We use risk management at the project, unit, and corporate level. Corporate risks are identified annually by senior leaders and communicated throughout the agency. Unit risks are assessed [and] rolled up annually for consideration as part of the national planning process. Unit activities must address top risks.

At our firm, we define risk as a product of Vulnerability, Hazard and Exposure. Hazard is generally defined as a threat to the structure. Probabilistically, it is defined as the likelihood of a hazard to occur. Vulnerability is a preexisting condition of the structure by which a hazard is more or less likely to enable or mobilize failure. Probabilistically, it is defined as the likelihood of a failure to occur given the existence of a hazard. And Exposure is the consequences associated with a failure. Of course, there is an Uncertainty Premium which is an adjustment factor to account for the inherent uncertainty of the evaluation methods used to generate the data that is used for risk assessment.

The agency does this by applying and enforcing a set of technical requirements on plant design and operations, described in Title 10 of the Code of Federal Regulations (10 CFR). Generally, these are written in terms of traditional engineering practices such as “safety margins” in design, construction, and operations. The NRC also uses risk in a risk-informed, performance-based framework. Specific risk techniques have been applied to various areas, under different titles which include Probabilistic Risk Assessment, Integrated Safety Assessment (ISAs). We have specialized expertise and experience in risk analysis, hazard mitigation, benefit/cost analysis, and emergency operations planning for natural disasters and technological hazards, and anti-terrorism force protection (ATFP) planning and blast analysis.

We typically provide seismic risk assessments (SRAs) for single buildings, or multiple individual buildings within a portfolio, including garage structures, for due diligence, real estate investment decisions, and insurance purposes. We also sometimes use the Thiel-Zsutty method of obtaining seismic losses.

Procedures are being developed for risk assessment of existing dams and levee systems, with numerous initial assessments performed in the past few years.

The agency uses both deterministic and risk-informed approaches in its regulatory activities. The Agency has established regulatory tools and guidance for risk assessments. Probabilistic risk assessment methods are well developed and used for nuclear power plants. Some of the natural hazards have well developed methods for probabilistic hazard assessments (e.g., seismic) that is crucial for a probabilistic risk assessment. For some hazards, for example flooding, the approaches are under development. The risk assessment approaches are and will be used in connection with the post-Fukushima evaluations of operating reactors and licensing of new reactors. An industry standard, ASME/ANS-RA-S-2008, Addendum B, is available.

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The purpose of risk assessment and management is to reduce risks to the society in general to an acceptable level. This level is not fixed and should be oriented toward social equity. This means that the acceptable risk level for a structure in hazard prone regions (e.g., mountains) would be different than in the almost hazard free regions (plains). Structural risk assessment requires a careful definition of relevant hazard scenarios, which include their probability of occurrence and their mostly cascading consequences.

We minimize risks and maximize opportunities to successfully manage a program. We assess and develop risk management strategies to mitigate potential risks that can adversely impact a capital program.

We developed our own approach that yields a numerical risk factor for each potential threat. Schemes are developed to mitigate the effects of the potential threat, and the risk factor is re-calculated for each scheme. The reduction in the risk factor in combination with cost of the scheme allows for a cost/benefit analysis.

In general, the risk issues can be categorized in different classes: (1) identifiable as well as quantifiable risks, (2) expectable risks which are non-quantifiable at the relevant time, (3) non-identifiable and non-quantifiable risks, (4) unknown and extreme risks, so that a certain danger or a risk does not occur and the condition remains safe, preventive and protective measures can be taken.

The design process in general is iterative in nature involving a process of selection and analysis until a set of specified performance criteria are satisfied. At the design stage the aim would be to achieve the set of performance targets set by the owner at minimum cost. The performance specs can be in terms of allowable probabilities for exceeding certain non-performance thresholds. Of course, more generally, one can cast the problem in terms of minimizing overall risk. But this is a difficult problem as it requires drawing the boundary within which the indirect components of risk are computed. Risk management also involves the process of maintaining a building. How often the building should be inspected, when should it be repaired, etc. Again, this requires solution of an optimization problem that minimizes the overall cost of inspection and repair, while not compromising the expected performance and safety of the building.

