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Evaluation of target seismic safety level and safety consciousness from user surveys

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ABSTRACT: This paper describes seismic safety requirements of citizens, using a quantitative evaluation of the target seismic safety level from a previous Japanese survey, and estimates of expected and "tolerable" damage from a survey in Vancouver, Canada. The Japanese survey derived user's willingness to pay premium combined with marginal cost data to determine the safety level in terms of a reliability index. In the Canadian survey, marginal cost of measurable increases in seismic safety for specific structural types in Canada were determined through interviews with practicing structural engineers, and opinions about tolerable damage levels were determined through a survey of non-experts. Subsequently to the earlier Japanese study, the Canadian survey provides insights into social needs and social response to seismic experience.
The paper is intended to contribute to the perceived need to involve public participation in the selection of safety levels, while at the same time recognizing that the public has little knowledge of structural safety. It is hoped that comparisons and contrasts from such results will improve our ability to formulate performance based design standards that meet the needs of society.

1 INTRODUCTION

The development of codes and standards has evolved over the past four decades from judgments of safety factors by a few eminent experts on the code committees, to elaborate studies and analyses of probabilities by code committees and designers. The group that has not yet been consulted is the lay public. In this paper, we focus on two very different groups from the lay public.

Japan is well-known to be an earthquake prone country. The safety level of Japanese buildings is largely determined by their seismic performance. Japanese society expects an adequate seismic safety level, yet no socially explicit consensus has been determined to quantify this level. The need for explicit target safety levels is further emphasized by the introduction of the performance-based design approach.

Vancouver Canada is also a location of high seismic potential, but the frequency of strong earthquakes is relatively low. There is much less experience with earthquake damage than in Japan. Members of the public are expected to have a lower awareness of seismic risk. There remains, however, a need to establish safety levels and damage control through codes that are acceptable to the public.

In both Japan and Vancouver Canada there is a need to retrofit old buildings to a suitable standard, hence a need to have a framework for rational decision making regarding the costs and benefits of a retrofit.

Determination of safety requirements is a challenging task. In the past several methods have been devised to address this issue: (1) Calibration to current, "accepted" design practice, (2) calibration to the background risk in society, (3) reliability-based optimal structural design, where the failure cost and probability is included in the objective function, and (4) determination of the social consensus level. In this paper, the last two approaches are explored and compared.

Following the Kobe earthquake of 1995 the public in Japan has been sensitized towards a need for a consensus safety level. Because users do not have a clear and consistent notion of safety levels, the first two authors conducted a survey in Japan that investigated the social consensus level by determining what people were willing to pay as a premium for seismic safety (Hirata and Ishikawa 2001).

This paper outlines a quantitative evaluation of the target seismic safety level from the foregoing Japanese survey and an additional survey in Canada.

The formulation uses the "willingness to pay" premium combined with marginal cost data to determine the safety level in terms of reliability index and damage percentages. Marginal cost of measurable increases in seismic safety for specific structural types in Canada was determined through interviews with practicing structural engineers. Subsequently to the earlier Japanese study, the Canadian survey provides insights into social needs and social response to seismic experience.

2 PERCEPTIONS OF SEISMIC SAFETY REQUIREMENTS IN JAPAN

We summarize briefly the result of a previous Japanese survey that was intended to determine a target safety level in terms of a probabilistic safety index as implied by non-experts' willingness to pay (Hirata and Ishikawa 2004). Respondents' data from the survey are shown in Table 1.

2.1 *Safety index and failure probability*

In this study it assumed that a respondent builds a house on his or her land. The strength R of a building and the seismic load effect S caused by an earthquake are random variables. The load effect is the peak acceleration response at the residential area caused by an earthquake in the calibration period (taken as 50 years). R and S are assumed as independent log-normal random variables. A house collapse is defined as a case in which S exceeds R at least once, i.e., the response of the first floor is greater than the strength of the building. The performance function Z is computed from the equation Z=R/S.

2.2 *Strength requirement of users*

The strength requirement R of a respondent for their own house is calculated by the relationship between cost the respondent chooses to pay and the structural safety level. Respondents were asked to provide their opinion as to the relationship between the cost and safety. The respondents then selected their willingness to pay as an increase (proportion) of the standard cost, where standard cost is the assumed base cost under current accepted practice. Fig. 1 is a histogram of the willingness to pay values for the respondents. The average is 109%, or a cost ratio of x = 1.09.

