Major Contributing Factors to Seismic Risk of Industrial Facilities

K.Nasserasadi [1] and M. Ghafory-Ashtiany [2]

[1] *Assistant professor, Civil Engineering Division, Dept. of Engineering , Zanjan university ,Zanjan, Iran & Transportation Research Institute, Tehran, Iran.*

[2] *Professors, Dept. of Structural Engineering, International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, Iran.*

Email: nasseasadi@gmail.com, ashtiany@iiees.ac.ir

ABSTRACT :

Experience of resent earthquakes such as Northridge- US (1994) or Izmit-Turkey (1999) earthquake have shown that industrial facilities are vulnerable to earthquakes and their associated economic loses are considerable. Noteworthy efforts have been made to reduce the amount of risk in these facilities in terms of public safety and environmental protection. Yet the risk of these facilities from economical point of view not fully studied. The main objective of this paper is to highlight the main contributing factors in the economic losses of these facilities which evaluated by the parametric study of a loss estimation model. The results have implication in risk management of industrial facilities. In this paper, first, a brief description of model is presented; then, effect of several influential parameters is quantified by conducting parameters study on the mathematical model. In this study, in addition to contributing parameters on direct losses, the effect of influential factors on secondary hazards and indirect loss has been studied. The results have shown that some unprecedented parameters such as dependency of factory to its household, financial condition of factory and speed of lifeline restoration have significant effect on the indirect loss of industrial facilities.

KEYWORDS: Industrial Facilities, Risk Assessment, Direct and Indirect losses, Economic losses, Risk management,

1. Introduction

Experience of recent earthquake such as Izmit-Turkey (1999) and Japan Earthquake (2007) have shown that Industrial facilities including the world's largest nuclear power plant are vulnerable to earthquake. Although safety concern has remained the most priority of seismic risk reduction of industrial facilities, the direct and indirect economic impact of damage to these facilities are significant. For instance, the recent damage to Kashiwasaki Kariwa nuclear power plant causes $4.3 Billion losses to market value, according to Bloomberg, yet, this value does not project the indirect loss of power plant due to revenue loss. The total loss in some cases could force some industries to go out of the business, especially in the current tight global economy and tough competitors.

A vital part of a comprehensive risk reduction program of industrial facilities is evaluation of direct and indirect losses. The first and the most importance step in total loss reduction is identification of the major contribution factors and create a priorities order list. Some studies for evaluation of importance of influential parameters on direct and indirect loss have been carried out. Porter et.al. 2002 in the framework of assembly-based vulnerability have shown that direct loss of a building has primary sensitive to uncertainty in assembly capacity and shaking intensity; moderately sensitive to details of the ground motion and the contractor's unit costs; structural characteristics such as mass, damping, and force-deformation behavior have a modest effect on the loss. Webb G. et. al. 2002 and Tierney K. 1995 studied the main contributing factors in indirect and loss after Loma-Prieta and Northridge earthquake. From the result of the survey, it is found that, business recovery time and the amount of indirect losses depends on the many external factors such as restoration of source providers, revives of consumer demand, managing the alternative sources and market, restoration of lifeline and etc. In this paper, contributing factors on direct and indirect loss are evaluated in an integrated environment.

To evaluate and manage all aspect of seismic risk in industrial facilities, a holistic probabilistic seismic risk assessment methodology has been adopted by Nasserasadi et.al. 2007. In this model, the probability of direct loss from direct effect of earthquake and secondary hazards such as fire and explosion are estimated. In addition, the probability of indirect losses from is estimated from the effect of internal/external factors on the production process and business interactions. Several diverse parameters have contributed to the result of the model. To identify the effect of contributing factors to the total loss, a deterministic parametric study have been conducted in this paper.

2. An Introduction to Risk Assessment Model

The probabilistic risk assessment model which has been introduced by Nasserasadi et.al. 2007 consisted of two major parts: direct and indirect loss estimation part. The direct loss of earthquake addresses the loss of direct effect of earthquake to the facilities and covers the reconstruction and recovery expenses. The indirect loss, in this model, refers to revenues losses of facility due to closure after earthquake during reconstruction and recovery time. The overview of the model architect is shown in Figure 1.

