OPTIMIZATION:
3-3-THE ONLY RATIONAL WAY OR ONLY A RATIONALISTIC WAY?

by

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SYNOPSIS

Optimization (selection of the design which maximizes an expected utility measures, e.g., one which minimizes expected cost) has been advanced for many years by some engineers as the ultimate design procedure. Yet few practical aseismic applications can be pointed to. Whereas the individual components of optimization (marginal cost analysis, probabilistic seismic hazard analysis, structural response prediction, and impact evaluation) are broadly encouraged and widely used, the total process which couples these results and suggests the preferred design strategy is at best passively ignored in practice. This discussion paper reviews some of the observed objections to optimization; it challenges the panelists and audience either to confirm and amplify these objections or to answer them in support of optimization.

INTRODUCTION

Optimization is based on rational arguments. Optimization is overwhelmingly appealing to the engineering mind. Optimization provides a formal logic and mechanism for incorporating quantitatively all relevant seismic design information (marginal construction costs, earthquake hazard probabilities, structural behavior predictions, and the economic and other impacts of system performance) into a final decision.

Engineers are in broad agreement that all these individual pieces of information should influence that decision and that each ought to be studied and reported in explicit terms. Optimization, the most attractive method for combining all this disparate information, has been widely studied and fully developed in many fields. It has been a part of civil engineering literature for more than 40 years and a part of the seismic design literature specifically for at least 20 years.

Nonetheless, it is difficult to point to any project (structure or code) in which formal application of optimization has been forwarded and accepted. The tool is simply not popular. Indeed, its application has been explicitly rejected by some designers and seismic decision policy makers.

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Why? Are these men not rational? Are they failing to base their decisions on all the available understanding and logical thought processes? Or is the theory deficient? Is optimization indeed only a rationalistic construction, one based on the popular technocratic belief that everything can be correctly reduced to a set of a priori assumptions and a logical reasoning process without the the test of experience? It is perfectly rational not to follow blindly an untested or incomplete rationalistic method.

Rather than explain again the ideas of optimization and reaffirm its "rightness", this panel paper will bring forward criticisms of optimization which have been expressed. Some responses to these criticisms will be anticipated, but this panelist would like to place the primary burden not, as usual, on the general audience to alibi for their past failure to design "in the only rational manner," but instead on its proponents to defend optimization as being more than simply rationalistic.

But first a very brief description in order to define what is meant by optimization in this discussion (and what is not). (See the bibliography for a list of representative references.)

In its simplest and most commonly presented form aseismic optimization considers (1) a structure the specified seismic resistance of which can be represented by a scalar parameter x such as lateral force coefficient (or design base shear); (2) a (construction) cost c(x) (perhaps in analytical form such as $c(x) = c_0 + c_1 x^{\alpha}$) which expresses the costs associated with any specific level of design; (3) a seismic hazard curve which expresses the exposure in terms such as $1/\nu(a)$, the mean annual return period between events with peak acceleration equal to or greater than a ($\nu(a)$ is the mean annual rate of occurence of such events); (4) a prediction of the structural response, y(a, x), for all pairs of design level x and motion intensity a (the vector $\underline{y}$ might include, for example, expected peak interstory displacements and ducility factors); and (5) some measure of the loss associated with each event that leads to response $\underline{y}$, $f(\underline{y})$. Combination of the last two items permits one to state an expected loss $\ell(a,x)$ for any design x exposed to any intensity a. Then for any design level x the expected loss in any time interval dt is the product of the loss and the expected number of events ($\nu(a)dt$) integrated over the possible intensity levels, or

$$dt \int_a \ell(a,x)\nu(a)da \qquad (1)$$

Under the simplest assumptions, TC(x), the expected total loss, discounted at rate γ to the present, is then simply

$$TC(x) = c(x) + \int_t \left[\int_a \ell(a,x)\nu(a)da\right] e^{-\gamma t} dt \qquad (2)$$

