The New IASPEI Manual of Seismological Observatory Practice

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ABSTRACT

The last edition of a Manual of Seismological Observatory Practice dates back to 1979. It covered analog techniques only and is out of print. Since that time, computer and communication technologies as well as the availability of modern broadband sensors have revolutionized seismological observatory practice. Related know-how is chiefly available in industrial countries only. Besides this, classical university curricula do not provide suitable education and training of observatory personnel. Therefore, the IASPEI Commission on Practice has launched an initiative to produce within the next few years a New Manual of Seismological Observatory Practice (NMSOP). It will be developed as an electronic database and will be freely accessible, together with the old manual, via the Internet. The systematic tutorial body of the manual, complemented by the use of hypertext features which will guide the user to additional resources, will assist station operators and analysts in their daily work and enable them to retrieve relevant pieces of information or teaching/training modules tailored to their specific needs. When finished, the NMSOP will also be available as a CD-ROM, and the publication of a condensed version as a text book is being considered. This paper outlines the philosophy, structure, and list of contents of the NMSOP and demonstrates it using several examples.

INTRODUCTION

Emil Wiechert (1861–1928) once said that the supreme goal of seismology should be to "understand each wiggle" in a seismic record. Only then would we understand or at least have a good model to explain the complicated system and information chain with its many interrelated components, such as the seismic source, the wave propagation through the real Earth, the additional masking and distortion of "useful signals" by interfering noise, and the influence of the seismic sensors, recorders, and processing techniques on the seismogram (*cf.* Figure 1 in Bormann, 2000, this volume, page 502).

Despite the tremendous progress made since Wiechert in understanding the most pronounced features in seismic records, long-period ones in particular, we are still well short of reaching the goal he set. In fact, most operators and analysts at current seismological observatories, even those equipped with the most modern equipment, have not yet advanced much with respect to their curiosity and capability to "understand each wiggle" in a seismic record since the mid-20th century. There are several reasons for this lack of progress in the deeper understanding of seismogram analysis by station operators. Early seismic stations were mostly operated or supervised by broadly educated scientists who pioneered both the technical and scientific development of these observatories. They took an immediate interest in the analysis of the data themselves and had the necessary background knowledge to do it thoroughly. After WWII the installation of new seismic stations boomed, and rapid technological advances required increasing specialization. Station operators became more and more technically oriented, just taking care of maintenance and raw data production with a minimum of effort and interest in routine data analysis, and they have tended to become alienated from the more comprehensive scientific use of their data products. Also, the seismological research community has become increasingly specialized, *e.g.*, in conjunction with the monitoring and identification of underground nuclear tests. This trend has often caused changes in priorities and has narrowed the view with respect to the kind of data and routine analysis required to best serve current scientific interests.

Hwang and Clayton (1991) published an analysis of phase reportings to the International Seismological Centre (ISC) by all the affiliated seismological stations of the global seismic network. Most seismic stations, even those equipped with both short- and long-period or broadband seismographs, reported only the first *P*-wave arrival out of the many—often clearly discernable onsets (*i.e.*, later arrivals) in teleseismic records of strong events, often not reporting even secondary phases with much larger amplitudes than that of the first *P*-wave onset. On average, the first *S*-wave arrivals have been reported to the ISC between 1974 and 1984 about twenty times less frequently than for *P*, and other secondary phases sometimes even hundred to thousand times less frequently (Bergman, 1991).

This incomplete reporting of phases with different travel paths through the Earth, together with the inhomogeneous distribution of seismic sources and receivers over the globe, results in a very incomplete and inhomogeneous sampling of the Earth's interior, of its discontinuities, 3D inhomogeneities, and properties. The consequences are ill-constrained Earth models of inferior resolution. In the late 1980's, this prompted seismologists (*e.g.*, Doornbos *et al.*, 1991) to propose a preliminary science plan for an International Seismological Observing Period (ISOP) aimed at:

- maximum reporting of secondary phases, from routine record readings, aimed at improved source location and sampling of the Earth;
- taking best advantage, in routine analysis, of the increasing availability of digital broadband records and comfortable data preprocessing and analysis software;
- improved training of station operators and analysts (*e.g.*, Bormann, 2000, this volume, page 499); and
- improved communication, coordination, and cooperation among the stations of the global and regional seismic networks.

