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Introduction to Return Periods

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Outline

1. Key Definitions

2. Hazard Return Periods used in design

Definitions

Deterministic vs Probabilistic

Deterministic Approaches[1]

– Deterministic hazard considers the behavior of a select earthquake scenario.
– Deterministic risk approaches are used to assess disaster impacts of a given hazard scenario.
– Ignores the recurrence rates of earthquake events and focuses on the outcome of a single event given its occurrence.

Probabilistic Approaches[1]

– Probabilistic hazard considers all possible scenarios, their likelihood and associated behavior.
– Probabilistic risk methods are used to obtain more refined estimates of hazard frequencies and damages.
– These assessments are characterized by inherent uncertainties, partly related to the natural randomness of hazards, and partly because of our incomplete understanding and measurement of the hazards, exposure and vulnerability under consideration (OECD, 2012).

[1] United Nations International Strategy for Disaster Reduction

Hazard vs. Risk

Hazard and risk are often used interchangeably, but there is a significant and meaningful difference between the two terms.

Probabilistic Seismic Hazard

- Describes the ground motions caused by earthquakes that have the potential to cause harm.
- Characterized by a ground motion intensity measure (IM) such as spectral acceleration or peak ground acceleration.
- Presented as “hazard curves”: probability of exceedance versus increasing IM

Probabilistic Seismic Risk

- The probability of occurrence (in some time period) of the adverse consequences to society due to the seismic hazard.
- Presented as probability versus specified loss.
- The risk is a combination of the seismic hazard and structural *exposure* to the hazard (structural fragility).
- The consequences are often expressed in abbreviated form by “the three D’s”:
  - Deaths (and casualties)
  - Dollars (loss due to damage)
  - Down time (livelihood and business interruption)
- The PEER PBEE framework (Moehle and Deierlein, 2004) is split into 4 components:
  - Hazard analysis (IMs)
  - Structural analysis (induced forces as a result of IMs)
  - Damage analysis (physical damage as a result of forces)
  - Loss analysis (the three D’s as a result of damage)

Probabilities and Return Periods

– “Return Period” and “Recurrence Interval” are synonymous terms.

– The concept of a return period is widely used in Engineering design. Structures and buildings are designed to withstand loads from natural events that are considered rare but nevertheless possible. As an example, a building might be designed to withstand ground motions imparted by earthquakes with a return period of 2,500 years as mandated by relevant design codes.[2]

– For a ground motion with an associated average return period, the annual probability of exceedance is simply the inverse of the average return period.
  - e.g. a 475-year average return period ground motion has an annual exceedance probability of 1/475 = 0.0021 or 0.21%.

– Assuming a random (Poisson) process, this can be expressed as a probability in a time frame.
  - e.g. 10% probability in 50 years is equivalent to 0.21% annual probability (475-year return period)

[2] David and Hodkinson (2018)

Probabilities and Return Periods

Misconceptions

- *The return period provides insight into the timing of an occurrence. (e.g. "The 100-year storm happened last year, so it won't happen for 100 more years.")*
- *The occurrence with 100-year return period is certain to happen in a 100 year time frame.*
- *The probabilistic ground motion with a given return period is known with certainty.*

Realities

- The return period is just an alternative representation of an annual probability. These annual probabilities are long-term averages.
- Our probabilistic tools are not prophetic and the future remains unpredictable.
- The probabilistic framework proposed by Cornell (1968) is well-established and widely used. However, the uncertainties in the results may be large due to the large variability in the earthquake process.

Hazard Return Periods used in Design

The following tables are highly simplified summaries of very complex and convoluted situations. They should be used only to provide a general frame of reference.

Various Hazards

The following table is a highly simplified summary of a very complex and convoluted situation. It should be used only to provide a general frame of reference.

Code/ Specification/ Agency	Hazard	Performance Level	Return Period
ASCE 7-16 (new buildings)	Flood	Design Flood	100 years
	Wind	Design Loads	50 years
	Rain	Design Drainage	100 years
	Tsunami	Maximum Considered Tsunami	2,475 years
	Ice	Design Loads	500 years
	Snow	Design Loads	50 years
U.S. National Flood Insurance Program	Flood-plain	Flood-plain definition	100 years

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Seismic Hazard in CA

The following table is a highly simplified summary of a very complex and convoluted situation. It should be used only to provide a general frame of reference.

Code/ Specification/ Agency	Structure	Performance Level 1 (Average Return Period)	Performance Level 2 (Average Return Period)
ASCE 41-13	Existing Buildings	Retrofit (225 years)	Stability Check (975 years)
ASCE 7-16	New Buildings	Design (~475 years equivalent)	Stability Check (2,475 years)
Caltrans	Toll Bridges	Design (~975 year equivalent of deterministic)	
DSOD	Dams	Design (~975 year equivalent of deterministic)	
US NRC	Nuclear Power Plants*	Design* (10,000 years)	Beyond Design Basis* (100,000 years)
OSHPD (CBC, ASCE)	Hospitals	Design (~475 years equivalent)	Stability Check (2,475 years)
CBC, ASCE	Schools	Design (~475 years equivalent)	Stability Check (2,475 years)

* Per ASCE 43-05, NPPs use a performance (risk-based) approach to determine design ground motions

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Seismic Hazard in CA - simplified

The following table is a highly simplified summary of a very complex and convoluted situation. It should be used only to provide a general frame of reference.

