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Long-term Response Analysis of Floating Bridges

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Chained Floating Bridge

- Development project organized by Multiconsult
- PhD at NTNU
  - Supervisors
    - Bernt Leira – Dept. of Marine Technology
    - Ole Øiseth – Dept. of Structural Engineering
- So far
  - Stochastic description of wave loads
  - Development of a new method for faster computations
- Today
  - Long-term extreme response of floating bridges

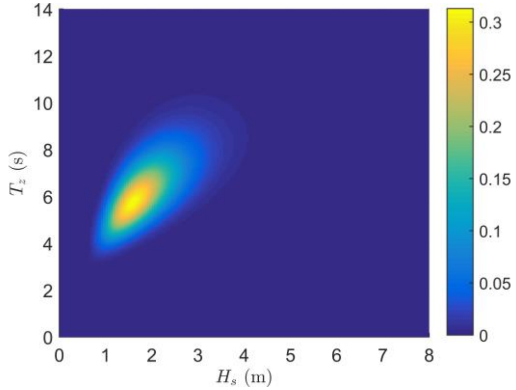
Short-term extreme value CDF

- Environmental parameters $\boldsymbol{S} = [H_s, T_z]$ considered constant for a short-term period $\tilde{T}$, typically $\tilde{T} = 3\text{h}$ for waves
- Given $\boldsymbol{S}$ we assume a stationary response process $R(t)$
  - $\tilde{R}|\boldsymbol{S} = \max\{R(t)|\boldsymbol{S}; 0 \leq t \leq \tilde{T}\}$

- Assuming independent upcrossings of high levels r
  - $F_{\tilde{R}|\boldsymbol{S}}(r|\boldsymbol{s}) = \exp\{-\nu_R^+(r)\tilde{T}\}$
- Also assuming Gaussian response process
  - $F_{\tilde{R}|\boldsymbol{S}}(r|\boldsymbol{s}) = \exp\left\{-\frac{\sigma_{\dot{R}}}{2\pi\sigma_R}\exp\left(-\frac{r^2}{2\sigma_R^2}\right)\right\}$

Long-term extreme response modelling

- Sequence of N short-term states, each of duration $\tilde{T}$
- Joint distribution $f_{\boldsymbol{S}}(\boldsymbol{s})$ for the environmental parameters
  - $H_S \sim \ln \mathcal{N}\left(\lambda_{H_S}, \xi_{H_S}^2\right)$
  - $T_Z | H_S \sim \ln \mathcal{N}\left(\lambda_{T_Z}(h), \xi_{T_Z}^2\right)$
  - $f_{H_S,T_Z}(h,t) = f_{H_S}(h) f_{T_Z|H_S}(t|h)$



- $\hat{R}$ – largest response during the long-term period $T = N\tilde{T}$
- $\tilde{R}$ – largest response in a randomly chosen short-term state
  - $F_{\hat{R}}(r) = F_{\tilde{R}}(r)^N$

Long-term CDF of the short-term extreme value

- Exact long-term CDF obtained by ergodic average
  - $F_{\tilde{R}}(r) = \exp\{\int_{\boldsymbol{S}} (\ln F_{\tilde{R}|\boldsymbol{S}}(r|\boldsymbol{s})) f_{\boldsymbol{S}}(\boldsymbol{s}) d\boldsymbol{s}\}$

- Common approximation using the population mean
  - $F_{\tilde{R}}(r) \approx \bar{F}_{\tilde{R}}(r) = \int_{\boldsymbol{S}} F_{\tilde{R}|\boldsymbol{S}}(r|\boldsymbol{s}) f_{\boldsymbol{S}}(\boldsymbol{s}) d\boldsymbol{s}$

- This integral can be solved approximately by using FORM
  - $\bar{F}_{\tilde{R}}(r) = 1 - \int_{g_r(\boldsymbol{u}) \leq 0} f_{\boldsymbol{U}}(\boldsymbol{u}) d\boldsymbol{u}$

    $\approx 1 - \Phi(-\beta)$

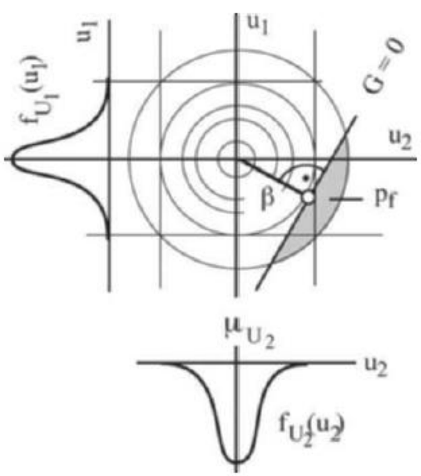


Figure from *Schneider 1997, Introduction to Safety and Reliability of structures*