Optimization theory suggests that the appropriate design is that level x which minimizes this expected total cost function. In simple terms it seeks the trade-off between the initial cost c(x) which increases with x and the expected losses $\ell(a,x)\nu(a)$ which are reduced as x is increased. In application many of these relationships may be discrete: only a simple set of alternative designs are reviewed, a discrete set of (Modified Mercalli, say) intensity levels are considered, etc. To be more thorough and precise certain generalizations and certain qualifications (e.g., utility linearity) should be made, but this simple model will suffice to define what is meant in this paper by optimization. In particular, it does not mean here (as it often does elsewhere in structural engineering literature) simply design for minimum cost or structural weight under stress or even reliability constraints.

ACCEPTANCE OF THE NEED TO STUDY THE COMPONENTS

With qualifications, most individuals involved appear to agree that each of the various components identified above deserves to be investigated because each potentially has an influence on aseismic design decisions. For example, if in some situation the marginal cost of providing increased seismic protection is extremely small, then no one would criticize very conservative design levels. In contrast, extremely high seismic reinforcing costs have led to the abandonment of existing buildings. In preparing to make changes in seismic code design levels the ATC commissioned marginal cost studies (ATC, 1974).

Perhaps the seismic hazard level is the single most influential factor governing current differences in seismic design levels. It is also now quite widely agreed that probabilistic statements of this hazard (e.g., mean return periods) are the most appropriate way to present this information. Many will argue, of course, as to how to estimate these probabilities and as to the confidence one can place in currently available estimates.

That any structural design should be investigated for its response to seismic motions is certainly the least controversial component in our list, at least among this audience. Such studies are routine in seismic countries both for particular individual buildings, power plants, etc. and for general classes of structures in aggregate. Unfortunately custom and training dictate that these studies are most typically of the form: "confirm that this design meets certain code constraints at earthquake intensity a," as opposed to analyses which attempt to estimate the response of the structure at each value over a wide range of earthquake intensities. Again confidence in engineers' response prediction (especially at relatively intense levels) may not be strong. Few will agree, however, that this response prediction is not germane to design decisions.

Those that might disagree with the significance of making structural response predictions are those who simply question their correlation with impact or loss experience, for ultimately the influence on a seismic decision is the system's expected economic and social response to an earthquake (repair costs, lives lost, disruption to operation of the building or the city, etc.). Other factors being equal (e.g., initial costs, seismic hazard, etc.) a design which promises lower losses in the event of an earthquake is to be preferred. Again virtually all concerned appreciate the desirability of making predictions of the impact of an earthquake on a structure (or city) and the dependence of these various losses on seismic intensity and on, say, the code design level. This is true even when those involved are equally aware of the difficulties in making such predictions. Where fundamental objections to such studies begin to arise, however, are when one attempts to collapse all these socio-economic impacts into a simple scalar measure, such as dollars. Particularly frequently objected to is the "cost of a human life" concept. Short of this step, however, impact predictions are universally applauded and not infrequently practiced (for example, see OEP, 1972).

TECHNICAL OBJECTIONS TO OPTIMIZATION

If we agree then that studies of all these components are encouraged, why has the professional response to optimization itself been so weak? Why has its patently logical scheme for coupling all this information into a design decision not been widely used? We put aside the (real) possibility that few engineers, especially senior decision makers, have been exposed to the methodology; its ideas have been in the open literature long enough that it could have spread in its application were it going to. (Contrast the wide adoption in one engineering generation of the economic principle of discounting future expenditures.) In fact, the basic ideas of optimization have certainly been presented to many practicing engineers and other decision makers. Most have apparently chosen not to apply it, some after informed consideration. Why? Let us first consider technical objections and concerns that have been raised against optimization.