	Structure	Return period for design	Remarks
ASCE 41-13	Existing Buildings	225	Cat I/II: residential/industrial
		975	Cat III: dense occupation, utilities, hazardous storage
		2475	Cat IV: police stations, shelters, emergency response
ASCE 7-16	New Buildings	Maximum Considered Earthquake (MCER) ~2475 years for life safety	Design is based on 2/3 of MCER
Caltrans	Toll Bridges	Deterministic ~975 year equivalent	Deterministic, equivalent to 975 yr in CA
DSOD	Dams	Deterministic ~975 year equivalent	Deterministic, equivalent to 975 yr in CA
US NRC (ASCE 43-05)	Nuclear Power Plants	Design 10,000-100,000 years	NPPs use a performance (risk-based) design
OSHPD (CBC, ASCE)	Hospitals	MCER ~2475 years	Design is based on 2/3 of MCER
CBC, ASCE	Schools	MCER ~2475 years	Design is based on 2/3 of MCER

Bay Area Examples

Bay Bridge: Bay Bridge Seismic Safety Project, 2014

– *"Caltrans has stated that the bridge is designed to experience only minor damage and be operational shortly after a Safety Evaluation Earthquake… The Safety Evaluation Earthquake ground motions used to evaluate the bridge are those estimated to be exceeded once every 1,500 years on average. This standard is higher than the 1,000-year "return period" that most bridges in the State of California are designed for. The Safety Evaluation Earthquake also corresponds approximately to 84th percentile ground motion amplitudes under maximum credible earthquakes on the San Andreas or Hayward faults... No formal Probabilistic Risk Assessment (PRA) was performed to understand the probability of a bridge failure and the most likely mechanisms of a failure."*

Technical Review of Design and Construction of New East Span of San Francisco-Oakland Bay Bridge (2014). J. Baker, R. DesRoches, R. Gilbert, Y. Hashash, R.T. Leon, S. Kumarasena. Submitted to: The California Senate Transportation and Housing Committee

Bay Area Examples

Golden Gate Bridge: Retrofit Project, Initiated 1996

– *"the site-specific design ground motions associated with different magnitudes of earthquakes and expected performance levels were defined as the basis for the Bridge retrofit design. The site-specific, moderate earthquake was defined as one having a 10 percent chance of being exceeded in a 50-year period or having an acceleration of 0.46g. The site-specific, maximum credible earthquake was defined as one having a return period of 1,000 years or having an acceleration of 0.65g, which is equivalent to the 1906 San Francisco earthquake of a magnitude 8.3 on the Richter scale."*

http://www.goldengatebridge.org/projects/retrofit.php

Bay Area Examples

Bay Area Rapid Transit: BART Retrofit, 2003

– *"BART retrofit design ground motions for checking life-safety performance were generated based on the spectral values being the greater of the deterministic median + ½ σ or the probabilistic 500-year return period values (DBE). Lower values, based on median deterministic spectra, were generated for checking functionality performance (LDBE). Higher values, based on the greater of the median deterministic + σ or the probabilistic 1,000-year return period values, were also developed to evaluate the critical Transbay Tube."*

BART Seismic Retrofit Program: Characterization of Design Ground Motion. (2003). J. Litehiser, N. Gregor, J. Marrone, F. Ostadan and R. Youngs. Sixth US Conference and Workshop on Lifeline Earthquake Engineering. August 10-13, 2003, Long Beach, California, United States

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Bay Area Examples

Tall Buildings

- *Based on the ASCE Standard. For example, the tallest building in San Francisco is the Salesforce Tower. The design of this building used performance-based engineering with performance objectives and ground motions defined by ASCE[1]; Maximum Considered Earthquake (MCER) ground motions are the lesser of the 2,500-year average return period probabilistic ground motions and the deterministic (median + σ) ground motions.*

- *For San Francisco, the MCER is based on the deterministic estimates so the average return period is less (approximately 1,200 years for a soil site)[2]. The performance objective for MCER ground motions is collapse prevention and the 2/3 MCER is used for design (life safety).*

(1) Salesforce Tower (2017). R. Klemencic, M.T. Valley, J. Hooper. Structure Magazine. https://www.structuremag.org/?p=11635

(2) San Francisco Tall Buildings Study (2018). Applied Technology Council.Prepared for the City and County of San Francisco Office of Resilience and Capital Planning.

Bay Area Examples

The following table is a highly simplified summary of a very complex and convoluted situation. It should be used only to provide a general frame of reference.

	Return period for design	Remarks
Most Typical Structures: Museums, Office Buildings, Hotels, etc	ASCE (~475 years equivalent)	
Bay Bridge Retrofit 2014	1,500 years	
BART Retrofit 2003	1) Greater of 500 years and Deterministic + ½ **σ** 2) Greater of 1,000 years and Deterministic + 1 **σ**	1) Life safety for typical sections 2) Life safety for the transbay tube
New Tall Buildings in downtown SF	ASCE 7-16 Deterministic MCER; corresponds to ~1,200 years for a soil site	ASCE MCER: lesser of 2,500 year and deterministic
Golden Gate Bridge Retrofit 1997	500 years (moderate) 1,000 years (severe)	
Original SFO International Terminal	Deterministic MCE	Zayas and Low (2000)
SFO Traffic Control Tower, 2017	Deterministic MCE	https://www.structuremag.org/?p=10863
Benicia-Martinez Bridge, 1962	Deterministic MCE	Zayas and Low (2000)
Hayward City Hall, 1999	Deterministic MCE	https://www.kpff.com/portfolio/project/hayward-city-hall
SF Ferry Terminal, 2015	ASCE 7-10 MCER	ASCE MCER: lesser of 2,500 year and deterministic
Moscone Center	Deterministic MCE	http://www.moscone.com/site/do/mediakit/view?id=12

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