ANNEX I

BASIC PARAMETERS FOR CALCULATING STRUCTURES

1. Introduction

The effects of an earthquake differ according to the structures involved and must therefore be defined by separate parameters. A list of the principal parameters covering most of the possible effects will be found below. Particular importance should be attached to the response spectrum, for it is in terms of this parameter that the effects of a nominal earthquake are defined in the most recent standards. This parameter is used in chapter VII in connexion with seismic microzoning.

2. Response spectrum

The response spectrum represents, approximately, the acceleration of the baricentre of a structure having a given natural period, which must be used to calculate the bending moment or action at the base. A precise definition, together with some comments, will be found in section 2.

A knowledge of this parameter is necessary for calculating the dynamic behaviour of a structure during an earthquake. As many data can be obtained from it as are provided by a set of accelerograms representing the ground motion during an earthquake or by the Fourier spectra, which are generally less easy to use.

The law requires that an appropriate nominal response spectrum be determined for all structures of a certain importance (nuclear power stations, dams, chemical plants using toxic substances, etc.) even if the zone is not, strictly speaking, a seismic one.

The response spectrum is taken into consideration in the national technical standards of most countries for ordinary buildings in seismic zones.

Response spectra can be obtained by analysis of earthquake recordings made on the building site or by comparison with spectra already obtained for well-known sites.

3. Seismic coefficient

The seismic coefficient is the ratio between the shearing effect at the foot of a building and the weight of the building. This ratio is independent of the natural period of the building. The seismic coefficient is used as a reference for private residential buildings of a few storeys, for which it is not considered necessary to carry out a dynamic analysis.

The seismic coefficient provides much more summary information than the response spectrum, of which it generally represents the mean ordinate for periods of 0.2 to 0.8 seconds, taking account of the damping generally accepted for reinforced concrete buildings (~ 10 per cent of the critical value).

For private residential buildings which are judged to be able to tolerate more or less extensive damage in the event of an earthquake of exceptional intensity, the seismic coefficient is between 0.05 and 0.15 depending on the seismicity of the zone.

4. Duration of the earthquake

The consideration of this parameter is explicitly required when calculating the stability of structures built on soil liable to liquefaction or thixotropy, such as sandy ground saturated with water, having a relative density of 65 per cent or less.

It should be noted that even earthquakes of very high intensity, but of small magnitude (local earthquakes) can be of brief duration. Conversely, an earthquake of greater magnitude (for example $\geqslant 6$) is generally of longer duration, even if it is of low intensity, i.e. low ground acceleration.

5. Displacement of faults

This parameter is unquestionably important when it directly concerns the foundations of a structure which, fortunately, seldom occurs. The displacement of a fault is nevertheless important in that it may cause relative displacement of the points of support of a structure extending over different geological zones; this may be the case with a dam, bridge, oil pipeline or tunnel (particularly an underwater tunnel).

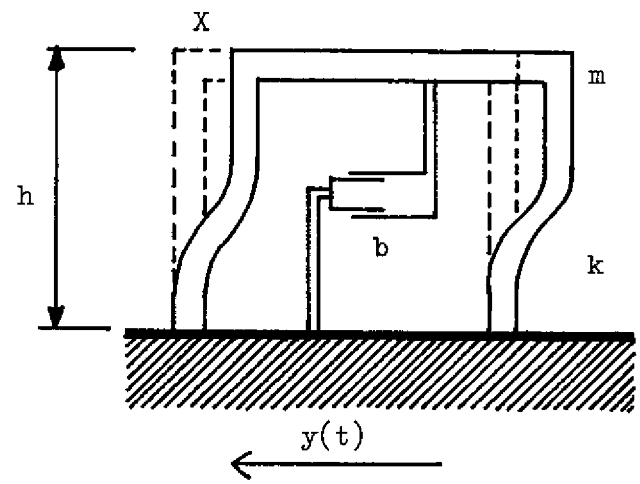

Fig. A-1

6. Determination of the response spectrum

Consider a linear oscillator with one degree of freedom. This may be represented by the system shown in fig. A-1, which consists of a rigid mass connected with the ground by elastic supports of negligible mass, deformable only by bending in the plane of the diagram.

