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SEISMIC DESIGN METHOD TO CONSIDER ‘‘ANTI-CATASTROPHE’’ CONCEPT - A STUDY FOR THE DRAFT OF DESIGN CODES

R. Honda(1), M. Akiyama(2), S. Kataoka(3), Y. Murono(4) , A. Nozu(5) and Y. Takahashi(6)

(1) Professor, The University of Tokyo, rhonda@k.u-tokyo.ac.jp
(2) Professor, Waseda University, akiyama617@waseda.jp
(3) Head of Earthquake Disaster Management Division, National Institute for Land and Infrastructure Management, kataoka-s92rc@nilim.go.jp
(4) Director, Center for Railway Earthquake Engineering Research, Railway Technical Research Institute, murono@rtri.or.jp
(5) Director of Earthquake Disaster Prevention Engineering Division, Port and Airport Research Institute, nozu@pari.go.jp
(6) Associate Professor, Kyoto University, takahashi.yoshikazu.4v@kyoto-u.ac.jp
(Authors 2-6 are listed in an alphabetical order.)

Abstract

In Japan, after the 2011 Tohoku Earthquake and Tsunami, importance for the preparation for the situation beyond what was assumed in the design process is widely recognized. In the field of seismic design, the concept of “anti-catastrophe” property was presented. Its implementation is requested, but it is not easy because “anti-catastrophe” concept has various significant differences from the existing design codes.

This paper explains the concept of “anti-catastrophe”-oriented seismic design, and proposes a framework of such seismic design code. In order to define the “anti-catastrophe” concept, its relationship to the concept of conventional seismic design is discussed. It is shown that the domain to be considered in the design should be extended in terms of three dimensions: (i) Phase: behavior or performance of a structure in a situation that is not explicitly assumed in the conventional design, must be considered; (ii) Time: performance in the time of recovery process after the earthquake event must be considered; (iii) Space: performance of a infrastructure system must be considered, in stead of that of a single unit of structure. Then, as essential elements of “anti-catastrophe” property, Reliability, Systematic Performance, and Resilience are introduced. Conditions required to implement the “Anti-catastrophe” concept in the design codes in Japan are also discussed.

Based on the discussion above, we propose a framework of the seismic design method to implement “anti-catastrophe” property. Since its core concept is different from a conventional design scheme, a class called “Category of Design” is introduced as a part of the framework. In the proposed framework, the design process consists from several stages and each of the stages is described, paying attention to practical application of the codes. On each of the stages, requirements are defined for both Categories of Design I and II.

We also discuss conditions required for the society and government to make such new design codes effective and sustainable. Since the presented design method requires qualitative approach and the design level will not be rigorously determined, it is necessary to have a social environment to support and assure the quality of the design. We utilize the theoretical foundation of risk governance, and present several practical policies, including avoidance of abuse of excessively conservative “anti-catastrophe” approach, and investigation by the third party.

Keywords: Anti-Catastrophe, seismic design code, extreme events, resilience

1. Introduction

Resilience is one of important keywords in disaster management and the performance of structures after severe disasters has been discussed as one of important factors [1,2]. In earthquake engineering communities, Bruneau et al. [3] presented a basic concept for the assessment of seismic resilience and that has been explored by various research groups for the development of analytical methodologies [4], seismic design methods [5] and also from wider viewpoint [6]. In Japan, after the 1995 Kobe Earthquake, there has been discussion of the resilience of infrastructure [7,8].

After the disaster caused by the 2011 Tohoku Earthquake, consideration of extreme events is of great concern [9, 10]. In Japan, the role played by infrastructures in the recovery activity after the severe disaster is widely recognized. The Operation Kushinoha (Operation Comb) [11], which succeeded in providing access roads to the severely damaged costal area quickly after the earthquake, was highly appreciated. Cooperation of multimode transportation, maritime transport, railways and flights, which contributed supply of oil to the Tohoku Area, was also reported by Ministry of Land, Infrastructure, Transport and Tourism. Many infrastructures utilized in these operations were actually damaged. However, their damage was not critical and they can start the service after appropriate treatment. These events indicate that damaged infrastructure can make contribution to the resilience of the society, if they can resume their service soon.

