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Influence of Skew and Nonlinear Deck on Elastic versus Inelastic Distribution Behavior and Ultimate Capacity of Steel Girder Bridges

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Purpose

Research Objectives

- Assessment of alternative load distribution methodologies for potential discrepancies that arise when evaluating distribution behavior of skewed steel girder bridges.
- Investigate the influence of skew and material nonlinearities (concrete cracking and steel yielding) on
  - Load distribution behavior (elastic versus inelastic).
  - System capacities (yielding and ultimate).

Load Distribution Methodologies

LRFD Semiempirical Design Equations (AASHTO 2015)

Two or more design lanes loaded

$$g_{moment}^{int.} = 0.075 + \left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12Lt_s^3}\right)^{0.1}$$

$$g_{moment}^{ext.} = e\left(g_{moment}^{int.}\right); \quad e = 0.77 + \frac{d_e}{9.1} \geq 1.0$$

$$\text{Skew } correction = 1 - C_1 (\tan\theta)^{1.5}$$

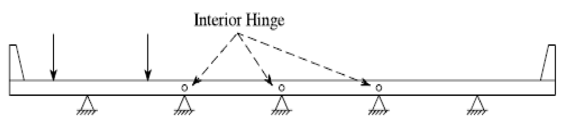
$$C_1 = 0.25\left(\frac{K_g}{12Lt_s^3}\right)^{0.25}\left(\frac{S}{L}\right)^{0.5};$$

if $\theta < 30°$, then $C_1 = 0.0$
if $\theta > 60°$, then $\theta = 60°$

'S-over' Method (AASHTO 1992)

$g = \frac{S}{D}$; Where D = bridge type factor

Lever Rule (AASHTO 1992, 2015)



Beam-Line Definition
(Barker and Puckett 2013)

$$g = \frac{F_{refined}}{F_{beam}}$$

Response-Fraction Definition
(Ghosn et al. 1986)

$$GDF_i = \frac{R_{max,i}}{\sum_{i=1}^{No.\,girders} R_{max,i}} N_{trucks}$$

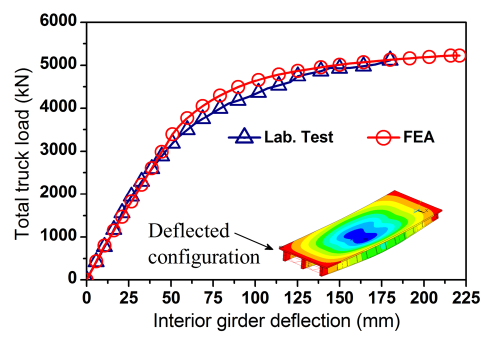
Girder distribution factor methods for comparison

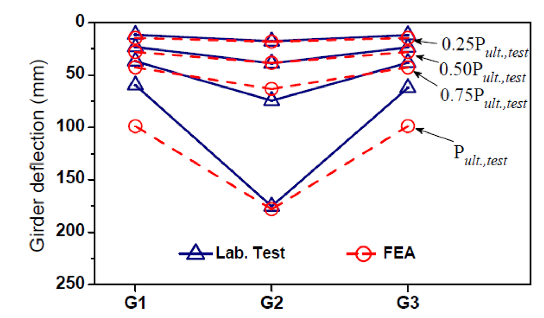
Method	g or DF equation	Approach	Location of response
1	$\frac{\Delta_{max,i}}{\sum_{i=1}^{\#\,girders}\Delta_{max,i}} N_{trucks}$	Load fraction	Bottom flange deflection
2	$\frac{\epsilon_{max,i}}{\sum_{i=1}^{\#\,girders}\epsilon_{max,i}} N_{trucks}$	Load fraction	Bottom flange strain
3	$\frac{\Phi_{max,i}}{\sum_{i=1}^{\#\,girders}\Phi_{max,i}} N_{trucks}$	Load fraction	Curvature of girder section
4	$\frac{M_{max,i}}{\sum_{i=1}^{\#\,girders}M_{max,i}} N_{trucks}$	Load fraction	Composite section bending moment
5	$\frac{M_{refined}}{M_{beam}}$	Beam-line	Composite section bending moment

Note: g or DF = distribution factor; M = moment; N = number of trucks; Δ = deflection; ε = strain; Φ = curvature.

