

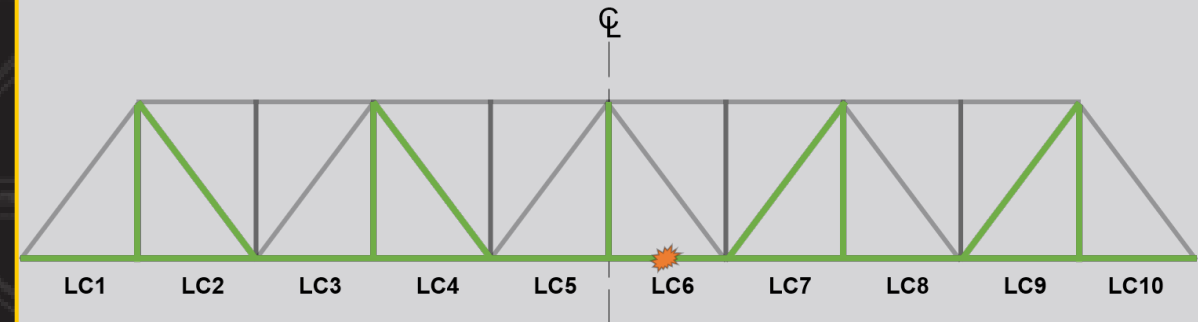
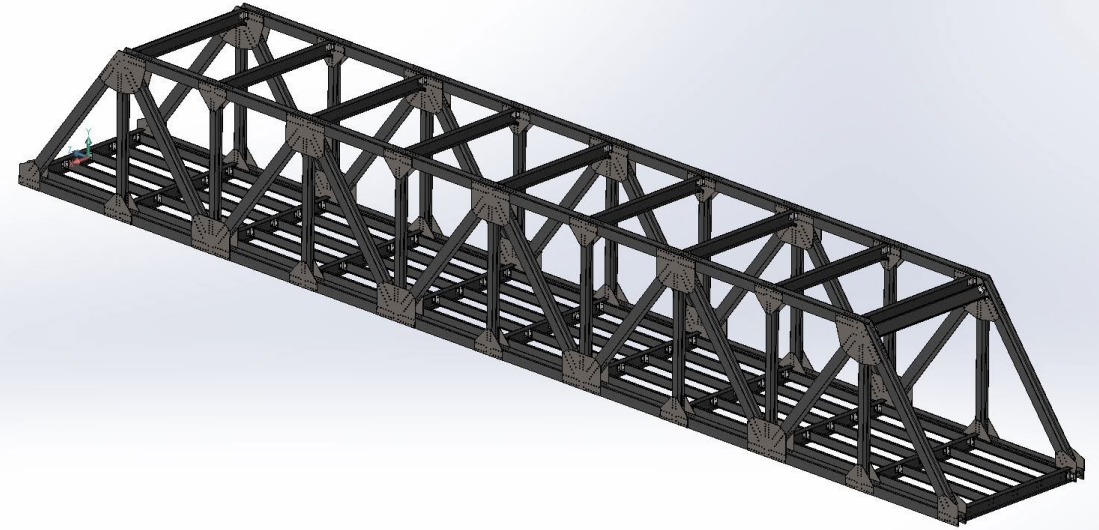
# Load Path Redundancy Study: Preliminary Test Matrix and Instrumentation Plan (Task 2)

