PROBABILISTIC TREATMENT OF UNCERTANTIES IN SEISMIC ANALISYS OF STEEL TANKS

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ABSTRACT

Seismic Risk assessment of industrial facilities requires integrated procedures to probabilistically quantify human, social, environmental and economical losses due to relevant accidents induced by earthquake action. Easy to manage tools for failure probability of equipments evaluation under seismic actions can be used in total risk evaluation of existing hazardous plants, Structural damage state getting probability calculation for each component is the first step for a subsequent consequences evaluation. Since the structural risk is related to site dependent seismic hazard and structural vulnerability, it is worth optimising distinct procedure for those quantities. In the present paper treatment of randomness sources is discussed with specific reference to steel tanks for oil storage in seismic environment. Failure modes and resistance formulation are analysed for this widely present and standardized plant components. Seismic vulnerability is considered as a time-variant reliability problem. Weight of uncertain parameters on seismic response and failure probability is discussed.

KEYWORDS: seismic reliability, steel tanks, risk analysis, fragility.

INTRODUCTION

Risk analysis of industrial facilities consists in evaluation of potential losses related to relevant accidents, investigating short and mid-long term health and environmental consequences of industrial accidents. Pollution, toxic releases, fires and explosions are just few effect of structural collapse of equipment of risk plants.

Seismically induced accidents can be very relevant and are triggered by structural failures of single components. Collapse of a plant subsystem can extend the accident involving near components or plants; this mechanism is called “Domino Effect”. Recent national and international rules require detailed quantitative analysis of risk in existing and new plants containing or treating hazardous materials [1]. Total risk evaluation taking into account domino effects and mitigation measures are required, but no detailed procedures or target levels of risk are provided mainly because general purposes suitable techniques have not been already established. Anyway the target of a risk analysis due to a given cause is well known: it is just the probability of a given system to do not survive to all the possible occurrence of the considered source of damage; in other terms it is one minus the probability that the considered system complete its mission successfully. Due to this top-down definition risk have to be related to a time period, that can be arbitrary, but generally is coincident with the design service life of the facility and/or of its main components.

It is worth noting that if deterioration mechanism and/or programmed repair intervention are scheduled during the system life they must be taken into account and can consequently affect the failure probability of the system.

Since the risk is just quantification of a failure probability, which is basically a non-dimensional quantity, it can include several failure sources (even airplane or meteorites accident). Events algebra allows keeping separate procedures for each considered mechanism and then combining the results.

This is why seismic risk is a failure probability also (related to a specific failure source that is earthquake) and can be treated by it. In the simplest way it can be considered as the combination of structural vulnerability and seismic hazard of the location site. These two terms are probabilities also. Seismic hazard depends on ground motion source of the site and it must be considered as a given data in risk analysis since cannot be reduced.

On the other hand, structural vulnerability is the core-topic of seismic risk analyses and can be very difficult to address since it depends on the dynamic behaviour of the structure subjected random excitations and on the limit states defined for each component or for the whole system. Vulnerability can be expressed by probability of failure as a function of seismic intensity parameters (*probability of event called "failure" since a given earthquake related parameter is already happened*); in such form it is called fragility.

Due the given definition seismic fragility represents the limit state getting probability if a seismic intensity is fixed. Since several failure mechanisms and paths can occur for each component, so limit states functions can be treated as independent events and then properly combined.

In other terms a seismic risk assessment procedure requires a first top-down phase in which the consequence of interest must be analysed in terms of definition of failure modes that can induce them. It requires a macro-analysis of the whole structural/industrial system. Then the evaluation procedures must continue from a bottom-up point of view that starting from each component defined as "critical" (i.e. tanks) defining quantitative analytical limit state function related to the all the possible damage phenomena. After that the results must be included in the "failure paths" that relates different components and/or failure modes to get the failure probability related to the known possible accidents.

In the present paper the framework of Quantitative Probabilistic Seismic Risk Analysis is discussed; addressing of structural uncertainty is analysed in the case of a reference industrial component as steel tank for oil storage are.

RISK OF INDUSTRIAL PLANTS: THE ITALIAN CASE

Occurred accidents and deregulation of power markets in many developed countries increased the attention on evaluation of industrial plants safety margins. These needs resulted in publication of restrictive rules, as happened in Italy in 1999. Italian guidelines have been released and a classification of risk plants all over the national territory has been promoted. Classification is dependent upon the quantity of each hazardous material.

The guidelines distinguish two types of facilities:

- ✓ Risk Plant;
- ✓ High risk Plant.

Review of present Italian situation [2]-[3] points out the presence of a large number of risk plants in urban areas, increasing the risk related to industrial processes. One thousand *industrial risk* plants and power systems have been recently registered in Italy (see Tab. 1), about 50% of them are considered as *relevant industrial risk plants*. It has been estimated that risk can involve the health of five millions of citizens and five thousand hundred can be direct victims [4]-[5].

