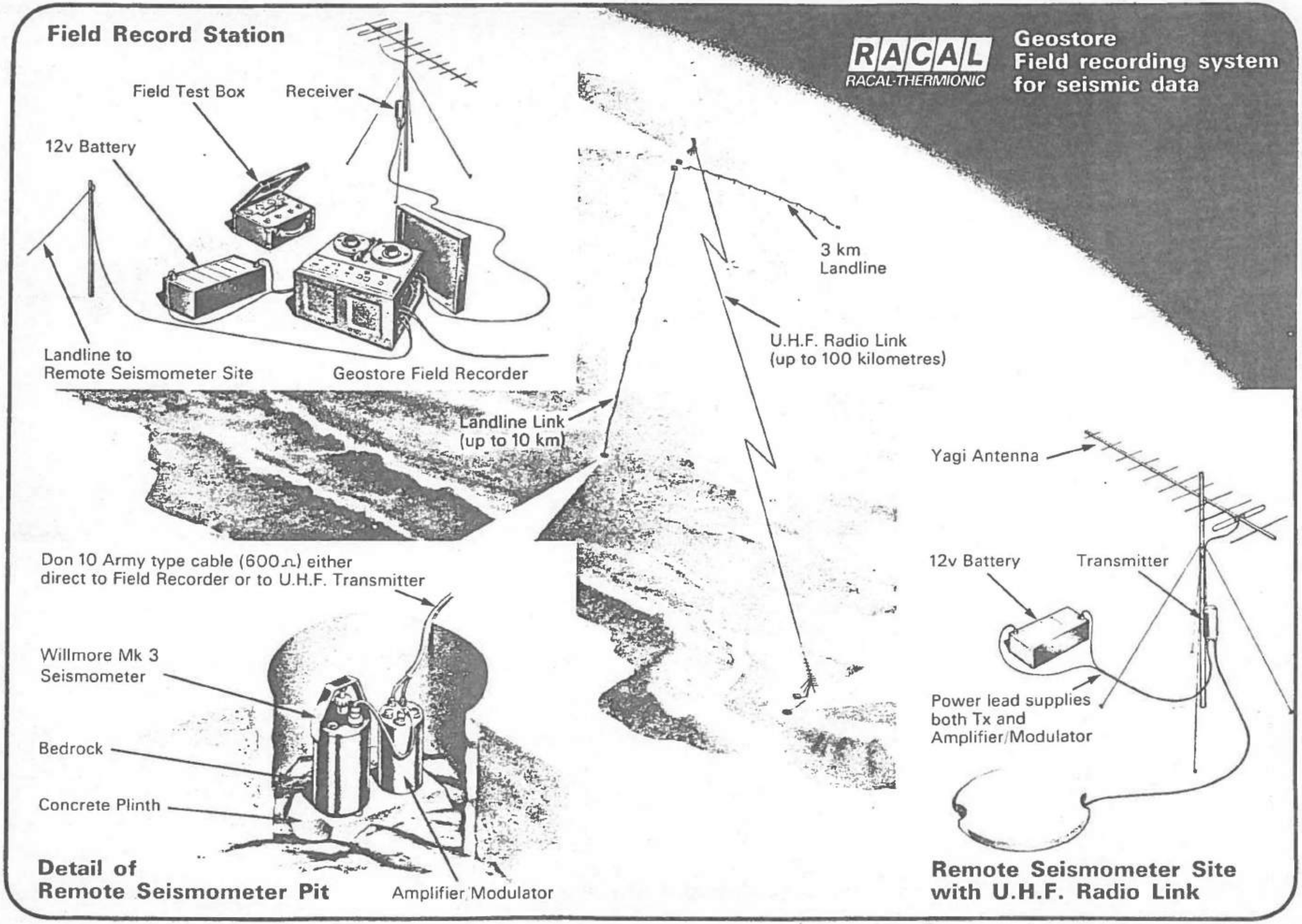
Using the Willmore Mark III Seismometer as a Transducer, the 4V/cm/sec output will provide 0.25 millivolts at the amplifier modulator input for an earth movement of 0.1 micrometer (10^{-7}m) peak at a frequency of 1 Hz. With the reproducer output coupled to a pen recorder and sensitivity set to give a base line noise amplitude of 5 mm trace thickness the 0.1 micrometer displacement would result in a pen movement of 25 cm. In this example the overall gain is:-

$$\frac{25 \times 10^{-2} \text{ metres}}{10^{-7} \text{ metres}} = 25 \times 10^5$$

Clearly this figure depends upon gain settings and output levels required but it serves to illustrate the detecting power of the system. Providing the site background noise is sufficiently low earth movements of less than one millimicron (10^{-9}m) at 1 Hz are detectable, i.e. earth velocity less than 5×10^{-9} m/s.

TECHNICAL SPECIFICATION

Seismic Data Sources	Maximum 11 points
Seismic Array Area	Approximately 150 kilometers maximum radius using radio link 10 km maximum radius using land lines
Recording time	Maximum of 680 hours (28 days) on single tape for a five channel system
System gain	20000 - 1
Microseism detection power	Better than 5×10^{-9} metre per second (earth velocity using Willmore Mark 3 seismometer better than 1 millimicron earth movement at 1 Hz).
Typical power consumption	3.75W for a typical 5-site system (two connected by landline and three by radio).


RACAL
RACAL-THERMIONIC
Geostore
Field recording system
for seismic data
Field Record Station
Field Test Box
Receiver
12v Battery
Landline to
Remote Seismometer Site
Geostore Field Recorder
3 km
Landline
U.H.F. Radio Link
(up to 100 kilometres)
Landline Link
(up to 10 km)
Yagi Antenna
Don 10 Army type cable (600Ω) either
direct to Field Recorder or to U.H.F. Transmitter
Willmore Mk 3
Seismometer
Bedrock
Concrete Plinth
12v Battery
Transmitter
Power lead supplies
both Tx and
Amplifier/Modulator
Detail of
Remote Seismometer Pit
Amplifier/Modulator
Remote Seismometer Site
with U.H.F. Radio Link

APPENDIX D

KINEMETRICS SEISMIC MONITORING SYSTEM FOR DAM SITES

December 21, 1976
Refer to: KMS 76-342

Subject: Seismic Monitoring System at Dam Site

Gentlemen:

In response to your conversation with Mr. Harry Halverson during his recent visit, we enclose our proforma invoice listing the instrumentation and equipment, which we consider appropriate for monitoring seismic activity beneath and in the immediate vicinity of a dam.

As indicated on the enclosed block diagram, each sensor site will consist of one SS-1 Ranger Seismometer (vertical) and one Amplifier/Filter. These should be installed at the sensor site in a housing or vault of the customer's choice, with provision for exit of the six conductor cable leading to the central recording location. The housing may be either above or below ground and should provide protection against any existing hostile environment. Because the moving mass of the SS-1 Ranger Seismometer is a magnet, the housing should be non-metallic or arranged so that the seismometer is at least 15 cm from the nearest ferromagnetic metal. If requested, we can suggest a type of vault and installation to meet the environmental requirements which you may specify.

The cable between the sensor site and the central recording location should be three twisted, shielded pairs. One pair is used to transmit data (signal). Two conductors and one common are used to provide plus and minus 12 volts DC from the central recording location to the amplifier/filter at each sensor site. The remaining conductor and the above mentioned "common" are connected to the calibration coil in the seismometer so that the calibration coil can be pulsed from the central recording location by application of the proper voltage for the amplitude of pulse desired.

The Central Recording Station will house the DDS-1105 Digital Data Acquisition System which requires 115 volt AC for operation. We assume that the commercial power available will be 220v AC; therefore, we will provide a transformer with the DDS-1105 to supply the required 115 volts AC. It will be necessary for the customer to provide plus and minus 12v DC to provide power to the amplifier/filters at each sensor site, as discussed above. We suggest four automobile-type, rechargeable 12 volt batteries and a suitable battery charger. Two charged batteries will be on-line and two will be on charge. We will provide a Power Control Assembly (listed on the proforma invoice) which will allow switching from the partially discharged batteries to the fully charged batteries, when required, with no interruption of input DC power and to eliminate the momentary surge which would otherwise occur when the fully charged batteries are switched into the system. Each of the two batteries will be required to provide approximately 0.15 amperes. The capacity of the batteries provided will determine how often this switch will be required.

It is our opinion that an array of seven vertical sensor sites, deployed as indicated on the enclosed block diagram, should provide data from which the epicenter and hypocenter can be located to within plus or minus one kilometer or better; the magnitude can be computed; and at least some indication of the focal mechanism can be determined. Six of the sensor sites should be located at distances of 500 to approximately 800 meters from the center of the array (probably the central recording station) at azimuths approximately 60 degrees separated, as surface conditions will allow. The seventh sensor site should be approximately at the center of the array. All sensors should be vertically sensitive.

The DDS-1105 is designed to monitor continuously but records data only from events of interest. The system will provide Sample-in-Retrospect (SIR) so that, whenever it is triggered by an incoming signal at or above the preset voltage threshold, approximately two seconds (1.95 seconds) of data immediately preceeding the triggering signal will be recorded, immediately followed without interruption by the incoming data at least as long as the incoming signal level is above trigger level. If a sampling rate of 150 samples per second, per channel, is selected, the 2400-foot tape proposed will record slightly in excess of two hours of actual data.