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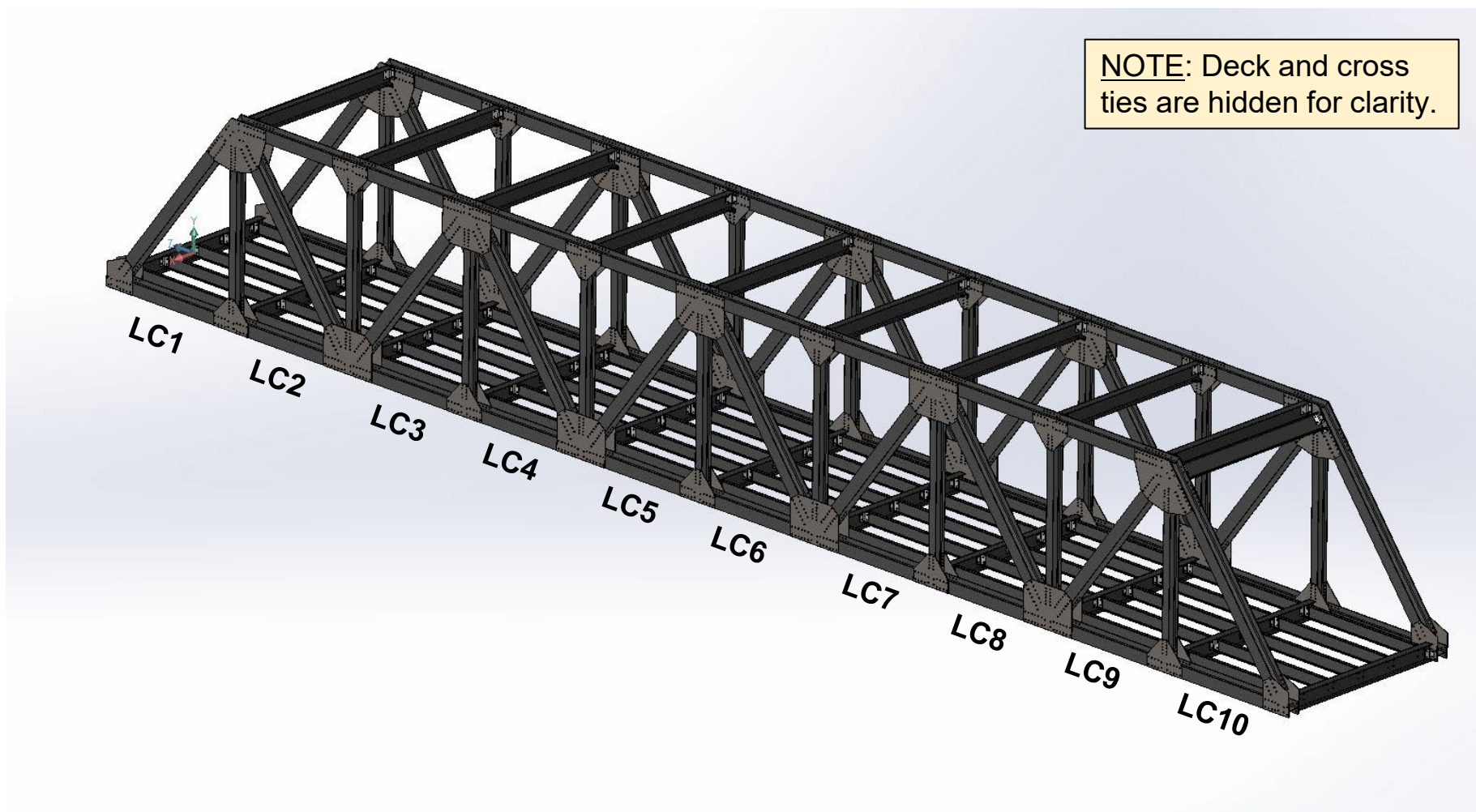
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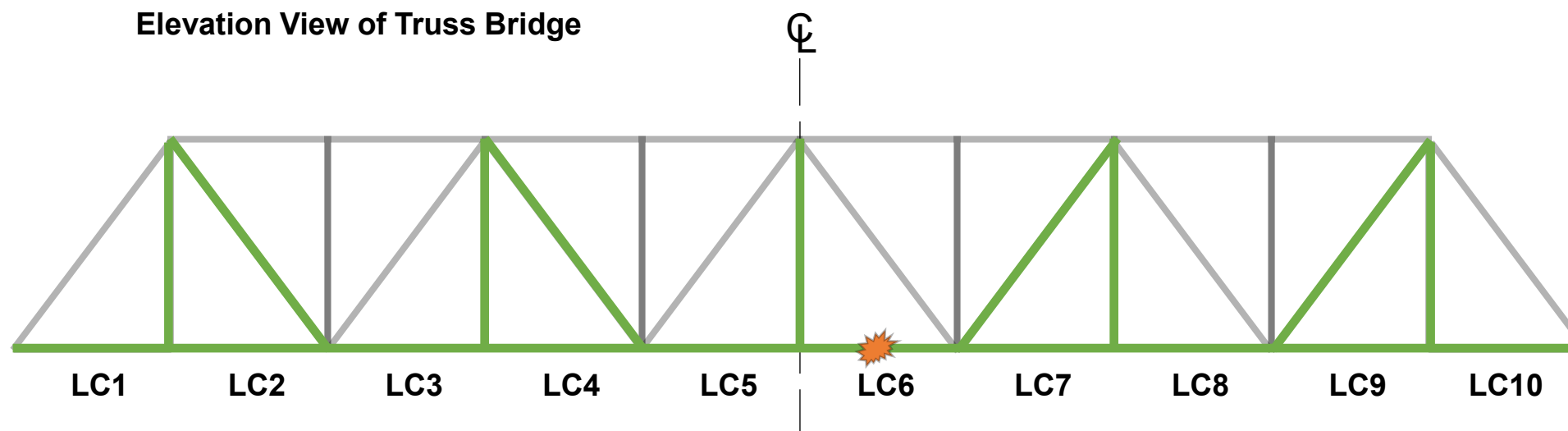
# Overview: Quarter-Scale Truss Bridge





