designing for resistance to disaster

Tsunami is a Japanese word from a double root: tsu, meaning port or harbour, and nami, meaning wave. The word looks innocuous in simple translation, but to those who live on the rim of the Pacific it can spell disaster. The designers of nuclear installations at coastal sites, in particular, must take the possibility of occurrence of a tsunami into account in their work.

Tsunamis are fast moving ocean waves which spread across the open water like ripples on a pond. They are generated by the deformation of the earth's crust on the deep sea bottom — sometimes by earthquake, sometimes by a large underwater landslide, sometimes by a submarine volcanic explosion. They may also arise from the passing of a hurricane, or typhoon. In the open Pacific, where 65 per cent of all tsunamis are generated, a tsunami may have a wave height of only two or three metres, decreasing gradually as it spreads; but in shallow water or when funnelled by coastal formations the wave height may increase dramatically. At the coastal village of Shirahama, in the Iwate Prefecture of Japan, the height of what has gone down in the books as the Sanriku Tsunami of 1933 was 24 metres when it reached the shore. Nearly 3000 people were killed. It has been calculated that the total energy of the series of tsunamis generated by the Sanriku earthquake was 16×10 ergs, or 16×10 Joules. An unnamed tsunami generated by an earthquake off Nankaido, Japan, in 1946 washed away 1451 houses and killed 1330 people. A tsunami generated by the Chilean earthquake of 1960 killed 62 people in Japan, and did large damage.

Tsunamis are thus one type of natural hazard which must be taken into account by the designers of nuclear installations for coastal sites in Japan and in other countries around the Pacific. A second, the cause of many tsunamis but itself a hazard of more widespread concern, is the earthquake.

The purposes of design

The recommendations of an IAEA panel on the Aseismic Design and Testing of Nuclear Facilities, held in Tokyo, Japan, in June 1967 were published two years ago in the Technical Reports Series. (No.88.) The introduction to that report points out that the nuclear industry has a high record of safety, achieved by ensuring high standards in the design and operation of nuclear reactors, and goes on:

"With the present development of nuclear power, many countries are faced with the problem of building nuclear plants in earthquake zones. In these zones, it is desirable to avoid a site where there is a reasonable possibility of a fault on which significant displacement might occur, although this alone does not ensure plant safety, as seismic forces may nevertheless produce displacements on a reactor site far from a fault. Furthermore, present nuclear plants tend to be large and heavy and constructed on bedrock, which means that the characteristics and intensities of vibration of this bedrock during an earthquake must be studied.

"A number of questions on these and allied matters are now being put to nuclear designers. In many cases answers are difficult to give because most of the research on earthquake engineering has been done for ordinary buildings which do not have to achieve high degrees of safety. ..."

Put so baldly that paragraph may give a misleading impression. It is of course true that office buildings, apartment blocks and the like must be built to withstand earthquake shock if they are sited in an area which is subject to this sort of disturbance. Nuclear reactors, however, have one overridingly unusual feature: they contain highly radioactive materials whose catastrophic release to the environment must be prevented. This is the main purpose of aseismic design; a subsidiary purpose is to reduce the likelihood of damage to plant which would involve no release of radioactivity although it could still be costly to repair.

The great deal of work which has been done on aseismic design is reflected in stringent building criteria which have been laid down in countries such as Japan, the USSR and USA where nuclear installations may sometimes have to be built in areas where earthquakes are frequent, though not necessarily damaging.

The designer's task may be eased by careful choice of site. Recognising this, the IAEA organized at its headquarters in Vienna in June 1970 a panel of experts from seven countries — Chile, France, Italy, Japan, the United Kingdom the USA and Yugoslavia — assisted by representatives of UNESCO, the World Health Organization and the International Association of Earthquake Engineering. This panel discussed and exchanged information on "Earthquake Guidelines for Selection of Reactor Sites"; the results of their work will be published by the Agency in a few months. Some general features of guidelines which are already in use may be described here.

Guiding principles

This article has already referred at length to tsunamis, which may invade the coastal areas of Japan, Alaska, Canada, the western United States, Chile, Peru and so on. The extent to which such areas may be affected depends largely on the steepness of the coastal shelf, and on particular features of the coastline — for example, the presence or absence of deep bays which may channel and amplify the wave. Here, the designer may be aided by careful study of these features, the history of tsunami occurrence and observed effects, and possibly by experiments using models in a water tank. It may be noted that, for the Pacific area, a Tsunami Warning Centre has been established at the Honolulu Observatory. Close contact is maintained between this centre and the Japanese Meteorological Agency in particular, which has set up its own system to analyse earthquake and other relevant data, and to give warning of the approach of a tsunami in time to take emergency precautions.

