PROBLEMS OF SEISMIC HAZARD AT BRITISH AND MEDITERRANEAN PETRO-CHEMICAL INSTALLATIONS

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Earthquakes pose a significant threat to the safety of petrochemical installations. This hazard is especially important for industrial facilities which either have not been seismically designed or which are located at sites of major tectonic faulting: many petro-chemical installations in Europe fall into one or both of these categories.

INTRODUCTION

The understanding of earthquake hazard has benefited from a wave of new research initiatives. Principia has followed a scientific approach to seismic hazard, shifting the emphasis away from 'state-of-the-art' procedures that focus on the manipulations of (often inadequate) data-sets to concentrate research on fundamental data-bases and locally derived parameters. From detailed studies of historical seismicity and an understanding of the geological and seismotectonic context it is now possible to quantify probabilistic seismic hazard with a new reliability, even for regions of comparatively moderate seismicity, such as northern Europe.

This hazard is remarkably non-uniform. While many areas are effectively aseismic, parts of England have a significant hazard-level that should be taken into consideration in the design of new petrochemical facilities. However the most serious problems exist with regard to pre-existing facilities for toxic and hazardous chemicals throughout Europe, most of which were built with no concern for earthquake hazard.

The new earthquake geology has also provided remarkable insights into the association of morphological features with active faulting. Around the Mediterranean coincidental neotectonic associations have inadvertently encouraged planners to locate several petrochemical complexes at those places prone to most catastrophic earthquakes.

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The nature of earthquake hazard

Petrochemical installations, along with other sensitive industrial facilities dealing with dangerous and toxic materials, must be designed with some acknowledgement of the risk posed by earthquakes. Every year as the number of petrochemical installations increases and as these installations becomes ever more sited in the developing parts of the world so the probability of a major facility being badly damaged or destroyed in an earthquake rises. Such damage may not just be restricted to the plant but through the release of toxic chemicals and through fire and explosions could also extend to the population living in the vicinity. Within the rapid phase of post-War expansion, both in technological advances in facilities and in global development, petrochemical installations have been fortunate (chiefly through geographical factors) to have so far remained relatively unscathed by earthquakes: notable perhaps is the incineration of oil storage facilities at Bakersfield, California following the earthquake of July 21st, 1952.

Within the past decade there have been important changes in the way in which earthquakes are understood. There is now a science of earthquakes, a science that like any other science is predictive, not as yet about the most sensitive topic of when a major earthquake will occur, but instead the all important where a majority of the major earthquakes will be located. Earthquakes are produced by fault movements: such displacements recur along the same fault-zones (planar crustal breakages), time after time. This repetition is a simple function of the surface of weakness provided by the fault. As the underlying cause of the deformation remains the same, and as stresses build up within the crust in the same way, so they are relieved through movement along the same fault-zones. The full significance of this repetition require an understanding of the appropriate time-scale of repeated fault-movements: measured from hundreds to hundreds of thousands of years. This repetition allows individual fault-movements of no more than a few metres to produce major components of topography: valleys, troughs, escarpments and mountains. The locations of major recurrent earthquakes can be read in the landscape.

The configuration of faulting is controlled by geometric relationships associated with the overall nature of crustal deformation. The most important and largest scale geometry to be found dictating fault-movements is that of plate tectonics: the movement of sections of rigid shell across the sphere. At a plate boundary the direction of movement along all the component faults is constrained.

This deformation would be extremely simple if it were not for the importance of pre-existing faults in determining the location of current failure surfaces within the crust. While oceanic crust is geologically very young, and remarkably unfaulted giving rise to simple narrow oceanic plate boundaries, continental plate-boundaries such as the 'Alpine' collision zone extending from Spain through to China, reveal a more diffused pattern of tectonic deformation. Behind the major axis of the Alps there is an offshoot of this collision zone extending into the North-West Europe, providing crustal deformation and associated seismicity.