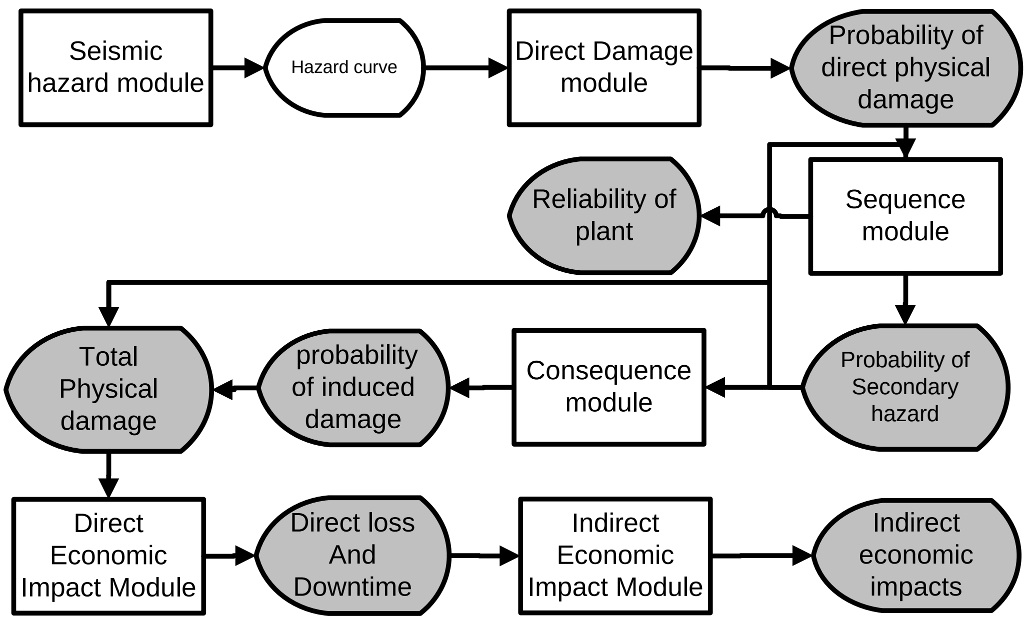


Figure 1. Procedure of seismic risk assessment of industrial facilities. Outputs of methodology have shown by shaded objects.

In this probabilistic model, first, the seismic hazard is estimated. Second, the probability of direct physical damage is computed using relevant vulnerability function in the direct damage module. Third, reliability of plant and probability of secondary hazards in the plant are assessed in sequence module. Fourth, consequences of secondary hazards in terms of physical damage probability of components are predicted in consequence module. Fifth, total probability of direct and induced physical damages is calculated and used to estimate the direct economic loss and repair time in the direct economic impact modules. In the end, results are utilized to evaluate the indirect losses through indirect loss module.

2.1. Evaluation of direct losses

In this methodology, the probability of damages is estimated by aggregating the damage probability from direct effect of earthquake on equipment and damage of secondary hazards such as fire and explosion:

$$P_k(D=d_i)=\sum_{\text{all } j} P_{kj}(D=d_i)-\sum_{j}\sum_{l} P_{kj}(D=d_i)\cdot P_{kl}(D=d_i).\gamma_{jl} \tag{2.1}$$

Where, $P_k(D=d_i)$ is probability of damage equal to damage state d_i as a result of direct effect of earthquake and secondary hazards. P_{kj} is the probability of damage in kth component due to jth hazards (primary or secondary) and γ_{jl} is correlation coefficient take into account the correlation of j^{th} and l^{th} hazards. The probability of direct damage is estimated by:

$$P[D > d_i] = \int F(D > d_i \mid im).\left|d\left[P(IM \ge im)\right]\right|.d(im) \tag{2.2}$$

Where $F(IM \ge im)$ is hazard curve which estimates the exceeding probability of ground motion Intensity Measure, *IM*, from a defied level, "*im*" and $F(D > d_i \mid im)$ is fragility function which estimates the conditional exceeding probability of damage, *D*, from a damage level , d_i , in given "*im*". For simplicity in parameter study, following assumption are being made: a power function for hazard curve, $P(IM \ge im) = K_0 im^{-k}$ and CDF of log-normal for fragility function (HAZUS 1997), $F(D > d_i \mid im) = \Phi\left[1/\beta_i.\ln\left(im/IM_i\right)\right]$. In which, *K* and K_0 are seismic hazard parameters and IM_i and β_i are seismic fragility function parameters.