	#	%
Relevant Risk Plants	406	39
Risk Plants	688	61
Chemical/Petrochemical Risk Plants	280	27
TOTAL	**1024**	

Table 1: Italian risk plants.

	#	%
Risk Plants in Seismic Areas	198	62
Relevant Risk Plants in Seismic Areas	119	38
TOTAL (SEISMIC)	**317**	**100**

Table 2: Italian risk plants in seismic areas.

Twenty seven percent on the total amount industrial risk plants are chemical or petrochemical facilities and the eighteen percent of them is located in seismic area (see Tab. 2).

Emergency level related to this situation is pointed out by further data concerning location of public buildings respect to industrial facilities; in fact on a total amount of seven thousand school buildings, 5% (233) are located within one kilometer far from a industrial facility and 1% (70) are far less then two hundred meters.

It is worth noting that the total amount of risk facilities is not a measure of risk since where the concentration level of different industries is higher the effects of an accident are non-linearly dependent on the number of plants. This is why domino effect must be taken into account for each

different risk installation.
Combining data concerning the geographical distribution of plants and the seismic classification of the national territory it is possible to obtain a first rough calculation of seismic risk of industrial facilities. About 30% of total amount of plants considered as hazardous is located in seismic area. In addition, a large number of existing facilities have been built before seismic classification, so they have been designed without any consideration of lateral seismic loads or according to obsolete seismic code provisions. Fabrication, design, structural maintenance and upgrading of existing facilities are a relevant aspect of seismic risk analysis, but on this subject data cannot be found.

QpsRA – QUANTITATIVE PROBABILISTIC SEISMIC RISK ASSESSMENT

Quantitative risk assessment agrees with new dealing theory of Consequence Based Engineering [6], but it is oriented to critical industrial facilities; it consists of steps to define the system and they performance under earthquake excitation; obviously its general purpose and widely applicable to different seismic affected systems (see Fig. 3). Phases of the procedure can be summarised as follows:

Consequences Assessment. The first step is estimation of main consequences on an accident induced by earthquakes. Different types of losses or mid/long-terms effects must be related to failure modes of the system. It is worth noting that potential consequences strictly depends on the context within the risk system is placed in terms of urbanization environment and so on. It should involve different integrated skills capable to link bad effects to structural collapse sources.

Critical Path Definition. Since the potential losses have been listed a failure mode and effect analysis based procedure (FMECA/FMEA) [7] to define the components considered as critical that need more detailed investigations. In that way a very complex system layout, common in the process industry, may be reduced to a relatively small number of facilities that requires a seismic vulnerability assessment. For instance in chemical industry, due to the relevant accident definition, the component considered as critical are:

- ✓ Tanks;
- ✓ Pressure vessel (horizontal/vertical);
- ✓ Tank sphere (pressure vessel);
- ✓ Pipe and pipe supports;
- ✓ Cooling towers, Fractionation columns, Extraction columns;
- ✓ Fired heaters, Regenerators;
- ✓ Reactors.

Hazard Estimate: Due to classical definition probabilistic definition for a certain system of seismic risk can be expressed as follows

$$Risk = Hazard \otimes Vu\ln erability \tag{1}$$

The dot product represents convolution of functions. Result, in statistical terms, is one minus system reliability that is probability of surviving during the reference time interval.
Traditional structural reliability methods define hazard and vulnerability in terms of *demand* and *capacity* respectively, that are the same performance index. In events *algebra* approach the failure can be expressed by the following

$$\mathrm{Risk} = \mathrm{P_f(T)} = \mathrm{P[failure|\,h]P[Hazard = h, T]} \tag{2}$$

All terms are related to a macro-seismic parameter that is the most common way to represent hazard for a certain site and fragility curves for a structural kind. Therefore it is possible to explore the relation between seismic hazard and fragility using a non-structural parameter (seismological). Peak Ground Acceleration (PGA) is commonly used to quantify ground motion in Probabilistic Seismic Hazard Assessment (PSHA) that is used to define lateral forces and shear stresses in the equivalent-static-force procedures of some building codes, and in liquefaction analyses. Another parameter, the Response Spectral Acceleration (SA), which gives the maximum acceleration experienced by a damped, single-degree-of-freedom oscillator (the simplest representation of building response), can be also used.

$$Hazard(T) = P[PGA > a \mid T] \qquad (3)$$

Therefore, a *hazard curve* (see Fig. 1) can be plotted for each site. It gives the probability that a given PGA is exceeded during a reference time interval; the latter is generally related to the service life of the structure.

Hazard is provided by geophysics on regional scale and by geotechnics at local scale; it depends on distance to the expected source of ground motion. It can be considered as hexogen data in risk analysis.