Kanda et al. (1994) have reported on the relationship between strength and cost. Based on the willingness to pay of each respondent, a corresponding strength was calculated. Coefficient of variation of the strength was estimated as about 0.4.

Table 1. Outline of Japanese user questionnaire

investigation	No.1	No.2
period	June-July, 1999	August, 1999
object person	female univ. students	female
age	10s-20s	10s-70s
place of residence	around Tokyo	all parts of Japan
numbers	208	377

2.3 *Evaluation of probable seismic load effect*

The load effect S and its coefficient of variation are based on the probable maximum load effect in the structure life, based on available statistics over the past 400 years, at the site of the respondent's home (calculated from the acceleration response ratio for the location).

2.4 *Target safety level requirements*

The safety index β was then calculated for each respondent. Fig. 2 shows the results for all respondents. From this figure, the average value of target safety level β required by social opinion is about 2.4. The corresponding P_f is $9*10^{-3}$. This is higher than the current estimated value of about 1.3-1.7. This confirms the general indications that especially after the 1995 Kobe earthquake, most people are sensitive to the need to improve safety of housing in Japan.

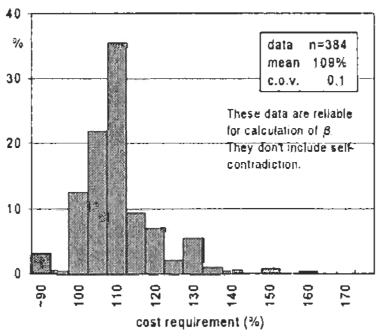

Fig. 1 Willingness to pay for upgrading of seismic level

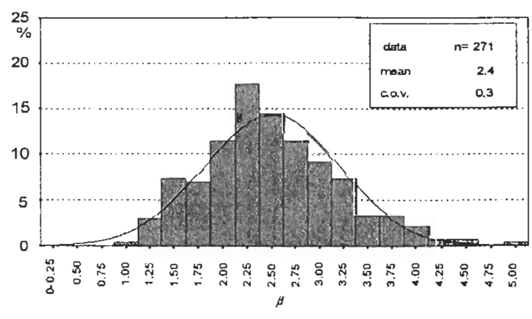

Fig.2 User requirements for target safety level standardized for a 50 year reference period

3 SEISMIC SAFETY REQUIREMENTS IN VANCOUVER CANADA

The purpose of this phase of the investigation is to establish a means by which users of structures can communicate their perceptions of seismic structural safety, after having been informed by structural experts as to the probabilities and costs associated with varying levels of safety. The investigation is focused on the seismic safety of several building types in the Vancouver, Canada, area. While the Japanese study aimed at determination of safety index, with its focus on failure or survival, the Vancouver study is aimed at proportion of damage, for example, damage cost as a fraction of building replacement cost. While current seismic codes focus on protection for life safety and collapse, recent earthquakes in major North American cities and in Kobe, Japan, have shown that the damage cost is extremely important.

3.1 *Predicted risk and damage*

The survey of a small number of citizens was conducted in order to determine their opinions about seismic risk and tolerance for damage. In order to obtain opinion from the lay public, it was first necessary to inform them as to some basics of the physical situation as it affects seismic safety. In the Vancouver area, there is almost no experience with earthquakes of significant size, yet there is potential for these, and there is news of faraway events along with reminders that these could happen nearby. Information provided to the lay public was based on a series of interviews with several experienced structural engineers in the area.

The citizen survey was carried out from November 2004 to March 2005. The results in this paper are computed based on a sample of 64 responses to the questionnaire (Table 2).

The Vancouver respondents were asked to rank a number of life risks. The Vancouver sample showed that earthquake risk is considered to be relatively low, along with snow damage, wind, and terror attack, compared with higher perceived risks such as global warming, air pollution, and motor vehicle accidents.

Table 2. Outline of user questionnaire in Vancouver

Group	Business people	General Citizens
Date	Nov. 2004	Mar. 2005
Answers	25	39
Collecting rate	69%	33%
Gender (M:F)	18:7	20:19
Age	20s-70s	20s-60s

This result is not surprising, because experience with earthquakes in Vancouver is almost nil, and an aware public recognizes that there are many life risks and that earthquakes are not among the likely ones. An implication of this result is that there would not likely be public support for significant expenditures to mitigate seismic risk when there are many other priorities for funds. Further, there is not likely a private market for significant seismic upgrading of housing.

