

# **Multi-Platform Simulation using VecTor Suite of Programs**

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# Outline

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- ◇ Introduction to the VecTor suite of programs.
- ◇ **Example 1:** Modelling a shear-critical reinforced concrete beam.
- ◇ **Example 2:** Modelling beam-column joints substructure module.

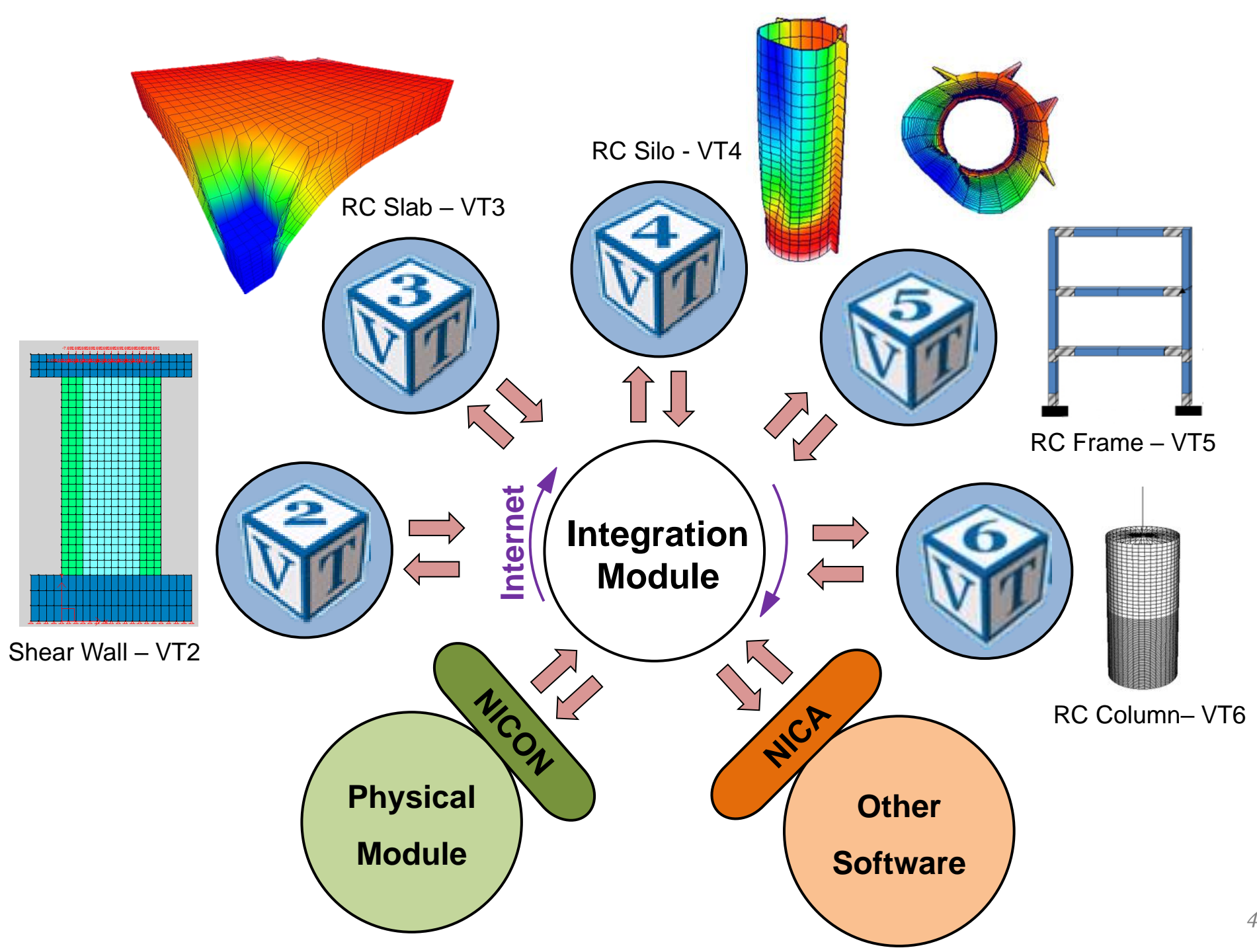


# Background

## □ VecTor Suite of Software

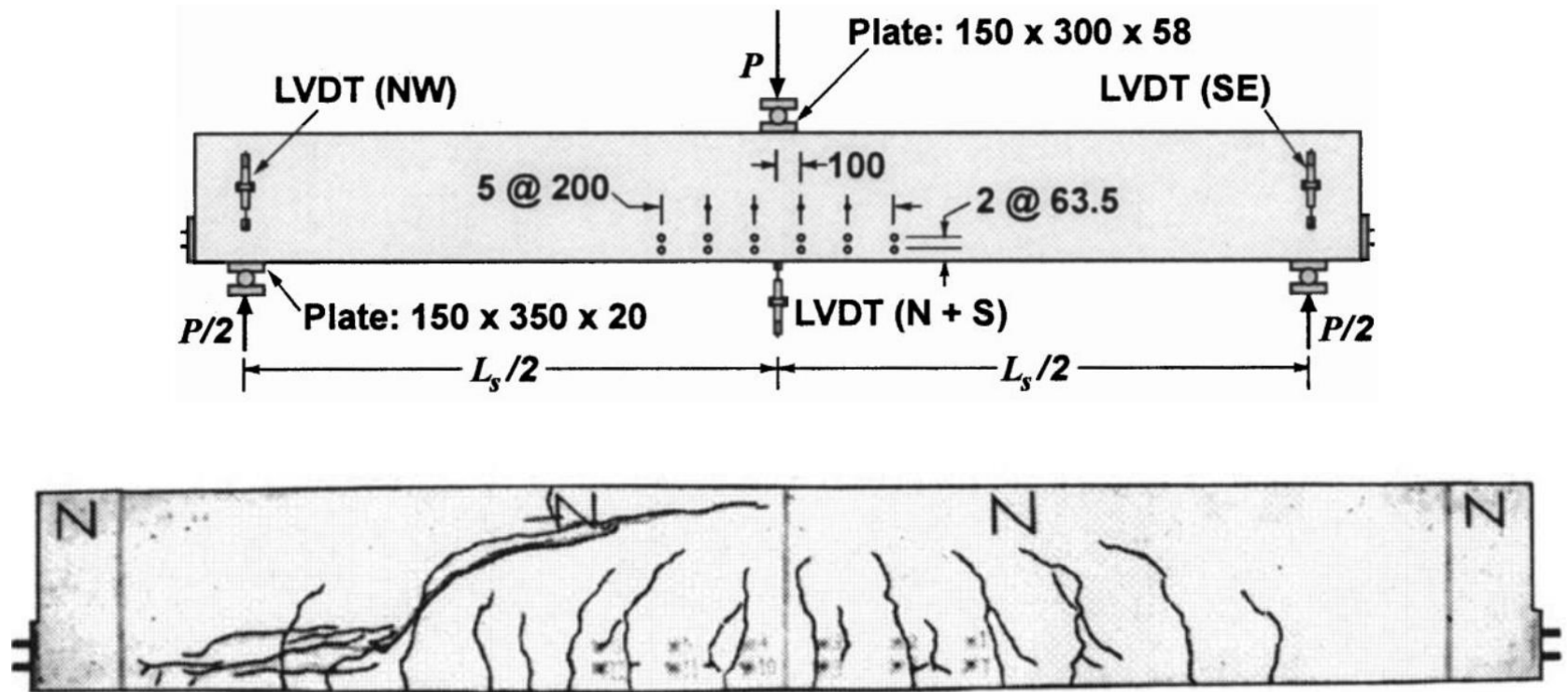
Software	Structure Type	Analysis Procedure	Element Library
VecTor2	2D Membranes	Repaired members with FRP sheets	
VecTor3	3D Solids	Nonlinear fire analysis	
VecTor4	Shells	Out-of-plane shear	
VecTor5	Frames	Computationally fast	
VecTor6	Axisymmetric Solids	Computationally fast	