Computational Modeling Validation

Nebraska Laboratory Bridge Test



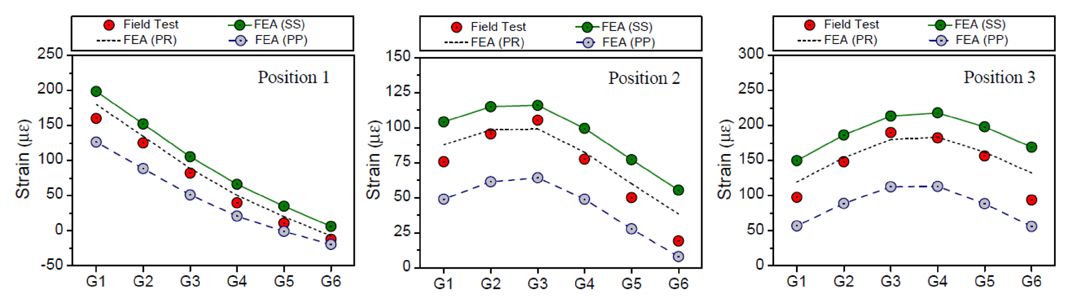


Comparison between FEA and experimental results

	Ultimate load kN (kips)	Deflection[a] mm (in)	Maximum deflection mm (in)
Testing	5,124 (1152)	175 (6.90)	-
FEA[b] Prediction	5,226 (1175)	178 (7.01)	220 (8.66)

[a] Corresponding to load level equal to ultimate test load.
[b]Convergence failure due to crushing in slab and plastic hinging in girders.

Huron Bridge Test

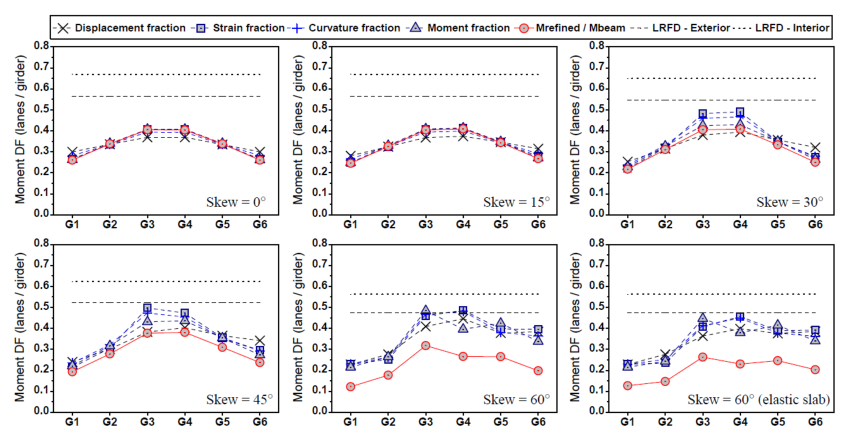


Load Positon 1 — Load Positon 2 — Load Positon 3

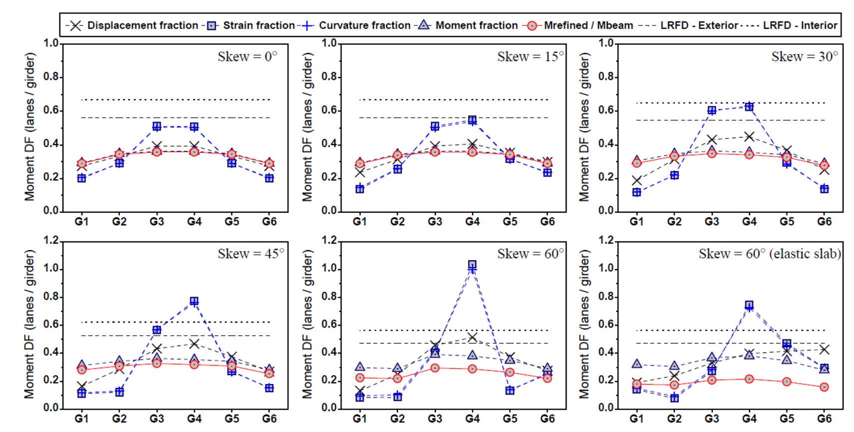
Note: G = girder; SS = simply supported; PR = longitudinal partial restraint; PP = pin-pin supported. For PR Case, K_{spring} = 60 kN/mm per girder (Nowak and Eom 2001).

