STRONG MOTION ACCELEROGRAPH SYSTEMS - PROBLEMS AND PROSPECTS

D. E. Hudson (I)
Presenting Author: D. E. Hudson

SUMMARY

The world's strong motion instrumentation systems are now so large and so expensive to operate that many problems of resource allocation are becoming critical. As a basis for choosing between various options, some of the general principles of strong motion accelerograph systems are discussed, with an indication of the current state of the art and some speculations as to future trends. New generations of direct digital recording accelerographs are described and compared with analog recording systems as to system flexibility, maintenance, and data processing potentialities.

INTRODUCTION

In the early days of strong motion seismometry there were so few accelerographs and so few measurements of destructive earthquake ground motion that it was easy to set goals and to decide where to put instruments. An instrument anywhere in a seismic region was certain to produce an interesting record within a short time. Today such decisions are much more difficult to make. With some 6,000 accelerographs installed in the world and with major economic investments in time and money now required to significantly improve many aspects of the coverage, the search for optimum solutions must engage everyone's attention.

A strong motion accelerograph is an instrumentation system from whose output an accurate determination can be made of the acceleration, velocity and displacement of the ground versus time for destructive earthquake ground motions covering a frequency range of the order of 0.05-50 Hz and having a dynamic range of at least 1000 to 1. The use of the word "accelerograph" in this connection implies neither that the basic instrument measures ground acceleration directly, nor that ground acceleration itself is alone a quantity of dominant importance.

ACCELEROGRAPH SYSTEMS

All accelerograph systems now in operation or known to be under development are combined analog-digital systems. They are analog in the sense that the basic transducer is an analog device, and digital in the sense that the final form of the data is digital, in readiness for various computational operations. The design decisions, therefore, concern the points at which A/D or D/A conversions can best be made. In practice, currently operating systems are spoken of as analog if the data are recorded in the field in analog form, as on a photographic film or smoked paper recorder, and as a digital system if the data are directly recorded in the field in a digital format (Ref. 1).

(I) Department of Civil Engineering, University of Southern California, Los Angeles, California, USA

Analog systems result in a simpler and less expensive device in the field, which tends towards reduced maintenance problems at the expense of increased laboratory data processing man-hours. Such devices are particularly well suited for independent stations in low density networks and adverse environmental conditions. Digital systems adapt more readily to the goals of extended frequency and dynamic range, permit pre-event memory and complicated trigger algorithms, and reduce considerably the time and effort required for data processing. They are thus indicated for dense arrays producing large quantities of data, and for wide dynamic range devices combining seismological and engineering applications which will produce a steady flow of data. The price to be paid is increased complexity and cost in the field, a larger standby power requirement which reduces unattended time intervals and increases maintenance problems, and the need for personnel of a higher level of training and experience.

Current commercially available analog systems have all gone through a long period of development and have achieved a highly reliable and stable state. Small improvements in power supply, calibration and control, automatic trace intensification, etc., may be expected, but it is unlikely that major changes in the technology will be forthcoming or cost-effective. Devices for automatic digitization of analog records by scanning techniques have also attained a reasonably satisfactory state. Automatic digitizers are now available with a sufficient degree of operator interaction so that intersecting and missing traces can be handled.

Digital technology on the other hand is going through a period of very rapid development and change, and new accelerographs involving major innovations are appearing yearly. Figure 1 illustrates schematically the first generation of such digital accelerographs. The analog transducer signal goes directly to an electronic A/D converter and is finally directly recorded on digital magnetic tape. Figure 2 shows a second generation device, with added pre-event memory, gain-ranging to extend dynamic range, and transducer-based trigger algorithms. A major step forward is illustrated in Fig. 3, which shows schematically a third generation accelerograph based on a microprocessor. The use of the microprocessor makes it possible to greatly increase the configuration flexibility, and enables the user to continually tailor the system to the particular signal being measured. By the use of multiple transducers, or by continually altering transducer characteristics, such systems may soon approach a goal which has for a long time been sought - that of producing one instrumentation system which simultaneously satisfies the research needs of seismologists and earthquake engineers. The microprocessor makes possible a whole new approach in instrument system design, that of the software based approach, in which input instructions from the user can continually redesign the system to meet the requirements of the research problem at hand.

