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CONSEQUENCES OF IZMIT (KOCAELI) EARTHQUAKE (TURKEY, AUGUST 17, 1999) ON INDUSTRIAL PLANTS AND SOME JETTIES

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ABSTRACT

After investigation of the consequences of the Izmit earthquake in nine industrial plants, a report was written for the French ministry of Environment. The main objective was the comparison with the situation of earthquake prone French industries.
General information on this earthquake and its economic consequences in the Izmit area are first given. Then, typical accidents induced by the earthquake (referring to nine visited plants) involving dangerous chemicals (five cases) are described and proved the need for assessing equipment and infrastructure vulnerabilities, referring to consideration of regulatory aspects. Risk assessment and preventive and protective measures are to be introduced in specific safety cases dealing with seismic effects for industrial plants and port areas. The objective of this safety case is to prove the stability of facilities (non total collapse), but also some functional and operational capability in order to avoid adverse effect on man and environment.

1 INTRODUCTION

The earthquake, arisen on August 17, 1999 to Izmit (Kocaeli), Turkey, of magnitude 7.4, is not exceptional in this region (7 earthquakes of magnitude superior to 7 have occured since 1939) ; accelerations on the ground, between 0.2 g and 0.4 g in the stricken zones, are rather moderate considering the magnitude.

The affected zone, situated in the southeast of Istanbul, near the Sea of Marmara, extends on 200 kilometres in length and 50 kilometres in width in a region with strong density of population and industrial plants. In the part of this region directly hit by the earthquake and depending of the Izmit Chamber of Industry, 30 % of industrial plants have had important damages, 20 % can be repaired within one month and 10 % cannot be repaired. 1 % of the workforce was killed and the production loss was estimated as 1-1.5 billion US dollars every month after the earthquake. Following the 7.4 magnitude earthquake in Turkey, current estimates of total insured loss have ranged from 1 bn to 2.75 bn US $ whereas the total damage is estimated at 16 billions US $. The earthquake involved a lot of industrial plants of the Izmit economic area (13% of Turkey industrial production).

The earthquake caused all possible underwater and on land phenomena such as landslides and ground collapses, rockfalls, ground liquefaction.

At the request of the Direction of the Prevention of Pollutions and Risks of the French Ministry of the Regional development and the Environment (MATE), the INERIS studied :

- intervention in emergency situation within the framework of the fire of six floating roof tanks of liquid hydrocarbons arisen in Izmit's refinery,
- the effects of the earthquake in industrial installations of Izmit's region.

First phase, realized from 19 till 21 August 1999, in contact with the Direction of the Defence and the Civil Safety of the French Home Office, allowed to put in evidence the difficulty of implementation of means of intervention on such a fire of petroleum products in tanks.

Second phase was assured from 2 till 11 September 1999 in contact with the mission, led to the same dates, of the French Association of Parasismic Engineering (AFPS).

Nine industrial plants were visited, for some of them with the assistance of the Izmit Chamber of industry. Damages on equipment, infrastructure and buildings were investigated for defining typology. More detailed information about damages on infrastucture can be found in 1) and 2).

2 VISITED PLANTS

These plants were generally located in the neighbourhood of the Sea of Marmara, often on alluvial grounds or embankments.

Visited installations were:

- a cement plant ; installation suffered only minor damages and was able to quickly restart,
- a refinery where damages concerned different tanks, a jetty, a stack which collapsed on a process plant, a control room, the underground network for water supply against fire,
- a storage of liquefied petroleum gas (LPG), for filling domestic bottles and lorries where damages were very minor and did not prevent a fast restart,
- an installation manufacturing chlorinated products, where chlorine was made by electrolysis, but was not stored ; a lot of electrolytic cells underwent damages, buildings presented minor damages, a jetty collapsed in sea on 125 m,
- an installation, including a jetty, where liquid organic products are stored and damages were minor,
- an installation manufacturing aluminium profiles where certain buildings with concrete frame (concrete beams walled in with bricks and mortar or concrete slabs) collapsed,
- an installation for manufacturing plastic pipes where buildings with concrete frame (concrete beams walled in with bricks and mortar or concrete slabs) collapsed killing two workers,
- an installation manufacturing acrylic polymers where three reservoirs let escape their content in the corresponding concrete retention pools. 250 m of jetty collapsed in sea and a concrete duct conveying some process water broke and had to be replaced.

3 TYPICAL ACCIDENTS INDUCED BY THE EARTHQUAKE

During the occurrence of this 7.4 magnitude earthquake in the Izmit area, close to the Sea of Marmara, some typical accidents (non exhaustive list) occurred in a refinery, in its vicinity (GPL pipeline), in an acrylic polymers plant and elsewhere.