Reducing the failure probabilities of the structure given those hazards. Reducing the consequences caused by structure failure.

The Air Force does not currently use risk assessments unless the deterministic damage tolerance approach cannot assure safety. This limits the application to fatigue and subsequent fracture of metallic airframe parts. We are trying to get the USAF more comfortable with risk assessments in order to have them start considering using risk assessments more frequently.

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Risk assessment and risk management can afford either a uniform or risk-targeted design of structures and infrastructure systems that provides safer, more cost-effective, and sustainable systems. I am interested in promoting this approach considering life-cycle performance of structures and infrastructure subjected to multiple natural hazards. Hence I suggest that the associated approach requires consideration of the individual and joint risks of hazard occurrence, characterization of the probabilistic response and performance of structures subjected to such hazards, account for the time-dependent effects of aging and deterioration on hazard performance, and quantification of impacts or consequences of structural damage.

(1) Identify hazards and loading intensities to be considered including recurrence, possibly multiple level consideration, if any. (2) Formulate/develop initial simplified model to determine necessary accuracy. (3) Couple load/response model(s) for analysis in either a known framework; or develop a framework specific to the problem at hand as part of step 2. And (4) risk management would be periodic assessment and applying optimization algorithms for resource allocation to maximize benefit, i.e. minimize risk. My group tends to focus on genetic algorithms lately but we have used all sorts of simpler optimizations.

My experience with risk assessment is for the purpose of assessing building performance given the occurrence of natural and man-made hazards (e.g., earthquake, wind, flood, and terrorist events). My approach involves quantification of the hazard in terms of some measure of intensity that can be equated to load (and the probability of occurrence or exceedance of that intensity), an assessment of the response of the structure to that load, a translation between structural response and potential structural damage, calculation of potential consequences in measurable terms such as costs, casualties, or downtime, and explicit or implicit consideration of uncertainties in each step of the process.

To implement structural risk assessment and management in the design of infrastructure systems, performance goals need to be established first. These performance goals indicate the quality of service and the restoration time that is acceptable for a particular lifeline system, and then individual manuals and guidelines need to prescribe requirements that result in the attainment of such system-level performance goals. Inverse system reliability methods are required, and approximated computational tools should be implementable in practice, so as to gain widespread use. Incentives should be part of the risk-based design process so that infrastructure owners and stakeholders embrace the shift in design paradigms.

(1) Identify all relevant threats for the specific systems of interest. (2) Develop probabilistic models of them. (3) For each specific system, develop probabilistic vulnerability functions under the action of each threat. (4) Perform a

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conventional risk analysis, including all relevant threats. (5) Formulate life-cycle risk-related optimum decision criteria. (6) Evaluate the influence of possible repair and maintenance actions on the vulnerability functions and on the life-cycle utility functions for existing systems, using information about accumulated damage and structural health monitoring. And (7) make optimum decisions using the information and the criteria mentioned above.

First, it is important to say that risk assessment is only meaningful within the context of decision making. The results of risk assessment are evidence, which should be complemented with other evidence that comes from different sources. Secondly, structural design and evaluation should move from a static evaluation to a time-dependent analysis. That means that assessments should focus on evaluating the reliability in terms of the analysis of time to failure. Thirdly, the analysis should have a wider scope and go beyond the mechanical performance of the system. For instance, it should involve at least costs/utility and financial aspects; e.g., incorporate LCCA.

ISO 13824 (General principles on risk assessment of systems involving structures) could present a general description for implementing structural risk assessment. Section 5 in the ISO 13824 presents structural context. The structural context defines the role of risk assessment in the framework of risk management for structures. The typical structural contexts are (1) design basis, (2) assessment of existing structures, (3) assessment of exceptional structures and/or extraordinary events, and (4) risk-based decision making. After the establishment of structural context, risk assessment could be conducted. Risk assessment consists of establishment of structural context, definition of structural system, identification of hazard and consequences, risk estimation, risk evaluation and evaluation of alternatives for risk treatment in case that risk shall be treated.

