

THE USE OF RETURN PERIODS AS A BASIS FOR DESIGN AGAINST EXTERNAL LOADS

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INTRODUCTION

The objectives of safety related design should follow a hierarchy of hazard elimination, prevention, control and mitigation. Where it is not possible to eliminate the hazard it is often feasible to prevent an incident or to ensure that there are no significant adverse consequences.

For example selecting a floating roof tank will prevent an explosion inside a tank storing flammable liquid. Similarly an explosives store may be sited in a remote area such that in the event of an explosion there would be no significant impact on populated areas. Under such circumstances the risk has been eliminated by design.

However, it is not always practicable to completely eliminate risk during design. This is because designing against extreme loadings, which might only occur at very low probabilities, could lead to a prohibitively expensive structure. This is often the case when designing against external loads. Such situations have traditionally been addressed by designing a structure to withstand a loading with a given return period. The required design loading can be determined by plotting severity of loading against probability of occurrence (known as an exceedance curve) and selecting a return period which it is believed will deliver an adequate level of safety. For example an offshore platform may be designed to withstand a wind or wave loading with a return period of say 100 years, or an earthquake loading of say 10,000 years. More recently the concept of return period has also been adopted for designing against other types of hazards such as blast loading from explosions[(1)], impairment of offshore temporary safe refuges[(2)] etc.

Whilst the return period provides information about the survivability of a structure when subject to a given level of loading, it does not necessarily reflect the risk of failure due to more extreme loadings.

We have identified some concerns with the use of simple return periods to control residual risks in that

– residual risk can be very dependant on the shape of the exceedance curve
– where the exceedance curve is very steep (i.e. there are relatively large increases in loading with relatively small decreases in probability) the design load can be very sensitive to changes in assessment data and assumptions
– the approach does not generally take into account "societal concerns"[(3)] associated with large accidents

We have chosen to illustrate this by reference to two examples — the design of blast resisting buildings and design of LNG storage facilities against seismic events.

USE OF RETURN PERIODS FOR DESIGNING BLAST RESISTANT BUILDINGS ON CHEMICAL PLANTS

The CIA guidance[1] requires buildings to be designed to resist an overpressure event which occurs at a frequency of 10^{-4}/yr (return period = 10,000 years) and suggests that less frequent events need not be considered. Further detailed guidance is provided by the UK HSE HID[4]. Adoption of this design basis is intended to provide a "negligible" level of individual risk (10^{-6}/yr) as defined in the HSE discussion document Reducing Risk Protecting People[3] (R2P2).

Figure 1 presents the overpressure exceedance curves from a hypothetical example in UK HSE HID document[4] marked "HSE". Also shown is the curve obtained from a study relating to a real project.

For the HSE example, the design overpressure for a return period of 10,000 yrs is approximately 430 mbars. The maximum possible overpressure at the building location is 500 mbars – only 15% greater than the design level. A building designed to resist the 10,000 yr event is likely to behave in a robust manner under the maximum possible loading and the residual risk to building occupants is therefore likely to be negligible ($<10^{-6}$/yr even for an occupant there for 100% of the time).

The real case study indicated an overpressure corresponding to a 10,000 yr return period of approximately 150 mbars. The maximum overpressure at the building location was predicted to be 500 mbars — some 3.3 times greater than the design level. In contrast to the HSE example, in this real case study a building designed to resist the 10,000 yr event would be extensively damaged when subject to the maximum possible loading. Table 1 sets out the Individual Risk calculation for an occupant in a building designed to resist

