Effects of climate change on bridge scour reliability

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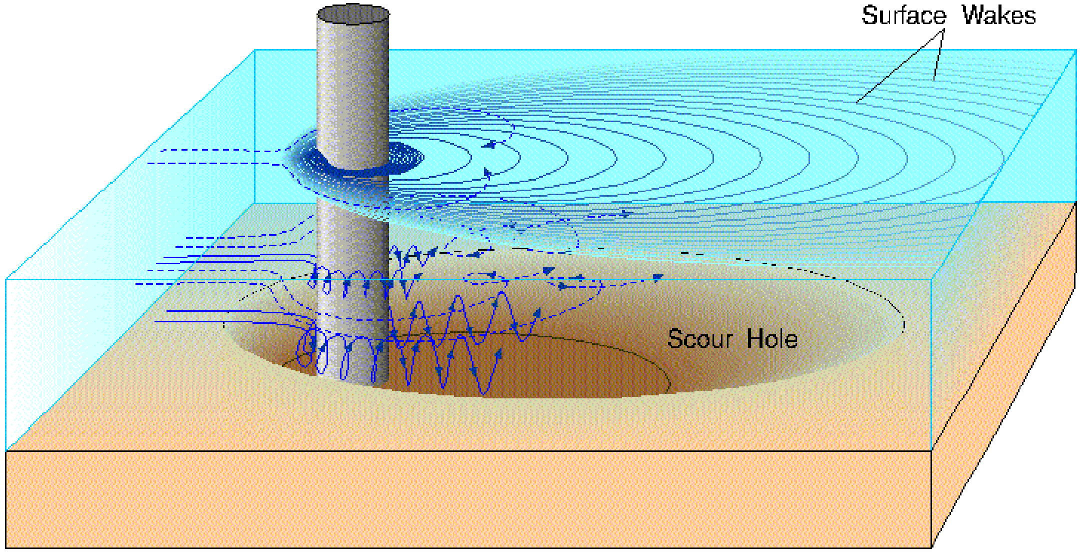
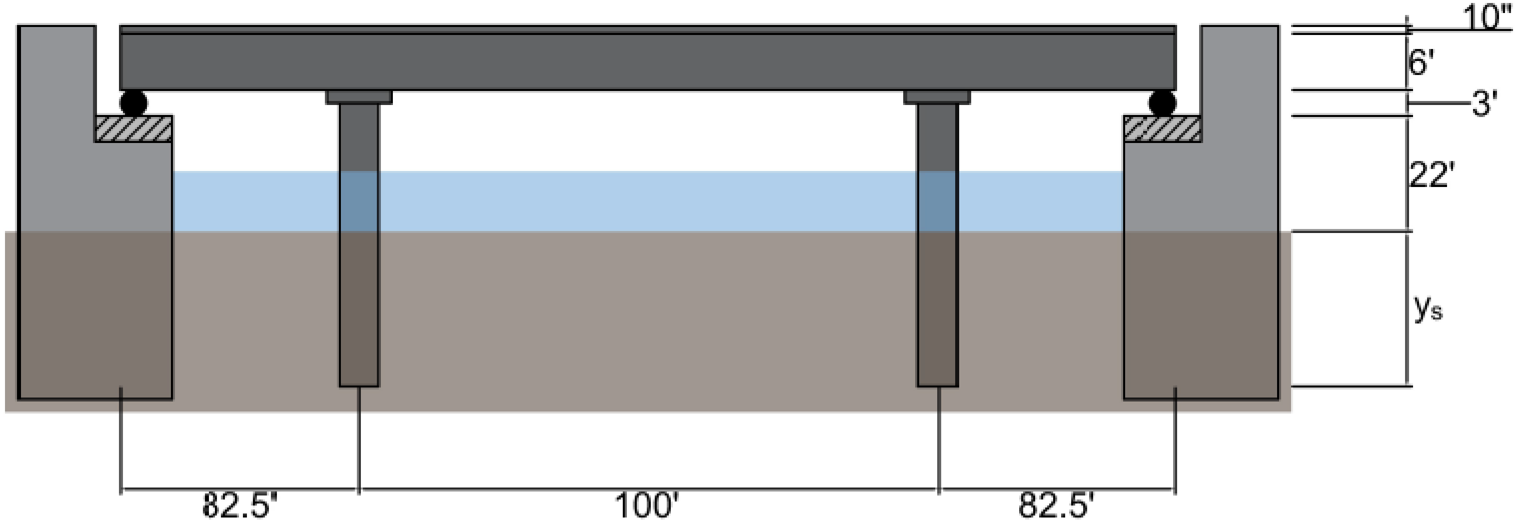
Purpose of this study