It is not exorbitant design to have margin to accommodate such uncertainty. There exists, however, trade-off between preparation for uncertainty and economic efficiency. Obviously, full preparation for all possible situations is not rational. The logic to judge how much of margin should be considered to be appropriate is required. It should be engineers' intention to prevent serious accidents and damage, even if little can be known in advance about such uncertain factors.

It is not an unthinkable concept for engineers, to consider the situation that exceeds the state assumed in the design. The concept has already been partially adopted in the design code of railroad structures after the Tohoku Earthquake [12]. Many types of such methodologies were available even before the Tohoku Earthquake (e.g. [13]). Nozu et al.[14] reviewed how such concept has been considered in seismic design in Japan with concrete examples. It was not clear, however, how those methodologies should be utilized in the design. Since it was not explicitly specified in the design specification, it must be conducted based on engineers' judgment, paying attention to the economic rationality to avoid over-specification.

Accountability is important for infrastructure, since their cost is paid by public budge. For the implementation of such margin of capacity, it is necessary to explicitly specify and request that in the design codes. This paper aims to present the concept for such seismic design, "anti-catastrophe" property, and discuss how it should be specified in the design codes, giving theoretical foundation. We also discuss other additional conditions necessary to have this concept accepted by the society.

2. "Anti-Catastrophe"

2.1 Definition

Idea of "anti-catastrophe" property is understood as the high ductility of structures, when it is exposed to extremely strong external force. But it is not equivalent with the "strong" structures. Let us define the concept of "Anti-Catastrophe" as

> *The capacity of structures to prevent the occurrence of catastrophic situations as the single structure or the system of varies structures, even when it is exposed to the situation that is not considered in the conventional design, which requires a procedure to verify the response of the structure against the specified external force is within the prescribed range.*

We learned that such property to deal with significant uncertainty in the aftermath of the disaster would not be realized just by improving the strength of the infrastructure. The achievement of The Operation Comb shows that infrastructure can make essential contribution to the recovery process of the society, if damage of infrastructure is recoverable. It indicates the importance of “anti-catastrophe”. It is reported that The Operation Comb was possible owing to the following three factors:

1. Quick and clear decision was made about the procedure and the order of rehabilitation of roads.
2. Local construction companies devoted their resources to this operation.
3. Retrofit of bridges prevented the occurrence of severe and un-recoverable damage.

It should be noticed that factors that are not directly related to the reduction of structural damage are included. “Anti-catastrophe” is not solely the property of structures, but it represents the disaster response capacity of the whole society.

2.2 Extension of Scope

The “anti-catastrophe” requires to consider the aspects that was not explicitly discussed in the conventional design, extending the scope of seismic design. We adopt three dimensions: (1) phase, (2) time and (3) space.

(1) Phase Domain: Behavior of damaged structures should be considered.

After the Tohoku Earthquake, role of seawalls and breakwater is recognized. The Japanese design codes of those structures require that those structures should be *ductile* so that they can contribute to the mitigation of damage due to tsunami whose height exceeds the specified value of the design tsunami height [15,16]. In the seismic design, importance of ductility has gained recognition and it is mentioned in the Japanese design code of railroad structures [17]. These design codes request us to pay attention to the situation after the structures are seriously damaged, which had not been explicitly mentioned to, and to take appropriate counter measure for such situation. It is the most important idea for “anti-catastrophe”.

(2) Time Domain: Recovery stage should be considered.

Resilience has been discussed for decades in various fields including disaster management [1, 2, 3]. Bruneau et al.[3] presented the framework to quantify resilience capacity. Performance of infrastructure in the community is denoted by the ratio Q(t) and it is supposed to drop and recover after the disaster as shown in Figure 1.

Resilience Loss function is given as

$$R_L = \int_{t0}^{t1} [100 - Q(t)] dt \tag{1}$$

Resilience is also quantified as [6]

$$R = \frac{1}{t1-t0} \int_{t0}^{t1} Q(t)\, dt \tag{2}$$

In these simple equations, time after the event is clearly included and contribution of infrastructure in the recovery process can be evaluated. This will help us to quantify the value of contributions in the design process before the actual disaster occurs.