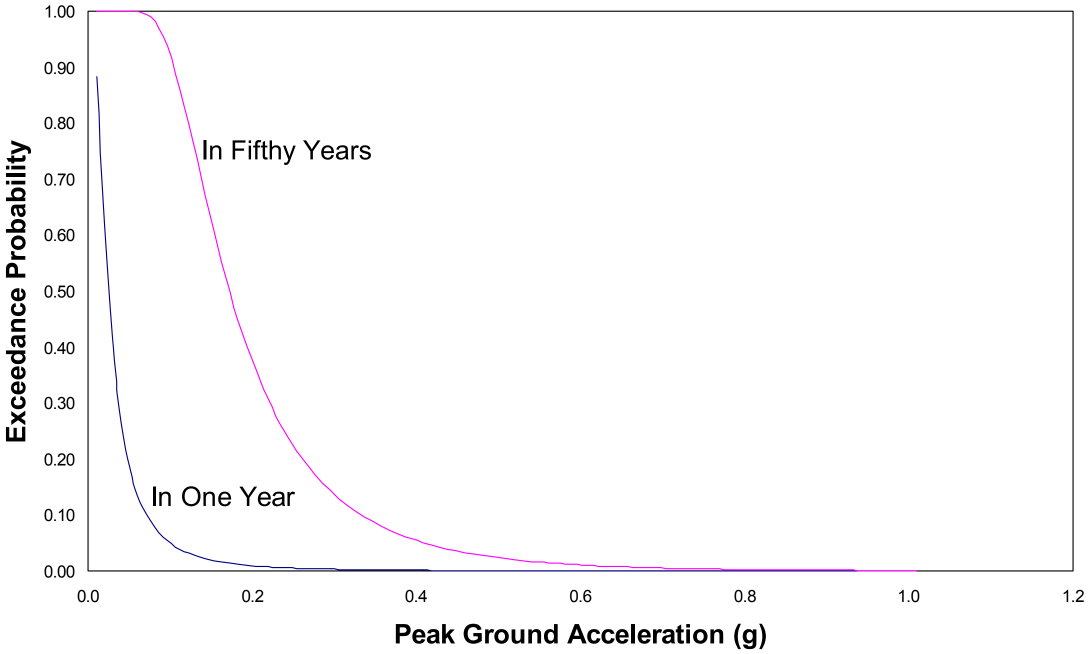


Fig. 1. Example of hazard curves in terms of annual exceedance probability of Peak Ground Acceleration.

Fragility Relationships. The development of fragility curves consists of probabilistic characterisation of the capacity as a parameter affecting the demand is given. This definition gives the probabilistic extension of the classical failure condition definition, which is the exceedance of the structural demand against the available capacity, and the risk is exactly this probability, as the demand and capacity change in their existence domain due to their probabilistic characterization.

Development of fragility formulation for each single industrial component is necessary basically for two reasons:

1. The structural complexity of an industrial layout does not allows to analyse effectively its global seismic behaviour;
2. Proper single fragility analysis helps to consider failure modes of a component as independent from failure of the others, therefore the global failure probability can be easily carried based on a classical system reliability approach.

Seismic vulnerability for each component of a structural, industrial or power system is the failure probability against the same seismic parameter as the hazard (see Fig. 2). In probabilistic terms

$$Vulnerability(a) = P[Failure \mid PGA = a] \qquad (4)$$

Since the vulnerability is the probability that a given structural performance parameter is exceeded, hazard and fragility curves are related to Cumulative Mass Functions (CDF) of two random variables that are load (S) and resistance (R). Probability that the system remains in the safe domain during its life is the probability that the S never exceeds R as discussed before.

$$Risk = P[S > R] = 1 - P[S \leq R] = \int_0^\infty \left[\int_0^s f_R(r)dr \right] f_S(s)ds \tag{5}$$