Interestingly, in an initial ISOP Pilot Project, run between 1 September 1993 and 10 April 1994 with 33 participating stations, all equipped with short- and long-period and/or (V)BB stations, 30% reported on average fewer than one secondary phase per event. Only five stations (about 15%) reported on average four and more secondary phases per event, among them three stations of the former East European countries (OBN, LJU, and PRU) (see Bergman, 1994), which have a longstanding tradition of making more complete phase readings at their observatories than station operators in western or developing countries after WWII and after the deployment of the WWSSN. Also, in former East Germany, very extensive regular secondary phase readings had been common practice since the mid-1960's based on a diversity of available response characteristics covering a frequency range of more than three decades, among them Kirnos broadband analog seismographs (*e.g.*, Bormann, 1972; Bormann and Stelzner, 1972). With modern digital high-resolution broadband records of large dynamic range, allowing for flexible record scaling, precision readings, suitable frequency filtering or restitution of true ground motion, diverse record transformations for eliminating pulse distortions due to internal caustics, etc. (*e.g.*, Choy and Richards, 1975), reconstruction of true ground particle motion, matching observed with synthetic seismograms, etc. could now be done much better than before.

In a workshop meeting entitled "Measurement Protocols for Routine Analysis of Digital Data", organized in late 1993 by ISOP in Golden, Colorado, it was highlighted that existing documents and publications are clearly inadequate to guide routine practice in the 1990's at seismological observatories acquiring digital data. It concluded that a new edition of the Manual of Seismological Observatory Practice (MSOP) is needed as well as a tutorial, showing examples of estimating important seismological parameters (Bergman and Sipkin, 1994). This recommendation prompted the Commission on Practice of the International Association of Seismology and Physics of the Earth's Interior, at its meeting in Wellington, New Zealand, January 1994, to establish a related MSOP working group. In the following we will report about the concepts defined by this group, the work done so far, and the prospects for a new MSOP in the very near future.

THE OLD MANUAL OF SEISMOLOGICAL OBSERVATORY PRACTICE

The old Manual of Seismological Observatory Practice (MSOP) arose from a resolution of the United Nations Economic and Social Council (ECOSOC). In response to this resolution the Committee for the Standardization of Seismographs and Seismograms of IASPEI specified in 1963 the general requirements for such a manual as follows:

- To act as a guide for governments in setting up or running seismological networks;
- To contain all necessary information on instrumentation and procedure so as to enable stations to fulfill normal international and local functions; and
- Not to contain any extensive account of the aims or methods of utilizing the seismic data, as these were in the province of existing textbooks.

The first edition of the manual developed along these lines was published in 1970 by the International Seismological Centre with the financial assistance of UNESCO. A sustained demand for copies and suggestions for new material prompted the Commission on Practice of IASPEI in 1975 to recommend the preparation of a second edition. The manual was also to contain a balance of representation between major Eastern and Western areas of practice. This resulted in the manual version of 1979, edited by P. L. Willmore (1979), in which the basic duties of seismological observatories were envisioned as follows:

- To maintain equipment in continuous operation, with instruments calibrated and adjusted to conform with agreed standards;
- To produce records which conform with necessary standards for internal use and international exchange; and
- To undertake preliminary readings needed to meet the immediate requirements of data reporting.

The "final" interpretation of seismic records was considered to be an optional activity for which the manual should provide some introductory background material. On the other hand, the manual was also to provide information needed by observatory personnel when they are occasionally required to collect and classify macroseismic observations. In general, the international team of authors "... sought to extract the most general principles from a wide range of world practice, and to outline a course of action which will be consistent with those principles."

Already at that time it had become obvious that there existed significant regional differences in practice and that the subject as a whole was rapidly advancing. Since this implied the need for continuous development, it was decided to make the book in loose-leaf form and to identify chapters with descriptive code names so as to allow for easy reassembling, updating, and insertion of new chapters. This modern concept was only partially achieved, and no updating or addition of new chapters happened after the 1979 edition, which is now out of print. Fortunately, in conjunction with the preparations for the IASPEI centennial publications such as the IASPEI Handbook and related resources, the complete 1979 edition of the MSOP has now been made available as PDF files on the Internet. It can be viewed and retrieved at http://caldera.wr.usgs.gov/msop/index.html. Major parts are also available on the home page of Global Seismological Services at http://www.seismo.com. The old MSOP is still a standard reference work for seismologists, particularly for those continuing to work at analog stations which are still operational in many developing countries. The general aims of the MSOP are still pertinent.