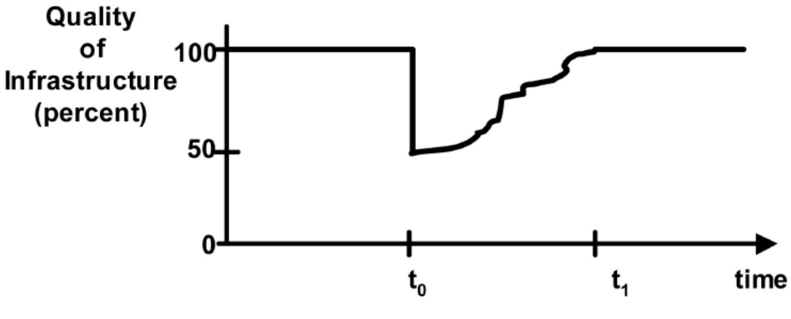

Figure 1: Performance recovery of infrastructure after the damage (%). Time t_0 denotes the moment of damage. (Bruneau et al. (2003)[3])

(3) Space Domain: Various scales should be considered.

The design should discuss not only the performance of the unit of infrastructure, but also the performance of the system of the whole society. For that purpose, infrastructure design concept should be expanded in terms of (a) space so that it should consider the role and position in the regional society, and (b) system domain so that network of infrastructure can be considered. After the 1999 Kobe Earthquake, JSCE (Japan Society of Civil Engineers) presented the design concepts based on their study [7, 8], in which "seismic performance of the system of infrastructure" was discussed. The currently presented concept is consistent with their idea.

The domain of the system should be defined in various manners in different scales depending on the required function. For the discussion of the performance of the unseating prevention device (girder restrainer), the whole bridge structure should be regarded as a system, while the performance of the seawall requires the social system of the community, in which people are supposed to evacuate in case of huge tsunami. When road network is discussed, transportation network covering broad area should be considered.

2.4 Definition in relation to the current seismic performance

How is "anti-catastrophe" defined in relation to the concept of current seismic design? "Anti-catastrophe" property is to assure the function for the situation that is extended in terms of phase, time and domain. It is supposed to enclose the elements of conventional seismic safety, that are, *safety*, *serviceability* and *recoverability*.

At the same time, "anti-catastrophe" is not just the combination of conventional *safety*, *serviceability* and *recoverability*. It should be classified as another property that is independent of these three elements. This indicates that seismic design can adjust the level of seismic performance in terms of safety, serviceability, recoverability and "anti-catastrophe". Even the structure with low recoverability or safety can be highly "anti-catastrophe". Those structures can provide some part of their function even after they are severely damaged. This concept should be applicable to seismic retrofit of existing structures, which had been designed with old design codes considering small design load.

Let us also discuss the relationship to other concepts of seismic performance concepts. Bruneau et al.[3] listed 4R as elements of resilience.

- *Robustness*: strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function.
- *Redundancy*: the extent to which elements, systems, or other units of analysis exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality.
- *Resourcefulness*: the capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis; resourcefulness can be further conceptualized as consisting of the ability to apply material (i.e., monetary, physical, technological, and informational) and human resources to meet established priorities and achieve goals.
- *Rapidity*: the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption.

These 4R are applicable for "anti-catastrophe". *Robustness* is obviously essential to deal with uncertainty of severe situation induced by earthquake. *Redundancy* is also necessary for "anti-catastrophe" to prepare some alternative function for the structure to function, or sufficient margin to the external force. We would like to emphasize the importance of *Resourcefulness*, which is about the capability to judge and manage the resource allocation in the response to the situation. This is not the physical condition of the structure, but that should be included as a seismic performance. *Rapidity* is close to the concept of recoverability, which explicitly discuss the time factor.