Results of Sensitivity Study

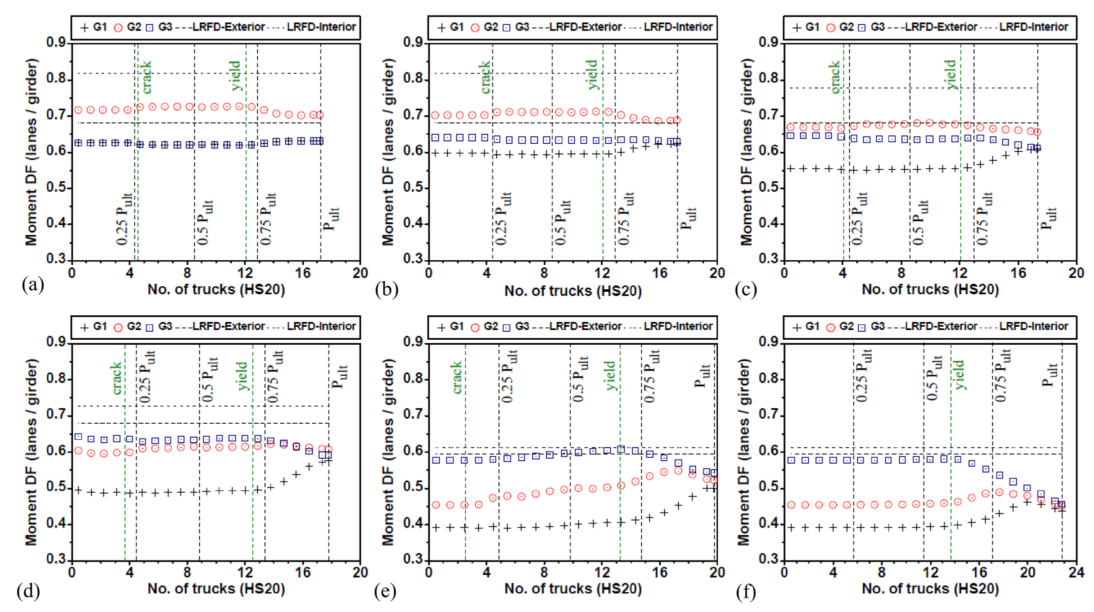
Load distribution methodologies: skew vs elastic distribution factors



Load distribution methodologies: skew vs inelastic distribution factors

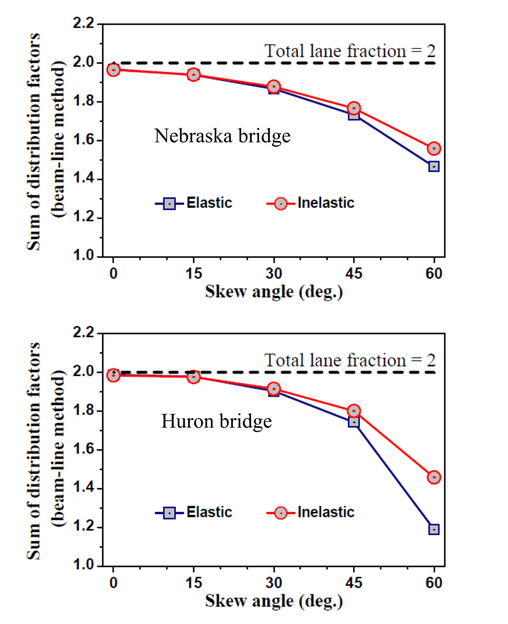


Evolution of load distribution behavior (Nebraska bridge)