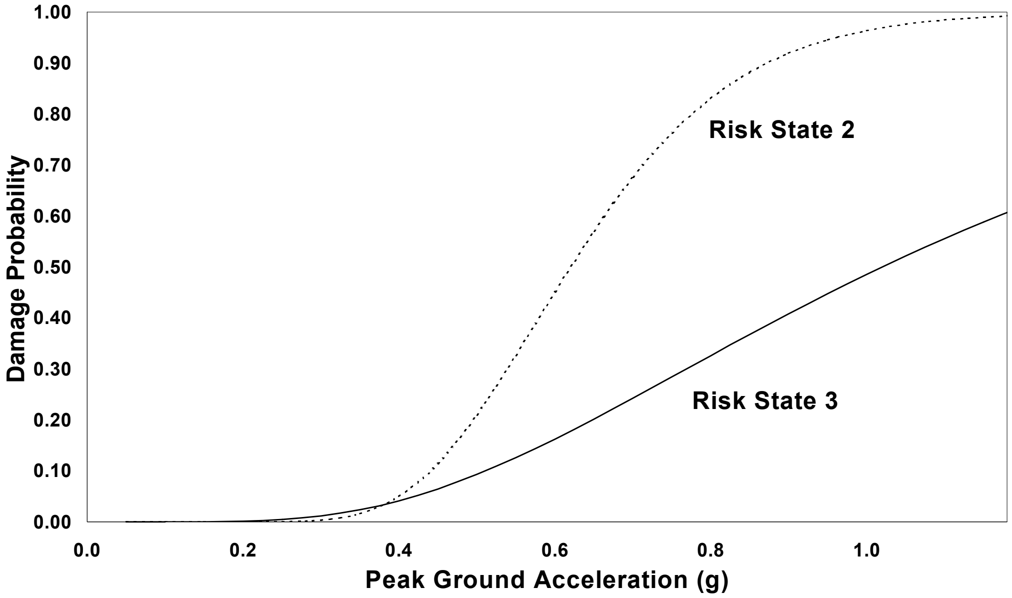


Fig. 2. Experimental fragility curves for moderate end large content loss [3].

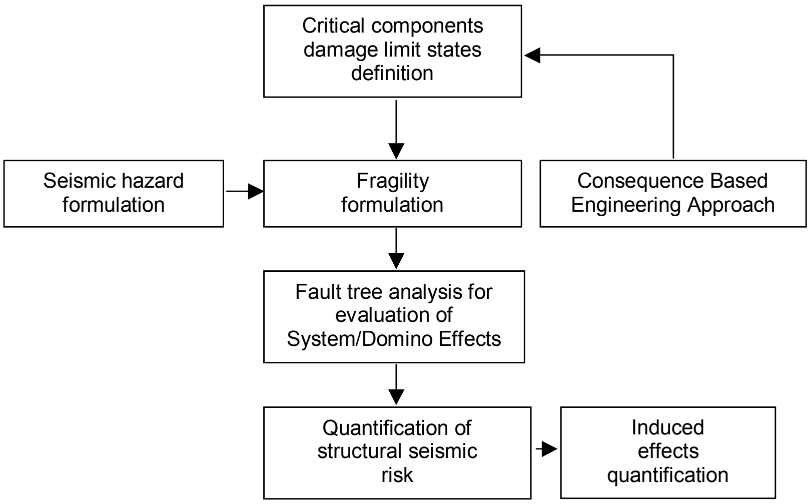


Fig. 3. Strategy of seismic risk evaluation of industrial plants.

Quantification of risk. Since failure probability for each critical component has been evaluated as a function of the chosen intensity parameter and for each limit state considered. A traditional technique to assess reliability of a complex system should addressed considering the failure paths. On this job is worth noting that the whole plant is reduced to its “critical layout” anyway logic connection must be saved in order to consider each real failure mode in the analysis.

SEISMIC BEHAVIOUR OF STEEL TANKS

Steel tanks for oil storage are a very common component of power, process and manufacture industry plants. They are also present in fuel storage subsystem for transportation facilities as seaports and airports. Since they can be very large containing huge quantities of fuel can be certainly considered “critical”. They are also characterised by a long established design and fabrication standards therefore the identification of a reference structure is easier than other industrial facilities. This circumstance not only enables the verification of theoretical results using experimental data, but also leads to make available a risk assessment tools that can be used in many countries and is applicable to both existing and new facilities.

Furthermore, a large amount of data concerning post-earthquake damage report for steel tanks exist and a collection of observations dating back to 1933 are available [8]-[12]. These data are very useful and have been also managed to get experimental vulnerability functions.

Steel tanks for oil storage are usually welded steel structures made of three elements that are the shell, the roof and the bottom plate. All the structural components are made of the same material and have a minimum thickness of 5-6 mm; the maximum thickness, usually in the shell, may be of few centimetres in very large tanks. International standards [13]-[22] provide simple but effective procedures to design the thickness of the shell under static content load while the other elements dimensions are just chosen in tabled ranges.

Seismic design is based in the check of maximum overturning moment and its axial stress induced by horizontal loads; only water tanks guidelines take into account the vertical component of the acceleration in the seismic analysis.

The dynamic behaviour of this kind of structure is ruled by fluid/structure interaction. It is well known that the main response affecting mechanism is the sloshing motion of a part of the content (below the free surface) with a different period respect to from the system made of remaining content and structures that behave basically as a single component.

Convective and impulsive masses and their centre of gravity positions are depending on the geometry of the tank [20]-[29]. Since the height to consider is the effective liquid filling level is possible to list the structural parameters affecting the structural dynamic response:

- ✓ Height;
- ✓ Radius;
- ✓ Capacity filling percentage;
- ✓ Specific weight of content;
- ✓ Friction coefficient between bottom plate and grade.

