Revista
Científica

La Revista Mexicana
de Ingeniería
Electromecánica

ISSN 1665-0654

Volumen 11, Número 3,
Julio-Septiembre
2007

Contenido

EDITORIAL

Continuando con su línea multidisciplinaría en la cual se abordan diversos campos de la ciencia y la tecnología, en este número *Científica* aborda temas relativos al enfriamiento de reactores nucleares, a la teoría de la propagación de ondas en guías de onda. Así mismo se abordan tópicos relativos a la ingeniería civil, aplicaciones de láser y turbinas.

Así, en el primer artículo se presenta el desarrollo de una metodología para la evaluación del daño acumulado en boquillas de inyección de agua de emergencia en recipientes a presión mediante el elemento finito, las cuales son utilizadas en sistemas de protección en reactores de agua en ebullición (BWR), siendo el principal objetivo bajar la temperatura del núcleo cuando éste aumenta arriba del rango de operación permisible por medio de una inyección de agua tratada. Se analizan, además, los efectos de las diferencias de temperatura entre la pared del reactor y la boquilla la cual podría producir fallas si no se controla adecuadamente. Seguidamente, en el segundo artículo se establece el comportamiento del campo eléctrico dentro de una guía de onda; para lo cual se usa el coeficiente de reflexión, el ángulo de incidencia, la frecuencia de operación y las dimensiones de la guía, con el objeto de determinar el patrón de radiación del campo eléctrico en el plano E y plano H.

Un aspecto de gran importancia en el la planeación y diseño de obras de ingeniería, son los aspectos de riesgo. Con esta finalidad en este número se propone un criterio para calcular relaciones costo/beneficio en términos del número esperado de fatalidades, las pérdidas esperadas y la inversión realizada en seguridad estructural. El criterio puede utilizarse para evaluar el riesgo en obras de ingeniería y para comparar la consistencia de gastos realizados por agencias nacionales para mitigación de riesgo en carreteras con el costo/beneficio involucrado en el incremento de seguridad estructural en edificios. Estos conceptos pueden ser considerados para generar una administración efectiva de riesgo para políticas óptimas de protección de la vida y la propiedad. La formulación presentada en este número se aplica al caso de edificios bajo exposición sísmica en la ciudad de México.

El diseño VLSI continúa siendo un tópico de gran interés, por lo cual este número también aborda este tema mediante la presentación del diseño de un amplificador operacional retroalimentado en corriente (CFOA) usando la tecnología estándar CMOS de 0.35 μ. El diseño se basa en la conexión en cascada de un circuito inversor de corriente con un seguidor de voltaje, siendo los voltajes de alimentación de ±2.5 V y una corriente de polarización de 20 μA. El CFOA se aplica al diseño de un filtro universal bicuadrático modo mixto y se extiende a la implementación de un oscilador caótico basado en el diodo de Chua (N_R). Los resultados de simulación en SPICE, muestran la utilidad del CFOA para realizar filtros en modo voltaje y modo corriente, así como para generar secuencias de comportamientos caóticos.

Seguidamente, se presentan dos aplicaciones de la tecnología láser. En la primera se describe la implementación de un sistema de estimación de distancias de una cámara a objetos. El sistema utiliza un láser de línea, una cámara y procesamiento de imagen. Con el procesamiento de imagen y simple geometría analítica se estiman distancias de objetos con respecto a la cámara que adquiere la imagen. Por su parte el segundo trabajo presenta el desarrollo de un espectrómetro con interfase a una computadora Personal (PC). El prototipo desarrollado sirve para obtener los espectros de diversas fuentes luminosas, particularmente en la obtención de espectros de fluorescencia emitidos por una muestra bajo estudio aplicando la técnica de fluorescencia inducida por láser (LIF).