# Member Loss Scenario Options

- Concerns for safety and practicality limit member removal to members in tension.
- All truss members put into tension by gravity loads are highlighted green.
- Considering symmetry, there are 10 different tension member removal scenarios that could be performed.
- The first test set will explore loss of LC6, which is adjacent to the center of the span.





# Preliminary Test Matrix – Tests w/o Deck



| Test no                | Test type                              | Concrete deck? | Added dead weight                                       | Anticipated behavior |
|------------------------|----------------------------------------|----------------|---------------------------------------------------------|----------------------|
| M-1                    | Modal analysis                         | N              | No                                                      | Elastic              |
| 1                      | Static                                 | N              | Add load in increments                                  | Elastic              |
| 2                      | Member loss (LC6)                      | N              | No                                                      | Elastic              |
| 3                      | Member loss (LC6)                      | N              | Equivalent deck                                         | Elastic/Plastic      |
| 4                      | Member loss (LC6)                      | N              | Equivalent deck + add'l amount<br>TBD                   | Elastic/Plastic      |
| 5                      | Member loss (LC6)                      | N              | Predict amount to cause appreciable plastic deformation | Plastic              |
| Repair damaged members |                                        |                |                                                         |                      |
| 6-A                    | Member loss (tension diagonal)         | N              | Equivalent deck                                         | Elastic/Plastic      |
| 6-B                    | Member loss (other LC members)         | N              | Equivalent deck                                         | Elastic/Plastic      |
| :                      | Additional member loss scenarios (TBD) |                |                                                         |                      |



# Preliminary Test Matrix – Tests w/ Deck

| Test no                                                                              | Test type         | Concrete deck? | Added dead weight                                       | Anticipated behavior |
|--------------------------------------------------------------------------------------|-------------------|----------------|---------------------------------------------------------|----------------------|
| Decision point: determine which member to use for member loss in tests with the deck |                   |                |                                                         |                      |
| M-2                                                                                  | Modal analysis    | Y              | No                                                      | Elastic              |
| 7                                                                                    | Static            | Y              | Add load in increments                                  | Elastic              |
| 8                                                                                    | Member loss (TBD) | Y              | No                                                      | Elastic/Plastic      |
| 9                                                                                    | Member loss (TBD) | Y              | Add'l amount TBD                                        | Elastic/Plastic      |
| 10                                                                                   | Member loss (TBD) | Y              | Predict amount to cause appreciable plastic deformation | Plastic              |



# Overview of Instrumentation Plan



Member removal simulations (using LS-Dyna) were used to identify members that satisfied:

- Participation in an alternate load path, and
- Experienced a measurable/appreciable change in internal force/moment due to member removal/loss

