COMPREHENSIVE SERIES OF TESTS ON SEISMIC PERFORMANCE OF REINFORCED CONCRETE BEAM-COLUMN JOINTS

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Background

- RC beam-column joint safety in seismic design
  - joint shear strength design
  - potential of joint shear resistance were evaluated by lot of tests empirically
  - specimens with beams and columns heavily reinforced have been tested to assess the potential
- No comprehensive data set is available for actual strength and post-yielding behavior of joints with realistic range of reinforcement ratio in the beams and the columns

Test Program

- Planed such that a dependable data set of RC interior beam-column joint subassemblages should be obtained
- Lateral capacity and post yielding behavior are discussed
- Test parameters; including combinations of 3 factors

  (1) amount of longitudinal reinforcement (3 levels)

  (2) ratio of the flexural strength of the beams to the flexural strength of the columns framing into a joint, (3 to 4 levels)

  (3) ratio of the depth of the beam to the depth of the column. (2 levels)

Conclusions

- Current seismic provisions for RC beam-column joints are deficient, because they can not secure the lateral strength of moment resisting frames predicted by the flexural theory of RC sections
- Hence a large number of existing moment resisting frame reinforced concrete structures may be more vulnerable than we expect.
- Serious consideration on this test results should be addressed by structural engineers, researchers and code writers.

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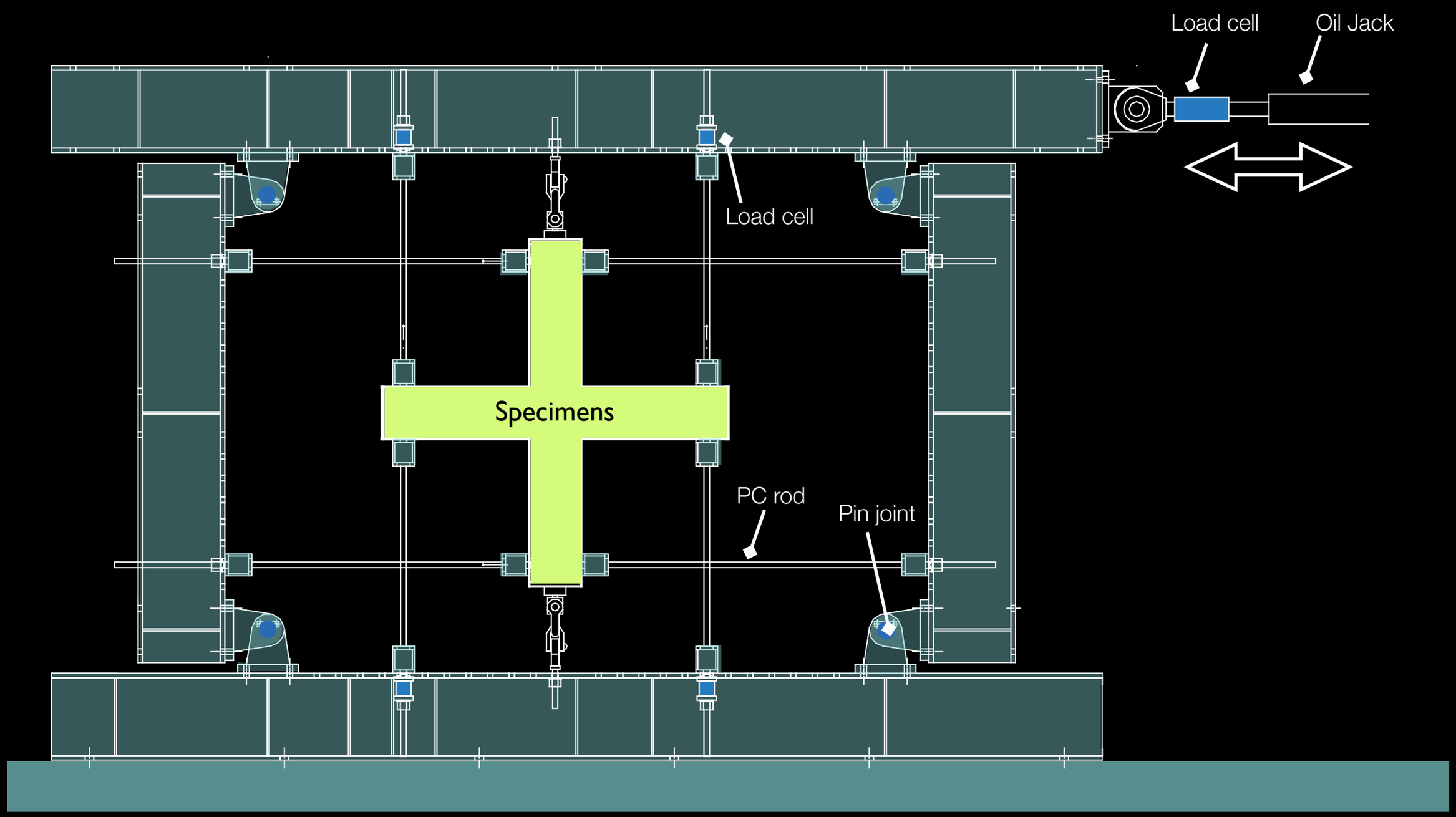

