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PROBABILISTIC EVALUATION OF DESIRABLE TARGET SEISMIC LEVEL DERIVED FROM REQUIREMENTS OF USERS

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SUMMARY

Many methods have been developed for evaluating the seismic safety performance of buildings. However, we have no adequate method for communicating with users directly on target safety level using easy words. In future, designers will need to communicate more with users regarding target levels of building performance, because structural safety performance is particularly important, and many users will require a performance indication and guarantee for their own houses. Therefore, the target safety level must be clarified quantitatively as soon as possible, based on users' needs. However, professional designers have never had a clear grasp of users' requirement as an indication of safety level. This paper evaluates probabilistically a desirable target safety level from user questionnaires using a structural reliability theory. Many users do not have an exact understanding of current seismic safety levels in Japan when the safety index is expressed by seismic intensity. Nevertheless, we should have a grasp of users' requirement quantitatively in the future. The results of this study show how users' requirement levels can be indicated as a reliability index.

INTRODUCTION

In Japan, performance-based design was introduced by a revision to laws in 1998. This was a turning point. In 1999 a new law was enacted to accelerate securing of the quality of house. From this law, we can easily indicate the performances of structures. The introduction of this new system also changed the social paradigm concerning ensuring of performance quality in Japanese society. This new paradigm needs informed consent or disclosure of information from professionals.

In the modern era, major technology has shifted from industry to information, and the performance-based design method moves with the times because this method is required to disclose information to users. Society requires a more meaningful communication method between users and professionals regarding performances of buildings. Structural performance of buildings is very important. However, there some research has been carried out to clarify user requirements for the structural safety performance, especially social requirements of target level of seismic safety. Most professionals do not have a clear grasp of user

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needs. No research has yet been carried out to clarify social needs quantitatively on target seismic safety level.

The target safety level has historically been decided by only professionals or designers. These target levels must be primarily based on social consensus. However, not enough professionals listen to opinions from society and users.

From the viewpoint of safety engineering, there are 4 bases for decision: calibrations, background risk, optimum level by utility theory, and social needs. This paper focuses on social needs. We propose a new method for communicating with users directly to decide a desirable target seismic level. Our research objectives are quantitative understanding of social needs for seismic safety level, and an analysis of the clarified levels available for structural design.

METHOD

This paper describes social needs for target safety level as a probabilistic safety index. A new quantitative evaluating method is proposed for calculating the level requirement of each user. User requirements data for calculation are shown in **Table 1**. These 585 data are derived from user questionnaires. Some confusion or misunderstanding is included in these answers because of lack of professional knowledge, but we can find a discrepancy in an answer and eliminate bad data from calculation by improving the questions. The probabilistic safety indexes are calculated as a reliability index β.

Table 1 Results of questionnaires

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

Outline of user data

The data shown in **Table 1** are for 585 ordinary women living in most parts of Japan. We surveyed only women to make the attribute even. Our previous surveys showed almost no difference between the cost images of males and females [1].

In this questionnaire, the user answers on the basis of her own house, and she can answer without technical knowledge. From the results of our 30 questionnaires, we were able to acquire answers with higher reliability. A house is assumed because many designers do not seem to understand that the target safety levels for houses are different from those of office buildings. The two questionnaire outlines are shown in **Table 1**, and age and residence area are shown in **Fig. 1**.

TARGET LEVEL EVALUATION BASED ON RELIABILITY THEORY

Appropriate safety index expressing target safety level requirement

Few users have an adequate way to express their requirements for target seismic safety of their houses or of other buildings. The most appropriate way to describe safety level requirements has not been established because users' answers have been misunderstood. Therefore we looked for a satisfactory way to express the safety level exactly. Our previous survey results show that many users consider the intensity scale to be the best expression of target level. However, users do not have an exact understanding of seismic level or damage level of buildings.

