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WHAT LEVELS OF SEISMIC GROUND MOTION TO USE FOR LIQUEFACTION EVALUATION?

ASCE
American Society of Civil Engineers

G-I
ASCE
GEO-INSTITUTE
SoCal Inland Empire Chapter

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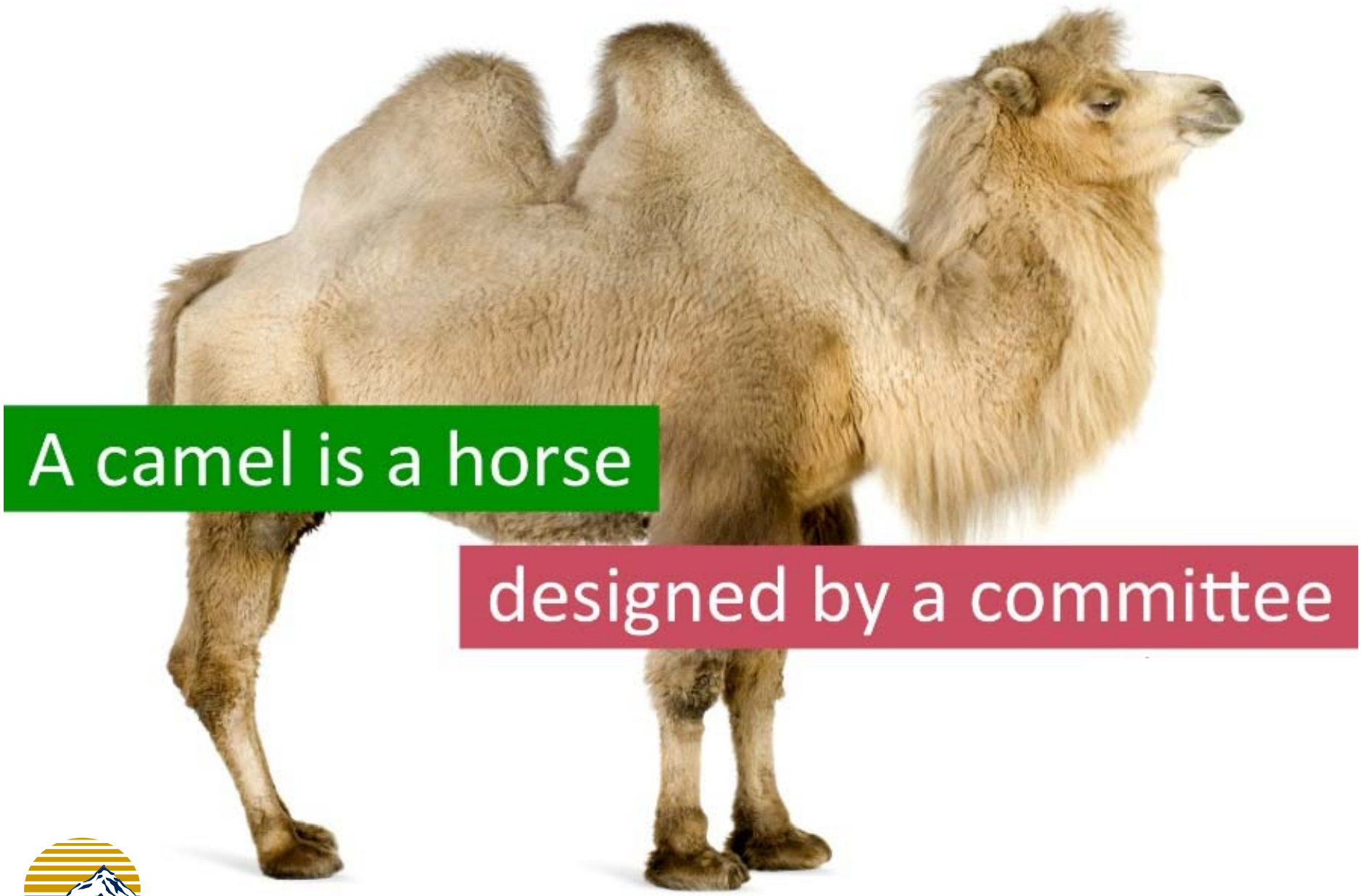

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ASCE 7-10

MAXIMUM CONSIDERED EARTHQUAKE (MCE) GROUND MOTION:
The most severe earthquake effects considered by this standard

MAXIMUM CONSIDERED EARTHQUAKE GEOMETRIC MEAN (MCE_G) PEAK GROUND ACCELERATION:
determined for geometric mean PGA and without adjustment for targeted risk. The MCE_G PGA adjusted for site effects (PGA_M) is used in this standard for evaluation of liquefaction, lateral spreading, seismic settlements, and other soil-related issues.

