GOLDEN GATE BRIDGE SEISMIC RETROFIT
DESIGN SUSPENSION BRIDGE STRATEGY
TECHNICAL REQUIREMENTS FOR DAMPERS

by

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DAMPER TYPE

Viscous dampers are the preferred type; dampers having a constitutive law of the form

$$F = C \cdot V^{n}\,{}^{1}$$

have been investigated. Powers n=0, ½, ¾, 1, and 2 have been investigated and the coefficient C optimized for each. The optimization has been done to minimize the stiffening truss chord and tower stresses, the expansion joint and wind-lock movements, and to maximize the energy dissipated by the dampers. Dampers having a small power n have been found to be superior, but the improvement is minimal below n=½. The power n=¾ has been selected for the strategy design, as being a good compromise between the known capabilities of manufacturers, and the technical needs of the project.

Based on *elastic* response of the stiffening truss, and a power n=¾, the coefficient C=100 kip·sec$^{3/4}$/in$^{3/4}$ has been found to be nearly optimum. Here, C is the coefficient of the dampers *at one chord* of the stiffening truss; the total requirement at any section of the bridge is four times this. All results and requirements given herein are *per chord.* The requirements at each chord will be split between multiple dampers, probably 2-4 dampers per chord.

The damper optimization has been conducted using an elastic model of the suspension bridge, but the final strategy design may involve some inelastic behavior of the stiffening truss. This may change the requirements for dampers, but it is likely that the requirements will be less than reported herein (in terms of force and number of dampers), rather than more.

Besides the seismic requirements, the dampers must accommodate three other environments: wind, thermal, and traffic. A description of each of these environments is given below, with the corresponding damper technical requirements.

OTHER TYPE OF DAMPERS

Other types of dampers, e.g., viscoelastic, hysteretic, or frictional dampers, will be considered if they can be shown to be qualitatively similar to the viscous dampers described herein, in terms of force, displacement, and energy dissipation under seismic excitation; and if they can be shown to be suitable for the wind, thermal, and traffic environments described below.

Viscoelastic dampers would appear to be unsuitable, however, given their sensitivity to temperature. Hysteretic dampers would appear to be unsuitable for wind and thermal excitation,

[1] Actually, $F = C \cdot |V|^{n} \cdot \dfrac{V}{|V|}$

because of fatigue of the dampers. Frictional dampers would appear to be unsuitable for wind and thermal excitation also, because of wear.

Manufactures are encouraged to submit alternative damper concepts, however. Although they are mathematically elegant, viscous dampers also present technical and practical problems. The perfect damper is yet to be found, so all proposals will be considered.

SEISMIC ENVIRONMENT

For seismic excitation, the basic requirements for viscous dampers are:

Parameter	Value, per chord	Note
Constitutive Law	$F = C \cdot V^n$	Viscous type of damper.
Coefficient, C	100 kip·sec$^{3/4}$/in$^{3/4}$	
Power, n	¾	Lower values may be troublesome for the wind environment.
Stroke	±24 in	Maximum value.
Velocity	75 in/sec	Maximum value.
Acceleration	500 in/sec/sec	Maximum value.
Force	2500 kip	Maximum value.
Peak Power	5000 kilowatts	Instantaneous peak, extreme peaks may be larger.
Average Power	600 kilowatts	Maximum value.
Energy Dissipated	15 kilowatt-hours	Maximum value.
Frequency	0.2-2.5 Hz	
Ambient Temperature	30-90°F	

As a general rule, larger dampers are preferable. Depending on the number of dampers used, the requirements for individual dampers are:

Parameter	Value, 2 dampers per chord	Value, 4 dampers
Coefficient, C	50 kip·sec$^{3/4}$/in$^{3/4}$	25 kip·sec$^{3/4}$/in$^{3/4}$
Force	1250 kip	625 kip
Peak Power	2500 kilowatts	1250 kilowatts
Average Power	300 kilowatts	150 kilowatts
Energy Dissipated	7.5 kilowatt-hours	3.75 kilowatt-hours

Again, the final values for force, energy, etc., may be less, depending on the other features of the stiffening truss retrofit design.

Attached are several plots of the above damper parameters, for two of the project design earthquakes, SA1 and SA2. Plots are given for each of the damper installations, between side span/pylon, side span/tower, and between main span/tower, for both the San Francisco and Marin sides of the bridge. Results for only one chord (out of four) are given, however, so that the maximum values may not be observed. Besides the time history plots, a plot of the Fourier transform of the damper force and a hysteretic plot of the damper force versus displacement are given to illustrate their behavior.

Degradation of the damper performance due to increase in the internal temperature of the damper is a primary concern. Performance of the damper in this respect will have to be proven by test, calculation, or some combination of the these.

WIND ENVIRONMENT

Besides seismic excitation, the dampers installed between the main span and the towers will be subjected to wind excitation. It is not necessary that the dampers perform in this environment, only that they *survive without damage*. Any added damping will be considered an incidental benefit.

A precise characterization of the wind environment is not yet available (a quantitative description of this *may* be obtained from the wind retrofit project currently underway). A qualitative description is available from observations made of the bridge during previous wind storms, however. Specifically, during the wind storm of 22 Dec 1982, the main span expansion joints were observed to be opening and closing ±15 inches in the first anti-symmetric vertical mode of vibration of the bridge. The duration of the storm was a couple of hours. Assuming that movements equal to the main-span wind-lock capacity are possible, and that the observed mode has a period of vibration of 11.5 seconds, the following parameters may be calculated:

Parameter	Value, per chord	Note
Stroke	±18 in	Main span wind-lock capacity.
Velocity	9.8 in/sec	Single amplitude.
Acceleration	5.4 in/sec/sec	Single amplitude.
Frequency	0.087 Hz	11.5 second period.
Duration	1000 cycles	About 3 hours at 0.087 Hz.
Ambient Temperature	30-90°F	

For C=100 kip·sec$^{3/4}$/in$^{3/4}$, n=¾ dampers, the following parameters may be derived:

Parameter	Value, per chord	Note
Force	550 kip	Single amplitude (1).
Average Power	325 kilowatts	Sustained average over cyclic motion (1).

(1) Split between 2-4 dampers.

The force demand on the dampers would not appear to be problematic, but the power demand likely is. This is about one-half of the seismic power demand, and must be sustained for a few hours! (Of course, the $V^{3/4}$ power law is only a *model* of the damper behavior, the actual behavior at small velocities may be different than predicted by the model.)

The following steps may be taken to ameliorate the power demand from wind excitation:

- Use several dampers at each location, designed for efficient dissipation of energy.
- Use linear dampers, with n=1. For the same peak force under seismic excitation, a linear damper dissipates only about one-half the energy of an n=¾ damper under wind excitation, because of its lesser sensitivity to small velocities.
- Use n=1, or n=2, dampers between the main span and the towers only.
- The wind retrofit of the bridge may significantly reduce movement of the main span at the design wind velocity. Since the power demand is roughly proportional to the square of the displacement amplitude (for power n near unity), a large reduction in power demand may result.
- The dampers themselves may reduce the movement of the main span, since they will add damping to the wind induced modes. But this is a nonlinear problem, if the damper efficiency is reduced by the high power demand.

The behavior of the damper seals during wind excitation is a primary concern also. These must tolerate movement of the main span for the given duration without damage. Also, the damper fluid must tolerate the increase in temperature resulting from energy dissipation without a permanent change in its properties.

If the power demand from wind excitation cannot be sufficiently reduced, the seismic retrofit will be done without installing dampers between the main span and the towers. These locations are the least effective in reducing side span stresses, anyway.

THERMAL ENVIRONMENT

Of course, the dampers must accommodate the seasonal thermal movement of the bridge. The thermal movement of the main span is ±4 inches at each tower. The dampers should have extra stroke capacity to accommodate this.

TRAFFIC ENVIRONMENT

The dampers may also be subjected to small amplitude (0.01-0.001 in ?), high frequency (10-100 Hz ?) vibrations excited by traffic on the bridge. The seals, etc., must tolerate these vibrations without damage. Otherwise, it may be possible to "isolate" the dampers from the traffic vibrations through a sliding connection of some sort.

PRACTICAL CONSIDERATIONS

Any damper design should address the following practical issues:

- The dampers will almost certainly be installed in a horizontal position. Therefore, they must be designed with maximum resistance to side loading.

- Because the dampers will be installed in a marine environment, maximum resistance to corrosion is required.
- Access to the dampers will be difficult after installation. The dampers should be designed to be virtually maintenance free. It may be possible to plan a program of factory maintenance at long intervals (every 10-20 years). *The dampers must be designed to have a 40-year life.*
- Inspection of the dampers will probably be possible. Provision should be made to monitor damper pressure or fluid level, as appropriate to the damper design.
- Damper fluids should preferably be non-toxic and non-flammable.

TESTING AND CALCULATION REQUIREMENTS

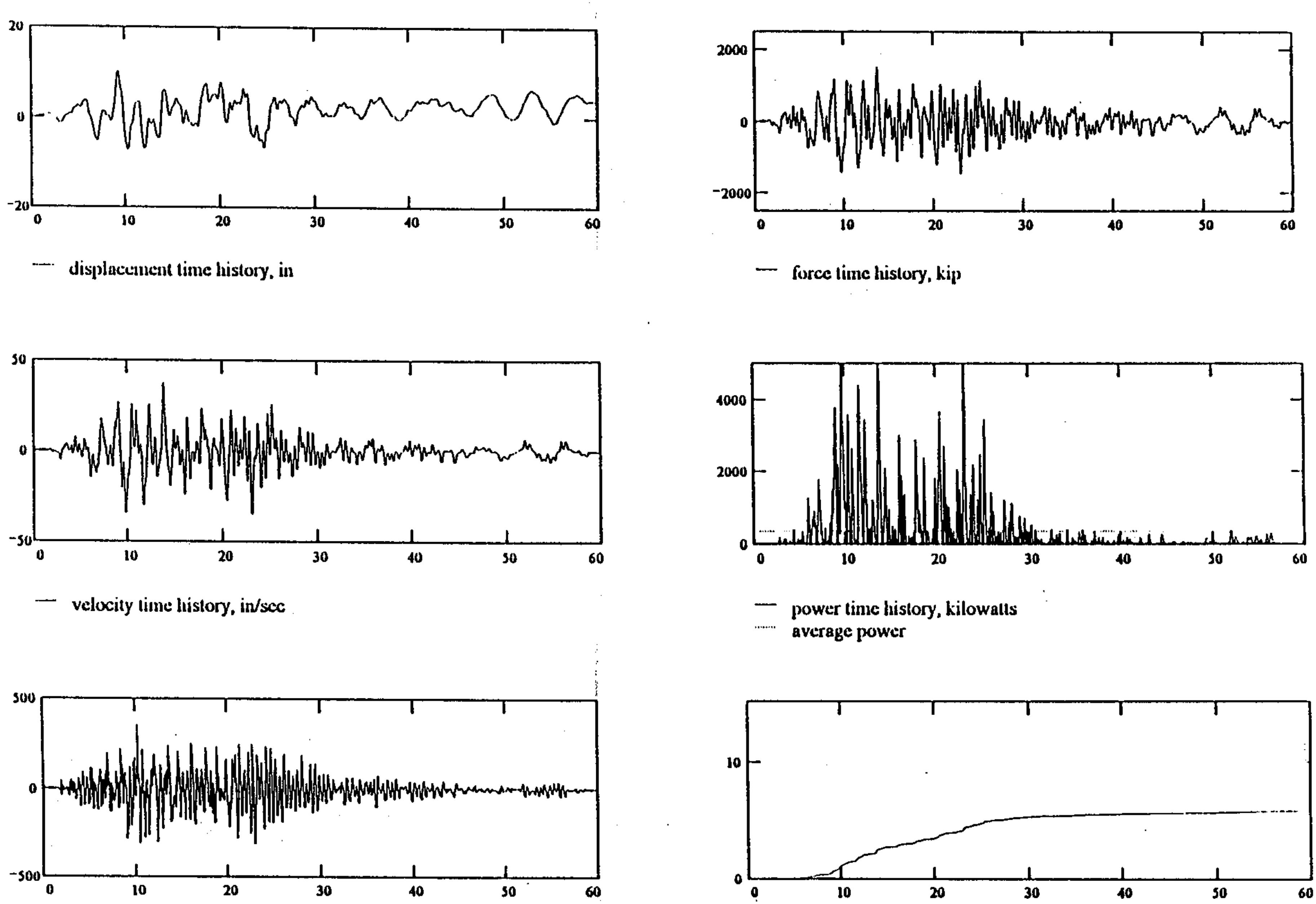
The following tests will be required (probably as part of the procurement process):

- Cyclic testing of model dampers to verify their consitutive law and their performance under seismic excitation. Manufacturers will have to provide the damper scaling laws needed to derive the characteristics of the actual dampers.
- Drop testing of model and actual dampers to help relate the cyclic testing of the model dampers to the behavior of the actual dampers.
- Cyclic testing of model dampers to verify the longevity of seals, etc. under wind excitation. Testing of the dampers for seismic excitation may be repeated after the wind testing.

Some combination of testing and calculation will be required to demonstrate the energy absorption capabilities (increase in temperature) of the dampers under seismic and wind excitation.

The size of dampers to be tested will be limited by the capabilities of the laboratories and equipment available. Full-size dampers probably cannot be tested, but dampers of 100-200 kip capacity can probably be tested at realistic velocities, if only for strokes of a few inches.