Although the diagram does not represent real conditions, its simplicity allows intuitive interpretation of the parameters defining the dynamic behaviour of an elastic system and clarifies certain elementary aspects of earth motion during an earthquake.

Here we shall consider only the case in which the movements of each point of the system in relation to the ground always remain slight.

Under such conditions, the mass can only make horizontal movements (A-1).

Let K be the over-all elastic constant of the supports, and x the movement of the mass in relation to the ground. The force exerted on the mass by the supports will then be Kx.

The inertia of the system on movement is also represented by means of a viscous damper of constant b, so that bx is the force exerted by the damper on the mass, x being the speed of m in relation to the ground.

If the ground makes horizontal movements y(t) in the plane of the diagram, the mass m is also set in motion by the forces exerted on it by the elastic supports and the viscous damper.

The problem is to calculate the displacement of the mass x(t) during the movement of the system, assuming that the excitation function y(t) and the constants of the system m, k, and b are known.

Using the notation adopted in the figure, the total displacement of the mass m is given by x-y.

The movement of the system is then governed by the equation:

$$m\ (\ddot{x} - \ddot{y}) + b\dot{x} + Kx = 0$$

that is to say :

$$m\ddot{x} + b\dot{x} + Kx = m\ddot{y}\ (t) \quad (1)$$

In this equation, the known term $m\ddot{y}$ is shown as an external force exerted on the system.

The mass is, of course, considered to be at rest at time zero, and the initial conditions are therefore:

$$x\ (0) = 0\ ; \quad \dot{x}\ (0) = 0$$

One aspect of the solution x(t) is shown in fig. A-2

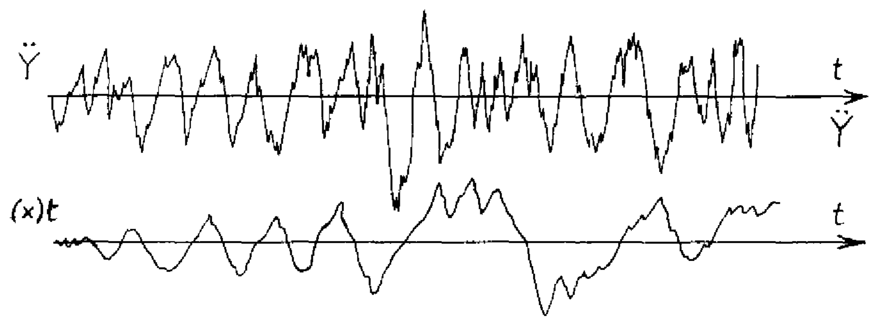

Fig. A-2 : Qualitative aspect of a solution x(t).

As regards equation (1) it is useful to note that if all the terms are divided by m we obtain :

$$\ddot{x} + \frac{b}{m} \dot{x} + \frac{K}{m} x = \ddot{y}(t), \qquad (2)$$

this equation demonstrates that the solution depends on the parameters which define the structure by two ratios only, namely, $\frac{b}{m}$ and $\frac{k}{m}$.

In structural dynamics it is preferred to express these two ratios by means of two other parameters, which are more familiar to construction engineers :

$$\nu = \frac{b}{2m\,\omega}$$ damping in relation to critical shock absorption;

$$\omega = \sqrt{\frac{K}{m}}$$ natural frequency.