RISK-TARGETED MAXIMUM CONSIDERED EARTHQUAKE (MCE_R) GROUND MOTION RESPONSE ACCELERATION:
determined for the orientation that results in the largest maximum response to horizontal ground motions and with adjustment for targeted risk.

ASCE 7-10

DESIGN EARTHQUAKE:

The earthquake effects that are two-thirds of the corresponding maximum considered earthquake (MCE_R) effects.

DESIGN EARTHQUAKE GROUND MOTION:

The earthquake ground motions that are two-thirds of the corresponding MCE_R ground motions.

ASCE 7-10 (2016 CBC)

- The potential for liquefaction and soil strength loss evaluation should be evaluated for site PGA, earthquake M, and source characteristics consistent with the MCE_G PGA.

CGS Note 48

- Evaluate liquefaction using highest historical ground water elevation.
- Evaluate using PGA_M
- Deaggregate for modal M and R
- Calculate liquefaction settlement for each layer where FS<1.3

Los Angeles
City and County

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COUNTY OF LOS ANGELES (2014)

- Liquefaction Analyses:
  - PGA = 2/3 PGA_M
  - PGA = PGA_M

$PGA = 2/3\ PGA_M$

- Magnitude calculated from deaggregation analysis (10% PE in 50 years; 475-year return period)
- Either modal or mean values may be used
- Potential seismic-induced settlements shall be determined when the FS is less than 1.1

PGA = 2/3 PGA_M (cont'd)

Settlement limits (inches):

Foundation type	Total combined settlement (seismic plus static)	Total combined differential settlement (seismic plus static)
Conventional spread/continuous	1 ½	3/4
Mat-type	4*	2*

* Where the above limits are exceeded, the Department requires the use of other foundation systems or ground improvement

$PGA = PGA_M$

- Seismic-induced liquefaction settlements shall be determined
- Magnitude calculated from deaggregation analysis (2% PE in 50 years; 2475-year return period)
- Either modal or mean values may be used
- Potential seismic-induced settlements shall be determined when the FS is less than 1.0
- Deformations of any foundations shall be such that the foundations of the buildings or other structures do not lose their ability to carry gravity loads and that collapse of the building or other structures is prevented

COUNTY OF LOS ANGELES (2013)
Department of Public Works

- Probabilistic (10% PE in 50 yr = 475 yr return period) or deterministic SHA
- Differential settlement is ½ total settlement over a horizontal distance of 30 ft
- In order to use less than ½ total settlement, there must be additional boring(s) and analyses to confirm the difference in the amount of seismically induced settlement

COUNTY OF LOS ANGELES (2013)

- Structural mitigation acceptable:
  - Up to 1 inch of diff. settl. over a 30 ft horiz. dist.
  - Up to 4 inches of total settlement
  - Up to 12 horizontal inches of lateral ground displacement
  - Anything in excess of these values will require ground modification
- A combination of mitigation measures that include ground modification, piles, and structural mitigation may be acceptable on a case by case basis

COUNTY OF LOS ANGELES (2013)

- Liquefaction and lateral spreading
  - Structural mitigation including, but not limited to, the use of mat foundations, may be considered for mitigating up to 4 inches of total settlement and up to 12 horizontal inches of lateral ground displacement
  - If exceeded, ground modification is generally required.
- However, deep foundations may be used in lieu of ground modification in certain cases if the permitted structures and all associated building code required appurtenances including, but not limited to, primary ingress/egress (including ramps, walks, and fire lanes from the proposed structures to the public right-of-way) are supported by deep foundations and protected against the geotechnical hazards.

Caltrans (2014)

EVALUATION OF LIQUEFIABLE SOILS

- Use the more conservative of the deterministic or probabilistic eq. GM (5% PE in 50 yr or 975 yr return period)
- Simplified procedure Youd et al (2001) (to depths of 50ft; with caution to 70ft; do not use below 70 ft)
- If groundwater below 50 ft, the site should be considered non-liquefiable
- Use the ground water elevation measured during the field investigation. A higher elevation may be used if there is clear evidence for seasonal or long-term fluctuations
- Use a FS against liquefaction of 1

CA High Speed Train (2012)

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DESIGN EARTHQUAKE GROUND MOTIONS

- **Maximum Considered Earthquake (No collapse) –** Ground motions corresponding to greater of (1) a probabilistic spectrum based upon a 10% probability of exceedance in 100 years (i.e., a return period of 950 years); and (2) a deterministic spectrum based upon the largest median response resulting from the maximum rupture (corresponding to M_{max}) of any fault in the vicinity of the structure.
- **Operating Basis Earthquake (Operability) –** Ground motions corresponding to a probabilistic spectrum based upon an 86% probability of exceedance in 100 years (i.e., a return period of 50 years).

