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PERFORMANCE EVALUATION OF BEYOND DESIGN BASIS EVENT BY UTILIZING NUMERICAL ANALYSIS

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ABSTRACT

Among the damages due to the 2011 off the Pacific coast of Tohoku Earthquake, a tsunami disaster and the accident of the nuclear power plant are the examples that the phenomenon except the assumptions in the designing caused serious impact on the society. Based on the damages, when the seismic design of critical infrastructure has been carried out in Japan, the performance which corresponds to the situation that the possibility that the influence that such a phenomenon gives to the society reaches the catastrophic state is small enough is named as anti-catastrophe, an approach for correspondence to the performance and the establishment of the evaluating method has been carried out.

When the impact to give to the society is catastrophic, for example, that is the following situations:

・An area which lost many functions such as the refuge, the rescue, the transportation of daily commodities, the structures supporting restoration is formed.
・Many human lives are menaced.
・Social activities and economic activities are threatened remarkably by the function loss of the structure.

As for the phenomenon except the assumptions in the designing, both the approach of ensuring safety of critical infrastructure based on the performance as anti-catastrophe in Japan and the approach to evaluate the impact as the risk based on the results obtained by evaluating the phenomenon quantitatively by using a numerical analysis are described.

INTRODUCTION

Among the damages due to the 2011 off the Pacific coast of Tohoku Earthquake, a tsunami disaster and the accident of the nuclear power plant caused serious impact on the society. Against the situation beyond scope of assumption in design for infra structure in Japan, the performance which corresponds to the situation that the possibility that the society reaches the catastrophic state is small enough was specified as anti-catastrophe.

As Required performance of infra structure for BDBE in Japan, not only the concept of Anti-Catastrophe in guideline of JSCE but also the implementation guideline for railway structure were specified after the he 2011 off the Pacific coast of Tohoku Earthquake. One of the objectives of this paper is to introduce the approach example of the correspondence for the performance called Anti-Catastrophe as following two.

- Design Standards for Railway Structures and Commentary (Seismic Design)
- Approach to evaluate performance of anti-catastrophe

Furthermore, the other one is to introduce the approach example of the countermeasure for BDBE in terms of accident management which is necessary to improve the safety of NPP based on defense in depth. As the example of the approach against geotechnical hazard such as slope failure, the following two are described.

- Risk evaluation for BDBE by use of numerical analysis considering nonlinearity of soil.
- Guideline for Verification and Validation by JSCE

TSUNAMI AND DAMAGES DUE TO THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE

At first, it was in a condition of the external power loss caused by the collapse of the transmission steel tower or the breaker due to the strong earthquake ground motion. Although emergency diesel generators (DG) started promptly, all AC power supply loss occurred because emergency DGs were inundated by the tsunami. Photo 1 shows Run-up Tsunami around Fukushima II NPP. Photo 2 shows the electric apparatus which was destroyed by the water pressure. The seawater pump for the cooling was also inundated by the tsunami and the loss of the de-heat function occurred finally. This accident caused a serious event of radioactive contamination of the surrounding area.

Photo 1 Run-up Tsunami around Fukushima II NPP

Photo 2 The electric apparatus which was destroyed by the water Pressure

Photo 3 All bridge girders carried away by Tsunami

Utatsu Ohashi bridge on Route 45, where all of bridge girders were carried away to by the tsunami as shown in Photo 3. Route 45 is an important social infrastructure of the coastal place. By the damage, long-term serious influence occurred for social activity, economic activity as well as a restoration activity.

DISSCUSSION ABOUT「BEYOND THE SCOPE OF ASSUMPTION」

One of discussions about 「beyond the scope of assumption」 after Fukushima Daiichi NPP accident due to The great East-Japan Earthquake is shown as follows (Kinoshita).

① The case that is excluded from an assumption as occurrence probability is extremely low

② The case which a few things to insist on there being occurrence probability existed, but took off from an assumption by considering it to be low probability as a major opinion of the organization

③ The case which it is understood that occurrence probability existed to some extent, but took off by the trade-off relations with other outside factors

④ The case which is excluded an assumption from overconfidence or self-conceit while feeling that occurrence probability exists

⑤ The case which is not noticed that there is occurrence probability

REQUIRED PERFORMANCE OF INFRASTRUCTURE FOR BDBE IN JAPAN

At least, for the case which is understood that occurrence probability will exist to some extent, and that the situation will be similar with the serious situation after The great East-Japan Earthquake, JSCE proposed that countermeasure should be considered against the BDBE case.

Definition of Anti-Catastrophe in Guideline of JSCE

Anti-catastrophic is defined as the performance that either the structure or the system including the structure does not suddenly reach the catastrophic state by the unexpected phenomenon (BDBE). The performance are provided to the structure etc. which are significant for not only social and economical activity but also restoration and refuge. The unexpected phenomenon is the situation which happens by the action beyond the scope of the assumption in design (BDBE).

Example of Implementation guideline (Railway) for Anti-Catastrophe

The L2 earthquake ground motion used in the seismic design of Japan is defined as the largest possible earthquake ground motion at the site, and as a result, the possibility of occurrence of earthquake ground motion exceeding that shown in Figure 1 cannot be excluded. For significant infrastructure, structural planning improves redundancy, robustness, recoverability, etc.