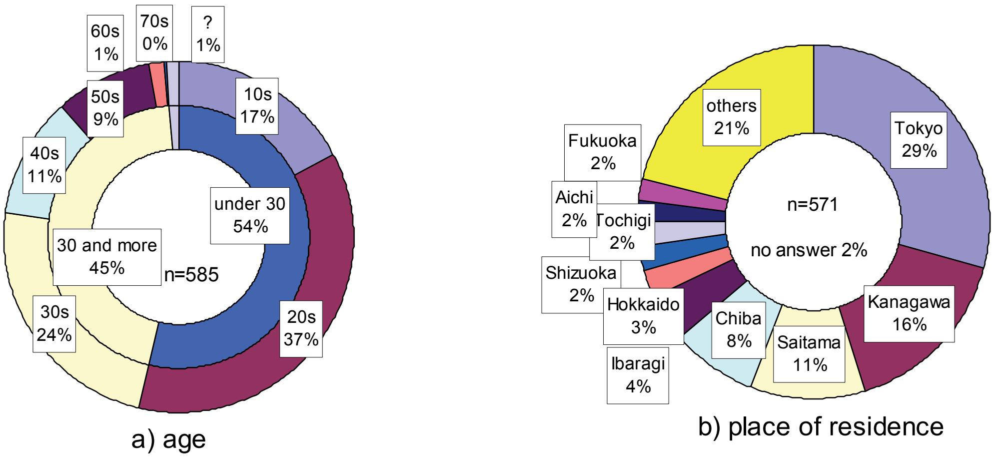


Fig. 1 Distribution of ages and places of residence

Fig. 2 shows the results of a question on standard safety levels that each user considers as a standard level for Japanese houses. The index is expressed in the range of the seven-point Japanese intensity scale in this figure. Many users consider that a standard house should have the strength to withstand a level 5 intensity earthquake at the limit state. This level falls below the minimum level set by the Building Standard Law of Japan. Many users have no exact recognition of safety level and cannot adequately express their requirements. Meanwhile, because most users don't always take a strong interest in safety level, they could not answer the real level until they carefully consider the cost. To derive quantitative values from users' requirements, it is important that users recognize that if the construction costs rise the safety level also rises. We consider that safety requirements can be expressed by the amount paid for their own house as a substitute for using seismic intensity scale.

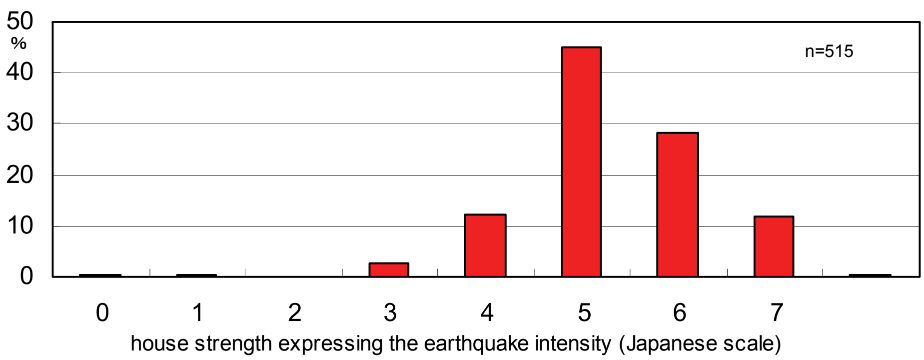


Fig. 2 Standard house strength based on user images expressed by Japanese earthquake intensity

If we can derive a cost and safety level from every user image, it is possible to calculate a target level requirement from their cost answer. Consequently, we propose a new reliability-based evaluation method for calculating target safety level for the real strength of a building by replacing the cost requirement of each user in calibration period. Cost is a concrete index, and it is a real way of calculating desirable target safety level. Structural designers can understand the level requirement of users.

Safety index and failure probability
Using the second-moment method, we can calculate the target reliability index β that a user requires for his house. **Fig. 3** is a flowchart of this calculation. In this calculation it assumed that a user builds a house on his land. Here, the seismic safety level is a probabilistic index, and we use a reliability index β.