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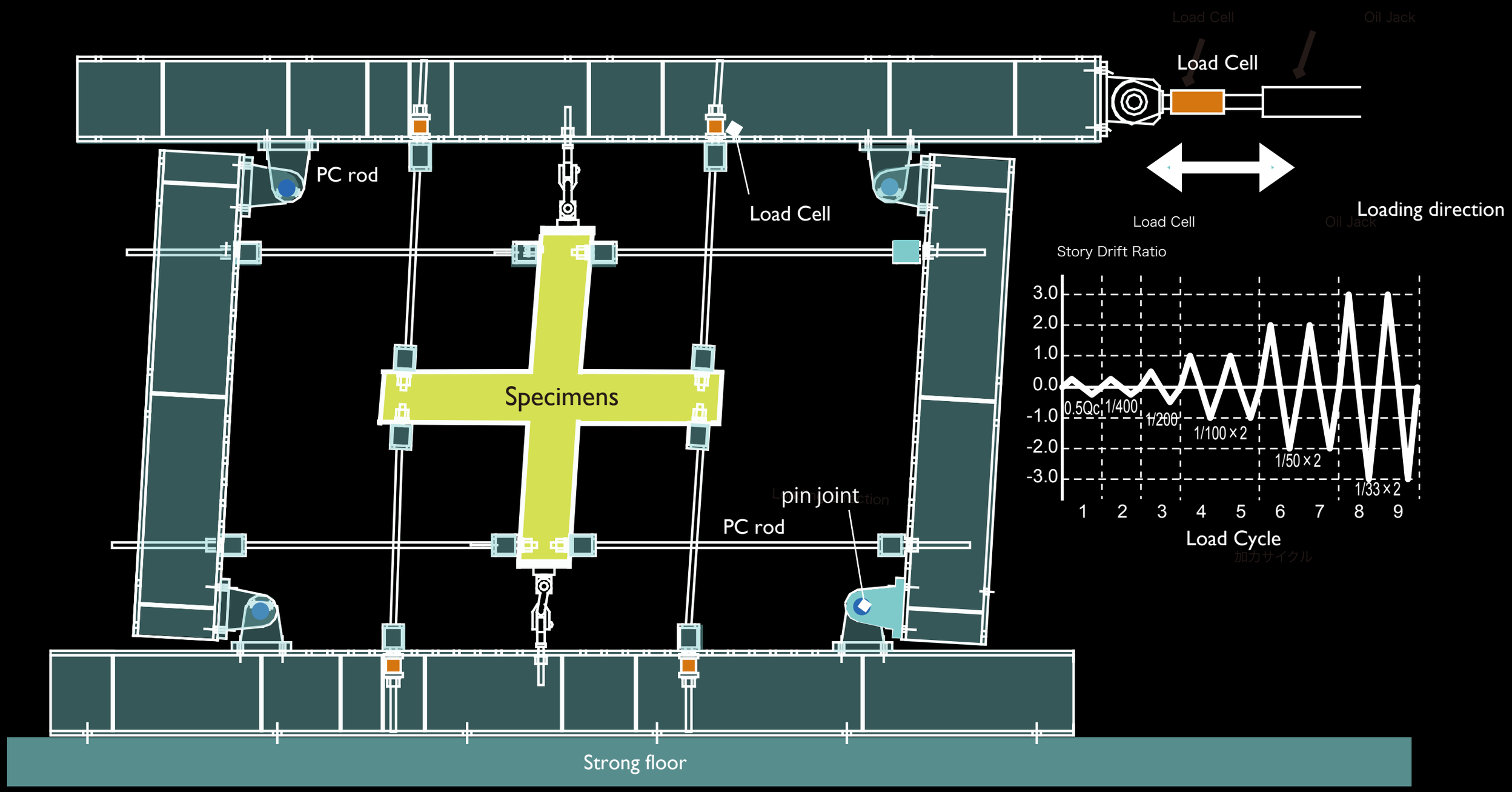

