日本建築学会荷重運営委員会信頼性工学利用小委員会・公開小委員会
「建築物に関する不確実さの取り扱いと対処技術の最新動向」

各国の構造設計における不確実さの取り扱い（荷重耐力係数の比較を通じて）

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DPRI-KU

Today’s talk

1. Comparison of design codes for structures in selected revision and countries
   - Europe (EUROCODE)
   - USA (ASCE 7-10)
   - Canada (CSA)
   - Australia (AS)

2. Benefits and motivation to introduce more numbers of partial factors:

   Discussion-based
   - Through examples in two industries:
     (1) Electricity
     (2) Wind energy
   - Robustness, target reliability and partial factors

1. Comparison of design codes for structures

1. Limit states, design situations, values for loads (actions), load factors and load combinations for ordinal structures

	Eurocode EN 1990	ASCE Standard 7-10	CSA	Australian code
Limit state	■ Ultimate limit state (ULS) ■ Serviceability limit state (SLS)	■ Strength limit state ■ Serviceability limit state	■ Ultimate limit state (ULS) ■ Fatigue limit state (FLS) ■ Serviceability limit state (SLS)	
Design situation	■ Persistent situation ■ Transient situation ■ Accidental situation ■ Seismic design situations			
Classification of actions (loads)	■ Permanent action, G ■ Variable action, Q ■ Accidental action, A	■ Permanent load ■ Variable load	■ Permanent load, G ■ Variable load, Q ■ Rare loads, E	■ Permanent action ■ Imposed action ■ Wind, snow and ice & earthquake action
Values of actions (loads)	■ <u>For permanent action</u> - Characteristic value, G_k ■ <u>For variable action</u> - Characteristic value, Q_k - Combination value, $\psi_0 Q_k$ - Frequent value, $\psi_1 Q_k$ - Quasi-permanent value, $\psi_2 Q_k$ ■ <u>For accidental action</u> - Characteristic value, A_k	■ Nominal load, Q_n	■ Specified loads - <u>For permanent load</u> the mean value - <u>For variable action</u> $R \geq 50$ years (or $P_{AE} \leq 0.02$) - <u>For rare load</u> $R \approx 2500$ years (or $P_{AE} \approx 0.0004$) R : return period P_{AE} : annual exceedance probability	■ Design events for safety Annual probability of exceedance Importance Level | Wind: Non-cyclonic | Wind: Cyclonic | Snow | Earth-quake 1 | 1:100 | 1:200 | 1:100 | 1:250 2 | 1:500 | 1:500 | 1:150 | 1:500 3 | 1:1000 | 1:1000 | 1:200 | 1:1000 4 | 1:2000 | 1:2000 | 1:250 | 1:1500
Partial factors for actions (load factors)	■ Partial factors for actions, γ_f	■ Load factor, γ	■ Load factor, α	■ None
Design value of action (factored load)	■ Design value ($F_d = \gamma_f F_r$)	■ Factored load, γQ_n	■ Factored load	■ Design value of action
Combination of actions (load combinations)	■ For example Varied by limit state and design situation (for example) $\sum_{j\geq1}\gamma_{G,j}G_{k,j}+\gamma_P P+\gamma_{Q,1}Q_{k,1}$ $+\sum_{i>1}\gamma_{Q,i}\psi_{0,i}G_{k,i}$	■ Load Combination $\sum_i \gamma_i (Q_n)_i$	■ Basic Combination $\sum \alpha_{G_i} G_i + \alpha_{Q_j} Q_j + \sum_{k\neq j} \alpha_{C_{jk}} Q_k$ ■ Rare Load Combination $\sum G_i + E + \sum_{k\neq j} \alpha_{C_{Ek}} Q_k$ α_{Q_j} : Principal load factor $\alpha_{C_{jk}}$: Companion load factor	

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2. Target reliability for ordinal structures

Target Reliability

Eurocode EN 1990

■ Minimum values for reliability index β (ULS)

Reliability Class	reference periods	
	1 year	50 years
RC3	5.2	4.3
RC2	4.7	3.8
RC1	4.2	3.3

■ Target reliability index β for Class RC2 structural members

Limit state	reference periods	
	1 year	50 years
USL	4.7	3.8
Fatigue		1.5-3.8
SLS (irreversible)	2.9	1.5