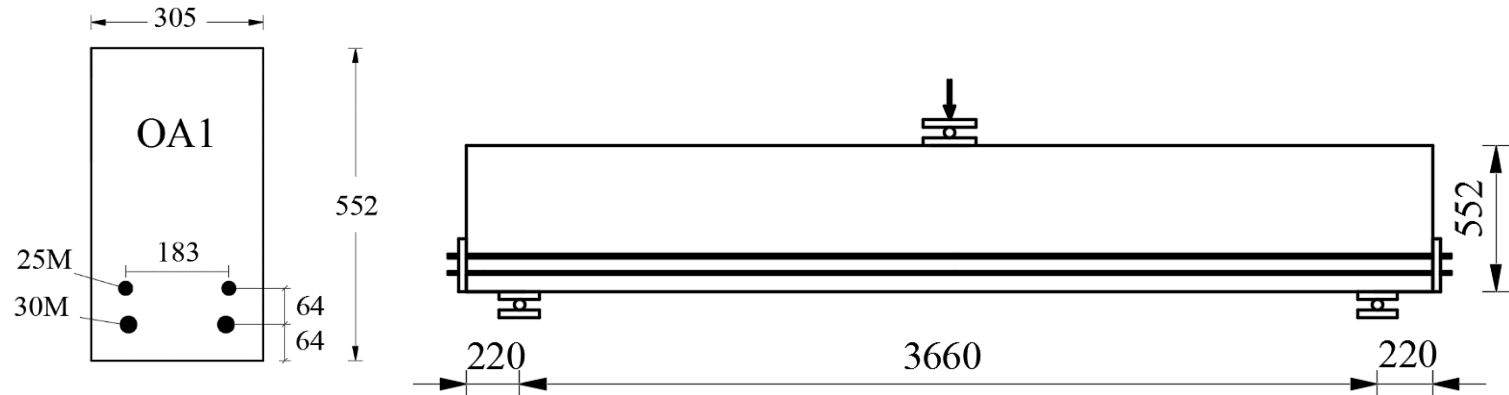
# Example 1

## Modelling a Shear-Critical RC Beam in VecTor2



(Vecchio and Shim, 2004)

# Example 1: Modelling a Shear-Critical RC Beam in VecTor2



Details of OA1 beam tested by Vecchio and Shim (2004)

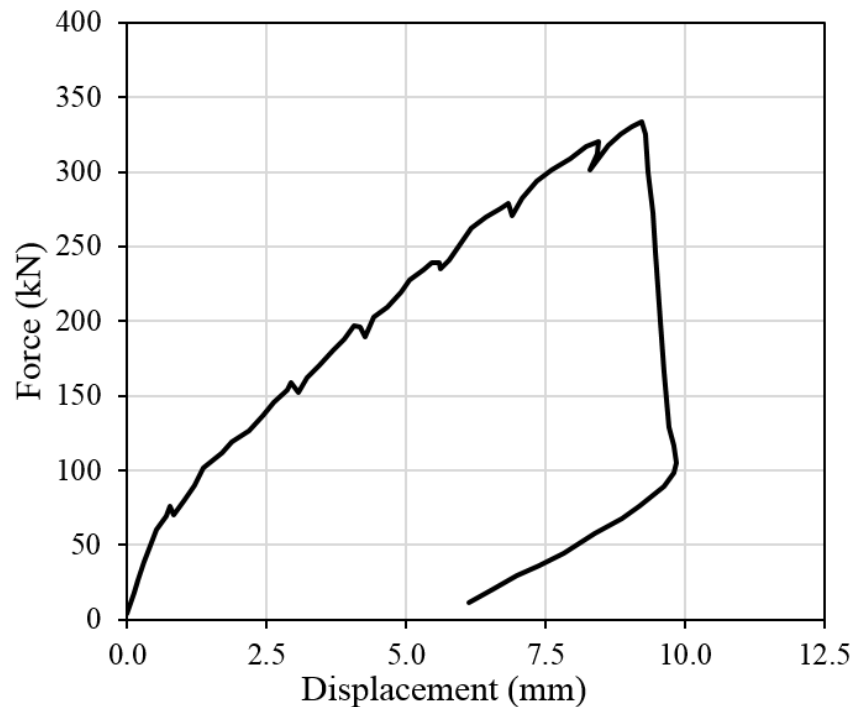
Concrete				
$f'_c$ (MPa)	$\epsilon_o$ ( $\times 10^{-3}$ )	$E_c$ (MPa)	$f_{sp}$ (MPa)	Max Agg. Size (mm)
22.6	1.6	36,500	2.37	20

Reinforcement							
Bar Size	Diameter (mm)	Area (mm <sup>2</sup> )	$f_y$ (MPa)	$f_u$ (MPa)	$E_s$ (MPa)	$\epsilon_{sh}$ ( $\times 10^{-3}$ )	$\epsilon_u$ ( $\times 10^{-3}$ )
25M	25.2	500	445	680	220,000	8.5	216
30M	29.9	700	436	700	200,000	11.4	175

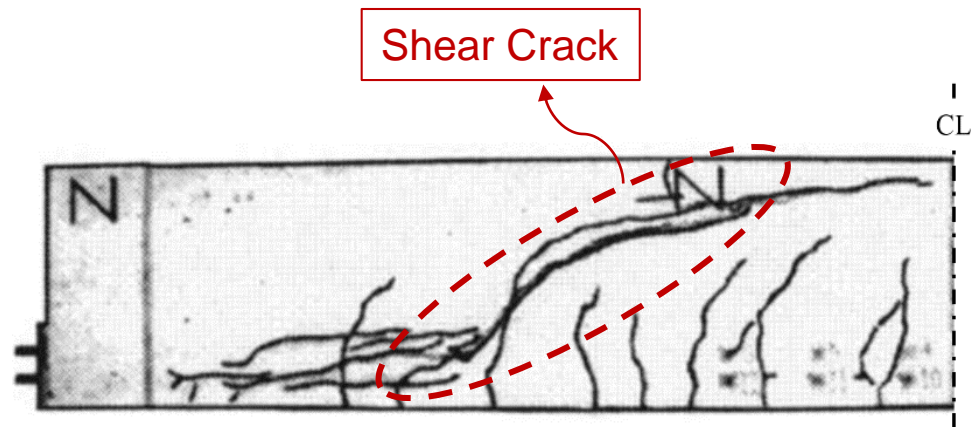


# Example 1: Modelling a Shear-Critical RC Beam in VecTor2

## □ Experimentally Reported Results



Load-deflection response



Crack pattern

# Example 1: Modelling a Shear-Critical RC Beam in VecTor2

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## ❑ Modelling Steps Overview