Damage reports [8] show that tanks can be affected by severe damages. Main problem are caused by large displacements experienced in uplifting of bottom plates or sliding of the whole tanks. In those cases the structure can remain within the stress levels prescribed by the codes, but the piping connections and/or the welds connecting the main structural elements can fail.

Capacity models for seismic analysis of steel tanks for oil storage have to take account of:

- ✓ Global phenomena (Seismic behaviour related capacities):
    - o Overturning moment resisting to uplifting of the bottom plates;
    - o Base shear to avoid sliding of the whole tank;

- ✓ Local phenomena (Connections/local failure capacities):
    - o Bending/tension for the pipes;
    - o Shear strength of the piping connections to the shell.

It is worth noting that these capacities will be related into the risk analysis since this mechanisms work together in the failure of the tank. Guidelines seems to do not take into account enough this phenomena capacity models for all damage states of interest are available, but elephant foot buckling of the shell.

UNCERTANTIES IN SEISMIC ANALYSIS OF STEEL TANKS FOR OIL STORAGE

Uncertainties that should be taken into account in a reliability analysis are generally less than those are meaningful in the outcome of the phenomena considered. Since the “length” of this vector affects the computational effort of the chosen reliability assessment method the significance, say weight, of each casual factor in the response should be estimated. It may be a not trivial job; anyway in the seismic fragility assessment of structures few assumptions can be done on the subject [30].

The random variables vector can be partitioned into two sub-vectors, one made of those parameters that are meaningful in monitoring of limit state as strengths that are ruled by materials constitutive

parameters but that does not "define" the structure and does not affect its response. The second portion of the vector is made of those quantities, usually in terms of dimensions or dimensions ratio, that a much more meaningful in determining the performance of the component and its relative state of risk. Due to this classification the factors listed above are part of this sub vector since the both identify almost completely the structural type and its seismic behaviour.
Instead the "local" parameters in tank analysis should be, according to the major observed seismic damages:

- ✓ Body steel constitutive properties and ultimate strength;
- ✓ Welding steel constitutive properties and ultimate strength;

It is worth noting that others factors should be taken into account if a probabilistic characterization is available. Any other random factor that does not concern strictly the structure can be processed, i.e. workmanship, suitability of mathematical model or degradation processes; anyway it can be done as a further development of the research.

Analytical Fragility Formulation

Most traditional way to address fragility curves is fitting experimental data observed as post-earthquakes damages or as laboratory tests. Without go deeply in the subject it is easy to understand that this approach leads to experience problems as:

- ✓ Unavailability of a reference type of the structure in terms of identification of an homogeneous model among the available data;
- ✓ Non-uniformity of boundary condition among the available data (i.e. large scatter in the soil interaction);
- ✓ Different degradation state at the time of the accident;
- ✓ Uncertainty on the failure mode experienced by the system/component in the post event assessment;
- ✓ Availability of a sufficient number of data to plot a statistically significant curve for each damage state considered.

This is why the analytical way to get the fragility is the only approach to assess the vulnerability of critical facilities. The main problem affecting the seismic reliability analysis is its time-dependent nature. It means that the function $G(X_1,X_2,\ldots)$ represents the crossing of the boundary surface between the safe and failure domains in the space of random standard parameters and it is time-dependent too, so that theoretical and computational problems can be experienced and transfer to field practice is not easy to perform.

$$G[X(t),t] > 0 \quad \forall t \in [0,T] \tag{6}$$

On the other side it allows to completely control the uncertainty considered since the reliability theory is just a mathematical framework to correctly address the state of knowing about a given phenomena into a consistent number.
By definition of limit state function as in (6) each damage state of interest is treated by itself then if getting of different damage state is considered as stochastically independent is easy to get the reliability of the system against different failure mode (7).
The fragility evaluation method that has been developed in the present paper for steel tanks has common basis with the FEMA 350 guidelines [31], [32] developed for steel moment resisting frames. The same principles can be applied to other kind of structures with different uncertainties models as is shown by Pinto et al. [30]. The core of the procedures is the deterministic simulation of dynamic (seismic) behaviour of the considered structure; this is why it can be adapted to each system or refined changing the deterministic engine. It could be considered as a "simulation" method since it uses time-history analysis in calculation of response probabilities. The main advantage against the traditional simulation methods is the reduced number of runs required if the failure mode is related to only one mechanism or multiple modes can be addressed to the same mechanism. The accelerograms used can be either recorded ones or spectrum-compatible. Scaling factor is spectral acceleration for recorded accelerograms or PGA if they come from the same spectral shape.
The structural core of the method is the deterministic non-linear time-history analysis. Randomness of phenomena is taken into account in two different steps. Uncertainty on structural response depends to the model considered then a probability distribution of the capacity of the mechanism. Then the failure probability is give by CDF of the maximum demand on the structure assessed by the dynamic analysis. Materials properties and strength are taken into account just one step later, by development of a P_f

response surface.