Finalmente, se presenta un estudio teórico que permite evaluar la influencia que ejercen diferentes parámetros físicos, estructurales y de régimen (presión de impulso, frecuencia de impactos, dimensión media de las gotas, etc.), sobre la erosión mecánica que se presenta en los álabes rotores en el último paso de la sección de baja presión de una turbina de vapor con generación eléctrica de 300 MW.

Científica Vol. 11 Núm. 3 pp.107-111
© 2007 ESIME-IPN. *ISSN 1665-0654.* Impreso en México

Cost-Benefit Ratios for Risk Mitigation on Structures in Mexico

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Recibido el 2 de octubre de 2006; aceptado el 25 de abril de 2007.

1. Abstract

Risk aspects of planning and design of engineering works in Mexico are usually considered into the mitigation and development plans only in a subjective and qualitative form. This practice does not produce the minimum costs in the long term. In order to optimally allocate limited funds used for mitigation purposes, a careful, systematic and objective estimation of the failure consequences as well as the underlying risk is required.

Also, mitigation policies for several regions in Mexico and different hazard types are not risk-consistent.

In this paper a criterion to calculate cost/benefit ratios in terms of the expected number of fatalities, the expected losses and the investment made on structural safety is proposed. The criterion may be used to appraise the risk on engineering works and to compare the consistency of risk mitigation expenditures made by national highway agencies with the cost/benefit involved on the increment of structural safety for buildings. These concepts may be considered to generate an effective risk management for optimal policies for life and property protection. This formulation is applied to the specific case of buildings under seismic exposure in Mexico City and expected life-cycle cost functions are developed for typical costs and practices.

Key words: cost-benefit relationship, risk mitigation, building on sismic zone.

2. Resumen (Relaciones costo-beneficio para mitigación del riesgo en estructuras en México)

Los aspectos de riesgo en la planeación y diseño de obras de ingeniería en México se consideran para mitigación y desarrollo solamente de una manera subjetiva y cualitativa. Esta práctica no produce los costos mínimos en el largo plazo. Para distribuir de manera óptima fondos limitados utilizados con fines de mitigación, se requiere una estimación cuidadosa, sistemática y objetiva del riesgo subyacente y de las consecuencias de falla.

También, las políticas de mitigación aplicadas a diversas regiones de México y para diferentes tipos de peligro no son consistentes en riesgo.

En el presente artículo se propone un criterio para calcular relaciones costo/beneficio en términos del número esperado de fatalidades, las pérdidas esperadas y la inversión realizada en seguridad estructural. El criterio puede utilizarse para evaluar el riesgo en obras de ingeniería y para comparar la consistencia de gastos realizados por agencias nacionales para mitigación de riesgo en carreteras con el costo/beneficio involucrado en el incremento de seguridad estructural en edificios. Estos conceptos pueden ser considerados para generar una administración efectiva de riesgo para políticas óptimas de protección de la vida y la propiedad.

Esta formulación se aplica al caso de edificios bajo exposición sísmica en la ciudad de México.

Palabras clave: relación costo-beneficio, mitigación de riesgo, edificio en zona sísmica.

3. Introduction

For infrastructure works, or facilities where the affected population is significant, life-cycle studies that explicitly takes into account the inherent uncertainties due to the occurrence of natural hazards and their consequences on human life and property, are widely justified and recommendable.

Two examples of such works are buildings located on a highly seismic zone and infrastructure, like bridges and breakwaters, exposed to wind and storm hazard.

4. Formulation

The expected life-cycle cost $E[C_L]$ is composed by the initial cost C_i and the expected damage costs $E[C_D]$:

$$E[C_L] = C_i + E[C_D] \tag{1}$$

The expected damage costs include the components of damage cost: expected repair $E[C_r]$, injury $E[C_{inj}]$ and fatality $E[C_{fat}]$ costs and each one depends on the probabilities of repair and failure of the structure.