Equation (2) then becomes: $\ddot{x} + 2\nu\omega_o \dot{x} + \omega^2{}_o x = \ddot{y}$ (3)

It should be noted that, in general, if no deformation problems arise, there is no advantage in knowing the full development of the time function $x(t)$; it is sufficient to know the maximum value x_{max} reached by this function during the whole of the seismic event. The equivalent static load, i.e. the force which, acting statically, is able to produce the same loads on the supports of the structure, is in fact Kx_{max}. A significant parameter is the ratio C between Kx_{max} and the weight of the mass, that is to say Kx_{max} / gm. This is a pure number, which it is significant to regard as the ratio between an acceleration and the acceleration of gravity. It represents a good approximation of the maximum acceleration of the mass m in g units (i.e. in relation to the acceleration of gravity).

The diagram of C as a function of T_o for different values of the parameter ν, is shown in figures A-3 and A-4. These diagrams are called response spectra of the accelerations (response spectra are also calculated in terms of velocity and movement). The parameter C is sometimes called the seismic coefficient.

Modern instruments for measuring strong shocks ("strong-motion recorders") supply direct recordings of the three components of earth acceleration. The most significant recordings are analysed at specialized research centres. Values of C corresponding to the different values of T_o and ν can be successively obtained from equation (3) by the use of electronic analysers.

A remark may be made here which will be useful in connexion with research on the response spectrum: the integration of (3) requires that the earth motion be described in terms of the value of the acceleration $\ddot{y}(t)$. In theory, once the functions $y(t)$ are known, the function $\ddot{y}(t)$ is also known. However, the operation of derivation from a recording, whether by an analog or a digital process, necessarily introduces considerable uncertainties. Consequently, research on earth motion in earthquakes today aims at direct recording of the three components of earth acceleration.

The diagram in fig. A-1, and equation (3) associated with it, lend themselves directly to practical applications only in the case of very simple structures. But this diagram plays a considerable part in the calculation of earthquake-resistant structures for at least two reasons. As we learn from structural dynamics, with the help of modal analysis the solution of the most complex problems can in many cases be reduced to solving a certain number of elementary problems of the type of that in fig. A-1.

The simplicity of the diagram also makes for easy understanding of certain fundamental aspects of the seismic problem including, first of all, the different behaviours of a rigid structure for which T_o is several seconds.

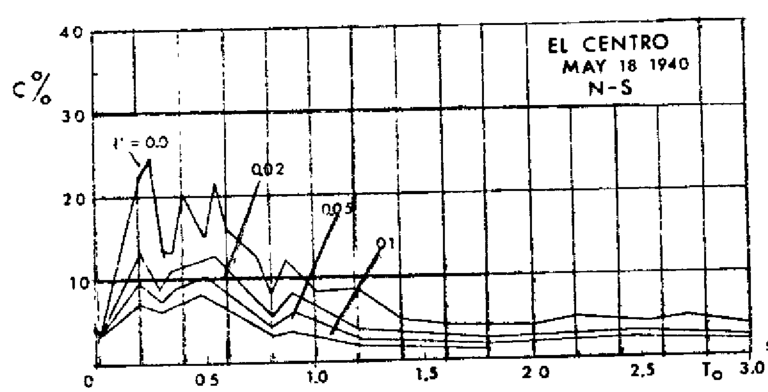

Fig. A-3

The diagrams in fig. A-3 can be studied, for example, for a given value of the relative damping. If the structure is rigid ($T_o \cong 0$), the maximum acceleration of the mass m is about 0.04 g, which coincides with the maximum earth acceleration during the earthquake chosen as an example. If the structure is very deformable ($T_o \geqslant 2$ s.), the maximum acceleration of the mass m is below that value;in the example chosen, it is about 0.01 g. In the whole range of values for the natural period lying between 0.1 and 1 s., $\ddot{x}_{max}$ considerably exceeds the maximum earth acceleration. These observations are confirmed by the diagrams in fig. A-4 and, in general, by the response spectra of all the earthquakes so far recorded.