The perhaps most frequent objections can be classed under the general heading: the decision model is too simple. We hear from some that ground motion cannot be accurately represented by a single parameter (such as ground acceleration) or that the seismic resistance is characterized by quality control, ductility requirements, and many factors in addition to the lateral force coefficient used. Such simplicity objections apply, in fact, only the simple model suggested above (as well as in most literature on the subject); the variables x and $\underline{a}$ are in principle vectors and can also index non-quantitative factors. In practice, however, optimization would become considerably more difficult to apply as the elaborations were introduced. In particular, the seismic hazard analysis is complicated significantly if $\underline{a}$ is a multi-component vector such as intensity, relative frequency content, and duration.

From engineers educated in economics and systems analysis we also hear that the model above is too simple. The use of an additive, scalar loss function (e.g., Eq. 2) is naive, dollar values are often not acceptable substitutes for human lives, and the expected-dollar-value decision criterion is crude. Again such objections can be met by decision theory (or seismic optimization), in this case by introducing a more general utility measure to replace dollars. According to a highly technical, value-theoretic argument, this utility measure (1) accounts for non-linearities in dollars versus perceived value, (2) allows for translating multiple attributes to a common value scale, and (3) establishes the legitimacy of the expected value decision criterion even in "one-shot" decision situations. The price paid for these benefits is not small, however; the resulting utility scale not only is subjective (i.e., the relative values depend on the individual establishing the scale), but also it is an ordinal scale (i.e., only order on the scale retains significance; any positive linear transformation is an equally valid utility scale). As we shall discuss below, the introduction of this utility scale apparently creates additional obstacles to the application of optimization.

Another line of criticism of optimization addresses the user's lack of confidence in the input information. It is difficult to get reliable cost information; seismic hazard data is often poor; interest rates are subject to different interpretations, etc. Nonetheless, the issue here is not, I believe, the weakness of the individual components *per se*; as discussed in the preceeding section, these kinds of studies are encouraged and valued by decision makers despite the often low confidence in their predictions. Rather, the concern is that when this "fuzzy" input information is processed by an optimization algorithm, the user finds difficulty evaluating the confidence he should have in the conclusion. He is not familiar with the optimization "processor" nor to the degree to which it might distort (suppress or exaggerate) uncertainty in the input. It is true that one can carry out sensitivity studies and/or formal analyses of the statistical uncertainty in the input, but it apparently remains difficult for even the experienced decision maker to develop the same "feel for" the weakness in the output of an optimization analysis that he has developed for the output, say, of linear dynamic structural analyses.

A major cause for the difficulty one has in developing an appreciation for the output of a formal decision analysis is the utility scale referred to above. Because it is strictly only an ordinal scale, the expected utility of each alternative design can be used for no more than ranking the alternatives. In principle (that is, according to those rationalistic arguments upon which optimization is formally founded) the engineer can place no weight on the expected-loss ratio or expected-loss margin by which one design alternative appears to outrank another. For example, despite its apparent rationality, it is only under very special circumstances (verified dollar-utility linearity, verified life-dollar equivalents, etc.) that one can make the statement that a designer should be prepared to recommend paying up to $10,000 more to buy a structure whose computed expected seismic losses (the double integral in Eq. 2) are $10,000 less than those of another. One implication is that any sensitivity analysis can ask legitimately only such questions as: does a change in this input parameter value change the order in the ranking of alternatives or not?

The concept of utility, introduced to permit a formal, rational basis for optimization, brings with it additional difficulties in application. It is explicitly both inclusive and subjective. One must in principle identify and evaluate <u>all</u> sources of loss or benefit. These should include in the event of seismic failure, loss of a professional's prestige and of the occupants' psychological sense of security. Such intangible items, as well as the impact of lives lost and injuries, must be assigned quantitative levels of preference. We have virtually no experience with such evaluations; few seem to find confidence in the artificial lotteries and other devices which have been used to elicit such preferences. Lack of confidence in such unfamiliar and untested techniques invariably transfers to the conclusions and finally to the total optimization concept. The inherent subjectivity of this utility scale is also a difficult concept for most engineers; it implies that one must define explicitly <u>whose</u> utility is being optimized. Optimization may suggest <u>different</u> optimal solutions for different individuals or groups concerned with the same decision. But this should be no surprise; it is simply reflecting reality. Unfortunately, optimization offers no way to resolve such intergroup conflicts. Even comparisons among groups are limited, as explained above, to no more than their rankings of alternative decisions; comparisons cannot extend to strength of preference.