These component costs of damage are defined:

$$E[C_r] = C_r\,(PVF)P_r \tag{2}$$

where:

C_r = average repair cost, which includes the business interruption loss, C_{bi},

PVF = present value function [1, 2].

$$PVF = \sum_{n=1}^{\infty}\left[\sum_{k=1}^{n}\Gamma(k,\gamma L)/\Gamma(k,\upsilon L)(\upsilon/\gamma)^k\right](\upsilon L)^n/n!\exp(-\upsilon L) \tag{3}$$

where

υ = mean occurrence rate of earthquakes that may damage the structure.

γ = net annual discount rate, and L = structure life.

And P_r = probability of repair, defined in a simplified way, as a factor of the failure probability P_f.

Similarly, the business interruption cost, is expressed in terms of the loss of revenue due to the repairs or reconstruction works after the earthquake, assumed to last T years.

$$C_{bi} = L_R(T) \tag{4}$$

where:

L_R = loss of revenues per year.

The expected cost of injuries is proposed to be:

$$E[C_{inj}] = C_{1I}(N_{in})P_f \tag{5}$$

C_{1I} = average injury cost for an individual

N_{in} = average number of injuries on a typical building in Mexico City given an earthquake with a mean occurrence rate v.

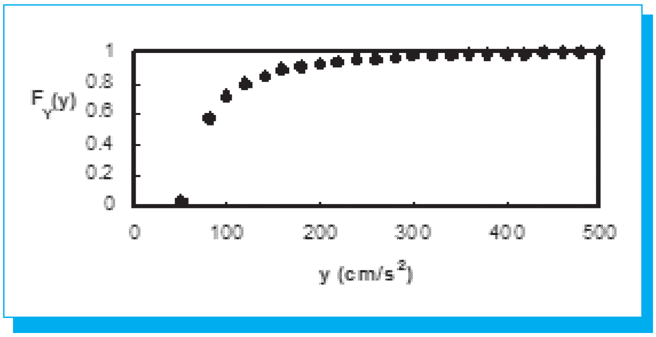

Fig. 1. Cumulative distribution of annual maximum soil accelerations in Mexico City.

For the expected cost related to loss of human lives, the cost corresponding to a life loss, C_{1L}, and the expected number of fatalities, N_D are considered. The cost associated with a life loss may be estimated in terms of the human capital approach, which consists in the calculation of the contribution lost, due to the death of an individual, to the Gross Domestic Product during his expected remaining life. The details of this calculation are explained in previous works [3, 4].

$$E[C_L] = C_{1L}\,(N_D)P_f \tag{6}$$

In the next sections, all the figures are estimated for typical costs in Mexico.

A typical geometry of a structure, a 7 stories regular framed building (Figure 3), located on the soft soil of Mexico City is selected to analyze its critical frame under seismic loads. Statistics of its maximum response, at critical joint level, are obtained from the frame analyses subjected to Poissonian earthquakes (with mean occurrence rate v) as scaled from the seismic hazard curve for Mexico City [3]. Figure 1 shows the annual cumulative distribution of maximum accelerations.

5. Number of expected fatalities

The expected number of fatalities if a failure occurs, $E[N_D]$, is estimated from a curve previously developed for typical buildings that collapsed due to earthquakes in Mexico, in terms of their plan areas, given an earthquake with a mean occurrence rate ν. See Fig. 2.

After curve-fitting data about the number of fatalities versus plan area of buildings from past earthquakes in Mexico, the following expression was obtained [3, 5]:

$$N_D = 45.48 + 5.53174\,(A/1000)^2 \tag{7}$$

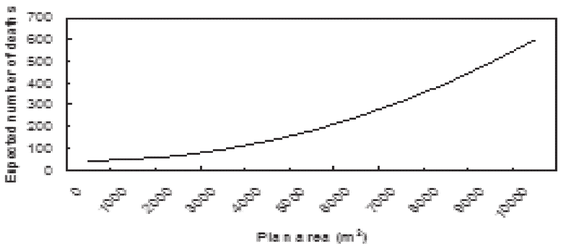

Fig. 2. Expected number of fatalities given the collapse of reinforced concrete buildings in Mexico City as a function of their plan area.

