COST CONSIDERATIONS CONCERNING EARTHQUAKE SAFETY AND LOSSES FROM BURIED LIFELINE FAILURE

Dr.Ing. Oswald Klingmüller

GSP Mannheim Germany

1 UTILITY ASSESSMENT

The optimisation of limit state values is related to the derivation of optimal safety indexes for the respective limit state. This problem can be faced by using well known results of reliability analysis theory and by implementing cost-benefit or utility analysis aspects. While the methodology is practical and general, there is not much quantitative data available on the economical aspects.The assessment of structured utility is extremely complex and depends on many factors which lie beyond the recognised orbit of structural engineering. However by noting that the influence on utility of conceptual structural design is effectively limited to variation of initial costs and structural failure costs, and noting that despite non-linearities it is often convenient to relate utilities, structural utility U may reasonable expressed as:

$$U = B - C_I - \mathrm{Sum}(C_{Fi})$$

where

B = Benefit derived from fully serviceable structure

C_I = initial costs

C_{Fi} = costs due to failure in mode i.

DR.-ING. OSWALD KLINGMÜLLER
Gesellschaft für Schwingungsuntersuchungen und dynamische Prüfmethoden mbH
D-68167 Mannheim, Germany, E-mail : gsp-ife-ok@t-online.de
Tel 0049 621 33 13 61 Fax 0049 621 33 42 52

For each mode of failure, the utility of a structure such as a pipeline can be expressed as a function of a design parameter (Reid and Turkstra, 1981). Consider the earthquake acceleration as the representative parameter in case of earthquake loading. Below a level PGA1 a pipeline can be considered as completely serviceable and above a level PGA2 as completely unserviceable. The real utility of the considered structure lies between the upper and lower bound.

The influencing parameter x (i.e. herein the peak ground acceleration) is random and its design value is directly related to the selected safety level and reliability index. Therefore the utility function is also related to the reliability index and optimal reliability indexes to maximise binary utility functions can be derived by the procedure illustrated next.

2 OPTIMISATION PROCEDURE

Cost functions are implemented herein to optimise the safety index for ULS and SLS. The expected cost is taken here in the sense of the mathematical expectation of the negative utility of the structure including direct (no selling of supply goods, etc.) and indirect costs (harm to people, malfunctioning of production etc.).

The expected total cost of a structure can be expressed as:

$$CT = CI + pF * CF$$

where:
CT = total cost;
CI = initial cost;
CF = failure cost;
pF = probability of failure.

The initial cost can be considered as linearly increasing with the earthquake design force or better the earthquake design parameter (for example the particle velocity):

$$CI = C0 * (1 + c1 * E^*)$$

where:

C0 = basic initial cost excluding the influence of the earthquake impact;
c1 = linear increase parameter;
E* = design value for earthquake design parameter.

The earthquake design parameter is related to the failure probability and consequently to the reliability index (Diamantidis, 1986) as:

$$E^* = F_E^{-1} [\Phi (-\alpha_E * \beta)]$$

where:

F_E = distribution of the earthquake parameter;
α_E = sensitivity of the earthquake parameter to the failure probability (or in general to the probability of exceeding a specified limit state condition).

For the earthquake parameter extreme types of distribution are usually applied (Klingmüller und Bourgund, 1992):

$$FE = \exp \{-\lambda T (\exp (-k (E - u)))\} \quad (2)$$

where:
λ = occurrence rate of earthquake events, which are assumed to follow a Poisson process;
T = period of observation;
k, u= distribution parameters (Klingmüller und Bourgund, 1992).

From Eqs. (1) and (2) follows:

$$E^* = u - \frac{1}{k} \ln[- (1/\lambda T) \ln \Phi (-\alpha_E \beta)]$$

By considering failure costs as a linear function of basic costs Co, i.e.

$$CF = \rho C0 \quad ,$$

the following relationship is obtained :

$$CT = C0 - \{1 + c1 - (u - \frac{1}{k} \ln [-(1/\lambda T) \ln \Phi (-\alpha_E \ \beta)])\}$$

$$+ \Phi (- \beta) \rho C0 \qquad (3)$$

The optimal design is given by the condition:

$$(\partial CT / \partial \beta) \quad = \quad 0$$

The solution of the above condition leads by use of some simplifications to:

$$\Phi (- \beta) \ln \Phi (-\alpha_E \beta) \quad = \quad - (c_1 * \alpha_E^2) / (k \rho)$$

Since: $k \quad = \quad p / (\mathrm{sqrt}(6) * \sigma_E)$

with σE the standard deviation of the earthquake design parameter:

$$\Phi (- \beta) \ln \Phi (-\alpha_E \beta) \quad = - c1 * \alpha_E^2 \ \sigma_E) / (1{,}28 \rho) \ (4)$$

Equation (4) can be numerically solved and optimal β-values can be obtained. The deviation σE can be also written as:

$$\sigma E \quad = \quad VE \ \ mE$$

where:

m_E	= mean value of earthquake parameter at which certain damage or utility loss may occur;
VE	= associated coefficient of variation.

The parameter mE depends on type of pipe under study (for example if the earthquake acceleration is considered as the design parameter mE < 0.05 g would not cause any damage at all while mE = 0.3 g could lead to complete failure) while VE is usually high, i.e. can be in the range of 40 percent.