These identified members could be chosen for instrumentation to validate member removal simulations

Instrumentation primarily consists of strain gauges applied on the web and/or flanges of members

Support reaction forces and displacements at several joints will also be measured

To optimize the use of gauges, the gauge layout is chosen based on the expected response of the member

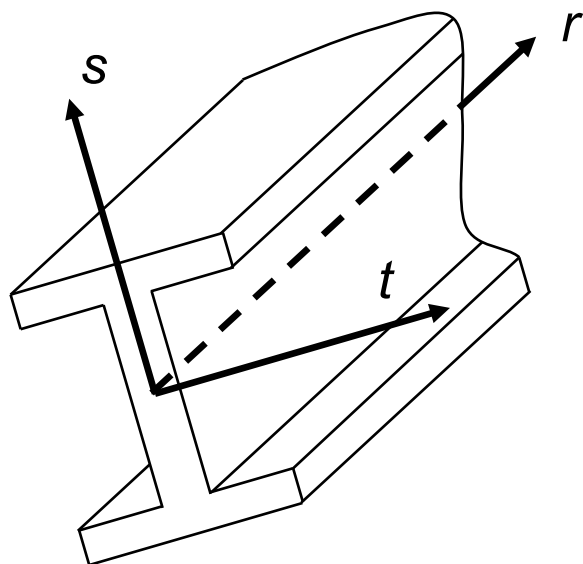
- E.g., a member that experiences negligible bending moment might be instrumented to measure axial force only

Outline of remainder of document

- Gauge configurations used to measure various internal force and moment resultants at a cross section: [slide 7](#), [slide 8](#)
- Proposed locations of instrumented members on bridge: [slide 9](#), [slide 10](#)
- Details of instrumentation at each proposed instrumented location: [slide 11](#)
- Proposed reaction and displacement measurements: [slide 12](#)



# Member Local Coordinates



Axial force:  $F_r$

Shear forces:  $F_s$  and  $F_t$

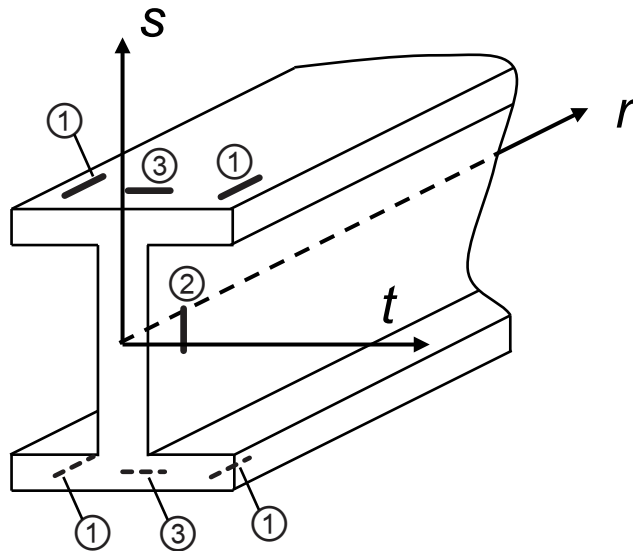
Torsional moment:  $M_r$

Bending moments:  $M_s$  and  $M_t$

- The  $r$ -axis is always along the longitudinal axis of the member.
- For horizontal members, the  $s$ -axis points up.
- For verticals or diagonals, the  $s$ -axis is in the plane of the truss.
- **Note:** The local  $rst$  coordinate system is independent of the orientation of the steel member's cross section.
  - For beams in an "I"-orientation, the strong axis for bending is the  $t$ -axis.
  - For beams in an "H"-orientation, the strong axis for bending is the  $s$ -axis.



