A processing system for old records of regional earthquakes: analysis of the 19 November 1923 earthquake in the Pyrenees

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Abstract
Instrumental data studies of earthquakes occurred during this century before the Sixties relies on availability of records of ancient seismographs. Old records of earthquakes recorded at short regional distances add problems to their digitization. Among them, a search for an increase of the digitization resolution at high frequencies is necessary. For this purpose, a search for techniques to reproduce and process these earthquake records has been done. As a result, enlargement and enhancement of the original records using graphic arts laboratory techniques have been selected and performed. The copies obtained, enlarging up to 5 times the original seismogram size allow digitization of such records by using a digitizing table. After digitization, in a second process, records are corrected for skew, uneven translation rate, pen curvature, etc. After throughout removal of the actual instrument response, and depending on the type and quality of the records, spectra are obtained.
From them, Wood-Anderson record simulation, local magnitude M_L and seismic moment M_O are estimated. This procedure is applied to the 19 November 1923 earthquake in the Aran Valley (Central Pyrenees). Obtained results are $M_L = 5.6$ and $M_O = 1.1 \times 10^{17}$ Nm.

Keywords *old seismograms – seismogram digitization – seismogram reproduction – regional seismicity*

Introduction

It is acknowledged that digitization of waveforms of old earthquakes, preserved in old records, and application of actual techniques and theories to their analysis allows the determination of new parameters concerning those earthquakes. Kanamori (1988) reviews the possibilities of such an analysis and, as an example, Stein *et al.* (1988) show concrete applications. It is quite usual that, in regions with moderate or low seismic activity, the most important earthquakes occurred prior to the installation of modern seismographs (it is acknowledged that generalization of modern instrumentation coincides with the deployment of the WWSSN, in the 1960s). Instrumental studies of such earthquakes impose the analysis of old records as well as their digitization.
This is the case of the North-Eastern part of the Iberian peninsula (Olivera *et al.* 1986, 1992). In the Central and Eastern Pyrenees, only few earthquakes occurred during this century have been potentially dangerous (Suriñach and Roca 1982). However, their size is not enough to be recorded at teleseismic distances. In such a case, the only possible way for an instrumental study is to deal with regional records performed on smoked paper by mechanical seismographs. Sometimes, it is difficult to digitize old records. In this case, the recording at regional distances introduces extra problems. This article shows the results of

our undertaking to improve the quality of records prior to their digitization and the following procedure to obtain results of seismological interest.

Seismogram reproduction

Sometimes, old seismograms recorded on smoked paper are not in the best conditions for digitization. Unfair preservation of the supporting paper can be, of course, the first problem. Another common and more interesting problem to analize arises from an inadequate contrast between the recorded waveform and the background. Normally, it is the result of inadequate paper smoking (sometimes, the supporting paper is burned; sometimes, it is insufficiently smoked). This poses a serious problem for digitization.

The efficiency of scanning systems relies mainly on image contrast and, even if records are digitized by hand on a digitizing table, it becomes a great trouble to follow the waveform. The solution can be provided, evidently, by an increase of the image contrast. Photographic techniques are, in principle, adequate for this kind of problems. Adequate photography of the original records can substantially improve the contrast.

Another problem arises from the signal frequency contents. Mechanical seismographs are, in general, damped harmonic oscillators. Frequency response of these systems is flat over its natural frequency, but lets us question which are the maximum frequencies we may expect to digitize from a record of such a type of instrument. Let us make a rough calculation on what it can be seen. Generally, trace thickness on smoked paper records is of the size of 0.1 *mm* (as a minimum). Usual record speeds for these records lie between 10 and 20 *mm/min*. The maximum resolution will be obtained if, on digitizing, all the peaks are picked up. The minimum peak resolution will be something around 0.1 *mm* (trace thickness), or 10 peaks per *mm*. Higher frequencies are on superimposed traces and, in principle, indistinguishable. Now, it is easy to figure out that the maximum wave frequencies we will be able to digitize lie between 1 and 2 *Hz* (always depending on the record speed).

