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ABSTRACT: The purpose of this paper is to outline the seismic regulatory requirements relating to the site licensing of new nuclear power installations in the UK, and to describe the background and justification of the seismic design basis level for such installations. It outlines the potential seismic related hazards which should be covered, the factors which are considered important in establishing the level of hazard under consideration, and the techniques which could be used for hazard evaluation. In addition, the paper covers the level of uncertainty associated with the methodology and analytical techniques used in evaluating the seismic hazards.

1. INTRODUCTION

During the last decade HM Nuclear Installations Inspectorate (NII) have been involved in the assessment of safety submissions for the Sizewell B PWR which is currently under construction, and for the proposed Hinkley Point C PWR. In both cases the Inspectorate has submitted evidence to, and been cross examined on, the assessment of the licensees safety cases, at Public Inquiries (Refs 1 & 2).

This paper outlines the general approach taken by the Inspectorate in the assessment of external hazards for those two sites, and then describes in detail the extent of information required from the licensees to satisfy the Inspectorate on the major factors which determine the seismic hazard. It is not intended that this paper be used as a check list, it reflects the Inspectorate's experience in this topic for the two most recently proposed nuclear power plants. It also discusses the Inspectorate's approach to the uncertainties which are inevitably present in seismic hazard determination.

Although not a consideration of this paper, the latest Advanced Gas Cooled Reactors (AGR) built in the UK are also designed against the seismic hazard, as are the more recent nuclear chemical plant. However these installations being designed whilst UK seismic standards were being developed have slightly different design basis criteria. There is nevertheless an equivalence to the UK PWR's. The older Magnox reactors and nuclear chemical plant whilst not designed with the seismic hazard in mind, clearly have an inherent seismic capability. This is being assessed, and strengthened where appropriate, under the Long Term Safety Review, and Fully Developed Safety Case for reactors and chemical plant respectively.

2. LEGISLATIVE BASIS

In the United Kingdom no site may be used for the purpose of installing or operating any commercial nuclear installation unless a nuclear site licence has been granted to a corporate body by the Health and Safety Executive (HSE). The Inspectorate is that part of the HSE which is responsible for administering this licensing function. Specific Acts of Parliament and supporting legislation provide general requirements for the safety of nuclear installations, but specific requirements are covered by licence conditions which are binding by law.

Under these Acts, absolute responsibility for nuclear safety rests with the licensee. The duty of the Inspectorate is to ensure that appropriate standards are developed, achieved and maintained by the licensee, to ensure necessary safety precautions are taken and to regulate and monitor the plant by means of its powers under the site licence. The Inspectorate independently reviews and assesses the licensees to ensure compliance with the requirements at all stages throughout the plant life. The Inspectorate does not operate a prescriptive regime, which means that licensees are free to develop their own safety standards and plant safety cases using appropriate methodologies.

3. NII SAFETY ASSESSMENT PRINCIPLES

In order that a consistent approach is adopted towards safety assessment the Inspectorate has developed Safety Assessment Principles, for nuclear power reactors (Ref 3) and nuclear chemical plant (Ref 4), which are primarily for the use of its own staff, but also with a view to assisting designers and operators. These assessment principles form a statement of the safety assessment related to new plant. They contain fundamental requirements and basic principles supported by a set of engineering principles. The two referenced documents are currently under revision.

The safety submission from a licensee for a new installation should show that the design meets their safety standards, the Inspectorate assesses the submission to ensure compliance with it's Safety Assessment Principles. Naturally licensees are encouraged to demonstrate that their standards comply with the Inspectorate's Principles. For plant faults, ie; faults which would occur in safety related plant or equipment the Inspectorate has adopted the following numerical criteria.

(1) For any single accident which could give rise to a large uncontrolled release of radioactivity, (more than a few ERL, which for the whole body is currently a dose equivalent of 500mSv) to the environment resulting from some or all of the protection systems and barriers

being breached or failed, then the overall design should ensure that the accident frequency is less than 1E-7 per year.