# Force and Moment Resultants and Gauge Placement



- ① { Axial force,  $F_r$   
Bending moment,  $M_s$   
Bending moment,  $M_t$
- ② Shear force,  $F_s$
- ③ { Shear force,  $F_t$   
Torsional moment,  $M_r$

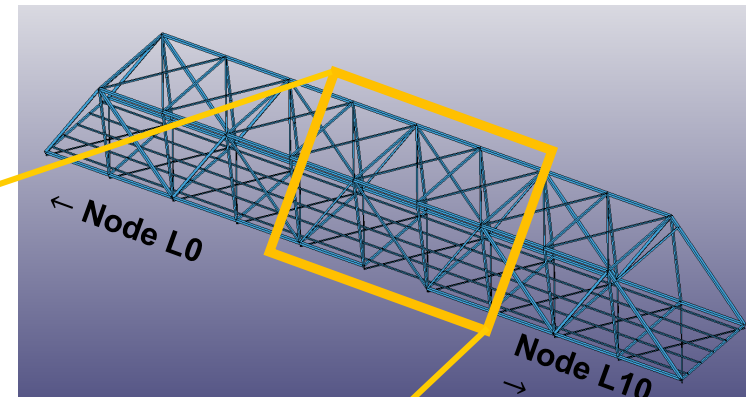
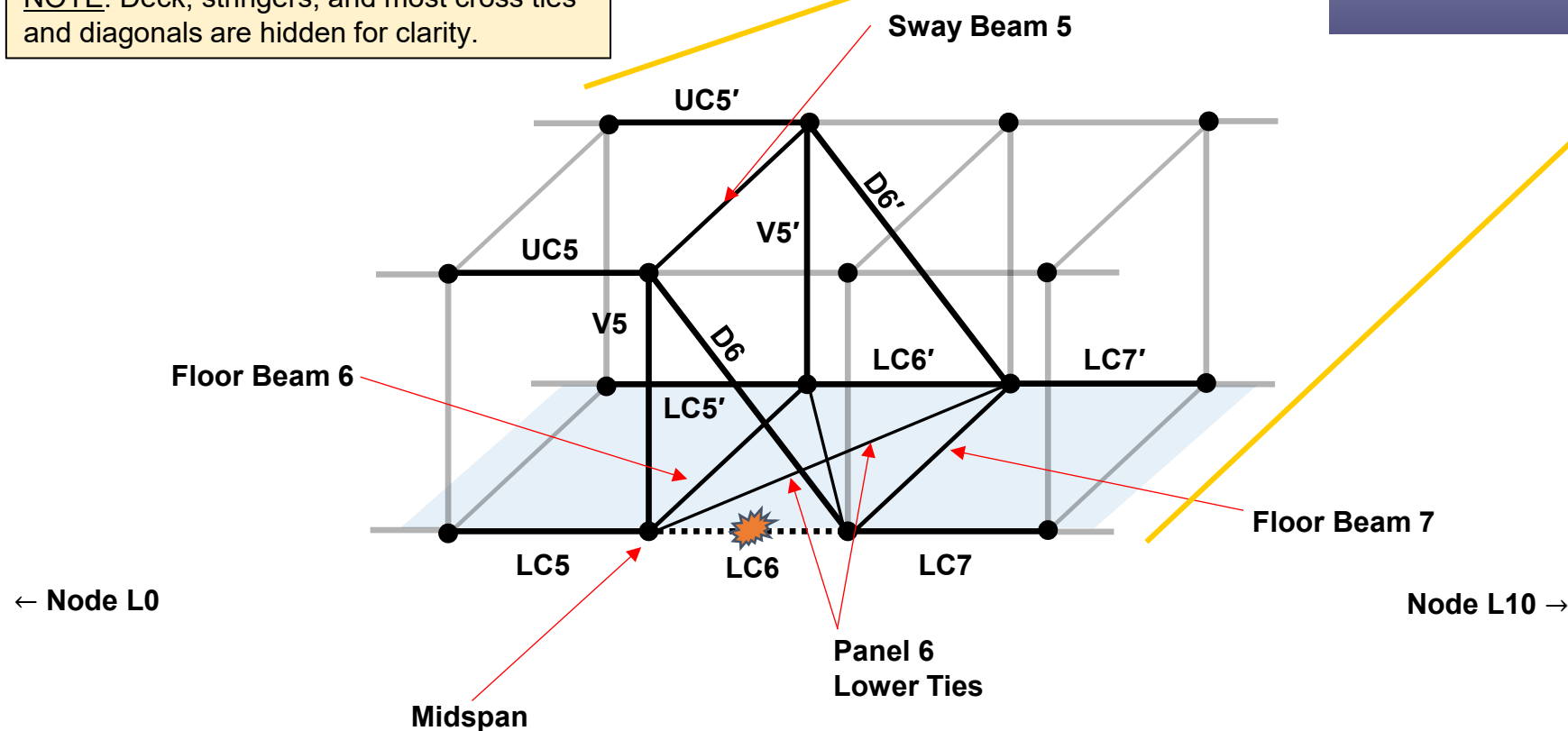
Theoretically, group ① needs only three gauges. A fourth gauge is not necessary but does provide redundancy.