SF side span/pylon, node 1, SA1



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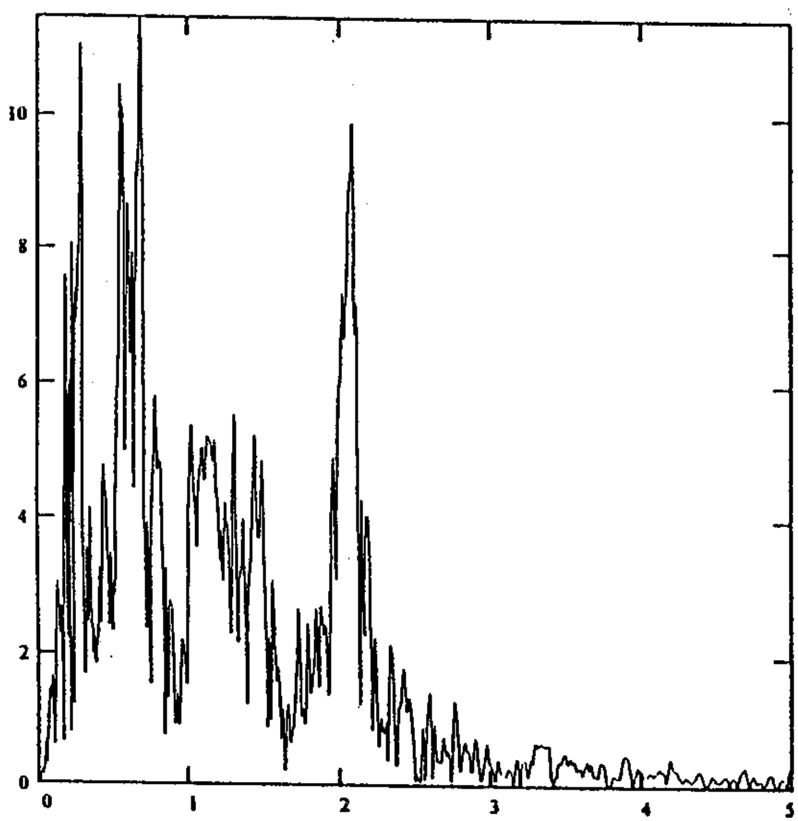
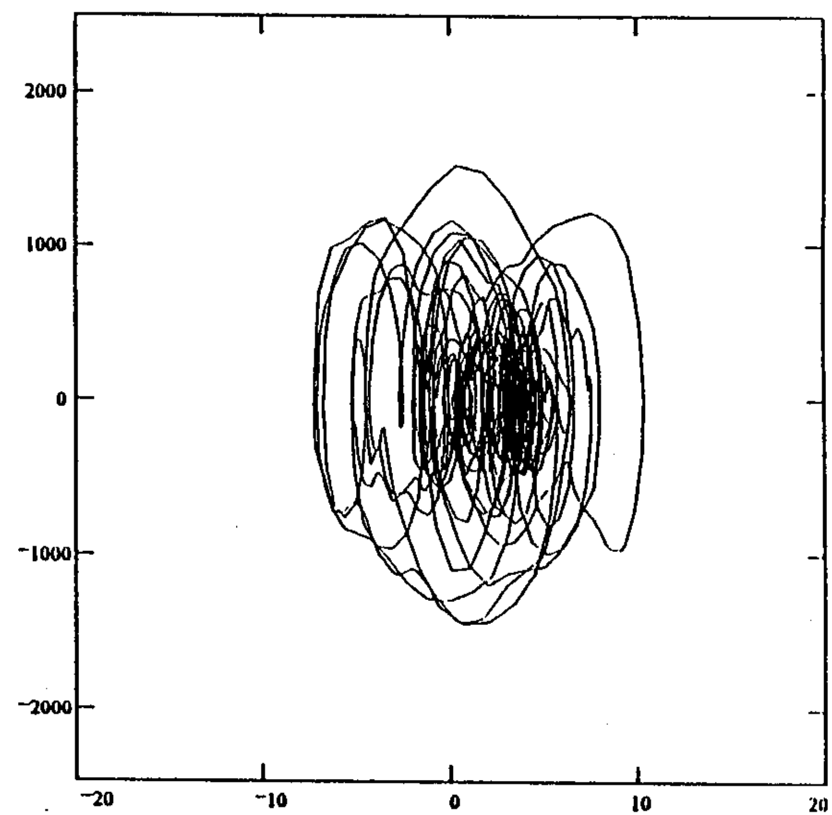
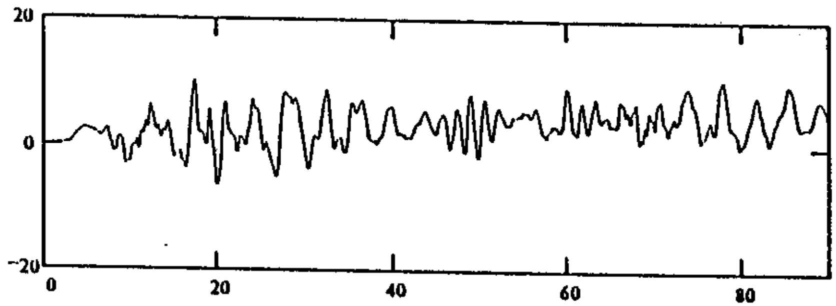




SF side span/pylon, node 1, SA2



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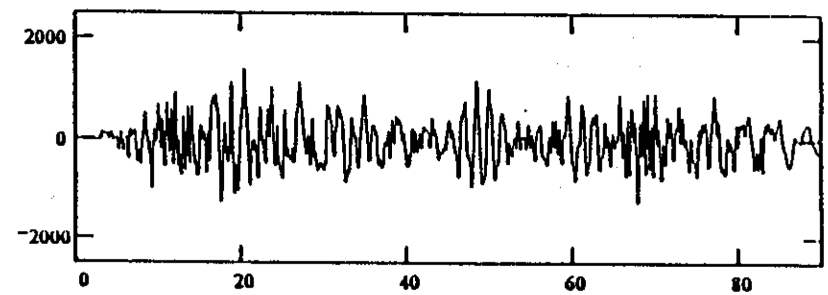

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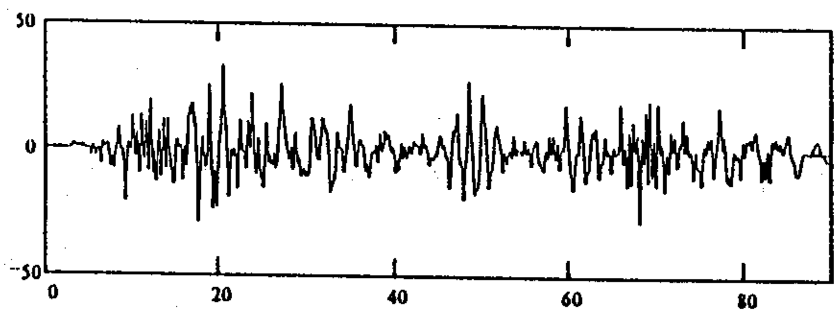

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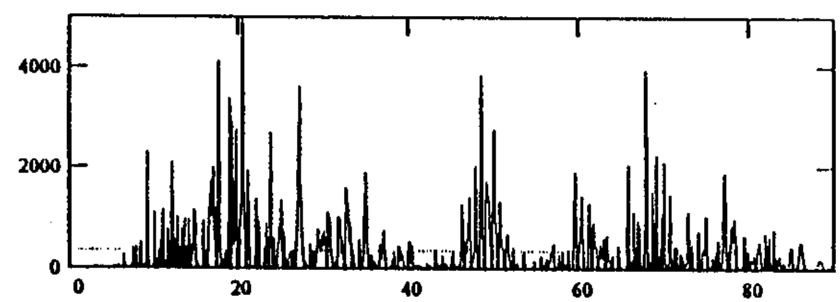

— power time history, kilowatts
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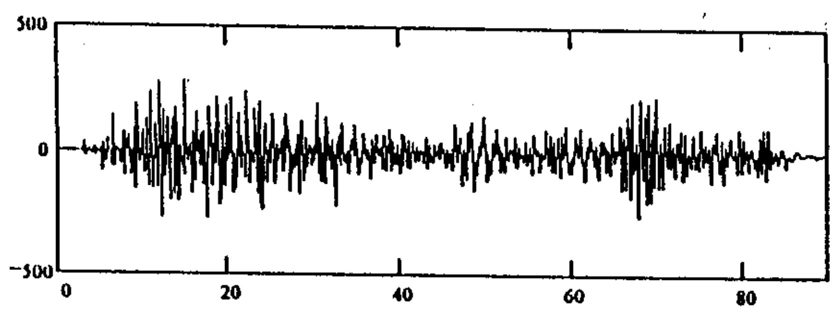
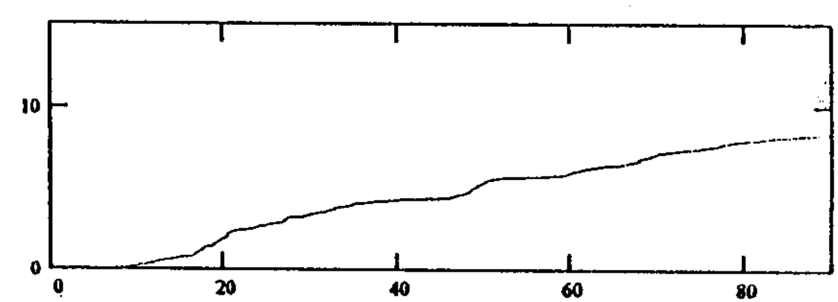
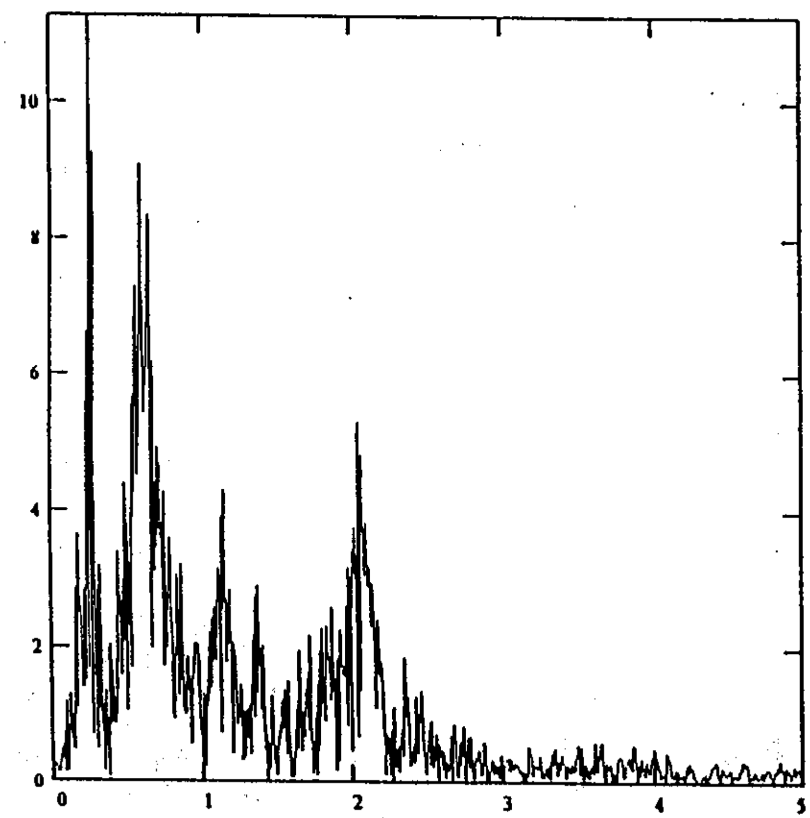
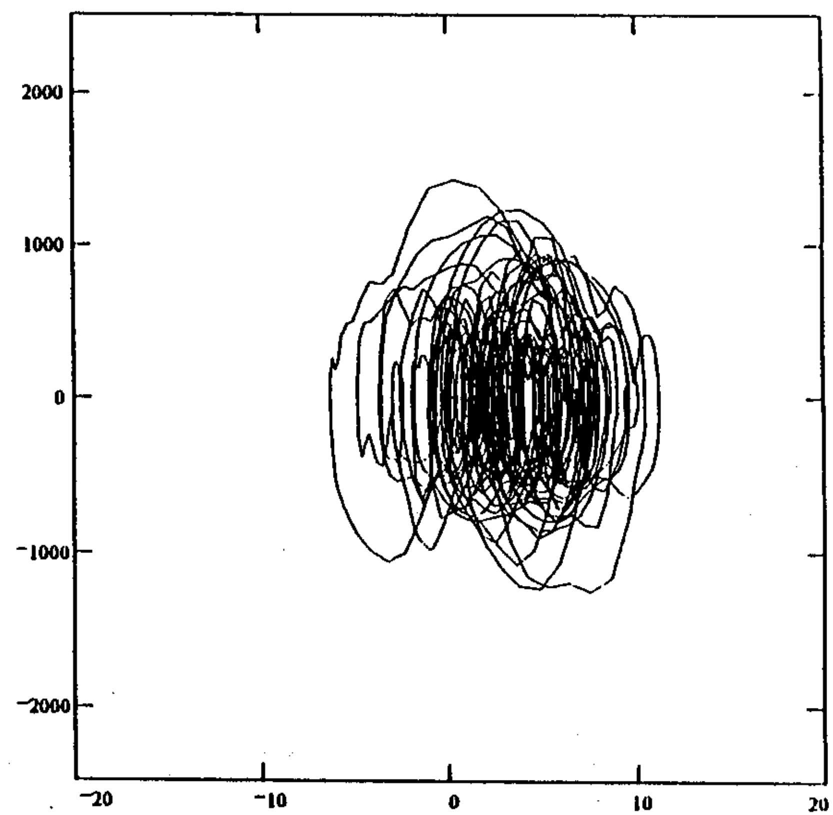


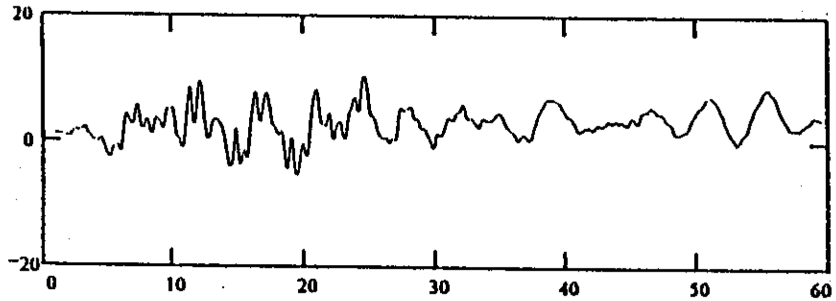


SF side span/pylon, node 1, SA2





SF side span/tower, node 1, SA1



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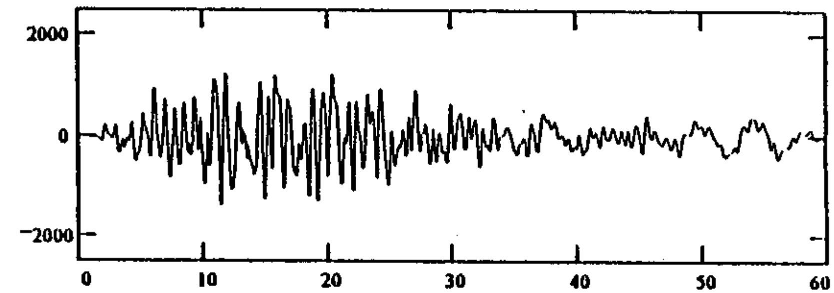

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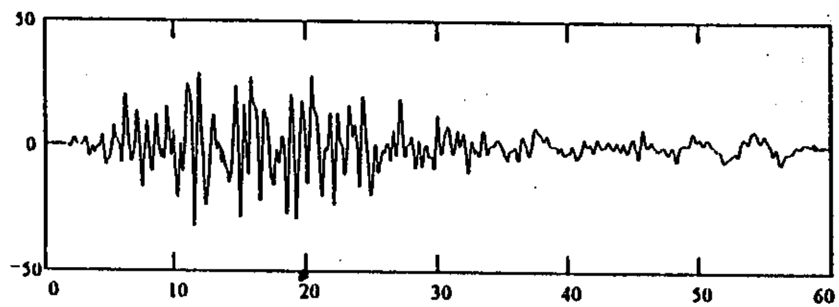