A major new scientific component to the understanding of tectonic processes that operate on a time-scale of many human generations has come from research into historical earthquakes extending back as far as records permit. Europe and the Middle East have an extraordinary resource of documentary evidence of earthquakes, evidence that is scattered through obscure histories, chronicles, diaries, newspapers etc. When comprehensively researched and re-analysed this database can provide the first scientific picture of the long-term regional pattern of seismicity:

the return periods, location and style of past earthquakes. This resource has only relatively recently begun to be quarried.

Previous neglect of the earthquake hazard in Britain owes nothing to any calculation but simply reflects the ignorance of actual risk. Up until the last two or three years the risk was unknown. Damaging earthquakes do occasionally occur, and have in the past felled churches and even a cathedral. Through the wealth of the new research initiatives it is now possible for the first time to evaluate the resultant hazard with some precision.

The comprehensive researching of the historical seismicity of Britain and Norway has recently been undertaken at Principia, and has involved the accumulation of an archive of 10,000 pages of original documentation. It is now possible for the first time to find accurate return periods of significant earthquakes, and to prove marked geographical regionalisation. One among many of the important results of this re-analysis of historical seismicity has been to define a zone of damaging earthquakes passing in from the Lower Rhine Graben, around Aachen, through Belgium into South-East England (fig 1). While the eastern end of this zone had been suggested by formerly recognised earthquakes (in particular events in 1938 and 1672 which caused widespread building damage and some fatalities), it was two similar previously poorly known events at the English end that have defined the continuation of the zone and its association with a known geological axis of deformation. The earthquake of 1382/5/21 caused great damage in central Kent around Canterbury and Hollingbourne, as well as producing minor building damage deep into Belgium (Melville, 1982). The 1580/4/6 earthquake caused damage and casualties around the Channel ports of Dover and Calais and as far away as London (Melville, 1981).

The seismicity of North West Europe is very regional: northern Germany, Southern Denmark, the south-central North Sea, north-eastern Britain and almost the whole of Ireland have had almost no seismicity throughout the past centuries of recorded history. In contrast parts of coastal western Norway are shaken every few years. Seismic hazard is correspondingly highly variable: from 'hot-spots' in parts of south eastern England, and South Wales, Belgium, the Rhine valley and coastal and offshore Norway to regions such as western Ireland for which any concern with local earthquakes would be unnecessary. This variability limits the need for simple national regulations on seismic hazard. As is already carried out for platform sites in the Norwegian sector of the North Sea, a local evaluation of hazard is required, to define the appropriate mitigating structural design requirements.

This seismic zoning is itself in part determined by the increasing knowledge of local fault activity. A number of faults have been found from geological evidence to show continuing activity in the North Sea (Muir Wood, 1984). Whereas in northern Europe the long-recurrence interval of significant fault movements gives priority to historical seismicity, in regions of higher seismicity around the Mediterranean it is impossible to rely simply on regional seismic zoning maps because the proximity to active faults will make the most significant contribution to the hazard at a site. Such active faults are only generally uncovered though detailed local investigation. While in northern Europe much attention has to be given (especially for seismic hazard projects for nuclear power plants) to the demonstration that local faults have <u>not</u> shown recent movement, in southern Europe it is necessary to locate those places where the crust articulates in order to find the local zones of crustal deformation and earthquake generation.

The new understanding of the geometric configuration of active faulting has highlighted an unrecognised interconnection between earthquakes and refinery facilities. This interconnection comes from the original siting decision. Once a planner's requirements can be framed according to the major morphological features of the site it becomes simple. Some flat-ground is needed, adjacent to a sheltered deep-water harbour.

The morphology of the earth's surface is itself sculptured according to some simple rules. Erosion is almost insignificant a few metres below sea-level. Unless a landscape is sinking slowly into the sea, is kept free of sediment by strong-tidal currents, or has been sculpted by glaciers, deep-water does not occur very close to shore.

These three descriptions respectively apply to the deep water harbours at Milford Haven in Pembrokeshire, Rotterdam, and the Norwegian fjords. In sheltered seas like the Red Sea and the Mediterranean in which tidal currents are almost insignificant, deep water adjacent to the land generally has a tectonic significance.