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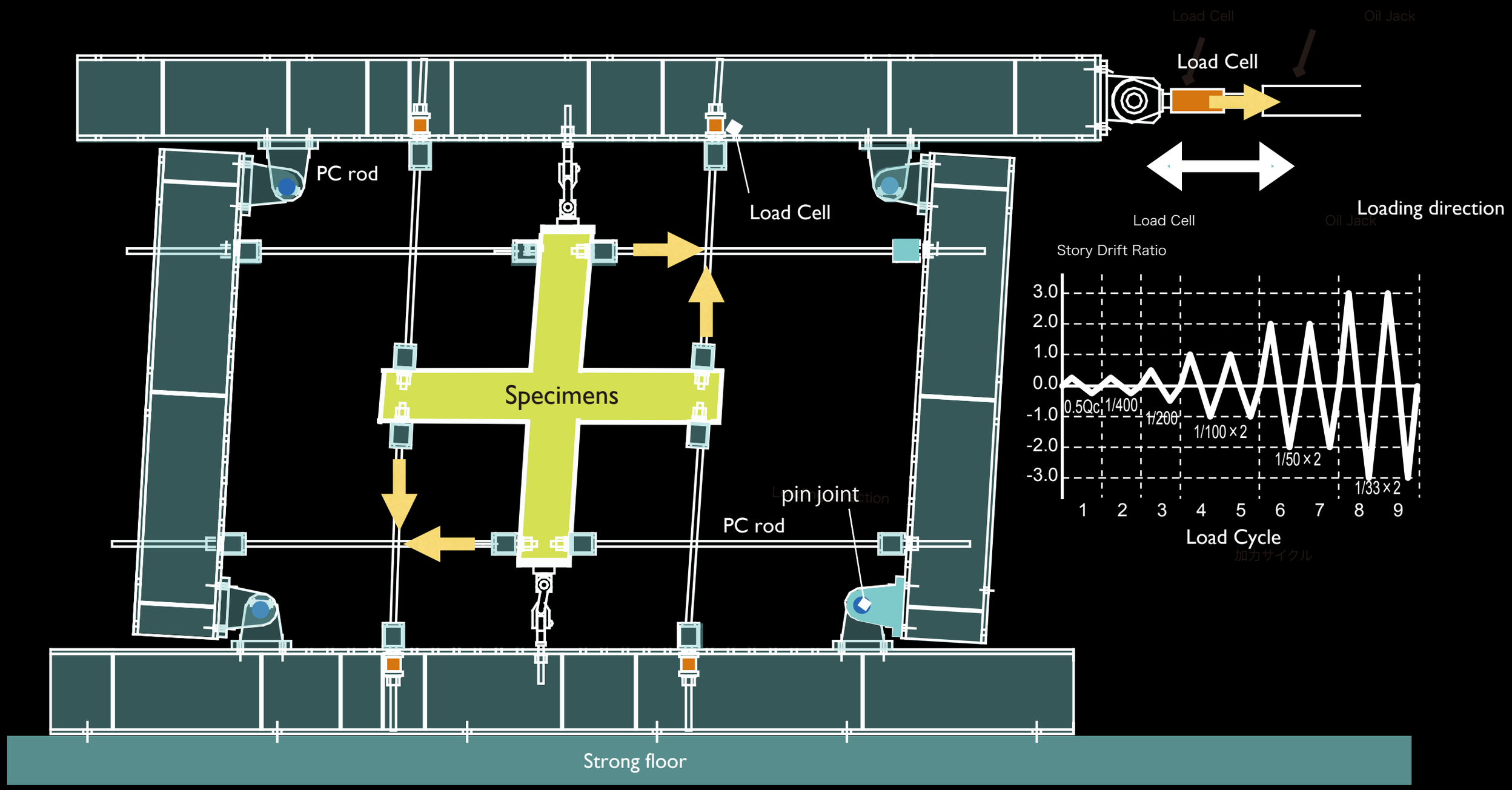
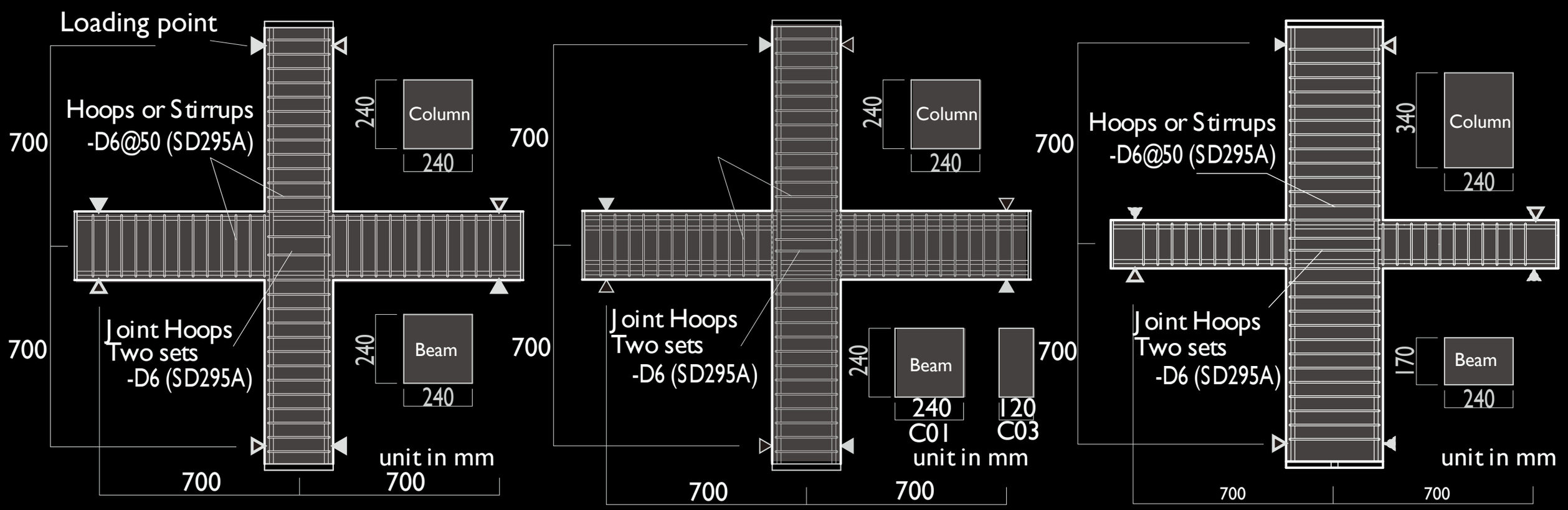


Specimens



(a) Series B

(b) Series C

(c) Series D

11 4 11

in total 31 specimens in FY2008

Three Major Test Parameters

(1) Amount of longitudinal reinforcement,

p_t : 0.98% - 3.98%

(2) Ratio of the flexural strength of the beams to the flexural strength of the columns framing into a joint,