(2) The total frequency of all accidents leading to uncontrolled releases should be less than 1E-6 per year.

Adoption of these criteria mean that a plant which meets them falls within maximum tolerable risk levels for individual members of the public and society as proposed in the HSE published discussion document on the Tolerability of Risk (Ref 5).

In case of the seismic hazard, the determination of an event for plant design having a nominal return period of about once in 10,000 years is not considered unreasonable for the UK. This event is more commonly known as the Safe Shutdown Earthquake (SSE) for nuclear power plant. For nuclear chemical plant it is generally referred to as the Design Basis Earthquake (DBE). Consequent upon such a design basis event and the criteria given in section 3(1) above, it is necessary that the protection system or barrier required to protect against the event has a reliability of the order of 1E-3 per year. Independently of this the Inspectorate considers that a well engineered safety system has a probability of failure between 1E-5 and 1E-3 per demand (Ref 3). It is therefore concluded that a plant appropriately designed and qualified against the SSE/DBE meets the Inspectorate's criteria for a single accident that could give rise to a large uncontrolled release of radioactivity.

The Inspectorate's Safety Assessment Principles are concerned generally with targets which should be met when establishing the seismic hazard at a site. More detailed guidance on establishing the seismic hazard for a potential nuclear site is given by the IAEA in their code of practice, (Ref 6), and Safety Guide, (Ref 7). The Inspectorate considers these documents to outline the minimum standards which have to be achieved.

4. SEISMIC HAZARDS

The Inspectorate expects a licensee to identify in the safety case for a potential site all those hazards associated with earthquake activity which could affect plant safety. For example; earthquake ground motion, ground rupture, liquefaction, ground subsidence, landslips, earthquake generated tsunamis and seiches generated by long period ground motions. In the case of Sizewell B, the first and third examples were of particular concern.

Initially the licensee should review all these potential hazards to determine whether any one is large enough to prevent use of the site.

Having demonstrated the site is viable each of the hazards should be assessed by the licensee and compared against the safety criteria. Depending on the location some of the hazards can be readily discounted, but others may require more rigorous assessment to ascertain the design basis level. The hazards which have been the subject of detailed safety cases by licensees in the UK in recent years are seismic ground motion, liquefaction and ground rupture. The Inspectorate's approach to the assessment of ground motion and ground rupture is covered in the following sections.

5. DETERMINATION OF SEISMIC HAZARD

Determination of the seismic hazard can be established in several ways, for instance; a deterministic route establishing the maximum potential earthquake, a probabilistic route with deterministic input parameters, or a full probabilistic route. In the UK licensees have generally favoured the probabilistic route with deterministic input parameters.

Determination of this hazard requires input from various sources. These can generally be defined as the geology of the potential site and surrounding region, and seismological information such as historical earthquake and instrumental data. Using this information it should be possible to build a model of the regional earthquake environment around the site. Figure 1 describes the process leading to the determination of the seismic hazard. Each of the topics is discussed separately below.

5.1 GEOLOGICAL INFORMATION

In determining the geology the objective is to understand the tectonics and consequently the seismotectonics of the region. One aspect is to attempt to obtain geological evidence to allow assumptions to be made about the size of the region where the seismotectonics can be considered to be similar. The other aspect is to determine whether any significantly active faulting occurs on or close to the site, which may have to be modelled as an independent source of seismic events in the hazard analysis.

The extent of the regional study will depend upon both the seismology and geology to ensure that all relevant data is obtained. Such data may be available from published sources and will require the assistance of specialists who have worked in the area of concern.

Close to the site the objective should be to establish the potential for permanent ground displacement. It is expected that detailed geological mapping would be carried out in the area to understand the site geology. In addition geophysical and geotechnical studies should be carried out supported by laboratory testing where appropriate. This could include the drilling of boreholes and trial pits.