In my opinion, the most important issue that is not addressed in the appropriate way at the moment is the systemic impact on risk associated with any action on individual structures. When a new building or infrastructure component is designed, it usually impacts several infrastructure systems (if not directly, through interdependencies). For instance, when a new hospital is built, it changes the relative importance of the roads and portions of utility networks that serve it. Changing the consequences associated with the failure of such infrastructure systems (or portions thereof), it changes the risk associated with them. Including these considerations in the design and planning phases can lead to very different decisions. These aspects are very complex and therefore usually disregarded or, at least, not treated in a rigorous way. I believe that our approach to risk should go in this direction.

Society must balance trade-offs of risk in the built environment with other demands of society; ones that often have more immediate and tangible short-term benefits. Therefore, it is important to be able to communicate the long-term costs and benefits of risk management across the spectrum of societal

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needs. Issues such as public risk perception, public involvement, incorporating community values, overcoming incompatibility of lifetimes, and cost presentation methods must be understood in order to communicate with the public and with elected/appointed decision makers.

Purpose: Include security (defined herein as the absence of risk) as an independent performance criterion in multiple-criteria decision making for transportation infrastructure investment analysis; thus, risk will be considered as an additional criterion for carrying out prioritization for a large number of projects. Circumstances: The context of the decision making is the conduction of investment evaluation either for a specific facility or for a network of facilities. The former case is where we are deciding on the optimal set of preservation actions over the life cycle or remaining life of the facility. The latter case is where, at a given year, we are faced with a large number of assets that deserve some preservation project but lack the resources to implement all these projects, so we carry out optimization to identify the optimal portfolio using knapsack (binary) optimization. The objective function and constraints are expressed in terms of multiple performance criteria which traditionally does not include security (lack of risk). So, we are introducing security into the formulation, and we are carrying out scenario analysis and trade-off analysis to quantify various trade-off relationships between the various performance criteria. Conditions: To incorporate the security rating into multi-criteria evaluation as a performance measure, the security rating can be used for the asset in its current state as a generic performance measure that is the same for each project alternative, as an "increase in security rating" that is alternative-specific and different for each proposed improvement, and as a "final security rating" which is again alternative-specific and based on the enhancement to security that the improvement provides.

A risk-based criterion may be introduced in design and evaluation of structures. Application should be region specific. Introduction of such a criterion may allow more flexibility in ULS (ultimate limit state) design.

The approach for structural risk assessment can be tailored for a component, structural sub-system or overall infrastructure system, depending on the fundamental characteristics of the decisions it is intended to support. Risk assessment can be implemented at the design stage of a new structure or at the evaluation stage of an existing structure. The key steps of risk assessment and management include: Define Objectives: Define performance targets that the structure should satisfy in terms of safety, security, functionality, serviceability, durability. Identify structural systems/components: Identify systems and components that contribute to the safety, serviceability, durability and functionality of the structure and collect information including analysis of dependencies and interdependencies. Assess Risks: Evaluate the risk, taking into consideration the likelihood of failure under different possible hazards and their potential direct

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and indirect consequences. Implement Risk Management: Make risk-informed decisions and implement risk management approaches to control, accept, transfer, or avoid risks through different mitigation measures, including prevention, retrofit, protection, and recovery activities. Monitoring and control, Communication.

Answers to question I.6

Gray shading indicates the answers in the version of the survey distributed to Engineers, and light blue, the answers of Researchers.

Please describe the structure of the risk analysis team and describe how the information flows between team members. *(version for Engineers)*

Please recommend a structure for a risk analysis team and describe how information should flow between its members. *(version for Researchers)*

Usually team is small and strict document control serves as information flow, along with person-to-person meetings.

Not sure what "Risk Analysis team" refers to?

Corporate level usually only one or two people. Units also have one or two. Communication is via web-conferences and SharePoint submission.

The team usually consists of bridge owner's representative, bridge inspector, the engineer who is performing the risk assessment, as well as risk experts. Risk assessment is performed when bridges in a network should be prioritized for either replacement, retrofit, or capital planning. In this case, the information flows from the bridge inspector, to engineers, to consulting firm in charge of the assessment, and finally to the client, or the owner of the bridges.