With respect to software for use with data recovered by this system, Kinemetrics would like to provide an analysis system for your computer. We would take published, non-propietary programs, presently operating on an IBM 370/158 OS/VS and redesign the system program for your computer with its operating system. This would involve system programming in Pasadena to your computer's specification and then, sending our programmer to you for the period of time required to get the system operational. If your computer is an IBM 360 or 370 series, the cost of this service should be $12,000.00 to $15,000.00.

We are pleased to submit these recommendations and our proforma invoice listing suggested instrumentation for your consideration. We look forward to receiving your comments, suggestions, and questions.

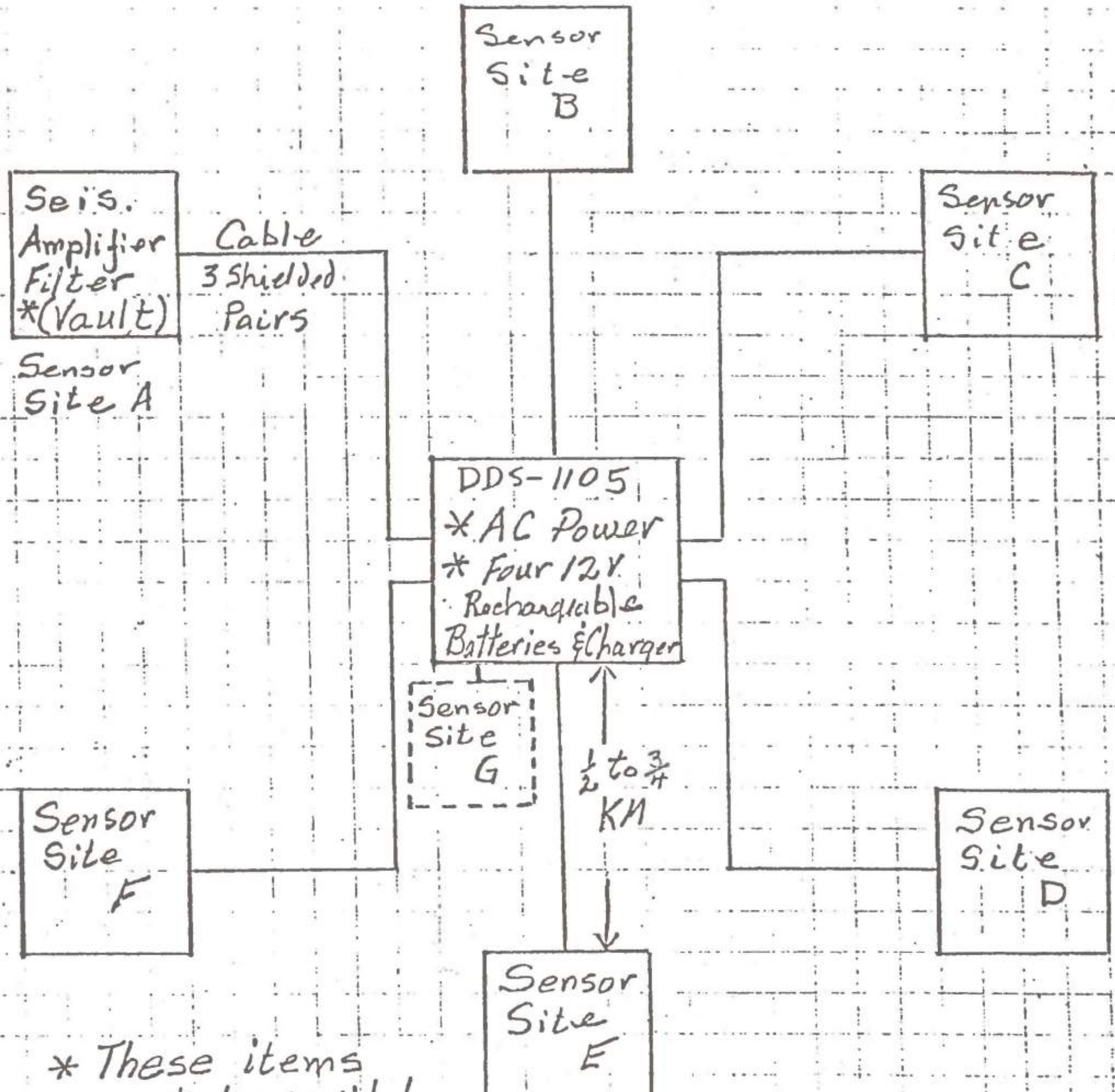
Very truly yours,

C. Boyd Forbes
Manager/Engineering Services

CBF/kh

Enclosures

CC:



* These items are to be provided by the Customer

Dam Site Seismic Monitoring System

CBF
12-14-76

APPENDIX E

KINEMETRICS SEISMIC MONITORING SYSTEM FOR NUCLEAR SITES

December 23, 1976
Refer to: KMS 76-348

Subject: Seismic Monitoring System for Proposed Nuclear Sites

Dear

In response to your conversation with Mr. Harry Halverson during his recent trip, we enclose our proforma invoice for instrumentation and equipment which we recommond for seismic monitoring of proposed nuclear sites. Attachment A discusses each component of the proposed array, as well as some available options.

As indicated on the enclosed block diagram, Figure 1, we recommend seven sensor sites. Six sites should be at distances of approximately 10 kilometers in directions approximately 60 degrees apart. Actual distances and directions will necessarily vary in order to select accessible quiet sites which will provide line-of-sight to the Central Recording Station. The seventh site should be in the vicinity of the Central Recording location. With such an array it should be possible to record earthquakes of -1 magnitude on the Richter scale from four sensor stations if extremely quiet locations can be found. If the average noise at the sensor sites is approximately 50 millimicrons in the frequency spectrum of interest, the smallest earthquake reliably detectable would be in the 0.5 to 0.7 range (Richter magnitude scale).

From the data recovered, it should be possible to determine the hypocenter and the magnitude. Accuracy of such determination will be increased as more events are recorded and studied from more sensor stations, because additional data will allow more accurate determination of the correction factor for each individual station. At least some indication of the focal mechanism can be determined.

We have not recommended use of any horizontal-sensitive seismometer If you feel that you would like triaxial, orthogonal sensors at some of the sites, we can provide a quotation for the additional instrumentation. No additional transmitters or receivers would be required, but additional seismometers, preamplifier/VCO's, and discriminators would be added. Also, an additional eight channel section would be required for the DDS-1105.

The function and utilization of the DDS-1105 would be exactly the same as described in our proposal KMS 76-342, Seismic Monitoring System At Dam Site. We appreciate the opportunity to submit this proposal for a Seismic Monitoring Array and invite any questions or suggestions.

Very truly yours,

C. Boyd Forbes
Manager/Engineering Services

CBF/kh

Enclosures

CC:

ATTACHMENT A

Recommended Equipment for a Seismic Array Utilizing Telemetry

The individual components required are listed below for reference in the discussion following the list.

A. At each sensor site

1. Sensor (seismometer)
2. Preamplifier/Voltage Controlled Oscillator (VCO)
3. Radio Transmitter
4. Transmitting antenna
5. Interconnecting cables
6. DC power at the unattended sensor site
7. Antenna Mast
8. Vault for sensor, VCO, and the DC power source.

B. Intermediate

9. Radio repeater stations, if required

C. At the Central Recording Station

10. Receiving antenna
11. Antenna mast
12. Radio receiver
13. Discriminator
14. Interconnecting cables
15. Power - AC and DC
16. Equipment housing
17. Data recorder

The following discussions refer, by number, to the above list.

1. The sensor most widely used and certainly most appropriate for this application is the SS-1 Ranger Seismometer, manufactured by Kinemetrics. We recommend the 5000 ohm coil, one second period, operated in the vertical position.

2. The preamplifier/VCO should be in a single "package". It should provide adequate amplification (approximately 90dB), adjustable over at least 48dB in 6dB steps; and high-cut and low-cut filters in order to pass data only in the frequency of interest. Power requirement should be low. Eight "standard" sub-carrier frequencies are typically available and additional frequencies can be provided, if required. Use of different sub-carrier frequencies allows multiplexing and transmission over one telemetry link, either radio or wire line, when sensors are sufficiently close together to make transmission from a common point economically feasible.

3. U. S. A. manufactured FM radio telemetry transmitters are normally available with power of the following wattages: 0.100, 0.500, 2.0, and 5.0. Intermediate values are available on special request. These are considered marginally acceptable for distances (in Kilometers) of 16, 35, 70, and 112, respectively, under average to good conditions, line-of-sight. Radio frequencies recommended are in the 152 to 174 MHz band. The preset transmission frequencies should be selected so that the absolute minimum separation between any two transmitter carrier frequencies is 25 KHz (0.025 MHz). 50 KHz separation is preferable to avoid interferrence. Because the transmitting carrier frequencies are set at the factory by selection of a crystal, and cannot be adjusted or tuned by the user, it is necessary to obtain any required governmental permits or allocation of specific frequencies before the transmitters are ordered, so that they can be built to operate at the specific frequencies allocated.

4. The selection of the transmitting antenna will depend upon such factors as distance between transmitter and receiver, potential outside interferrence, directional factor ("beaming") required, and amount of additional gain required at transmitting (or receiving) location.

5. All required mating connectors are provided with each instrument. Completely wired interconnecting cables, utilizing these supplied mating connectors, are offered by Kinemetrics. These cables will be of sufficient lengths to meet the requirements of typical installations. At the request of the customer, longer cables will be provided if specific lengths are specified in advance. When the interconnecting cables are ordered, they are included in our system final test and check-out to ensure that the system will function properly when assembled by the customer.