### ◇ Step 1) Define Materials

Concrete Material ; Steel Material ; Bearing Material

### ◇ Step 2) Create finite element Mesh

Concrete Regions ; Longitudinal Reinforcement ; Constraint Point

### ◇ Step 3) Define Support Restraints

### ◇ Step 4) Define Loads

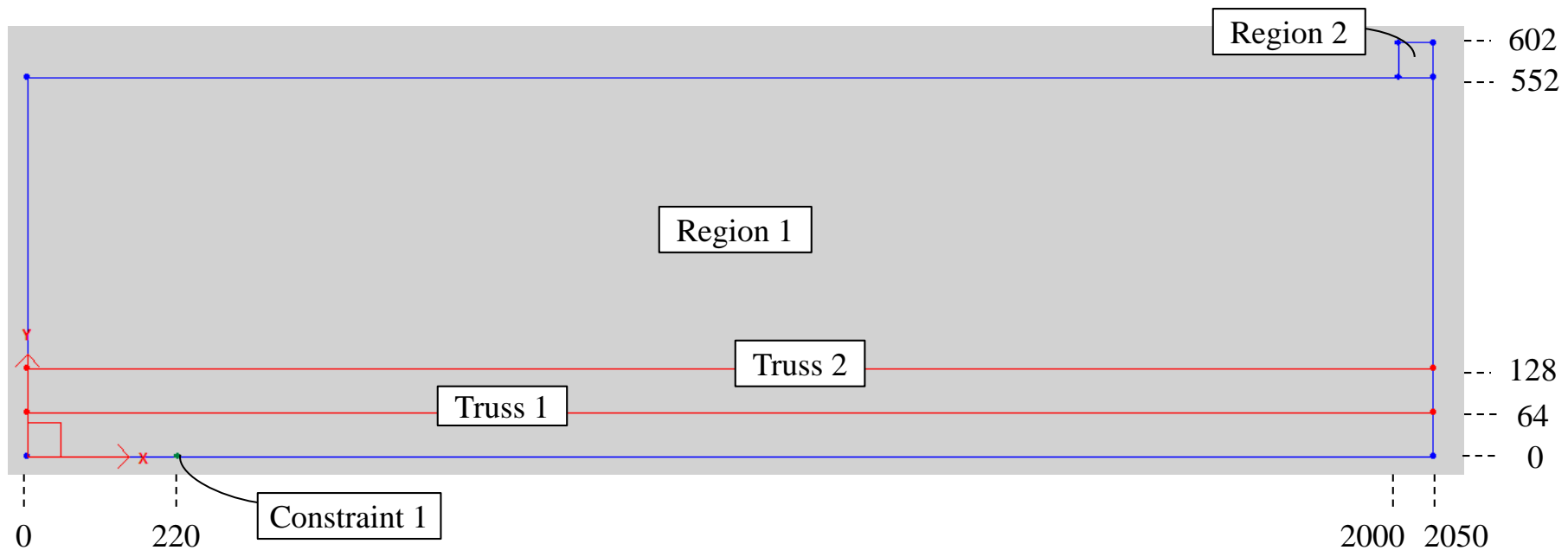
### ◇ Step 5) Select Analysis Options





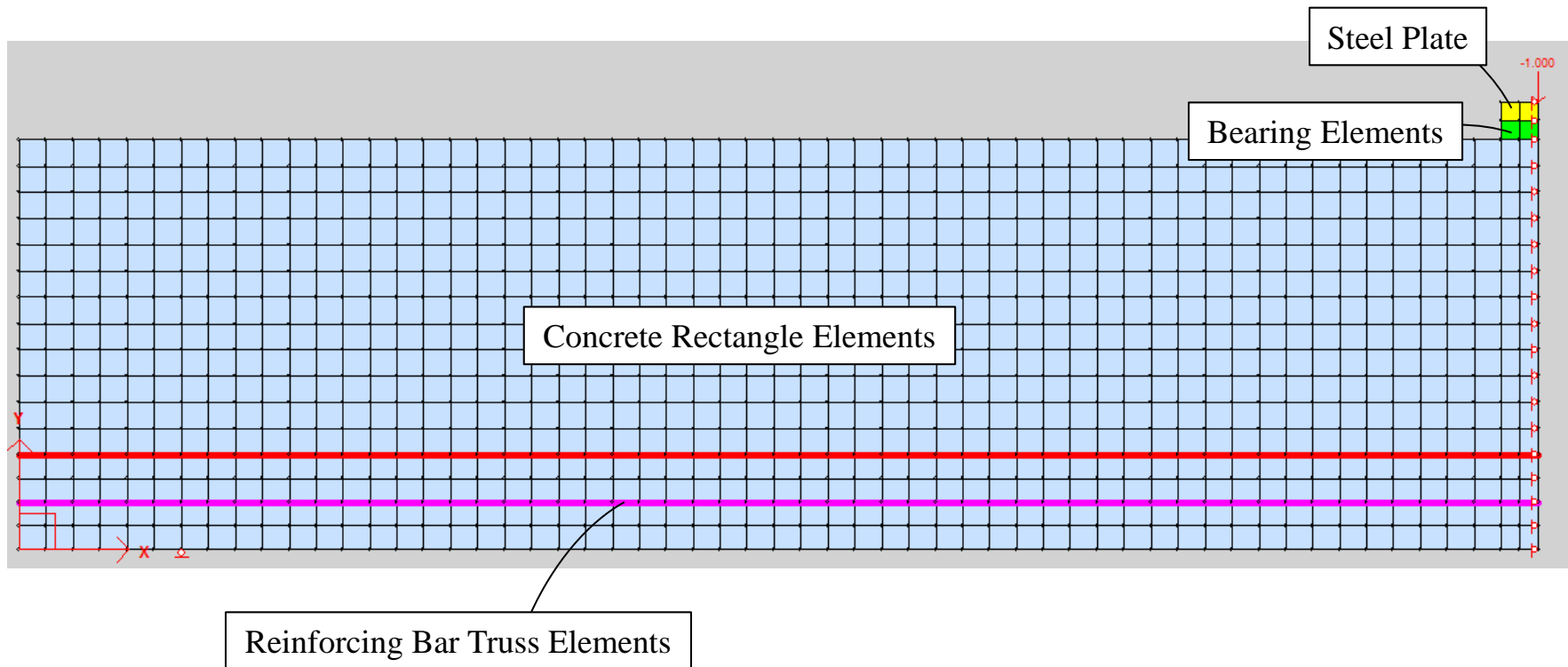
# Example 1: Modelling a Shear-Critical RC Beam in VecTor2

## ❑ Create Finite Element Mesh



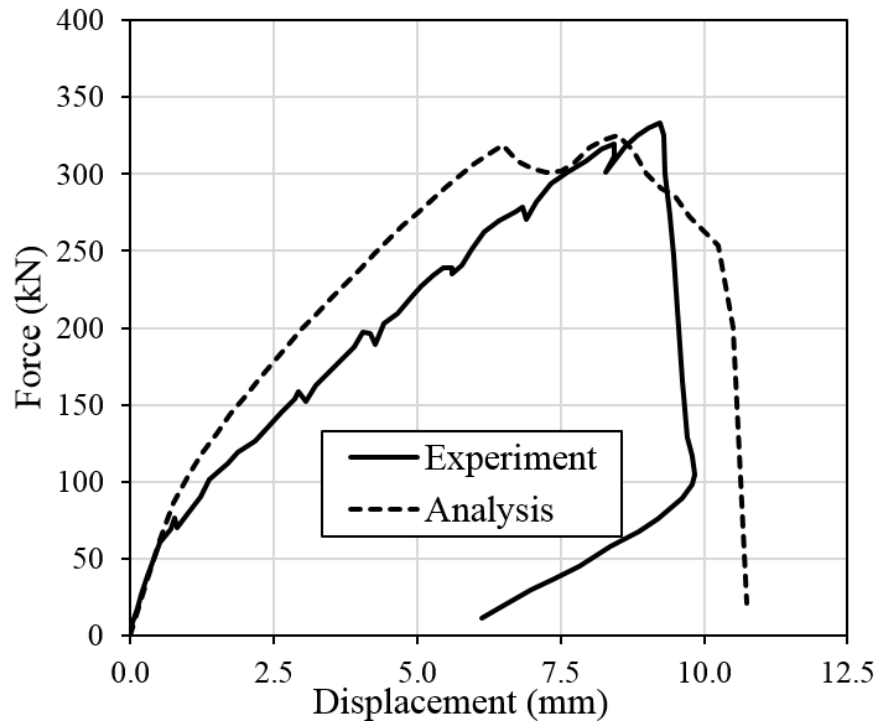
# Example 1: Modelling a Shear-Critical RC Beam in VecTor2