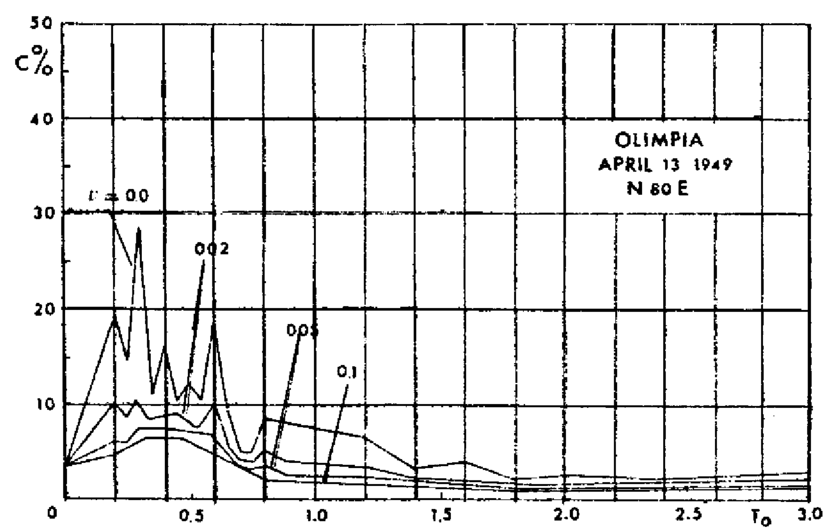

Fig. A-4

7. Nominal response spectrum

When considering a nominal earthquake, the basic data are generally defined by a response spectrum, not by recordings of $\ddot{y}(t)$. In such a case, the response spectrum must represent the effects of all possible earthquakes on the site considered: for example, the response spectra of earthquakes regarded as representative, or an average response spectrum, depending on the objects in view. In any case, we shall call it a "nominal" response spectrum.

Moreover, it is easy to see that it would not be possible to construct a "nominal" accelerogram on the basis of a set of recordings of y (t) (i = 1, 2, ...). Such an accelerogram would have to provide, for each natural period T_o of the structure, a response offering the desired safety margin in relation to the responses of each $\ddot{y}(t)$.

In order to define the nominal response spectrum it is necessary, first, to introduce a few considerations on the spirit of the standards now applied to building in seismic zones. It will be remembered that, as has already been said in chapter X, the present aim is to stipulate two conditions :

1/ The building must be able to withstand, under conditions of elasticity, an earthquake of an intensity corresponding, for the zone considered, to a return period equal to the nominal life of the building (the nominal life of private residential buildings is generally taken to be 100 years).
The foregoing explains the spirit of the technical standards for building in earthquake zones in different countries, which are in general agreement that the resultant F of the horizontal seismic forces to be taken into consideration when calculating

structures shall be represented by an expression of the form:

$$F = C\ (T_o)\ \cdot \Psi \cdot \alpha \cdot w$$

- where Ψ is a coefficient depending on the type of structures, which increases in inverse proportion to the assured ductility of the structure;
- α is a coefficient depending on the nature of the foundation soil;
- w is the weight of the building, including a fraction for accidental overloading;
- $C(T_o)$ is the response spectrum of the nominal earthquake, in accordance with fig. A-5.