The NRC has a significant number of risk analysts that have either general PRA expertise and/or are focused on specific areas (e.g., Seismic/Flooding Hazards, Human Reliability Analysis, Internal Fire). Traditionally, risk analysts will work in individual groups or divisions focused on specific activities (i.e., licensing, oversight) and applications (i.e., operating reactors, new reactor licensing, advanced and small reactor designs). There is also a significant amount of interaction between risk analysts in different areas to support common projects where specific expertise may be needed.

Usually only one engineer conducts a site visit and performs the assessment, however sometimes a junior engineer or architect is relied upon to collect field data. We also sometimes use junior engineers to research hazards and ground motions.

The risk assessment team is a multidiscipline team with facilitators from the USACE risk management center and technical members usually consisting of

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geotechnical engineers, hydraulic engineers, structural engineers, economists, and a member with background in risk and reliability computation.

Generally, the risk assessment team consists of hazard specialists (e.g., geologists and seismologists for seismic hazard), plant response and fragility analysts (various engineering disciplines), system and risk analysts, and human factors specialists. Key interfaces are established among the activities of different groups to maintain overall coherency. The interactions between system analysts and fragility engineers are crucial to assure that all structures, systems, and components important to risk and their relevant failure modes are captured in a risk assessment.

The risk analysis team should include: (1) Hazard analyst, who may or may not be a structural engineer but is knowledgeable with regard to hazard and actions that a structure may be exposed to. He collects relevant data from meteorologist, geologist etc. (2) Action analyst, who transform general hazards into actions on structure define their magnitude and occurrence rate. (3) Failure analyst, who estimates the response of the structure for various hazards and their magnitudes. This results in estimation of direct consequences of a failure, e.g., structural damage. (4) Consequence analyst, who estimates for a given structural damage the societal consequence and evaluates them perhaps in monetary terms. Clearly all members of team should work closely together and exchange their experience.

In the current economic climate, many organizations continue to face significant financial pressures and uncertainties. Consequently, the need to deliver projects and programs which meet schedule and budget, whilst minimizing risk and maximizing opportunities, is a top priority. We understand the challenges facing our clients and we look to provide more certainty of delivery with lower costs and improved performance across programs and projects.

Normally, workshop sessions that involve all impacted disciplines are conducted. Each workshop might last up to few days.

A risk assessment requires probabilistic information related to quantifying epistemic or aleatory uncertainties. Such uncertainties are best quantified from analysis of large statistical databases derived from operating experience, and field or experimental studies.

The team should include an engineering risk analyst who is an expert in statistics/probability and well-versed in the methods of risk and reliability analysis. The team should include one or more structural analyst/designer, and someone who can assess direct and indirect costs of various design alternatives, various damage states, inspections, repair, etc. The overall framework for the analysis should be developed by the risk analyst, with the others contributing to their specific parts in the framework.

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Systems modeling, Risk analyst, Domain knowledge engineers, Management (policy/decision makers).

A Risk Analysis Team should consist of members with social, environmental, economic, and probabilistic background to evaluate various aspects related to hazard occurrence, failure occurrence, and failure consequences, and make rational risk-informed decisions.

Risk Assessment Team should be responsible for: Risk Identification, Risk Analysis and Risk Priority. Risk Control Team should be responsible for: Risk Strategy, Risk Action and Risk Closure.

Lead / overall system risk analyst / party interested in applications of probabilistic methods (this person may have core competencies in one or more of the areas below). Hazard modeler(s), Load characterization specialist, or Environmental exposure analyst (passes info on hazard, load, or exposure potential). Structural system behavior/response and vulnerability modeling (provides estimates of anticipated structural performance for individual structures or portfolios of structural infrastructure). Infrastructure systems modeler (considers the estimates of structural component performance to evaluate reliability of overall infrastructure network providing estimates of likelihood of system). Consequence modelers from diverse fields such as Economics, Social Sciences, Public Health, etc. (provide probabilistic estimates of the consequences of damage/downtime in structure and infrastructure systems).

Again, I'll focus on hazards since this is my area: (1) Each hazard should have a team leader, or one person could potentially handle two. (2) The level of complexity needs to be decided before the model is developed, for example, avoid having a complex nonlinear model and a very simple binary model. And (3) each group or team or individual would provide either a conditional distribution or an unconditional, but conditional may be preferred so it can be de-conditioned in the same way.