In all these studies the Inspectorate considers that information from deep reflection surveys can be of valuable assistance in establishing the extent of faulting at depth. In addition the crustal stress of a region will assist in the understanding of the current tectonics. Satellite imagery can also provide valuable information on surface features which are not readily visible from the ground.

5.2 HISTORICAL AND INSTRUMENTAL SEISMICITY

It is clearly very important to understand the historical seismicity of the region and to identify any possible trends. It is considered that all relevant historical seismicity should be determined back to the earliest possible time. The UK is extremely fortunate in having primary records from ecclesiastical and other sources dating back to before 1000 AD. The information should be used to determine parameters such as intensity, epicenter, focal depth, or any spatial or temporal trends. The techniques used in establishing such information should be well founded, (Ref 8).

More recently instrumental data has become available, and it is necessary that all relevant measurements for the region should be collated and estimates of, for instance; magnitude, focal depth, and epicenter be determined. Such information should be reviewed to ensure that it is due to earthquake ground motion rather than man induced events, such as mining activities or quarry blasting. From the interpretation of instrumental and macroseismic data it is possible to assign magnitudes to historical events.

6.0 METHODS FOR ESTIMATION OF THE SEISMIC DESIGN BASIS GROUND MOTION

In order to determine the ground motion hazard, the information derived from the geological and historical databases established from information in sections 5 should be merged to establish a seismotectonic model of the region. In general in the UK, it is considered that such a model will comprise areas of diffuse seismicity which originate from earthquakes not attributable to specific structures, and areas attributed to known seismic sources. It is necessary that all that is reasonably practicable should be done to establish a model that takes into account the most recent geological understanding of the region under consideration.

The design basis ground motions can be characterized by time histories and response spectra for a suite of damping values. If sufficient data is available then it would be appropriate to calculate specific site response spectra. Otherwise a more generic approach is taken as is described later.

6.1.1 DETERMINISTIC TECHNIQUES

As stated above the deterministic route would in all probability involve establishing the maximum earthquake potential for the site. This would be expected to be based upon the information established from the studies covered in section 5. The maximum earthquake potential associated with the structures identified from the seismotectonic model would be established using conservative assumptions. It is considered that such a route may well be appropriate in regions where there are well defined structures showing regular seismicity. However in areas of low seismicity the maximum potential earthquake may be difficult to determine due to the lack of seismic activity and could lead to the assignment of a very conservative value, with little scientific support.

6.1.2 PROBABILISTIC TECHNIQUES

Probabilistic techniques which use data derived by deterministic means are considered by the Inspectorate to be a suitable method for establishing the earthquake hazard in areas of low seismicity. Such methods should use the details and parameters which have been established from the seismotectonic model. This would include modelling potential sources of activity and areas of diffuse seismicity which will have been derived from the instrumental, historical and geological databases.

It is currently considered that a full integrated probabilistic analysis is not realistic. However an analysis such as that developed by McGuire (Ref 10), based on a probabilistic model but with deterministic input data is a more appropriate method, and has been used by a licensee, (Ref 11). This does not mean that other methods would not be acceptable. It is the responsibility of the licensees to determine suitable methodologies which the Inspectorate will assess.

The results of such models would give a best estimate peak free field acceleration hazard curve for varying confidence levels. Such calculations are subject to uncertainty in the input parameters which should be addressed by means of sensitivity studies. It is the Inspectorate's opinion that for UK seismicity the most important factors are the input parameters associated with the geological interpretation of the region. Experience in the assessment of licensee's safety cases has shown that this area is the most sensitive in determining the seismic hazard level.

7.0 GROUND RUPTURE

Ground rupture as a potential hazard was noted in section 4. However it is for the licensee to decide how his safety case will address the hazard. There are a number of possible approaches the licensee could use to demonstrate compliance with the Inspectorate's Assessment Principles. For example; to show that there are no faults under the potential site which would cause ground rupture leading to the failure of structures, and to a large release of radioactivity. Alternatively they could demonstrate that there is a less than one in 10 million chance per year of a significant fault rupture occuring. Currently licensees have attempted to meet the latter option.