On the other hand, seismology has undergone a technological revolution since the publication of the MSOP. This was driven by cheap computer power, the development of a new generation of seismometers and digital recording systems with very broad bandwidth and high dynamic range, and the discovery of the Internet as an effective vehicle for rapid, large-scale data exchange. As the seismological community switches from analog to digital technology, many sections of the 1979 Manual are becoming obsolete or even irrelevant, and the Manual contains no guidance in many areas which have become of critical importance.

PHILOSOPHY OF THE NEW MANUAL OF SEISMOLOGICAL OBSERVATORY PRACTICE (NMSOP)

The concept for the NMSOP was developed on the basis of the benefits and drawbacks of the old manual, taking into account the technological developments and opportunities which have appeared during the last twenty years, as well as the continuing inhomogeneities in scientific-technical conditions and availability of trained manpower worldwide (see Bormann, 1994).

Seismological stations and observatories are currently operated by a great variety of agencies, staffed by seismologists and technicians whose training and interests vary widely, or they are not staffed at all and are operated remotely from seismological data or analysis centers. They are equipped with hardware and software ranging from very traditional analog technology to highly versatile and sophisticated digital technology. While in industrialized countries the observatory personnel normally have easy access to up-to-date technologies, spare parts, infrastructure, know-how, consultants, and maintenance services, those working in developing counties are often required to do a reliable job with very modest means, without much outside assistance, and lacking textbooks on the fundamentals of seismology. To ensure that under these diverse conditions data from observatories can be properly processed and interpreted once they have been acquired and compiled, it is necessary to establish protocols for all aspects of observatory operation which may affect the seismological data. In addition, competent guidance is often required in the stages of planning, bidding, procurement, site selection, and installation of new seismic observatories and networks so that they will later meet basic international standards for data exchange and processing in a cost-effective and efficient manner.

One drawback of the old manual appeared to us to be that its chapters were organized purely according to components or tasks of observatory practice, namely:

- Organization of station networks;
- Instruments;
- Station operation;
- Record content;
- Determination of earthquake parameters;
- Reporting output;
- Macroseismic observations; and
- International services.

A consequence of this structuring is that the seismological fundamentals required to understand the relevance and particulars of the various observatory tasks are sometimes referred to in various chapters and dealt with in a fragmented manner. This approach makes it somewhat difficult for observatory personnel to comprehend the interdisciplinary problems and aims behind observatory practice and to appreciate the related, often stringent requirements with respect to data quality, completeness, consistency of procedures, etc. Furthermore, this approach puts together in the same chapter basic scientific information, which does not change so quickly, with technical aspects, which evolve quickly. This makes it difficult to keep the Manual up to date without the frequent rewriting of entire chapters.

The IASPEI WG on MSOP agreed, therefore, to structure the new manual differently:

- The body of the manual should have a more long-term character, outlining the scope, terms of reference, philosophy, scientific-technical, and social backgrounds of observatory practice. It aims at creating the necessary awareness and sense of responsibility to meet the required standards in observatory work in the best interest of scientific progress and social service. This main body or backbone of the Manual should be structured in a didactically systematic way, introducing first the scientific-technical fundamentals underlying each of the main components in the "information chain" according to Figure 1 in Bormann (2000, this volume, page 502) before going on to the major tasks of observatory work.

- This core manual should be complemented by instructions or worksheets which give detailed descriptions of specific jobs, procedures, data formats, nomenclature of phases, pieces of equipment, etc. They may require more frequent updating or changes.
- Annexes with glossaries, indices, program manuals for data analysis, extensive reference data such as Earth models, travel-time tables, calibration functions, master event recordings and phase interpretations, etc. These are typically too bulky to be included in the body of the manual or as complementary individual work/instruction sheets. They are usually available already in external databases, which could be linked in a suitable way to the manual. This also applies to the old MSOP, which should remain an important reference source for all aspects of classic seismometry, analog data acquisition, and processing and be accessible via links from the NMSOP.

With this new structure it is hoped that a new manual will be produced which is a rather complete, self-explanatory reference source ("cook and recipe book"). Its aim is to provide complex problem awareness, basic background information, and specific instructions for the self-reliant execution of any "routine" or "preresearch" job by the technical and scientific staff at seismological stations, observatories, network centers, or arrays. This includes system planning, site investigation and preparation, instrument calibration, installation, shielding, data acquisition, processing and analysis, documentation and reporting to relevant national and international agencies, data centers, or the public, and occasionally also assessing and classifying earthquake damage.