## □ Finite Element Mesh

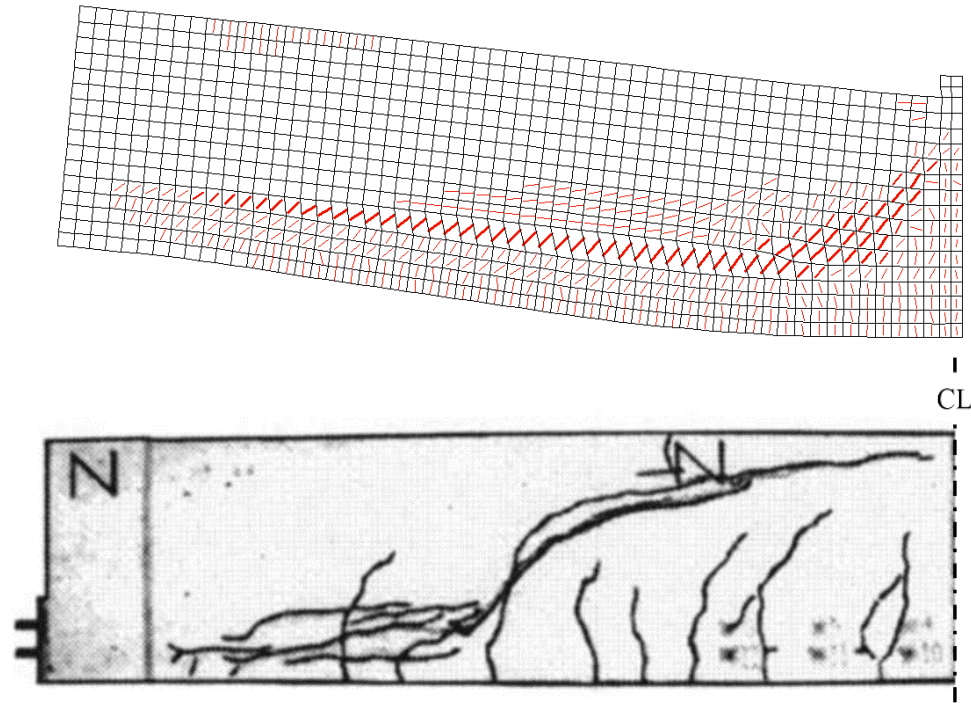


# Example 1: Modelling a Shear-Critical RC Beam in VecTor2

## □ Comparison of the Results



Load-deflection responses

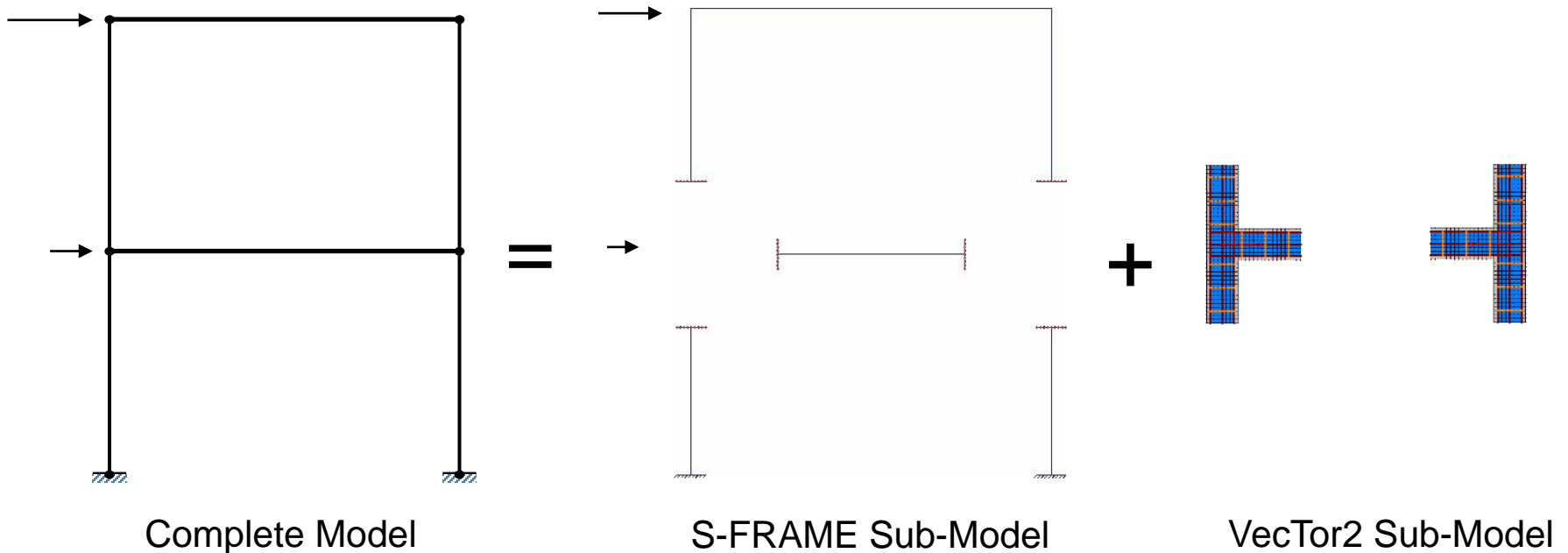


Crack patterns

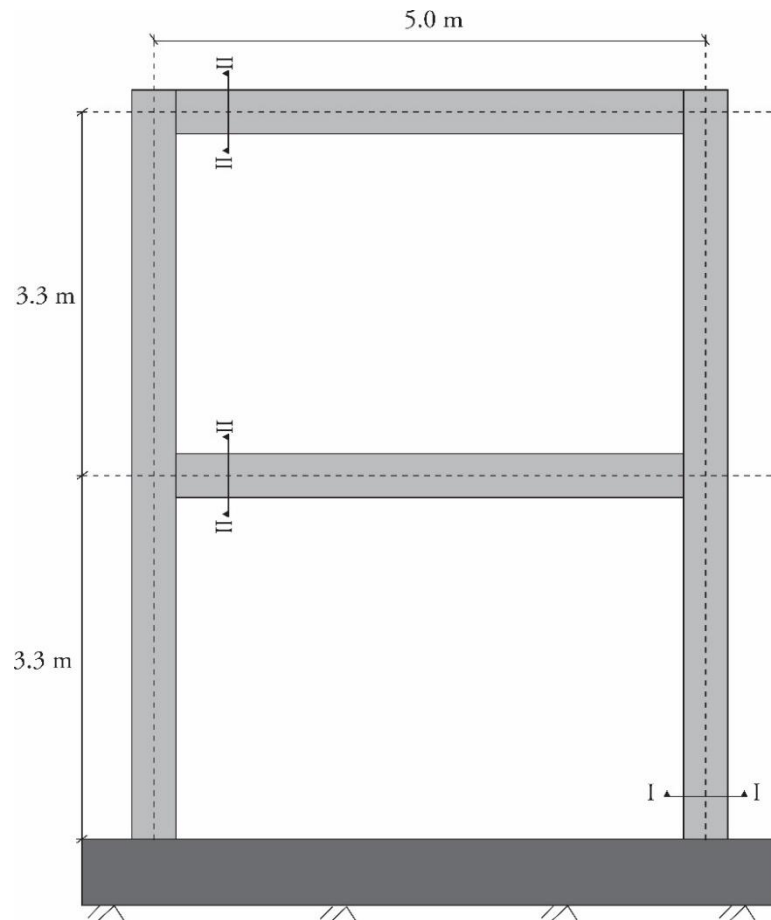
## Example 2

### Modelling Beam-Column Joints Substructure Module in VecTor2

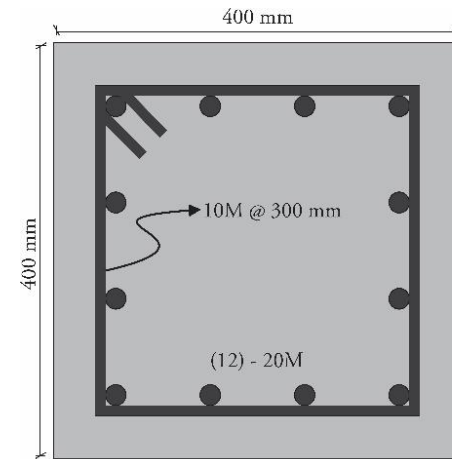
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# Example 2: Beam-Column Joints Substructure in VecTor2