As it has been said, we are dealing with earthquakes recorded at regional distances (approx 200 *km* or even shorter). At these distances it is expected to record high frequency waves; but it has been seen that record conditions impose a high frequency limit to our digitizing resolution. In addition, it will be impossible to digitize by hand with resolution of 0.1 *mm*. Also, in the higher frequency limit it is almost impossible to correlate the peaks on each side of the seismogram base line, that is, to digitize the peaks correlatively as they have been recorded. To increase resolution, a solution will be to obtain enlarged copies of the original seismograms.

After several trials (photographic contacts, enlarged photographies, etc.), we got a solution through techniques used in editorial task. For many years, reproduction of originals for lithographic printing has been done using a system called *repromaster* (the system is commonly used in graphic arts for photographic edition). Physically, it is composed of two simple machines.

The first one is roughly similar to a photographic laboratory amplifier but with some special characteristics: the photographic film is directly substituted by the original drawing (in our case, the seismic record).

Vacuum can be made at the places where the original record and a kind of negative photographic copy paper are placed. This ensures that both papers are thightly subjected to the glass and that there is no deformation due to paper ondulation. Modern machines have a total control on the magnification scale and exposition times. The second machine is used for "positivation". It is a relatively small recipient containing the positivation fluid and two parallel cylinders in contact and submerged. The "negative copy" obtained by the amplifier machine is introduced, attached face to face to a "positive paper" through the turning cylinders. Once this is done, it is necessary to wait 30 seconds, to separate the two papers (negative and positive) and the copy is already done. In fact, the technique is similar to what is done in a photographic laboratory, but it is much easier. Also, it is relatively easy to find such kind of equipment. Almost every printing shop (or any place where litographic printing techniques are used) owns one of these machines.

As it has been said, special paper is used for this work. The "negative paper" is similar externally to dark photographic positive paper; but it has some special features. First, it generally needs longer exposition times. The "positive paper" looks like a common positive photographic paper but it has not any gray scale. Any point of its surface turns just black or white, whitout any gradation between these extremes. This is equivalent to take the image contrast to the limit. Summarizing, the "repromaster" system shows three main advantages: it is easier to use than classic photographic techniques, exposition times are longer (this allows a better control of them) and it offers the maximum contrast level.

The "pseudophotographic" papers used for reproduction can be commercially found in different versions to allow different types of copies. The "negative paper" is almost one-type. However, various possibilities are available for the positivation, depending on the "positive paper" used. It is possible to obtain common black and white (but without contrast) copies, inverse copies (white points of the original turn black and viceversa), photolitho and litographic plates.

Fig. 1 shows an example of the results obtained with this reproduction process. Fig. 1(a) shows the original seismogram. For reproduction problems, similarity with regard to the tonalities of the original seismogram is not good, but the contrast level of the image is representative of that one found on the original record. As it can be seen, it is almost impossible to use this record for digitization. Fig. 1(b) shows the repromaster copy. It is reproduced on the same scale of the original seismogram (Fig. 1a). The "repromaster" copy is 5.6 times larger than the original one and has and improved contrast. Now, the trace is clearly seen and digitization of waveforms contained in these copies is much simpler than on the original seismogram.

Seismogram digitization

Once the waveform has been enlarged and enhanced through the use of "repromaster" the following technique has been followed to digitize and preprocess the waveform.

A *digitization worksheet* paper is prepared. It is elaborated in the following way. A grease-proof paper is superposed to the seismogram to be digitized. The peaks and other features of interest of the waveform are pointed out with a thin pen. Digitization worksheet is superposed to the seismogram and the previously marked points on the worksheet are