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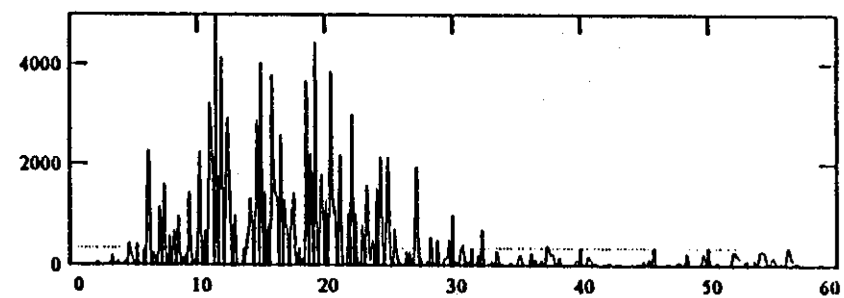

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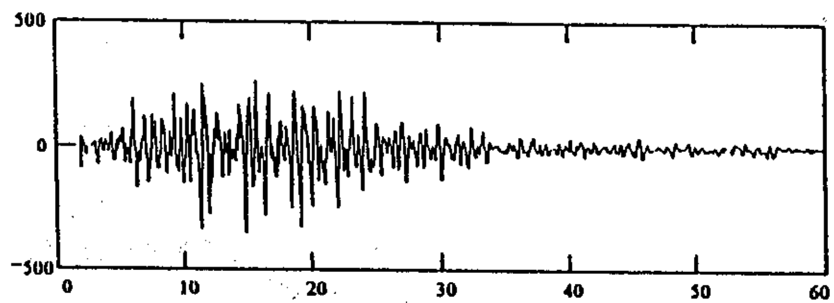

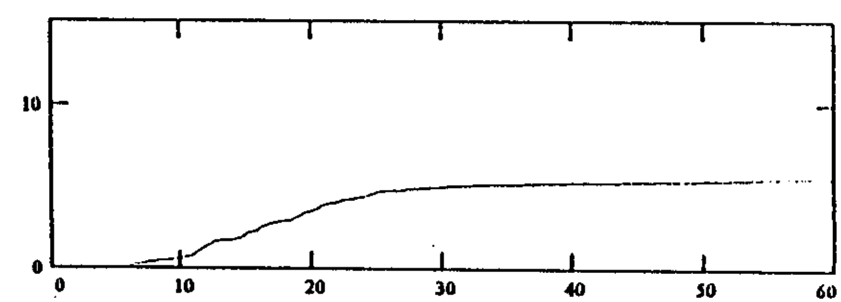

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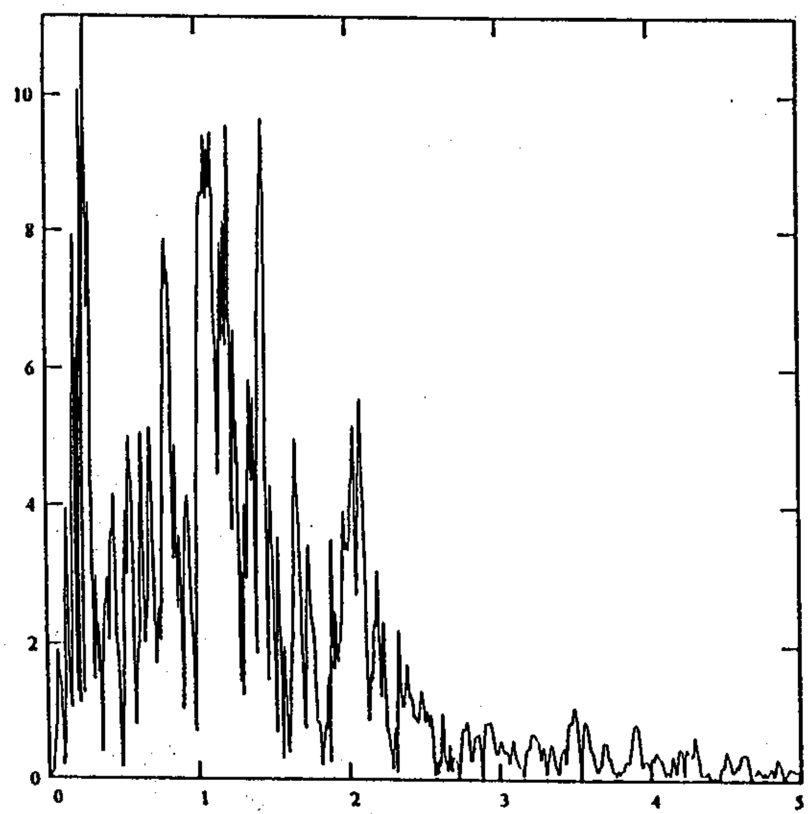
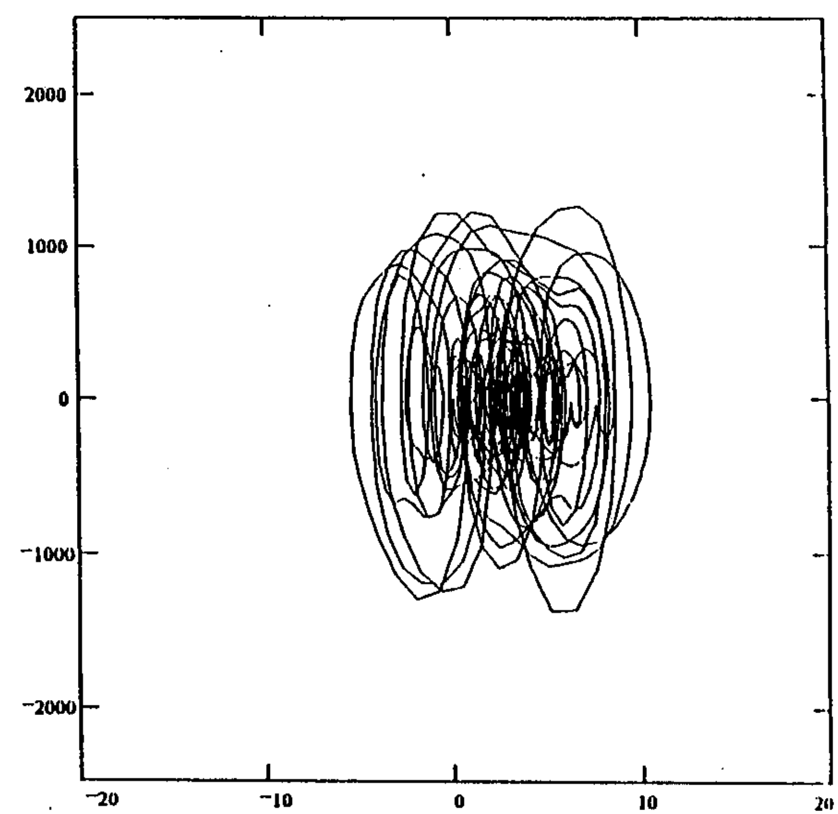
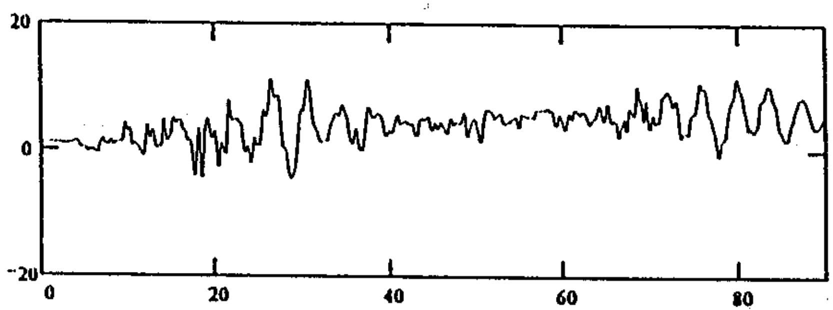




SF side span/tower, node 1, SA2



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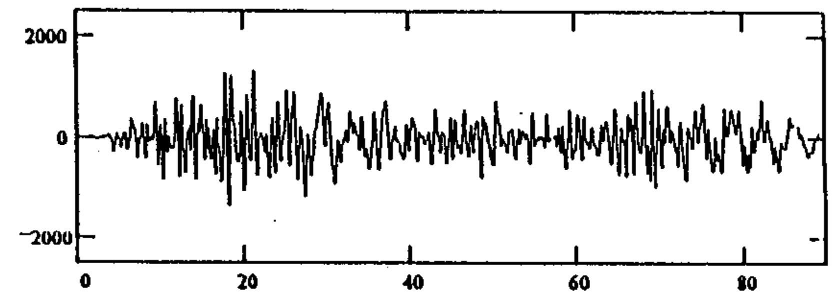

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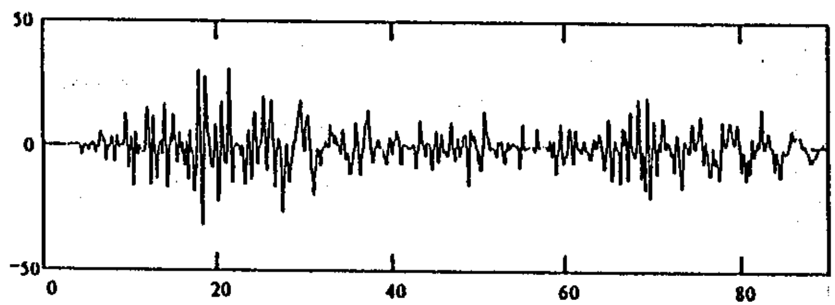

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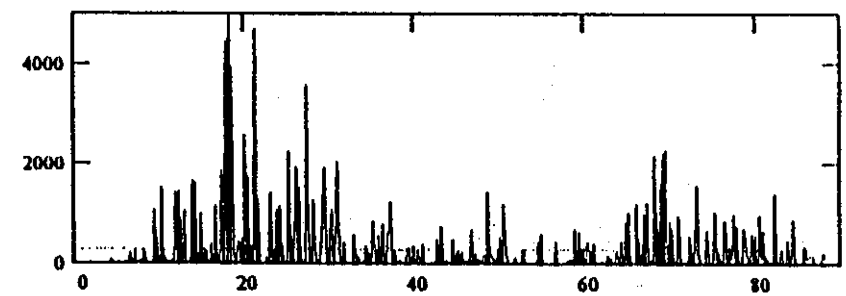

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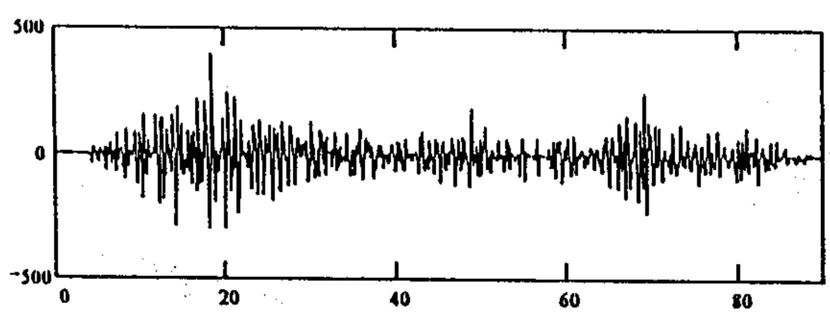
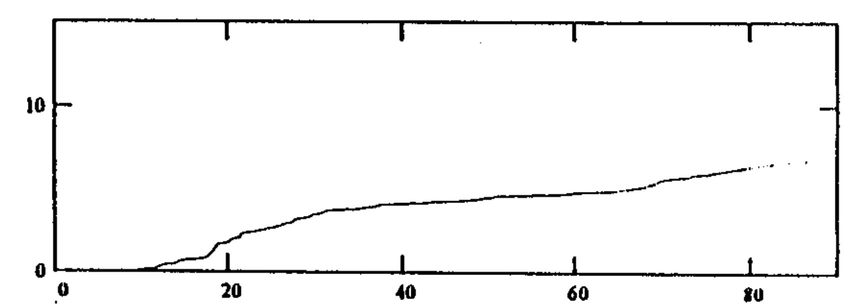
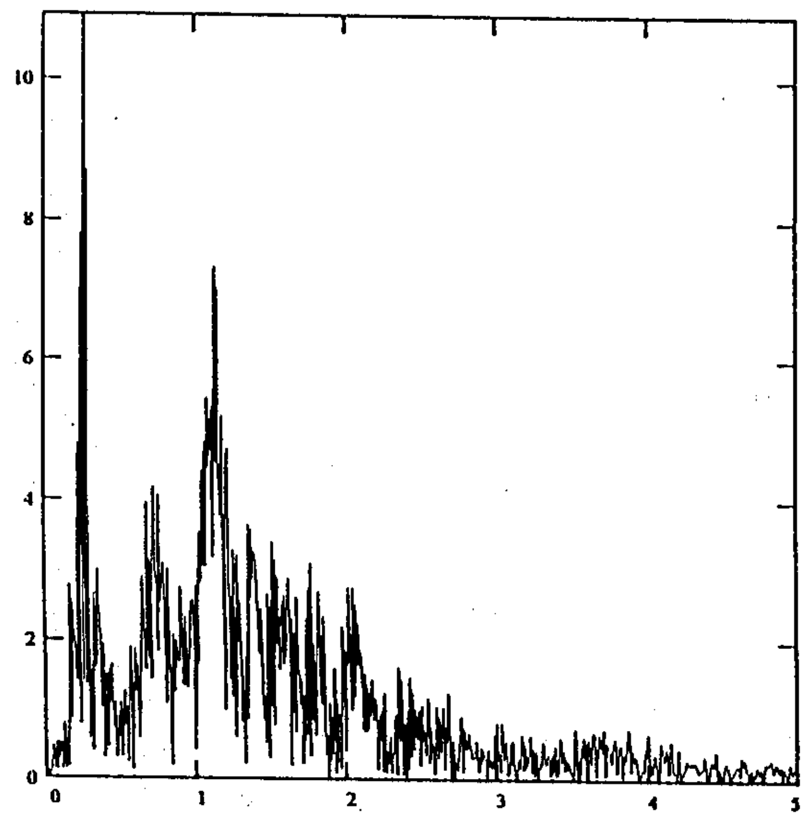
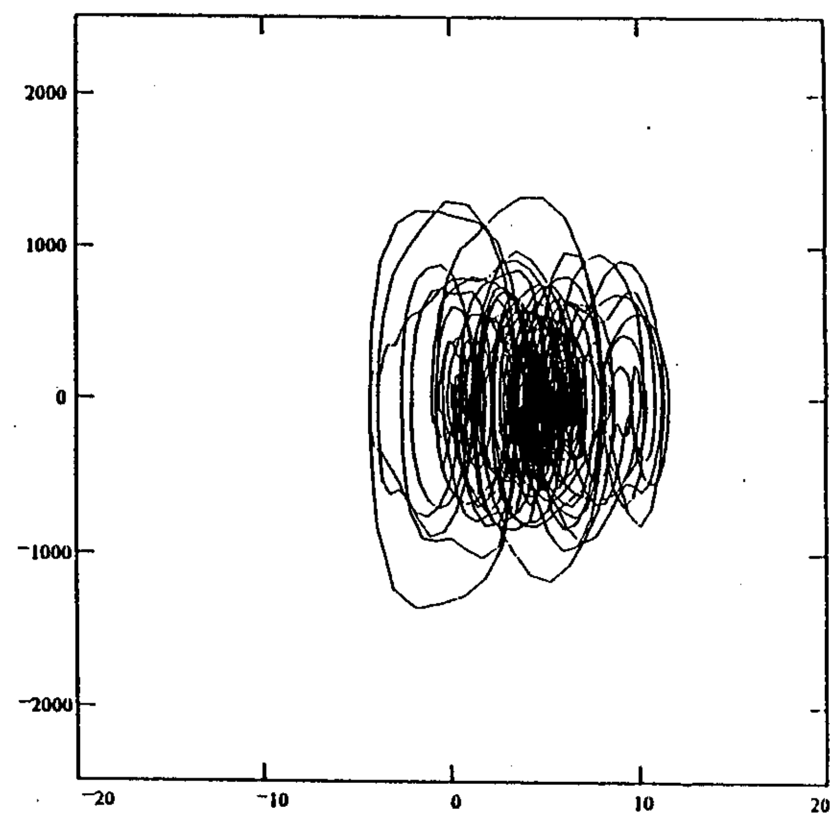