$\sum M_{uc} / \sum M_{ub}$: 72% - 268%

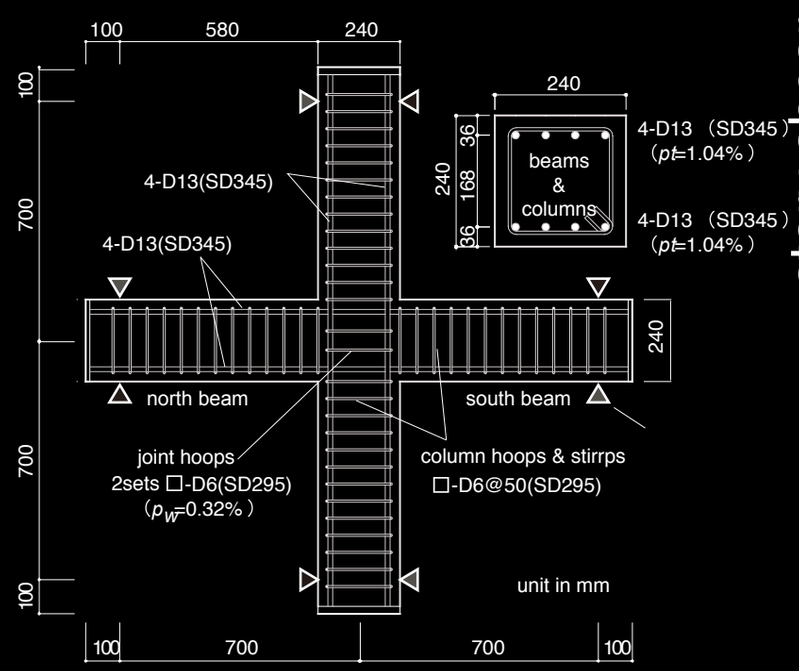
(3) ratio of the depth of the beam to the depth of the column.