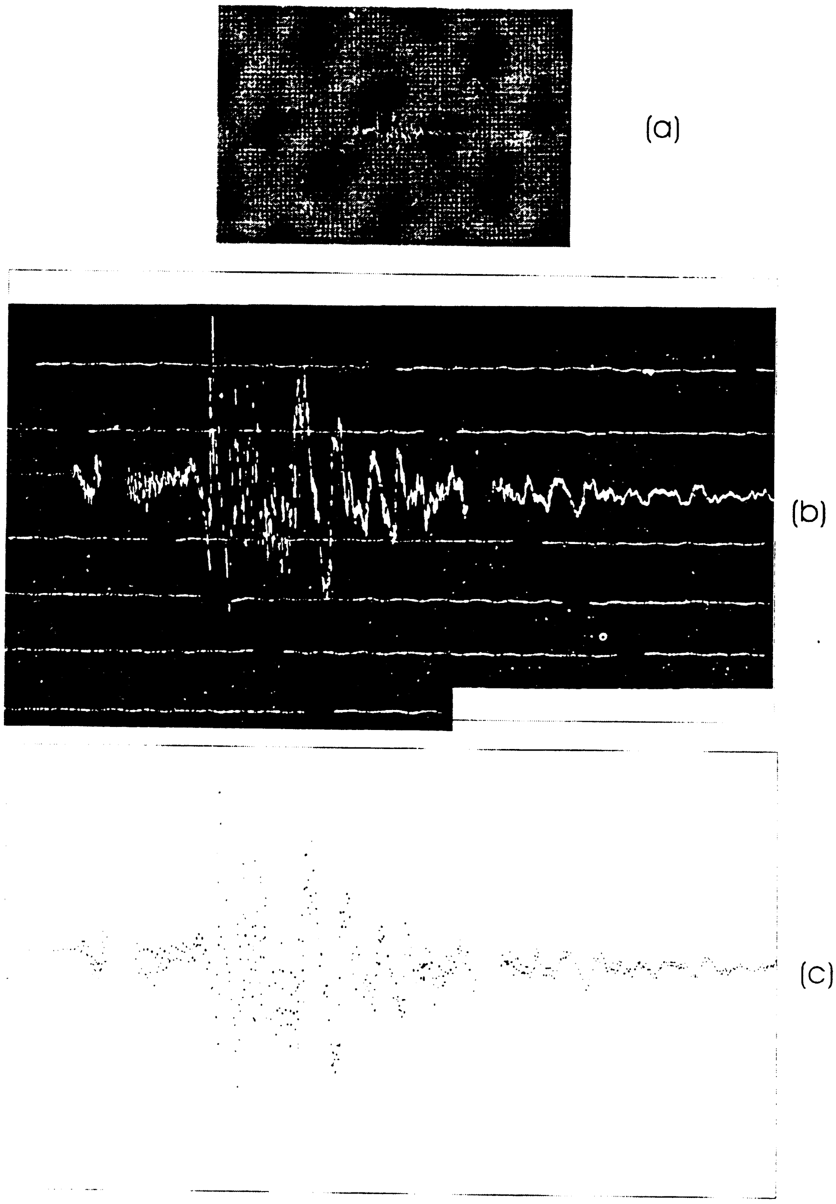

Fig. 1. (a) Reproduction of the original seismogram of the earthquake of 19 November 1923 in the Aran Valley (Central Pyrenees) recorded at the Mainka N-S seismograph of FBR seismic station. (b) Enlarged copy ("repromaster") of the same seismogram. Note the size enlargement (5.6 times) and the contrast enhancement of the image. (c) "Digitization worksheet" of the same record.

digitized. This procedure adds an extra step to the digitization process, but it is preferable to digitize previously selected points instead of the seismogram for several reasons. First, because in this way the reproduction (repeatability) of the process is ensured. Second, it has been shown previously our interest for high frequency resolution. This procedure ensures a careful search for peaks and special features of the waveform and allows to point out all of them. In case of waveforms showing complex features, it gives the opportunity to design digitization procedures. Fig. 1(c) shows the digitizing worksheet elaborated from the seismogram shown in Fig. 1(b).

After the digitization worksheet is ready, seismogram is digitized using a digitizing table. Any digitization software should be useful. In our case, AutoCad v.10 is used and a raw seismogram in *DXF* format is obtained. The AutoCad output file is transformed into ASCII. After digitization, the waveform is processed through a first program (VELLSIS). This program is designed to preprocess the waveform. Digitized pairs of points are rescaled to their original size, and, if option is selected, they are corrected as follows: for uneven paper speed, skew (arm inclination) and pen curvature (minute marks, skew angle and arm lenght are given as input data). They can be also reordered. This last option has been added for cases where it is impossible to follow the waveform. In this case it has been decided to pick out the trace peaks sectorially, to perform the previously stated corrections (note that it is possible to apply them independently to every digitized pair of points), and to reorganize the resulting points. The resulting output file contains two columns: time and displacements.

The next step is the interpolation of the corrected digitized file to obtain a regularly spaced file. The VELLSIS output file is interpolated by cubic splines (program INTRPSIS). In fact INTRPSIS is designed to interpolate seismograms with polinomies of any degree up to order 10.

