DESIGN EARTHQUAKE LOAD AS AN APPLICATION OF MATHEMATICAL PLANNING

Satoshi Kurita, Assoc.Prof.
Tohoku University, Sendai, 980-8579, Japan
kurita@strmech.archi.tohoku.ac.jp

Masanori Izumi, Counsel
Izumi Res.Inst., Shimizu Co., Fukoku-seimei Bldg., Tokyo, 100-0011, Japan
izumi@ori.shimz.co.jp

Abstract

A study group including authors made the concept of Mathematical Planning as an analogy of applied mechanics, completed the prototype soft and published several papers. Japanese building codes were recently revised, and structural engineers have been able to use performance-based design method in return for their increased responsibility. For engineers in earthquake countries, determination of design seismic loads is the most troublesome work, as it much influences structural cost and engineers may easily be blamed in both of safe & expensive and risky & reasonable cases. In the paper, authors briefly explain the concept and content of mathematical planning, then point out problems in design earthquake load. Authors also show an example of the application of this mathematical planning method to determine the design earthquake load, and conclude that the engineers can satisfy their accountability for their planning-acts by using the mathematical planning.

Introduction

1995 Hanshin-Awaji Earthquake bereaved more than six thousand lives and claimed Japanese government to revise its building codes. Under the new codes, it has become possible for structural engineers to choose one of two design methods; method of specification-based-design and performance-based-design. The former, the usual method, takes some design-freedom away from engineers, and, in return, protects them from litigious society. The latter is very new in countries of natural disasters like Japan, and the engineers may have to clearly plead their non-guilty in front of people with direct evidence on 'they designed' structures damaged by natural actions.

In planning and designing, so-called engineering judgment is essential, as it is synthesized knowledge of engineers concerning behavior and safety of structures. However it cannot be direct evidence for engineers without explanation understandable for the people. In other words, tacit knowledge like engineering judgment should be analyzed into formal knowledge. Engineers must explain how to get accurate information, why it is accurate and how to cook the stuff for getting plans. It is exactly what Mathematical Planning practices. Mathematical planning has wide range of application, and it can also serve the engineers in a very limited problem like determination of design earthquake load for buildings.

Mathematical Planning

When people find out gaps between desirable and real states in some matters, they recognize them as problems and would like to make the gaps smaller by carrying out a project. Then, they contrive possible processes of achieving their aims in the project using

their knowledge and available information, and this act is called 'planning', and the products are called ' plans'. Decision-making steps select a plan out of the plans, and then design processes come in to make the plan concrete before the start of the project.
When planners make plans based on the common language of various fields of science, that is, logic and mathematics, the planning is called the mathematical planning. Some people say that all plans are mathematical if they are worth to be called plans. Others insist that abduction is the base of planning, so planning essentially differs from mathematics which stand on induction and deduction. A group including authors started study of mathematical planning, published papers in English and Japanese, and concluded that process of planning was a repetition of analyses and syntheses and there existed both mathematical and non- mathematical planning. The latter may be named by non-accountable planning. As the majority of the group member are structural engineers, they have analogy of mathematical planning in applied mechanics which is ruled by natural laws like energy principles. In the planning, the ruler is a man, and his 'selfish gene' can be the principle. If, in a plan, selfishness of each person is so satisfied that people can compromise to each other, then the plan is acceptable, provided that the plan include the consideration to its influences to the society and to the nature. Authors think the relation of plans to the society may act as constitutive equations. (A few of our group members think that decision-making connects the imaginary and real project and can be called constitutive equations.) Simple linear relations in constitutive equations lead simple Navier's Equation, but the more complicated ones make the complicated force-displacement relations. If someone declares other principles and relations, another space will be provided in the mathematical planning cosmos. Our group proposed VRI (Virtual research institute), a kind of network where scholars, engineers, and institutions are connected. VRI has an agency which visits the connected persons and institutions, in response to the customers' requests, and which, if conditions meet, buys knowledge . The major parts of the knowledge are hidden, and only a few parts, which are directly available to the planning, are sold unless further requests from customers come. The agent has standardized processes to cook the purchased stuff into plan, but customers can contrive their own purchase and process under their own responsibility. Knowledge-rating system may be required to assure the quality of the connected knowledge.