The probability of induce damage is evaluated by:

$$P_{bl}[D > d_i] = \int_{is}\int_{sh} F(D > d_i \mid IS = is).f(IS = is \mid SH = sh).f(sh)d(sh) \tag{2.3}$$

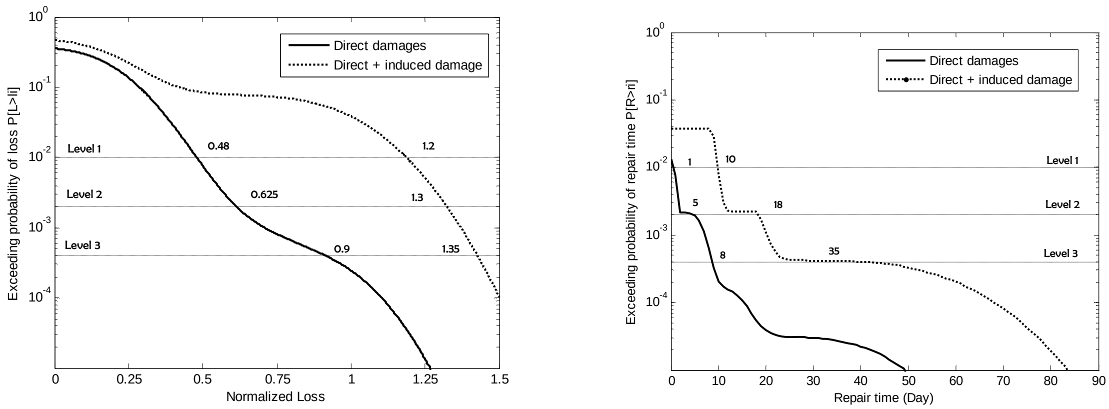
Where $f(sh)$ is Probability Density Function (PDF) of Secondary Hazards *SH* estimated from sequence analysis module of the model through fault-tree analysis of sequences of direct damages which could potentially triggered secondary hazards, $f(IS = is \mid SH = sh)$ is conditional PDF function of Intensity of Secondary hazard (*IS*) in given "*sh*" which shows the attenuation of secondary hazard intensity and is derived for four major secondary hazards (fire, explosion, inundation and equipment falling) based on their propagation characteristic and $F(D > d_i \mid IS = is)$ is conditional probability of exceeding damage from d_i in given "*is*", estimated form a function similar to seismic fragility function.

The probability of total direct loss of plant is estimated from aggregating loss of individual components in plant where direct loss of each component is:

$$P[C_i > c] = \sum_{j=1}^{NDS_i}\left[1 - F\left(C_{ij} \mid D = d_j\right)\right].P\left(D = d_j\right) \tag{2.4}$$

Where, $P[C_i > c]$ is exceeding probability of loss in component *i* from *c*, $F\left(C_{ij} \mid D = d_j\right)$ is cumulative conditional distribution function of loss in component *i* in given damage state d_j defines by the normal distribution function with mean and deviation of $\hat{C}_{ij}$ and σ_{ij} and $P\left(D = d_j\right)$ is probability of damage equal to d_j calculated from Eqn. 2.1. The same formulation can be derived for probability estimation of reconstruction time. The detail of the model and input/output parameters can be found in Nasserasadi et.al. (2006).

The outputs of the first part of the model which are probability of direct loss and anticipated reconstruction time are presented in loss/reconstruction time probability curve, shown as an example in Figure 2. As it can be seen in the figure, the effect of secondary hazards, in some cases, can be significant. The effect of secondary hazards depends on the type of the secondary hazards, and equipment type, prevention measures in place, distance of equipments from the hazard source and etc.



(a) Direct loss (b) Reconstruction time

Figure 2. Sample expected direct loss and anticipated reconstruction time, estimated by the loss model for two cases: when direct damage of earthquake is considered only and aggregated of direct and induced damages from secondary hazards.