Summarizing the method: a deterministic capacity formulation is needed for each considered failure mode. Then a probabilistic distribution definition has to be associated to each capacity model. Parameters describing that function are coming from previous evaluations i.e. experimental observations if available. Since the response is deterministic defined a certain load probabilistic comparison between demand and capacity is performed by

$$P(R \leq d) = CDF_R(d) = P_f \tag{7}$$

It is worth noting that this function provides the failure probability, but it is not a fragility curves because the random variable is in terms of a structural demand quantity (i.e. maximum stress) instead of a seismic intensity parameter (i.e. PGA). Therefore to obtain aimed vulnerability a set of time-history analyses is required, accelerograms have to be generated (or scaled if recorded) in order to express the functional intensity-failure relationship. The probability evaluation procedure is not affected by the analysis so the model can be different for each failure modes or may be refined for more accurate results.

If each investigated failure mode may be considered as stochastically independent the collapse probability can be simply assessed by events algebra considerations.

Once the fragility function related to capacities is calculated structural response affecting parameters may be calculated with a traditional simple response function method.

Each failure probability calculated previously contains the mean value of response parameters so to take into account the variability of the response a variation of standard deviation amplitude is imposed. This method is suitable if ultimate capacity modes can be set up. Dimension of described vector is related to the minimum required number of needed simulation if no materials properties are concerned. Collection of “minor” parameters has to be set at mean values vector. Now the capacity-affecting factor must be considered, so the dimension of the capacity vectors depends on the number of failure mechanisms considered.

The structural demand is assumed as the maximum amplitude of the monitored parameter obtained from a time-history analysis of the structure. Since the fragility function dependence from the intensity parameter must be considered a suitable number of runs have to be performed for each PGA set considered. Therefore the number of complex run is the dimension of vector X multiplied by the number of considered PGA sets, i.e. ten.

Independent failure mode must be considered in the running analysis. Stochastic independence of failure mechanisms allows dealing them separately and then just combines to get the global associated failure probability.

$$P_{f,k} = 1 - \prod_i (1 - F_{Ri}(S_{i,k})) \tag{8}$$

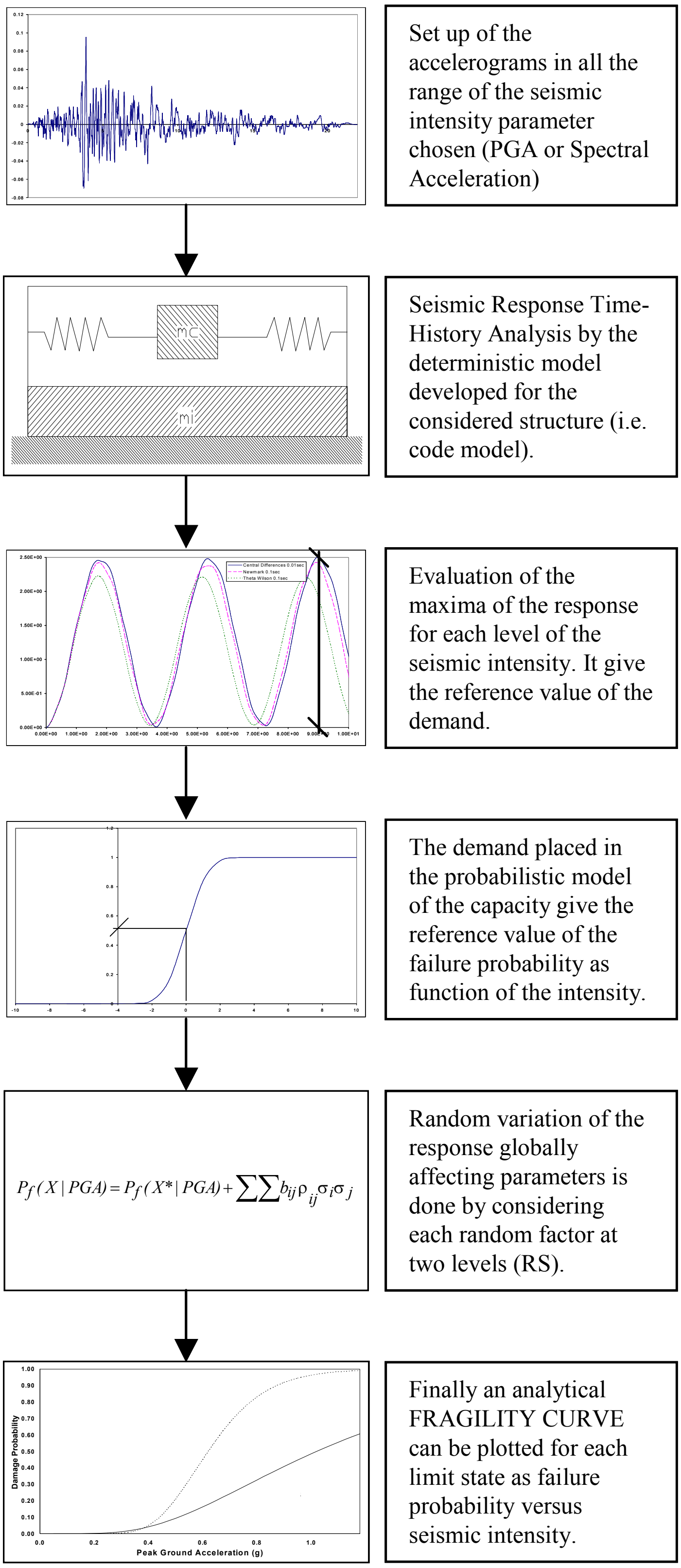
Set up of more than one dynamic model allows taking into account the most important failure mechanisms observed for steel tank subjected to seismic actions in a more comprehensive way.