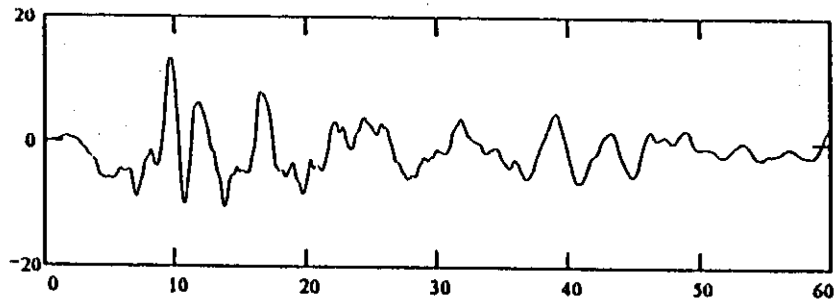


SF side span/tower, node 1, SA2





SF main span/tower, node 1, SA1



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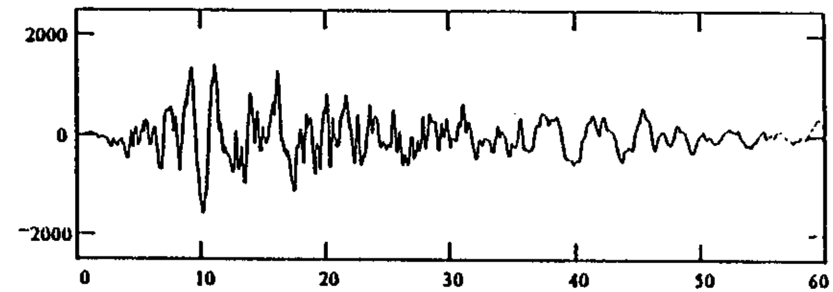

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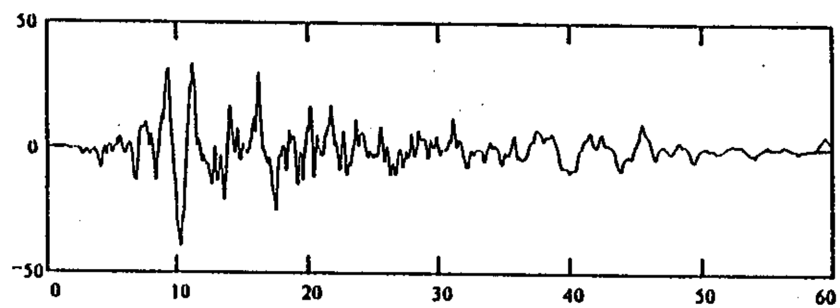

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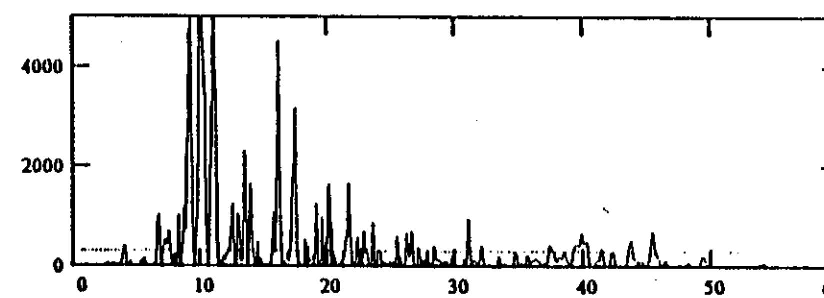

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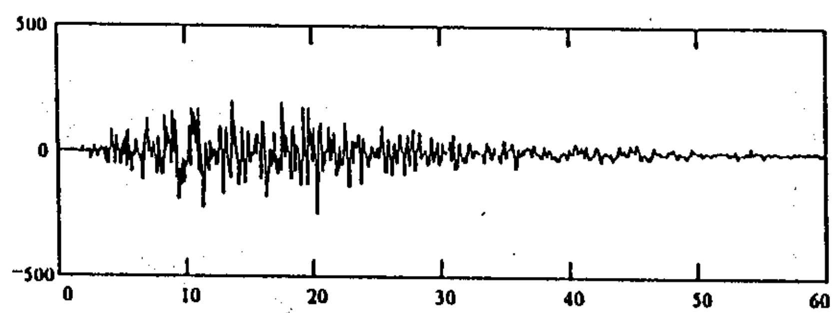
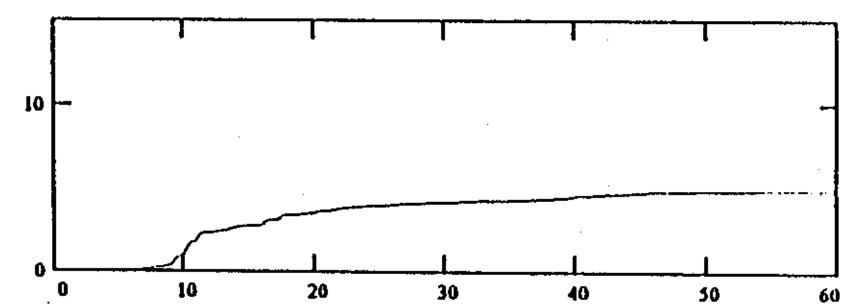
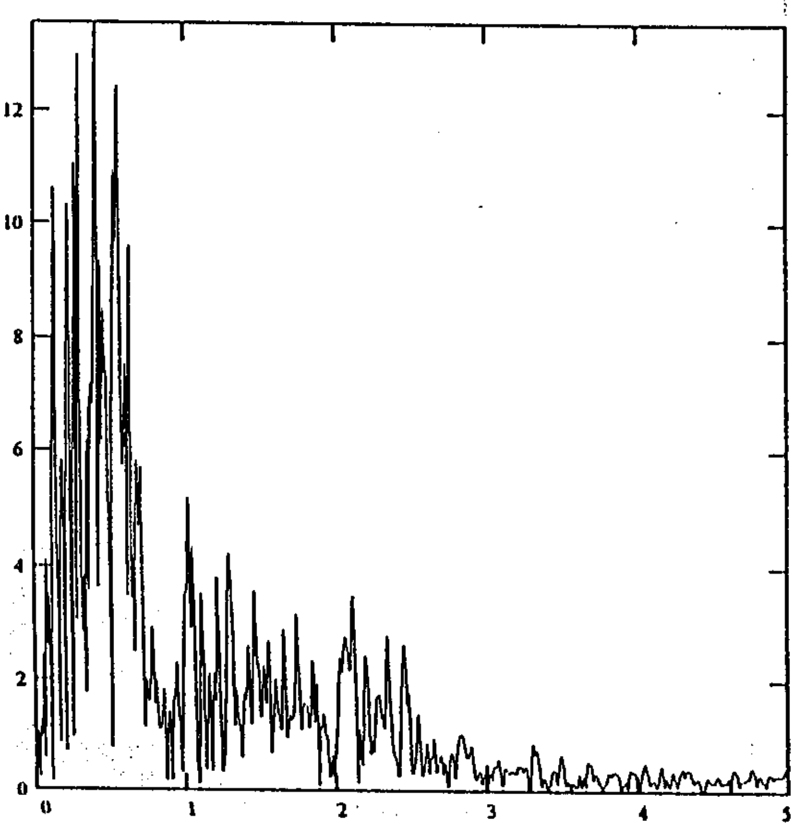
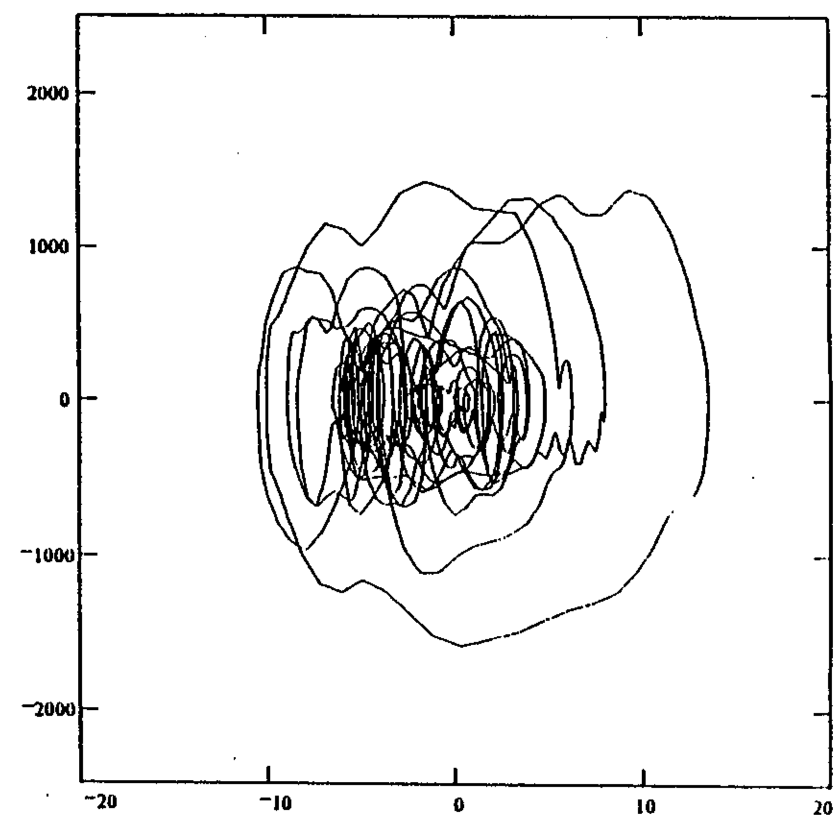


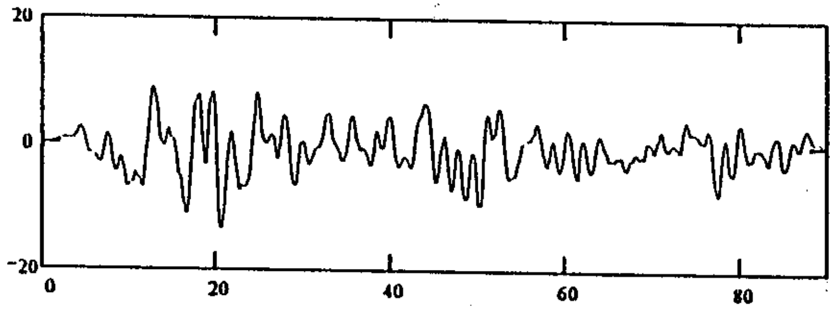


SF main span/tower, node 1, SA1





SF main span/tower, node 1, SA2



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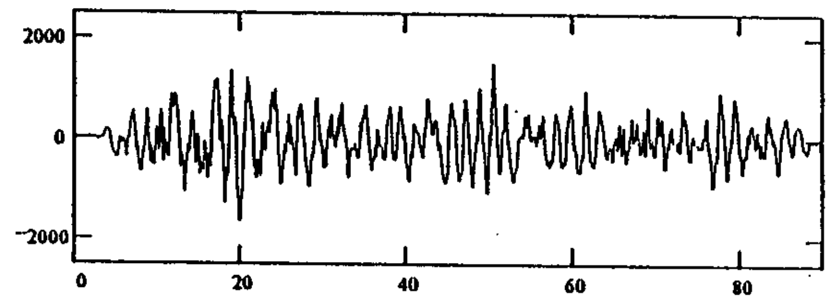

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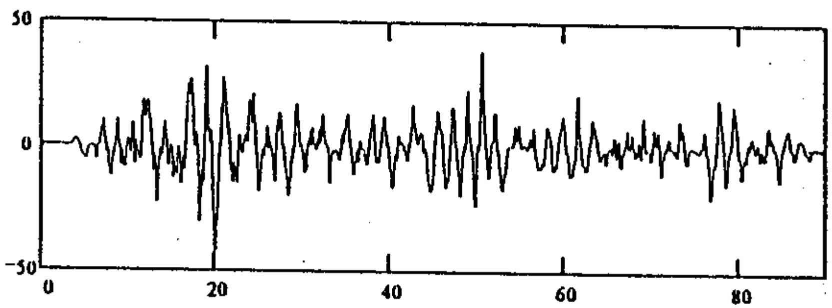

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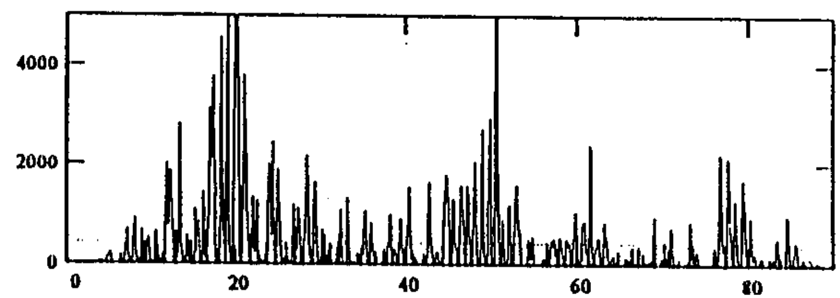