2.1. Evaluation of indirect losses

The indirect loss of the industry is estimated from the business interruption of the facility during total restoration time of facility which includes, and not limited to, the reconstruction time of the facility. Since, the restoration time of the facility described by the time in which the facility return to its pre-earthquake state, other factors such as the restoration time of the lifelines, households, consumers and suppliers are contributing to that. These ties can be shown in a conceptual diagram of the factory's conceptual model diagram shown in Figure 3. . The factory needs supply from supplier to produce the goods, needs consumer to sell the products, and makes profit. Labours from households and services from local lifelines are needed for production process. The services of lifelines are also used for transferring the supply from supplier and products to consumers. Any disruption and delay in the production process, such as shortage of supply or services as well as drop in consumption, make interruption in the business, reduction in the profit and indirect losses as well. For example, a factory with fully dependency to outside electricity supplies may be forced to stop its products if any event cut off the supply of electricity power. To model these complex and interdependent phenomena, a system dynamic approach and agent modeling technique are utilized and a simulation based model is developed (see Nasserasadi et.al. 2006). The restoration history of the factory in a given earthquake probability and total indirect loss curve of factory in any earthquake probability is the result of the model which is shown in Figure 3. These results can be obtained for any factory and external conditions such as properness level of factory/ household for earthquake, dependency of factory to household.

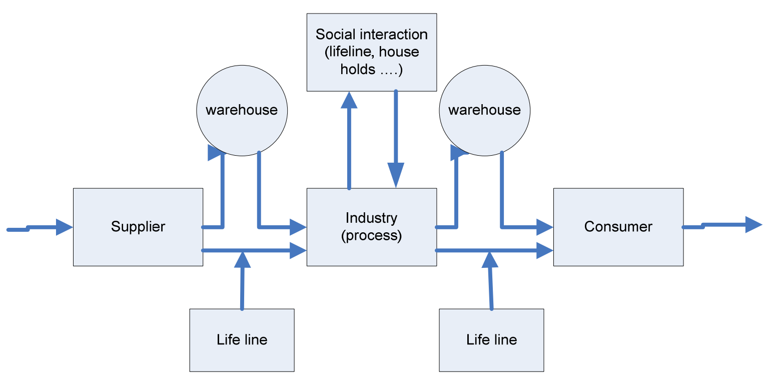
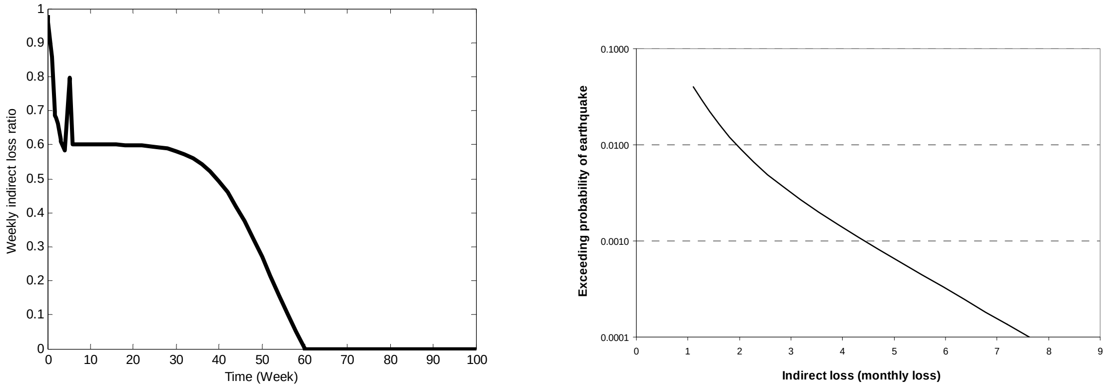


Figure 3.Conceptual model diagram of factory's process



(a)Restoration History (b) Indirect loss curve in monthly revenue loss

Figure 4. Sample of indirect loss modeling module.

3. Underlying parameters and parameters study

Based on the above mentioned model, several parameters contribute to the seismic risk of industrial facilities. Apart from the numerous contributing parameters to the secondary hazards, seismic loss parameters fall to two general groups: parameters contribute to the direct loss and parameters contribute to the indirect loss. The first type of parameters consisted of: severity of seismic hazard or seismicity (K in hazard curve see section 2.1), vulnerability of structure/equipments (IM_i and β_i in fragility function see section 2.1), and economic value of the components ($\hat{C}_{ij}$ and σ_{ij} in the loss function see section 2.1). The second type of parameters consisted of: factory preparedness (the availability of spare parts and action plan for quick response), financial resources for restoration, dependency of industry to the household/lifeline (the ratio of services and labor coming from local household) and earthquake severity.

