# Appendix: Numerical Modeling of Inverted-U-Shaped Connectors to Enhance the Performance of Composite Beams

**Milad Khatib and Zaher Abou Saleh**

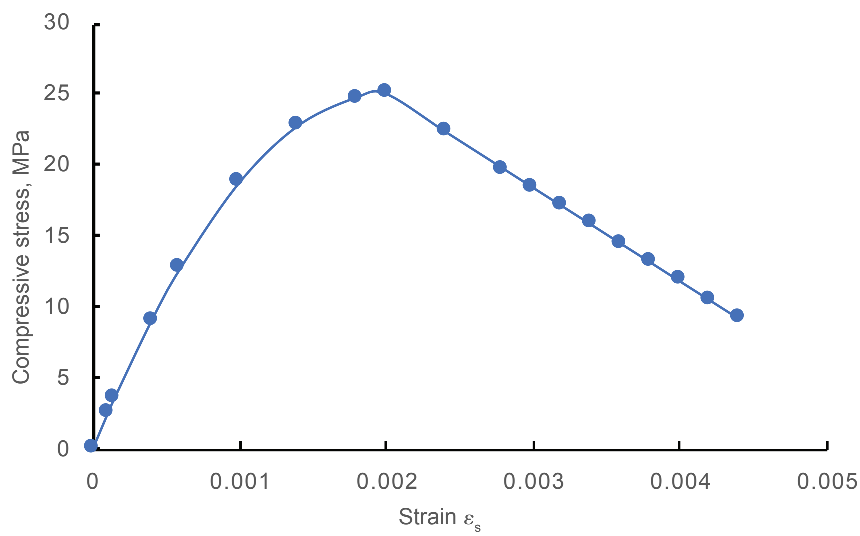
This appendix contains additional tables and figures for “Numerical Modeling of Inverted-U-Shaped Connectors to Enhance the Performance of Composite Beams,” by Milad Khatib and Zaher Abou Saleh, which appears on pages 72–94 in the May–June 2023 issue of *PCI Journal*.

**Table A.1.** Concrete properties for solid element model

| Linear, elastic, isotropic | |
|---|---|
| Modulus of elasticity $E_c$, MPa | 20,000 |
| Poisson’s ratio $v_c$ | 0.20 |

**Nonlinear**

| Strain | Stress, MPa |
|---|---|
| 0 | 0 |
| 0.0001 | 2.4375 |
| 0.00015 | 3.6094 |
| 0.0004 | 9.0000 |
| 0.0006 | 12.7500 |
| 0.00100 | 18.7500 |
| 0.00180 | 24.7500 |
| 0.00200 | 25.0000 |
| 0.00240 | 22.3720 |
| 0.00280 | 19.7430 |
| 0.00300 | 18.4290 |
| 0.00320 | 17.1150 |
| 0.00340 | 15.8000 |
| 0.00360 | 14.4860 |
| 0.00380 | 13.1720 |
| 0.00400 | 11.8580 |
| 0.00420 | 10.5440 |
| 0.00440 | 9.2290 |




| Nonlinear—inelastic—nonmetal plasticity | | |
|---|---|---|
| Open shear transfer | 0.3 | The value for each of these coefficients ranges between 0 and 1.0. The closed shear transfer coefficient value should be greater than the open shear transfer coefficient value. These two parameters determine the cracked concrete’s stiffness. |
| Closed shear transfer | 1.00 | |
| Uniaxial cracking stress, MPa | 3.02 | $f_t$ = 0.30 × 2/3 |

Note: $f'_c$ = concrete compressive strength; $f_t$ = concrete tensile stress. 1 MPa = 0.145 ksi.

| **Table A.2.** Material data for 140 mm deep steel I-beam (HEB 140) | |
|---|---|
| **Linear—elastic—isotropic** | |
| Modulus of elasticity $E_s$ | $2.00 \times 10^5$ MPa |
| Poisson's ratio $v_s$ | 0.3 |
| Note: 1 mm = 0.039 in.; 1 MPa = 0.145 ksi. | |

| **Table A.3.** Material data for steel reinforcement model | |
|---|---|
| Modulus of elasticity $E_s$ | 2.00 × 105 MPa |
| Poisson's ratio $v_s$ | 0.3 |
| **Nonlinear-inelastic-plasticity** | |
| Yield stress $f_y$ (hard), MPa | 410 |
| Yield stress $f_y$ (mild), MPa | 275 |
| Note: 1 MPa = 0.145 ksi. | |