— power time history, kilowatts
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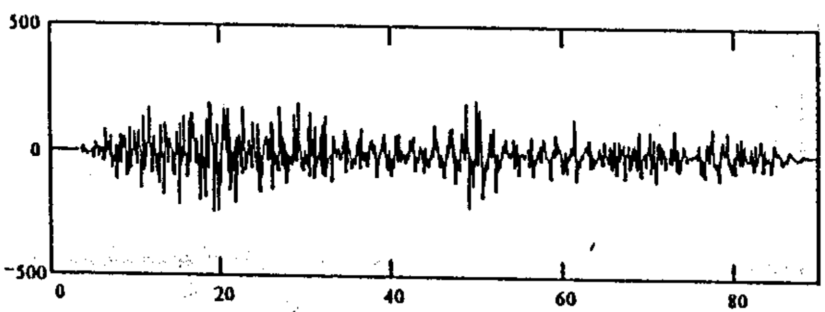
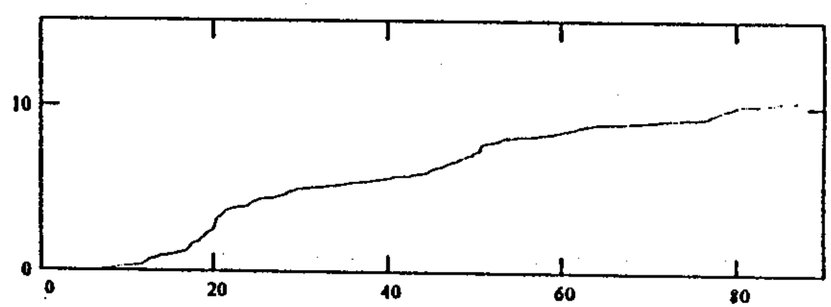
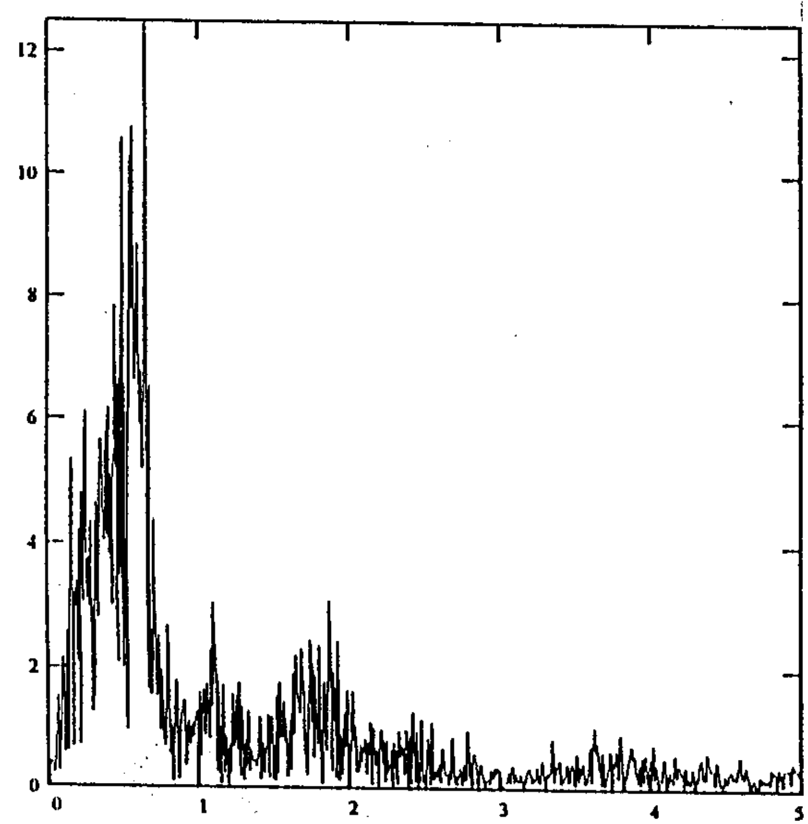
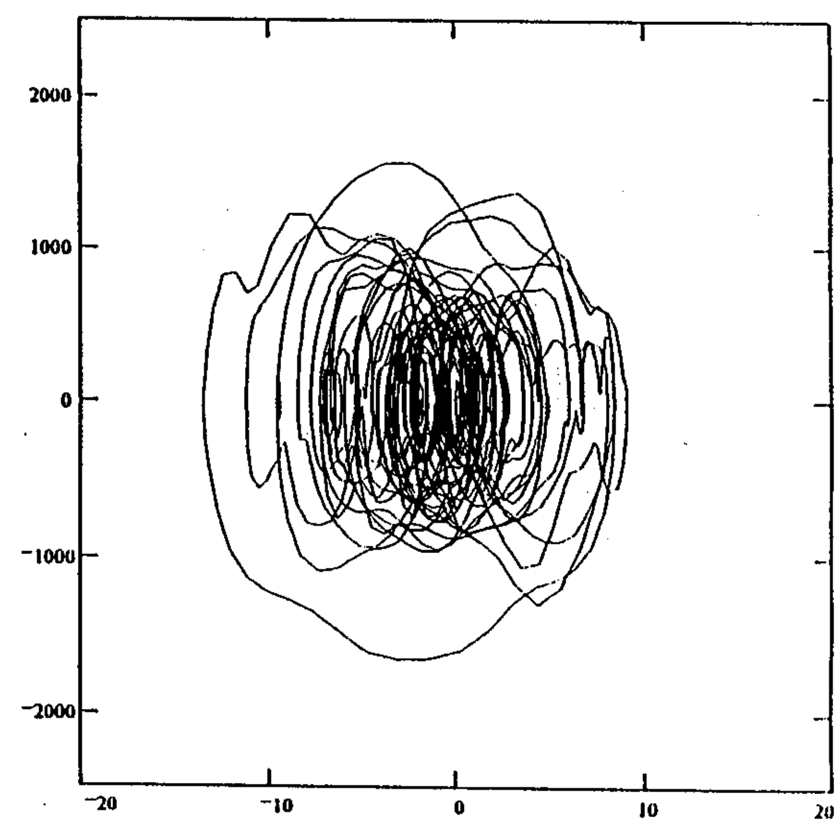


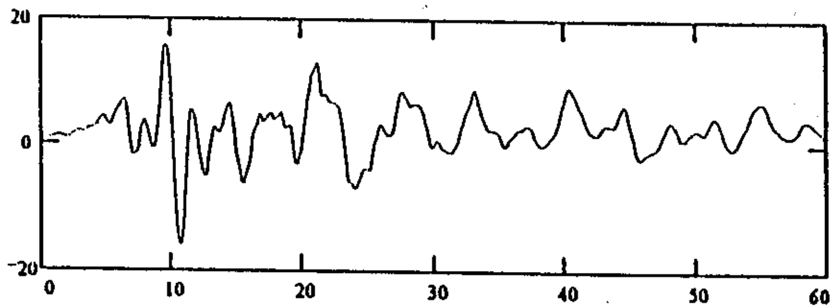


SF main span/tower, node 1, SA2





MA main span/tower, node 1, SA1



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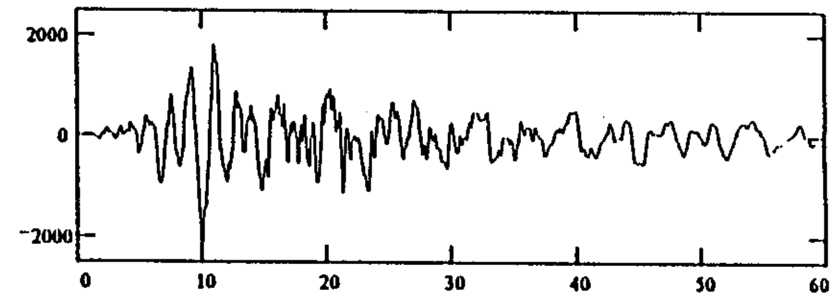

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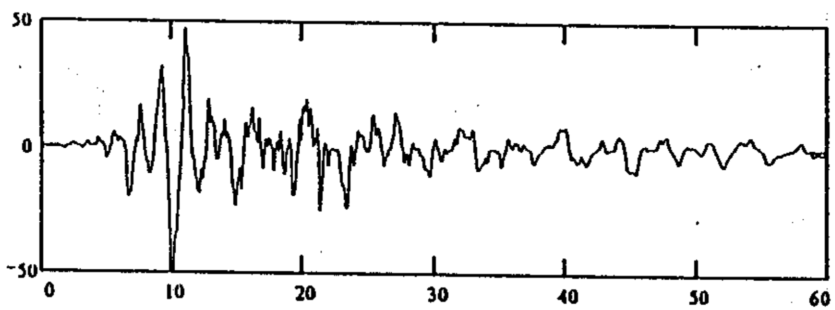

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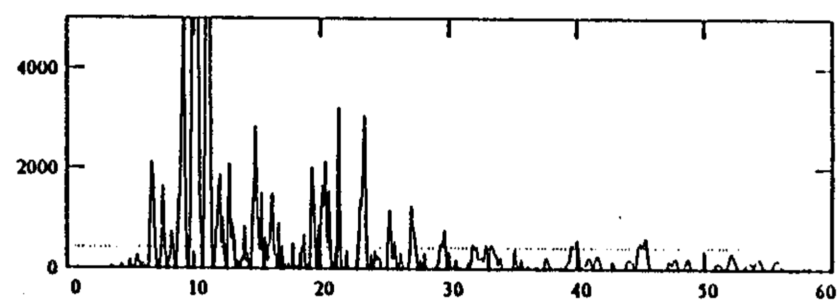
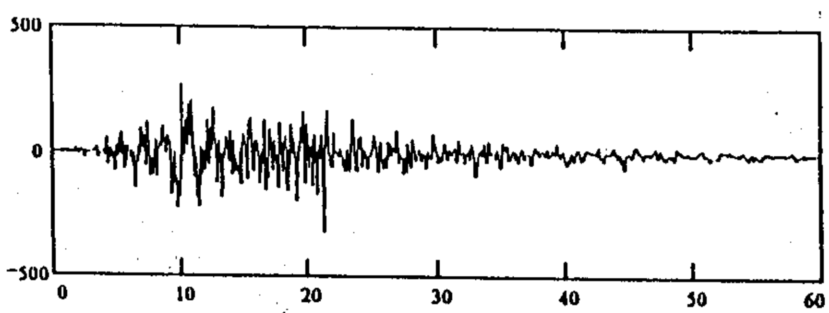
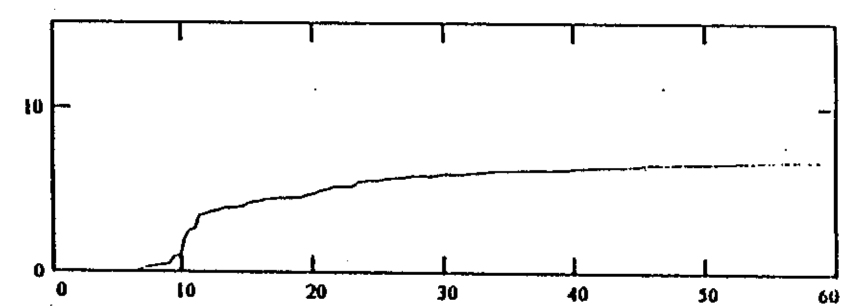
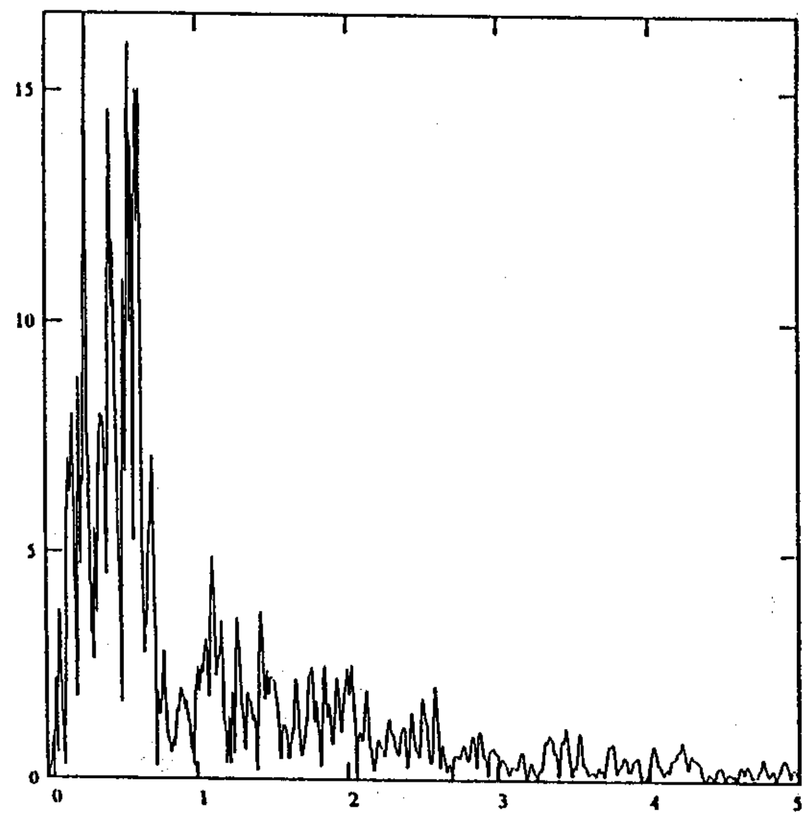


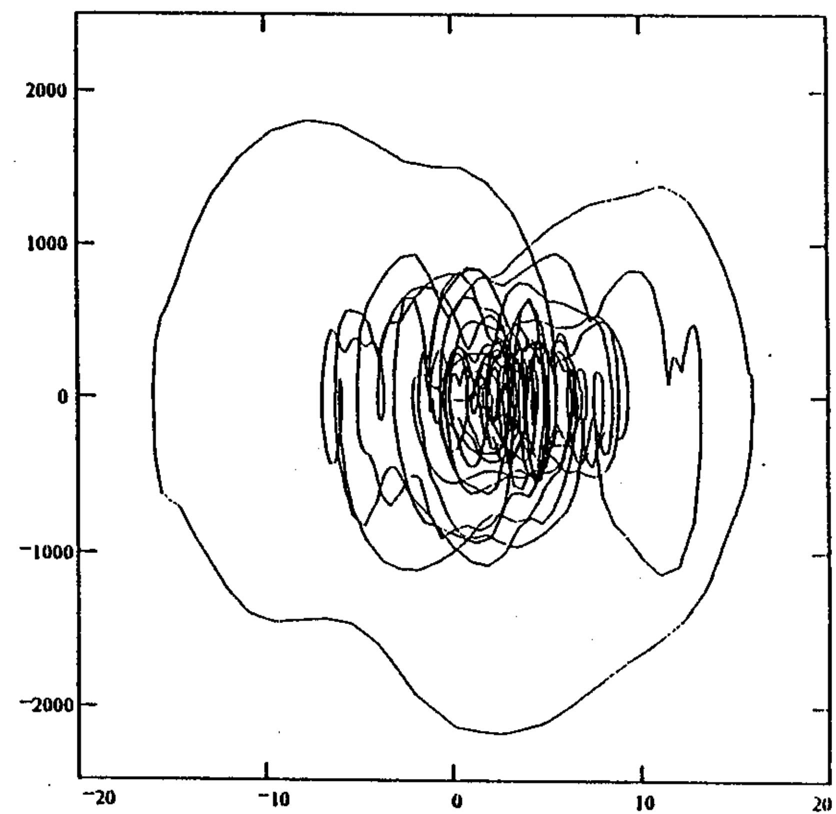
— power time history, kilowatts
average power