To determine the effect of each factor to the direct/indirect losses, parameters study has been conducted. In the study, differentiate of the direct/indirect loss with respect to each parameter is estimated and parameters with more differentiate or parameters with more effect are identified. The numerical parameter study has been conducted for two parts of the mode and differentiates of the results for each parameter is estimated. For each parameter, the result of total loss for fixed percentage of parameter's swing value is evaluated. Due to limitation of this paper, the results are shown in abstract. For example, in the case of parameter of seismicity, and fragility parameter, differentiate of the direct loss and its swings are estimated and shown in Figure 5 and 6 respectively. As it can be observed from the figure, the maximum swing value of two parameters are significantly different and suggests that difference in the seismicity have greater impact on the loss than fragility parameter (vulnerability of components).

The result of the parameter study which shows the effect of each component on the final result, the loss, has been used for ranking of underlying parameters. The results are shown in the Table 1. As it has shown in these results, the seismicity of site, vulnerability and financial value of components are respectively the most influential parameters in the direct loss. And, financial condition, preparedness and dependency of the firm are the most influential parameters before seismicity of the site.

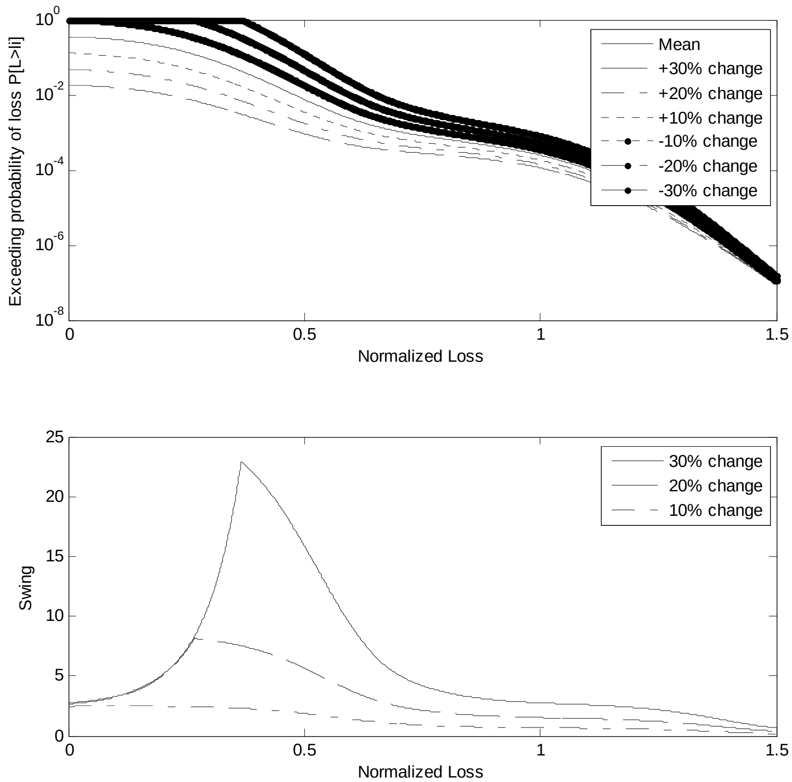


Figure 5. Differentiate of direct loss with respect to changes to parameter of seismicity.