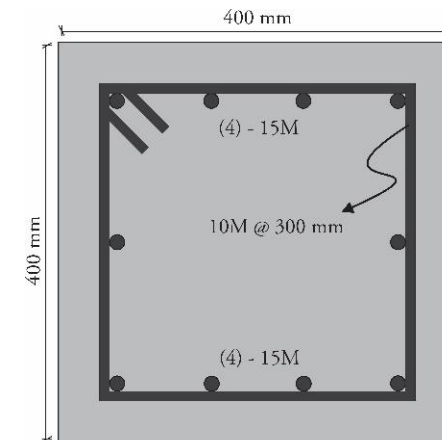


Structure details



Column details

SECTION I - I : COLUMN DETAIL



Beam details

SECTION II - II : BEAM DETAIL



# Example 2: Beam-Column Joints Substructure in VecTor2

## ❑ Step 1) Create Concrete Materials

### ◆ Material 1: Concrete cover (unconfined concrete)

**Define Material Properties**

**Material Types**

Type:

- Material 1
- Material 2

Add Update Delete

**Reinforcement Components**

Component:

Add Update Delete

**Material Properties**

Reference Type: Reinforced Concrete

Thickness, T: 400 mm

Cylinder Compressive Strength,  $f'_c$ : 30 MPa

Tensile Strength,  $f_t$ : \* 3.28 MPa

Initial Tangent Elastic Modulus,  $E_c$ : \* 24647.5 MPa

Cylinder Strain at  $f'_c$ ,  $\epsilon_c$ : \* 0 me

Poisson's Ratio,  $\mu_r$ : \* 0

Thermal Expansion Coefficient,  $C_c$ : \* 0 /°C

Maximum Aggregate Size,  $a$ : \* 0 mm

Density: \* 0 kg/m<sup>3</sup>

Thermal Diffusivity,  $K_c$ : \* 0 mm<sup>2</sup>/s

Maximum Crack Spacing...

perpendicular to x-reinforcement,  $S_x$ : \* 350 mm

perpendicular to y-reinforcement,  $S_y$ : \* 350 mm

Color

**Smeared Reinforcement Properties**

Reference Type: Ductile Steel Reinforcement

Fibre Type:

Out of Plane Reinforcement: ☐

Reinforcement Direction from X-Axis: 0 °

Reinforcement Ratio,  $\rho$ : 1 %

Reinforcement Diameter,  $D_b$ : 10 mm

Yield Strength,  $F_y$ : 400 MPa

Ultimate Strength,  $F_u$ : 600 MPa

Elastic Modulus,  $E_s$ : 200000 MPa

Strain Hardening Strain,  $\epsilon_{sh}$ : 10 me

Ultimate Strain,  $\epsilon_u$ : 150 me

Thermal Expansion Coefficient,  $C_s$ : \* 0 /°C

Prestrain,  $\Delta\epsilon_p$ : 0 me

Unsupported Length Ratio,  $b/t$ : 0

Material types to be used for rectangular, quadrilateral and triangular elements only. \* Enter '0' for VT2 default value.

OK Cancel

# Example 2: Beam-Column Joints Substructure in VecTor2

## ❑ Step 1) Create Concrete Materials

### ◆ Material 2: Confined concrete

**Define Material Properties**

**Material Types**

Type:

- Material 1
- Material 2

Add Update Delete

**Reinforcement Components**

Component:

- Reinforcement 1

Add Update Delete

**Material Properties**

Reference Type: Reinforced Concrete

Thickness, T: 400 mm

Cylinder Compressive Strength,  $f'_c$ : 30 MPa

Tensile Strength,  $f_t$ : \* 3.28 MPa

Initial Tangent Elastic Modulus,  $E_c$ : \* 24647.5 MPa

Cylinder Strain at  $f'_c$ ,  $\epsilon_o$ : \* 0 me

Poisson's Ratio,  $\mu_u$ : \* 0

Thermal Expansion Coefficient,  $C_c$ : \* 0 /°C

Maximum Aggregate Size,  $a$ : \* 0 mm

Density: \* 0 kg/m<sup>3</sup>

Thermal Diffusivity,  $K_c$ : \* 0 mm<sup>2</sup>/s

Maximum Crack Spacing...

perpendicular to x-reinforcement,  $S_x$ : \* 350 mm

perpendicular to y-reinforcement,  $S_y$ : \* 350 mm

Color

**Smeared Reinforcement Properties**

Reference Type: Ductile Steel Reinforcement

Fibre Type:

Out of Plane Reinforcement: ☒

Reinforcement Direction from X-Axis: 361 °

Reinforcement Ratio,  $\rho$ : 0.222 %

Reinforcement Diameter,  $D_b$ : 10 mm

Yield Strength,  $F_y$ : 400 MPa

Ultimate Strength,  $F_u$ : 600 MPa

Elastic Modulus,  $E_s$ : 200000 MPa

Strain Hardening Strain,  $\epsilon_{sh}$ : 10 me

Ultimate Strain,  $\epsilon_u$ : 150 me

Thermal Expansion Coefficient,  $C_s$ : \* 0 /°C

Prestrain,  $\Delta\epsilon_p$ : 0 me

Unsupported Length Ratio,  $b/t$ : 0

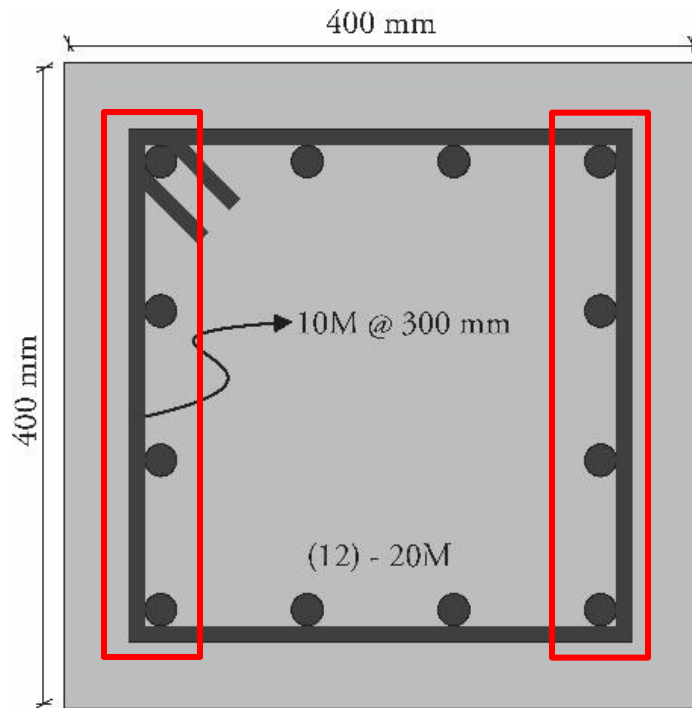
Material types to be used for rectangular, quadrilateral and triangular elements only. \* Enter '0' for VT2 default value.

OK Cancel

# Example 2: Beam-Column Joints Substructure in VecTor2

## ❑ Step 2) Create Reinforcement Materials

### ◆ Reinforcement 1: Column longitudinal reinforcements



Define Reinforcement Properties

Reinforcement Type

Type:

- Reinforcement 1
- Reinforcement 2
- Reinforcement 3
- Reinforcement 4
- Reinforcement 5

Add

Update

Delete

Reinforcement Properties

Reference Type: Ductile Steel Reinforcement

Cross-Sectional Area: 1200 mm<sup>2</sup>

Reinforcement Diameter, Db: 20 mm

Yield Strength, Fy: 400 MPa

Ultimate Strength, Fu: 600 MPa

Elastic Modulus, Es: 200000 MPa

Strain Hardening Strain, esh: 10 me

Ultimate Strain, eu: 150 me

Thermal Expansion Coefficient, Cs: 0 /°C

Prestrain, Dep: 0 me

Unsupported Length Ratio, b/t: 0

Color

Reinforcement material types to be used for truss elements only.