They are further developed in the White paper on the SDR grand challenges [18] and works by Renschler et al.[19], as the property that considers the contribution of social capacity. They pay attention to the recovery, which is defined as R in Eq.(2). It corresponds to *resilience*, which is also essential for "anti-catastrophe". Resilience corresponds to the time axis among the three axes of "anti-catastrophe", however, requires phase and domain axes, too. It evaluates the influence on secondary damage and recovery. It also considers the effect on community. The concept of *sustainability*, which is more widely accepted for longer time, shares the similar idea. They should be helpful for each other. Sustainability should be considered in the gradual deterioration such as aging of infrastructure, while "anti-catastrophe" for the instantaneous damage such as the collapse due to earthquakes.

3. Implementation of "Anti-Catastrophe"

This section discusses the required conditions to implement the idea of "anti-catastrophe" as the design codes. In the following, the context of Japan is assumed, but the discussion should be applicable to other regions.

3.1 Framework of Design

The design method for "anti-catastrophe" must be performance-based design approach, which is the main trend of infrastructure design. The basic idea of "anti-catastrophe" is consistent with that of performance-based design. As discussed below, the function and strength of the infrastructure should be determined considering the physical and social conditions. It should be flexible and dependent on various factors, and it defines the required "performance" of the structure. For the realization of "anti-catastrophe" property, therefore, the design code should not take prescriptive approach, because there should exist various measures for a single structure. It can be realized by additional devices, or even by some organizational or social countermeasures. It is not practical to prescribe all applicable methodologies in the design code.

3.2 Validation with qualitative evaluation

It is desirable to quantitatively verify the behavior of structures after it is exposed to an extreme phase which exceeds the assumption of the seismic design, by using numerical simulations and experiments. Innovative methods may not be accompanied by appropriate procedure to verify its performance. Efforts should be made to establish proper methods. However, absence of such methods should not prevent the employment of new methods, if its performance can be rationally verified with sufficient reasoning and evidence.

Even if various conditions such as input conditions and verification of performance of devices structures are not given quantitatively, accountability for the design is required. For that purposes, disclosure of the information including the data for design and the selection of methods, etc. should be promoted. Evaluation by the third party could be an option.

3.3 Consistency with the current seismic design codes

Current seismic design code in Japan has been improved for decades and the order and logic of those design code should not be disturbed by newly introduced "anti-catastrophe" concept. Even if an innovative concepts or technologies of seismic design are introduced, when it is implemented as a design code, consistency with the current design code must be preserved.

4. Categories of Design

Conventional prescriptive seismic design requires structures to satisfy the specified safety performance. Damage of structures exposed to specified external force must be rigorously under the specified value. On the other hand, "Anti-catastrophe" requires structures to exhibit reliability under various kinds of uncertainties. Structures with "anti-catastrophe" property are supposed not to lose its fundamental function even when it is under un-assumed conditions. Difference between the current seismic design and "anti-catastrophe"-oriented scheme can be summarized as

1) Design the structure, considering the performance of the structure when it exceeds the limit considered in the design. Accept that the validation of such performance may be conducted in a qualitative manner.
2) Consider the time line after the disaster. Role of the structure in the circumstantial conditions after the disaster should be determined in advance and it must be checked in several scenarios. Quantitative validation is even more difficult than 1) in the above.
3) Consider not only the unit of the target structure, but also several scales of social systems that include the target structure. For the implementation of this concept, engineers should participate in the upper stream of the design process.

Since current design and design for "anti-catastrophe" are different in many points, as shown above, the design codes should be different in many points. To avoid misinterpretation of the concepts of design, they should be referred to as different names. For that purpose, we propose that the current design is classified as "Category of