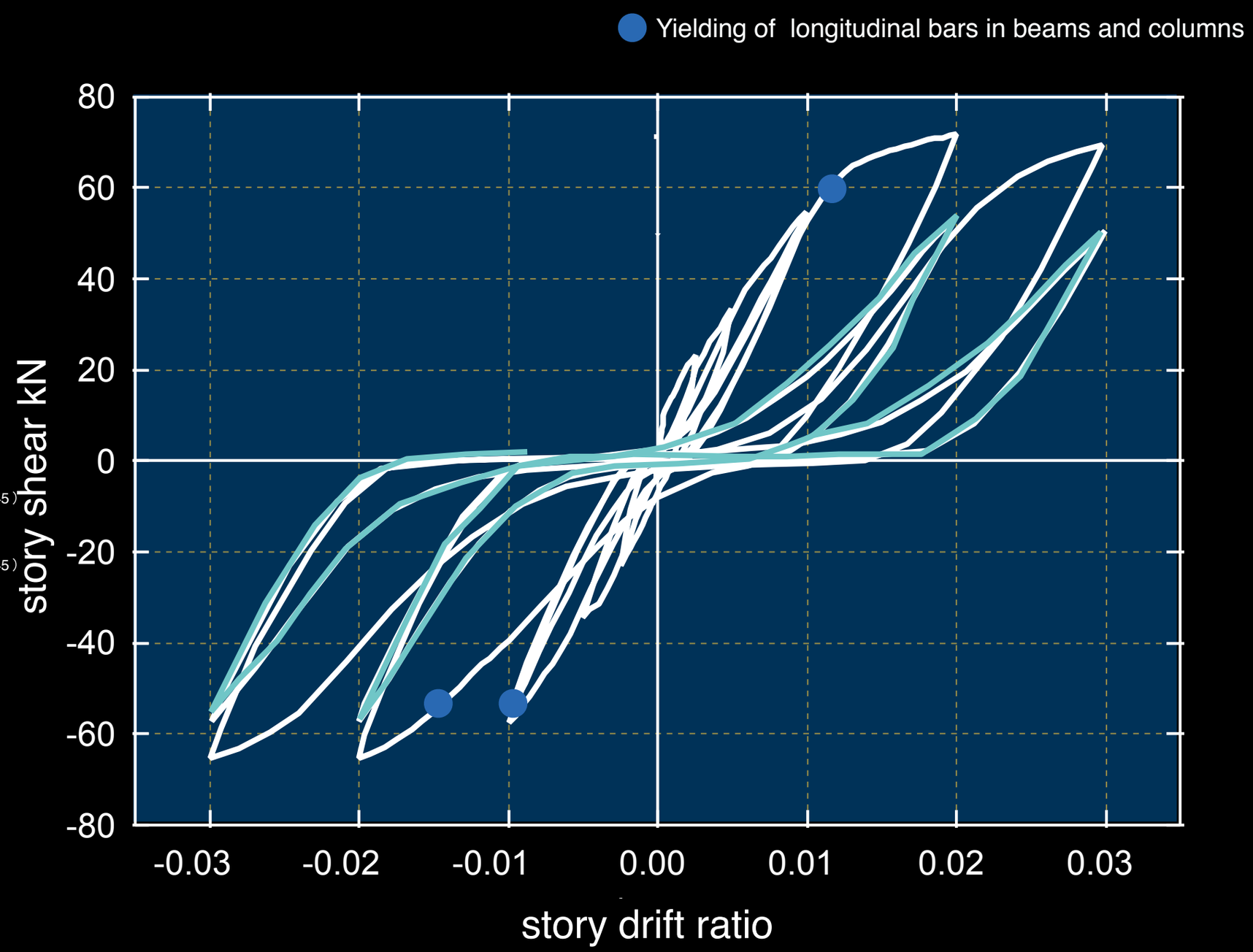
b_b / b_c : 1.0 and 0.5

Common Parameters

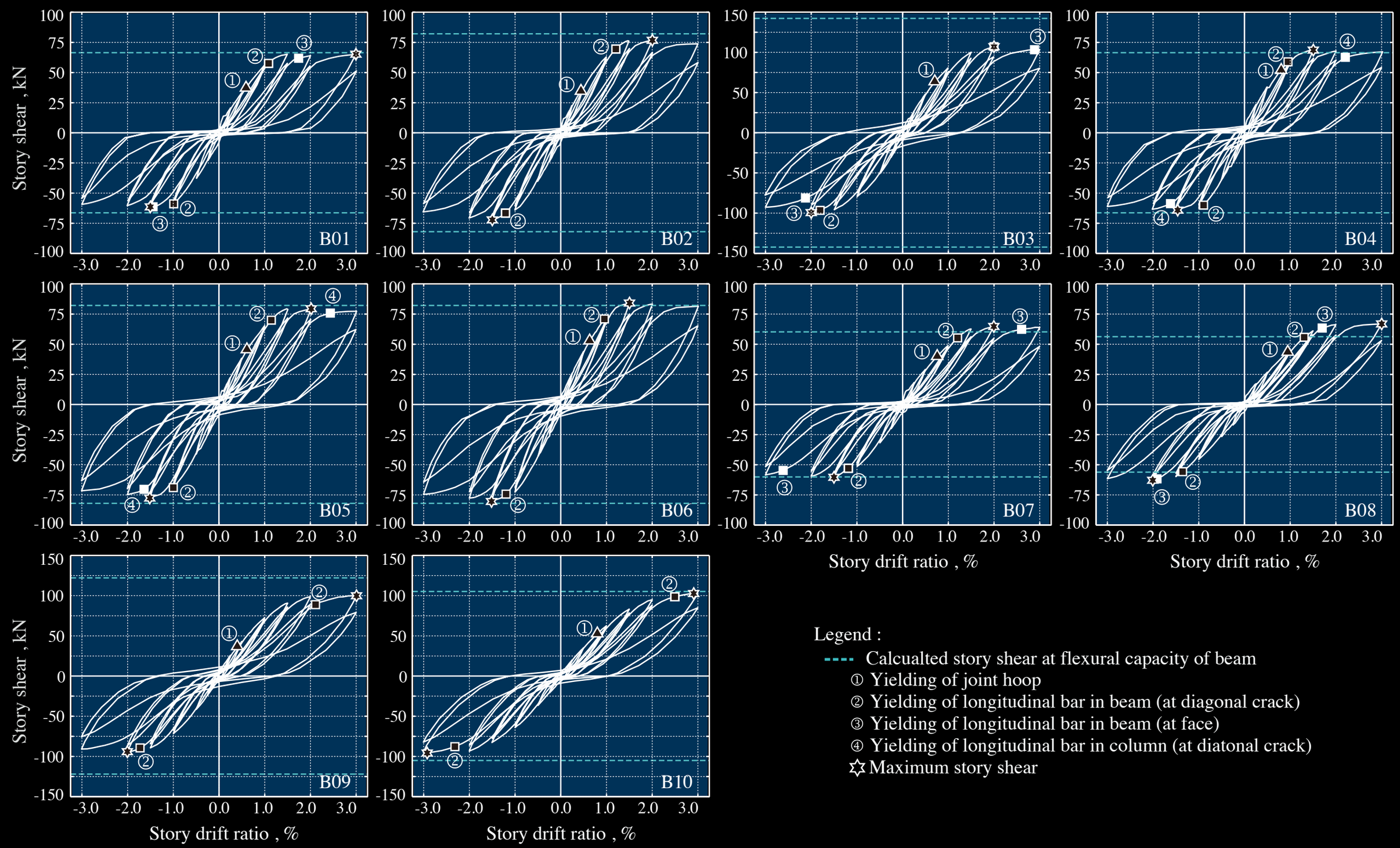
- Normal strength deformed steel bars
- Concrete strength = 30 MPa
- Beam width and column width = 240 mm
- Joint shear reinforcement = 2 sets of D6 rectangular hoop
- Column axial load = 0 kN