SIMPLIFIED PRODECURES (cont'd)

- The potential consequences of liquefaction and (if necessary) liquefaction hazard mitigation measures shall be evaluated if the FOS against liquefaction is less than 1.05.

Committee on State of the Art and Practice in Earthquake Induced Soil Liquefaction Assessment; Board on Earth Sciences and Resources: Division on Earth and Life Studies; National Academies of Sciences, Engineering, and Medicine

State of the Art and Practice in the Assessment of Earthquake-Induced Soil Liquefaction and Its Consequences

2016

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11 Recommendations

Recommendation 8

- Refines, develop, and implement performance-based approaches to evaluating liquefaction, including triggering, the geotechnical consequence of triggering, structural damage, and economic loss models to facilitate performance-based evaluation and design

NAVFAC (1997)

	Ordinary Buildings	Piers & Wharves	Essential Buildings	Hazardous or Polluting Construction
Navy Provisions	NAVFAC P355		NAVFAC P355.1	
Performance Objectives	Minor earthquake no damage Moderate earthquake no structural damage Major earthquake no collapse	Level 1 no structural damage Level 2 controlled inelastic behavior, repairable	Level 1 minor damage no loss of function Level 2 repairable damage	Prevent release of materials breach, or loss of contents
Design Earthquake (Exceedance Probability)				
Structure	50% 50 years (72 yr)	Level 1 50% 50 years Level 2 10% 50 years	Level 1 50% 50 years Level 2 10% 100 years	10% 250 years (2400 yr)
Liquefaction	Level 1 50% 50 years Level 2 10% 50 years (475 yr)	Level 1 50% 50 years Level 2 10% 50 years	Level 1 50% 50 years Level 2 10% 100 years	10% 250 years
Design Response Limits				
Structural	Code stress and drift limits	ductility limits	ductility & drift limits	no collapse/breach limits
Liquefaction	Level 1 FS 1.5 Level 2 FS > 1.0 controlled deformation	Level 1 FS 1.5 Level 2 FS > 1.0 controlled deformation	Level 1 FS 1.5 Level 2 FS > 1.1 controlled deformation	FS > 1.1 controlled deformation

ASCE 7-16
Minimum Design Loads and Associated Criteria for Buildings and Other Structures

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SECTION 12.13.9
REQUIREMENTS FOR FOUNDATIONS ON LIQUEFIABLE SITES

- Where the geotechnical investigation report…identifies the potential for soil strength loss caused by liquefaction in MCE_G earthquake motions, structures shall be designed to accommodate the effects of liquefaction

SECTION 12.13.9.1
FOUNDATION DESIGN

- Foundations shall be designed to support gravity and design earthquake loads, as indicated in the basic load combinations…, using the reduced soil bearing capacity, as indicated in the geotechnical investigation report, considering the effects of liquefaction caused by MCE_G earthquake motions.
- The anticipated lateral spreading, differential settlement values, and foundation design shall be permitted to include the mitigating effects of any planned ground improvements for the site

SECTION 12.13.9.2
SHALLOW FOUNDATIONS

- The geotechnical investigation report indicates that permanent horizontal ground displacement induced by lateral spreading associated with MCE_G earthquake motions does not exceed the value in Table 12.13-2

SECTION 12.13.9.2
SHALLOW FOUNDATIONS (CONT'D)

- The foundation and superstructure are designed to accommodate differential settlements caused by liquefaction without loss of the ability to support gravity loads

COLLAPSE RISK

- FEMA P-695 suggested acceptable collapse risk of 10% given MCE motions
- ASCE 7-10 adopted this criterion and developed MCE_R with this basis
- However recent earthquakes do not support a collapse risk this high

ASCE 7-22

- Basis for:
  - 2020 NEHRP Provisions
  - 2024 IBC
  - 2025 CBC

ASCE 7-22

- MCE_R at 1,475 yr without deterministic cap (currently 2,475 yr with deterministic cap)
- Peformance based? Two levels for liquefaction??

CONCLUSIONS

- Makes sense performance-based
- Different levels of earthquake hazard: more reasonable
- MCE and DE levels should not be mixed
- Different approaches, different needs
- Aleatory and epistemic uncertainties
- Judgment, experience, discussion…

Thank you.

YOUR QUESTIONS

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