The size expected (by lay people) of a major earthquake in Vancouver represented by Modified Mercali Intensities (MMI) is shown in the Fig. 3.

MMI VIII, which most respondents expected, corresponds to peak ground acceleration slightly higher than the current code value for Vancouver (NBCC 1995). The NBCC code is based on a peak ground acceleration and velocity with 10% probability of exceedance in 50 years (a 475 year return period).

Fig. 4 shows the return period estimated by the respondents, and the mode corresponds to the code value. These results indicate a fairly realistic understanding of the seismic hazard, and a conformance with what seismic experts would estimate. The variability in responses would be expected, since there is such a scarcity of actual data in the region.

Predicted damage of respondents own houses is shown in Fig. 5. Most respondents assume the damage would be moderate (or about 10-30 percent of replacement cost). The variability of responses is consistent with the actual variability of the performance of housing, since the structural performance of detached houses is highly variable and dependent on architectural style and arrangement as much as by structural details.

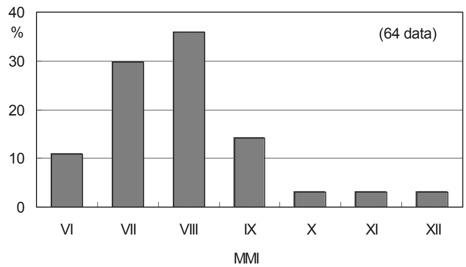

Fig. 3 Predicted earthquake in Vancouver

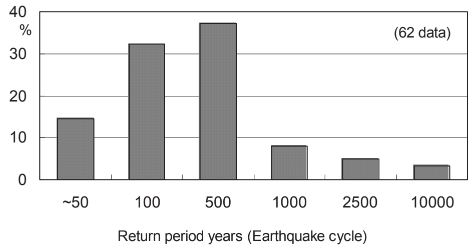

Fig. 4 Return period prediction as earthquake cycle

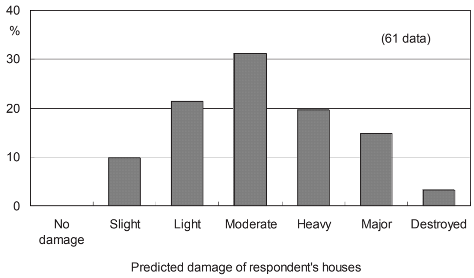

Fig. 5 Predicted damage of respondent's houses

3.2 *Damage evaluation*

Respondents were asked about the relationship between safety and cost of housing. 81% of respondents agree there is a relationship and most agreed that there is an upper limit to safety. The implication here is that they understand that 100 % safe is not possible, and that houses in particular contain many surprises in behaviour that cannot be rationally overcome by normal structural design. Further, most houses are not structurally designed – rather they are layed out by architects or designers and built to accepted rules.

Respondents were shown an estimate (based on experts' opinions) of the damage to be expected (percent of replacement cost) as a function of seismic intensity (Mercali intensity) for a typical house, office building, and unreinforced masonry schools (of which there are many in the Vancouver region). They were then asked for their comfort level with the current safety as represented by the predicted damage levels, and the percent increase they would be willing to pay to reduce the damage. The damage reduction cost was presented to them, based on experts' estimates (from the structural experts survey described in the next section).

In the case of their own house, about two third of respondents were comfortable with current risk that implies about 10 to 30 percent damage in a seismic event of MMI VIII, which is slightly greater than the design code basis. Fig. 6 indicates the proportion of

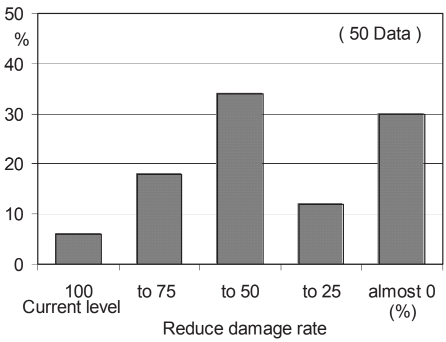

Fig. 6 User estimate of reduction rate for existing wooden detached house

responses that would be willing to pay to reduce the damage rate (by retrofit of their house). It shows that this willingness to pay varies greatly. About 6% of respondents would not pay to reduce the damage levels, while 30 % would pay about 8% of replacement cost to reduce the damage to almost zero (experts' estimates indicated that retrofit costing about 8% of house value could reduce damage to almost zero. This is a very crude estimate.)