The final step producing a fourth generation digital accelerograph has just appeared (1983) in a commercial version. The mechanically driven digital magnetic tape forming the last step in Figs. 1, 2, and 3 has been replaced by a solid state memory, thus producing a completely non-mechanical recording system. This eliminates one element which has been a major source of maintenance problems, particularly for instruments under adverse environmental conditions. In this form the digital accelerograph has finally realized the full potential offered by digital technology, and there remains only the problem of refining the designs so that high field reliability can be obtained at reasonable cost.

FIFTY YEARS OF STRONG MOTION SEISMOMETRY

The first accurate measurements of destructive earthquake ground motions were made during the Long Beach, California, earthquake of March 10, 1933. To suitably commemorate the 50th Anniversary of this notable event in the history of earthquake engineering, a Golden Anniversary Workshop on Strong Motion Seismometry was held in March 1983 at the University of Southern California. In addition to background papers on the history of accelerograph development, and an exhibit of historical instruments along with the latest technology, a series of panel discussions were held to summarize the current state of the art and to define current problems and prospects. The five panels were entitled (1) Strong Motion Instrumentation Systems; (2) Existing Networks and Arrays in the United States; (3) Field Reliability and Maintenance; (4) Data Processing; and (5) Data Storage, Retrieval and Dissemination. The summaries of these topics presented below will represent the author's condensation of the views of some twenty experienced experts in the field as presented during these panel discussions (Ref. 2).

STRONG MOTION INSTRUMENTATION SYSTEMS

For array stations which may be expected to record a considerable amount of data, and for which pre-event memory and accurate timing are usually essential, direct digital recording in the field is the optimum choice for future applications. For isolated stations, especially those with adverse environmental conditions and unusual maintenance problems, analog devices are probably still cost effective. A main limiting factor for digital applications is the relatively high standby power requirement and the consequent need for better and hence more expensive batteries. At present minimum standby power for digital systems appears to be of the order of 1 watt, with little immediate prospect of significant reduction - about five times the standby power of typical analog accelerograph systems. Since all current and presently contemplated systems, both analog and digital, use a force-balance type transducer, it is surprising that so little work has been reported on the characteristics of such devices, and more should be undertaken. A pressing need is for a central evaluation facility with an accurate and convenient shaking table for calibration work. Such an instrumentation test table should be able to produce accurately defined wave-forms over a wide frequency range, should be free of extraneous modes of vibration and of significant cross-axis components, and should contain a reference transducer whose calibration characteristics can be accurately ascertained. The overall potential of telephone interrogation systems needs further study. There are no technical difficulties in the way of remote interrogation systems for monitoring instrument condition as a means for reducing field visits, but the cost-effectiveness is much dependent on the extent to which field visits are needed for non-repair functions, such as routine replacement of film and batteries, and on the widespread adoption of such devices to reduce unit manufacturing costs. As the available dynamic range of instrumentation systems increases, there is more and more convergence of engineering strong motion systems and wide-range seismograph systems used by geophysicists. It may now be feasible to equip many of the existing seismographic stations in telemetered networks for simultaneous use as strong motion accelerograph sites.

EXISTING NETWORKS AND ARRAYS IN THE UNITED STATES

The goal of obtaining at least one significant record from every destructive earthquake has probably now been attained for the United States, but the equally important objective of ensuring adequate near-field measurements for all magnitude 7 earthquakes has not. The general consensus is that while the total number of installed accelerographs in the U.S. is perhaps not far from sufficient, the distribution is far from optimal. There has been inadequate planning of arrays for specialized applications, particularly for engineering studies of special structures such as bridges, dams, and power plants. As a comparison, in Japan the emphasis seems to have gone more towards special arrays rather than general coverage with individual stations, with arrays often tied in to major construction projects. The present accelerograph installations in the U.S. comprise some 900 free-field sites, 500 building sites, and 400 special array sites. The general feeling is that to complete the U.S. network an additional 250-300 free-field sites might be contemplated, with another 15-20 dense arrays. At present in the U.S. down-hole arrays are few in number, and true three-dimensional arrays are non-existent. Arrays for such studies as soil-structure interaction, liquefaction, and the response of special structures are limited in number and even more in scope. There is some difference of opinion as to the engineering importance of aftershock studies, and as to the importance of very rapid deployment of mobile arrays after a big earthquake. Experience in California has been that field deployment has been reasonably rapid, but that the recovered data, while useful for seismological investigations, have perhaps been of less direct importance for engineering applications.