In the aftermath of some normal (extensional) fault earthquakes near Corinth in early 1981 the phenomenon of footwall uplift was described for the first time (Jackson et al 1982). While a normal fault movement involves the downward motion of the block above the fault, the block under the fault (the footwall block) becomes unloaded and rises, a distance of about one tenth of the total fault-movement (fig 2). The land raised by the footwall uplift will originally have been at, or even below, sea-level, where through wave-erosion and associated sedimentation the surface is likely to have been flat. Movement on the normal fault will uplift this surface; for a moderate displacement of a hundred metres on the normal fault the uplift will be of ten metres.

Regions undergoing tectonic extension characteristically present a configuration of faulting in which the normal faults lie en echelon, parallel but offset from one another. Where the pattern of normal faulting lies adjacent to a landmass, the en echelon faulting and the footwall uplift combine. The most landward normal fault provides subsidence that forms a deep water inlet. The neighbouring more seaward sections of an echelon faulting provide footwall uplift in their own right that will form partial barriers to the sea to either side of this inlet (fig 3). A simple process of tectonics operating according to the simplest geometrical 'rules' has constructed an excellent deep-water harbour. Adjacent to the most landward normal fault the footwall uplift has elevated a section of formerly sea-level land-surface and provided a slightly raised platform adjacent to the deep water anchorage.

To the planner this ideal location must indicate the beneficience of the natural world. In terms of earthquake hazard the site is equivalent to a mousetrap for a hungry rodent. Not only is there an active fault running within a few metres of the refinery location but should a fault-rupture emerge it will intersect any pipeline connecting the refinery with the deep-water anchorage.

The natural world is never quite as straightforward as the model in fig 3, but such tectonic locations are fairly common, and a number of major refinery and storage installations have been built in this general situation: in regions such as Greece and Western Turkey, in the Red Sea in Zeit Bay, Egypt where a refinery complex is at the moment being constructed, and at Augusta, on the east coast of Sicily. The threat to the facilities that line the bay of Augusta for ten kilometres has yet to be fully evaluated with regard to the localy active faulting, but can be seen more directly from the historical record of the region's earthquakes. The towns and cities of the Eastern seaboard of Sicily have already been devastated in two great Earthquakes in 1169 and 1693 (Caputo, 1983).

Conclusions

In locations such as those noted above the function of any seismic hazard (where it is applied at all) comes too late, after the location has been chosen. The normal fault harbour location is merely the simplest of a series of tectonic locations that produce appropriate settings for refinery-port complexes. Extensional tectonics associated with horizontal or strike-slip faulting has provided the natural San Francisco Bay, while deep-water anchorages along the northern coast of Algeria and around Gibraltar owe their existence to the tectonic configuraton of active compressional thrust faulting.

The new scientific understanding of earthquakes and the configurations of active tectonics should be applied within any sitting decision to evaluate the economic significance of a high earthquake risk. Where the risk is unacceptably high, an alternative location may be sought.

The implications, both economic and social of a major earthquake-induced accident are considerable. These implications go far beyond the facility damaged (as the nuclear industry has learnt; and the chemical industry is learning following the calamitous gas storage explosions in Mexico City, and chemical leakages in Bhopal, India towards the end of 1984). An accident anywhere in the world implicates all facilities. Should a catastrophic petrochemical accident be earthquake induced it is likely that a re-assessment of earthquake design procedures would be required for all local facilities.

The majority of pre-existing chemical plants were not designed specifically to withstand earthquake ground shaking. There exists a possibility that a relatively small local earthquake could produce a major accident, in particular if the chemical released involves a pressurised or liquefied gaseous agent of high toxicity or flammability.

As yet, largely through luck, rather than judgement, problems of earthquake hazard have not implicated chemical and petrochemical installations. All too often the understanding of a hazard has postdated its occurrence. It is necessary for the petrochemical industry to follow the example set by the nuclear industry and prove that its facilities are safe. As has been shown by the chemical released at Bhopal, chemical accidents have not only the possibility of being as devastating as nuclear accidents, but through the neglect of this possibility, the lack of regulation, and the large number of plants, they may present a more serious global hazard.