6. Commercial power is rarely available at remote sensor sites. Therefore, it is necessary to provide 12V DC power (batteries) to operate the preamplifier/VCO and the transmitter. This power is frequently provided by one 12 volt, heavy duty automotive-type battery with minimum capacity of approximately 100 ampere-hours to minimize the frequency of visits to each sensor site with a fully charged replacement battery. Other types of 12 volt batteries may be used where frequency of visits to the site for battery replacement is not an important consideration. For any site to which access is very difficult or expensive, the air-cell such as the Edison ST Carbonaire battery is recommended for long, trouble-free life. This battery is designed to supply at least 1000 ampere-hours before the voltage begins to drop, without limit as to lapsed time so long as a current of at least 0.015 amperes is maintained with no more than occasional interruptions. It is not rechargeable.

7., 8. Kinemetrics cannot supply the antenna mast or the vault or housing required at the remote sensor site. These are items which the customer will need to select and provide to meet his specific, local requirements. If requested, we will suggest installation procedures to meet specific environmental conditions.

9. Radio repeater stations may be required when line-of-sight distances between the transmitter and the receiver exceed the distances listed in paragraph 3, above; or when direct line-of-sight is not available because of topography. Required equipment for a repeater station (not including antenna mast and DC power) will be quoted, if required, to meet specific conditions at a typical cost of approximately $2,000.00.

10. Refer to paragraph 4, above.

11. Refer to paragraph 7, above.

12. The radio receiver must be accurately tuned, by the manufacturer, to a fixed frequency to match that of the corresponding transmitter.

13. One discriminator per channel is required at the Central Recording Location with its center frequency selected to match the center frequency of the preamp/VCO (paragraph 2). For either single channel or multiplexed transmissions this provides recovery of the frequency modulated signal (discrimination) and demodulation to provide the (amplified)

analog signal originally generated by the sensor. A Discriminator Rack is recommended to provide convenient "plug-in" housing for up to as many as 16 discriminators, and to convert available commercial AC to the required DC for operation of the discriminators.

14. Refer to paragraph 5, above.

15. DC power is required at the Central Recording Station for operation of the radio receiver and the discriminators. The receivers will operate on 12V DC, but most discriminators require plus and minus 12 volts. At least one discriminator (Interproducts) is available which requires only 12V DC.

AC power is required for operation of the Racal Store 14 Reporducer (used with the Geostore 5-11 tape recorder) or the DDS-1105 Digital Data Acquisition System; however, if AC power is available at any location, it can be used to operate an on-line battery charger in order to eliminate or reduce the requirement for periodically changing batteries. Batteries and battery chargers are normally a customer supplied item.

16. The specific requirements for Central Recording equipment housing will very from one location to another and will be customer supplied. The only basic requirement with respect to Kinemetrics equipment is that the housing provide adequate protection from weather, including environmental temperatures within the specified operating range for each instrument supplied.

17. The choice of data recorder will depend upon several factors including but not limited to:

   .1 planned use of data or data reduction and interpretation procedure.

   .2 cost.

   .3 availability of proper power to operate the recorder selected.

   .4 local environmental conditions which might be hostile to the recorder.

   .5 requirement for continuous recording, or for the recording only of signals exceeding a preset amplitude (voltage-sensitive) trigger. Three basic types of recording systems are offered by Kinemetrics, namely: DDS-1105 Data Acquisition System (digital), VR-1 Direct Write Drum Recorders, and Geostore 5-11 slow speed FM Magnetic Tape Recorder.

DIGITAL DATA ACQUISITION SYSTEM

The Kinemetrics DDS-1105 Digital Data Acquisition System accepts input analog voltages representing data from the sensor locations; digitizes these data at a preselected appropriate sampling rate; stores the data for a predesignated maximum number of seconds (constantly updating the stored data); compares incoming data from any one or all sensor locations (switch selectable) with a predesignated voltage level ("trigger" level); and, when the trigger level is reached or exceeded, begins recording the digital data on tape beginning with the stored sample in retrospect (2048 data words), and continuing as long as the input voltage exceeds the trigger level and continuing for a short period of time thereafter, depending upon the number of post-event scans selected, the number of data channels, and the sampling rate selected. Recording is on IBM compatible synchronous tape transport. This mode of recording offers the advantage of eliminating the necessity of inspecting many hours of nothing but noise on the record, between the recorded events of interest.

It should be pointed out that a digital computer is required for complete interpretation of the data; or, as a minimum, a digital/analog converter and strip chart recorder to allow visual inspection of the data. These items are not available from or through Kinemetrics. The power requirement of the DDS-1105 is such that either commercial power or a 1-KW Generator at the recording location is required.

VISIBLE RECORDER

The VR-1 Direct Write Drum Recorder accepts the input analog (demodulated) data and produces a visual ink/paper record 30cm x 90cm. The "standard" model of the VR-1A operates on 115V 60 Hz. (115V/50 Hz or 220V50 or 60 Hz optionally available.) Recording time for one data channel, recording at a chart speed of 60mm/minute and trace separation of 2.5mm, is approximately 25 hours; therefore, recording paper must be changed daily. Options available include dual-pen or three-pen models, simultaneously recording two or three channels of data, respectively. The chart speed and the translation speed (which determines the time-duration of one record) may be selected from the options listed on the data sheet to provide longer duration records (up to 96-hours) or different chart speeds for better frequency resolution or different trace separation.

The VR-1B operates from plus and minus 12VDC (automobile type batteries or DC power supply, for example) with power frequency control provided by a crystal timing system (DTS-1 or TS-1) with constant temperature accuracy of 1 x 10^{-8}. This is in contrast to the motor speed and time mark accuracy provided by commercial power, which is exactly the accuracy of the frequency of the 60 Hz (or 50 Hz) supplied by such commercial power.

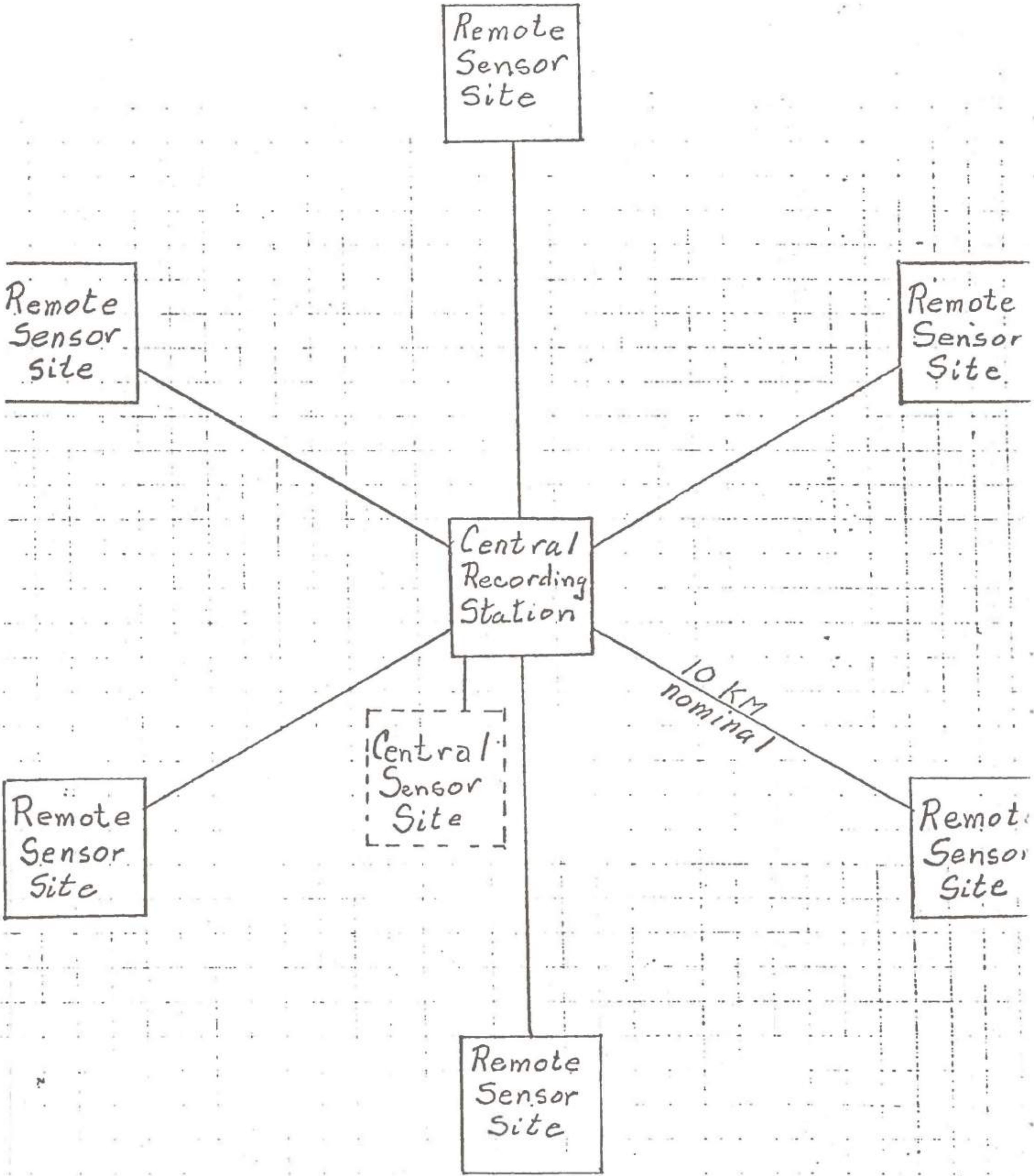
Two or more VR-1A Recorders can be interconnected to record time marks simultaneously from a single source. Multiple VR-1B Recorders can be operated from a single appropriate DC source and a single crystal power frequency control source. Circuitry is available which allows batteries to be changed (replaced with fully charged batteries) without interruption of the VR-1B operation.