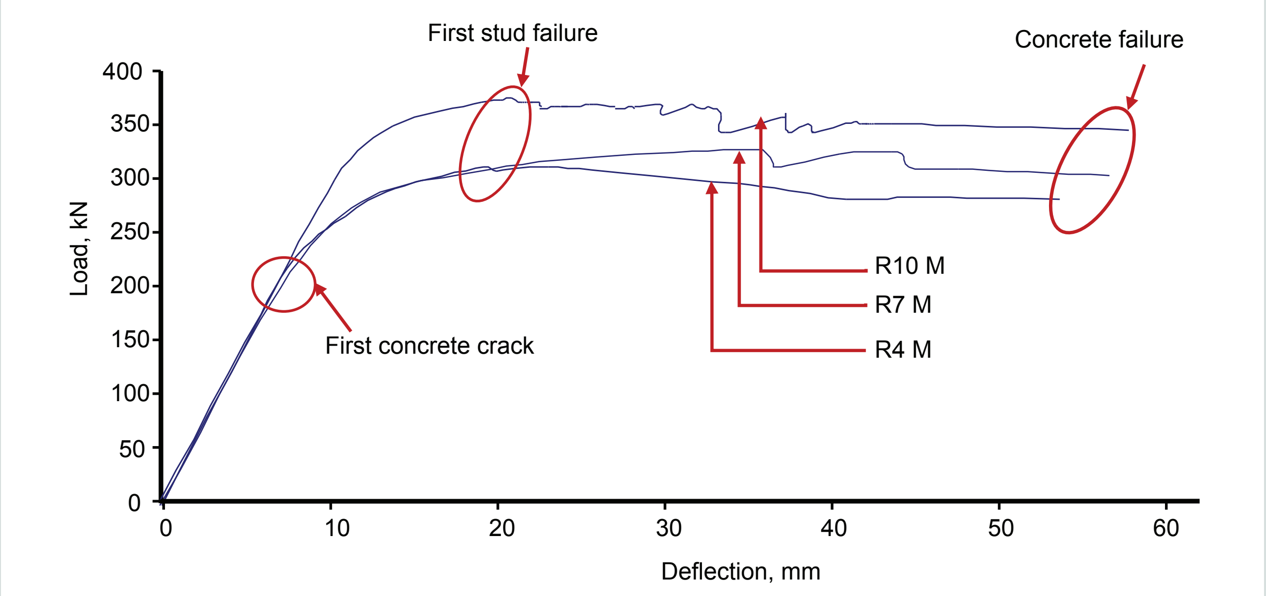



**Figure A.1.** Experimental load deflection curves for mild (low-stiffness) stud connectors. Source: Reproduced with permission from Daou et al. (2021). Note: R4 M = specimen with four mild stud connector rows; R7 M = specimen with seven mild stud connector rows; R10 M = specimen with ten mild stud connector rows. 1 mm = 0.039 in.; 1 kN = 0.225 kip.

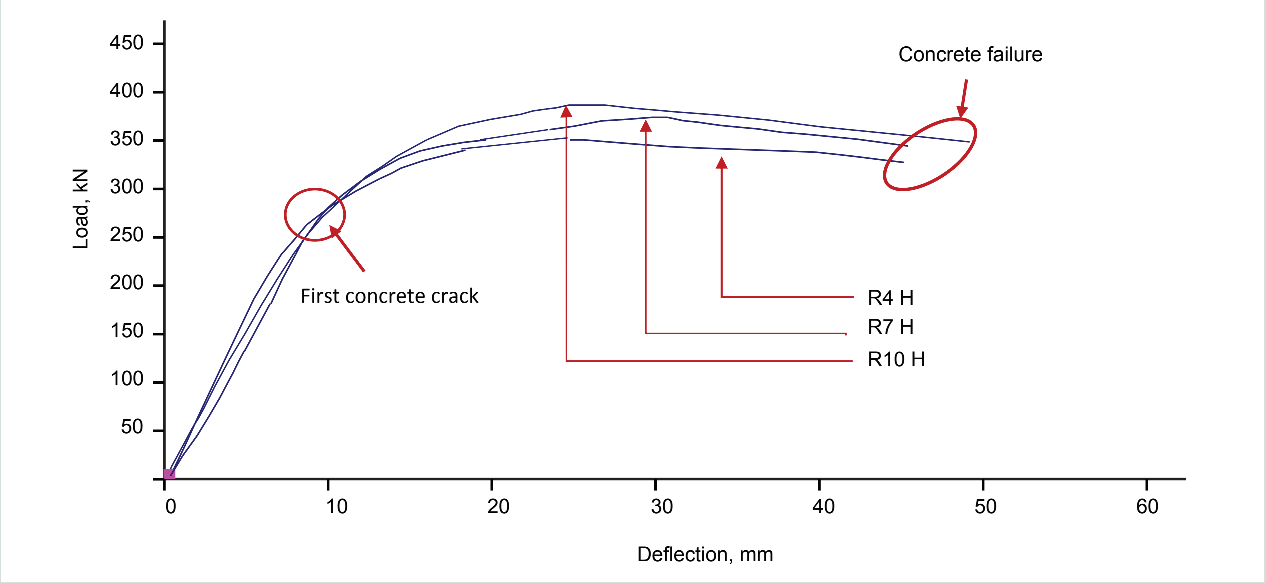



**Figure A.2.** Experimental load deflection curves for rigid (high-stiffness) stud connectors. Source: Reproduced with permission from Daou et al. (2021). Note: R4 H = specimen with four rigid stud connector rows; R7 H = specimen with seven rigid stud connector rows; R10 H = specimen with ten rigid stud connector rows. 1 mm = 0.039 in.; 1 kN = 0.225 kip.