Typical Test Result





Story shear-story drift relationships



Series B

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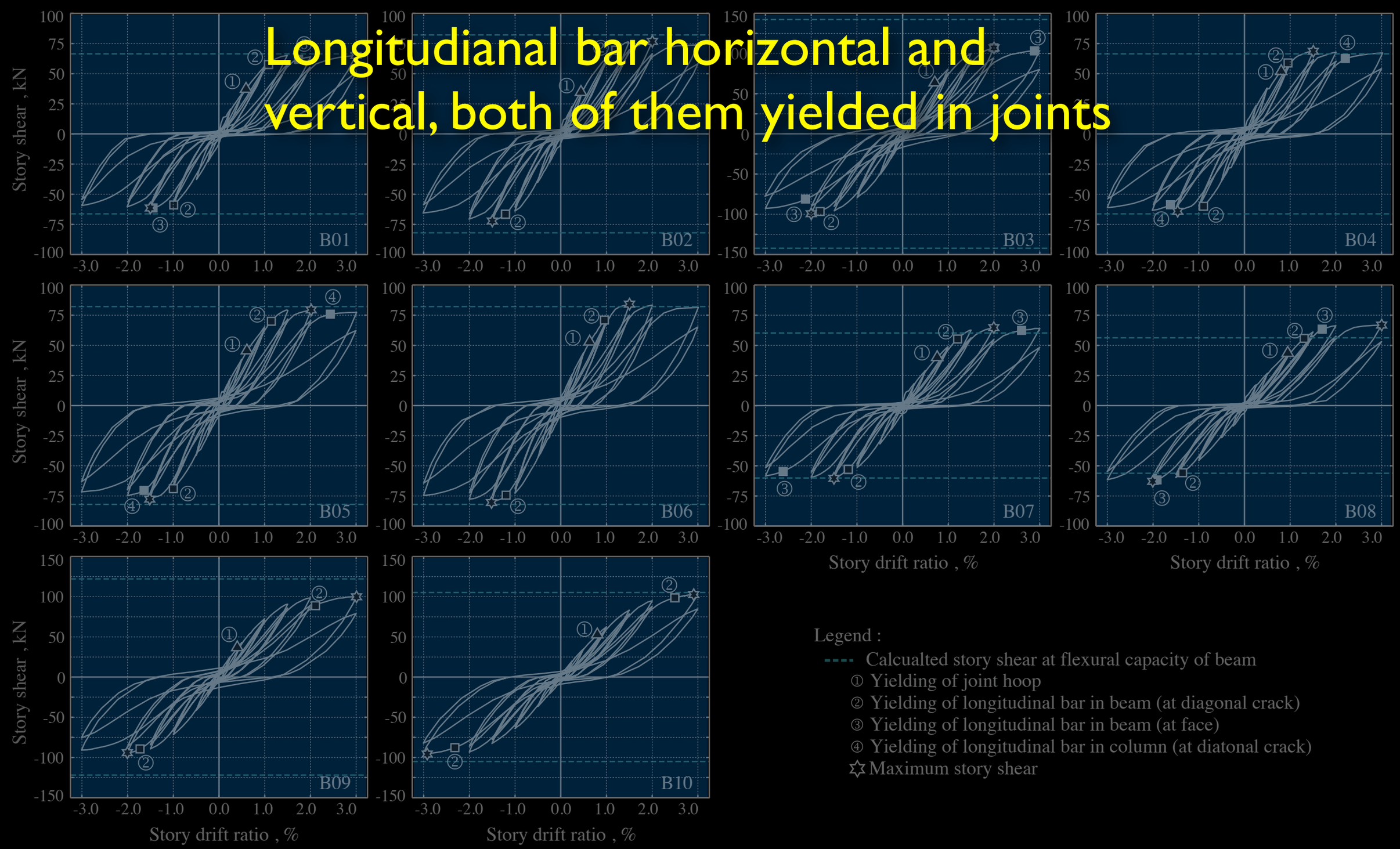

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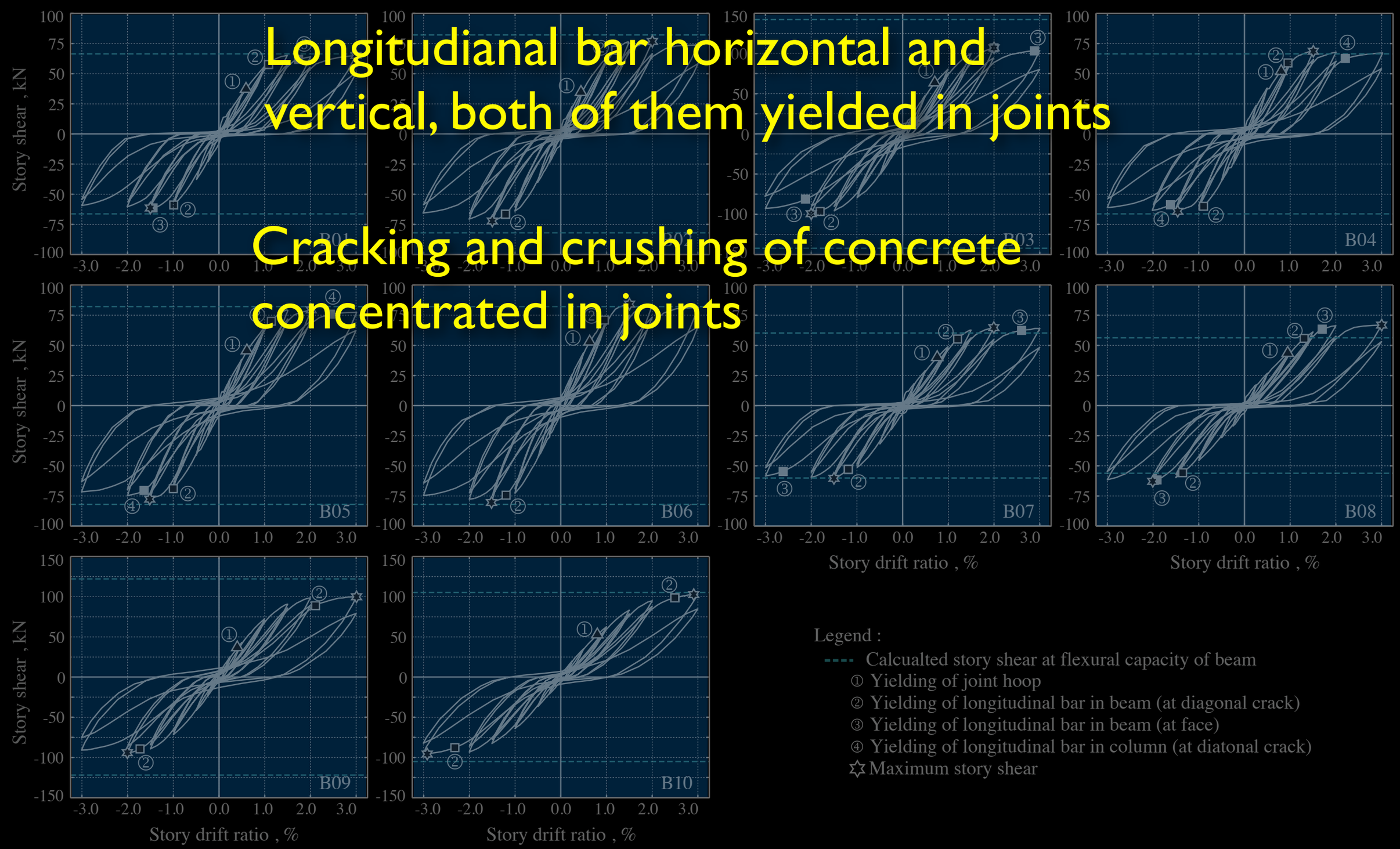