The AF-1 Amplifier/Filter, internally mounted in the base of each VR-1, provides gain and filtering at preselected, fixed corner frequencies. An optional gain-selector toggle switch may be mounted on the rear of the VR-1 base to provide either of two preselected amplifications x500 or unity gain. The GAIN potentiometer with control on the front panel of the VR-1 provides accurate, fine adjustment of the system amplification. Telemetered data from remote sensor stations will have been adequately amplified, but filtered only to attenuate the sensor output above 30 Hz and below approximately 0.1 Hz. Therefore, preselected filters of 6dB, 12dB or 18dB/octave at appropriate corner frequencies should be specified for the AF-1. If the VR-1 is ever to be used to record direct output of the sensor (not telemetered) such as the Central Recording Station, unity gain is inadequate and the toggle switch selectable gain of 500 will be required. This optional gain selection also increases the versatility of the VR-1 so that it is able to function properly as an independent unit, separate from the network and without telemetry.

FM MAGNETIC TAPE RECORDING

The Geostore 5-11 is a 14 track slow-speed, FM Magnetic Tape Recorder providing one-way tape recording of 11 channels of data or two-way tape recording of up to 5 channels of data. Three channels are available for internal time, external time, and compensation. Switch selectable tape speed of 1/640 inch per second, (ips) 1/320 ips, or 1/160 ips allow continuous, unattended recording of 5 channels of data for four weeks, two weeks, or one week, respectively; and provide frequency response up to (-3dB point) 10 Hz, 20 Hz, or 40 Hz respectively. Up to 11 channels of data can be recorded on one pass of the tape for durations one half those listed above.

Power required for the Geostore 5-11 is 12VDC (e.g., automotive battery) and 0.125 milliamperes. An external preamplifier/modulator (Mk. II) is required for input to the Geostore 5-11. This can be located at the Sensor Site, eliminating the requirement for a discriminator at the Recording Location. Tapes recorded on the Geostore can be played-back only on the Store 7 or Store 14 Reproducer. These reproducers provide play-back speeds as slow as 15/16 ips, and up to 60 ips, automatically providing the proper demodulation at the speed selected. With an appropriate visible recorder capable of responding to the high frequencies played back at the faster speeds, it is possible to identify "events" by amplitude pattern, even when the chart speed of the visible recorder is very slow. Such identified events of potential interest can then be recorded at a faster chart speed suitable for frequency resolution and analysis.

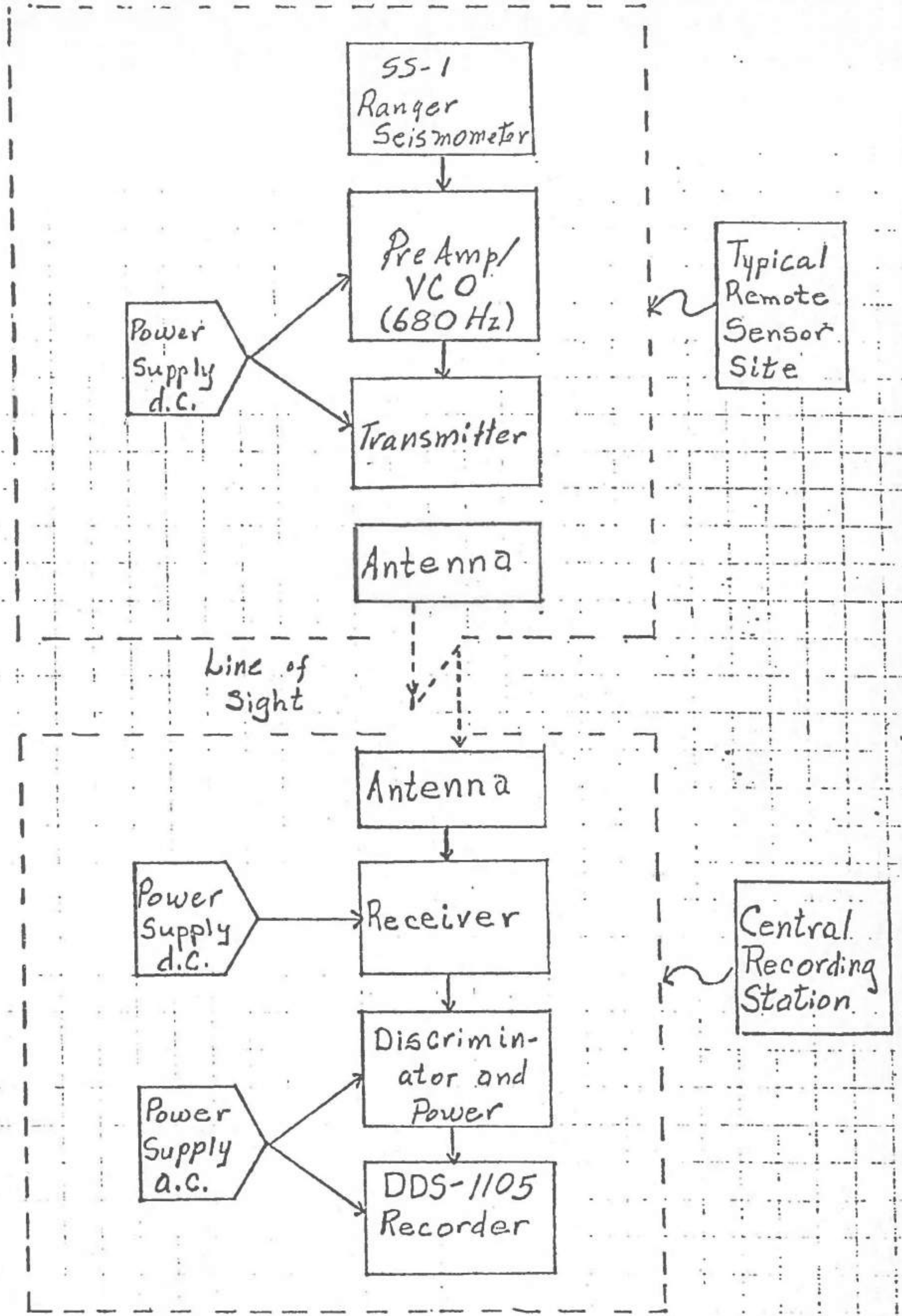


Proposed Nuclear Sites
Seismic Monitoring System

See Fig. 2 for Details

Figure 1

CBF
12-20-76



Central Recording Seismic System
with Radio Telemetry Data Transmission
(One typical Data Channel)