ASCE Standard 7-10

■ Acceptable reliability (maximum annual probability of failure) associated reliability indexes for load conditions that do not include earthquake

Basis	Risk Category			
	I	II	III	IV
b1	2.5	3.0	3.25	3.5
b2	3.0	3.5	3.75	4.0
b3	3.5	4.0	4.25	4.5

- b1: failure that is not sudden and does not lead to widespread progression of damage
- b2: failure that is either sudden or leads to widespread progression of damage
- b3: failure that is sudden and results in widespread progression of damage

■ anticipated reliability (maximum probability of failure) for earthquake

	Risk Category		
	I & II	III	IV
f1	10%	6%	3%
f2	25%	15%	10%

- f1: total or partial structural collapse
- f2: failure that could result in endangerment of individual lives

CSA

■ CAN/CSA-S6-06 : β = 3.50
- for bridges with a 75-year design life

■ Bartlett et al. (2003) : β ≥ 3.0
- normal building components with a 50-year design life for ductile failures

■ CSA(1981)
- steel and concrete buildings for ULS based on 30-year life

Safety Class	Type of Failure	
	Gradual	Sudden
Not serious	2.5	3.0
Serious (normal buildings)	3.5	4.0
Very serious	4.0	4.5

■ CSA S408-81 : β=3.5
for brittle failures with a ??-year design life

■ Bartlett (2007) : β=4.0
for brittle failure of concrete element with a ??-year design life

■ CISC 2010 : β=4.5
for fracture of steel on net section with a ??-year design life

Australian code

■ Annual structural reliability indices (β) for structural components and connections

Importance Level	Permanent & imposed actions	Wind, earthquake & snow actions
1	3.8	3.2
2		3.4
3		3.6
4		3.8

Factor for importance of structure (reliability modification)

Eurocode EN 1990

■ K_{FI} factor for actions,

	Reliability Class		
	RC1	RC2	RC3
K_{FI}	0.9	1.0	1.1

ASCE Standard 7-10

■ load modifier, η_i

a factor relating to ductility, redundancy, and operational importance

CSA

■ Importance factor, I

Australian code

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2. Benefits and motivation to introduce more numbers of partial factors

(1) Electricity industry

- Necessity to develop codes consistent with international tread
  Note: international trend = reliability-based design
  e.g. IEC60826 Design criteria of overhead transmission lines

- Safety checking format (石川(2009))

$$\phi R_n \geq \gamma_W W_n + \gamma_D D_n$$

- Safety checking format considering response modeling uncertainty

$$\phi R_n \geq \gamma_W \eta_W W_n + \gamma_D D_n$$

R_n : Nominal resistance
W_n : Wind-induced response
D_n : Response under no wind
ϕ : Resistance factor
γ_W : Load factor (wind)
γ_D : Load factor (others)

η_W : Modeling uncertainty

石川智巳, 送電用鉄塔の耐風信頼性設計法に関する検討(その2)― 風向特性を考重した荷重・耐力係数法に基づく設計式の提案―,電中研報告.2009.7
電力中央研究所, http://criepi.denken.or.jp/jp/env/outline/2007/64.pdf

(2) Wind energy

- IEC61400-1 (Wind turbines - Part 1: Design requirements)

e.g. blade corrosion failure:

$$R_c \geq \gamma_n \gamma_m \gamma_f S_c$$

$$M = X_{capacity} R - X_{demand} S$$

$$X_{demand} = X_{\exp} X_{st} X_{aero} X_{str} X_{sim} X_{ext}$$

R_c : characteristic capacity (clearance)

S_c : characteristic demand (deflection)

γ_n : partial safety factor accounting for consequence of failure

γ_m : partial safety factor accounting for material uncertainty

γ_f : partial safety factor accounting for load uncertainty

Robustness, target reliability and partial factors

- Structural elements to structure
  - ASCE 7-10 (brittle, progressiveness)

- Structure to society and economy
  - Consequence class (ISO2394)
  - Risk Category (ASCE 7-10)

Discussion

- Why more number of partial factors?

- Different nature of different hazards; how to differentiate in reliability-based design formats?
  - Need to consider different affected sizes by different hazards for some load combinations?