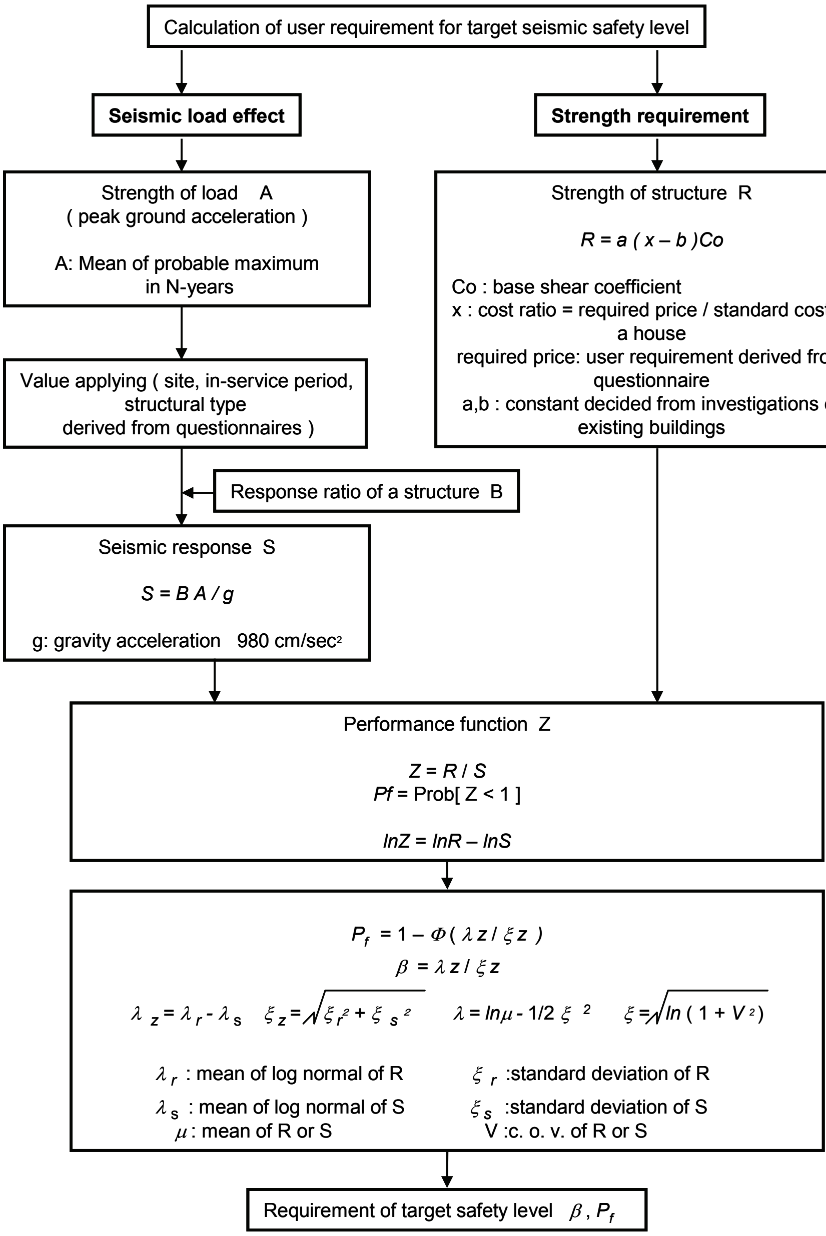


Fig. 3 Flowchart of level calculation process

In this case, the strength *R* of a building is a random variable, and the seismic load effect *S* caused by an earthquake is a random variable. We see that the load effect is the peak acceleration response at a user's residential land caused by an earthquake in the calibration period. *R* and *S* are independent log-normal distributions. It is assumed that a house collapses when *S* is more than *R* at least one time, i.e., that the

response on the first floor is greater than the strength of the building. The performance function Z is $Z=R/S$. The probability of failure P_f in the calibration period is given by
$P_f = Prob[Z<1]$

Because R and S are log-normal distributions, lnZ is given by
$lnZ = lnR - lnS$

The averages of R , S are λr and λs, and the standard deviations ξr and ξs are given by
$\lambda_Z = \lambda r - \lambda s$
$\xi_Z = [\xi r + \xi s]^{1/2}$

and
$\lambda = ln\mu - 1/2\xi^2$ μ: the average
$\xi = [ln (1+V^2)]^{1/2}$ V: coefficient of variance

Hence, the probability of failure P_f and the target reliability index β are given by
$P_f = 1 - \Phi(\lambda_Z / \xi_Z)$ $\Phi(\cdot)$: the standard normal density distribution
$\beta = \lambda_Z / \xi_Z$

CALCULATION PROCESS OF TARGET SAFETY LEVEL DERIVED FROM USER REQUIREMENTS

User images for safety level and cost
From the results of this investigation, the present user images between house cost and target safety level are shown in **Fig. 4**. These images have a similar tendency to the previous investigations for male and female objects. In this figure, point A is the standard cost (100%) of a house in Japan, point B is 110% of this cost. Many of objects have images where the cost has a proportional relation to safety level, and there is an upper limit of safety level.