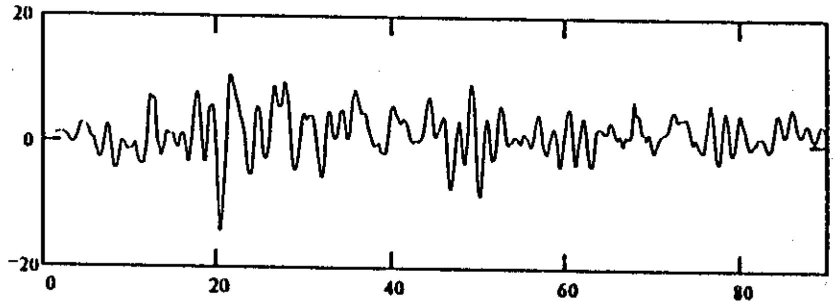


MA main span/tower, node 1, SA1

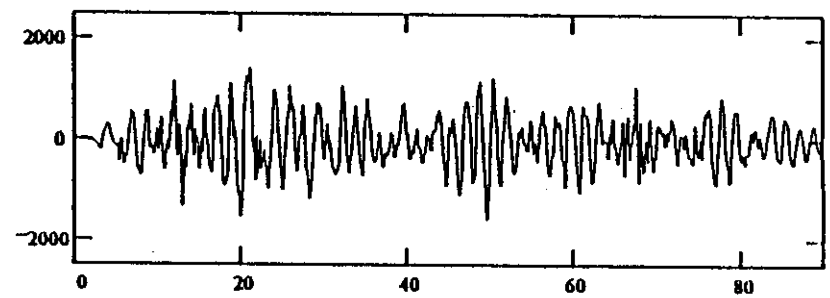




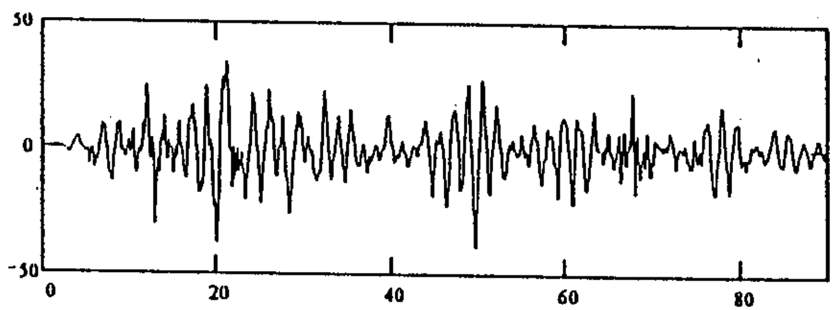
MA main span/tower, node 1, SA2



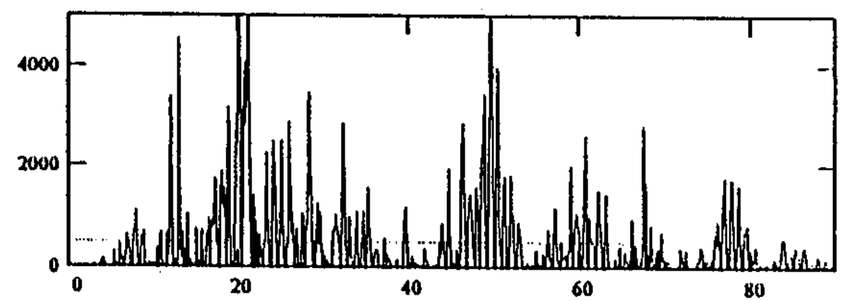
— displacement time history, in



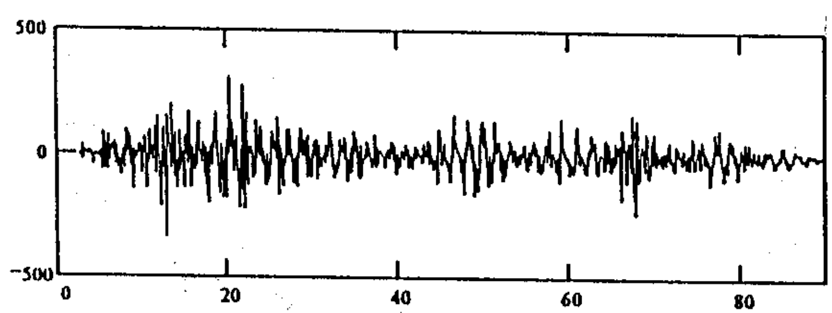
— force time history, kip

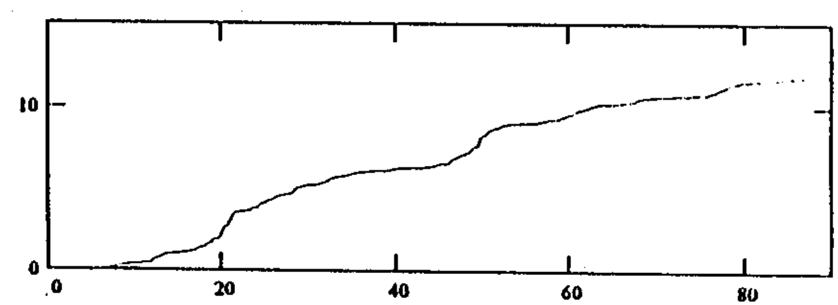


— velocity time history, in/sec

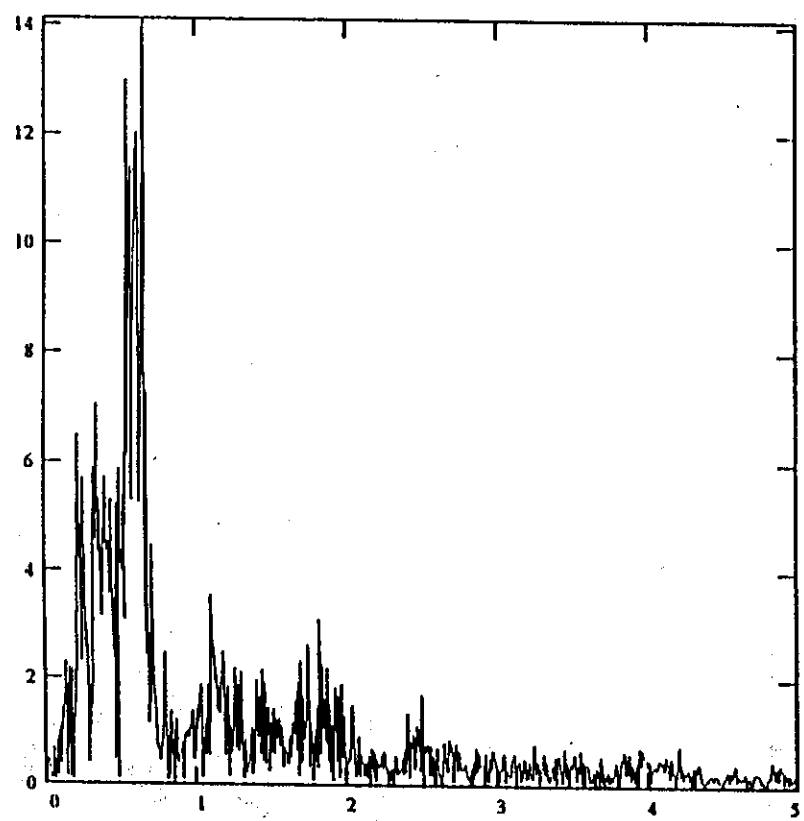


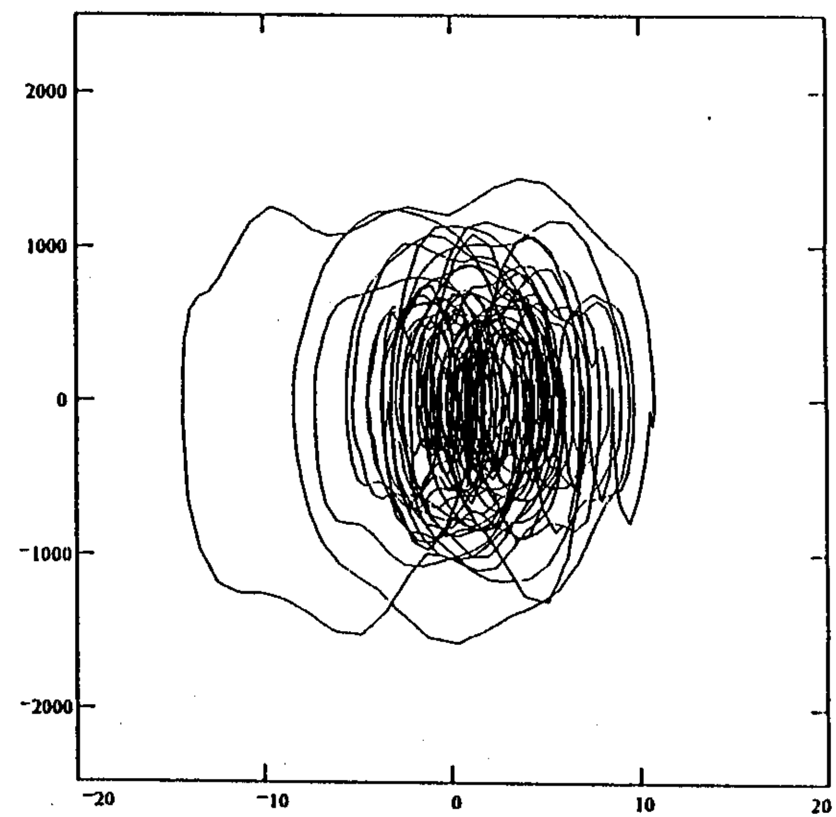
— power time history, kilowatts
····· average power