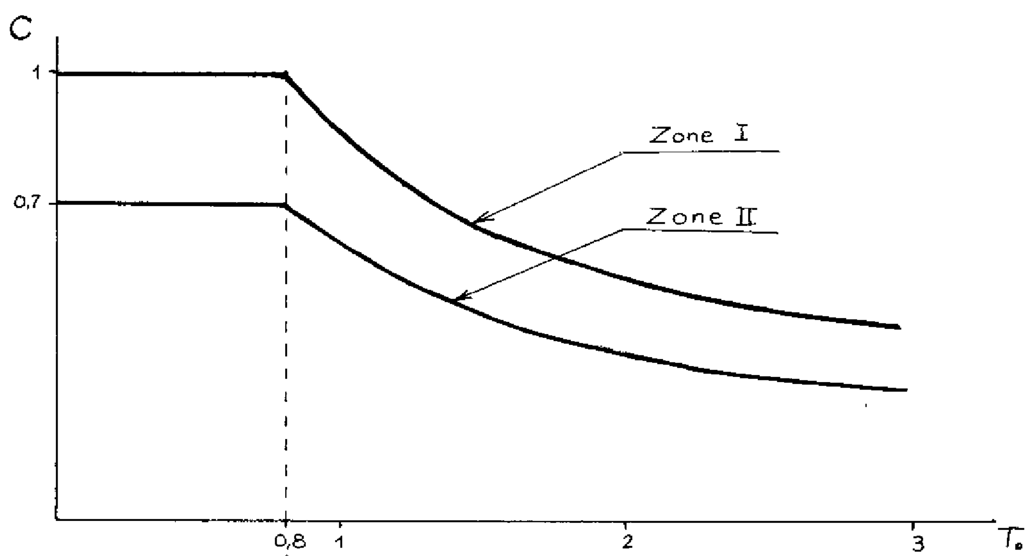

Fig. A-5

Diagrams of this kind are characterized by an intensity parameter and by a certain shape. Intensity is represented either by the area of the diagram $C(T_o, \nu)$ within the range of natural periods considered, $0.1 < T_o < 3$s. for the appropriate damping or, more simply, by the ordinate at the origin C(0). This last value, which is easily determined, represents the earth acceleration during the nominal earthquake. The parameter C(0) will be chosen to indicate the intensity, because of its direct significance. As regards the shape of the diagram, it should be noted, in particular, that this formula does not take into account the incidence of damping; furthermore, the seismic coefficient $C(T_o)$ does not depend on T_o in the interval $0 \leq T \leq 0.8$ s., whereas for $T_o > 0.8$ s., C decreases in proportion to $T_o - 2/3$.

2/ The structure must also have a sufficient margin of strength beyond the elastic limit to withstand, without collapsing (even if it sustains substantial damage), an earthquake more violent than that considered above, i.e. of an intensity such that the probability of its being exceeded by earthquakes to which the building may be subjected in the future is negligible.

It must be pointed out at once that the practical possibilities of satisfying these two conditions with a reasonable degree of reliability are quite different. The first condition involves calculating the response of a linear system to a movement of the foundation soil, which can be done with a good degree of reliability. It also involves making forecasts of the earthquakes which will occur within a period of time comparable to that on which the information on past earthquakes is based; and this is an extrapolation which can properly be made by the methods of statistical data analysis.

The second condition, on the other hand, involves taking account of the little-known dynamic behaviour of non-linear systems; moreover, there is a tendency to base calculations on the intensity of earthquakes having a period of return which is too long in relation to the observation period. This is, therefore, a branch of research in which there is much uncertainty.

Attempts are now being made to solve this problem for private residential buildings by a single procedure, which roughly satisfies the two conditions stated above :

1/ to define the behaviour of a building, in addition to the elastic parameters, an empirical coefficient is introduced which depends on the type of structure and represents an estimation of the capacities of resistance beyond the elastic limit;

2/ the structure is calculated on the basis of the seismic data and of its elastic parameters. Empirical evaluation of the structure's assured ductility then determines the safety coefficients to be applied.

In reality, as was pointed out in connexion with the graphs in fig. A-3 and A-4, the earth acceleration during seismic movements - the function $C\ (T_o \nu)$ - may assume various aspects. It is therefore important to explain that the spectrum $C(T_o)$ prescribed by the standards is not supposed to represent the spectrum of the most probable earthquake on the site in question. It is only a criterion for the minimum resistance to horizontal forces required of a building erected in a given earthquake zone.

Regulations generally authorize the use of all data on local seismicity which can be collected at the site; it is therefore permissible to use $C\ (T_o\ \nu)$ diagrams different from those indicated by standards. It is clearly an advantage to be able to prepare, zone by zone, a $C\ (T_o\ \nu)$ diagram representing the response spectrum of an earthquake which can be regarded as nominal for each particular zone.