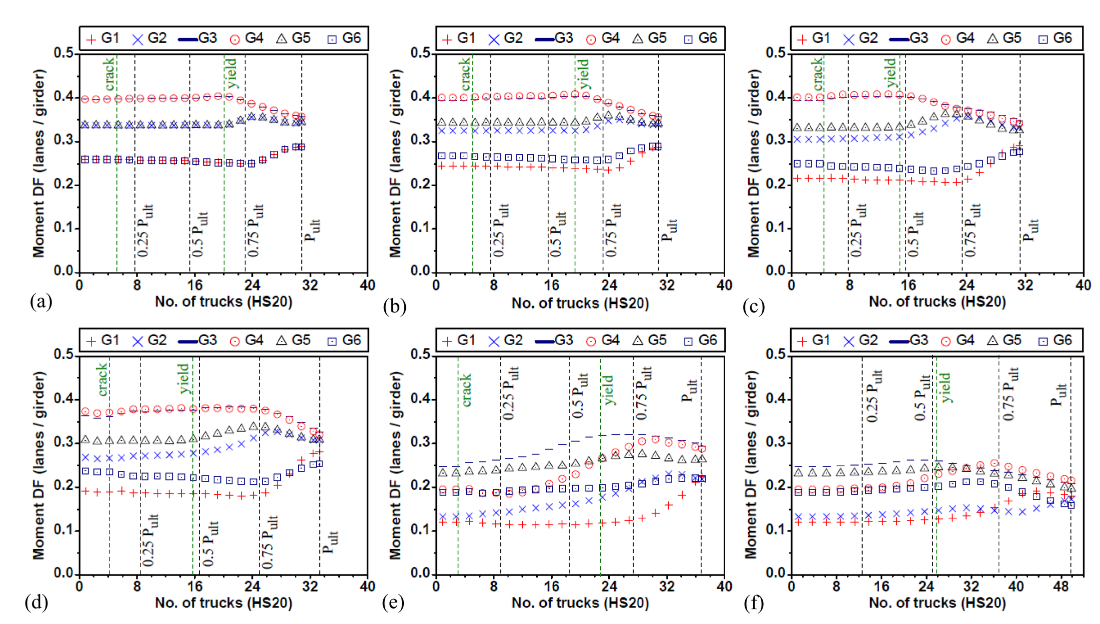


(a) skew = 0°; (b) skew = 15°; (c) skew = 30°; (d) skew = 45°; (e) skew = 60°; (f) skew = 60° (elastic slab).

Effect of skew on cumulative moment demand

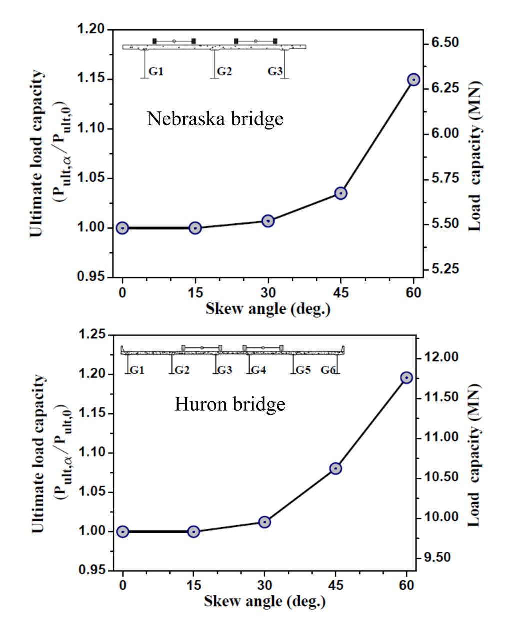


Evolution of load distribution behavior (Huron bridge)

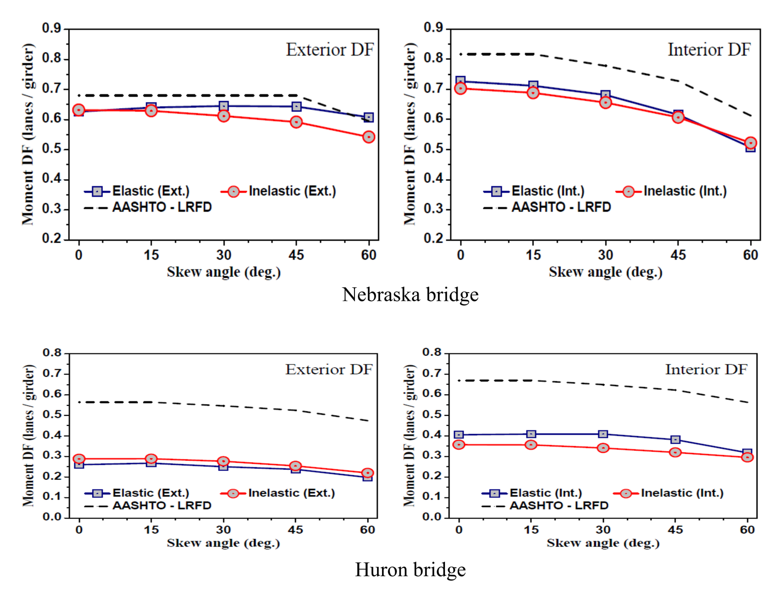


(a) skew = 0°; (b) skew = 15°; (c) skew = 30°; (d) skew = 45°; (e) skew = 60°; (f) skew = 60° (elastic slab).