- Six naphta tanks of a refinery were involved during five days in a fire, which did not fortunately propagate to other reservoirs or installations. A 120 m high stack collapse during the earthquake with major effects on a process plant closed several months for complete repair.
- In an installation manufacturing acrylic polymers, a leak of 6500 tons of acrylonitrile led to the death of the fauna nearby because of the forming of a toxic cloud after release and evaporation of this liquid in concrete retention pools following a break of three pipes at the bottom of three tanks; a ground pollution occurred also because of cracks appeared in these retention pools during the earthquake making a pathway to ground pollution.
- An underground liquid petroleum gas (LPG) pipe connecting a refinery with storage spheres in a nearby installation broke during the earthquake, led to the forming of a cloud which was ignited (flashfire) by a lorry crossing the cloud and led to the fire of a nearby paint storage facility and of lorries with two fatalities : the lorry drivers.
- Broken pipes, breakage of equipment and storage facilities and on jetties let release chemicals on ground; from collapsed jetties a sea pollution was also possible at some locations, but no information was available.

Some accidents occurring in the aftermath of an earthquake shall be avoided partly by a proper design and maintenance of plants considering the effects of the seismic waves on plants, buildings and facilities.

Other accidents or their consequences are avoidable by proper action at the very beginning of the earthquake considering :

- functions to be maintained
- operations to be stopped.

Such approaches should be related to risk assessment methodologies where the effects of sismic waves are to be related to soil structure

4 EQUIPMENT VULNERABILITY IN INDUSTRIAL PLANTS

4.1 Consideration of regulatory aspects

The investigation was devoted to the evaluation of potential damages in relationship with the types of facilities and their location and possible accidental scenarios in relationship with the probability of " overaccident " (risk increase related to a dangerous plant) for vulnerable points in a plant as requested in French regulation.

4.1.1 French regulation

According to the French law, industrial plants considered as a special risk need parasismic construction, planning and operation rules explained in a specific study "étude parasismique ". Consideration is to be paid to seismic zoning (national and local), active faults and site effects, the important parameter being the Likely Historical Reference Earthquake -LHRE- (considering historical data). At the very end of the process the intensity to be considered is equal to the intensity of LHRE+1. The above mentioned specific study, part of the safety case, has the objective, knowing the seismic hazard, to define vulnerable equipment (and parts thereof) and possible accidents, the last phase being the verification of adapted dimensioning against the seismic effects.

The objective of the study is to prove the stability (non total collapse), but also some functional and operational capability in order to avoid adverse effect on man and environment.

4.1.2 Turkish regulation

In Turkey, for dangerous plants, a sanitary protection cordon has to be established on the basis of a risk assesment but information is missing about the licensing process and the inspection, land use and emergency planning and specific consideration of earthquake effects.

4.1.3 Approach of the experts

Conclusions from the observations in Turkey could only be validated if detailed files for the plant (geotechnic studies, engineering documents, risk assessment) are made available. Until now, this work has not been undertaken.

However, it was possible to define potential damages by reference to the ground stability. Then, taking into account the overaccident, vulnerable equipment were globally analysed on the basis of reported observations either in industrial plants or in infrastructure.

4.2 Influence of ground stability on potential damages

The cement plant was the only plant partly located on solid rock, the others were built on natural or artificial embankments ; 5 from the 9 visited plants were close to the seashore. Five plants were located in an industrial estate and surrounded by other hazardous plants where domino effects are possible.

Table 1 summarises the potential damages considering ground stability.

Table 1 : Potential damages related to unstable ground

Plant type and equipment	**Location and surrounding conditions**	**Potential damages related to unstable ground**
Cement plant Rotating kiln, coal powder storage	Built on rock, no housing in the vicinity	Negligible
Manufacturing chlorinated products tanks Electrolysis cells Pipes Salt storage	Seashore, alluvial ground	Possible, alluvial ground and possible landslides (seashore)
Refinery Tanks for crude oil und petroleum products LPG spheres Buildings Process Jetty	Seashore, alluvial ground (housing in the vicinity)	Possible, alluvial groundl and possible landslides (seashore)
Liquid chemicals storage Tanks, Jetty	Seashore, alluvial ground (housing in the vicinity)	Possible, alluvial ground and possible landslides (seashore)
Liquefied petroleum gas storage LPG spheres and cylinders de GPL, Filling stations for containers and lorries Pipes	1 km from seashore, alluvial ground, (housing in the vicinity)	Likely but less probable than in the three previous cases
Acrylic polymers Process under pressure, tanks, pipes, jetty	Seashore, alluvial ground, no housing in the vicinity, land under cultivation and orchards	Very likely, alluvial and landslides
Car factory	Seashore, alluvial ground	Possible, close to the fault and ground movement

4.3 Equipment vulnerability in industrial plants

Considering the possible overaccident and possible hazards, the vulnerability was qualitatively analysed for the nine visited plants.

4.3.1 Energy and utilities

Electric energy was lost shortly after the earthquake. Generally, emergency supply was operating with apparently an exception in the acrylic polymers plant where a lack of energy lasted 39 hours.

In some cases (refinery), public water supply (especially for fire fighting) was also lacking.

4.3.2 Jetties and port areas

Some examples of the general findings are given in table 2.