The resulting file is processed through a third program (KDVA). This program is already designed to perform calculations of seismological interest. The interpolated input trace is windowed (cosinus window is used), filtered (gauss filter is applied), and its Fourier spectrum calculated. Seismograph response is removed at this stage (seismograph constants are needed as input).

Displacement, velocity and acceleration spectra are calculated. Finally, as output files, ground displacement, velocity and acceleration are calculated.

Also, it is possible to calculate the Wood-Anderson simulation of the input record.

Application

The 19 November 1923 earthquake (T_o = 03h 54m; Loc. 42.6°N, 0.7°E) in the Aran Valley (Central Pyrenees) is one of the most intense (I_o = VIII) occurred in the Pyrenees within the present century. A study of this earthquake from analysis and process of old instrumental records has been carried out.

Susagna *et al.* (1994) studied the macroseismic and instrumental data for this earthquake and Kárník (1968) gives a magnitude of M = 5.4.

First at all, on the basis of the information contained in the ISS (International Seismological Summary) a request for old records preserved in observatories in Europe and North Africa was made. The collected records came from FBR, EBR, PAR, DBN and UPP seismic stations.

Records of FBR (Observatori Fabra, Barcelona), EBR (Observatori de l'Ebre, Roquetes), PAR (Parc Saint Maur, Paris) corresponding to Mainka type seismographs and DBN (De Bilt) corresponding to Galitzin have been digitized following the procedure presented above. Fig. 1 shows a fragment of the record obtained at FBR station with a Mainka (N-S) seismograph.

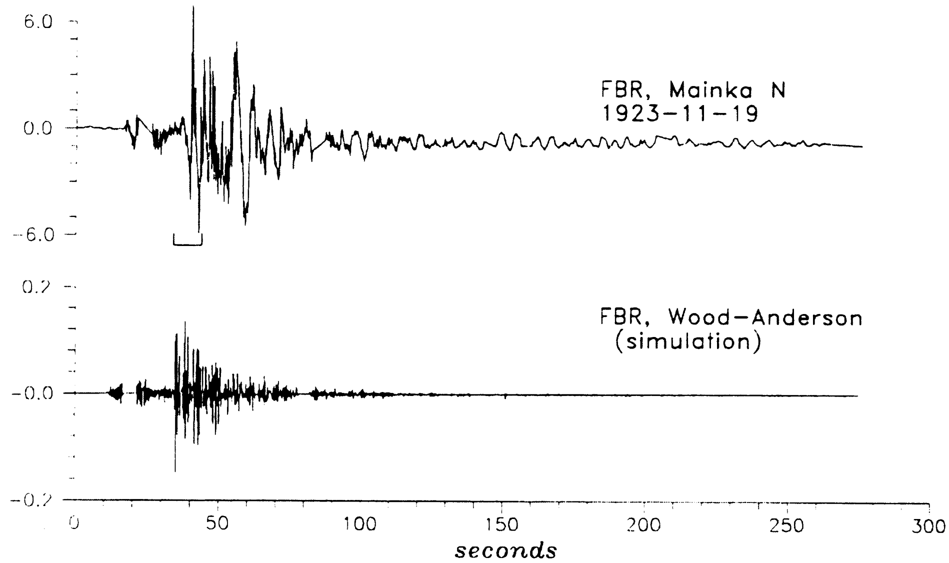

Fig. 2. (Top) Digitized waveform of the seismogram shown in figure 1. The small mark under the seismogram shows the selected S-wave train for seismic moment calculation.
(Bottom) Wood-Anderson record simulation for the same even at the same place (FBR seismic station).

Some of the Mainka seismographs were badly damped and the digitized records proved to be of no use. Finally, only seismograms from PAR (Mainka N and E) and FBR (Mainka N) have been succesfully processed. Galitzin records from DBN are of good quality but their frequency content is not adequate to our purposes. For example, Fig. 2 (top) shows again the FBR, Mainka N-S record obtained after preprocessing it (output of VELLSIS program). The different outputs of KDVA program are also shown. Fig. 2 (bottom) shows the Wood-Anderson simulated record.