The NMSOP will not cover the often highly automated procedures now in use at many international seismological data centers. These normally neither record nor analyze seismic records themselves but rather use the parameters or waveforms reported to them by stations, networks, or arrays. Such centers have the expertise and the scientific-technical environment and international connections needed to carry out their duties effectively. Rather, the NMSOP should serve the needs of the many seismological station operators and analysts in developing or less advanced countries. They often do not have the qualified manpower at their stations or network centers or the overall expertise available in the country to assure that all necessary tasks within the scope and required standards for national and international data acquisition and exchange can be properly performed.

With this understanding the following preliminary list of contents has been selected by the IASPEI and ESC Working Groups for NMSOP:

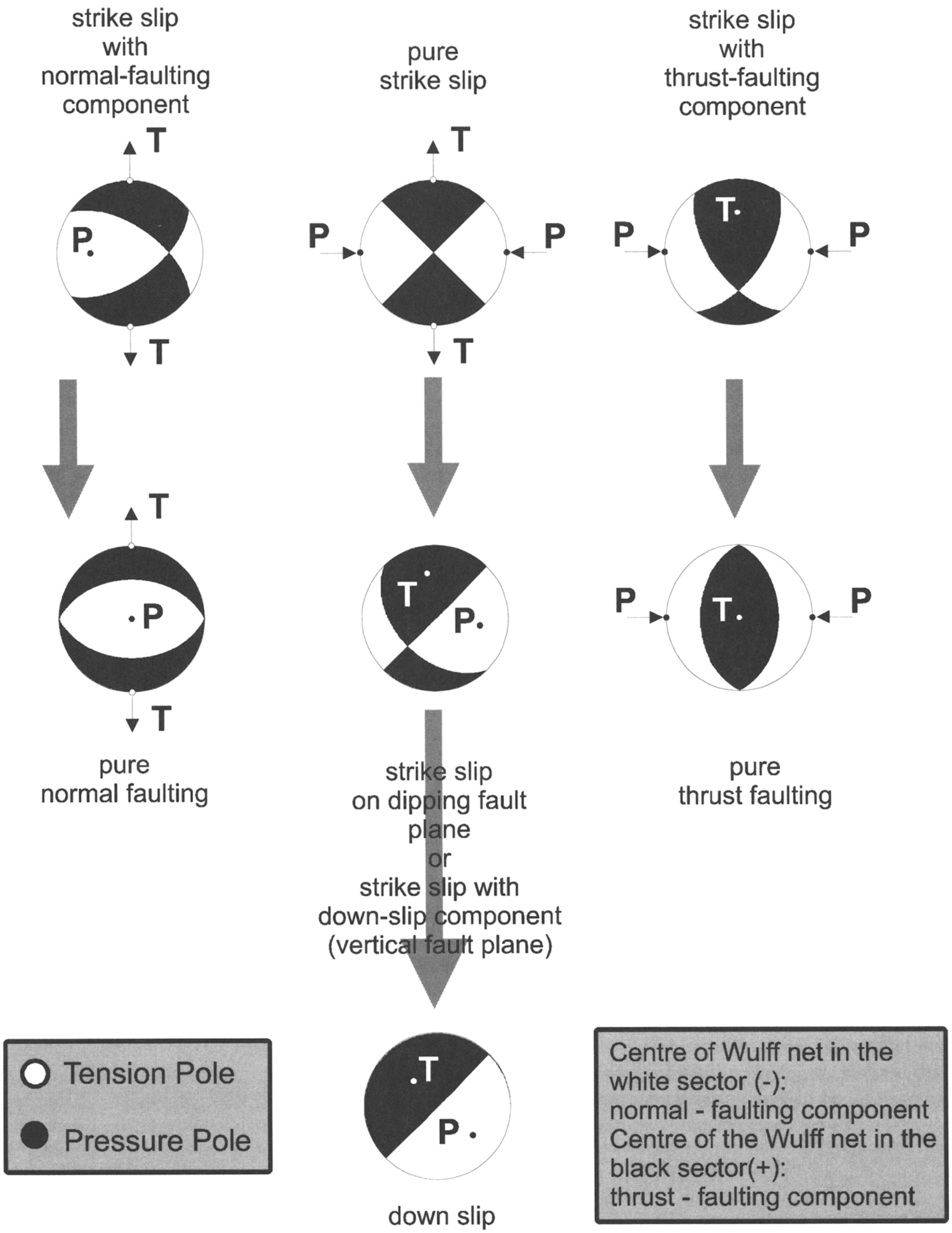
1. The Scope and Nature of This Manual
2. Seismic Waves and Earth Models
3. Seismic Source Processes and Parameters
4. Seismic Signals and Noise
5. Seismic Sensors
6. Seismic Recorders
7. Site Selection, Station Site Preparations, and Installation of Seismic Stations
8. Communication and Networks
9. Network Planning and Procurement
10. Seismic Arrays
11. Data Formats, Storage, and Exchange
12. Routine Processing of Seismological Records
13. Volcano Seismology
14. Macroseismology: Intensity and Intensity Scales