In the case of office buildings (workplace) the experts' estimate of damage was slightly higher (about 15% for MMI VIII). About two third of respondents were comfortable with this. Fig. 7 indicates the proportion of responses that would support reduction of the damage by retrofit (it is implied that they recognize that office rent would have to pay for this). Most respondents would prefer some reduction, but few would support the cost of reduction of damage to almost zero.

The situation with unreinforced masonry schools in Vancouver is of great interest. Estimated damage in a MMI VIII event is about 30% or more, and experts' estimate was that it would cost about 30% of building cost to reduce this to almost zero. About 30% of respondents indicated comfort with the current situation, most would like to see expenditures to reduce the damage by at least half, and about 30% would support damage reduction to almost zero (Fig. 8).

This situation illustrates what Section 4 shows analytically. From a cost-benefit viewpoint, it is clear that it does not make sense to spend 30% of replacement value now, to eliminate a probability of 30% damage in the future, when the damage probability is very small. Retrofit expenditures to reduce future damage will generally prove to be unjustified from a cost-benefit viewpoint when the damage costs are only the direct building repair costs. The more important reasons for retrofit are protection of life, protection of home, school or

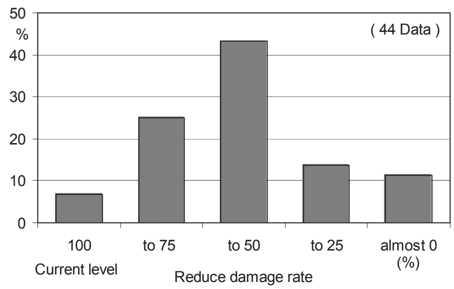

Fig. 7 User estimate of reduction rate for existing medium-rise RC office building

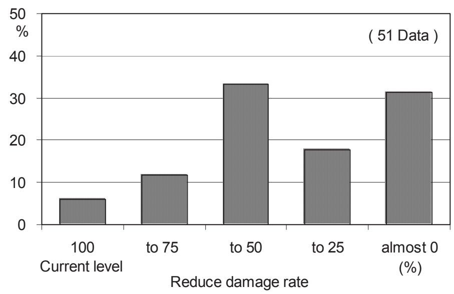

Fig. 8 User estimate of reduction rate for existing unreinforced masonry school

business continuity, and mitigation of possible community large-scale disruption.

While most of the foregoing is concerned with current buildings and their possible retrofit, respondents were also asked about the future code provisions. Cost-safety relationships based on experts' opinions were used as a basis.

For a future new house, Fig. 9 indicates the cost-safety relationship as estimated by structural experts. Respondents were asked to plot their estimate of willingness to pay on the indicated line. Most respondents indicated willingness to pay up to 5% of total cost extra to achieve greater than 50% increase in safety (seismic force level).

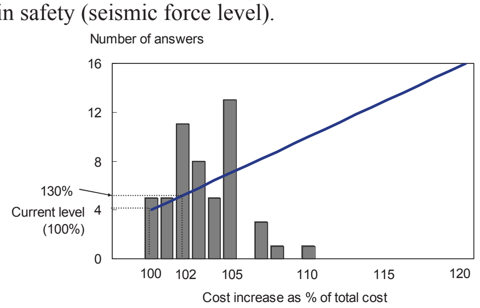

Fig. 9 User's willingness to pay for future house

An important observation here is that the cost of increases in force level and safety is very small for new structures, and there is willingness to pay a small increase as indicated above. Experience with building developers, however, is that there is strong resistance to even a small increase to pay for seismic safety. This dichotomy between developers and owners poses an interesting dilemma for code writers, who get strong resistance to any changes in the code that increase requirements, yet strong demands from the public to provide improved safety.

General satisfaction with the building code was examined by finding that respondents would prefer a slight improvement in human life protection and in function of buildings, as indicated in the histogram of Fig. 10.