Fig. 3 shows the ground motion (bottom), velocity motion (middle) and acceleration (top) obtained from the same record.

Wood-Anderson record simulations allow to directly apply Richter's M_L local magnitude formula. As station FBR lies 180 *km* from the epicenter, M_O = 5.6 is obtained. This is a first instrumental estimation of the earthquake magnitude.

From the stated seismogram and from the Mainka N-S and E-W records of PAR seismic

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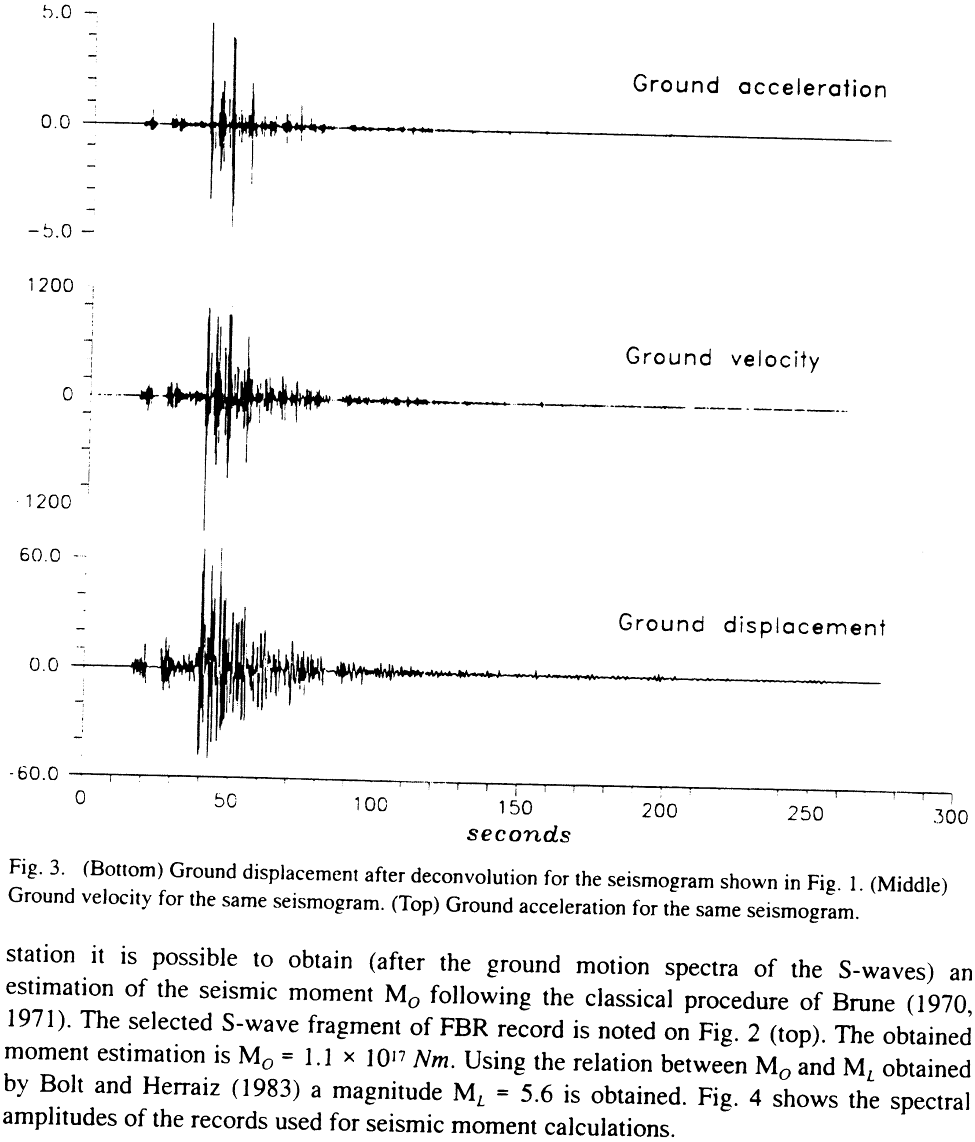

Fig. 3. (Bottom) Ground displacement after deconvolution for the seismogram shown in Fig. 1. (Middle) Ground velocity for the same seismogram. (Top) Ground acceleration for the same seismogram.

station it is possible to obtain (after the ground motion spectra of the S-waves) an estimation of the seismic moment M_O following the classical procedure of Brune (1970, 1971). The selected S-wave fragment of FBR record is noted on Fig. 2 (top). The obtained moment estimation is $M_O = 1.1 \times 10^{17}$ *Nm*. Using the relation between M_O and M_L obtained by Bolt and Herraiz (1983) a magnitude $M_L = 5.6$ is obtained. Fig. 4 shows the spectral amplitudes of the records used for seismic moment calculations.