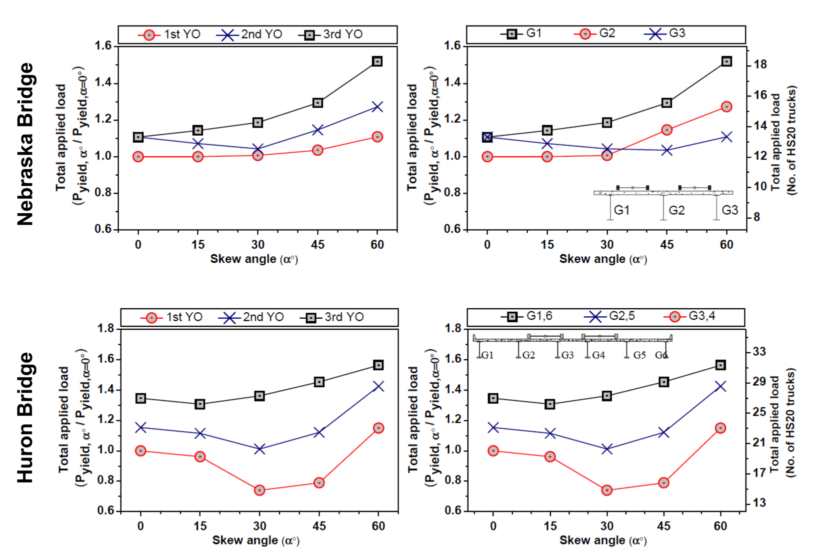
Effect of skew on ultimate load carrying capacity