We put two questions to objects where the strength of a house when the standard cost (point A) was paid as a seismic intensity scale, and the strength of a house when point B cost was paid. The seismic intensity scale was the most popular safety index for users among various indexes expressing level. In this case, the strength is expressed in a questionnaire sheet where the strength gives a no–collapse state but the building may suffer severe damage.

The mode of answers was the 5th scale of designed safety level of a standard house, which is nearly equivalent to 80 to 250 gal of ground acceleration (**Fig. 2**). The Building Standard Law of Japan ordains the seismic target level higher than these answers, which are from about the upper 6th to 7th in intensity. There is thus a level gap between users and professionals. Therefore, we try to describe a desirable target level from the cost that users pay for their house instead of from the intensity scale.

Calculation of strength derived from user requirement
The strength requirement of a user for his own house is calculated in the following way. We asked questions about cost the user wants to pay based on the image figure (**Fig. 4**). Then the real strength is derived from this cost answer. This strength is expressed as a base shear coefficient Co using the cost ratio, and the answer is calculated from the following formula. If the cost ratio is 1, that is the standard cost and it is expressed as 100% in this case.

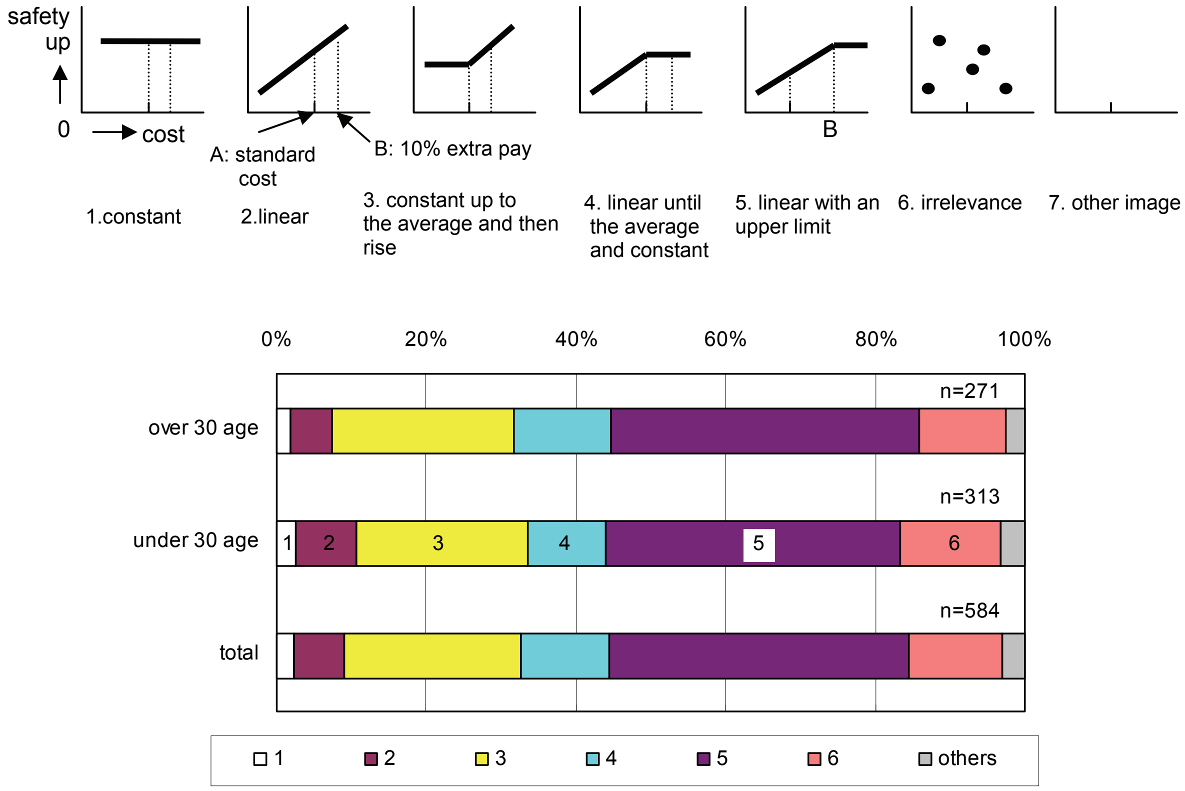


Fig. 4 User images of relation between house cost and seismic safety level

$R = 10.4\ (x - b)\ Co$
R: strength of a house
x: cost ratio (required cost divided by standard cost of a house)
b: a wooden independent house 0.923, non-wooden independent house 0.843, apartment 0.842