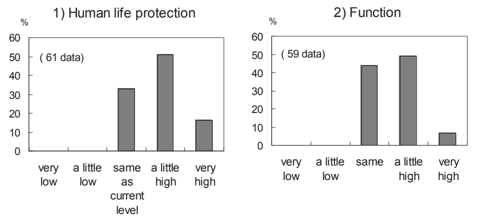

Fig. 10 Code requirement

4 RATIONAL DECISIONS BASED ON DAMAGE ESTIMATES FOR VANCOUVER

This investigation is focused on the seismic safety of several building types in the Vancouver, Canada, area. While the Japan study aimed at determination of reliability index, with its focus on failure or survival, the Vancouver study is aimed at proportion of damage, for example, damage cost as a fraction of building replacement cost. While current seismic codes focus on protection for life safety and collapse, recent earthquakes in major North American cities and in Kobe, Japan, have shown that the damage cost is extremely important.

4.1 *Rational retrofit decisions based on structural experts' opinions*

"Rational" in this discussion means a strategy aimed at minimizing total present value of expected cost in decisions as to the need and amount of retrofit to improve seismic safety. This discussion also assumes that damage costs (not life loss) dominate the consequences of major earthquakes in North America, and even in the 1995 Kobe, Japan earthquake.

Seismic damage can be represented by a *Damage Probability Matrix* (DPM), or by a *Mean Damage Factor* (MDF) (ATC-13 1985). The MDF is the expected value of damage as percentage of replacement cost, for a sequence of Modified Mercali Intensities (MMI). The MMI values were related to peak ground acceleration (pga) through an empirical relationship (Trifunac and Brady 1975). Structural experts in California developed DPM's (from which MDF can be calculated) for many building types (ATC-13 1985). These were modified by Onur (Onur 2001) to adjust for Vancouver conditions. We have used these as a basis, but have derived specific MDF's from our survey of structural experts in the Vancouver area.

At the very high MMI values, damage levels rated "major" or greater become more likely, and near collapse or full collapse, with loss of life, is possible. We assume damage levels of 60 percent and higher (rated as "major damage" in the ATC-13 document) represent "failure". From the DPM the conditional probability of failure given the occurrence of earthquakes of the various magnitudes was estimated, and then the unconditional probability of failure based on the estimated probabilities of the various MMI magnitudes was calculated.

Based on the DPM collected by Onur (Onur 2001, 2004), the estimated probabilities of failure (for 50 year reference period) are: 5×10^{-5} corresponding to $\beta \approx 4$ for detached houses, almost 0 for office buildings, and 5×10^{-3} corresponding to $\beta \approx 2.5$ for unreinforced masonry schools. These can be compared with failure probabilities and safety indices determined in the Japan study outlined in the foregoing.

This result indicates that safety for Vancouver structures is generally acceptable (compared with other norms for structures) in the case of housing and office structures, but is not satisfactory for unreinforced masonry schools. This result is consistent with the citizen's survey which showed a strong preference for improving the safety of the unreinforced masonry schools. It should be noted that the Government of British Columbia has pledged a program of retrofit or replacement of such schools, thus the lay opinion, expert opinion, and government policy all seem to be in harmony on this issue.

The several structural experts in the Vancouver area were asked to examine the DPM's and MDF's that were developed in California, and to modify them to agree with their own opinions, based on local experience. The experts' opinions were determined through a personal interview process with a questionnaire to focus the discussion.

The low, average, and high values of MDF's from the interviews were tabulated for each MMI value and for each of three structural types: a typical existing wood detached house built prior to 1990, medium-rise concrete frame office, and unreinforced masonry school. The interview also determined estimates of the upgrade costs of the same building types, in terms of the percentage of replacement cost that would be required to attain a quantified value of reduction in damage estimate.

Table 3 gives the MDF for these three basic structural types. The MDF values represent estimates of the fraction (of replacement cost) of damage to be expected in the structure for an earthquake of the MMI value in the column. There was considerable variation among the experts. This should be expected, since the definition of the building types was broad, and each respondent would have their own sense of what a "typical" building in the class would be like. The low estimate generally conformed to the values suggested earlier by Onur (Onur 2001), while the high estimates represent a less optimistic view of what may occur in a seismic event.