FIELD RELIABILITY AND MAINTENANCE

Current standard analog accelerographs are now as reliable in the field ($\approx 99\%$) as is likely to be attained by field instrumentation systems. Service intervals are governed more by standard replacement policies rather than by repair considerations, for example by USGS practice to replace film once per year and batteries at three-year intervals. Basic inspection intervals can be extended to nine months, but present policy is to visit critical structural array sites at three-month intervals. It now appears feasible to plan for dual maintenance objectives at critical and non-critical installations. Unit maintenance costs have steadily decreased, with a bigger fraction of technician time going to other activities. Direct digital recording in the field has suffered the usual initial development pains, with the expected need for a retrained or more versatile type of field technician. Adverse environmental conditions of high and low temperatures, dust, humidity, and erratic power supply have posed problems for early-generation digital systems. Many digital problems have been associated with the relatively high standby power requirement and the consequent need for better batteries. Transient power conditions have also been troublesome in field applications. An unexpected problem resulting from the ease of changing circuit boards in digital systems is a loss of calibration resulting from inadequate field records of such changes. A common problem with many accelerograph stations, both analog and digital, has been difficulties in maintaining accurate absolute timing. With either radio time or internal time-code generators, recent experience has indicated a disappointing 50 percent reliability in the field. With time code generators and standard power supplies, drift characteristics are such that the station must be visited within 36 hours to maintain 0.1 sec accuracy with 95 percent reliability. There is a considerable difference of opinion as to the cost effectiveness of telephone interrogation systems to reduce overall maintenance costs. For some special situations, such systems might pay off in something like three years; in others they would be clearly inappropriate. It appears that there has been no systematic approach to the problem of updating and retrofitting of old instrumentation. As the accelerograph networks of the world continue to age, this will become a more pressing economic problem with increasing incentives for optimization. There should also be a more systematic interchange of information on field maintenance problems. The USGS has organized some technician meetings to bring together people from various organizations to exchange experiences, and such activities should be supported and pursued on a more extensive scale.

DATA PROCESSING

After passing through an era of standardization there is now a tendency towards diversity in data processing methods, with many organizations introducing new procedures, some involving slight changes from past practices, while others may significantly modify the basic data. An increasing amount of accelerograph data is being obtained from other countries, for much of which the details of data processing may be unknown or uncertain. One point of view is that data processing methods should be flexible to adapt to the latest research requirements of the user, who should be able to exercise his own judgment as to the compromises to be made between signal-to-noise ratio and frequency range. Another opinion is that a unification of approaches would give the standard user the best chance of avoiding misunderstandings. Hopefully these two goals can be combined, with standard processed data available for general use and "uncorrected" data provided for the research user. A central item in any processing scheme is the filtering process used to control noise content. It is generally recognized that there are many different ways of carrying out essentially the same filtering process. What should be agreed upon is the definition of an acceptable filter and a general realization of how standard characteristics could be departed from without significantly altering the data. At present various filters have been advocated in the literature without a clear indication of the conditions under which they might introduce significant improvements over past standard procedures. There is a difference of opinion between some engineers who feel that any filtering operation should preserve the ground signal wave shapes, and some seismologists who for special purposes would like to distort wave shapes, for example, to sharpen up a phase arrival time signal. What can be agreed upon is first that the data processing should involve enough flexibility so that it can supply standard data for general use as well as specially treated data for research applications, and second, that whatever procedures are used should be so completely documented that the user can judge applicability without making a research project out of it.

DATA STORAGE, RETRIEVAL, AND DISSEMINATION

The number of digitized accelerograms in the world in 1980 was of the order of 1,000; this had increased by 1983 to some 3,000, with every indication that an almost explosive growth of such basic data should be expected in the near future. At present there are no international centers attempting to archive such data, and in the two countries with the major accelerograph networks, Japan and the United States, there are literally dozens of separate organizations in the data management business, with no central group to coordinate efforts. A key need is a general catalog of all recovered records, with such information as location of station, time of event, basic earthquake parameters, peak accelerations, and available data formats and source. Although a number of groups in several countries regularly publish such catalogs for their own installed instruments, the major attempt so far to issue them on a collected basis is that of the National Geophysical Data Center of the U.S. National Oceanic and Atmospheric Administration in Boulder, Colorado, which is far from complete. Of special importance is the early and convenient availability of unprocessed acceleration-time curves from important earthquakes. A glance at these preliminary accelerograms is very informative to the experienced investigator, and can give the potential user a quick idea as to which records are likely to be important for special studies. Such plots are available in the preliminary reports issued by some agencies, but for some important earthquakes and stations may be incomplete or unavailable. Catalogs of the above type can be easily adapted to a computer search technique, so that the user with a terminal and a telephone link can ask, for example, for a list of recorded accelerograms within a prescribed distance of a prescribed location. At a higher level of information availability, several systems have been developed which will present to the user with a terminal and plotter such additional items as integrated velocity and displacement curves, and frequency spectra in various standard forms. At least three different automated data retrieval systems of this kind have been independently developed in the U.S., and it would appear that an increased cooperation in this field would improve the overall acceptance and usefulness of the systems. All attempts at computer processing of strong motion data have been much hampered by the multiplicity of digital data formats. For example, the National Geophysical Data Center is now preparing to issue basic strong motion data on floppy disks in 80 different formats. Attempts to decipher tape records have consumed a large number of research man-hours that could certainly have been put to better use. Another deficiency is that information on accelerograph site conditions is far from adequate for any part of the world. Some of the most significant California accelerograms, for example, are from sites that recent studies have reclassified from rock to alluvium.