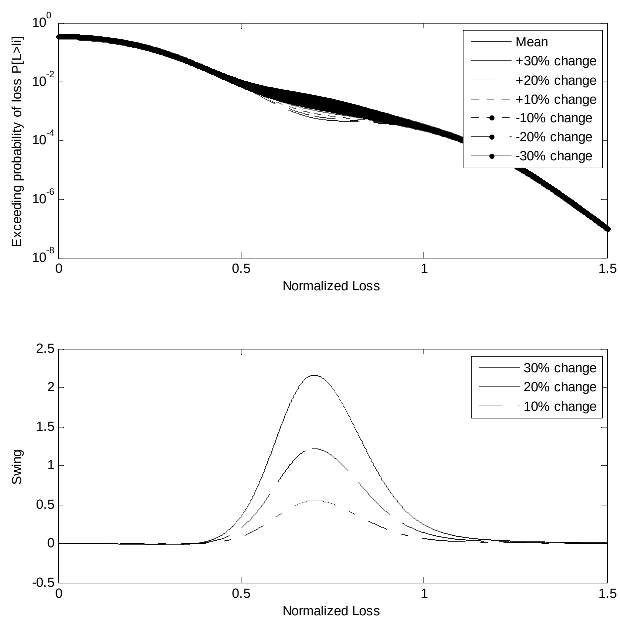


Figure 6. Differentiate of direct loss with respect to changes to fragility parameter.

Table 1. Major contribution factors, definitions and importance rankings.

Loss type	Importance Ranking	Contributing factors	Parameter(s) in the model/Indicators
Direct loss	1	Seismicity	K in hazard; $K_0 im^{-k}$
	2	Vulnerability	IM_i and β_i in fragility function; $\Phi[1/\beta_i.\ln(im/IM_i)]$
	3	Loss/Value	$\hat{C}_{ij}$ and σ_{ij} in the loss function; parameters of the normal distribution
Indirect loss	1	Financial condition	Availability of financial resources for reconstruction/restoration
	2	Dependency of firm to society	Percentage of resources/products from/to local household
	3	Preparedness of firm	Ability of restoration after disaster without outside help
	4	Seismicity	Earthquake return period

4. Discussion and Conclusions

The outcome of the model may show contradicting results in the direct and indirect losses, but in fact, this result is showing a fundamental difference between the direct and indirect losses. Although the seismicity of the site and vulnerability of components may play importance role in the direct loss, it is not that much significant in the indirect losses. In contrast, financial condition of the firm, dependency of firm to household which is not an influential parameter in direct loss, is considerable factor in indirect loss. The differences between the nature of direct and indirect loss is the main reason. Where the direct loss refers to reconstruction and repair expenses and is constant over time, the indirect loss corresponds with loss of revenue and changes over time. result of the study suggest, severity of earthquake and vulnerability of facility which all related to physical damage of facility are more important where, fast restoration of the facility and ability to return to normal operation by having enough financial resources for restoration actions and not that much dependent to society may help to reduce the indirect loss.

These finding are the keystone of the risk management. Where, the risk management measures to control the direct loss should focus on the strengthening of facilities and conducting some physical activities, for reduction of indirect losses, a management approach for reduction of dependency of facility to household and fast recovery of the firm will helpful. A successful risk management program should consist of both hard and soft approaches.

Another noteworthy outcome is the role of the financial condition of the firm in the indirect losses. In the simulation case studies, it has been observed that the restoration process is very much dependent on this parameter. In a case, a firm with no financial capacity for restoration, there restoration of firm never happened. In other words, if a business have not enough resources for reconstruction or provide basic needs, it literally cannot be survived. It is also observed that having more accessible resources may facilitate the restoration and reduce the indirect loss.

REFERENCES

K. Nasserasadi, R. Mechler and M.G. Ashtiany (2006). Seismic Indirect Loss Model for Industrial Facilities. In proceeding of 1th European conference on earthquake engineering and seismology, Geneva, Switzerland.

K. Nasserasadi, M. Ghafory-Ashtiany, S. Eshghi and M. R. Zolfaghari (2007). Probabilistic Holistic Seismic Risk Assessment Methodology for Industrial Facilities. In proceeding of 4th International Structural Engineering and Construction Conference, Melbourne, Australia.

K.A. Porter, J.L. Beck, and R.V. Shaikhutdinov (2002). Sensitivity of Building Loss Estimates to Major Uncertain Variables. **Earthquake Spectra**, **18:4**, 719–743.

K.J. Tierney (1997). Business Impacts of the Northridge Earthquake. **Journal of Contingencies and Crisis Management**, **5:2**, 87-97.

G.R.Webb, J. Kathleen, J. Tierney and M. Dahlhamer (2002). Predicting long-term business recovery from disaster: a comparison of the Loma-Prieta earthquake and hurricane Andrew. University of Delaware disaster research center, preliminary Paper No. 328.