When such a spectrum is known, calculations can be made for seismic forces which are more specifically defined, i.e. dependent on the effective characteristics of local earthquakes.

ANNEX II

TSUNAMIS

1. General

Tsunamis have occurred in all the oceans and in the Mediterranean Sea, but the great majority of them are observed in the Pacific Ocean, which is ringed, from New Zealand through East Asia, the Aleutians and the western coasts of the Americas as far as the South Shetland islands, by zones of high seismic and volcanic activity. About 180 tsunamis were recorded in the Pacific between the years 1900 and 1970. Of these, 35 caused casualties and damage near the source only, whereas 9 spread destruction throughout the Pacific.

Tsunamis spread outwards in all directions from the point of origin, travelling at a speed proportional to the square root of the depth of water and reaching 1,000 km/h in the deep ocean. The distance between successive wave crests may be as much as 500 km. As the waves reach coastal areas, this speed decreases, though the interval of time between the passage of successive waves remains unchanged (usually between 20 and 40 minutes). A single tsunami may comprise up to a dozen large wave crests.

The destructive power of tsunamis derives from the fact that the amplitude of the waves, which is usually less than 1 metre in the deep ocean, increases sharply as the waves reach shallow water near the coast, and may be further enhanced by funnelling or resonance effects in bays and estuaries. In extreme cases, wave heights may reach as much as 20 or 30 metres.

In such cases, waves may sweep a considerable distance inland. During both their advance and their retreat, they damage and undermine buildings, roads and other structures and sweep with them movable objects such as ships and automobiles, which add to their destructive power.

There are in general three lines of defence against natural hazards: prevention, protection and warning. In the case of tsunamis, prevention is out of the question: there are no known means of action to prevent the earthquakes which give rise to tsunamis, or to modify the propagation of the waves across the oceans. The scale of the phenomenon is such that protective works can hardly be expected to do more than mitigate slightly the impact of the waves, and this only in the most favourable circumstances. There remains only warning, which can be instrumental in saving lives if not in preventing destruction. Fortunately this is possible in most cases, and a detailed description will be given of the international tsunami warning system in the Pacific.

2. Protective measures

The most systematic measures to protect coastal areas against tsunamis have been taken in Japan, the country in which the largest number of people live in areas liable to tsunami attack. The measures have consisted in the construction of sea-walls along low-lying stretches of coast, of breakwaters at the entrances to bays and harbours, and in planting belts of pine trees.

Although they do not afford protection against flooding, belts of pine trees can play an important role by ridding the tsunami of some of its energy and by acting as a filter for solid objects carried by the tsunami, thus reducing its destructive power. To be effective they must be at least 200 metres broad (perpendicular to the coast) and should be planted with dense undergrowth in addition to the trees themselves. A typical example of such protective pine belts is that near Rikuzen Takada in Iwate Prefecture.

The town of Yoshihima, in the Sanriku District of Iwate Prefecture, which was completely destroyed by a tsunami in 1896, is now protected by a sea-wall some 800 metres long and 6 metres high. This proved effective against the Chilean tsunami of May 1960 which, being of distant origin, produced waves of long period, but there is some doubt as to whether it would provide complete protection against a tsunami of local origin.

Ofunato Bay, also in Iwate Prefecture, has been the site of extensive industrial development in recent years. After the severe damage caused by the tsunami of May 1960, the entrance to the bay has now been partly closed by breakwaters extending from each side of the bay entrance, leaving a 200 metre-wide passage for ships between them. Similar breakwaters are under construction at other points on the coast of Japan, but sufficient experience of their performance against actual tsunamis has not yet been accumulated for a firm assessment to be made of their effectiveness.

