

Material Model for Reinforcing Bars with Buckling for Concrete Structures under Seismic Loads

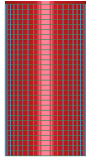
Thrust Area: Simulation and Information Technologies

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3-D Full Column Model

Model description in LS-DYNA:

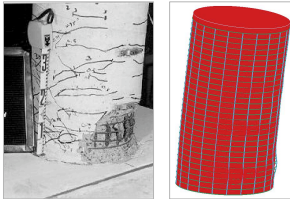


- Part I (red): concrete (solid elements)
- Part II (blue): longitudinal reinforcing bar (beam elements)
- Part III (green): transverse reinforcing bar (beam elements)

Constraints and boundary conditions:

- Longitudinal and transverse reinforcing share the **same nodes** at intersections
- Contact between concrete and rebar nodes
- Axial displacement **constraints** between rebar and concrete surface nodes
- Base fully restrained
- Lateral **displacement control** applied at top surface

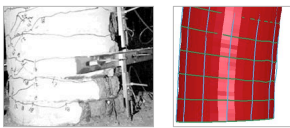
Model Validation:



Column test by Kunnath et al. (1997)
(buckling length=5 hoop spacing)

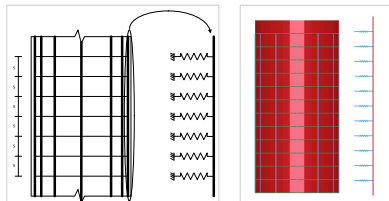


Column test by Fretag et al. (2006)
(buckling length=4 hoop spacing)



Column test by Moyer et al. (2001)
(buckling length=1 hoop spacing)

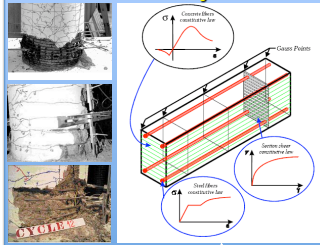
From Full Column Model to Bar-with-spring Model



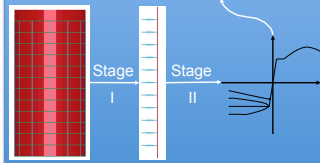
Model description in LS-DYNA:

- Isolate buckling-prone bar from column
 - Place springs at each tie position to simulate constraints from transverse steel
 - Part I (red): Longitudinal reinforcing bar (beam element)
 - Part II (blue): Springs (discrete beam elements)
- Boundary conditions:**
- Pure axial loading condition
 - Displacement control at two ends

Objective and Method



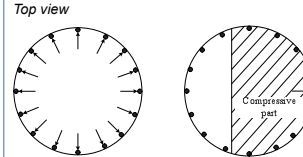
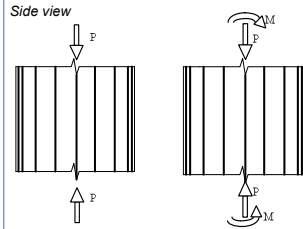
- The **objective** is to develop a **simple** and **efficient** damage-based constitutive model including **buckling** for concrete columns.
- A **two-stage method** is used to study longitudinal bar buckling behavior.
- The two stages are:
 - I → transform a full column model to a bar-with-spring model
 - II → develop constitutive equations from parametric study of bar-with-spring models



Bar with Spring Model

Spring Properties:

Different mechanisms for two load cases
Pure compression Eccentrically Compression

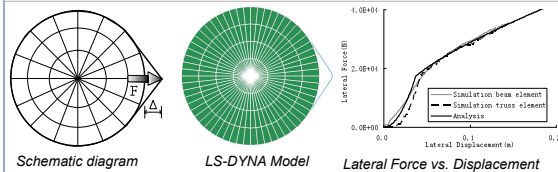


Equivalent spring properties depends on different **load cases**

Initial spring stiffness under seismic loading is **much smaller** than that under pure compressive loads