Longitudianal bar horizontal and vertical, both of them yielded in joints

Cracking and crushing of concrete concentrated in joints

Series B

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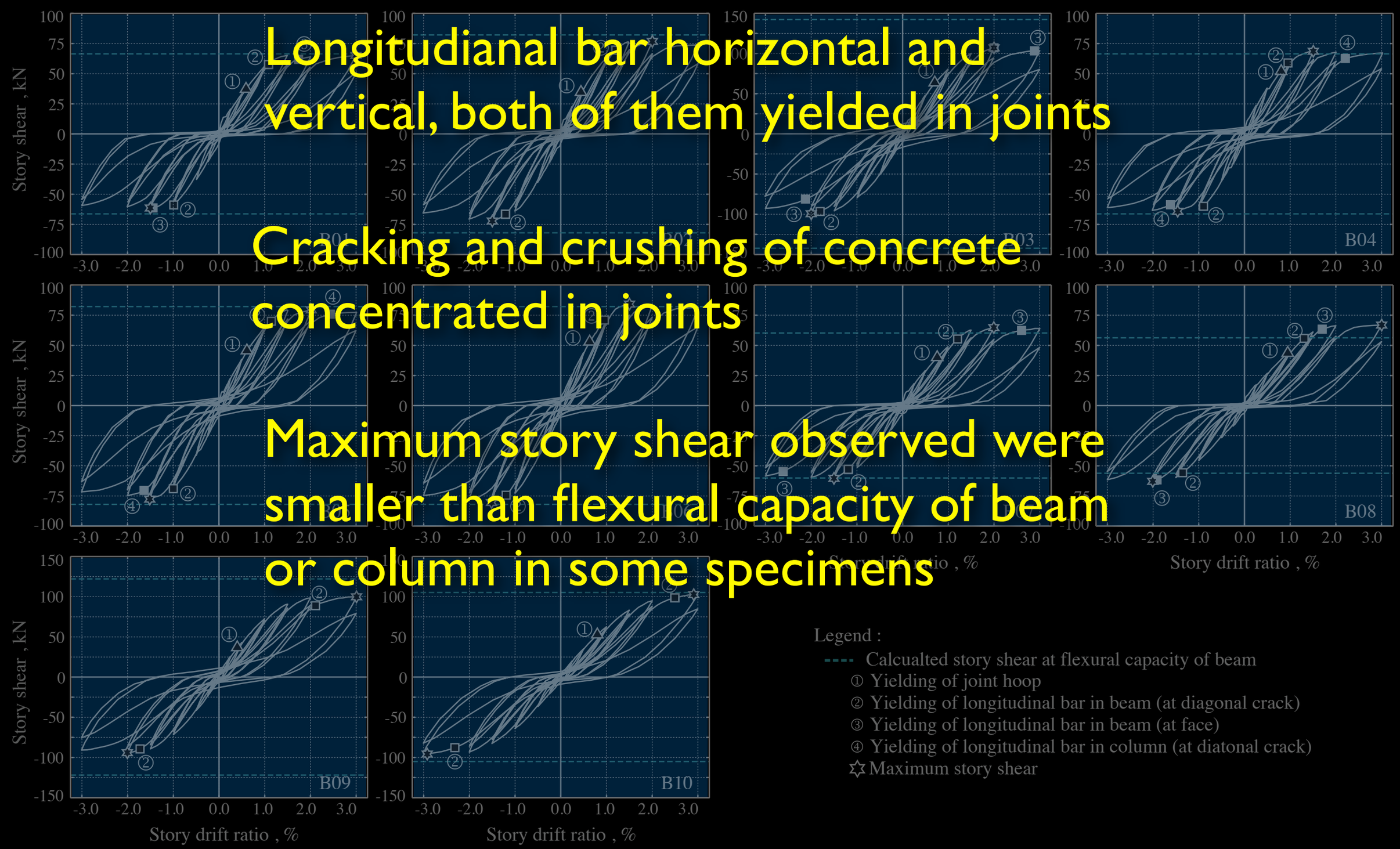