Earthquakes

Seismology has made a remarkable progress in the latest half century, and yet only gives insufficient information to structural engineers in earthquake countries. The most valuable information for the engineers is the size and characteristics of earthquake ground motions expected in DL (design-working-life) of structures. As it belongs to a future event, no one can tell it without stochastic language. Earthquake prediction is still unsuccessful, and, at present, earthquakes are still the most unfavorable and very dangerous phenomena as they attack people suddenly, severe one rarely comes and results a catastrophe. Engineers used to divide the ground motions into three processes; a) source mechanism, b) transmission to bedrock surface and c) transmission to ground surface. The each process includes vague and important parameters. For example, fundamental natural periods of almost all building structures are possibly within the predominant periods of earthquake ground motions which are ruled by small variation of parameters at source mechanism like asperitylocations. For some structures, strong and comparatively long period surface wave may dangerous, but only body waves are mainly considered in the above mentioned method.

Seismic Actions on Structures

Not only seismology, but earthquake engineering still gives structural engineers insufficient and unbalanced information. A very progressed field is application of computer technology, and three dimensional models of structures and the ground are easily obtained and expected behavior of structures and ground to input excitation can be calculated. The input excitation should have three or more degrees of freedom, but even single degree of freedom data in time domain are not reliable. Present seismology and earthquake engineering may give engineers various kinds of spectra at the bedrock which include parameters of the size, distance and some characteristics of source and route mechanisms, etc.. Model of seismic actions still has many problems. For brittle structures, forces related to acceleration may be proper physical measure, and energy and work may be better measure to ductile structures. For flexible structures, deformation is critical sometimes. As fracture theory has not sufficiently developed in meso- and macro-applied mechanics, behavior of structures may have to been checked against various physical measures.

Design Earthquake Load

Many seismic codes have the bases similar to those of ISO: the structure should not collapse nor harm human lives by severe earthquake ground motions that could occur at the site (5. Bases of seismic design, ISO/CD 3010). People, except earthquake engineers, take it for granted that these bases are the minimum requirements in the codes. Development of tertiary industry very raises up the population density of urban areas, and motivates multi-story buildings and houses of insufficient lateral strength against severe earthquakes. Thus the risk of urban areas in earthquake countries has been raised up in spite of the progress and development of seismology and earthquake engineering. At present, many loss models of earthquake disaster in urban areas are proposed and the computed results are published. Though they are rough and the results have big variations even at a same area, still they surely predict great catastrophe. It is not only the problem of design earthquake force but that of administration. Tell the truth to people concerning the dangerous areas in the nation, show them the results of loss simulation and applicable mitigation methods. First, people may be unrest, and soon forget. It is a work of administration to keep people in anxious state, and let them do something for themselves to mitigate the disaster.

Application of Mathematical Planning

Mathematical planning forms an cycle which consists of Problems (Gaps), Aims, Analyses, Syntheses, Solution and assessment and Decision making. Then Design and Practice come. It makes small loops after assessment unless the plan is approved. If new gaps are found out after the practice, another cycle starts.

In the paper, the process after assessment is not explained, but it depends to some extent on the personality and conditions of the man who decides. In order to explain the process, an example of an engineer who uses VRI to decide design earthquake load is shown.

Problems

Problems to an engineers exist in their determination of design earthquake load.
First, the aim of laws and regulations is too high for engineers to achieve. Engineers may possibly be against laws like previously mentioned article in ISO. Besides, the values of seismic actions on structures shown in the regulations in many earthquake countries are too small to be the model of the real effects of severe motions to real structures. they can satisfy the contents of regulation, and yet cannot fulfill the conditions described in the law.
Second, information required to seismic design of structures is insufficient, and none can expect high accuracy in estimated behavior of structures through numerical analyses.
For Japanese engineers, there is an additional problem such as; not only the specification-based-design method, but the performance-based-design method has recently become applicable, and design-engineers may be naked to litigious society after earthquake disasters.

Aims

The aim of planning differs according to the position of the engineer even for a same subject. If he is at a position of making laws and regulations, he has to consider the risk balance in his society. For example, when the improvement of social sanitary systems saves much more lives than those saved by reinforced structures in earthquake disaster for the same cost, he cannot insist a big design seismic load. He should describe in the law that design load is only social required minimum and it does not mean the guarantee of the structural safety. At the same time, he has to make a law that prohibit people to build unsafe structures in high risk areas like those in seismic gaps. In the paper, laws, regulations and codes are not discussed. Instead, how an engineer determine design earthquake load to a structure in performance-based design is explained.