Chapters 2 to 6 and 12 deal with fundamental aspects related to the main components of the "Information Chain of Seismology" as depicted schematically in Figure 1 of Bormann (2000, this volume, page 502), namely wave generation, propagation, noise distortion, recording, and data processing, while other chapters relate to specific tasks, technologies, or methodologies of data acquisition and processing. Within most of these chapters there will be links to instruction/worksheets, often with related exercises, and to relevant annexes/databases.

OUTREACH OF THE NMSOP

More information on the various chapters and their contributors (not yet final and complete) can be found at http://www.seismo.com. First drafts for Chapter 3, on the determination of fault plane solutions and spectral source parameters, by P. Bormann, M. Baumbach, and H. Grosser; Chapter 6, on FIR filters (problems and cures), by F. Scherbaum; the main parts of Chapters 7 and 9, by A. Trnkoczy; and Chapter 14, by R. Musson are already available on the Manual Web site. Figures 1 to 5 give examples from these chapters. Chapter 5, by E. Wieland, on seismic sensors, is also available at http://www.geophys.uni-stuttgart.de/seismometry/man_html/index.htm. First drafts of all other chapters will follow in the course of years 2000 and 2001. Critical feedback by users and expert colleagues to P. Bormann as the overall editor or to the chapter/section authors directly with copy to P. Bormann are highly welcome. This will help us to correct mistakes, to close gaps, and to keep the manual home page in tune with most recent developments. It is intended that maintenance and regular updating of the Manual Web page will be a permanent obligation of the IASPEI Commission on Practice and its relevant working groups.

Since many people, in particular potential users in developing countries, do not yet have routine, reliable Internet access, it is planned to produce in 2001, with IASPEI support, first a paperback collection of preliminary manual drafts. Later, a rather comprehensive and reviewed CD-ROM edition of the NMSOP is expected to follow. This will help assure a wide dissemination and usage. Finally, it is



▲ **Figure 1.** Manual figure from the chapter "Seismic Source Processes and Parameters" explaining various "beachball presentations" of fault plane solutions in lower focal hemisphere projections for different faulting mechanisms. White sectors correspond to negative and black sectors to positive first-motion polarities.

This Web page is intended as contribution to the New Manual of Seismological Observatory Practice. Its final quality depends on **YOUR** feedback! Suggestions for improvement, fair criticism and Fan mail is always welcome!

Zero Phase Digital Anti-Alias Filters: Problems and Cures

Version 1.0 (1997 May 11, revision history)