- Over 55% of bridge failures in the United states are caused by flood-induced scour
- Climate change increases the frequency of extreme precipitation, leading to larger and more frequent floods
- A new reliability analysis framework should be created accounting for the effects of climate change on bridge scour design



Experimental site



- The Schoharie Creek is in the Catskill Mountain region of southeastern New York is the experimental site

- 115 years of peak flow and precipitation data from 1908-2022 is available

- A statistically significant long term, increasing trend on peak flow is observed at the 5% rejection level

Calculation of scour depth

- The bridge foundation depth is designed for a 100-year design flood. The bridge reliability is assessed over a service life of 75 years.
- Y0 value was obtained using solver functions for each flow rate when using the theoretical Manning's equation
- λ_{sc} is a bias correction factor

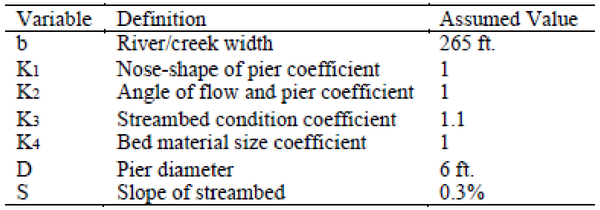
$$y_{expected} = 2\lambda_{sc} y_0 K_1 K_2 K_3 K_4 \left(\frac{D}{y_0}\right)^{0.65} Fr^{0.43}$$

$$\lambda_{sc} \sim Normal(\mu = 0.55, cov = 52\%)$$

$$\eta \sim Lognormal(\mu = 0.028, cov = 28\%)$$

$$K_3 \sim Normal(\mu = 1.1, cov = 5\%)$$

$$\boxed{y_{\max\ design} = 2y_0 K_1 K_2 K_3 K_4 \left(\frac{D}{y_0}\right)^{0.65} F_0^{0.43}}$$



Variable	Definition	Assumed Value
b	River/creek width	265 ft.
K1	Nose-shape of pier coefficient	1
K2	Angle of flow and pier coefficient	1
K3	Streambed condition coefficient	1.1
K4	Bed material size coefficient	1
D	Pier diameter	6 ft.
S	Slope of streambed	0.3%

$$y_{max\ design} = 15.21\ ft$$

$$Q_{design} = 52{,}449\ cfs$$

$$F_0 = \frac{V}{\sqrt{gy_0}}$$

$$Q = A_0 V$$

$$Q = by_0 V$$

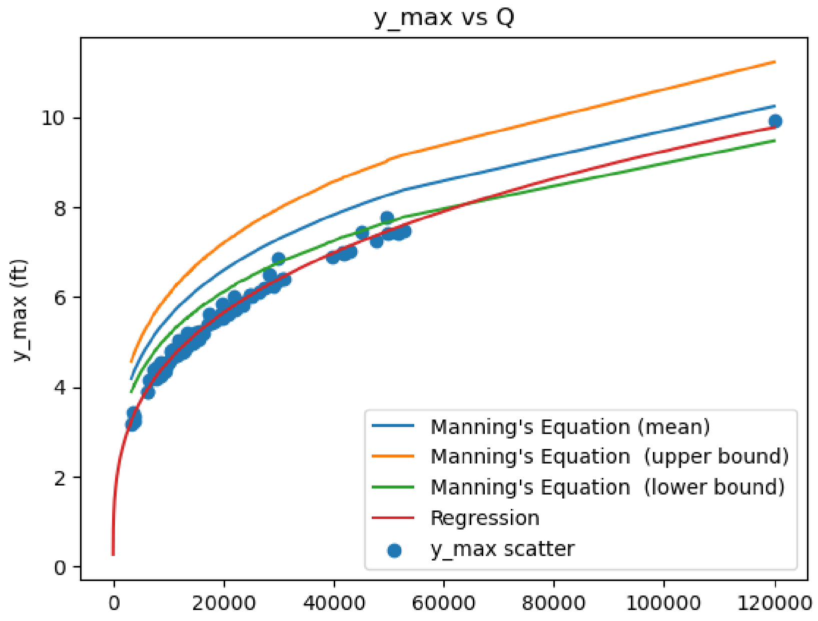
$$V = \frac{\Phi}{n} R^{\left(\frac{2}{3}\right)} S^{\left(\frac{1}{2}\right)}$$