Effect of skew on elastic and inelastic distribution factors



Effect of skew on applied-load levels that initiate yielding



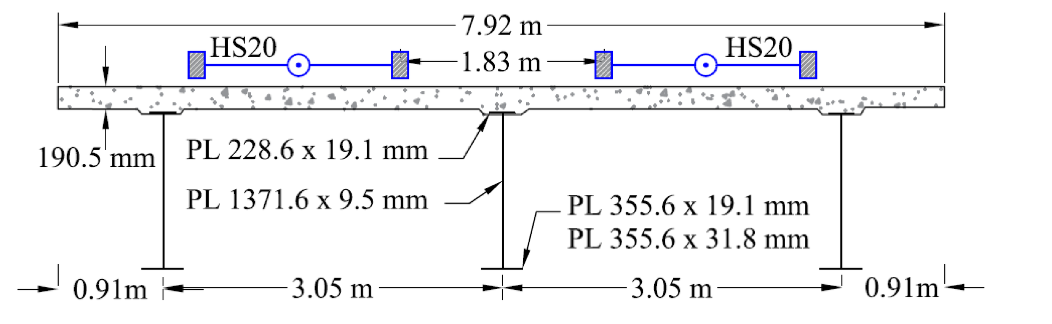
Concluding Remarks

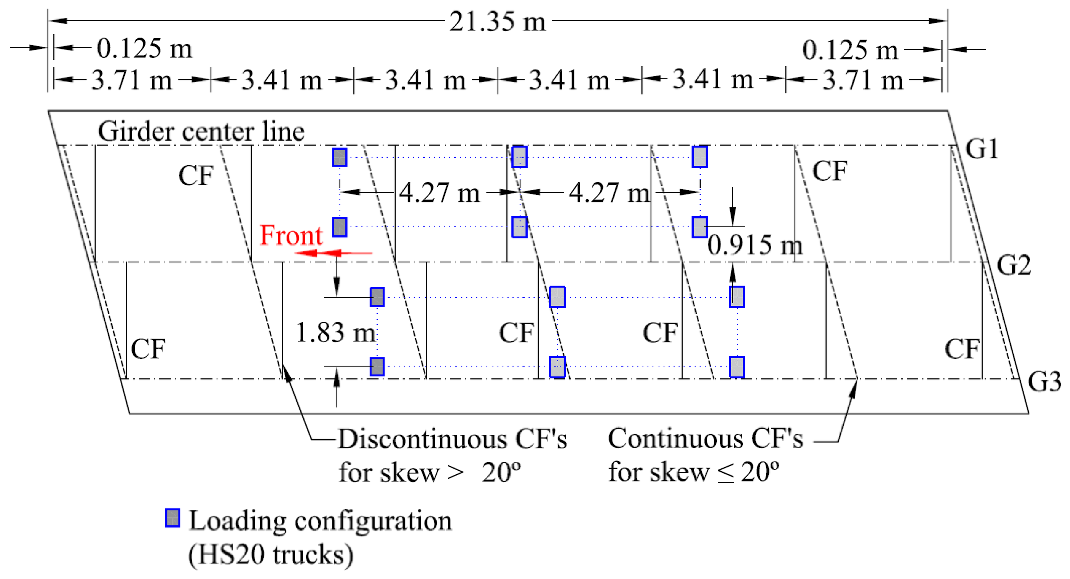
Summary and Conclusions

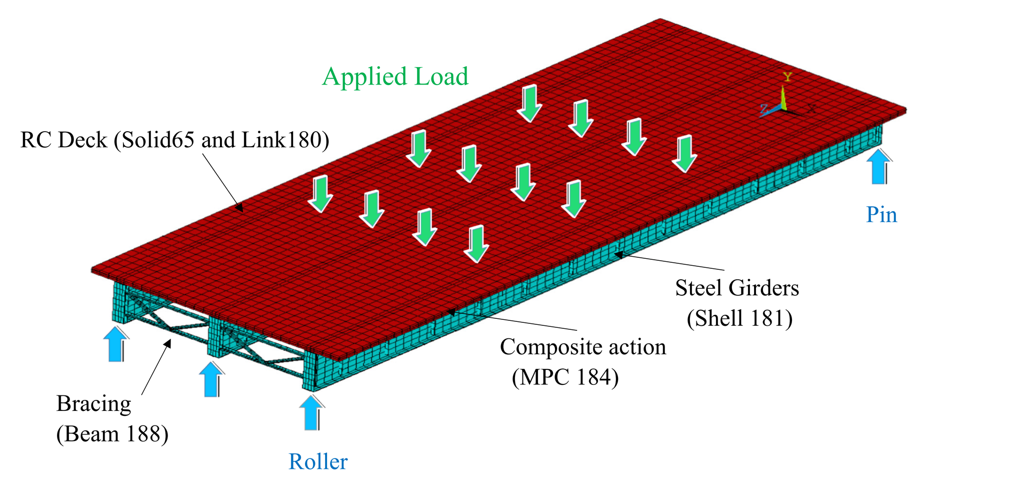
- Influence of skew was examined on load distribution behavior, and nonlinear system-based capacities (yielding and ultimate) of composite steel girder bridges in presence of full material nonlinearities. In addition, assessment of two general definitions (beam-line and response fraction approaches) for quantifying load distribution behavior was performed for a range of skew variations on a validated in-service bridge model.
- Response-based fractions (such as deflections, strains, curvatures and moments) have limited applicability at higher skews (≥ 30°), significantly biasing load effect distribution factors compared to the reference beam-line definition.
- The propagation of concrete cracking results in a substantial increase in distribution factors at higher skews. For 60° skew, an increase up to 36% in distribution factor of girders relative to the uncracked elastic state was observed for the case study in-service bridge.
- Load distribution factors decreased with increasing skew as load progressed from elastic to ultimate states. However, AASHTO LRFD based distribution factors were overly conservative in predicting distribution behavior at all load levels (on average 66% higher at elastic and 90% higher at ultimate for critical girder).
- System-based ultimate capacity increased with skew, but the first yielding initiation load capacity was poorly correlated with skew despite the reduction of moment demands in girders.

Bridge Information

Nebraska Laboratory Bridge Test (Kathol et al. 1995)







Huron Bridge Test (Nowak and Eom 2001)