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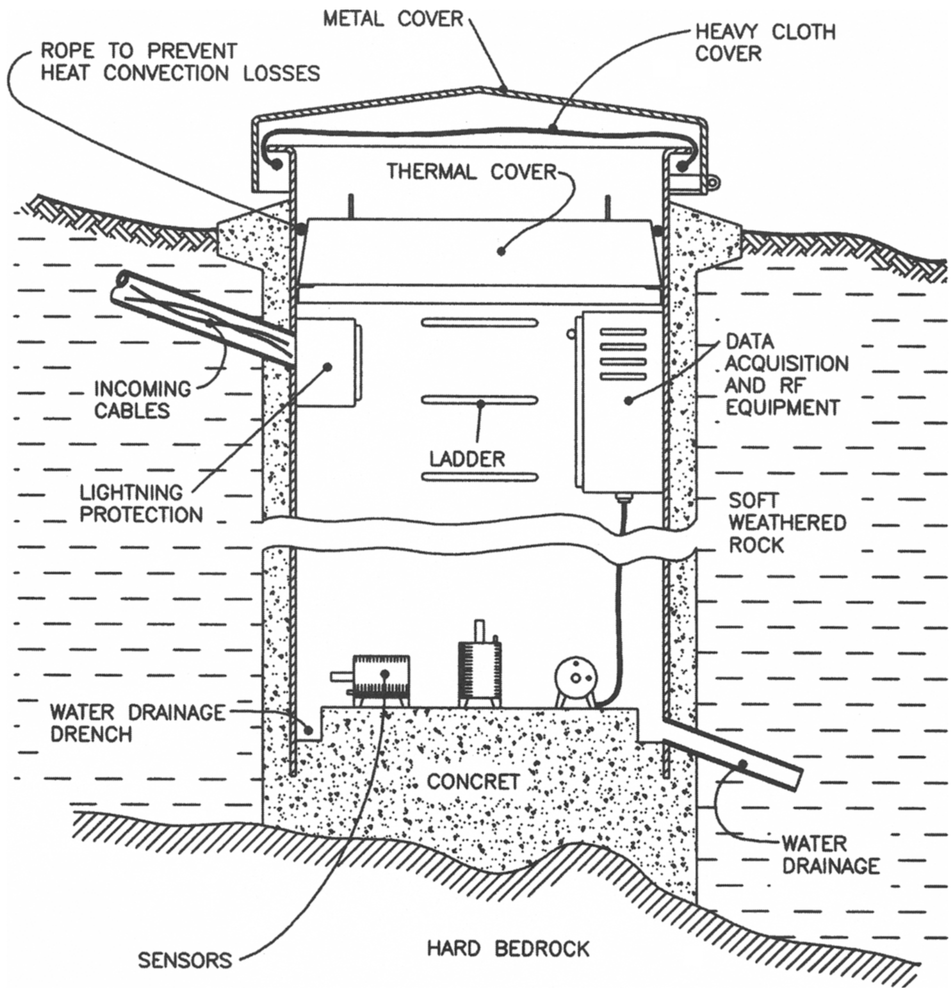
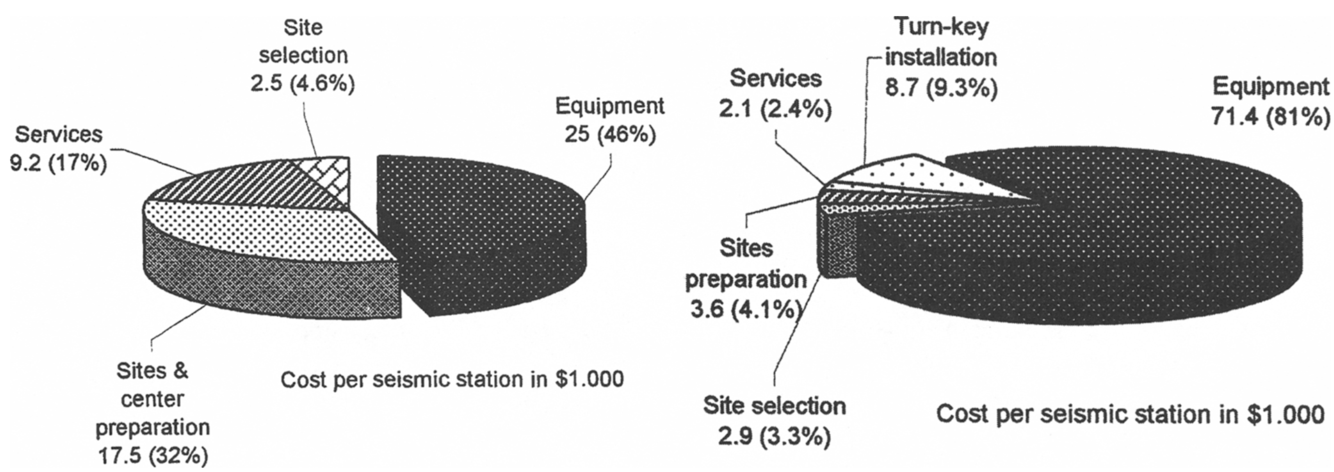
INTRODUCTION

The high performance of modern digital seismic acquisition systems is commonly obtained by use of oversampling and decimation techniques. In order not to violate the sampling theorem each digital sampling rate reduction must include a digital anti-alias filter. To achieve maximum resolution during oversampling, the filters have to be maximally steep. In addition they should be stable and cause no distortion of the input signal, at least not within the filter's passband. This requires linear phase filters (Oppenheim and Schafer, 1989) which are passing signals without phase changes, causing only a constant time shift. If this time shift is zero or is corrected for, the filter is called a zero phase filter. Digital anti-alias filters are generally implemented as zero phase FIR (Finite Impulse Response) filters.
Click here for a short discussion on discrete filters.