This formula replaces the user's strength image with a base shear coefficient *Co* based on the assumption that the construction cost has a correlation to the base shear coefficient. Japanese case studies have clarified the proportional relation between the strengths of various buildings and construction costs [2]. The result shows that construction cost is proportional to *Co*, and if *Co* doubles, the cost increases by approximately 10%.We used those line slopes in the above formula. This relation has equality from 0.5 to 2.5 of *Co,* except for wooden houses. We assume the relation applies to all structural types.

House strength was calculated for three structural types: a wooden independent house, a non-wooden independent house (RC), and an apartment building (from 4 to 9 stories high). The standard strength (cost ratio is 1) means the ultimate limit strength of a standard strength building prescribed by the Building Standard Law of Japan. Three building type models of restoring force characteristics were prepared, as shown in **Fig. 5**.

Co for standard cost, c.o.v. of strength, and response ratio of acceleration are shown in **Table 2**. These values are calculated for real structural design or research. Using these values, a user’s requirements for house strength is calculated as shown in **Fig. 3**.

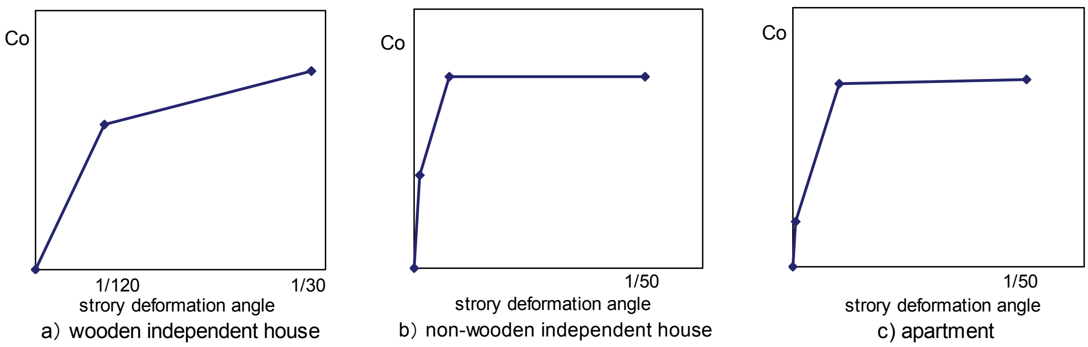


Fig. 5 Building models of restoring force characteristics

Table 2 Data of structural types

model	supposed building	Co of the standard cost	c.o.v. of strength of building	response ratio of acceleration
wooden independent house	traditional 2stories	0.80	0.4	1.5
non-wooden independent house	RC 3 stories	1.63	0.5	2.1
apartment	RC 4-9 stories	1.64	0.5	2.5