6. Reduction on fatalities and losses

The expected number of fatalities may be expressed:

$$E[N_D] = E \left\langle N_D \mid Failure \right\rangle P_f \tag{8}$$

where: $E \left\langle N_D \mid Failure \right\rangle P_f$

is the expected number of fatalities given the building failure. The failure probability *Pf* depends on the vulnerability of the structure and might be reduced through an increment on the structural design resistance. Therefore, the cost/benefit ratio of the investment made to increase the resistance versus the number of fatalities avoided may also be assessed.

$$CB_1 = (C_{i2} - C_{i1}) \,/\, (E[N_D]_1 - E[N_D]_2) \tag{9}$$

Another cost/benefit ratio is the investment made on resistance versus reduction on total losses.

$$CB_2 = (C_{i2} - C_{i1}) \,/\, (E[C_L]_1 - E[C_L]_2) \tag{10}$$

These two ratios may be estimated by assuming alternative designs with additional resistances and by calculating the expected reductions on fatalities and losses as derived from the increased resistance of the structure.

7. Application to a typical building in Mexico

A 7-storeys reinforced concrete building in Mexico is used to estimate the cost-benefit ratios from Eqs. (9) and (10). The floor plan area of the building is 6 750 m^2. See Figure 3 for the plan and elevation views.

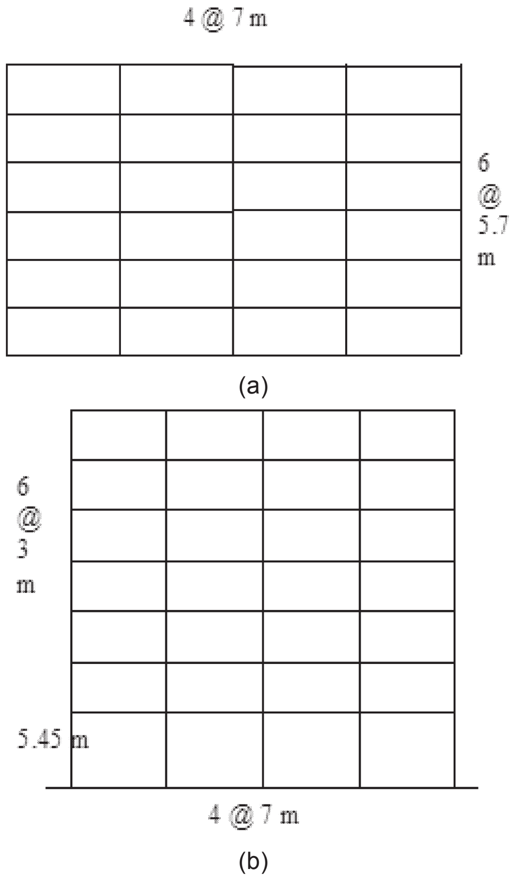

Fig. 3. (a) Plan and (b) elevation of a typical reinforced concrete building in Mexico City.

In the worst scenario case, it is assumed that there are no injuries but all people inside the building, at the collapse time, die.

The mean occurrence rate of significant earthquakes is $\nu = 0.142$/yr.

The following costs are all in US million.