Both analytical and numerical simulations are performed to study effective spring properties

Lateral force vs. displacement relations from numerical simulations are shown to match analytical solution



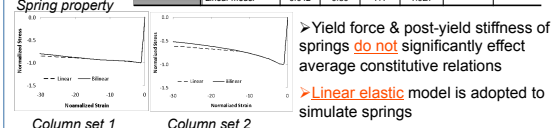
Lateral Force F

$$F = \begin{cases} 2 \left(\frac{R(\tan \alpha - \alpha)}{\pi R} \right) E_A \sin(\alpha \cos(R/(R+\Delta))) & \text{if } \frac{R(\tan \alpha - \alpha)}{\pi R} < \epsilon_p \\ 2 \left(\epsilon_p + \left(\frac{R(\tan \alpha - \alpha)}{\pi R} - \epsilon_p \right) E_p \right) A_s \sin(\alpha \cos(R/(R+\Delta))) & \text{if } \frac{R(\tan \alpha - \alpha)}{\pi R} \geq \epsilon_p \end{cases}$$

Analytical Simple Hoop Model and Formulations

Spring Parameter Sensitivity Analysis:

Model category	D _s (m)	S (m)	S/D _s	K (N/m)	F _y (N)	K _t (N/m)	
Column set 1	Bilinear model	0.025	0.08	3.2	2.3E6	4.0E4	1.4E6
	Linear model	0.025	0.08	3.2	2.3E6	-	-
Column set 2	Bilinear model	0.042	0.30	7.1	1.0E7	8.3E4	0.5E7
	Linear model	0.042	0.30	7.1	1.0E7	-	-

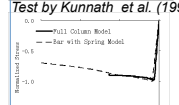
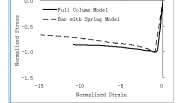


Yield force & post-yield stiffness of springs **do not** significantly effect average constitutive relations

Linear elastic model is adopted to simulate springs

Bar with Spring Model (cont'd)

Model Validation:



Comparing bar-with-spring models and full column models indicate:

- average stress-strain curves are similar in both cases
- buckling shapes predicted by both models are comparable

Bar-with-spring models are **computationally more efficient** than full column models

Bar with spring models are being used for detailed **parameter study**.

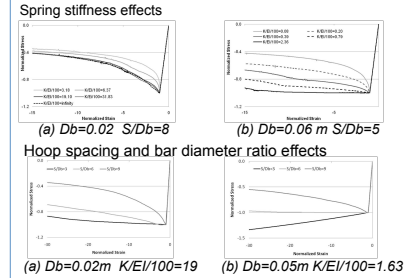
Main parameters: D_b (bar diameter), s (hoop spacing), K (effective spring stiffness) and bar material properties.

Model Application:



Buckling of longitudinal bars significantly **affects** the **global response** of concrete columns both in **push over** analysis and in **cyclic** analysis

Combined Parameter Sensitivity:

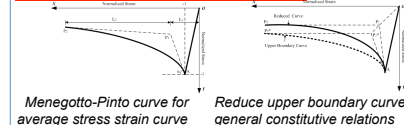


After yielding, stresses are **lower** for a **larger S/D_b** or a **smaller K/EI**

With increasing spring stiffness, average stress strain curves **converge** to immovable curves (upper **boundary curves**) corresponding only to its S/D_b ratio

General constitutive relations will be **reduced** from its upper boundary curves based on its effective stiffness

Developed Constitutive Model:



Reduce upper boundary curve for general constitutive relations

Ongoing work:

- Parameter study to generate constitutive model
- Buckling length prediction
- Apply buckling models in simulation of RC structural response

Conclusion

- Proposed a **two-stage** method to study longitudinal bar buckling behavior.
- Presented a **constitutive model** of longitudinal bar incorporating effects of buckling.
- Buckling behavior of longitudinal bar has considerable effects on concrete structure response under seismic loads.

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