These destructive waves are of interest, however, to designers in comparatively few countries. Of far more general interest is the problem of selecting and evaluating proposed sites in areas where earthquakes may strike. It is a fundamental of nuclear installation design that all structures and equipment necessary to shut down the reactor, and to maintain safe conditions for workers and the public, should be able to withstand what is known as the "site design earthquake", the strongest probable earthquake expected in the near vicinity. In Japan it has been found that an earthquake severe enough to cause heavy damage to buildings which are not specially constructed takes place about once every three years; in other countries such an earthquake may never have been recorded. Design criteria may thus differ from place to place while maintaining the same standard of safety.

For some countries, maps showing seismic zones — areas of greater or lesser probability of earthquake shock — have been prepared. In the USSR a Seismic Zoning Map of the entire union is included in the building code, and in regulations for building in specific regions which are known to be subject to earthquakes. This map was prepared on the basis of a study taking into account the interaction of soils of different types with building foundations, engineering inspection of the results of disastrous earthquakes, and instrumental observations. Following upon this work, instructions have been prepared for the compilation of data on "seismic microzones" — areas within the earthquake-prone regions where special investigation to show site safety are required. The US Atomic Energy Commission has prepared tentative regulatory criteria for nuclear power plants describing the nature of the investigations required to obtain the geological and seismic data necessary to determine site suitability, and to give reasonable assurance that a nuclear power plant can be built and operated at a proposed site without undue risk. Work in Japan is again relevant. There, a number of studies have been made of the effects of earthquakes, their intensities and frequency during a time span of about 1000 years. For one city records going back to 818 AD were available. Seismic zoning maps are relatively easy to prepare for that country, and statistical forecasting for the broad pattern of the occurrence of damaging earthquakes is possible — though it is not yet possible to predict earthquakes at particular sites with anything approaching accuracy.

The General and the Particular

Although the generalized study of earthquake zones is valuable, it may turn out to be almost irrelevant with respect to a particular proposed site. The possibility of damaging ground motion may depend on strictly local rock or sub-soil formations which are not typical of the region as a whole. The earlier panel report points out that "there appears to be a reasonably consistent influence of the 'softness' or 'hardness' of the soil deposit on the predominant periods of the ground motions, and the amplitude of ground accelerations may vary with the soil conditions." Underlying rock motion may be either attenuated or amplified, depending on such factors as the magnitude of the earthquake, the proximity of the site to the causative fault and actual soil conditions; indeed, it has been found that the same site may amplify ground motion in one earthquake and attenuate it in another.

It is clearly desirable to identify nearby fault zones and to assess the probability that auxiliary faults will be created. This can be a real hazard in some areas, although it is not one shared by all fault zones or even by all areas where earthquake frequency is high. To quote the earlier report again, "so little is at present known about this phenomenon" [of auxiliary or branch faulting] "that it emphasizes the critical need for further research, especially in the intensive investigation and documentation of auxiliary faulting during future large earthquakes anywhere in the world."

Most earthquakes in the United States take place on the western seaboard in an area which is strongly affected by the San Andreas fault system — 650 miles long, and passing within eight miles of San Francisco and 30 miles of Los Angeles. The characteristics of this fault system are well known, and it is under continuous and careful study. During the great San Francisco earthquake of 1906 the San Andreas fault slipped 20 feet in one disastrous upheaval. At present, the land on the eastern side of the fault system is moving slowly to the south-east, and on the western or Pacific side it is moving to the north-west. The average movement is about two inches a year. What is giving rise to some concern — as is borne out by recent newspaper reports — is that it is only the middle third of the fault which is moving: the northern third, near San Francisco, has not moved since the disastrous displacement of 1906, and the southern third, near Los Angeles, has not moved since an earlier severe earthquake in 1857.

Ensuring against risk

Of course, fault movement is not always spectacular; but those responsible for selection of reactor sites must consider whether it is likely. As in all this work, the relationship between fault movement and earthquake damage distribution is far from simple. The Japan Electric Association, in a document placed before the panel in June, pointed out that "in some particular cases there is a report stating that a house standing just on the fault showed almost no damage."

The designer must also study the local geology and topography carefully to assess the likelihood of damage by landslide or other subsidence of the soil. It may be that part of a reactor site would compact if it were subjected to strong earthquake motion, while other parts of the site would be unaffected. Again, although the main structure of a nuclear power station would not be built on soils of a type which "liquifies" during an earthquake, such as saturated loose sands, ancillary structures might be. In either case, even if the reactor itself were not damaged essential services could be disrupted. Nuclear power stations are usually located close to a large body of water — either a river, or a lake, or near the shore. It is clearly desirable that the designer should take care to avoid siting an installation at a place where a landslide could either flow on to the site itself, or deprive the installation of cooling water by creating a dam, or cause flooding.

The conditions found at one site may be duplicated nowhere else in the world. Nevertheless, the results of the necessary study of soil and rock types, the ways in which foundations and structures interact with them during earthquake movement, the mechanisms of fault formation and so on may be applicable in many countries. In particular, internationally acceptable guidelines for use in selection of reactor sites, such as those drafted by the IAEA panel in June, should help to ensure that the increasing use of nuclear power is accompanied by no unacceptable risks.