In my experience, this process has involved an expert in the probabilistic assessment of the given hazard (e.g., seismologists in the case of seismic) who communicates the intensity measure and the probabilities associated with it, a structural engineering practitioner who is skilled in response simulation, performance assessment, and loss estimation, and a decision-maker in terms of an owner or other stakeholder who is responsible for making decisions based on the risk information. Information flow to the decision-maker must be non-technical in nature and must be aligned with the types of decisions that the stakeholder is accustomed to making (e.g., construction costs, cost-benefit ratios, downtime). In addition, communication of risk in probabilistic terms has proven to be very difficult and often needs to be boiled down into discrete decision-making points.

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A lifeline system is used in this question. Take for instance the power transmission and distribution systems, including their facilities, equipment, and other distributed structures. A risk analysis team should be divided so that one subgroup identifies the failure modes of the system and its components, another subgroup identifies the hazards in the region the system is located, and another subgroup evaluates the consequences of failure modes triggered by potential hazards. This will constitute a risk analysis exercise, which should be used as input for risk management exercises that explore mitigation, trade-offs, and strategic planning as well as decision making.

The team should include (a) A specialist in each of the relevant threats to be considered in the analysis, (b) One or more engineers with capacities in the design of structures and foundations of the different systems considered and in the estimation of their vulnerability functions, (c) One or more specialists in probabilistic risk analysis, including the quantitative assessment of possible consequences for different types of damage, (d) For decisions related with acceptable risk levels, the team should include persons with knowledge about social attitudes related to this concept.

Considering bridges belonging to a transportation network, a risk analysis team needs information on seismic hazard, fragility curves associated with bridge, assessment of the impact of direct and indirect costs, and post-disaster functionality of road network.

If “systemic risk” is considered, a risk analysis team will have to involve analysts with competencies in different branches of civil engineering. The flow of information should be handled in a very rigorous way so that each analysis can use the results of the others to feed his own calculations.

We have not developed a team structure. Instead, we plan to adopt that developed by AASHTO in the AASHTO Vulnerability Guide for team composition.

Civil engineering team should interact with social scientists to prepare preliminary design plans that can be used by decision-makers. Law makers should also be involved in the framework at a point when it might be beneficial to introduce and enforce new laws in order to facilitate sustainable and resilient (not just “safe”) infrastructure design.

A possible structure for a risk analysis team could include several members who will undertake the following tasks: Risk identification, Risk assessment, Risk mitigation, Risk acceptance [Communicate risks to stakeholders (Internal and External stakeholders), Review implemented mitigation measures and monitor risk].

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Answers to question I.7

Gray shading indicates the answers in the version of the survey distributed to Engineers, and light blue, the answers of Researchers.

Please describe respondent's duties and responsibilities and role in the team. *(version for Engineers)*

Please describe your research focus / background and how it contributes to key elements of question 5. *(version for Researchers)*

Completing calculations and drafting reports to be reviewed by supervisor.

Not sure what "Risk Analysis team" refers to?

Team leader.

The respondent is part of the risk assessment team in the consulting firm. My responsibilities include identification of hazards, exposures and vulnerabilities for bridges, and formulating the risk.

My role is specific to the evaluation of the risk significance of events and findings identified by NRC inspectors or self-identified by the licensees.

Principal investigator for the firm's research work on wind, earthquake, tsunami, and flood hazard analysis with emphasis on GIS mapping, building damage data and loss function studies.

I am responsible for both conducting and reviewing SRAs as well as managing and providing guidance to junior through senior associate engineers. I have been responsible for developing and updating company policies regarding seismic risk assessment.

I am a structural engineer and also perform the risk calculations.

As a manager, train and guide staff members in review of new plant applications, risk assessments, and all of the issues associated with natural hazards for both new and operating reactors. Also, interface with the research group to identify needed regulatory research. Interact with standard bodies and code committees. Collaborate with international regulators and IAEA on issues of common interest.

My research addresses all elements of Risk Assessment and Risk Management. However I address these elements in planning process in rather crude manner. Additionally for management purpose I try to group relevant situations in order to deal not only with one structure but with the whole inventory.

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