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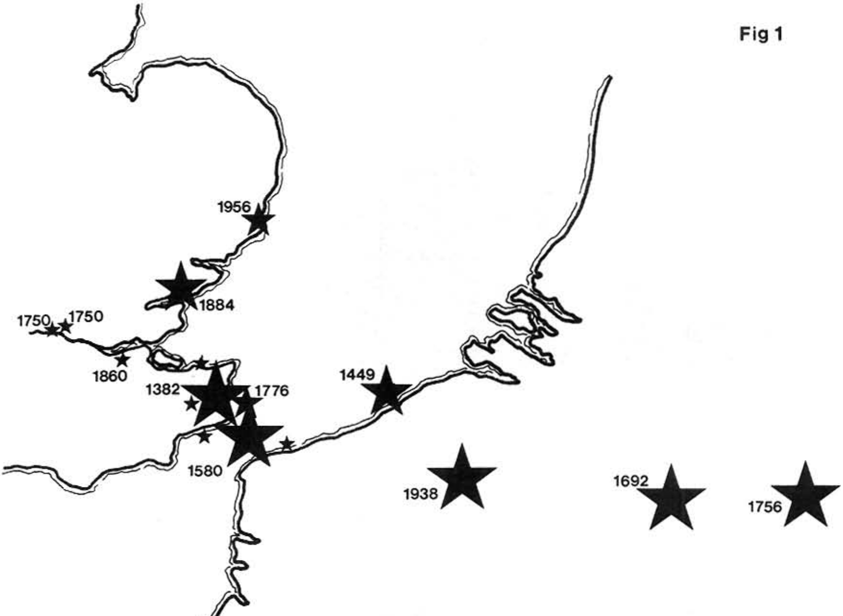
Fig 1



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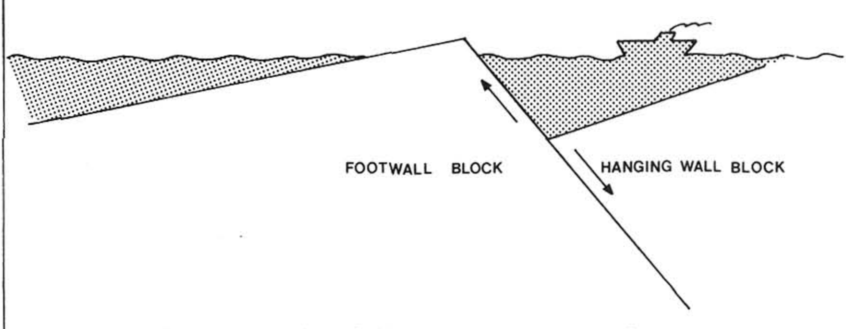
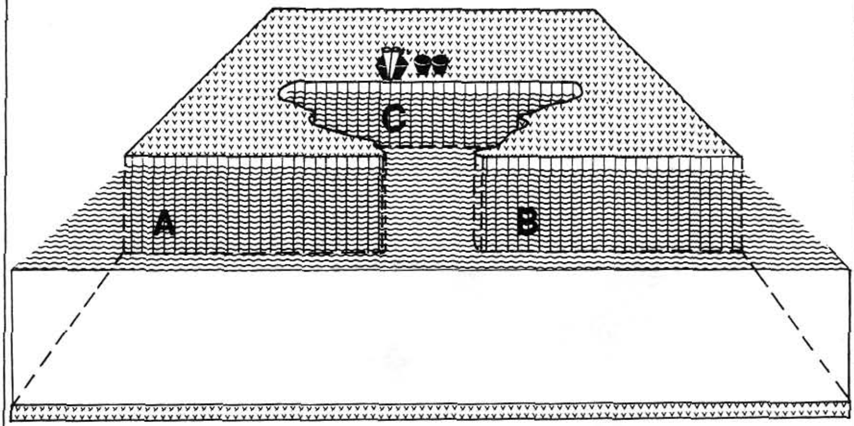
Star size proportional to event size.

Fig 2



CROSS SECTION THROUGH NORMAL FAULT SHOWING FOOTWALL UPLIFT

Fig 3



IDEALIZED MARGINAL EN ECHELON NORMAL FAULTING (A, B, C)
PROVIDING NATURAL REFINERY LOCATION