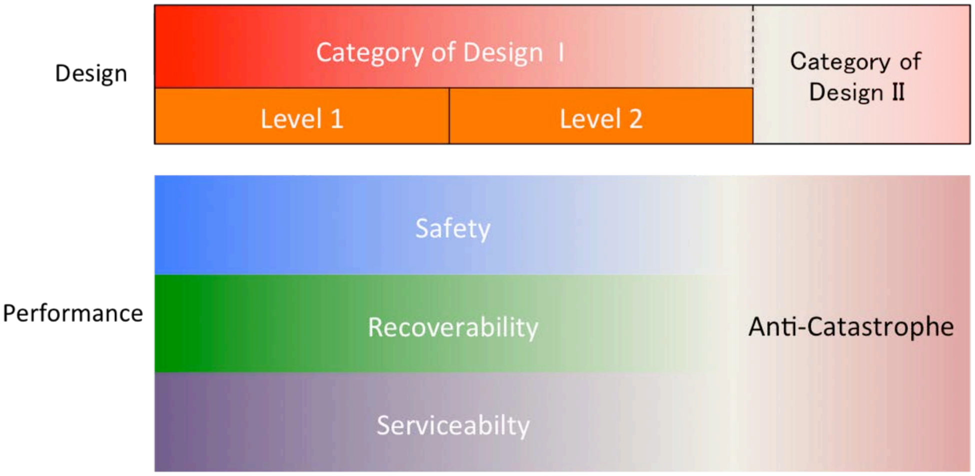

Figure 2: Seismic performance and Categories of Design

Design I" and the design for "anti-catastrophe" as "Category of Design II". However, if the current seismic design and "Category of Design I" are regarded as rigorously identical, it raises inconsistency with the current design, because current design already includes some technologies for "anti-catastrophe". They were accepted as an option for ordinary seismic design. If such technologies are labeled as those for "anti-catastrophe", they may be regarded as over-specification for the current seismic design. It must be averted.

Discussion suggests that boundary between "Category of Design I" and "Category of Design II" should not be strictly the same with the boundaries between "safety" and "anti-catastrophe".

Figure 2 illustrates our concept. The bottom box illustrates the concept of seismic performance and Design methods. The left box consists from three elements, safety, recoverability and serviceability, of current seismic design. This gradually changes to "anti-catastrophe", and they are not clearly separated. The top boxes show the concept of "design method". Category of Design I includes both Level 1 and Level 2. The dotted vertical line, which separates the Categories of Design I and II, is located above the domain of "anti-catastrophe". It means that some part of the "anti-catastrophe" is covered by the design scheme of Category of Design I. In the design codes, distinction between the Categories of Design I and II should vary depending on the types of infrastructures, their roles in the society, and the level of associated technologies. It should be determined also considering physical conditions such as seismic environment, social circumstances such as budgetary constraint, and consistency with current design codes. The final decision should be made by the owner or the code writers who are in charge of and responsible for the management of the infrastructure.

5. Framework of "Anti-Catastrophe"-oriented Design

This section presents the basic framework of the seismic design code. The process should have following five stages.

1) *Design Condition*: Required performance is determined.
2) *Situation Setup*: Damage types, circumstantial conditions, input ground motions are determined.
3) *Conceptual Design*: Structural types are determined.
4) *Structural Design*: To design to the detail.
5) *Validation*: To confirm items 1) to 4) are satisfied and consistent with each other.

Each of items is discussed in the following, where we will discuss mainly about Category of Design II, because Category of Design I is mostly the same as the current seismic design.

5.1 Design Condition

The concept of “anti-catastrophe” is consistent with performance-based design and its framework is applicable for the implementation of “anti-catastrophe”. The process starts with the specification of the required performance. The design condition is important because it determines the foundation of the design concept. It must be consistent with the social needs and must be feasible under the constraints such as budget and geographical conditions. At this stage, feasibility of all following stages should be roughly estimated in terms of budget, time, technologies, etc. To determine concrete conditions for “anti-catastrophe”, both empirical and theoretical discussions in the three axes of phase, time and domain (See the section 2.3) are required.

Let us discuss from the viewpoints of physical and social conditions.

(1) Physical significance

As physical conditions, factors such as seismic environment, ground conditions, active faults, past earthquake records, etc. should be considered. Most of them are also considered in the current seismic design and the treatment of the data may be almost identical. Careful attention, however, is required about how the extreme situations should be setup with rational scientific background, which is essential for the design for “anti-catastrophe” but not explicitly included in the conventional design scheme.

(2) Societal significance

Infrastructure is expected to support various activities after the disasters. It indicates that its role is dependent on the capacity of the society. Societal significance must be evaluated based on the analysis of the role of the infrastructure in the recovery process and its feasibility, which includes the capacity of the society itself, maintenance policy of the infrastructure, budgetary constraints, and so on. Regional disaster management plan of the area should be also taken into account.