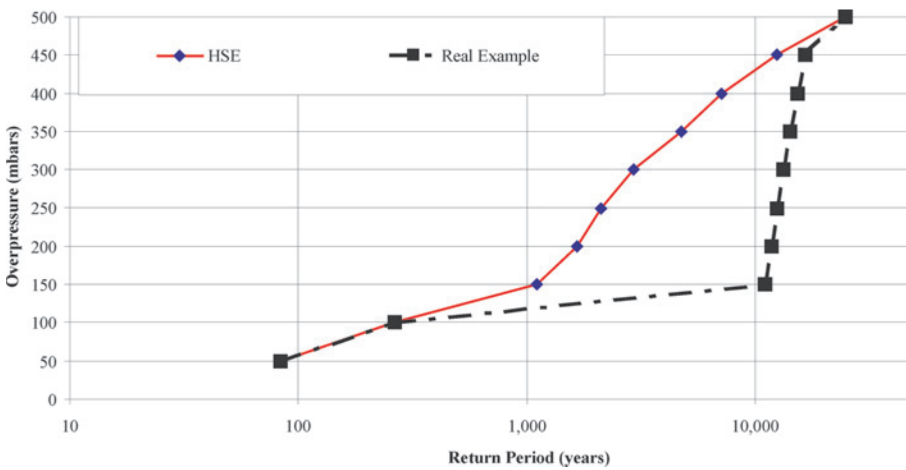

Figure 1. Blast overpressure return period

Table 1. Calculation of individual risk

Overpressure mbars	Event Frequency (/yr)	Vulnerability	Individual Risk/yr (100% individual occupancy)	Individual Risk/yr (20% individual occupancy)
50	8.20E-03	0.001	8.20E-06	1.64E-06
100	3.71E-03	0.001	3.71E-06	7.42E-07
150	5.00E-06	0.01	5.00E-08	1.00E-08
200	5.00E-06	0.1	5.00E-07	1.00E-07
250	5.00E-06	0.6	3.00E-06	6.00E-07
300	5.00E-06	0.7	3.50E-06	7.00E-07
350	5.00E-06	1	5.00E-06	1.00E-06
400	5.00E-06	1	5.00E-06	1.00E-06
450	2.00E-05	1	2.00E-05	4.00E-06
500	4.00E-05	1	4.00E-05	8.00E-06
TOTAL	1.20E-02		**8.9E-05**	**1.8E-05**

a 150 mbar overpressure assuming occupancy of 100%. The risk is more than two orders of magnitude above the R2P2 "negligible" level of 10^{-6}/yr. Even where a more realistic worker individual occupancy factor of 0.2 is employed, the individual risk remains above the R2P2 negligible level.

It should be recognised that the approach advocated by the CIA only addresses individual risk and does not reflect any societal concerns associated with events leading to large numbers of fatalities. In other words the same design basis would be adopted whether there were 1 or 100 occupants present in a building.

In addition, for the real case study, the design overpressure using a 10,000 yr return period proved to be very sensitive to the input and assumptions in the QRA. Figure 2 illustrates the effect of a simple doubling of the predicted frequency (i.e. halving the return period) of explosions that affect the building. This resulted in an increase in design loading by a factor of 3.

USE OF RETURN PERIODS FOR SEISMIC DESIGN OF LNG STORAGE TANKS

NFPA 59A 2001 standard for design of LNG facilities requires storage tanks to meet two criteria:

1. An operating basis earthquake (OBE). When subject to such an earthquake the tanks will remain in operation. The defined acceleration for this event corresponds to 2/3 the acceleration with a return period of 2,500 years.

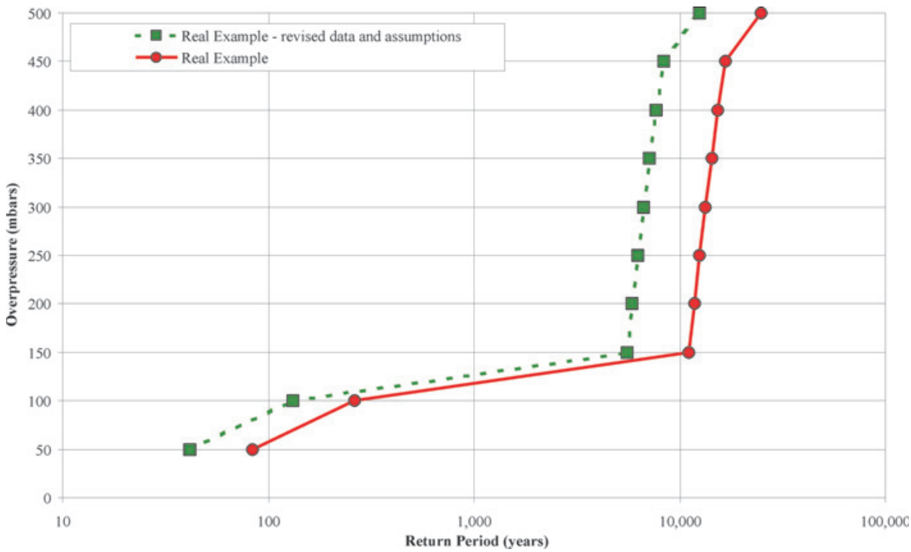

Figure 2. Sensitivity of design loading to data and assumptions

2. A safe shutdown earthquake (SSE). When subject to such an earthquake the tanks will contain the LNG but the facility is not required to remain operational. The defined acceleration for this event corresponds to 2 × OBE or the acceleration with a return period of 5,000 years, whichever is the minimum.

For major hazard risk assessment, only the SSE is relevant since exposure to accelerations below this value, by definitions should not lead to a major release.

If we consider application of this code in two different areas in the US — one of high seismicity – San Francisco and one of low seismicity — New York, we can see that it would lead to very different levels of residual risk. Acceleration versus return period is shown in Figure 3 for the 2 locations (based on data contained in[5]).