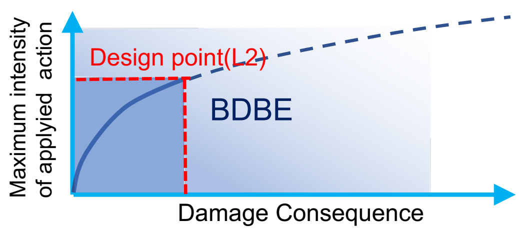

Figure.1 Relationship between intensity of design earthquake ground motion and damage consequence

Approach to evaluate performance of anti-catastrophe

A For confirming the improvement of performance quantitatively as shown in Figure 2, index of anti-catastrophe R is evaluated. The index is evaluated by the equation.

$$R=\sum Ci\times Pi \tag{1}$$

C : Influence of the situation to avoid on railway
P : Avoidance performance of structures against situations to avoid on railway
Items i consist of the following 5 components; Redundancy, Robustness, Recoverability, Aftershock resistance, Availability of surrounding space. Each component of P is evaluated by probabilistic approach based on fault tree. Each component of C is evaluated by questionnaire survey.

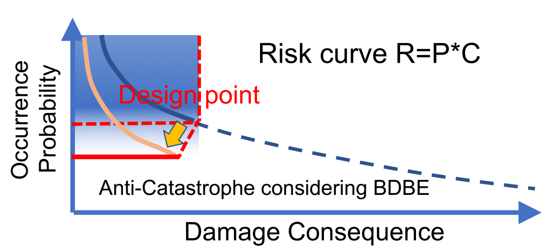

Figure.2 Image of performance improvement on Risk curve

The performance of Anti-catastrophe is the effect of the structural plan as the degree of increase in the index R as shown in Figure.3 and is confirmed by the infrastructure manager.

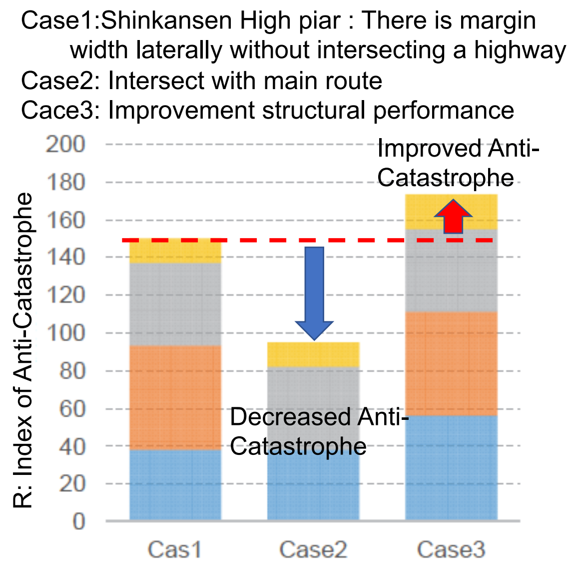

Figure.3 Example of evaluation about index of Anti-catastrophe

COUNTERMEASURE FOR BDBE IN TERMS OF ACCIDENT MANAGEMENT AGAINST GEOTECHNICAL HAZARD

Nuclear Regulatory Authority in JAPAN has examination guide for stability evaluation of foundation ground and surrounding slopes. The guide had established as the guide to respond to new regulatory standards created based on the damage caused by the The 2011 off The Pacific Coast of Tohoku Earthquake. It is based on evaluating ground stability (safety against slope failure) on the slip surface in the surrounding slope. As beyond the scope of assumption in design which maintain seismic stability of slope, impact of slope failure on buildings, water intake facilities and access roads is evaluated by probabilistic approach considering impact scenario against geotechnical hazard.

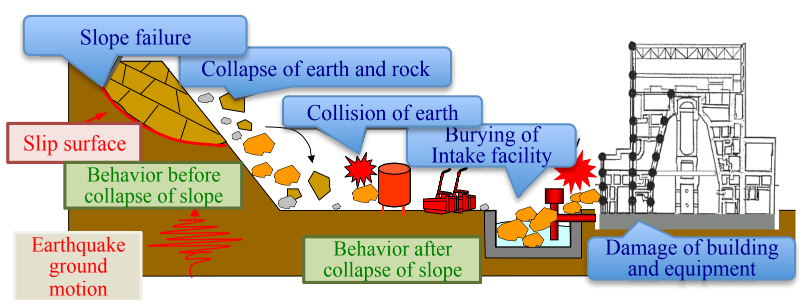

Figure 4 Image of impact scenario against slope failure as the geotechnical hazard

Flow of Risk evaluation and fragility evaluation based on numerical method

The flow to evaluate risk caused by slope failure around important facility in NPP is shown in Figure.5. In order to evaluate fragility curve, the limit state which correspond with the scenario have to be defined. In this situation, three limit states (Stability limit state, Reachable limit state, Damage limit state) are defined as order of occurrence in the behavior to lead to collapse from slope failure. As for fragility curve as stability limit, numerical method such as FEM and particle method is used to evaluate response values of slope. As for fragility curve as reachable limit, numerical methods such as DEM and MPM are used to evaluate run-out characteristics such as run-out distance etc under the assumption that soil and rock in the collapse domain collapse by its own weight. As for fragility curve as Damage limit, numerical method is used to evaluate response collusion characteristics against soil and rock which collide.