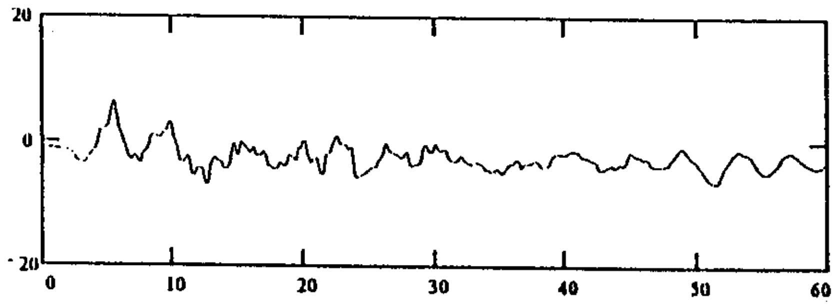


MA main span/tower, node 1, SA2

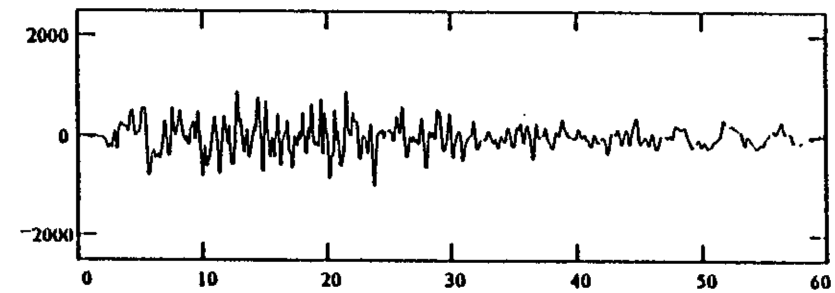




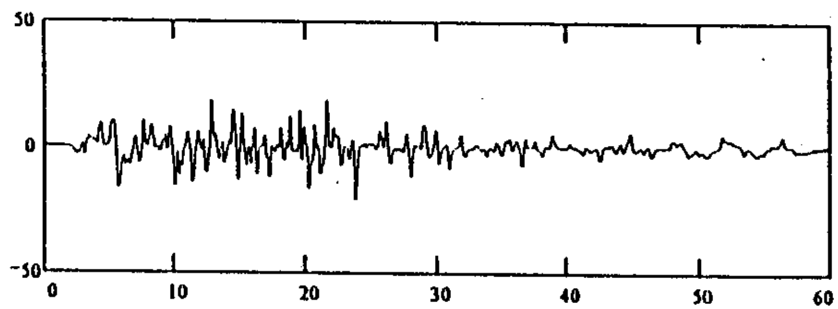
MA side span/tower, node 1, SA1



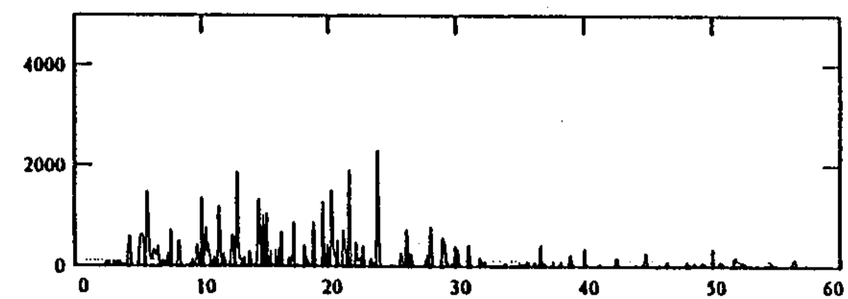
displacement time history, in



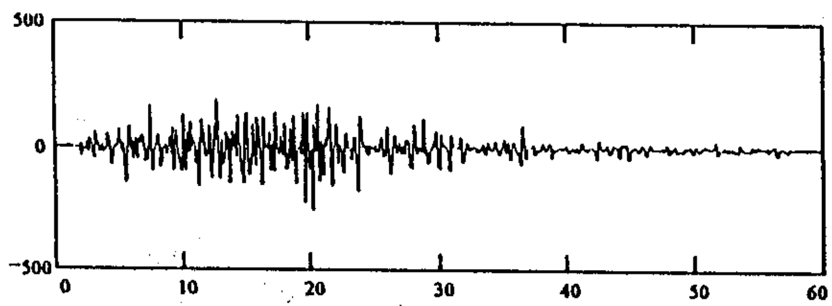
force time history, kip

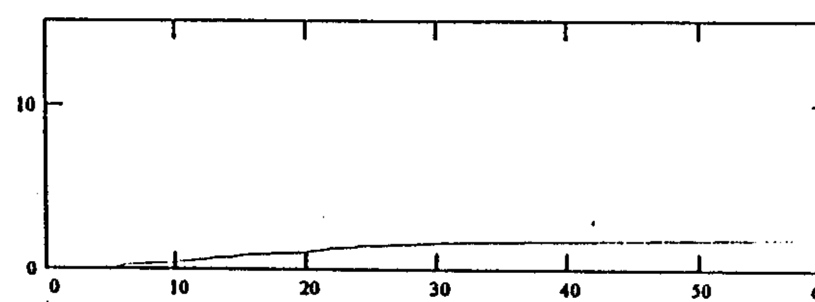


velocity time history, in/sec

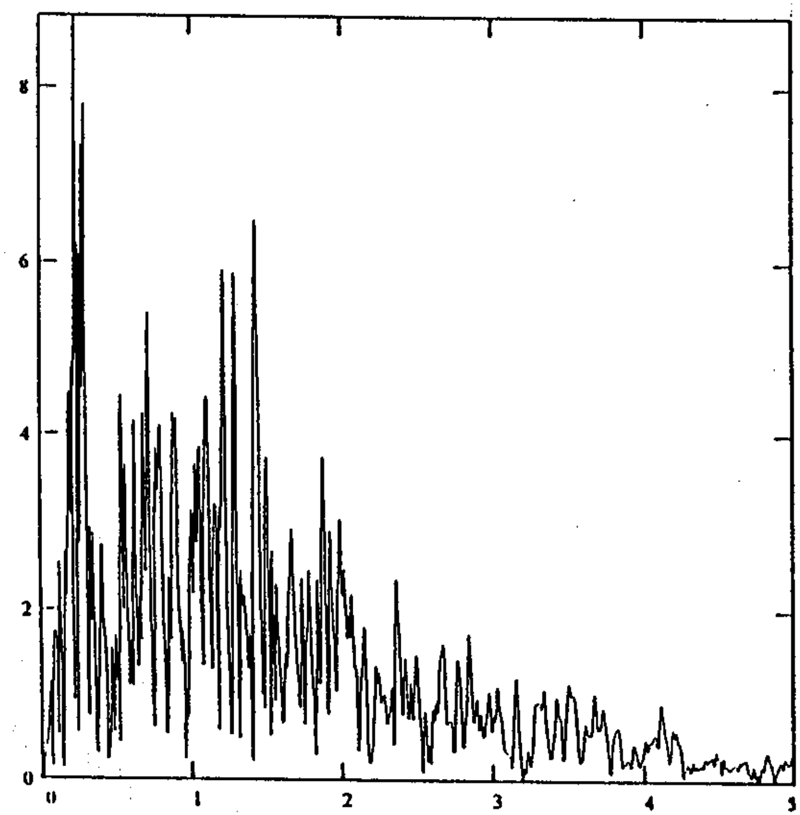


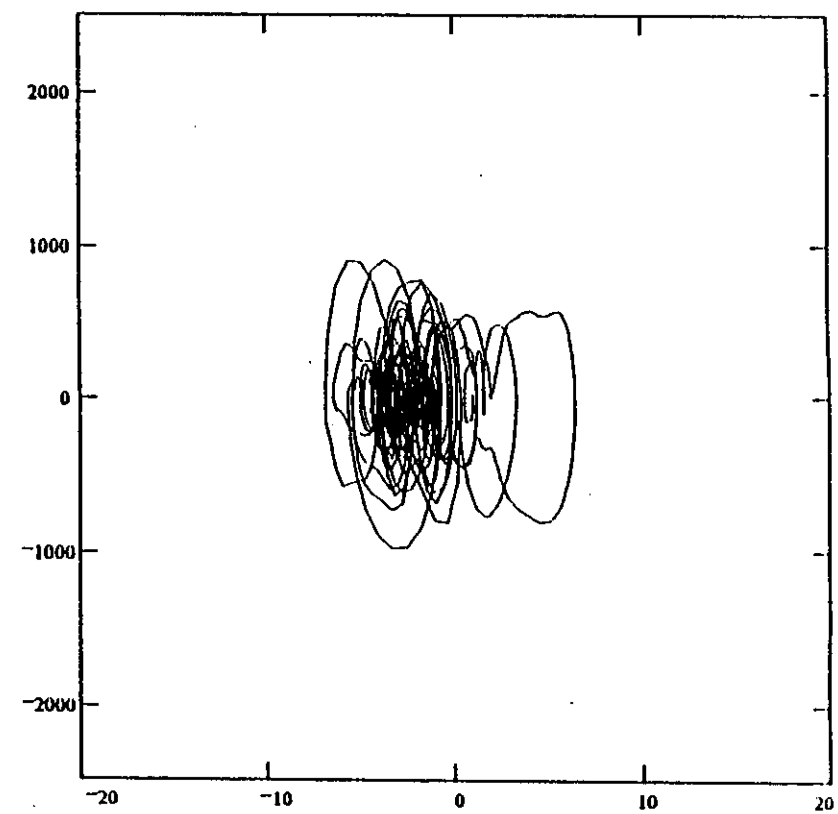
power time history, kilowatts
average power