▲ **Figure 2.** Manual Web cover page to the section on FIR filters in the chapter on "Seismic Recorders."



▲ **Figure 3.** Example given in Chapter 7 of the Manual of a seismometer vault to accommodate a short-period three-component seismic station made of a large-diameter metal pipe with thin concrete walls (from Trnkoczy, 1999).



▲ **Figure 4.** Examples given in Chapter 9 of the Manual for reasonable (left) and inappropriate (right) cost distribution between funds spent on equipment, services, site selection, and preparation (from Trnkoczy, 1999).

$$M = a\,Io + \sum b_i \ln r_i + c \qquad (14.4)$$

in which all isoseismals (values for each i) are used as well as the epicentral intensity (see Albarello et al 1995).

In the above equations, M has been used for generic magnitude; for any particular magnitude equation it is important to specify what magnitude type the derived values are compatible with (Ms, ML, Mw etc). It is also useful to determine the standard error, which will give a measure of the uncertainty attached to estimated magnitude values.

14.3.3.4. Estimation of focal depth

The estimation of focal depth from macroseismic data was first developed by Radó Kövesligethy. His first paper on the subject presented the formula

$$I - Io = 3 \log \sin e - 3\,\alpha\,(r/R)\,(1 - \sin e) \qquad (14.5)$$

where sin e = h / r and R is the radius of the Earth (Kövesligethy 1906). A second paper, (Kövesligethy 1907) contains a different equation:

$$I - Io = 3 \log \sin \varphi \qquad (14.6)$$

where φ is the angle of emergence. This work was developed further by Blake (1941) and Sponheuer (1960). The latter author rewrote Kövesligethy's first equation as

$$Io - I_i = 3 \log (R_i / h) + 3\,\alpha \log e\,(R_i - h) \qquad (14.7)$$

in which form it has been much used (e.g. Burton et al 1985); R_i is the hypocentral distance to the isoseismal i, h is depth, and α is a constant representing anelastic attenuation. However, Sponheuer references Kövesligethy (1907) instead of Kövesligethy (1906), and the inaccessibility of these papers, and this misreference, has caused some confusion. The constant value of 3 used by Sponheuer represents an equivalence value between the degrees of the intensity scale and ground motion amplitudes. Some workers accept it, others prefer to find their own values by fitting to data (Levret et al 1996). The attenuation parameter α should be determined regionally by group optimisation on an appropriate data set - not for individual earthquakes

Io here is properly the barycentral intensity, which has to be solved for as well as solving for h. This is usually done graphically - one can fit the isoseismal data to all possible values of h and Io and find a minimum error value consistent with the observed maximum intensity (eg Musson 1996).

14.3.4. Intensity attenuation

Intensity attenuation, the rate of decay of shaking with distance from the epicentre, can be expressed in two ways. Firstly, there is the drop in intensity with respect to the epicentral intensity. This is shown by the Sponheuer (1960) formula in equation 14.6; this form of intensity attenuation and depth determination from intensity are closely linked.

One can also express intensity attenuation as a function of magnitude and distance. Such formulae usually have the functional form

$$I = a\,M + b \log R + c\,R + d \qquad (14.8)$$

▲ **Figure 5.** Example of a Manual page from Chapter 14 (by R. Musson) dealing with focal depth determination and intensity attenuation by means of macroseismic data.

planned to publish a condensed version of the body part of the Manual as an international text book on modern seismological observatory practice.

The user community of the NMSOP will not be limited to observatory personal. Many chapters and sections will be of general interest for lecturers and students in seismology. They will find there both suitable lecture and exercise materials. With the NMSOP on the Internet, institutions specializing in training in the field of applied seismology may make use of this data resource. They can retrieve self-tailored training modules according to their specific requirements, provided that the data source and the individual authors are properly cited. Therefore, it is foreseen that the NMSOP will have a long-term and far-reaching benefit to a rather diverse user community.

ACKNOWLEDGMENTS

Our thanks go to all members of the IASPEI Manual Working Group who have actively contributed to the development of the concept and the currently available drafts.

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