Figure 2

CBF
12-20-76

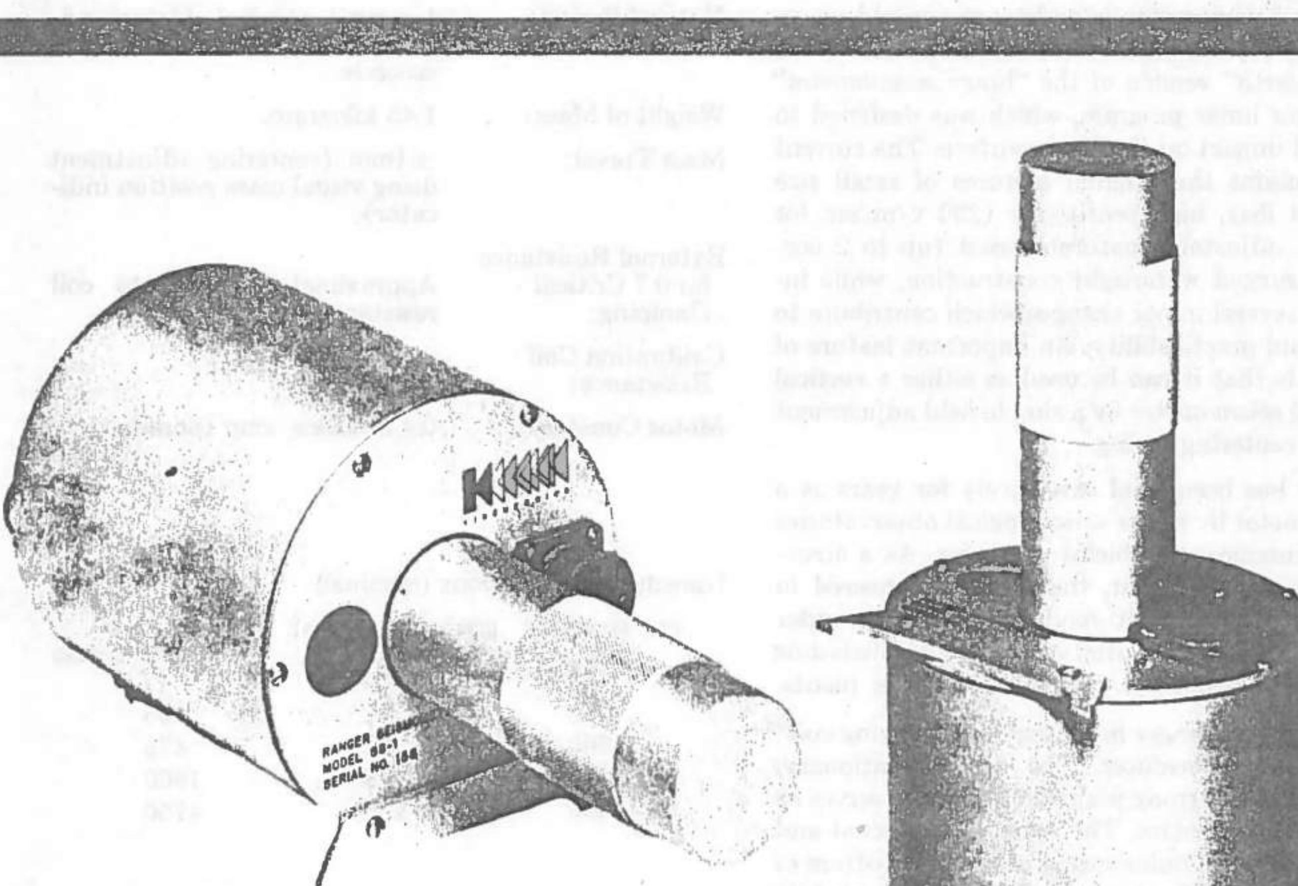
APPENDIX F

VARIOUS KINEMETRICS EQUIPMENT

KINEMETRICS

SS-1

Ranger Seismometer



The SS-1 Ranger Seismometer is the current version of the short period "Lunar Seismometer" used early in the U. S. Space Program. The present design incorporates the basic original features of small size, light weight, and high sensitivity, coupled with very rugged construction for portable field applications.

KINEMETRICS

SS-1

Ranger Seismometer

General Description and Applications

The Ranger Seismometer is widely recognized as an excellent short period field seismometer. It is essentially the "earth" version of the "lunar seismometer" of the Ranger lunar program, which was designed to survive hard impact on the lunar surface. The current "Ranger" retains the original features of small size (less than 9 lbs), high sensitivity (290 v/m/sec for 5000Ω coil), adjustable natural period (up to 2 seconds), and rugged watertight construction, while incorporating several minor changes which contribute to versatility and practicability. An important feature of the Ranger is that it can be used as either a vertical or horizontal seismometer by a simple field adjustment of the mass centering spring.

The Ranger has been used extensively for years as a field seismometer by major seismological observatories with no maintenance problems whatever. As a structural dynamics instrument, the Ranger pioneered in the determination of multi-modes of vibration under low-level excitations of a variety of structures including dams, high-rise structures, and nuclear power plants.

Mechanically, the Ranger incorporates a "moving coil" (velocity type) transducer. The coil is stationary, however, while the strong permanent magnet serves as the seismic inertial mass. The mass is supported and constrained by an annular spring at top and bottom of the moving mass. The basic natural period of 0.35 second is extended to one second or more by means of small rod magnets around the periphery of the coil, which interact with the primary magnetic field. For transportation, a clamp for the moving mass is incorporated into the base of the Ranger, thus providing additional protection. The unit is 5″ in diameter, 6″ high, with a mass positioning extension which also serves as a carrying handle.

The separate calibration coil in the base provides a simple and accurate means of field calibrating the Ranger using only a known-voltage battery and a fixed precision resistor.

Specifications

Natural Period:	1 second nominal, factory adjustable from 0.5 second to 2 seconds.
Weight of Mass:	1.45 kilogram.
Mass Travel:	±1mm (centering adjustment using visual mass position indicator).
External Resistance for 0.7 Critical Damping:	Approximately equal to coil resistance.
Calibration Coil Resistance:	100 ohms.
Motor Constant:	0.4 newtons/amp (nominal).

Transducer Coil Options (nominal)

COIL RESISTANCE OHM	GENERATOR CONSTANT VOLTS/METER/SEC	CDR AT 1 SECOND
50	29	47.5
100	41	95
500	92	475
2000	185	1900
5000	290	4750

Ordering Information

Please specify:

1. Normal operating mode, e.g., vertical or horizontal.
2. Natural period desired, if other than one second.
3. Transducer coil resistance.

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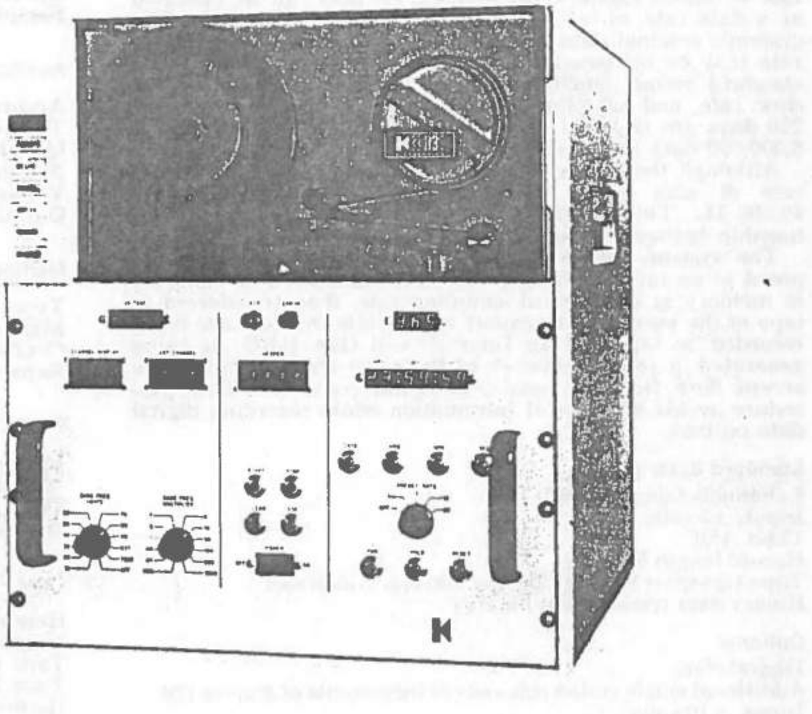
KINEMETRICS

DDS-1103

Digital Data Acquisition System



An ideal addition to many experimental programs, the DDS-1103 will allow the investigator to record multiple channels of analog data in digital form on computer-compatible tape.

A minimum of effort is required in the use of this system and the generated tape record is immediately compatible with standard scientific batch-processors such as IBM and CDC computers.

A high degree of flexibility is available with this system; for example, the number of data channels available can vary from 8 to 128, and the maximum data rate can be as high as 20,000 samples per second or as low as one sample every 20 seconds.

K I N E M E T R I C S

DDS-1103

Digital Data Acquisition System

GENERAL DESCRIPTION

Two methods of operation are common with the DDS-1103. A particular measurement program may require a digital data acquisition system dedicated solely to that program, or a number of investigations may generate FM analog tape recordings which the acquisition system subsequently converts to digital format and records on computer compatible magnetic tape. In both cases, the output digital magnetic tape is removed from the tape transport/recorder of the DDS-1103 System and directly mounted on any IBM compatible tape transport used as the input device for a digital computer.

Many transducers; pressure, strain, velocity, acceleration, etc., are used in scientific, engineering and medical experiments and monitoring. The standard DDS-1103 System accepts up to 8 of this type of data as input. This may be expanded in increments of 8 channels to a maximum of 128 channels.

The DDS-1103 uses a 12 binary bit analog to digital converter. The standard system has an input range of ±5 volts and will resolve 2.5 millivolts with the 12 bit converter.

A DDS-1103 System can be operated at its maximum data rate of 20,000 samples per second, yet also can be operated at a data rate as low as one sample every 20 seconds. The system's nominal data rate is 1800 samples per second. This rate may be increased to 3700, 7000, 10,000 or 20,000 using standard record length and tape transport options. At the slow rate, and sampling 8 channels once every 20 seconds, 250 days are required to fill a 2400 foot reel (approximately 8,600,000 data samples).

Although the system data rate is variable the DDS-1103's rate of scan across multiple input channels is always 40,000 Hz. This rapid scan rate will retain the phase relationship between channels for most applications.

The systems utilize a synchronous tape transport, as opposed to an incremental recorder. The data are first collected in memory at the desired sampling rate, then transferred to tape at the maximum transport rate. While the data are being recorded on tape and an Inter Record Gap (IRG) is being generated, a second memory of the same size is available to accept data from the analog-to-digital converter. This procedure avoids any loss of information while recording digital data on tape.