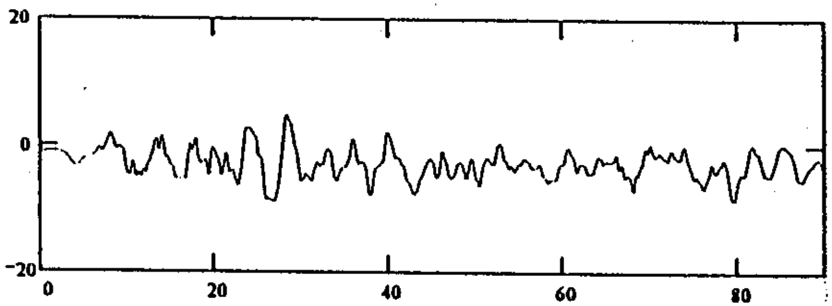


MA side span/tower, node 1, SA1

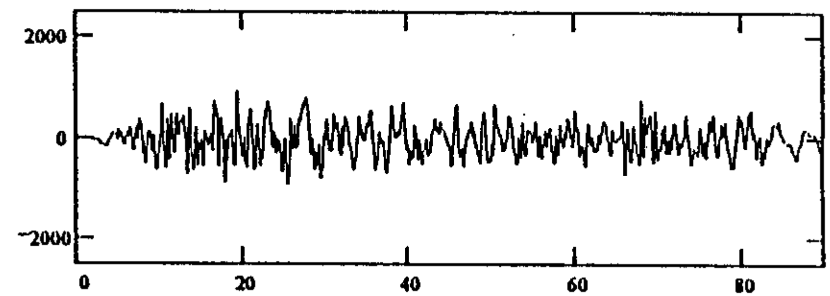




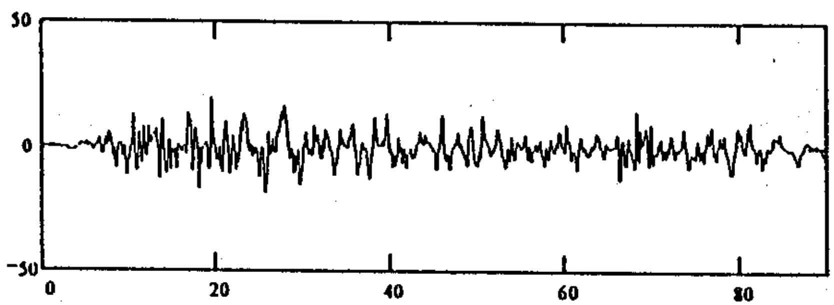
MA side span/tower, node 1, SA2



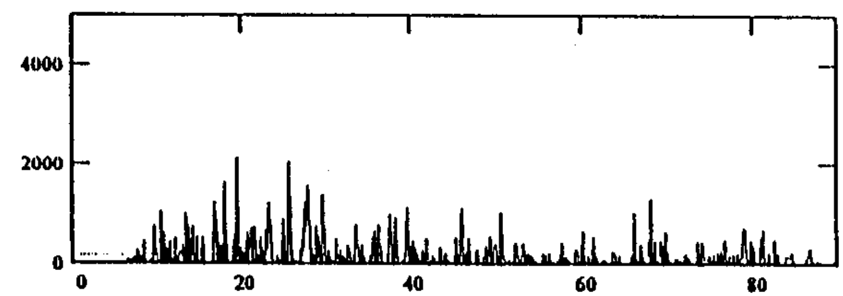
— displacement time history, in



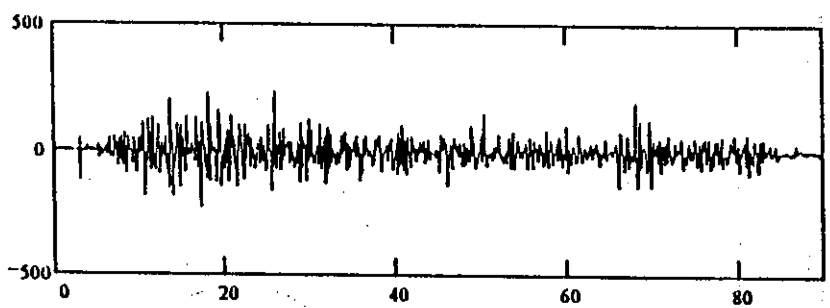
— force time history, kip

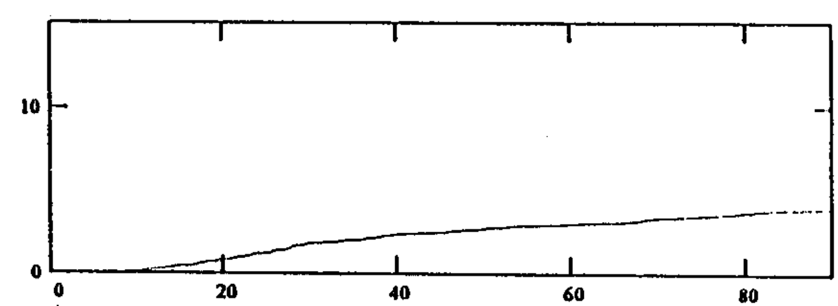


— velocity time history, in/sec

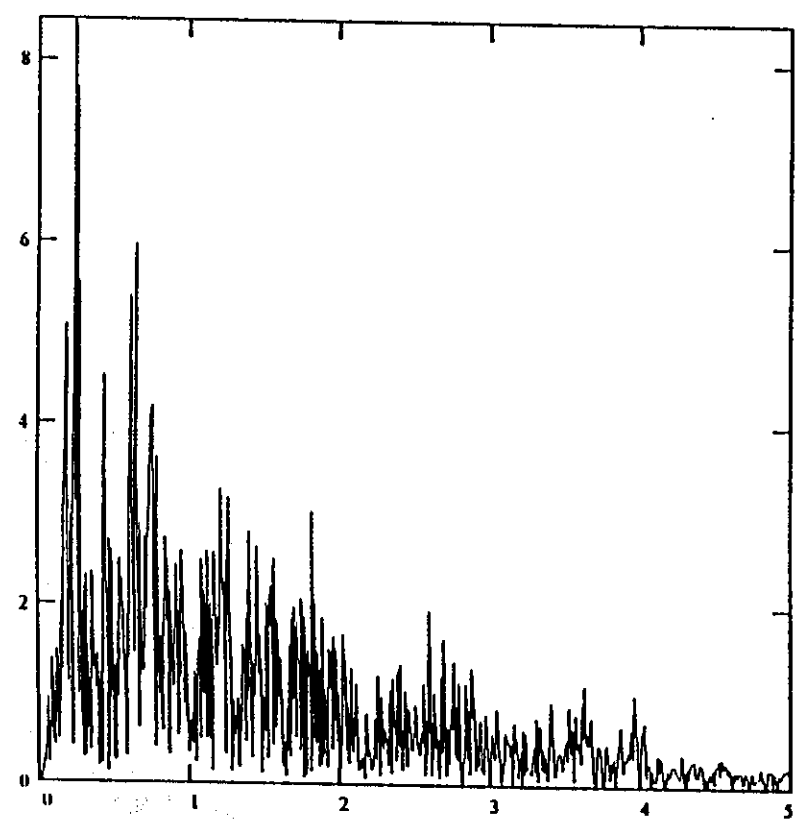


— power time history, kilowatts
average power

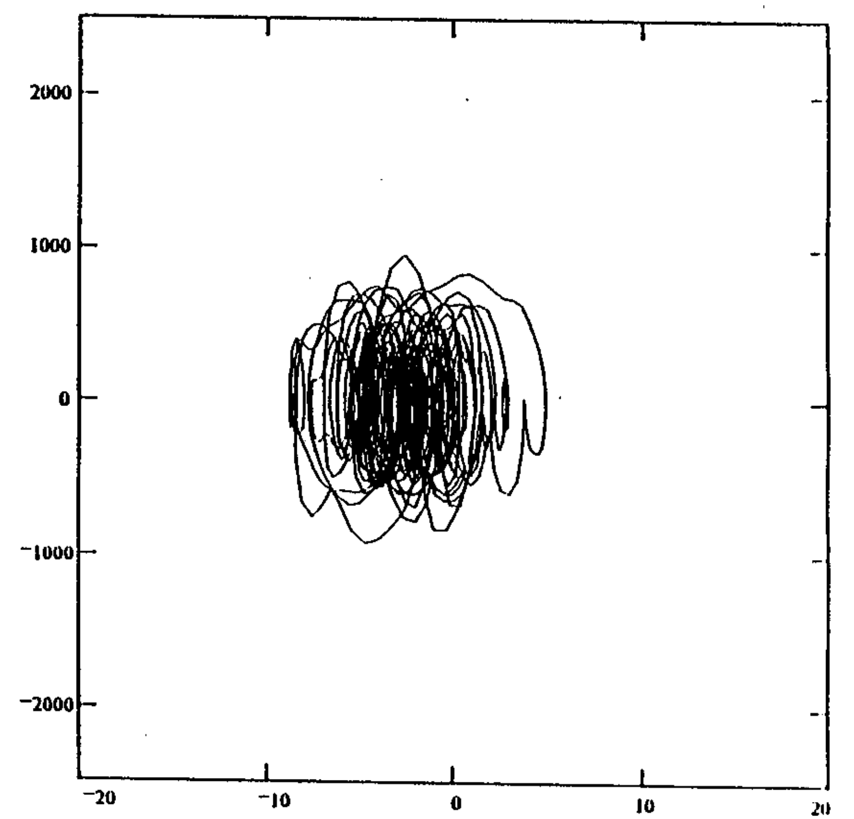




MA side span/tower, node 1, SA2

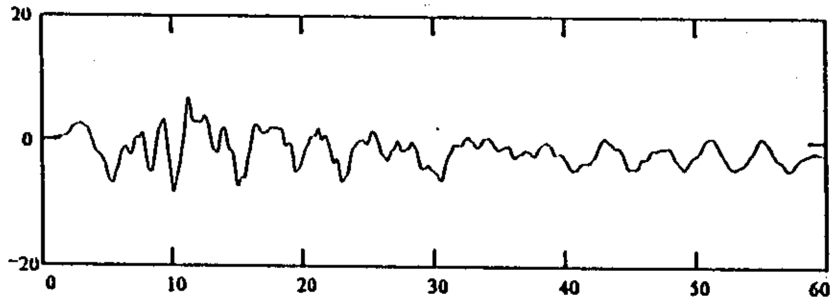


Fourier transform of force vs. frequency Hz

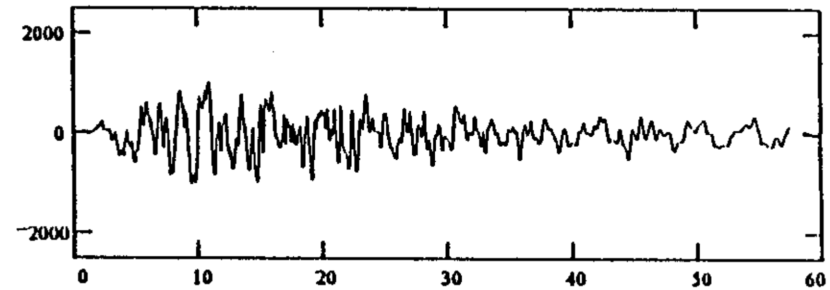


force displacement hysteresis

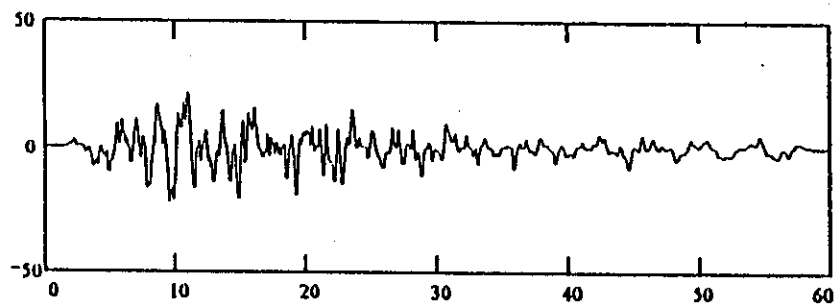
MA side span/pylon, node 1, SA1



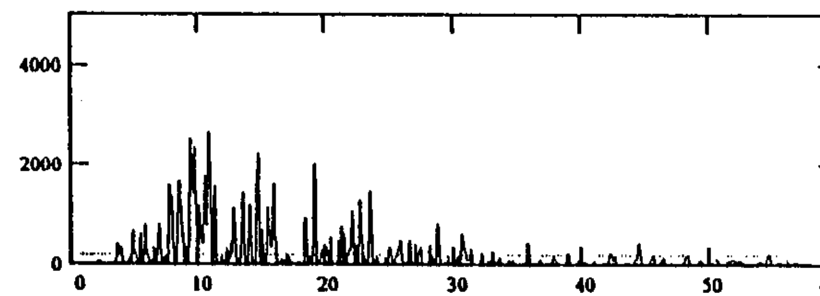
— displacement time history, in



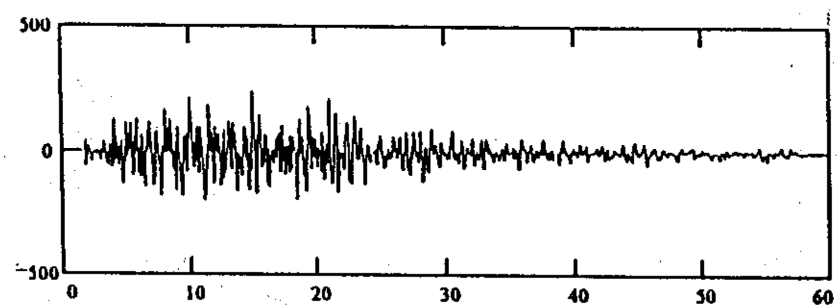
— force time history, kip



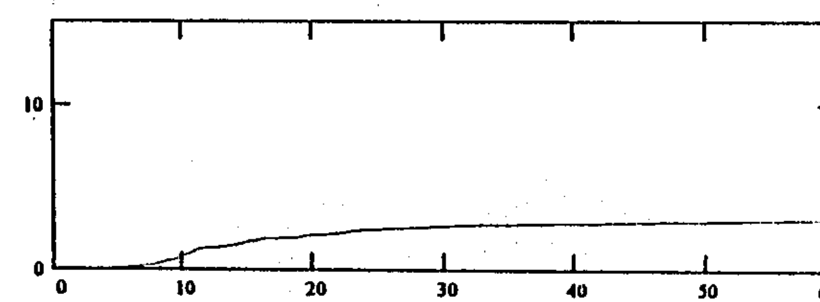
— velocity time history, in/sec



— power time history, kilowatts
····· average power

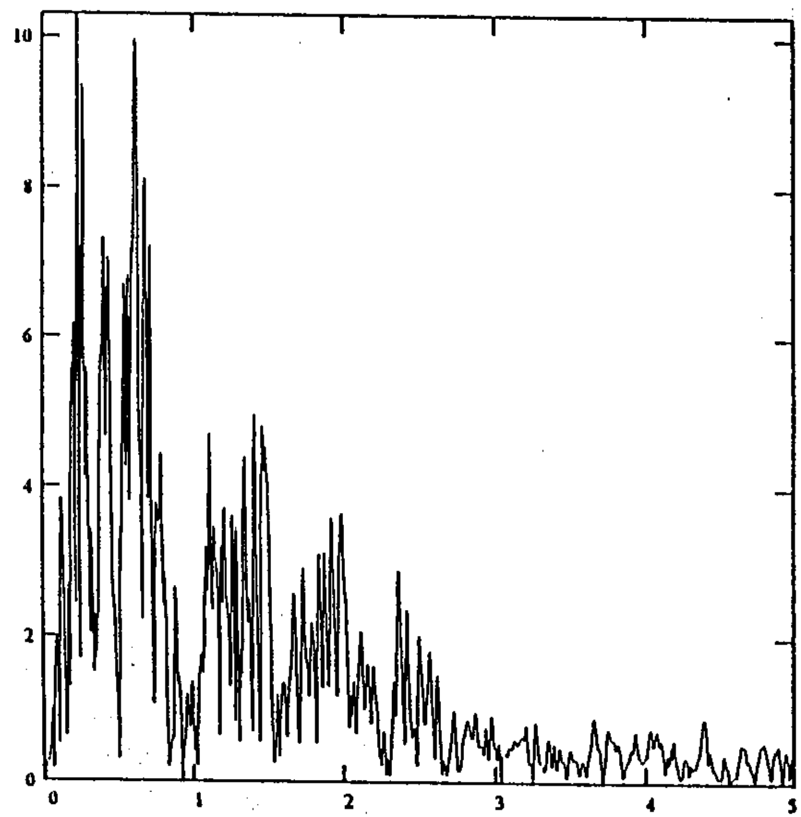


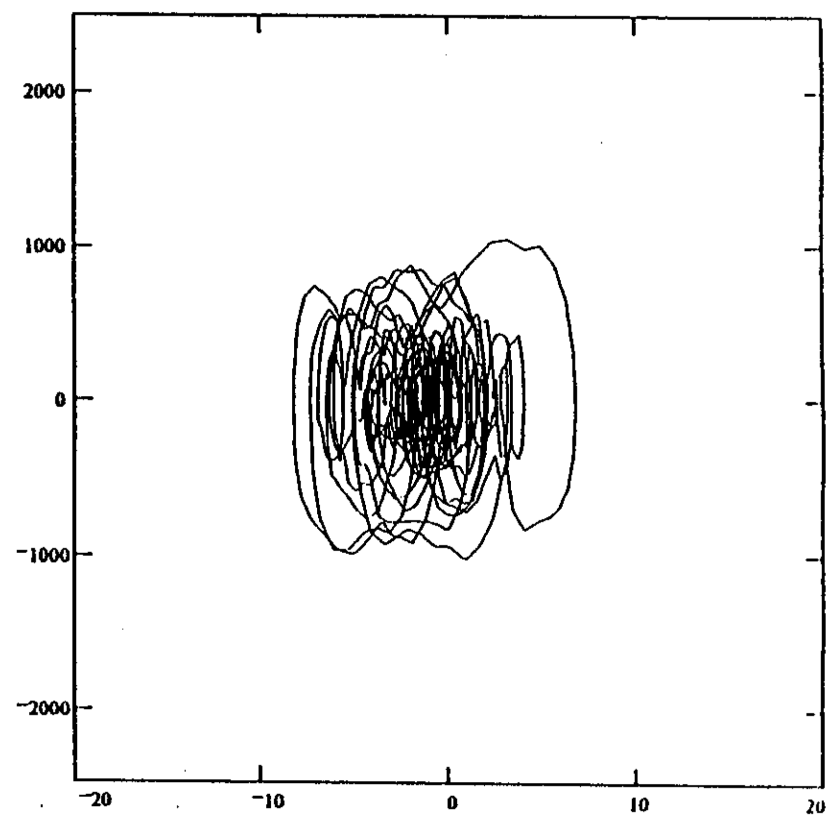
— acceleration time history, in/sec/sec



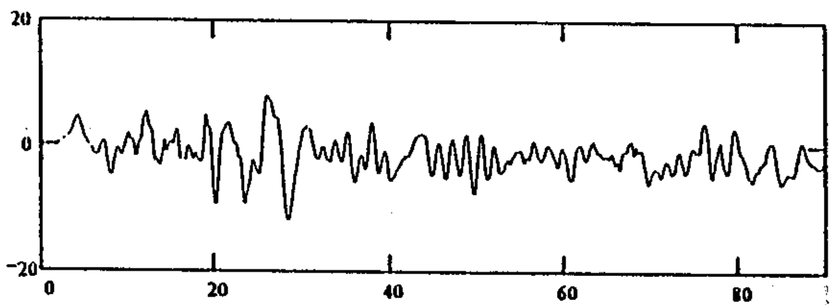
— energy dissipated time history, kilowatt hours

MA side span/pylon, node 1, SA1

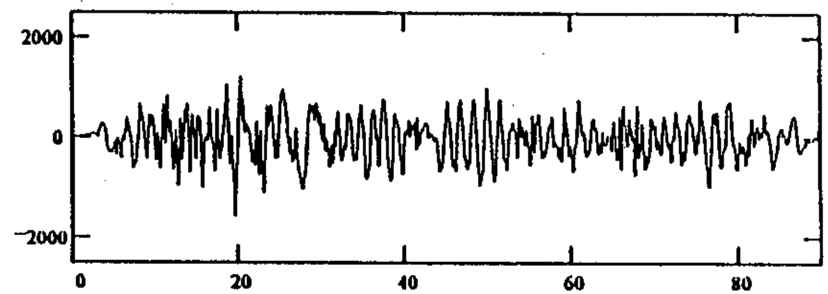




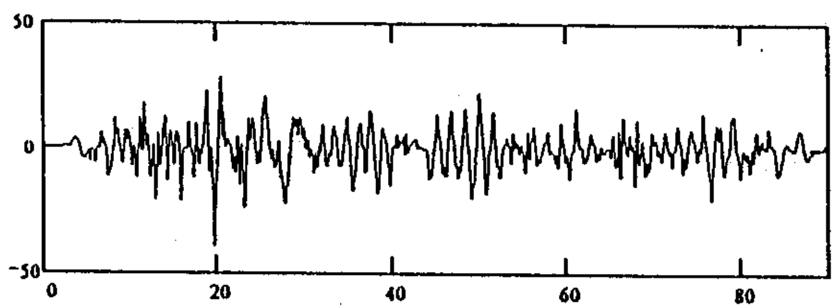
MA side span/pylon, node 1, SA2



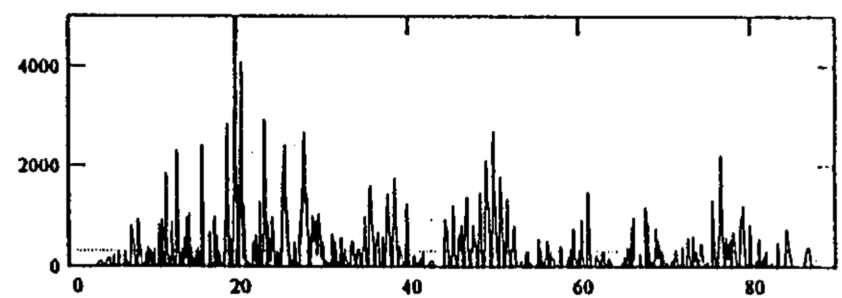
— displacement time history, in



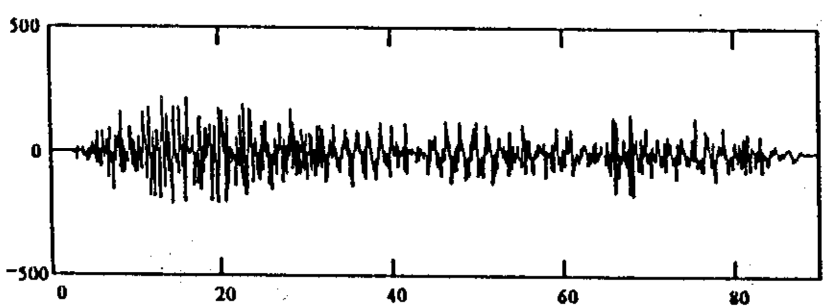
— force time history, kip

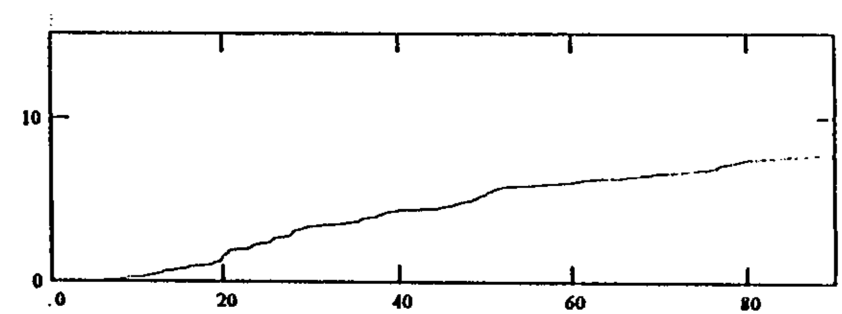


— velocity time history, in/sec



— power time history, kilowatts
.... average power





MA side span/pylon, node 1, SA2