The number of performed analyses depends on several factors; anyway it is mainly induced by the dimensions of the two vectors of considered parameters and by the accuracy in terms of PGA step that is pursued. Looking at the observations base existing fragility curves [9], [33], mean value to get a certain damage states.

Since the response surface is applied to take into account the probabilistic meaning of structural response affecting factors, the number required analyses to assess the problem is dependent from the order of the polynomial function representing the surface.

Summary of the method for uncertainty treatment and fragility evaluation

The first step of the procedure is the definition of the capacity for each limit state of interest. For each elementary failure mode considered a structurally consistent limit state function have to be formulated in terms of both the random and the deterministic parameter. To each failure mode a capacity formulation needs to be associated.



Set up of the accelerograms in all the range of the seismic intensity parameter chosen (PGA or Spectral Acceleration)

Seismic Response Time-History Analysis by the deterministic model developed for the considered structure (i.e. code model).

Evaluation of the maxima of the response for each level of the seismic intensity. It give the reference value of the demand.

The demand placed in the probabilistic model of the capacity give the reference value of the failure probability as function of the intensity.

$$P_f(X \mid PGA) = P_f(X^* \mid PGA) + \sum\sum b_{ij} \rho_{ij} \sigma_i \sigma_j$$

Random variation of the response globally affecting parameters is done by considering each random factor at two levels (RS).

Finally an analytical FRAGILITY CURVE can be plotted for each limit state as failure probability versus seismic intensity.

Fig. 4. Flow chart of fragility evaluation.

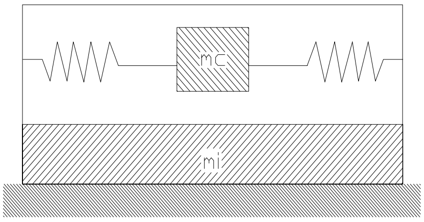
Then the casual variables have to be set in two different vectors of “locally” and “globally” capacity/response affecting parameters.

For each random variables and/or capacity model a probabilistic characterization is needed. It means that at a Probabilistic Distribution Function should be assumed and its parameters quantified definition.

A deterministic time-history simulation model must be set up to point out the dynamic response at each level of PGA in the range of interest. The maxima of seismic response will be the demand that will be computed in the capacity Cumulative Probability Function (7) to get the failure probability as function of the intensity parameter.
In this while the globally response affecting parameters are set at their mean value. Now they're random effect are calculated by a response surface. Assuming a II order polynomial function each factor is tested with two levels mean +- the standard deviation. (it is because it is the same that considering 95% of distribution in the normal distribution case). Then the fragility curve can be plotted. The procedure set for the analysis of the fragility of steel tanks for oil storage (see Fig. 4) in relation to the two failure modes determined by sliding and elephant foot buckling is shown below. It is worth noting that the random parameters considered and their features have been already discussed then only the computation a procedure is reported.