OK

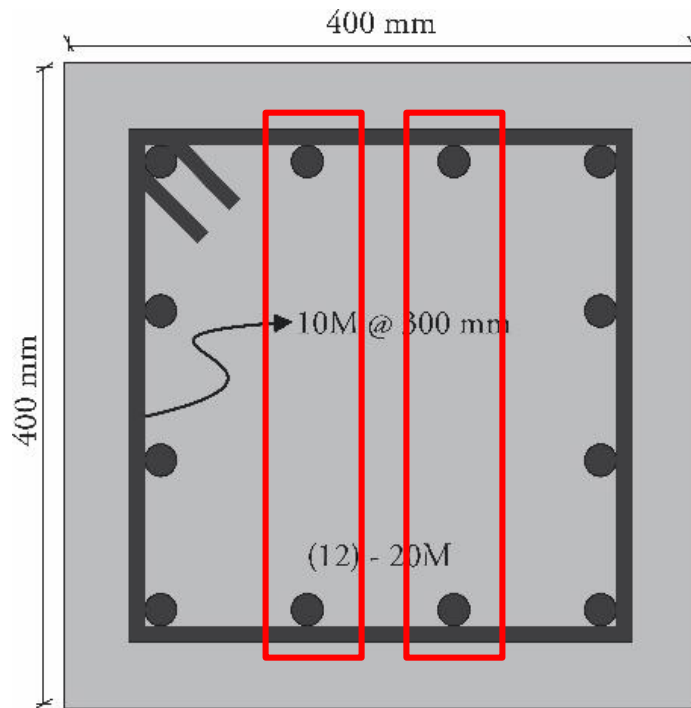
Cancel



# Example 2: Beam-Column Joints Substructure in VecTor2

## ❑ Step 2) Create Reinforcement Materials

### ◆ Reinforcement 2: Column longitudinal reinforcements



SECTION I - I : COLUMN DETAIL

Define Reinforcement Properties

Reinforcement Type

Type:

- Reinforcement 1
- Reinforcement 2**
- Reinforcement 3
- Reinforcement 4
- Reinforcement 5

Add

Update

Delete

Reinforcement Properties

Reference Type: **Ductile Steel Reinforcement**

Cross-Sectional Area: **600** mm<sup>2</sup>

Reinforcement Diameter, Db: **20** mm

Yield Strength, Fy: **400** MPa

Ultimate Strength, Fu: **600** MPa

Elastic Modulus, Es: **200000** MPa

Strain Hardening Strain, esh: **10** me

Ultimate Strain, eu: **150** me

Thermal Expansion Coefficient, Cs: **0** /°C

Prestrain, Dep: **0** me

Unsupported Length Ratio, b/t: **0**

Color

Reinforcement material types to be used for truss elements only.

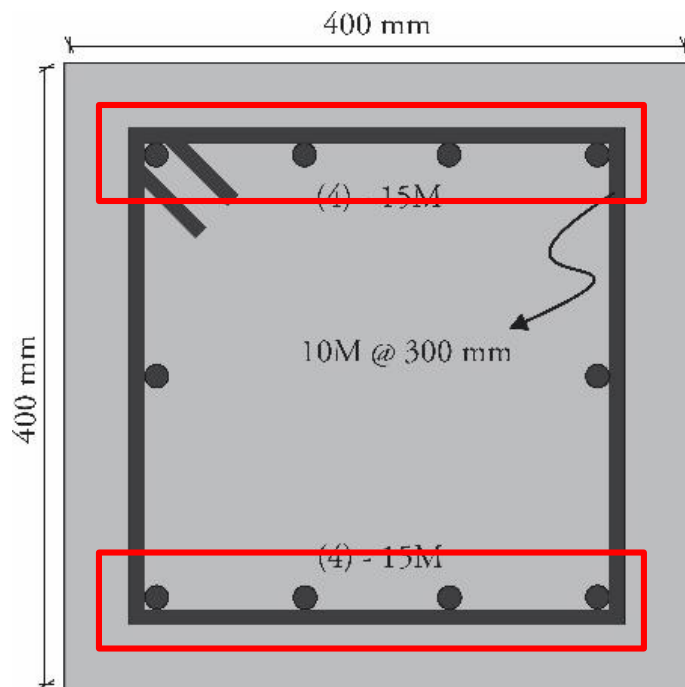
OK

Cancel

# Example 2: Beam-Column Joints Substructure in VecTor2

## ❑ Step 2) Create Reinforcement Materials

### ◆ Reinforcement 3: Beam longitudinal reinforcements



SECTION II - II : BEAM DETAIL

Define Reinforcement Properties

Reinforcement Type

Type:

- Reinforcement 1
- Reinforcement 2
- Reinforcement 3
- Reinforcement 4
- Reinforcement 5

Add

Update

Delete

Reinforcement Properties

Reference Type: Ductile Steel Reinforcement

Cross-Sectional Area: 800 mm<sup>2</sup>

Reinforcement Diameter, Db: 15 mm

Yield Strength, Fy: 400 MPa

Ultimate Strength, Fu: 600 MPa

Elastic Modulus, Es: 200000 MPa

Strain Hardening Strain, esh: 10 me

Ultimate Strain, eu: 150 me

Thermal Expansion Coefficient, Cs: 0 /°C

Prestrain, Dep: 0 me

Unsupported Length Ratio, b/t: 0

Color

Reinforcement material types to be used for truss elements only.

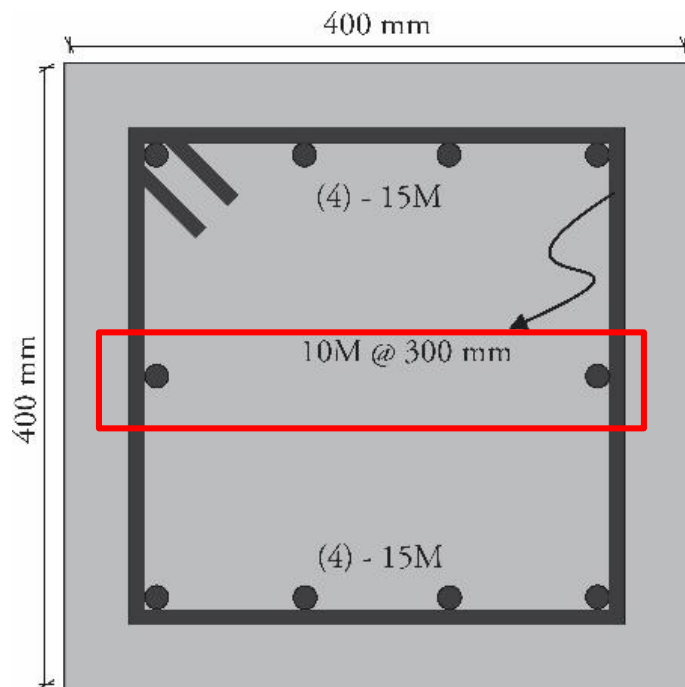
OK

Cancel

# Example 2: Beam-Column Joints Substructure in VecTor2

## ❑ Step 2) Create Reinforcement Materials

### ◆ Reinforcement 4: Beam longitudinal reinforcements



SECTION II - II : BEAM DETAIL

The dialog box is titled "Define Reinforcement Properties". It contains the following sections:

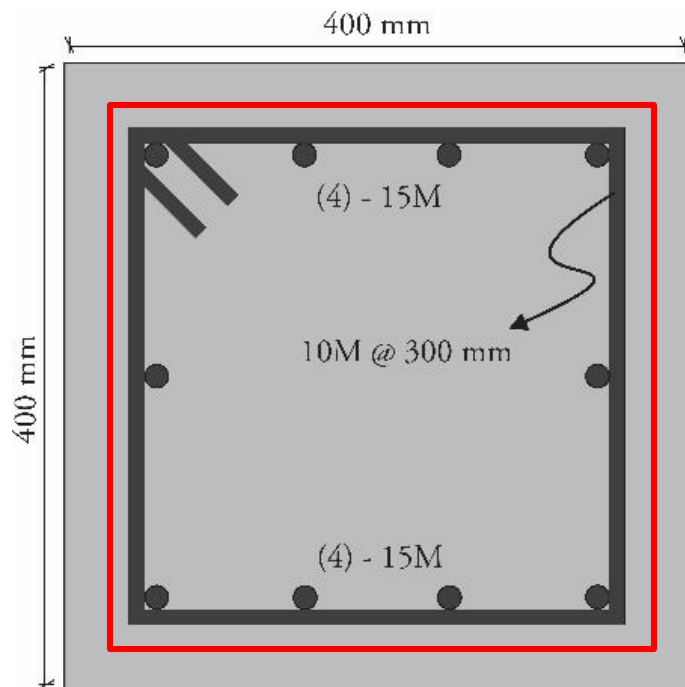
- Reinforcement Type**
  - Type: A list box containing "Reinforcement 1", "Reinforcement 2", "Reinforcement 3", "Reinforcement 4" (highlighted in blue), and "Reinforcement 5".
  - Buttons: "Add", "Update", and "Delete".
- Reinforcement Properties**
  - Reference Type: A dropdown menu set to "Ductile Steel Reinforcement".
  - Cross-Sectional Area: 400 mm<sup>2</sup>
  - Reinforcement Diameter, Db: 15 mm
  - Yield Strength, Fy: 400 MPa
  - Ultimate Strength, Fu: 600 MPa
  - Elastic Modulus, Es: 200000 MPa
  - Strain Hardening Strain, esh: 10 me
  - Ultimate Strain, eu: 150 me
  - Thermal Expansion Coefficient, Cs: 0 /°C
  - Prestrain, Dep: 0 me
  - Unsupported Length Ratio, b/t: 0
  - Color: A pink color swatch.

At the bottom, there is a note: "Reinforcement material types to be used for truss elements only." and "OK" and "Cancel" buttons.

# Example 2: Beam-Column Joints Substructure in VecTor2

## ❑ Step 2) Create Reinforcement Materials

### ◆ Reinforcement 5: Transverse reinforcements



SECTION II - II : BEAM DETAIL

Define Reinforcement Properties

Reinforcement Type

Type:

- Reinforcement 1
- Reinforcement 2
- Reinforcement 3
- Reinforcement 4
- Reinforcement 5

Add

Update

Delete

Reinforcement Properties

Reference Type: Ductile Steel Reinforcement

Cross-Sectional Area: 200 mm<sup>2</sup>

Reinforcement Diameter, Db: 10 mm

Yield Strength, Fy: 400 MPa

Ultimate Strength, Fu: 600 MPa

Elastic Modulus, Es: 200000 MPa

Strain Hardening Strain, esh: 10 me

Ultimate Strain, eu: 150 me

Thermal Expansion Coefficient, Cs: 0 /°C

Prestrain, Dep: 0 me

Unsupported Length Ratio, b/t: 0

Color

Reinforcement material types to be used for truss elements only.

OK

Cancel

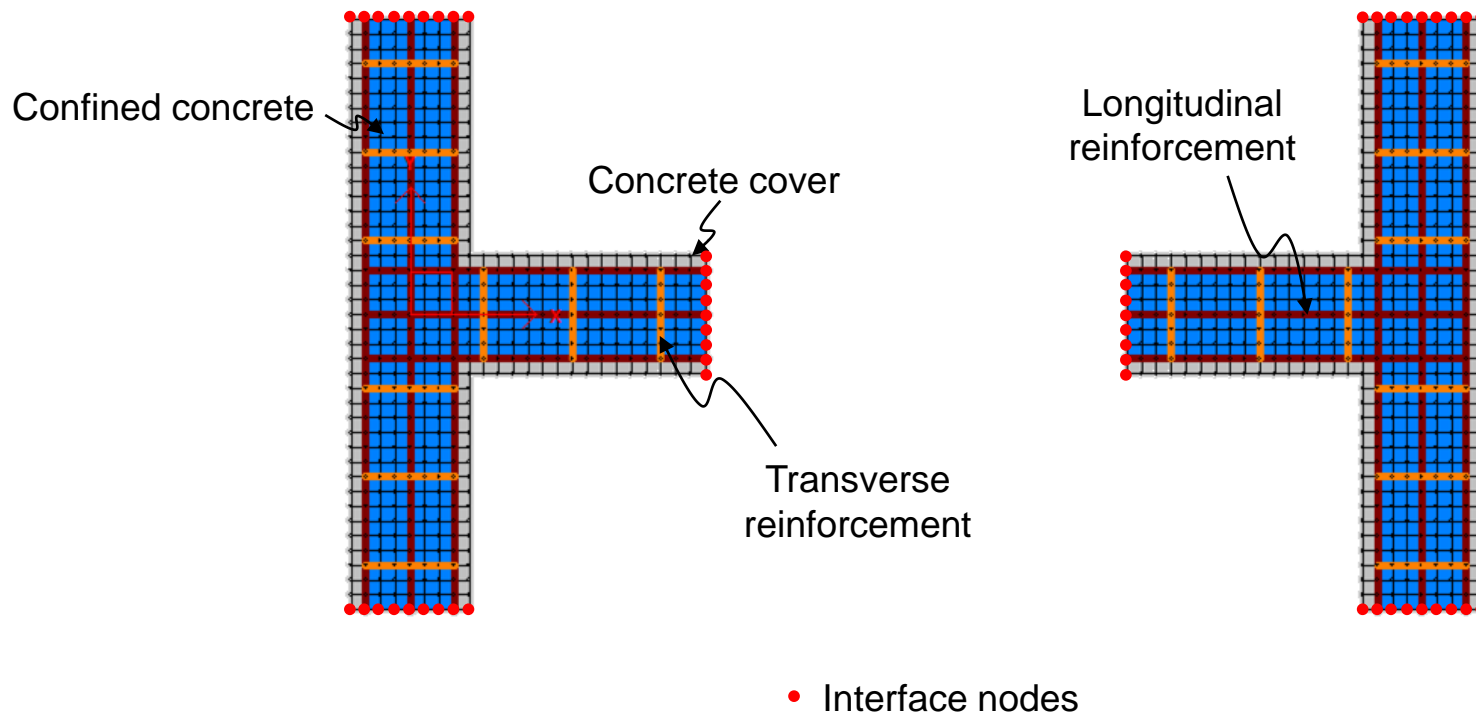
## Example 2: Beam-Column Joints Substructure in VecTor2

### ❑ Step 3) Create Concrete Regions and Truss Bars



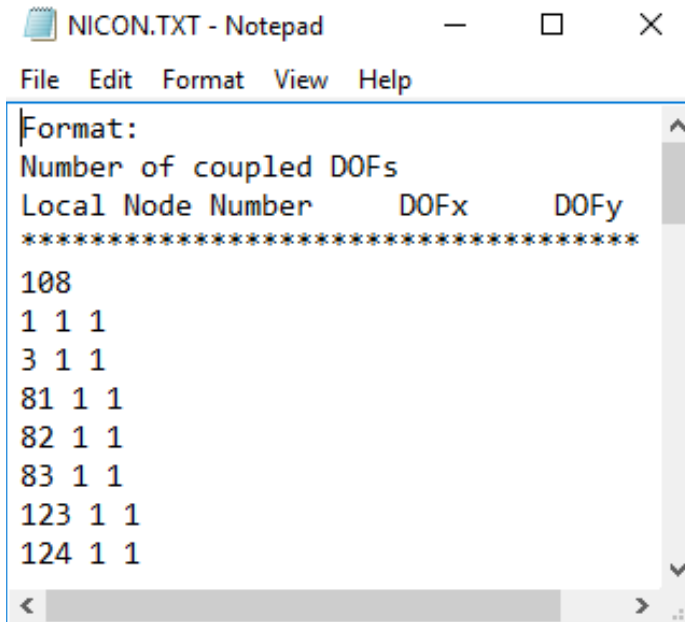
# Example 2: Beam-Column Joints Substructure in VecTor2