Figure 3 shows that:

– the predicted acceleration level for the OBE is 2/3 × 0.43 g (acceleration return period of 2500 years) = 0.29 g in New York and 2/3 × 1.9 g = 1.3 g in San Francisco
– the predicted acceleration level for a return period of 5,000 years is 0.66 g in New York and 2.0 g in San Francisco
– the design basis for a SSE would therefore be 0.58 g (limited to 2 × OBE) in New York and 2.0 g in San Francisco
– the design basis for SSE for a LNG tank in New York corresponds to a return period of 4,000 years as compared to 5,000 years in San Francisco

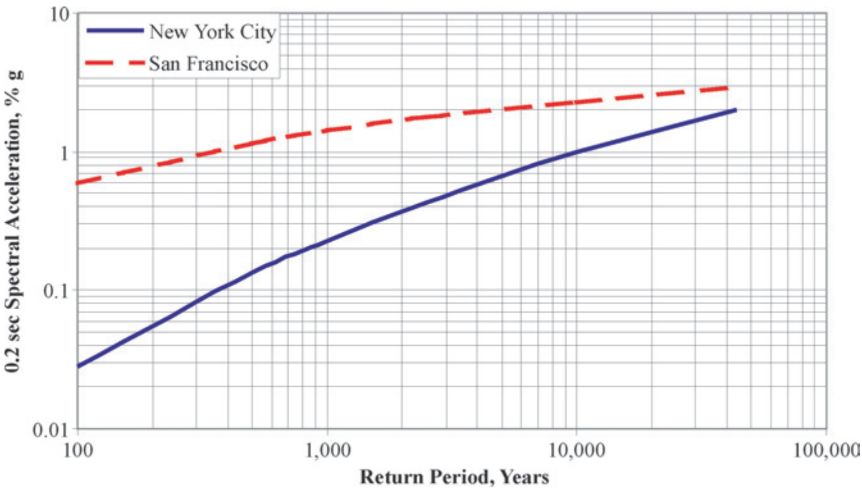

Figure 3. Seismic acceleration versus return period

At first sight the difference in residual risk between the 2 locations is only slight when based on a comparison of the return periods relating to the SSE. However when larger loadings are considered at longer return periods the difference in residual risk becomes more evident. For example if one considers an earthquake with return period of 50,000 years then:

– the predicted acceleration level for San Francisco is a factor of only 1.5 × SSE, whereas for New York the loading increases by a factor of 3.5 × SSE.
– the likelihood of a major failure on a tank exposed to 3.5 design loading will be higher than that on a tank exposed to 1.5 design loading.
– hence the residual risk of tank failure will be higher in New York than in San Francisco.

This illustrates that (counter intuitively) the adoption of a prescriptive design return period is likely to result in a higher failure frequencies in region of lower seismicity.

The NFPA standard is based on preventing failure rather than controlling the risk associated with a release. We have already shown that the frequency of failure can be different in different regions. However, the consequences may also be very different from one site to another based on the amount of material stored and the location of surrounding populations. This aspect is recognised in the NFPA standard which states:

> "The objective of the selection and use of the SSE is to provide a minimum level of public safety in the event of a very low probability seismic event. It is recognised that the required probability level to achieve acceptable public safety varies from project to project, depending on such factors as

location and population density. It is desirable to allow the owner flexibility in achieving the required level of public safety."

However, the NFPA standard provides no specific guidance on how the above objective may be met. In designing a recent facility (outside of the US) the following approach was adopted:

1. A site specific study was carried out to determine the relationship between acceleration levels and return periods. The relationship showed the area to be of relatively low seismicity.
2. A study was carried out to determine the performance of the proposed tank under loadings in excess of SSE values of 1 in 5,000 years (NFPA 59A 2001) and 1 in 10,000 years (EN 1473).
3. A QRA was performed to define the required frequency of catastrophic tank failure to deliver tolerable risks to onsite and offsite populations.
4. Based on the above, it was recommended that a return period of 10,000 years be used for the SSE design level.

CONCLUSIONS

Facilities are often designed against external loadings on the basis that they will survive an event with a particular return period. We have shown that this approach can result in very different levels of residual risk in that:

1) Loadings at longer return periods can lead to failure of the equipment which could result in harm to people.
2) The overall frequency of failure, not survival, is important in defining the residual level of risk.
3) The shape of the load versus return period curve is important in determining the frequency of failure — a single point survival design criterion will not necessarily deliver the same frequency of failure in all cases.
4) Risk is a combination of frequency and consequence. Designs based solely on return period will not reflect any variability in the potential consequence (which depends on the number of people exposed to the hazard).

An alternative QRA based approach has been described which establishes the required performance against external loadings based on residual risk

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