Standard System:

8 channels (single ended)
Input, ±5 volts
12 bit ADC
Record length 512 bytes
Tape transport 9 track 12½ ips, 800 bpi, 7-inch reel
Binary data (code: offset binary)

Options:

- Digital clock
- Additional single ended channels in increments of 8 up to 128
- Input, ±10 volts
- Record length 2048 bytes
- Tape transport
  - 25, 37½, 75 ips
  - 800, 556, 200 bpi
  - 10½-inch reel
- 7 track tape recorder
- Pre-set record counter with automatic stop and EOF upon completion.
- External digital data inputs
- ADC output to rear panel
- Internal timing to rear panel (±0.02%)
- Remote start and stop

Maximum Data Rate (samples per second at 800 bpi):

	Record Lengths	
Tape Speed	512 Bytes	2048 Bytes
12½ ips	1,850 sps	3,335 sps
25 ips	3,700 sps	7,081 sps
37½ ips	5,550 sps	10,617 sps
75 ips	11,100 sps	21,244 sps

Accessories:

Cabinet
Pre-recorded master tapes
Blank data tapes

TECHNICAL SPECIFICATION

Multiplexer

Number of Channels (expandable to 128):	8
Input Voltage:	±5 volts
Selectable Scan Rates:	0.05 Hz to 20 KHz
Channel to Channel Time Skew:	25 Microseconds
Addressing:	Sequential
Channel Input Impedance:	10^9 Ohms
Overvoltage Limit:	±15 Volts
Crosstalk:	−80 dB
Channels Selected (last channel):	Thumbwheel Switches

Sample & Hold Amplifier

Gain (Unity):	Fixed
Aperture:	50 Nanoseconds
Sampling Time:	5 Microseconds

Analog to Digital Converter

Accuracy (% of full scale):	±0.025%
Temperature Coefficient:	±5 ppm/°C
Quantizing Resolution:	1 Part in 4,095
Maximum Word Rate:	40 KHz
Voltage Display (Channel Selectable):	3 Digits, Plus Sign
Output Code:	12 Bits Offset Binary

Memory

Type:	Coincident Current Magnetic Core
Maximum Shift Rate:	5 MHz
Configuration:	1024 Bytes x 8 Bits
Expansion Increment (option):	4096 Bytes

Digital Clock Option

Minimum Increment:	1 Second
Maximum Time:	365 Days
Time Base:	Crystal Oscillator
Display:	9 Digits

Tape Transport (IBM Compatible)

Rate at 800 bpi:	12½, 25, 37½ or 75 ips
Number of Channels:	7 or 9
Tape Reel Size:	7 and 10½ inches
Tape Length:	600 and 2400 feet
Record Lengths:	512 Tape Bytes
Expansion Increment (option):	2048 Tape Bytes

Physical

Data Module: 19" x 12¼" x 21", 50 pounds
(48cm x 31cm x 54cm, 23 kg)
7" Tape Transport: 19" x 8¾" x 7½", 25 pounds
(48cm x 22cm x 19cm, 11 kg)
10½" Tape Transport: 19" x 24½" x 12½", 80 pounds
(48cm x 63cm x32cm, 36 kg)
Cabinet: 21" high x 24" deep, 30 pounds
(54cm x 61cm, 14 kg)
: 55" high x 24" deep, 120 pounds
(140cm x 61cm, 54 kg)
Operating Temperature: 5°C - 45°C
Non-condensating Humidity: 10% - 90%

Power

Power Requirement: 115 VAC, single phase, 48 Hz - 400 Hz.
Power Consumption: Data Module — 175 Watts
7" Tape Transport — 120 Watts
10½" Tape Transport — 400 Watts

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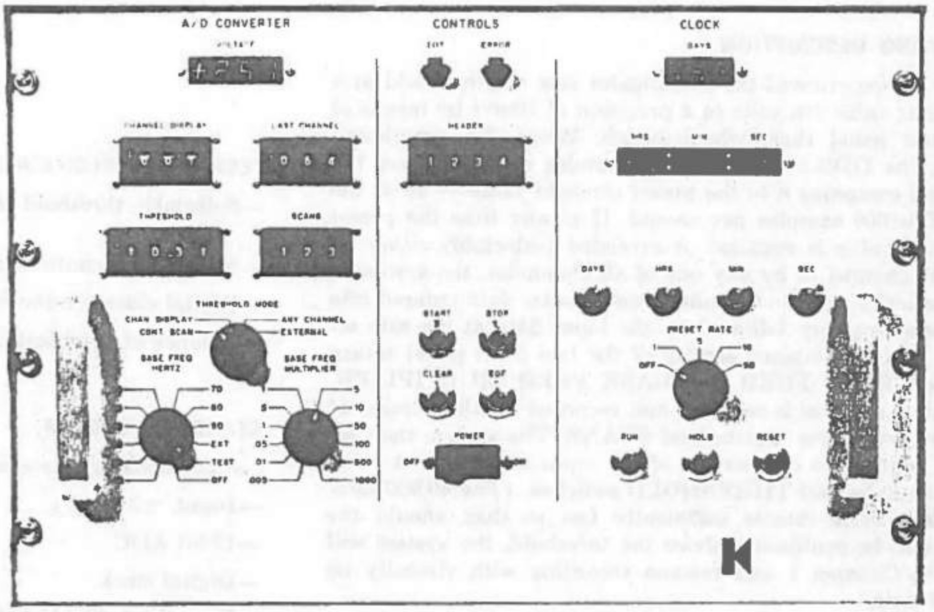
KINEMETRICS

DDS-1105

Digital Data Acquisition System



FRONT PANEL DDS-1105

Data from many tests and experiments are intermittent in character. The DDS-1105 allows the continuous monitoring of such experiments, but will record only data from events of interest on tape. This is accomplished by presetting a threshold value of input voltage. When incoming data exceeds threshold the system automatically starts recording data on tape, automatically terminates based on a preset number of scans, and resumes monitoring.
Thus the DDS-1105 retains the computer-compatible tape and high data rate features of the DDS-1103 plus the threshold capability. This permits data compression and conservation of tape with the consequent minimization of computer processing costs.

Technical specifications for the DDS-1105 are those described on the DDS-1103 data sheet plus those contained on this data sheet.

KINEMETRICS

DDS-1105

Digital Data Acquisition System

OPERATING DESCRIPTION

Before an experiment the investigator sets the threshold at a particular value (in volts to a precision of 10mv) by means of the front panel thumbwheel switch. When the experiment begins, the DDS-1105 accepts the analog data, digitizes the data and compares it to the preset thrshold value — all at the rate of 40,000 samples per second. If at any time the preset threshold value is equalled or exceeded (selectably either by a single channel or by any one of all channels), the system is automatically reset to Channel 1 and header data entered into the buffer memory followed by the input data at the rate selected by the combined setting of the two front panel rotary switches, BASE FREQ and BASE FREQ MULTIPLIER. Each data channel is sampled and recorded for the number of data preset by the thumbwheel SCANS. The system then resumes continuous comparison of the input to the preset value of the thumbwheel THRESHOLD switches. (The 40,000 sample per second rate is sufficiently fast so that, should the event still be continuing above the threshold, the system will reset to Channel 1 and resume recording with virtually no loss of data.)

When a memory buffer is filled with data, its contents are written synchronously onto the computer compatible tape as a record and subsequent data samples are entered into an alternate memory buffer. Each record on tape includes a standard header section of front panel thumbwheel switch status for Scans, Number of Channels and Header. Each event is preceeded by the digital clock data of day, hour, minute, second and millisecond to a resolution of one millisecond.

Rotary switch selection of the Threshold Mode is provided. The CHAN DISPLAY position causes the threshold comparison to be based on the channel designated by the CHAN DISPLAY thumbwheels. The ANY CHANNEL position causes the comparison to be done for all channels being sampled. The EXTERNAL position allows an external device to provide a signal and cause the recorder to start. Using the CONT SCAN mode, the DDS-1105 will operate identically to the DDS-1103.

Often the retention of data received just prior to threshold actuation is desirable — sometimes essential. An optional sample-in-retrospect (SIR) memory (2048 data words) will provide this capability.

TECHNICAL SPECIFICATIONS

—Selectable threshold range: ±.01 volt to ± Full Scale (nominally ±5.00)

—Multiplexer continuous scan rate: 40 KHz

—Digital clock minimum increment: 1 millisecond

—Balance of specifications are same as the DDS-1103

STANDARD SYSTEM

—8 channels (single ended)

—Input, ±5 volts

—12 bit ADC

—Digital clock

—Record length 512 bytes

—Tape transport 9 track, 12½ ips, 800 bpi, 7 inch reel

—Binary data (code: offset binary)

OPTIONS

—SIR memory 2048 data words

—Balance of options are same as the DDS-1103

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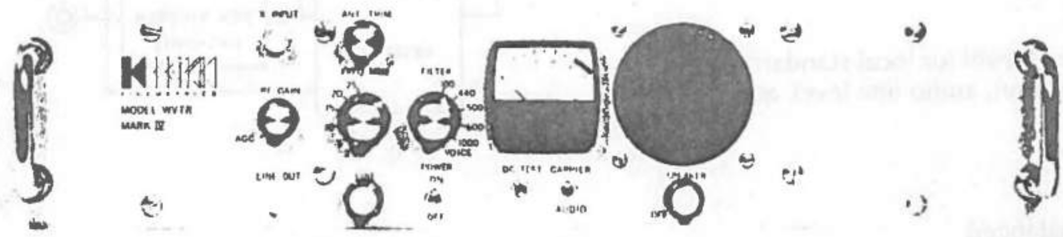
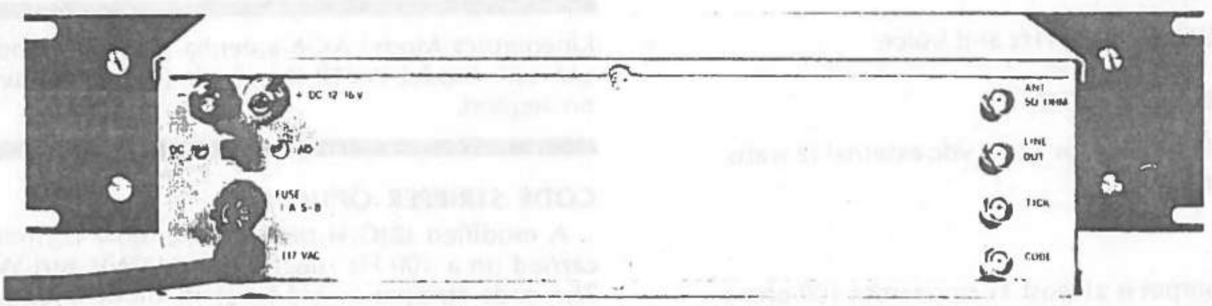
KINEMETRICS