In the context of *catastrophe*, infrastructure must have suffered some damage. It is important to think how to minimize the secondary effect of the damage, and how to maximize the contribution to the response and recovery of the whole social system.

When recoverability is discussed in the design for “anti-catastrophe”, societal condition should be more emphasized than in the current seismic design. As is introduced above, the Operation Comb after the 2011 Tohoku Earthquake was possible only with the help of management factors, such as appropriate decision of administration, contribution of construction companies based on the agreement. It would be advisable to consider those factors in the design stage.

It is also essential to consider the environmental conditions to maintain the performance and condition of the infrastructures. Various conditions could be taken into consideration: availability of monitoring data, capability of society and organization for the maintenance management, such as preparation for the emergency response, skill and budget for the infrastructure maintenance. They are external conditions for the structures and have only indirect effect, but they can be considered as elements of the performance of the structure in the design for “anti-catastrophe”. They do not make physical contribution but they correspond to *resourcefulness* of the 4R for the resilience.

It should be admitted that some structures do not require “anti-catastrophe” property, because of their role and effect in the aftermath of the destructive events.

<u>Category of Design II</u>: In order to determine the required performance, the societal significance of the infrastructure in the aftermath of the occurrence of severe natural disasters must be identified, considering both physical and social conditions, such as seismic environment, damage mechanism, technologies and capacity for fast recovery, high-quality maintenance, and availability of various resources, such as construction companies, human labors, heavy machineries.

5.2 Situation Setup

Current seismic design determines the external forces corresponding to the Levels 1 and 2, and structures are supposed to resist them. In the design for “anti-catastrophe”, various situations exceeding those situations should be considered. Accepting an obvious fact that seismic design is not perfect, various scenarios in which “structures are severely damaged” should be assumed. Such situations can be setup by extending the scenarios in terms of phase, time and domain. Instead of considering what kind of external condition can cause such scenarios, we can take severely damaged situation as the starting point of discussion. Emphasis should be put on how further severe damage can be prevented, and how functions of structures can be recovered in a short time. One of the methods to setup the extreme situation is to consider the strong external force, or strong ground motion that exceeds the L2 class ground motion. It is widely accepted that ground motion can exceed the ones specified in the design codes, but countermeasure for them is not mentioned to in the current seismic design.

Method for computation and evaluation of the response of structures against such severe ground motions is not established yet. However, even if detailed analysis is not available, it is possible to estimate the damage and disaster scenarios with certain confidence. Structural analysis can provide us with insight about the possible damage modes and that suffices for design purposes. In this analysis, a *stress test* with artificially synthesized very strong ground motion can be a useful option since it clarifies the weak point of structures and damage mode to be prepared for. The ground motion used for this analysis can be a virtual time series, and it does not have to be an observed strong motion record. However, it should be based on scientific knowledge of seismology, etc. It must be accepted that perfect protection against very strong virtual ground motion should not be expected. Lack of the countermeasure for such extreme ground motions should not be regarded as mismanagement with any legal responsibility.

Category of Design II: Situation that exceeds the state (damage) that is accepted in the Category of Design I. For that purpose, *stress test* should be carried out. Several virtual scenarios after the damage or disaster should be determined. They should be setup in different scales, such as how some device is broken, how some structures collapses, and how the transportation network is disrupted. It can be given as an extreme external force or damage scenarios. It should be emphasized that they are hypothetical scenario for *stress test* and perfect countermeasure is not required for them.

5.3 Conceptual Design

For efficient and appropriate realization of “anti-catastrophe”, engineers should not only make efforts to improve the quality of structure, but also they should be involved in the upper stream of the design process, where various factors are considered such as disaster environment, social environment, geographical conditions, and so on. They should consider the role of the structure in the regional disaster management plan, expected damage mode, resources required for swift recovery of the service, and other severe accidents. The output of *stress test* should be taken into consideration when feasibility of the plan is evaluated. Various concepts for structural plan are possible such as:

- Stable even after severely damaged: e.g. girder restrainer that can support the full weight of the girder.
- Robust against the change in conditions: e.g. low sensitivity to the change in parameters, predictability of behavior even under uncertain conditions.
- Strong enough against very large external force: e.g a structure that can resist the external force that is much larger than the force specified in the design code.