REFERENCES

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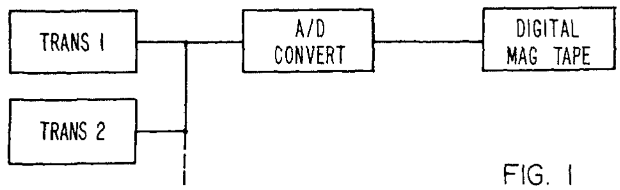

FIG. 1

FIRST GENERATION DIGITAL ACCELEROGRAPH SYSTEM

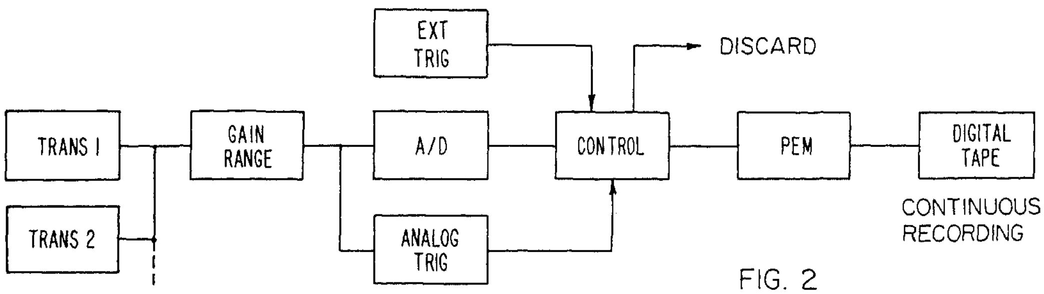

FIG. 2

SECOND GENERATION DIGITAL ACCELEROGRAPH SYSTEM

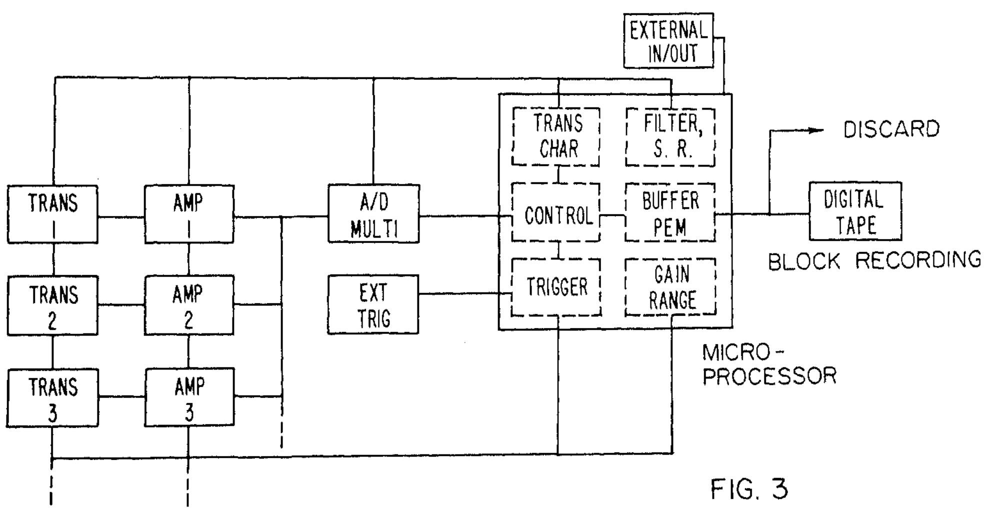

FIG. 3

THIRD GENERATION DIGITAL ACCELEROGRAPH SYSTEM