Calculation of probable seismic load effect

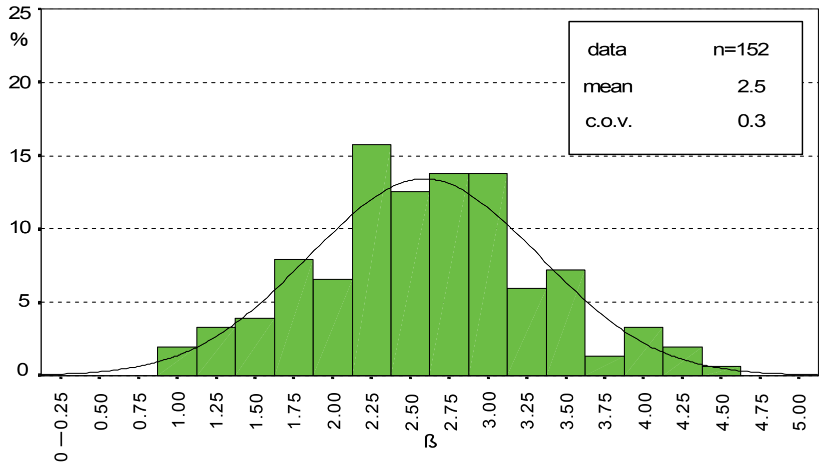
The load effect *S* is the seismic hazard of a site where a user builds his own house. It is expressed by an application of probability distribution, which is the peak acceleration response. Briefly, it is evaluated by the peak ground acceleration of in-service years (N years). Then, by multiplying the response ratio of a house, the value is expressed as a response shear coefficient. The questionnaires asked for the user's required in-service years.

The mean of load effect μ_s and c.o.v. V_s were converted to the probable maximum load effect and its c.o.v. based on 400 years of statistical data for extreme value type III (Weibull distribution). The average *A* of probable maximum value in N-years is multiplied by the response ratio of acceleration *B* and divided by the gravitational constant *g*. The load effect *S* can be calculated from the following formula.

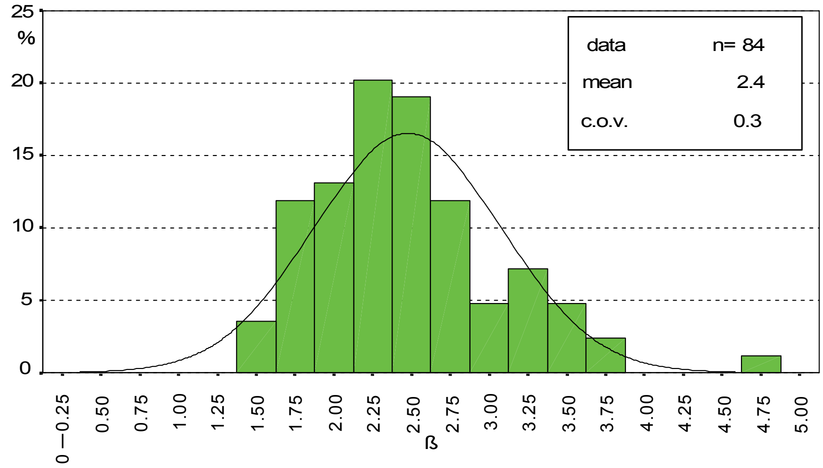
$S = B * A / g$

RESULTS OF TARGET LEVEL REQUIREMENTS

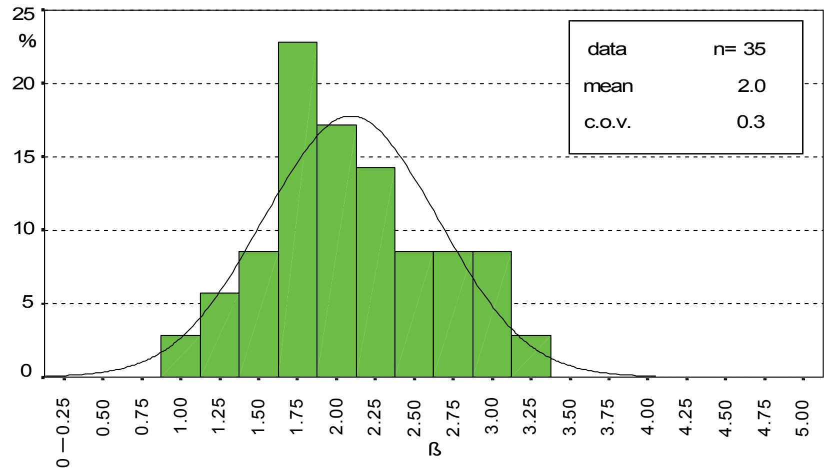
The desirable target seismic safety levels of each user were calculated from the 585 user questionnaires. 271 reliable data were calculated. **Fig. 6** shows the trisecting results from three structural models. User requirements for in-service years are kept in this calculation. **Fig. 7** shows all the results for users standardized in-service years as 50 years. From this figure, the average value of target safety level required by social opinion is about 2.4 β for all structural types. P_f is $9*10^{-3}$. **Fig. 8** is the cost requirements in the answers.