The relationship of faulting at or near the site with regional faulting should be determined, to ascertain whether there is any correlation with faults known to be significant in terms of regional activity. This area is subjective and requires the expertise and skill of geologists with previous experience of the region.

Having identified any fault which could be considered as potentially active, ie; those relating to major fault structures, the time of last activity should be determined. This could be achieved from an understanding of the regional tectonics if the potential activity is small. If there is strong evidence from seismicity data suggesting very recent movement (by geological timescales), or the structure is close to the site, further more detailed investigations may be necessary. The Hinkley Point C site was an example of this, where detailed investigation of a neighbouring fault was necessary, (Ref 12).

Currently this is an area where there exists a variety of techniques which can be used to date fault movement in areas of low seismicity such as the UK. These are often used in other areas and their validity and degrees of error are known, and therefore their use is generally accepted. One of the main difficulties is identifying the material which should be taken from the fault to determine the date of last movement. Consequently the dating process often gives rise to large uncertainty. This is not to denigrate the techniques, rather it is necessary that the licensee does all that is reasonably practicable to establish a realistic result.

8. GENERATION OF RESPONSE SPECTRA AND TIME HISTORIES

In the UK a generic set of response spectra have been developed by the licensees which are considered to be representative of UK seismicity. Current practise in the UK due to a sparsity of real earthquake time history measurements is based upon choosing a number of earthquake time histories from other regions. These are European and US events that are considered to represent UK earthquakes. From these records, standard response spectra are generated using the USNRC approach (Ref 9). For a given installation the spectra would be normalized to the peak ground acceleration for the site. Furthermore the spectra are classified as hard, intermediate and sort ground conditions which are related to depth to a competent rockhead level. Time histories can then be derived from the appropriate spectra.

This overall approach has been assessed by the Inspectorate and found to be realistically conservative.

9. UNCERTAINTIES IN THE HAZARD DETERMINATION

As is apparent from above the determination of the seismic hazard is subject to uncertainty, because of this the Inspectorate requires that sensitivity analyses be carried out on the calculations to establish whether any one parameter, if changed, would significantly affect the results. In addition it is also expected that this would include investigations into the constraints of the chosen model, such that if a different model were chosen the significance of the change on the results of the hazard analysis could be determined.

Furthermore, since the hazard is calculated for SSE which generally has a mean return period of 10,000 years the Inspectorate has asked licensees to demonstrate the capability of their structures at a hazard level beyond this value. This is to demonstrate that there is no sudden disproportionate increase in the risk for an increase in hazard level beyond the SSE.

Currently the hazard level at which plants are assessed for their performance beyond the SSE is forty per cent greater than the SSE. The licensees do not design their structures to meet this level, but assess the capability of the plant to ensure that no condition exists such that there is a disproportionate increase in the risk from the plant due to radioactive releases. Clearly safety margins will be less than at the design basis, and this is accepted.

10. REPORTING AND RECORDING OF INFORMATION SUPPORTING THE SAFETY CASE FOR A PLANT

In the preparation of a safety case for the seismic hazard it is important that the information used is properly reported and recorded. Such a process should be subject to quality assurance procedures which are auditable.

One of the more important contentious aspects of a safety case is where judgements by experts have been made, either through a committee or individually. The Inspectorate considers that in particular in such cases they should be recorded so the assessor is able to establish how and why decisions were made.

11. CONCLUSIONS

It is considered that the determination of the seismic hazard is still in an evolutionary stage and subject to many uncertainties. Nevertheless the work carried out in support of siting nuclear plant in the UK is considered to use realistic models based upon the best available geological and seismological data. Consequently, it ensures that the design basis levels determined are scientifically and technically justifiable and not overly conservative.