It is obvious that such large engineering works are extremely costly and can be undertaken only when the value of the property to be protected and the frequency of occurrence of tsunamis are sufficiently high to justify them on economic grounds. In most exposed coastal areas, there is little hope of providing effective protection to property. All that can be done is to ensure that loss of life is reduced to a minimum by the timely evacuation of people from areas liable to flooding by tsunamis. This entails preparation by the civil defence authorities of detailed plans for the rapid evacuation of people to high ground, or far enough inland to be out of danger, and requires the ready co-operation of the population. We shall not enter here into a discussion of the social and human problems involved. It is obvious, however, that timely and reliable warnings of approaching tsunamis are an indispensible element of any such evacuation procedure.

3. Warning systems

The only permanent tsunami warning system in operation at the present time is that operated for the Pacific Ocean by the United States National Weather Service, based on the Tsunami Warning Centre in Honolulu, Hawaii. This Centre was established by the US Coast and Geodetic Survey after the Aleutian tsunami of 1 April 1946 had caused major damage and many casualties in the Hawaiian islands. Originally designed to provide a warning system for these islands only, the Centre gradually extended its operations to cover first the Pacific coast of the United States and later the coasts of other countries bordering on the Pacific. Since 1965, it has operated under the auspices of the Intergovernmental Oceanographic Commission, which in 1966 set up an "International Co-ordination Group for the Tsunami Warning System in the Pacific". As of March 1975, this Group comprises the following countries: Canada, Chile, China, Ecuador, France, Guatemala, Japan, Korea, New Zealand, Peru, the Philippines, Thailand, the USA and the USSR.

The Intergovernmental Oceanographic Commission maintains an "International Tsunami Information Centre" which works closely with the Warning Centre in Honolulu and is responsible for:

1/ giving technical advice on the equipment required for an effective warning system and providing assistance in the establishment of national warning systems;
2/ evaluating the performance of the Tsunami Warning System;
3/ co-ordinating the development of an observing system;
4/ maintaining a tsunami data acquisition, storage and retrieval system.

The mode of operation of the Warning System can best be described by the following extract from the document entitled "Communication Plan for Tsunami Warning System (Seventh Edition)", issued in January 1971 by the US Department of Commerce (National Oceanic and Atmospheric Administration):

" The Tsunami Warning System requires the participation of many seismic, tide, communication and dissemination facilities operated by the participating countries (most of the nations bordering the Pacific). Operational control of the System is maintained by the Director of the Tsunami Warning Centre at Honolulu Observatory (HO).

Functioning of the System begins with the detection, by any participating seismic observatory, of an earthquake of sufficient size to trigger the alarm attached to the seismograph at that station. The alarm thresholds are set for each station so that ground vibrations of the amplitude and duration associated with an earthquake of approximate magnitude 6.5 or greater, anywhere in the Pacific region, will cause them to sound. This magnitude is below the threshold for issuing watch and warning messages. Personnel at the station immediately interpret their seismograms and send their readings to Honolulu Observatory. Upon receipt of a report from one of the participating seismic observatories, or as a consequence of the triggering of their own seismic alarm, Honolulu Observatory personnel send messages requesting data to the observatories in the System.

When sufficient data have been received for Honolulu Observatory to locate the earthquake and compute the magnitude, a decision is made as to further action. If the earthquake is strong enough to have caused a tsunami and is located in an area where tsunami generation is possible, Honolulu Observatory will request participating tide stations located near the epicentre to monitor their gauges for evidence of a tsunami. Watch bulletins are issued to the dissemination agencies for earthquakes of magnitude 7.5 or greater, alerting them to the possibility that a tsunami has been generated and providing data which can be relayed to the public, so that necessary preliminary precautions can be taken. A watch may also be disseminated by Honolulu Observatory upon the issuance of warnings by regional warning centres.

Since the regional systems use different criteria for their disseminations, a watch may at times be issued by Honolulu Observatory for earthquakes with magnitudes less than 7.5.