# Proposed Strain Gauge Locations

Simulation indicated members in directly adjacent panels to removed member would experience appreciable changes to internal forces. For LC6 member loss, the labeled members below would be instrumented.

**NOTE:** Deck, stringers, and most cross ties and diagonals are hidden for clarity.

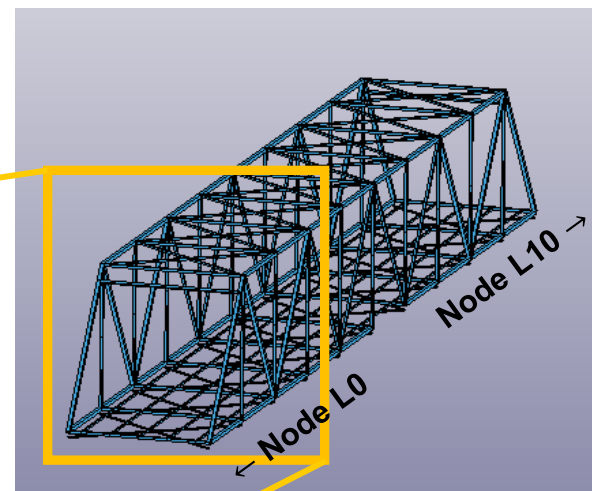
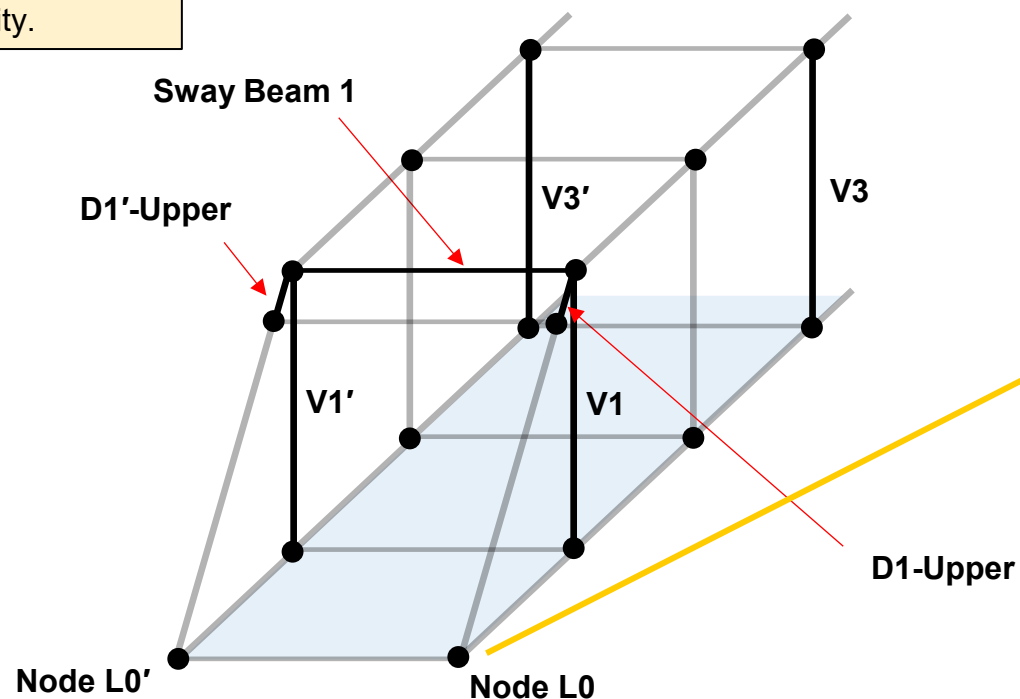




# Proposed Strain Gauge Locations

Simulation also indicated members in the portal panel would experience appreciable changes to internal forces. The labeled members below would be instrumented.