a) Requirements of target β in case of wooden independent house



b) Requirements of target β in case of non-wooden independent house



c) Requirements of target β in case of apartments

Fig. 6 User requirements regarding the target safety level for their houses

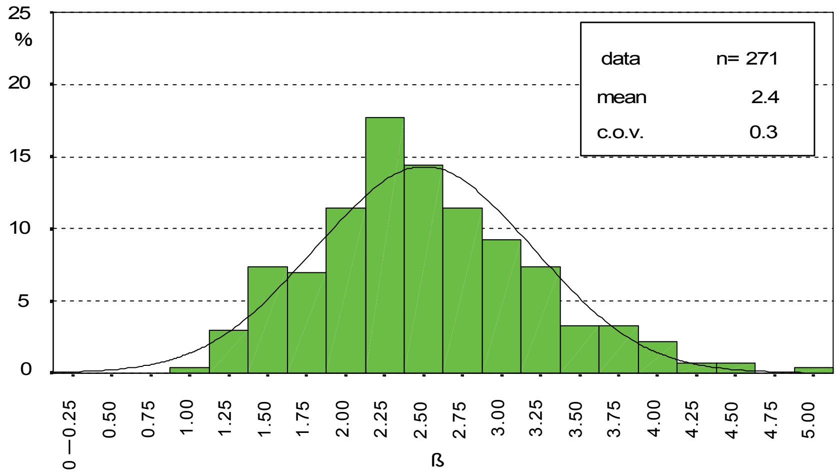
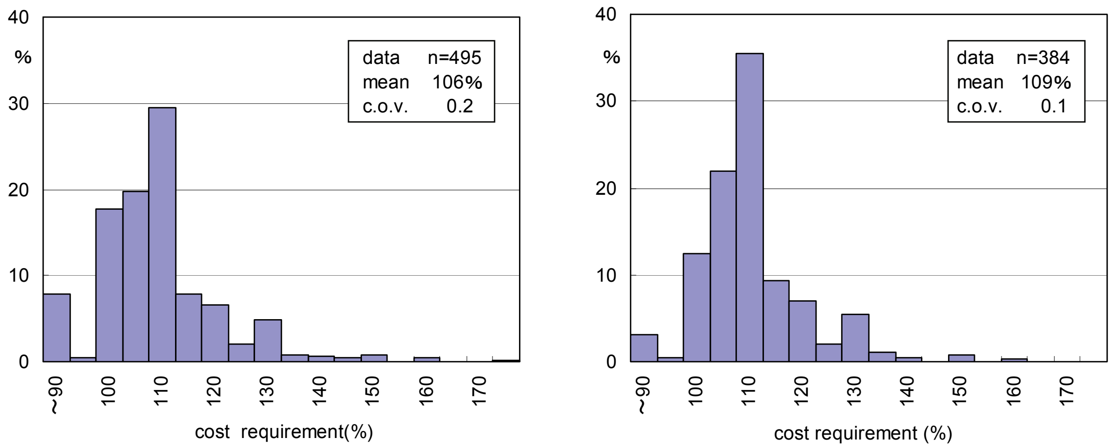


Fig. 7 User requirements for target safety level standardized for 50 years as calibration periods



a) All answers **b) Reliable answers for calculation**

Fig. 8 Cost answers for seismic safety

CONCLUSIONS

This paper clarifies user requirements on seismic safety quantitatively to establish a desirable safety level based on social consensus. There will be many discussions regarding assumption of values or degree of accuracy. However, engineers should listen to opinions from users, and a new evaluation method is desired reflecting user needs. More communication will be needed on safety level between professionals and users.

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