Table 2 : Possible hazards from jetty malfunction probability

Plant type and equipment	Jetties Overaccident probability	Possible hazards
Cement plant Rotating kiln, coal powder storage	Extremely low	Local fire
Manufacturing chlorinated products Tanks Electrolysis cells Pipes Salt storage	High	Sea and ground pollution
Refinery Tanks for crude oil und petroleum products LPG spheres Buildings Process	Mean to high	LPG and oil spills Explosion Fire Sea pollution BLEVE Toxic cloud ?
Liquid chemicals storage Tanks,	High	Fire Sea pollution
Acrylic polymers Process under pressure, tanks, pipes, jetty	High	Fire Sea pollution Toxic cloud Explosion

From an industrial source it was mentioned that for a total amount of 34 industrial jetties ; 10 % sunk partly or totally in the sea.

It should also be mentioned that the Turkey Naval Base in Gölcuk, located on the fault, suffered extensive damage with collapse of buidings killing several hundred military personnel.

4.3.3 Pipes

Above ground polyester pipes located in a plant were broken but without major damages; some underground concrete ducts (process water) in another plant (avoiding plant operation) or steel pipes (LPG release with a flash fire induced, water release impeding an efficient fire fighting) in a third one have been broken.

A special attention is to be paid to connecting pipes and their connections to enclosures (three " guillotine" breaking in a chemical plant inducing a 6.500 tonne release of a liquid toxic chemical.

4.3.4 Tanks and reservoirs

Liquid movement is certainly at the origin of the damages. The damages are the most important in atmospheric metallic tanks of a rather moderate volume (between 1000 and 10000 m3).

4.3.5 Process equipment

In the EQE Briefing (2) was reported the collapse of a cooling tower in a petrochemical plant, of cranes in a steel factory. The direct impact of the earthquake can also be mentioned on a lime tank in an acrylic polymers plant and for the collapse of a 230 m high heater stack in the refinery.

4.3.6 Industrial buildings

In many cases, buildings were built as concrete framed (concrete beams walled in with bricks and mortar or concrete slabs) and collapsed. In one plant two people were killed. Partial collapse was also mentioned for a tire factory.

Without an assessment of the mechanical resistance of the buildings, it is not possible to draw valid conclusions : the design, the construction and the behaviour of the ground need to be considered altogether.

4.3.7 Prevention measures and emergency response

With the exception of fires in floating roof tanks, the fire in other bcations of the refinery were extinguished rapidly using the means available in the refinery.

As regards the floating roof tanks, it was decided to allow burning the content of tanks and to protect the neighbouring tanks by pouring water to avoid a temperature increase and fire propagation. This strategy was successful but a bit risky in an area where LPG and ammonia tanks were in the vicinity, respectively 300 m and 500 m.

5 VULNERABILITY OF INFRASTRUCTURE (1) (2)

Turkey lost electric power shortly after the earthquake because of damage to a 380kV substation in Adapazari. Effects were also obtained in other substations and 172 transformers, mainly owing to buildings collapse (out of 240).

In the Izmit area, water is supplied from a 60 million-cubic-meter dam which experienced 2 meter-sloshing in the event. Water treatment plants and major distribution systems performed reasonably well, sustaining minor damages, local failures were suffered owing to the collapse of buildings and soil subsidence.

Roads suffered damages (especially collapse of a bridge on a bus on the main highway Istanbul-Ankara), in areas where the roads intersected the fault and where subsidence occurred. Otherwise the majority of bridges, motorway and local roads performed well.

It was mentioned a leak on the main distribution pipeline of compressed gas at the location where the underwater part merges on land. The distribution system was more severely hit. 30% of gasmeters (3600) were shut off and 500 connections had to be changed owing to buidings collapses mainly.

As reagards communications, 385.000 lines and 101 centres were located in the area hit by the earthquake ; in general, the buildings did not suffer large damages, but various consequences were obtained (flooding in a centre, batteries ruptures, cables cutting).

In Golcük and Izmit, the hoispitals did not suffered damages.

The main building of the fire brigade in Golcük collapsed with 20 fatalities.

6 CONCLUSIONS

In Izmit area, industry suffered heavy losses either related to buildings collapses, or to process failures or to internal or external infrastructure failures. In general, not unknown phenomena were involved. The main lesson should be the need of risk assessment referring to regulatory requirements by experienced structural and process engineers jointly with the application of common rules for seismic prone areas.

As regards the effects of overaccident (risk increase related to dangerous plant) the occurrence of a release of toxic liquid in acrylic polymers plant and a five-days fire in storage tanks in a refinery are of particular concern. It means for the future the need for more detailed risk assessment of seismic effects including consideration of soft ground motion, the location versus the fault, the severity of the damage, the safety measures for avoiding and mitigating the effects, the domino effects from accidental scenarios and the application of the emergency response in a specific study. Specific studies are also needed for port areas and jetties.

The business interruption losses are also to be taken into consideration. Last but not least the environmental effects especially related to the vast releases of chemicals in ground and water must be considered in situations where logistic means for fighting and remediating are missing for hours or days.

REFERENCES

1) Report for the AFPS mission (Kocaeli earthquake, Izmit, Turkey) (in French) (1999), 28 rue des Saints-Pères, 75343 Paris Cedex 07.
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