WVTR

WWV Standard Time and Frequency Receiver



FRONT



REAR

MARK IV

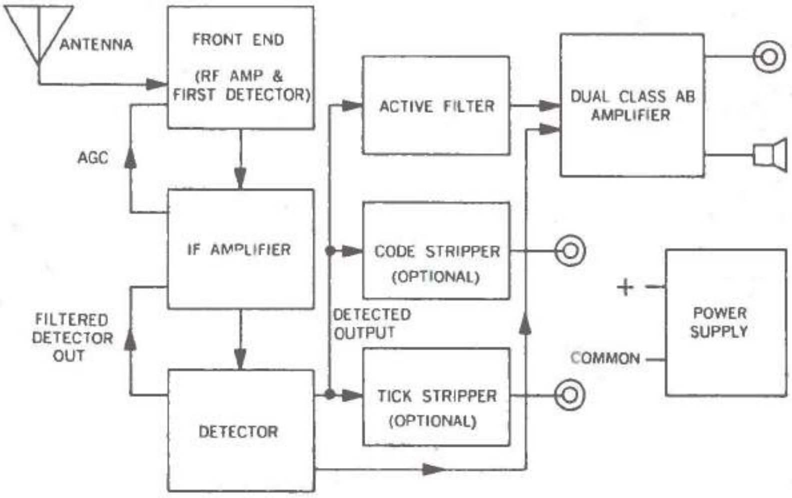
The WVTR rack mounted WWV receiver is all solid state design and modular construction. It is a highly sensitive, crystal-controlled, double-conversion superheterodyne, and has ceramic filters at 455 kHz (2nd I.F. frequency) for high selectivity reception of the six short wave frequencies from Station WWV, Fort Collins, Colorado, WWVH, Hawaii, and foreign broadcast stations such as Station JJY (Japan) and ZUO (South Africa).

An electronically similar receiver — Model WWVT — is offered as a portable battery-operated version.

KINEMETRICS

WVTR

Standard Time and Frequency Receiver



SPECIFICATIONS

OPERATING FREQUENCIES:

2.5, 5, 10, 15, 20 and 25 MHz (other freqencies available on special order).

MODE

AM and MCW

SENSITIVITY

1 μv with better than 15 db (S+N)/N

BANDWIDTH (Selectivity)

±1 kHz at 3 db down

AGC ACTION

Less than 5 db change in audio output from 10μv to 100 mv input

PANEL METER

3 positions: carrier level (or local standard beat frequency difference), audio line level, and power supply test

R. F. INPUT

1. 50 ohm unbalanced
2. High Z (X input)

AUDIO FILTER

100, 440, 500, 600, 1000 Hz and Voice

POWER REQUIREMENTS

117V AC, 50-400 Hz, or 12-16 vdc external (2 watts approximately)

OUTPUT

Class AB output is at least 1v rms across 100 ohms

SIZE

3½"x19"x6¾" deep

WEIGHT

Net 4½ kg (9½ lbs.) Shipping 5½ kg (12 lbs.)

OPTIONS AVAILABLE

Tick Stripper. (See opposite column for description.)
Code Stripper (See opposite column for description)
600 ohm balanced output
Operation from 220 VAC

ANTENNA

Kinemetrics Model AK-8 antenna is recommended for use with Model WVTR Receivers. Data Sheet available on request.

CODE STRIPPER OPTION

A modified IRIG-H time code is now continuously carried on a 100 Hz subcarrier on WWV and WWVH. The code stripper board takes its input directly from the receiver second detector and converts 100 Hz pulse width code to a dc level shift. The code is reproduced at an external connector with a 0-9 vdc level shift, capable of supplying 30 ma current to an external circuit. It operates from the internal power supply of the receiver.

TICK STRIPPER OPTION

Radio Station WWV broadcasts time ticks (5 cycles of 1000 Hz) every second. The tick stripper is a 1000 Hz bandpass active filter and diode shaping circuit which converts the time tick to a sharp, positive, 2.5 v. spike. The stripper output should be connected to a 10k or greater load.

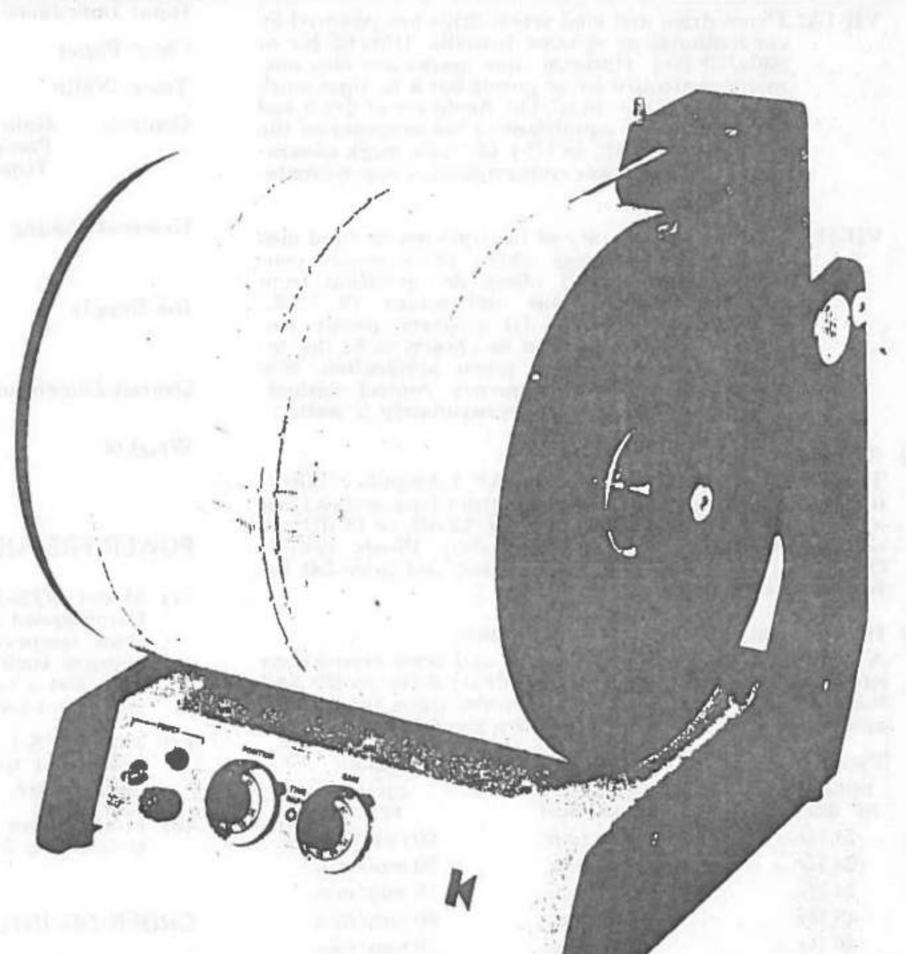
SPECIFIC PRODUCTS DIVISION

KINEMETRICS, INC./THREE THIRTY-SIX AGOSTINO ROAD, SAN GABRIEL, CALIF. 91776/TELEPHONE (213) 287-9731

KINEMETRICS

VR-1

Direct Write Recorder



The VR-1 Direct Write Recorder is an advanced pen writing drum recorder with several outstanding features, including:

- — Outstanding record visibility
- — Economical operation
- — Integrated pen drive amplifier
- — Optional DC operation
- — Optional crystal timing controls
- — Optional speeds of both drum and pen
- — Table, rack mount, or portable options

KINEMETRICS

VR-1

Direct Write Recorder

GENERAL DESCRIPTION

The VR-1 Direct Write Recorder is a visual writing, precision seismograph and is offered in two basic configurations: Model VR-1A and VR-1B. The record size is the standard 30 x 90 cm. Paper, ink capillary pen, and pen motor/amplifier have been carefully selected and matched to optimize clarity of record, minimum maintenance, and lowest operating cost. Wide flexibility for a variety of applications is offered.

OPTIONS

(1) Timing and power:

For some applications, the accuracy of commercial ac power is sufficient for driving the VR-1 motors and providing time marks. However, many investigators may require operation in remote locations where frequency of ac power is inaccurate. For this reason, Kinemetrics offers the VR-1 in two timing/power configurations.

VR-1A: Drum drive and lead screw drive are powered by conventional ac sources (usually 115v/60 Hz or 230v/50 Hz). Optional time marks are also normally controlled by ac power but a dc time mark generator is also available. Accuracy of drive and time marks are equivalent to the accuracy of the ac source (±0.5% in US) (dc time mark generator ± .01%). Power consumption is approximately 9 watts.

VR-1B: To improve accuracy of the time marks (and also drum drive in areas where ac is poorly controlled), the VR-1B offers dc operation from customer-supplied plus and minus 12 VDC. Additionally ,the VR-1B requires power frequency control which can be chosen to fit the required accuracy for a given application. See opposite for power frequency control options. Power consumption is approximately 2 watts.