When reports are received from tide stations, they are evaluated and, if they show that a tsunami has been generated which poses a threat to the population in part or all of the Pacific, a warning is transmitted to the dissemination agencies for relay to the public. The dissemination agencies then implement predetermined plans to evacuate people from endangered areas. If the tide station reports indicate that either a negligible tsunami or no tsunami has been generated, Honolulu Observatory issues a cancellation of its previously disseminated watch.

The above operations are normally completed within one or two hours of the first detection of a dangerous earthquake.

A tsunami originates in or near the epicentral area of the earthquake which creates it. It travels outward in all directions from this epicentre at a speed which depends on ocean depths. In the deep ocean, the speed may exceed 900 km/h; thus, the need for rapid data handling and communication becomes obvious. Because of the time spent in collecting seismic and tidal data, the warnings issued by the Honolulu Observatory cannot protect areas against tsunamis generated in adjacent waters. To provide some measure of protection against local tsunamis in the first hour after generation, regional warning systems have been established in some areas.

In order to function effectively, these regional systems generally have data from a number of seismic and tide stations telemetered to a central headquarters. Nearby earthquakes are located, usually in 15 minutes or less, and a warning based on seismological evidence is released to the population of the area. Since the warning is issued on the basis of seismic data alone, it is to be anticipated that warnings will occasionally be issued when tsunamis have not been generated. Since the warnings are issued only to a restricted area and confirmation of the existence or non-existence of a tsunami is rapidly obtained, dislocations due to the higher level of protection are minimized. Among the most sophisticated of the regional systems are those of Japan and Alaska. A description of the Japanese system may be found in the publication presented by the Japan Meteorological Agency to the Inter-governmental Oceanographic Commission Working Group meeting in Honolulu, April 27, 1965, or in the International Union of Geodesy and Geophysics Monograph Number 24, pp. 138-146".

Thanks to this international warning system, civil defence organizations in most of the countries bordering the Pacific Ocean now receive warnings of tsunamis several hours before they reach the coasts of their respective countries, and are thus able to put into action previously prepared plans for the evacuation of people from the endangered coastal areas.

However, despite the development of the ocean-wide warning system, which uses the most advanced techniques of detection, measurement and communication, in many countries there are still obstacles to the rapid diffusion of warnings in thinly-populated areas or in regions where modern communication networks do not yet exist. In such areas, it is essential that the local population be informed about tsunamis and be educated to recognize the signs which are the forerunners of an approaching tsunami and to take appropriate action on their own initiative. An example of the type of information which is useful in such situations are the following "Tsunami Safety Rules" issued by the United States Department of Commerce:

" 1/ All earthquakes do not cause tsunamis, but many do. When you hear that an earthquake has occurred, stand by for a tsunami emergency.

2/ An earthquake in your area is a natural tsunami warning. Do not stay in low-lying coastal areas after a local earthquake.

3/ A tsunami is not a single wave but a series of waves. Stay out of danger areas until an "all-clear" is issued by competent authority.

4/ Approaching tsunamis are sometimes heralded by a noticeable rise or fall of coastal water. This is nature's tsunami warning and should be heeded.

5/ A small tsunami at one beach can be a giant a few miles away. Don't let the modest size of one make you lose respect for all.

6/ The Tsunami Warning Centre does not issue false alarms. When a warning is issued a tsunami exists. The tsunami of May 1960 killed 61 in Hilo, Hawaii, who thought it was "just another false alarm".

7/ All tsunamis - like hurricanes - are potentially dangerous, even though they may not damage every coastline they strike.

8/ Never go down to the beach to watch for a tsunami. When you can see the wave, you are too close to escape it.

9/ Sooner or later, tsunamis visit every coastline in the Pacific. Warnings apply to you if you live in any Pacific coastal area.

10/ During a tsunami emergency, your local civil defence, police and other emergency organizations will try to save your life. Give them your fullest co-operation. "

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