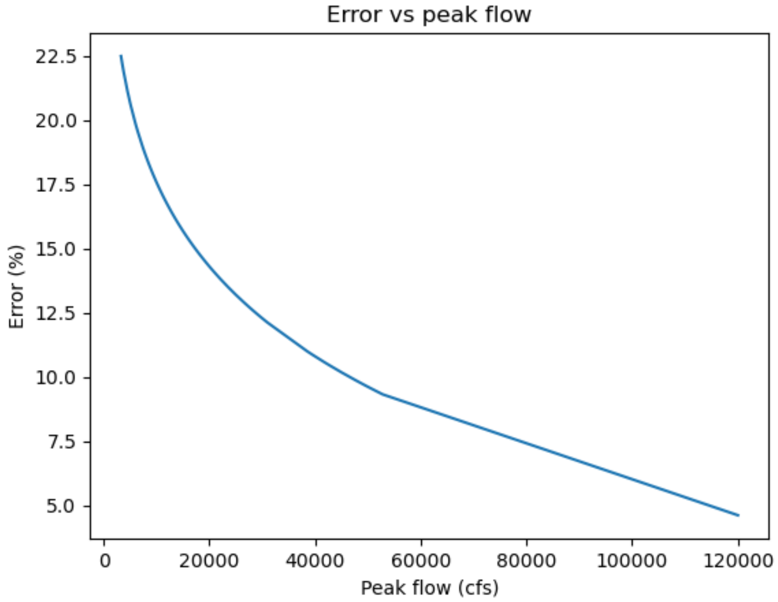
$$R = \frac{by_0}{b+2y_0}$$

$$Q = by_0 \frac{\Phi}{n} \left(\frac{by_0}{b+2y_0}\right)^{\left(\frac{2}{3}\right)} S^{\left(\frac{1}{2}\right)}.$$

Rating curve

- Non-linear regression was performed to obtain an equation relating measured gage height and peak flow
- 5 and 95 percentile for Manning's coefficient was used as the bounds due to uncertainty in the coefficient
- Regression equation falls within bounds for higher values of flow rate
- Theoretical values of y0 were obtained using Python's solver function
- Rating curve was used in place of theoretical equations for more efficient computations





Reliability analysis

- Monte Carlo simulations were performed for safety factors applied on design scour depth ranging from 0.1 to 2 to obtain corresponding reliability index

- For non-stationary models, Gumbel parameters were estimated using maximum likelihood estimation method (MLE) as a linear function of time, and separately as a function of precipitation using historical data

- Future precipitation predictions from 2023-2097 were obtained from 20 different climate change models, for both 4.5 and 8.5 emission scenarios