Conceptual design will give the baseline to determine the detail of the design: required structural strength, function and state after the damage, selection of construction site, and other elements of design.

Category of Design II: It is required to clarify the conditions for efficient and reliable realization of “anti-catastrophe” property. Conditions to be considered includes wide range including social, structural, geographical, and physical conditions.

5.4 Structural Design

This stage is close to the procedure of current seismic design based on structure mechanics and dynamics, detail of the structure is determined so that it realizes the specified performance. The most advanced technology should be utilized for that purpose. Even if evaluation/verification method applicable for such advanced technology may not be established yet, some alternative scheme based on engineers’ judgment should be permitted for reliable and useful technologies.

Category of Design II: It should be requested to implement appropriate countermeasure to prevent the situation to develop to either physically or socially critical states. Lack of evaluation method should not impede the employment of the advanced technologies.

5.5 Validation

The last stage evaluates that each of the previous stages satisfies correctly the intended performance. They need to be checked not only in terms of structural mechanics, but also consistency among all stages of 5.1 to 5.4. The condition specified in “Design Condition” (5.1) must be also evaluated in terms of feasibility. For example, recoverability defined in “Design Condition” (5.1) must be evaluated from both technical and organizational viewpoints. Effectiveness of countermeasure for the damage mode assumed in “Situation Setup”(5.2) must be judged using structural mechanics. Some of these evaluations may not be evaluated quantitatively. For those aspects, qualitative evaluation must be adopted and procedural framework for those must be determined.

Qualitative evaluation should be accepted for the validation of the performance with respect to societal significance, which is one of essential elements of “Category of Design II”. Both qualitative and quantitative methods should be utilized fully considering their merits and demerits.

Category of Design II: It is necessary to assure that all factors set for “anti-catastrophe” are consistent and that it is practically feasible and effective, based on the evaluation in terms of both theory and practice. It is also necessary to validate the performance of the design in various scenarios, such as severe structural damage, influence on the evacuation of community, and recovery process of damaged structures and infrastructure networks. It is preferable that their effect on the recovery of socio-economic activities be also estimated.

6. Implementation— Discussion from viewpoints of Risk Governance

6.1 Risk Governance

The “anti-catastrophe” accepts certain level of damage on structures. It means that the risk must be accepted and shared by the society. It is to some extent consistent with ISO 2394 [20], which has adopted new concept of risk in their recent revision in 2015. The “anti-catastrophe”-oriented design leaves high degree-of-freedom to designers, depending more on qualitative judgment. It suggests that risk control is essential.

The “anti-catastrophe” concept allows various useful design methods, and it is impossible to prescribe them because they must be designed modifying the original design adjusting to the context. For efficient implementation of “anti-catastrophe”, we need an endogenous mechanism where society can make decision, set appropriate safety standards, and realize and sustain them. This social mechanism requires proper risk management.

Risk management has been discussed and implemented by various research activities. Reason discussed the risk management of organizations [21]. Hollnagel et al. [22, 23] presented Resilience Engineering, which defines Resilience as [23],

> *The intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions. They put more emphasis on endogenous mechanism to maintain the society.*

Renn presented the concept of risk governance [24], which includes risk commutation and risk management. Our discussion is based on this definition hereafter. International Risk Governance Council (IRGC) reported that [25] the risk governance can prevent or mitigate the problems as:

- Inequitable distribution of risks and benefits between countries, organizations and social groups
- Differing approaches to assessing and managing the same risk
- Excessive focus on high profile risks, to the neglect of higher probability but lower profitable risks
- Inadequate consideration of risk trade-offs
- Failure to understand secondary effects and linkages between issues

- Cost of inefficient regulations
- Decisions that take inappropriate account of public perception
- Loss of public trust

They are all important issues when risk of extreme events is considered. IRGC presents the risk governance framework consisting from the five stages [25] as Pre-assessment, Appraisal, Characterisation and Evaluation, Management, and Communication. We consider how these elements should be utilized for the "anti-catastrophe"-oriented seismic design.

