VECTOR ANALYSIS GROUP

VecTor5: Nonlinear Modeling Software for Concrete Plane Frames

Current Challenges

Structural engineering is evolving to meet today's requirements including longer and maintenance-free service life, robust performance, and sustainability. While computational modeling plays a critical role in achieving these requirements, current modeling software has not been widely embraced by structural engineers due to their complexity, a large variety of options that impact the results, and long analysis run times.

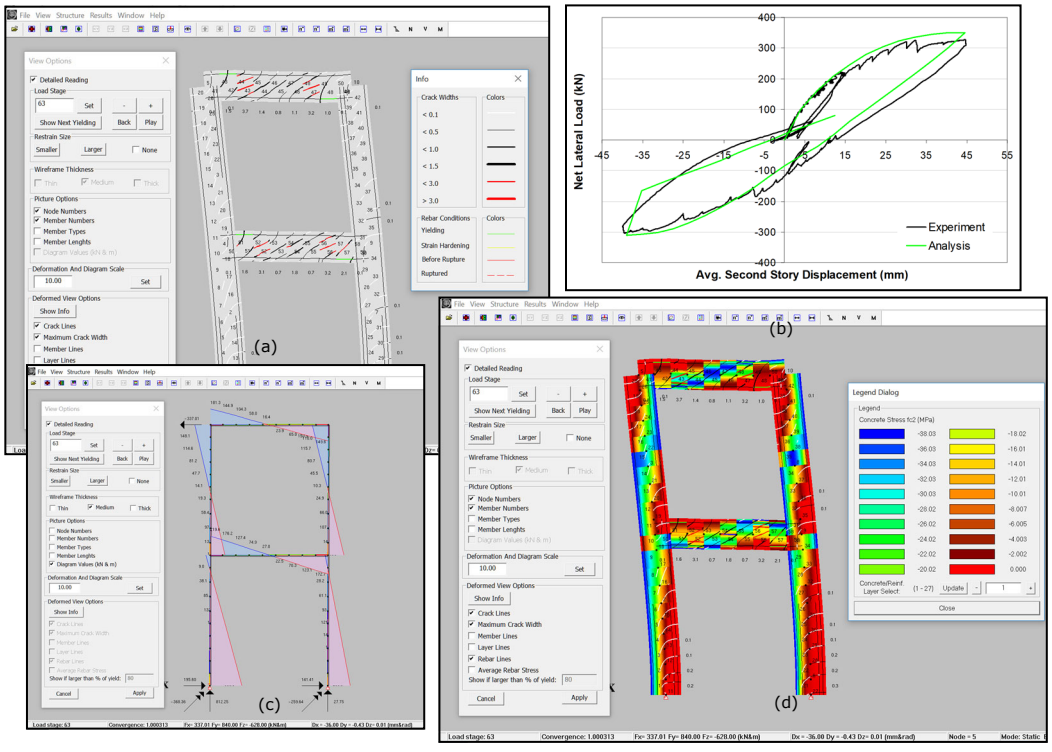
VecTor5

VecTor5 is a nonlinear modeling software developed to provide:

- **Simple yet accurate modeling process** suitable for design office applications,
- **Simplified material modeling** developed for only concrete frames with pre-set material models,
- **Excellent accuracy** validated with 150+ large scale experiments in the past two decades, and
- **Great addition** to any consulting engineering office for design verification.

Key Benefits

- Discover expected behavior at the serviceability and ultimate limit states, including
  - concrete and reinforcement stresses
  - crack pattern and widths
  - deformations and deflections
- Discover governing damage mechanisms; improve or refine the design
- Verify the reinforcement design obtained from linear-elastic analysis (from SAP2000, ETABS, etc.)
- Analyze unusual or unique systems
- Perform proof-of-concept analysis of critical design details
- Conduct performance-based design
- Perform nonlinear dynamic analysis for seismic, impact, and blast load cases
- Analyze existing structures when questions or problems arise; assess their performance and safety
- Perform retrofit or upgrade analysis; determine most suited retrofit or upgrade scheme
- Train junior engineers for a better understanding of structural behavior and nonlinear analysis