$$Q \sim Gumbel(\mu_t, \gamma_t)$$

$$u(t) = \alpha_u + \beta_u * t$$

$$\gamma(t) = \alpha_\gamma + \beta_\gamma * t$$

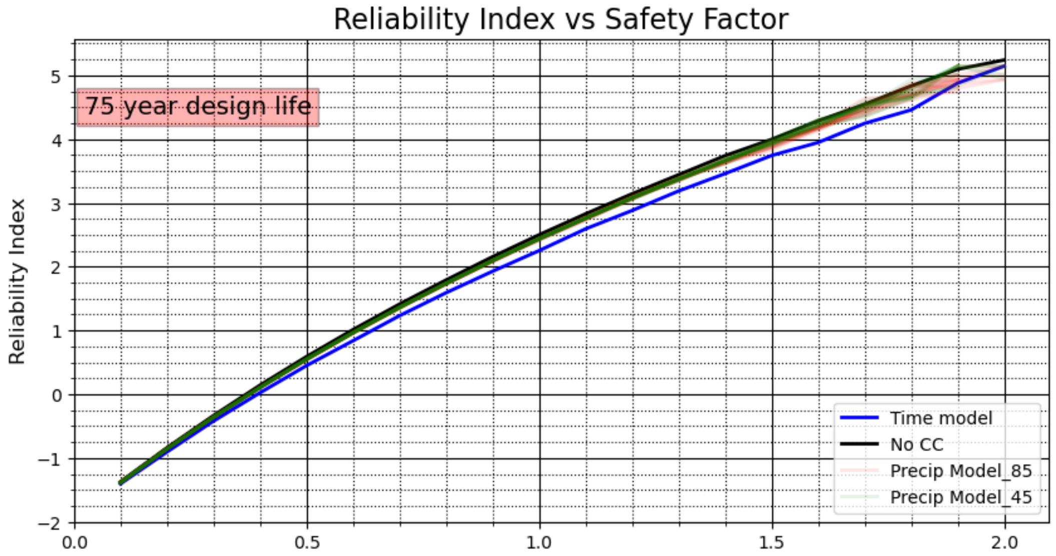
$$u(p(t)) = \alpha_u + \beta_u * p(t)$$

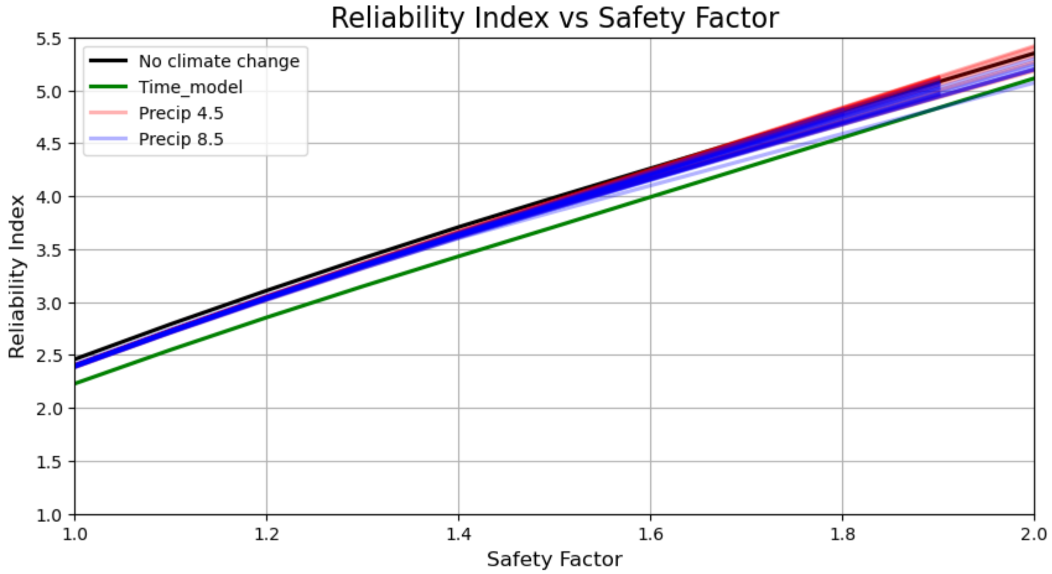
$$\gamma(p(t)) = \alpha_\gamma + \beta_\gamma * p(t)$$

	Location, α_u (intercept)	**Location, β_u (slope)**	**Scale, α_γ (intercept)**	**Scale, β_γ (slope)**
No Climate change	13376 cfs	0	8494 cfs	0
Time dependency	12131 cfs	29.67 cfs/year	7198 cfs	24.41 cfs/year
Precipitation dependency	12131 cfs	42.7 cfs/year	7197 cfs	36.95 cfs/year

Results

- To achieve a selected reliability under a possible future scenario, the design depth should be multiplied by the corresponding safety factor. (i.e. for an index of 3.5 and no climate change: 15.21 ft * 1.31)
- There is a large uncertainty associated with the bias correction factor


Reliability Index vs Safety Factor


Reliability Index vs Safety Factor

Reliability Index

	No climate change	Time dependent	RCP 4.5	RCP 8.5
Safety Factor = 1	2.5	2.25	2.44	2.43

Safety Factors

Reliability Index	No climate change	Time dependent	RCP 4.5	RCP 8.5
2.5	1.0	1.08	1.02	1.02
3	1.15	1.23	1.17	1.17
3.5	1.31	1.4	1.33	1.33

Future direction

- This reliability analysis framework will be applied or other big rivers within the United States and will also be tested for various service lives.
- Multiple trend link functions will be explored beyond the linear link assumption that was assumed in this study for the Gumbel parameters.
- The current study uses a bias correction factor proposed by Johnson et al (Probabilistic bridge scour estimates). Future studies will explore possible updates to the bias correction factor if any.

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