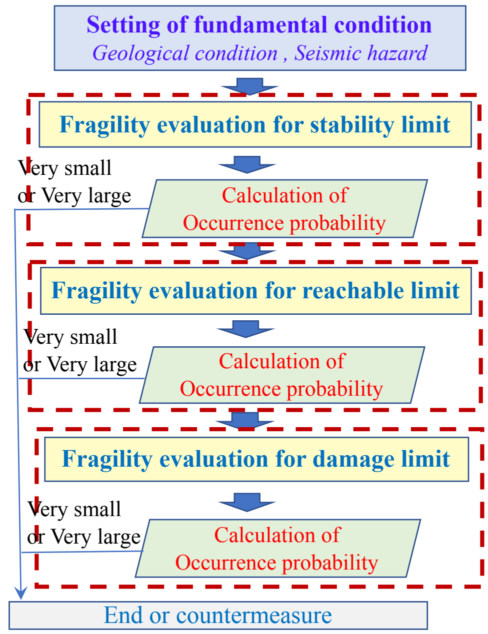

Figure 5 Flow to evaluate risk caused by slope failure

As the example to evaluate seismic risk for each limit state (Nakamura 2018), Table 1 shows the comparison of Occurrence probability for each limit state. Occurrence probabilities about stability, reachable and damage limit are evaluated by convolution of seismic hazard with fragility curve for each limit state.

Table 1 Comparison of Occurrence probabilities about stability, reachable and damage limit

Limit state	Probability
Damage limit	4.6×10^{-5}
Reachable limit	1.4×10^{-2}
stability limit	1.4×10^{-2}

Credibility and validation of numerical analysis are very important to evaluate the risk reliability.

Guideline for Verification and Validation by JSCE

Verification and validation of the numerical code to use are necessary to apply numerical analysis in a design and an evaluation. As the method of V&V for the non-linear analysis had not been presented yet, JSCE made guidelines based on the concept of model V&V specified in ASME V10. As for the code verification, it is decided to perform by the comparison with one of the existing numerical code, the manufactured solution, the theory solution. Validation is evaluated by confirming that the following two criteria satisfy the judgment criteria in accordance with the intended purpose of use with regard to the simulation results of the analysis model that takes into account of the uncertainty of the structural shape and material properties of the ground or the ground-structure system.

a) Degree of certainty due to reproducibility
b) Range of variability due to predictive performance

The procedure of the validation in the proposed V&V flow consists of two stages as the flow shown in Figure 6. The structural system with the material in which strong nonlinear behavior appears is the target of the simulation in this approach. At first stage, the validation of the initial analysis model whose material behaves linear is carried out at the first stage. At second stage, validation of the analysis model is carried out by the simulation that the material property behaves to nonlinear from linear.

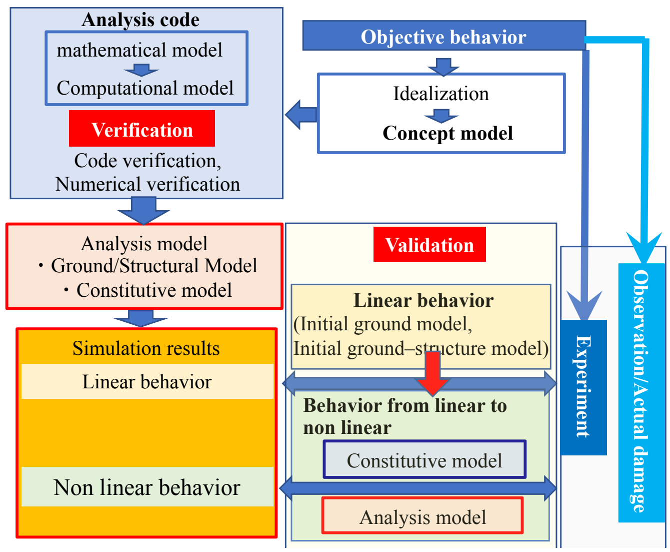

Figure 6 Flow of verification and validation specified in JSCE

CONCLUSION

For significant infrastructure in Japan, **Anti-catastrophic** is defined as the performance that either the structure or the system including the structure does not suddenly reach the catastrophic state by the unexpected phenomenon (BDBE). The performance of **Anti-Catastrophe** is quantitatively determined based on index R of **Anti-catastrophic**, and the infrastructure manager confirms the effect of the structural plan as the degree of increase in the index R.

As beyond the scope of assumption in design which maintain seismic stability of slope in NPP, Japan (BDBE), impact of slope failure is evaluated by probabilistic approach based on non-linear analysis.As the method of V&V for the non-linear analysis had not been presented yet, JSCE made guidelines based on the concept of model V&V specified in ASME V10. Credibility and validation of numerical analysis are very important to evaluate the risk reliability.

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