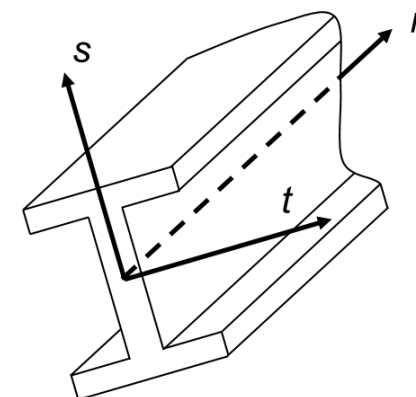
**NOTE:** Deck, stringers, and most cross ties and diagonals are hidden for clarity.





# Proposed Strain Gauge Configurations

| Member                | Section 1  |        | Section 2  |        | Total Gauges |
|-----------------------|------------|--------|------------|--------|--------------|
|                       | Measured   | Gauges | Measured   | Gauges |              |
| LC5                   | All        | 7      | Fr, Ms, Mt | 4      | 11           |
| LC6                   | Fr         | 1      | -----      | -----  | 1            |
| LC7                   | Fr, Ms, Mt | 4      | Fr, Ms, Mt | 4      | 8            |
| LC5'                  | Fr, Ms, Mt | 4      | Fr, Ms, Mt | 4      | 8            |
| LC6'                  | Fr, Ms, Mt | 4      | Fr, Ms, Mt | 4      | 8            |
| LC7'                  | Fr, Ms, Mt | 4      | Fr, Ms, Mt | 4      | 8            |
| D6                    | Fr, Ms, Mt | 4      | Fr, Ms, Mt | 4      | 8            |
| D6'                   | Fr, Ms, Mt | 4      | Fr, Ms, Mt | 4      | 8            |
| D1-upper              | Fr, Ms, Mt | 4      | -----      | -----  | 4            |
| D1'-upper             | Fr, Ms, Mt | 4      | -----      | -----  | 4            |
| Sway Beam 1           | Fr, Mt     | 2      | Fr, Mt     | 2      | 4            |
| Sway Beam 5           | Fr, Mt     | 2      | Fr, Mt     | 2      | 4            |
| Panel 6 Lower Tie (/) | Fr         | 1      | -----      | -----  | 1            |
| Panel 6 Lower Tie (\) | Fr         | 1      | -----      | -----  | 1            |
| Floor Beam 6          | All        | 7      | All        | 7      | 14           |
| Floor Beam 7          | All        | 7      | All        | 7      | 14           |
| V1                    | Fr, Ms     | 2      | Fr, Ms     | 2      | 4            |
| V1'                   | Fr, Ms     | 2      | Fr, Ms     | 2      | 4            |
| V3                    | Fr, Ms     | 2      | Fr, Ms     | 2      | 4            |
| V3'                   | Fr, Ms     | 2      | Fr, Ms     | 2      | 4            |
| V5                    | Fr, Ms     | 2      | Fr, Ms     | 2      | 4            |
| V5'                   | Fr, Ms     | 2      | Fr, Ms     | 2      | 4            |



$F_r$  Axial force

$M_t$  In-plane bending moment

$M_s$  Out-of-plane bending moment

Refer to slide 7 for details on the coordinate system.

**22 instrumented members**  
**130 strain gauges**



# Other Instrumentation

| Instrument Type      | Quantity | Total Channels |
|----------------------|----------|----------------|
| Uniaxial load pin    | 4        | 4              |
| String potentiometer | 10       | 10             |

## KEY



Uniaxial load pin



String potentiometer  
(Y-axis orientation)



String potentiometer  
(X-axis orientation)



String potentiometer  
(Z-axis orientation)