$C_{i1} = 0.4$
$C_{i2} = 0.55$
$C_r = 3.24$
$C_{1L} = 8.29$

In addition, the following data are used:

$\gamma = 8\%$
$L = 50$ years
$T = 2$ years

$N_{in} = 0$
$p_{f1} = 0.00875$
$p_{f2} = 0.003$

With the above figures, the expected number of deaths and total loss are:

$$E[N_D]_1 = 297.5*0.00875 = 26 \tag{11}$$

$$E[N_D]_2 = 297.5*0.003 = 0.89 \tag{12}$$

And the cost-benefit ratio for fatality prevention is:

$$CB_1 = 0.081 \tag{13}$$

Also,

$$E[C_L]_1 = 0.65 \tag{14}$$

$$E[C_L]_2 = 0.45 \tag{15}$$

And the cost-benefit ratio for losses prevention is:

$$CB_2 = 0.75 \tag{16}$$

8. Data of highway investment and fatalities in Mexico

The investment in Mexican highways in 2003 was 470 million USD [6, 8].

The number of fatalities in Mexico, due to transit accidents in 2000, was 35 000(.43) = 15 050 [9].

The number of fatalities in Mexico, due to transit accidents in 2005, was 14 000 [11].

A rough estimation of the economic effectiveness CB_3 on the highways safety investment may be obtained as:

$$CB_3 = 470/(15050 - 14000) = 0.4285$$

million USD per fatality avoided.

9. Optimal restoration time for constructed facilities

Other interesting aspect for the risk management of constructed facilities is the decision about when to restore the capacity of a damaged structure in order to maximize the profit or minimize the risk [12]. The optimal restoration time depends on the restoration cost, the profit lost during the restoration and the annual discount rate and it is calculated from the following cost/benefit expression:

$$[R/C_D] = [1 - e^{-i*T^*}]*\ i/\{e^{-i*T^*} - [1 + i*(L - T*)]*e^{-i*L}\} \tag{17}$$

where: R is the restoration cost and $T*$ the time to restore the structure.

The optimal restoration time is shown in Figure 4 for several ratios of restoration to failure costs and several annual discount rates. The restoration time is represented as a percent of the structure lifetime.

10. Discussion

The formulation and illustration above presented include, in a systematic and explicit way, the socio-economic aspects underlying the failure of a typical building located on a highly seismic risk zone, as Mexico City.

Decisions about the necessary design safety level of the structure may be supported on the cost-benefit ratios in order to keep a balance between safety and costs.

Although it may be argued that the main mitigation measures, to reduce traffic accidents, is the promotion on the use of passenger belts and the driving without alcohol, the investment on highway safety has also a positive effect.

The difference on the values between CB_1 and CB_3 may be explained because of the different range of human lives at risk. Highway, as other infrastructure accidents require much more prevention measures than isolated buildings. However, for code making or updating purposes, which involve a

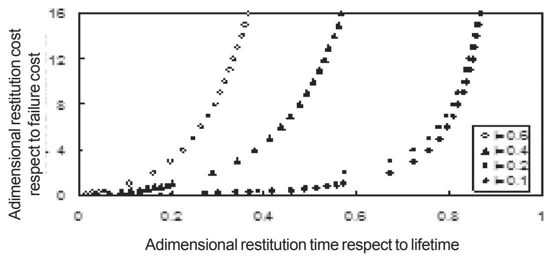

Fig. 4. Optimal restoration times for several discount rates.

massive number of structures and a high percent of population at risk, the cost of all the consequences involved should be taken into account.

The optimal restoration time is short as the ratio between the restoration and the failure costs is also short. As this costs ratio gets larger, the restoration time gets also larger. For small discount rates (stable economies) the restoration time may be postponed close to the end of the structure lifetime, for optimal results. Larger discount rates require the restoration time to be taken sooner because of the increasing value of money with time.

11. Conclusions and recommendations

A criterion for risk-based assessment including socio-economics has been proposed. The criterion includes cost/benefit ratios which are used to compare the economic effectiveness of investments made on highway and building safety. It is observed that the highway safety receives more investment than the building construction industry.

The formulation intends to contribute on the risk management area and some of the ideas provided may be extended to support government decision-making on the civil protection sector, to optimize resources allocation for mitigation measures and to locate infrastructure for development of industrial areas.

Acknowledgements

Data from the Mexican government is acknowledged and thanked by the author.

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