Table 4 provides, for the MMI values of interest, peak ground acceleration as percent of gravity (pga), annual probability of occurring or exceeding (ape) estimated for the Vancouver area (usually called the probability of exceedance), based on estimates from NBCC (1995), with the resulting annual probability of occurrence u_j. The latter is based on the approximation that the given increments of pga and MMI constitute a set of discrete possibilities.

The probability of MMI less than VI is large, with negligible damage. The probability of MMI greater than X is negligible. Thus the only consequences (losses) of interest are included with the annual probabilities given in the table.

Table 3. Mean Damage Factors for three building types in Vancouver

Detached house	MMI						
	VI	VII	VIII	XI	X	XI	XII
High estimate	0.01	(0.16)	0.20	(0.4)	0.60	-	-
Mean	0.01	0.04	0.11	0.13	0.33	0.31	0.39
Low estimate	0.01	0.04	0.06	0.12	0.23	0.28	0.38

( ) : Interpolated value for the lack of answer.

RC office	MMI						
	VI	VII	VIII	XI	X	XI	XII
High estimate	0.07	(0.26)	0.45	(0.73)	1.00	-	-
Mean	0.03	0.09	0.18	0.16	0.43	0.39	0.51
Low estimate	0.01	0.04	0.08	0.17	0.24	0.39	0.51

Unreinforced masonry school	MMI						
	VI	VII	VIII	XI	X	XI	XII
High estimate	0.25	(0.43)	0.60	(0.80)	1.00	-	-
Mean	0.08	0.13	0.36	0.35	0.65	0.67	0.80
Low estimate	0.03	0.10	0.23	0.35	0.52	0.66	0.80

Table 4. Peak ground acceleration, annual probability of occurring, and annual probability of occurrence

MMI	pga	ape	u_j
VI	0.07	0.015	0.010
VII	0.13	0.005	0.004
VIII	0.26	0.001	0.0005
IX	0.53	0.0005	0.00045
X	1.00	0.00005	0.00005

The occurrence of any of the events represented by the various MMI values may be taken as a sum of Poisson processes, each with the occurrence rates u_j as given in Table 4. Hence the total expected annual damage cost (as a percentage of replacement cost) is

$$C_a = \sum MDF_j u_j \quad (1)$$

Where j distinct values of MMI and u are considered. C_a could be considered the fair annual insurance premium that should be paid to indemnify the owner for the damage.

Damage in this investigation is represented by the MDF values, and is the direct damage to the structure due to the earthquake, as a fraction of replacement cost. Most real decisions about retrofit would include other damage costs, such as death and injury, loss of use, disruption of business or community, etc.

Seismic damage is usually mitigated by retrofitting. In order to achieve an appropriate balance (minimum of total cost) with initial or retrofit cost and damage cost, we require the present expected value of the damage cost. This is the present value of an annuity of annual amounts C_a, with an appropriate real interest rate i.

The present expected value of the damage cost, assuming continuous compounding and Poisson occurrence rates for each MMI level (Sexsmith 1983) is

$$C_p = \sum [(MDF_j u_j) / (i + u_j)] \quad (2)$$

Where MDF_j is the MDF for MMI value j, and u_j is the annual occurrence rate of MMI_j. i is the interest rate or discount rate.

For annual occurrence rates of the order found for earthquakes of the intensities considered ($u<<i$), this can be approximated by

$$C_p = C_a / i \quad (3)$$

Structural engineers were also asked to estimate the cost of retrofit construction C_r to reduce the damage percentages to lower values. From this information we can develop a policy for retrofitting, based on minimizing the expected value of total present cost. C_r is the cost to perform the retrofit as a fraction of replacement cost of the structure.

For a proposed retrofit a new value of C_p is calculated using the new projected values of MDF. Denote this as C_{pr}. If the retrofit is to result in “almost zero” potential damage, then C_{pr} becomes zero. The total cost of achieving the retrofit C_t is the retrofit cost C_r plus the new present expected value of damage C_{pr}:

$$C_t = C_r + C_{pr} \quad (4)$$

Table 5 Result derived from expert survey

Structure type		Ca	Cp	Cr	Cpr	Ct
Wooden detached house	High estimate	0.0011	0.021	0.10	0.0	0.10
	Mean	0.0004	0.009	0.08	0.0	0.08
	Low estimate	0.0004	0.008			
RC office	High estimate	0.0023	0.047	0.20	0.0	0.20
	Mean	0.0008	0.017	0.20	0.0	0.20
	Low estimate	0.0004	0.007			
Unreinforced masonry school	High estimate	0.0049	0.099	0.60	0.0	0.60
	Mean	0.0016	0.031	0.30	0.0	0.30
	Low estimate	0.0010	0.020			