Forward FORM and inverse FORM

- Forward FORM
  - Calculate $\bar{F}_{\tilde{R}}(r) \approx 1 - \Phi(-\beta)$ for a given value of r
  - β found by solving a minimization problem
  - Iteration required for each value of r

- Inverse FORM
  - Calculate r_p such that $\bar{F}_{\tilde{R}}(r_p) \approx 1 - p$
  - $\beta = -\Phi^{-1}(p)$ is given
  - r_p found by solving a maximization problem
  - Iteration to find r_p directly

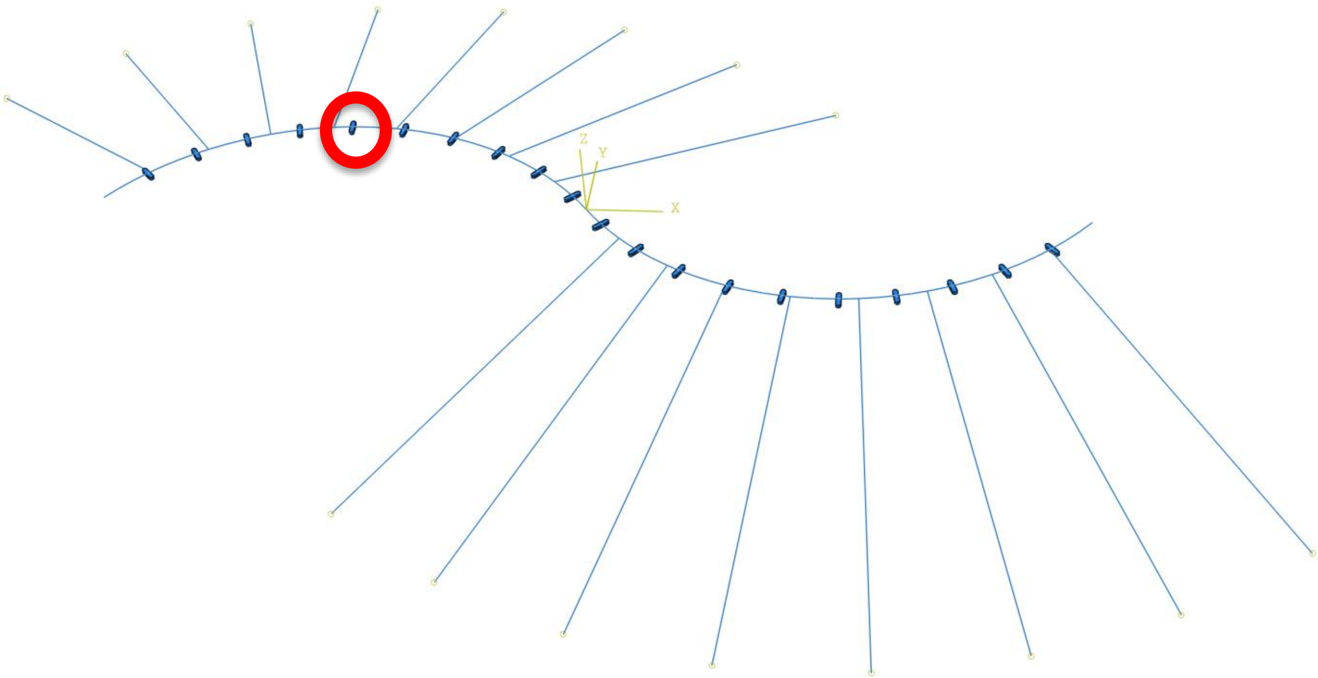
Response value with 100-yr return period

- Seek the value r_q which has a probability q of being exceeded per long-term period
  - Require $\bar{F}_{\tilde{R}}(r_q) = (1-q)^{1/N} \approx 1 - q/N$

- Response value with 100-yr return period
  - $T = 1$ yr, $\tilde{T} = 3$ hr, $N = 365 \cdot 8 = 2920$ and $q = 1/100$.
  - $\bar{F}_{\tilde{R}}(r_q) = 1 - 1/292000$
  - $p = 1/292000 \Rightarrow \beta = -\Phi^{-1}(p) = 4.5$

Response value with 100-yr return period

- Simplified linear model of the chained floating bridge
- $R(t)$ – Horizontal transverse displacement of pontoon 5
- Not realistic environmental model



Response value with 100-yr return period

- Full numerical integration
  - $r_q = 13.64$ m
  - 7350 short-term response calculations

- IFORM
  - $r_q = 13.83$ m
  - 32 short-term response calculations

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Thank you!