(2) Amplification/Filtering:

The VR-1 can be supplied with an AF-1 Amplifier/Filtering offering a selection of low pass corner frequencies from .02 Hz to 230 Hz and rolloffs of 6 dB, 12 dB, or 18 dB per octave. Standard amplification is x500. Please consult Ordering Information, AF-1 data sheet, and price list for further details.

(3) Recording speeds and trace separation:

A wide variety of recording speeds and trace separations can be achieved by changing the drum drive motor and the lead screw motor. Typical speeds, trace separations and resulting duration of record are given below:

Typical Recording Operations for Single Channel

DURATION OF RECORD	TRACE SEPARATION	CHART SPEED
24 Hr.	2.50 mm	60 mm/min.
24 Hr.	5.00 mm	30 mm/min.
24 Hr.	10.00 mm	15 mm/min.
48 Hr.	1.25 mm	60 mm/min.
48 Hr.	2.50 mm	30 mm/min.
96 Hr.	1.25 mm	30 mm/min.
96 Hr.	2.50 mm	15 mm/min.

(4) Multiple channel recording:

Up to three available by adding pen motor assemblies.

(5) Mounting configurations:

Table mount is standard, rack-mount or portable versions are optional.

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July 1975

SPECIFICATIONS COMMON TO VR-1A AND VR-1B

Overall Amplification		0.2 mm pen deflection per millivolt input 100 mm/mv max with AF-1 amplifier/filter
Full Scale Pen Deflection		±5 cm (adjustable to less)
Frequency Response at 3 dB Down		20 Hz at 10 cm double amplitude 30 Hz at 2 cm double
Input Impedance		100 k ohm, single ended
Chart Paper		30 x 90 mm (12" x 35")
Trace Width		0.2 mm
Controls	Gain	—Precision potentiometer
	Pen-position	—Precision potentiometer
	Time Marks	—Time Mark amplitude adjustment
External Timing		External provision for 12 volt timing pulses (6 v or 24 v available on special order)
Ink Supply		½ oz. ink supplied standard which is sufficient for 2 - 3 months operation
Overall Dimensions		40 cm x 40 cm x 40 cm (16" x 16" x 16")
Weights		18 Kg (40 pounds), Shipping 32 Kg (70 pounds)

POWER FREQUENCY CONTROL OPTIONS (FOR VR-1B)

(1) Model DTS-1 Digital Timing System (external option). Drum speed and time mark accuracy ± 1 x 10^{-8} at constant temperature. The DTS-1 has many other useful features such as digital readout, radio time synchronization, and a variety of outputs. Please consult the DTS-1 data sheet for further details.

(2) Model TS-1 Timing System (internal option). Drum speed and time mark accuracy ± 1 x 10^{-8} at constant temperature.

(3) Motor Drive PN-100287 (internal option). Drum speed accuracy ± 5 x 10^{-3}, does not supply time marks.

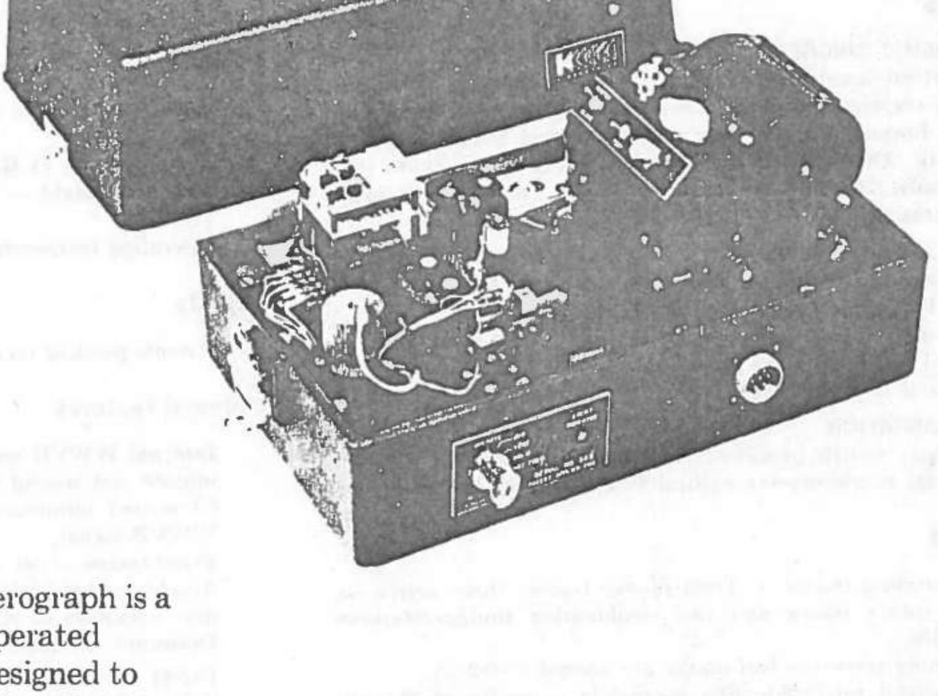
ORDERING INFORMATION

1. Specify Model VR-1A or Model VR-1B
2. For Model VR-1A, specify ac or dc time mark pulse generator (optional)
3. For Model VR-1B, specify power frequency control unless customer-supplied source is available
4. Specify drum speed, trace separation, duration of recording (two variables required)
5. Specify number of channels (up to three available)
6. If AF-1 Amplifiers Filter option is desired, specify:
   a. Corner frequency (range from 0.02 Hz to 230 Hz)
   b. High frequency rolloff (6, 12, or 18 db/octave)
   c. Amplification if other than standard (x 500)
7. Specify table, rack mount, or portable
8. Specify supplies and spare parts (see price list for details)

KINEMETRICS

SMA-1

Strong Motion Accelerograph



The SMA-1 Strong Motion Accelerograph is a low-cost, high precision, battery operated earthquake recorder specifically designed to measure ground acceleration and structural response resulting from strong local earthquakes. The SMA-1 is earthquake triggered, providing automatic triaxial photo recording of all major local earthquake events and subsequent aftershocks. Worldwide usage of the SMA-1 is extensive, involving more than 25 countries and close to 2,000 instruments.

KINEMETRICS

SMA-1

Strong Motion Accelerograph

Operation

The seismic trigger senses the vertical component of the initial earthquake ground motion ("P" wave), and actuates the SMA-1 to full operation within less than 0.05 second. The SMA-1 operates for as long as the seismic trigger detects the earthquake, plus an additional 6 to 20 seconds (adjustable) to permit the exposed photo record to be stored in the light-tight film magazine. The SMA-1 thus can record a single earthquake or a sequence of earthquakes and aftershocks lasting as long as 25 minutes (for a full roll of film). After the earthquake is recorded, the storage film magazine can be replaced by a spare magazine and removed to a darkroom for processing. Direct write photo paper requires no processing.

Sensors

SEISMIC TRIGGERS

Vertical acceleration-sensitive type (standard), providing flat response to acceleration from 1 to 10 Hz. Integral 15 Hz lowpass filter further reduces impact triggering sensitivity. Omni-horizontal displacement-sensitive type (optional). Solid state control circuit provides minimum operating time, 6 to 20 sec. (adjustable).

ACCELEROMETERS

Triaxial flexure-type accelerometers (x, y, & z).
25 Hz natural frequency (1g).
Available sensitivities — 1g, ½g or ¼g full scale.
(full scale deflection on film is 1.9 cm — standard)
Quartz coated first surface mirrors throughout.

CALIBRATION

Rotary switch provides semi-automatic recording of individual accelerometer natural frequency and damping.

Camera

Recording traces — Total of five traces: three active acceleration traces and two combination timing/reference traces.
Timing traces — two marks per second (±0.2%).
Identical removable film magazines, capacity of 25 minutes at 1 cm/second (approximately 50' total) of 70mm perforated film, with film supply indicator.
Recording medium — 70mm black and white mylar base photo film (standard). 70mm direct write photo paper (optional).
Adjustable light source intensity.
Slave/master timing switch for network installations.
Bubble level for coarse leveling at installation.
12 VAC drive motor operates from multi-vibrator to eliminate brush noise.
Actuates to full operation in 50 millisecond, or less.

June 1974

Case

Rugged cast aluminum watertight base and cover.
External connector on base for ganged (common) starting and timing in accelerograph networks, battery testing, event alarm signal, and external (radio) time.
Built-in event indicator on base to indicate visually that accelerograph has been triggered.
Watertight and light-tight O-ring seal between cover and base with padlock latches for security.
Cast-in tripod feet on base.
Single tie-down bolt hole in base for fastening to floor.

Power Requirements

Internal rechargeable 12V battery pack.
Standby current — 0.15 ma.
Operating (event) current — approximately 1 amp.
External battery float charger (110VAC or 220VAC) supplied as standard equipment. (Solar cell charger — optional.)

Physical Data

Watertight case to several feet of water (factory pressure tested).
Net weight — 11 Kg, Case size — 20 x 20 x 31 cm.
Shipping weight — 13 Kg (28#), shipping size —.3130 cm^3 (1.1 ft.^{3}).
Operating temperature — 0°F to 130°F.

Patents

Patents pending on certain key features.

Optional Features

Internal WWVB receiver (CS-60B) to provide day, hour, minute and second timing for each recorded event.
60 second minimum recording duration to accommodate WWVB signal.
Fixed traces — one or two.
Accelerometer electrical output (SMA-1A) to accommodate telemetry or Kinemetrics EFM-1 requirements.
Desiccant envelope.
Direct write paper for immediate visual record.
Solar cell battery charger.

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