POLITICAL OBJECTIONS TO OPTIMIZATION

Other forms of resistance to optimization are encountered among decision makers who must be politically sensitive. These include government administrators and politicians as well as engineers who must explain or justify their decisions to others, especially the general public. Such is often the case in the development of seismic codes.

All of the technical objections cited above become more intense in political situations. For example, it becomes more difficult to identify the "decision maker" whose expected utility is to be maximized. If it is defined to be the utility of society at large, there are added problems with the measurement of this utility, with rules for aggregating the losses and benefits that differ from one individual or group to another and with the treatment of the losses of future generations (see, for example, Rosenblueth, 1976 and 1973). As the proposed solutions to such problems of implementation become more abstract and philosophical, the appeal of optimization to most practicing decision makers is reduced.

For various reasons the indicated optimal decision may be impractical to implement in the public environment (for example, the optimal code level may be too markedly different from past practice). Again optimization proponents would argue that in principle such difficulties should have been quantified in the utility assigned to that alternative. Or is it the responsibility of the optimization analyst or the politician to convince the public that according to the theory at least they are not acting in their own best interests if they block particular decision? Informing the general public on such issues is seldom effective. Typically only limited factions (e.g., in a capitalistic system producers of threatened construction products, real estate developers, etc.) are strongly interested in any given political decision; only they will react to make their opinions known and their political weight felt. No matter what the political environment, any decision analysis method which does not properly reflect such realities is not going to be given any more credibility by responsible individuals than its limitations permit.

On the other hand, an explicit realistic representation of the decision environment may also be undesirable to many involved. For example, decision makers may believe that it will impair the implementation stage of a seismic design decision to state that it is based on a calculated trade-off between economics and public safety. There are innumerable people who simply refuse to accept this notion; even if a rationalistic argument concludes that they are "wrong", they usually remain unchanged in their convictions and hence unimpressed by the indicated optimal solution. Many decision makers would prefer even not to make public explicit probabilistic predictions about deaths; public reaction may be more dictated by perceived risks (as influenced, for example, by news media treatment) than by statistical risks.

For the reasons above if not simply because it produces a unique answer, optimization is looked upon by many responsible decision makers as reducing their flexibility to negotiate a satisfactory decision in the complex, often competitive public administration and political realm.

FINAL REMARKS

Perhaps optimization is a complete, correct theory. If so, it may be more rational than man himself is ready to be. We may just not be able to provide it with the information it requires to satisfy its promise of yielding the optimal solution. In my opinion, unless and until the theory and its practical application are demonstrably complete, it is not irrational to fail to use optimization. It is eminently rational to question not only the decision alternative that optimization indicates, but also the use of only this tool. By the same token, it would also be irrational to ignore optimization. Any application represents at least one model of the decision situation and hence information of some potential weight. The burden remains, however, on the proponents of optimization to develop and test the techniques necessary to apply it with confidence and, while doing so, to listen carefully to the criticisms of its potential users.

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A complete reference list is infeasible. Here are a very few references to seismic optimization that are representative and that contain many more references for the interested engineer.

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DISCUSSIONS

A.K. Vaish (U.S.A.)

In using optimization as a tool for obtaining the most "cost-effective" design i.e. where the generalized cost function is minimized the problems are elegantly highlighted by Prof. Cornell - lack of complete information, disagreement on the relative cost values, politics etc. Most of these problems do not exist in using optimization as a method for the relative evaluation of different design aspect of a complex system.