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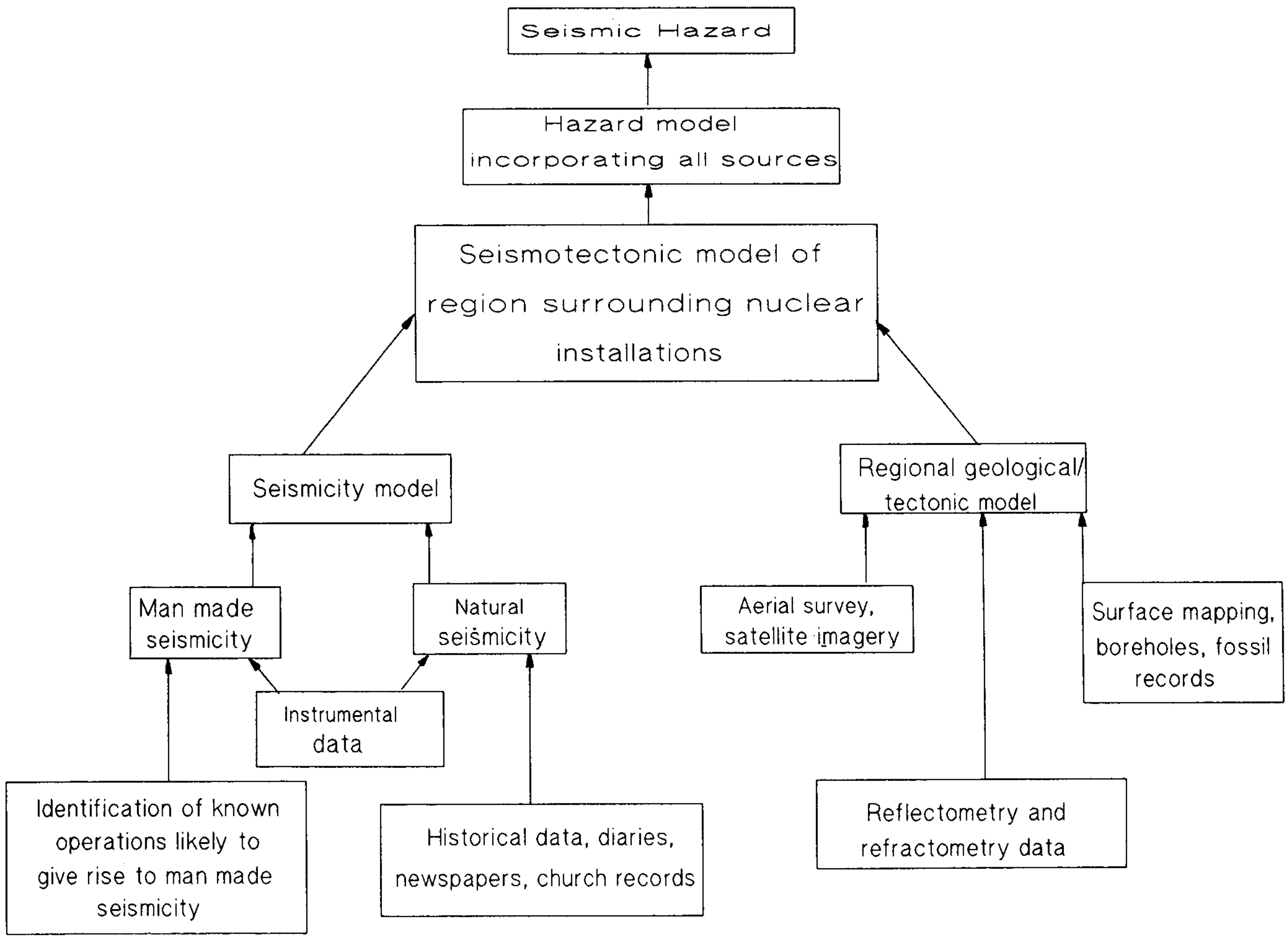

Typical flow chart for evaluating the seismic hazard
Fig 1