## □ Step 4) Create FE Mesh and Assign Materials

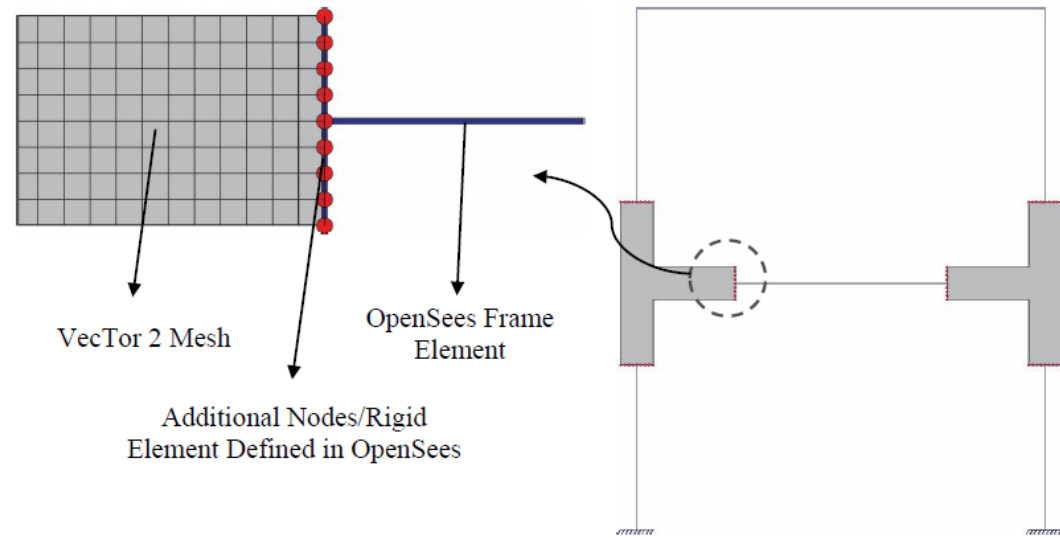


# Example 2: Beam-Column Joints Substructure in VecTor2

## ❑ Step 5) Map Interface Nodes: OpenSees-VecTor2 Integration

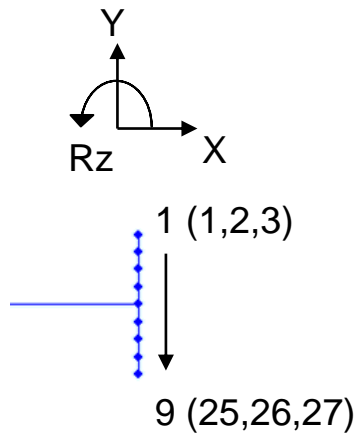


```
Format:
Number of coupled DOFs
Local Node Number    DOFx    DOFy
*****
108
1 1 1
3 1 1
81 1 1
82 1 1
83 1 1
123 1 1
124 1 1
```

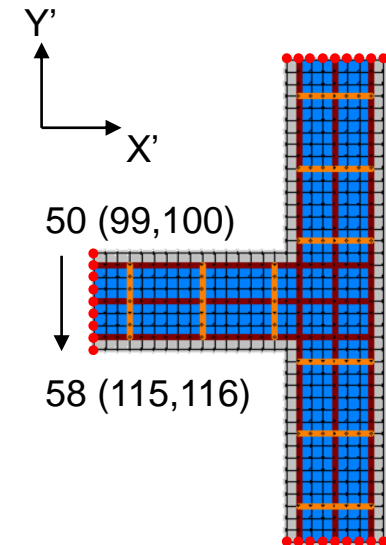


# Example 2: Beam-Column Joints Substructure in VecTor2

## □ Step 5) Map Interface Nodes: SFRAME-VecTor2 Integration



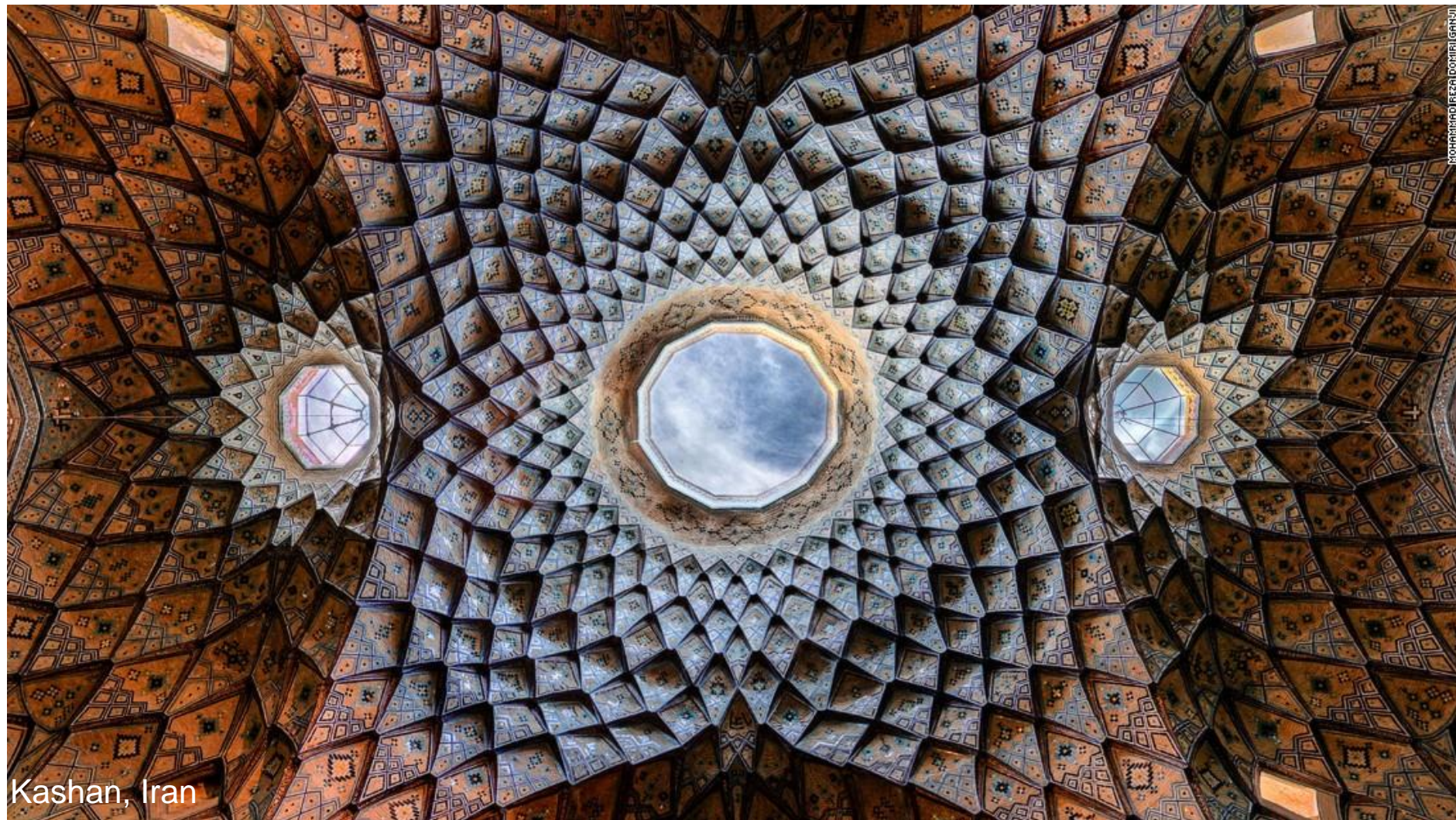
S-FRAME		VecTor2s	
Node	DOF	DOF	Node
1	1	99	50
	2	100	
2	4	101	51
	5	102	
3	7	103	52
	8	104	
4	10	105	53
	11	106	
5	13	107	54
	14	108	
6	16	109	55
	17	110	
7	19	111	56
	20	112	
8	22	113	57
	23	114	
9	25	115	58
	26	116	





# Thank You

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Kashan, Iran