3 DISCUSSION OF INFLUENCING VARIABLES

The derivation of optimal design values for limit state analyses of buried lifelines subjected to earthquake loading depends on a number of parameters entering equation (3). These parameters are discussed next.

Sensitivity factor αE

The sensitivity factor αE reflects the influence of the random earthquake loading (represented by its dominating parameter such as the particle velocity). The importance of the earthquake load in a general limit state formulation was studied by Diamantidis and Moghtaderi-Zadeh (1986), and it was concluded that the earthquake input parameter is the most dominating variable, while other uncertainties such as those related to threshold displacement or damping are of second importance. Therefore the sensitivity factor αE can be assumed in the range of -0.7 to -1.0, in accordance also to general recommendations given by König and Hosser (1982).

Cost Factor c1

The initial costs of a buried pipeline can be subdivided as follows (Reimann, 1973):

☐

a) material costs (ranging from 5% to 20% of the total costs);
b) excavation/trenching costs (of the order of 35%);
c) construction costs (ranging from 30% to 40%);
d) general costs including planning and design (of the order of 20%).

An increase of the pipe thickness due to earthquake loading would have mainly an impact on the costs of category a) and b), i.e. on the costs which are representing c.a. 50% of the overall basic costs. Since the pipe should be designed also for other loads such as dead load, traffic load and earth pressure the impact of the earthquake design load would be reduced.

For the purpose of parametric studies herein c1 has been reasonably selected as 1,0 and thus has the character of a factor to clear dimensions. By use of c1 = 1 the initial cost will increase with the design earthquake value, i.e. 50% cost increase for a mean peak ground acceleration of 0.5 g.

Cost ratio ρ

The cost ratio reflects the influence of the failure consequences. Different failure consequences can be assumed for the SLS and ULS. It appears here appropriate to establish on the basis of existing damage data and engineering judgement ratios ρ for each safety category (ULS, $\rho = 10 \div 100$; SLS, $\rho = 1 \div 3$ for example).

Statistical Properties of Earthquake Parameters V_E , m_E

Several values for mean damaging earthquake parameters have been reviewed in the available literature with the coefficient of variation V_E has been selected as 1.0 (i.e. 100% variability). An optimal set of safety and serviceability indexes can be derived for the various safety classes.

4. DISCUSSION OF REPRESENTATIVE RESULTS

Several sensity analyses have been performed with the aim to achive the influence of the discussed parameters on the optimal safety index βopt. The optimal index for SLS is associated to ρ–values ranging from 1 to 5 and therefore takes values between 1.5 and 2.0. The optimal safety index for ULS is associated to ρ–values between 10 and 1000 and takes therefore values between 2,7 and 3,7. The influence of the mean value of the PGA is not very significant.

5. CONCLUSIONS AND RECOMMENDATIONS

An optimal set of safety indexes has been derived on the basis of reliability analyses and cost-benefit/utility considerations. This set of values represents the annual target safety level for the design of buried lifelines subjected to earthquake. In order to achieve the target safety design loads and resistances must be defined. These parameters can be represented by design return periods and allowable limit state values/criteria respectively. It is noted here that the return period is directly related to the safety index β (Diamantidis et al., 1991) as:

$$T = 1 / (F(-\alpha_E \beta))$$

The proposed criteria are compatible with state-of-practice current European code formats and with state-of-the-art reliability analysis tools.

REFERENCES

Diamantidis, D., 1986, „Reliability Aspects for the Design and Redesign of Offshore Structures“, Fifth International Offshore Mechanics and Arctic Engineering Symposium, Vol. 2, Tokyo, Japan.

Diamantidis, D. and M. Moghtaderi-Zadeh, 1986, „Probabilistic Earthquake Response Analysis“, Proc. 8th ECEE (European Conference on Earthquake Engineering), Lisbon, Vol. 1, pp. 2.5/2.5-2.5/32.

Diamantidis, D., F. Zuccarelli, C. Vardanega and E. Valente, 1991, „Deterministic versus Probability Based Seismic Design Criteria, Experience Gained from Seismic Risk Studies in the Adriatic Sea“, Proceedings OMAE Conference, Stavanger.

Klingmüller, O. and K. Bourgund, 1992, Sicherheit und Risiko im Konstruktiven Ingenieurbau, Vieweg & Sohn, Braunschweig/Wiesbaden.

König, G. and D. Hosser, 1982, „The Simplified Level II Method and its Application on the Derivation of Safety Elements for Level I“, CEB-Bulletin d'Information No. 147.

Reimann, D., 1973, „Baukosten größerer Abwasserleitungen von NN-600 bis NN-1800“, Kommunalwirtschaft, Heft 9.

Reid, S.G. and Turkstra C.J.: 1981 „Probabilistic Design for Serviceability“, Proceedings of 3rd ICOSSAR, Trondheim, Norway

European Commission

Directorate General
Science, Research and Development

Environment and Climate Programme
International Cooperation Programme

EU - JAPAN Workshop on Seismic Risk

Proceedings of the first expert meeting held in Chania, Greece on 24 - 26 March 1998

Edited by

C. P. Providakis and **M. Yeroyanni**

Assistant Professor
Department of Applied Sciences
Technical University of Crete
GR-73100 Chania
Greece

Scientific Officer
European Commission
200, rue de la Loi
B-1049, Brussels
Belgium