Analyses

Analyses in mathematical planning are made on the problems and the circumstances.
1. Problems
Administrators and engineers often attribute the cause of disaster to happening beyond human experience and knowledge, but most of disaster take place as probable phenomena, and administers and engineers, as well as people, should share the responsibility.
One can tell the future events only in stochastic language, provided that his circumstances are stable. Geophysical phenomena are said to be stable for recent several hundred thousand years, and earthquakes are regular phenomena in geophysical history, though they look very random to us. Instead of the declaring no loss of human lives, clarification of probabilistic safety is acceptable to engineers as they need not take the responsibility of very rare events. Society has a common sense concerning the level of rare events: rare (less than 5%), very rare (less than 1%) and extremely rare (less than 0.5%). On the

assumption of Bernoulli's trial (though this assumption is not correct), relation in safety, DL (design working life) and RT (return period) of a phenomenon is obtained. Because of insufficient information, one cannot estimate future behavior of structures accurately, and the level of risk analyses cannot be high. Japanese design engineers are facing to performance-based-design. Though customers do not know how to design structures they know the contents of contract and real performance of their structures in a strong earthquake. The engineers have to explain the owners the possible accuracy in risk analyses.

2. Circumstances

Natural, social and economical circumstances are objects of analyses. Natural circumstance is not of the primary importance in structural design except problems on keeping the nature clean without harmful wastes, and saving the natural resources including recycle of building materials. Related to the problems, DL (design working life) of structures in Japan tends to be longer. Change of social and economical circumstances in the future influences the values of structures and, consequently, their LCC (Life cycle Cost). The change is very hard to make prediction except very stable phenomena like future population -constitution. Therefore one has to rely the prediction on experts connected to the net, and estimate the LCC in the best, medium and worst scenarios.

Syntheses

1. Strong earthquakes

All areas in Japan are not far enough from plate boundaries in the sea, where about three quarter of total earthquakes in and around Japan take place .

Comparatively regular movement of plates cause comparatively regular occurrence of big earthquakes which RT (recurrent time) are several ten years to two hundred years with the standard deviation of about four fifth to five quarter of the mean value., thus those in the sea areas can be the object of stochastic inference. As they are big, wide areas are suffered by an earthquake. Therefore, a site has been shaken by near and far earthquakes, and has records of probabilistic distribution. The Great Kanto Earthquake 1923 was an example. On the contrary, the rest are in-plate earthquakes which occur at or near active faults on the land with long recurrent time of several hundred years or longer. Even the size (magnitude) is not very big, a limited area near the moved fault is severely shaken. The Hanshin-Awaji Earthquake 1995 belonged to this type. This type of very extremely rare earthquakes causes the most difficult issue. Besides, some faults are hidden in underground, and there might be new faults. Except for very important structures, they were not considered before 1995. Many efforts to estimate the time of next movement of this kind of faults have been made : read the fault history at dug trench, estimate the accumulated strain through rock tests, or guess the stress concentration with GPS data. One may expect some solution in the future. At present, stochastic estimation is impossible, and worst scenario of ground shaking should be written for design load, if the site locates not far enough from this kind of fault. Reduction of seismic actions on the structure be consider not in design loads but in structural design.

2. Stochastic process
Risk estimated from RT and DL is high in the codes of many earthquake countries, and it becomes higher when aging effects on structures are reckoned.
The value of structures drops faster than the decrease of structural strength by aging, it does not effect LCC consideration. Monte Carlo Method is used for this kind of calculation, though it is time consuming.
3. LCC
Construction companies have accumulated data and information on initial and reparative cost. In the assumption of very stable circumstances, it is not difficult to get the relation of LCC and the design earthquake load. When structures are used for 'quick-earn' purpose like convenience-stores lower values of design load have advantage. It is natural that design earthquake loads are apt to approach to the minimum required small values in regulations.

Solution and assessment

The important outputs of syntheses are LCC-design load relation and time dependent value of the structure. Though they cannot be accurate caused by the vague estimation of future conditions, they are accountable to be the best guess possible at design-stage. When the solution does not pass the assessment, the process jumps back to the analyses. The design engineer may persuade owners with the output to select the best solution in Decision making process. Time dependent variation of insurance ratio is included in the process.

Conclusion

Outline of MP is shown, and example of its application to design load decision is explained. Authors hope this method will be more developed, and applied to various problems like the finite element method in applied mechanics. Like other networks, VRI will be opened to public after it is completed.

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