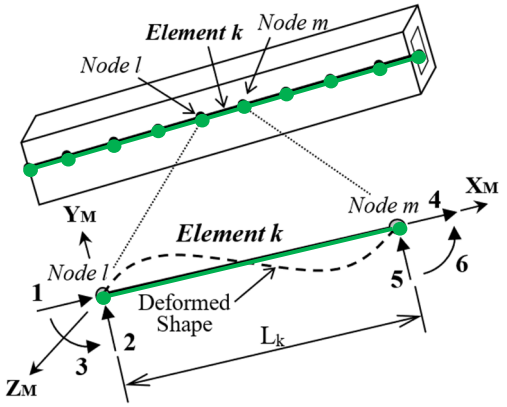


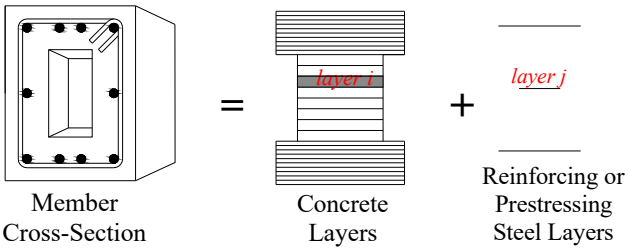
Pushover analysis of a frame: (a) *Deflections, crack pattern, crack widths, and reinforcing bar stresses at failure;* ***(b)*** *experimental verification;* ***(c)*** *moment diagram and support reactions;* ***(d)*** *concrete stresses.*

Formulation

- Distributed-plasticity, layered section approach
- Total load, secant stiffness solution
- Based on the Modified Compression Field Theory
  - a rational theory with proven record
  - smeared, rotating crack model
  - shear cracking and failure modes are modelled
  - adopted by several international design codes

VecTor5 employs fiber-section elements using a distributed-inelasticity approach, and an iterative, total-load, secant-stiffness formulation. The nonlinear sectional analyses provide an accurate representation of the concrete response, including the shear effects coupled with axial and flexural responses based on the Modified Compression Field Theory (MCFT). The nonlinear dynamic analysis algorithms employ an explicit three-parameter time integration method, and accounts for the effects of high strain rates.





How VecTor5 compares with other software?

Most frame analysis software uses plastic-hinge approach, with the following challenges.

- Exact determination of hinge locations is required.
- Proper calibration of the moment and shear hinge properties is required.
- Default hinge models may have low accuracy even for typical cross sections.
- Consideration of the shear-moment-axial force interaction is not possible unless advanced modeling approaches are undertaken.
- Once a hinge yields, an analysis typically terminates, being unable to predict the load redistribution and post-peak ductility.
- Cracking and serviceability information not provided.
- Deflections are only approximately calculated using an effective stiffness value input by the user.

Validation

VecTor5 is extensively validated with large-scale experimental tests in the past two decades. 13 journal papers summarize the results. Considering 151 large-scale experiments, an average of **1.00** and a coefficient of variation of **11.6%** is achieved for the predicted-to-experimental nominal strength ratios. These results show excellent accuracy with much less variations than those accounted for by the material resistance factors.

			Predicted-to-Experimental	
		Number of Experiments	Average	Coefficient of Variation (%)
Static	Pushover	33	1.03	11.9
	Pushover (Deep beams)	17	1.09	12.6
	Pushover (Eartquake)	5	0.93	10.7
	Cyclic	22	0.97	6.0
Dynamic	Impact	20	0.99	9.5
	Blast	24	1.02	16.0
	Eartquake	30	0.96	12.6
	Total	**151**	**1.00**	**11.6**

Why VecTor5?

- Concrete material models are calculated from a single input (f'_c)
- Most suited concrete and reinforcement material models are pre-selected as default models
- Simple modeling process via graphical user interface FormWorks+
- Secant stiffness solution algorithm ensures robust convergence even in the heavily cracked post-peak stages of the analysis
- Total load formulation eliminates the need to use small load steps – the load step size has no influence on the solution accuracy
- Concrete cracking, concrete crushing, and reinforcement yielding are calculated
- Failure modes including flexure, shear, compression, and reinforcement buckling are provided
- Crack spacing, widths, and orientation are presented in the graphical interface Janus

Who is VecTor Analysis Group?

Since 1979, VTAG has been pushing the bounds of advanced modelling and analysis of reinforced concrete structures under the leadership of Dr. Frank J. Vecchio at the University of Toronto. VTAG now comprises eight professionals with a wide spectrum of expertise and experience. In developing our proprietary analysis tools, we have employed a six-phase approach that has led to industry-leading analysis software.