For example a nuclear plant must be designed for a variety of extreme loads - earthquakes, hurricanes, missiles etc. In setting relative design levels for each of these optimization procedures can be used to ensure that the cost-effectiveness of each of these design aspects is the same. In this way even though the optimization procedure does not provide any information on the absolute cost-effectiveness of the overall design it does ensure that each link in the chain of design is equally strong - that we have not needlessly overdesigned for earthquake (in terms of the basic cost function) as compared to say for aircraft impact.

S.C. Gupta (India)

It appears that for optimization we need to evaluate extent of loss a structure would suffer when designed for a particular level of seismic forces. Accuracy of optimization would depend upon accuracy with which such loss can be quantified. Will the author kindly clarify it in present state of art such a quantification is possible and if so to what reliability ?

B.R. Seth (India)

I feel the reason for optimization not being used so extensively is due to its unjudicial use. As usual, say, if it is used to find the shape of truss to support two loads the answer surely shall be two struts only, and the shape of bridge truss for a rolling load may come as a plate, or optimum size for an house may come as a sphere.

So to avail the high potentials of optimization our other practical knowledge and judgement based on experience must be used than to start from the scratch.

P. Dayaratnam (India)

Objections to optimization in structural design are something natural and very similar to those come up whenever a change is introduced. We all realize that optimization has considerable value in structural design. Imagine several years ago when some one introduced the I-section for beams as an optional section. People at that time who were used to only rectangular sections must have critisized and complained beyond doubt. But now, the I-section has become one of the most common ones. Therefore I personally feel that optimization has considerable importance in structural design.

Y.C. Das (India)

In my opinion, optimization has excellent good effects like (a) improving the existing design philosophies and (b) improving analytical capabilities.

Miss. Elizabeth Pate (U.S.A.)

The notion of monetary value of life can be replaced (in public policy) by the one of an "order of priorities" based upon the

$$\text{ratio} \quad \frac{C - \Delta D}{\Delta L} \quad \left(\frac{\text{costs - avoided damage}}{\text{lives saved}} \right)$$

This cost of saving a marginal life allows for a comparison with money spent in other sectors and a global optimization over the number of avoided casualties.

Herbert Tiedemann (West Germany)

If one analyses earthquake losses statistically one finds that it is not the more sopisticated structure which causes much of the LOSS OF LIFE and that it is not reinforced concrete which contributes to monetary losses.

How can one explain that a WORLD CONFERENCE (to which many ordinary engineers look for guidance) does not realize the importance of discussing things which are most important for society ?

Author's Closure

Most of the discussors have made statements of opinion rather than having asked questions, and therefore little response is required. Mr. Seth and Mr. Dayaratnam have apparently taken the common but narrower definition of optimization, namely that associated with optimum (e.g., minimum weight) design of structural components under deterministic stress and deformation constraints; this topic is interesting but not the thrust of this presentation.

Mr. Vaish's and Mr. Das's optimistic opinions are subject I believe, to the limitations of optimization cited by the author; in the former case one must ask only if relative failure probabilities and relative costs can be evaluated reasonably well.

Mr. Gupta's question about the state of the art of quantification of losses of given structures under given input motions is not easily answered. My general opinion is that the current state is rather low. The difficulty lies in predicting structural behaviour in the non-linear range, and equally important, translating conventional structural response measures into economic losses. There has been very little hard information collected and analyzed for the latter problem.

Ms. Pate's observation is important because the public monetary value of human life is one of the most troublesome points of disagreement in practical application of optimization. Her suggestion permits a broad class of public decision problems to be addressed without this confrontation. In particular, this class includes the decision problem implied by Mr. Tiedemann's well-founded statement. Perhaps engineers simply apply themselves most to what they can do. Or in terms of a decision analysis of the problem, perhaps the seeming discrepancy arises because there is apparently a low marginal improvement in the unsophisticated-structure seismic topic per engineer-year of effort.