(1) Pre-assessment

It is essential to know what the damage of infrastructure means to the community. There can be a situation that exceeds the state described in the design codes, but it does not mean the structure is completely destroyed. If the "anti-catastrophe"-oriented design considers such partially damaged state, it may mean the structures are assumed to be damaged by large earthquake. If the "anti-catastrophe" is not applied to some structures, it may mean those structures are not safe. These kinds of misunderstand should be recognized.

(2) Appraisal

If we design structures with some residual risk, we are responsible to understand the significance of the outcome due to the risk. If we want to claim that those kinds of risk should be acceptable, we need to have evidence to support that concept.

(3) Characterisation and evaluation

It is expected to conduct analysis of critical situation, influence of its output. If possible, quantitative evaluation would be preferable.

(4) Management

The way to realize the property of "anti-catastrophe" is essential. Besides that, it is important to explore what government can do when situation assumed in the design codes are exceeded.

(5) Communication

Bi-directional information exchange between the government and the society is essential to establish trust in the "anti-catastrophe". It will help the government to have meaningful feedback from the society, and it will also encourage the society to recognize the risk and to have responsibility for their decision. It can prevent social amplification, or diffusion of groundless and agitating rumors through some media and the Internet.

6.2 Implementation

The policy of risk governance suggests some policies required for sound implementation of "anti-catastrophe"-oriented design methods. Discussion requires further study, but let us present some items.

(1) Appropriate application

It must be understood that not all infrastructures requires "anti-catastrophe" property. Application of "anti-catastrophe" concept should be selective and abuse should be prevented. If that is applied to too many infrastructures without proper selection, it may cause misunderstanding that the structure without "anti-catastrophe" property is unsafe. The implementation of "anti-catastrophe"-oriented design should send out the message that mitigates the fear or anxiety identified in Pre-assessment. Selective realization of infrastructure should be consistent with the processes of Appraisal and Characterisation and Evaluation.

(2) Check by the third party

Because "anti-catastrophe"-oriented design process has high degree of freedom, transparency is essential. Objective reasoning and accountability for the appropriateness are required. For example, it is possible to use intentionally weak input ground motion in the situation setup. One of effective measure to prevent such problems is the investigation of the design process by the third party. The organization should be free from interest of private companies and therefore it can be public institutions.

(3) Information disclosure

Information disclosure is obviously important from the viewpoints of Management and Communication. Information such as the situation assumed in the design, which includes the input ground motions and other external loads, are of great concern of the society and it should be shared in the society. Government may hesitate this because, if new information such as existence of active faults in the neighborhood is revealed, that may require revise of the design and may cost a lot for retrofitting or even replacement, which can be very costly and difficult in case of infrastructure. However, the framework of “anti-catastrophe”-oriented design should provide a tool to exploit qualitative discussion efficiently so that we can deal with such unexpected extreme situations rationally. Then the discussion should become productive and provide good opportunity to gain the trust from the society, which is essential for risk governance.

(4) Collaboration with the society

Pre-assessment process requires the government to understand the risk recognition of the society and associated factors. Risk communication process demands the information exchange with the society. The output of these processes should be realized and that is possible only when the government and community work together.

7. Summary

This paper introduced the concept of “anti-catastrophe” that is gaining attention in Japan after the 2011 Tohoku Earthquake. The “anti-catastrophe” concept is an essential and useful concept of the seismic design to deal with the extremely severe conditions with practical solutions. We defined the concept and discussed the conditions required for the implementation of “anti-catastrophe”-oriented design as a design code. The discussion covers only fundamental part and further efforts are required for the realization and diffusion of this concept. It reveals the importance of not only technical issues, but also social issues. Concept of risk governance is presented as a framework to develop the strategy for the implementation. That can help the “anti-catastrophe”-oriented design be accepted by the society as an efficient and rational methodology to prepare for extreme disasters, which will enhance the role of the infrastructure as the foundation of activity of the society in the modern world.

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