THE DETERMINISTIC ENGINE

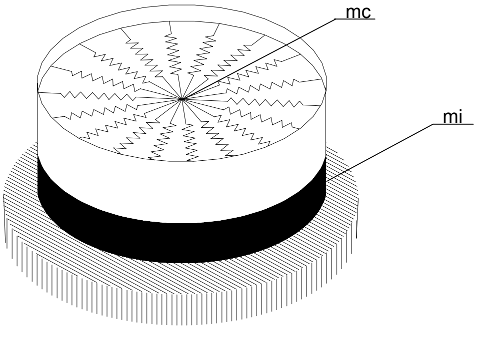
Since the procedures requires a deterministic relationship between a given input and the demand on the structures a suitable model must be chosen to properly simulate the dynamic behaviour of the steel tanks for oil storage. It is worth noting that the fragility evaluation procedure is independent on the type deterministic time-history analysis that has been performed at all. This is why the response id this procedures will improve its accuracy not only if uncertainty probabilistic modelling is enhanced or uncertainty on factors affecting reduced, but also if the deterministic engines use a more accurate structural model.
As previously discussed, only tanks experiencing filling level greater than 50% should be considered, since the time dynamic behaviour of atmospheric tanks is ruled by the motion of the content history-analysis and it is not so easy to model numerically a simplified model is needed. International codes and guidelines suggest a very simple model instead of the solution of the Laplace's equation associated to the sloshing motion of the liquid content of the tank. The model, proposed by Malothra [29], is a Multiple Single Degree of Freedom System made of two superposed masses corresponding to the impulsive and convective mass of the oil or water stored. The main assumption of that model is neglecting of the interaction between the two masses.



$$T_i = C_i \frac{h\sqrt{\rho}}{\sqrt{h/r}\sqrt{E}} \quad (9)$$

$$T_c = C_c \sqrt{r} \quad (10)$$

Fig 5. Simplified MSDOF model



$$k_i = \frac{2\pi m_c T_c^2}{\sum_{i=1}^{n/2} 2\cos^2\theta_i} \quad (11)$$

Fig 6. 3D Model

The model shown in Fig.5 is used by designers worldwide and is suggested also by Eurocode 8 Part 4 [19], but is not fully reliable for engineers involved in risk assessment of structural facilities, since no local failure mechanisms as welding failure are taken into account. For this purpose a more refined detailed model but numerically effective can be considered. It is a 3D model based on the principle that since the earthquakes come in only one direction, no matter what, the real dynamic motion of the tank evolve along that direction due its polar-symmetrical shape. This is why a finite element model of the tank can be set up without modelling the liquid content (quite hard computational stuff), just attaching the previously calculated convective mass to radial spring running to the shell (see Fig. 6).

This model may be considered dynamically as equivalent to the previous one, which is taken as reference, if the oscillating properties are the same, in other words periods have to be similar. This is why comparing the two periods the stiffness of spring system is easily obtained. Suitability of that model to represent the dynamic behaviour of steel tank is calculate the maximum pressure on the shell and comparing it with the results of the Laplace's equations that rules the problem, as the Eurocode 8 suggest. The same model is suitable for EFB and sliding fragility analysis. It is useful in monitoring both of the failure modes although in a very simple way. Assuming a not anchored tank the constraining pipes can neglected in the sliding analysis. Calculating sliding displacement and overturning moment at each time integration step provide the time-history of demand quantities of interest.

CONCLUSIONS

Modern approach to safety and risk management of critical industrial facilities leads to take account of accidents due to structural failures induced by earthquakes. This task is difficult and needs the integration and interaction of different skills. Furthermore, the innovative concept of Consequence Based Engineering is founded on the availability of reliable tools to forecast losses (human, economical, etc.) due to collapse under seismic actions of civil engineering structures.

In the above contexts, the deterministic analysis does not seem to be the best answer, since it is not able to take account of all the knowledge base on the different phenomena affecting the dynamic behaviour of complex systems as industrial layouts are. Conversely, a probabilistic framework has to be developed.

In the present paper, the main aspects related to the development of a risk assessment procedure taking into account site features (hazard) and structural performances (vulnerability) have been reported. The proposed procedure is optimised for existing facilities and provides a full probabilistic approach to relate socially percept consequences to structural damage in a "fish eye" point of view.

The method has been described with reference to steel tanks for oil storage that are characterised by design and fabrication standardization that allows a simple focusing of the problem. This is a significant advantage because in that way obtained fragility results are applicable in a general purposes risk assessment of critical facilities.

The core topic is the seismic capacity definition of industrial components since their structural dynamic behaviour is not easy to analyse and take into account in the design guidelines worldwide; then further work is needed on it.

Uncertainties probabilistic characterisation is not trivial to address. Parameters as mean and standard deviation of the random numbers of interest should come out from a large and meaningful database of seismic damage observation or from specific tests. Completing these tasks for the most common critical component of the process industry will give the proper knowledge base to make the seismic risk analysis a firmly established procedure for engineers without specific seismic engineering skills by manageable tools as fragility and hazard curve are.

ACKNOWLEDGEMENTS

The authors would like to acknowledge funding and support received from the *Geophysics and Volcanology Italian National Institute (INGV)* within the research project "Reduction of Infrastructures and Environment Seismic Vulnerability" (VIA).

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