Conclusions

A reproduction technique for digitization of old records has been implemented.
It is specially useful for seismograms presenting a poor image contrast or if enhancement of high frequency is needed. Also, a set of programs to process the raw digitized waveform has been developed. At this stage, owing to the non automatic parts involved in the process, the method is designed to be applied to individual earthquakes of special interest.

To show its possibilities the developed technique has been applied to analize regional records of a Pyrenean earthquake. Instrumental estimation of the local magnitude M_L and the seismic moment M_O have been obtained and show good agreement among them. Only body waves have been investigated in this case (this is the part of the waveform containing the highest frequencies), but it is clear that the digitization process is valuable for the whole seismogram. Just the techniques of analysis applied after digitization and preprocessing should be changed.

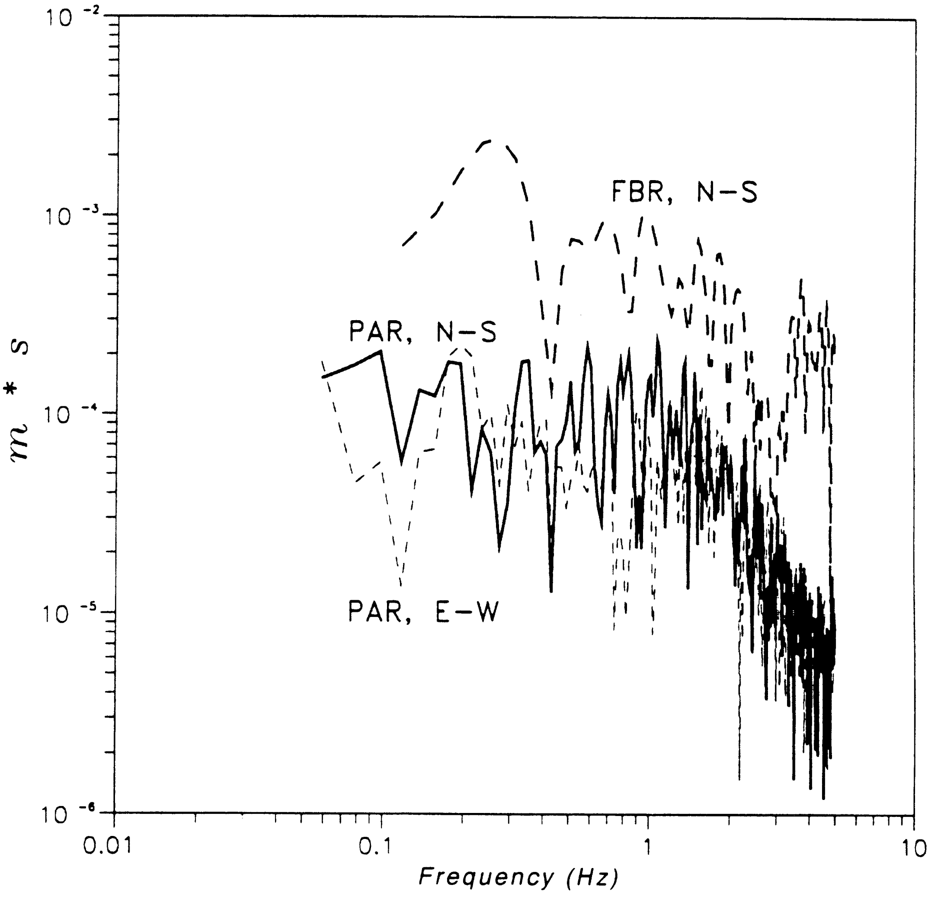

Fig. 4. S-wave spectral amplitudes calculated for FBR, Mainka N-S recording (large dashed line); PAR, Mainka N-S recording (thick line) and PAR, Mainka E-W recording (short dashed line).

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