And the retrofit should be performed if this total is less than the original value of C_p that is in effect before the retrofit. Table 5 provides results of a calculation that serves as an example for “rational” retrofit policies for the three building types. In Table 5, retrofit costs are based on the costs estimated by the experts to bring the expected damage to almost zero. The costs represent fraction of replacement cost. C_{pr} is therefore taken as zero in all cases. The interest rate was assumed to be 0.05.

In all cases, the value of C_t is substantially greater than C_p, indicating that retrofit costs are not justified. In the case of housing and office buildings this is due to the fairly low probabilities of damage, reflected in low values of C_p. In the case of schools, the damage costs are relatively high, but the retrofit costs are also very high. In such cases it will be necessary to consider demolition and replacement rather than retrofit.

This calculation was done using consequence costs reflecting only cost of repair as a fraction of replacement cost. Other consequence costs, which could be estimated and included, include loss of use of the facility, disruption, life loss, medical costs, and other items. Thus the conclusions are limited to the cases in which damage costs dominate.

4.2 *Conclusions from the Vancouver Survey*

The Vancouver survey of non-experts showed a surprising consistency with the expert opinions. The non-experts required slightly more safety in the sense of damage reduction than was currently in the built structures, but of course the codes have generally improved this in the past decade and it will be reflected in new structures.

The structural experts provided information that was used to examine existing safety and costs for retrofit. It indicated that existing safety index values were generally within accepted norms. Survey results and an expected cost minimization procedure outlined above, indicated that retrofits are unlikely to be cost effective in generic structural types. This does not mean that specific structures should not be considered for retrofit, based on individual analyses. In particular, consideration of a specific, rather than generic, structure will no doubt raise issues of other consequences, including medical, life loss, disruption, and loss of use. All such costs need to be estimated and included where they are relevant. This will generally increase the benefit of retrofit.

The interviews with experts show that the cost of retrofit of existing structures is generally very high in proportion to the damage reduction that can be obtained. Even if additional damage costs (eg. loss of use, community disruption, etc.) were included it is likely that retrofit would be difficult to justify in many cases. Only if life loss is an issue will retrofit be generally cost-effective. In contrast, the cost of increasing the safety substantially is very low for new structures being designed. Thus the new design codes are justified in continuing to improve the prescribed safety, at very small increases in cost.

Finally, the safety requirements of Vancouver respondents and of Japanese respondents appeared to be consistent with what should be expected. The Japanese have much higher probabilities of damage, hence the required safety level as indicated by β is slightly lower than the value for Vancouver.

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REFERENCES

Applied Technology Council. 1985. *Earthquake damage evaluation data for California ATC-13 Report*. Redwood City, California.

Hirata, K. & Ishikawa, T. 2001. Probabilistic evaluation of target earthquake-resistant level derived from requirements of users - For better indication of performance reflecting user's needs -. *Journal of Structural and Construction Engineering of Architectural Institute of Japan.* (No. 543): 23-29. (in Japanese)

Hirata, K. & Ishikawa, T. 2004. Probabilistic evaluation of desirable target seismic level derived from requirement of users; *Conference Proceedings 2004 13th World Conference on Earthquake Engineering.* Vancouver, Canada, Aug. 1-6, 2004.

Kanda, J. et al. 1994. An evaluation of the effect of economic factors in optimum reliability; *The Building Center of Japan Report*. Japan. (in Japanese)

NBCC. 1995. National Building Code of Canada. National Research Council, Ottawa, Canada.

Onur, T. 2001. Seismic risk assessment in southwestern British Columbia, *Doctoral Thesis of the Department of Civil Engineering*, The University of British Columbia.

Sexsmith, R. G. 1983. Bridge risk assessment and protective design for ship collision, *IABSE Colloquium, Copenhagen, Denmark 1983*: 425-433.

Trifunac, M.D. & Brady, A.G. 1975. On the correlation of seismic intensity with peaks of recorded strong ground motion, *Bulletin of the Seismological Society of America*, Vol. 65(No. 1): 139-162.