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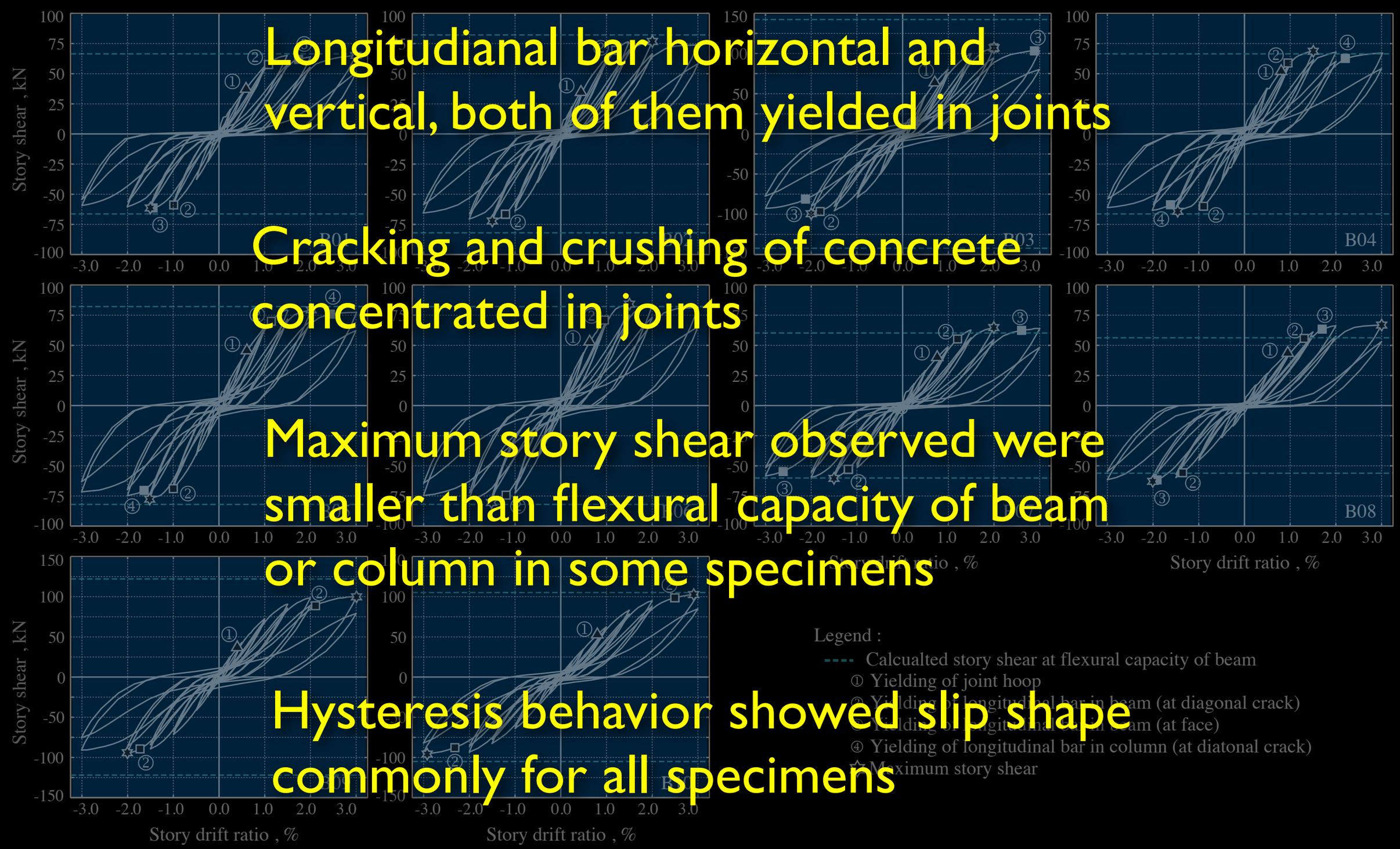

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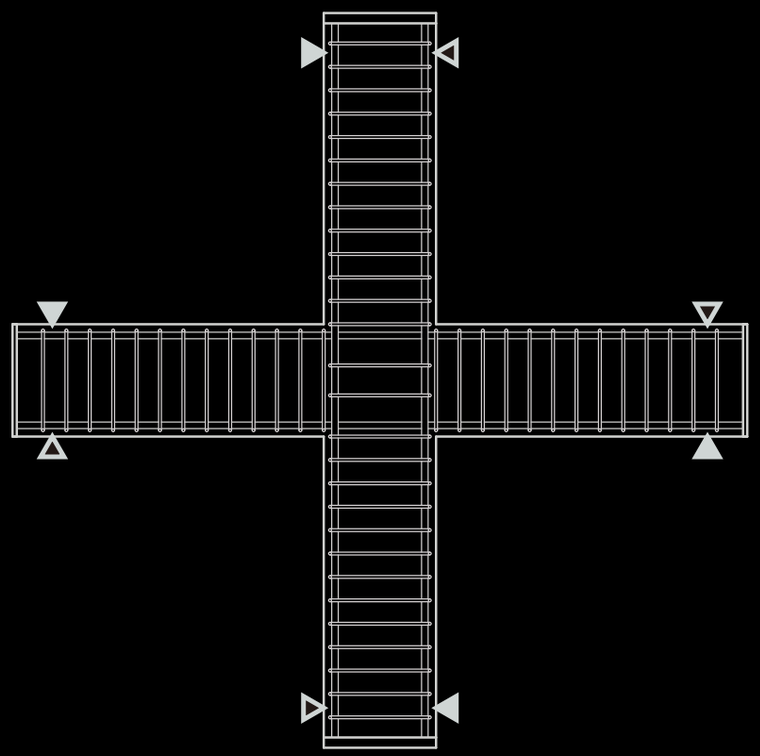
Series B

Evaluation of Current Design Equations



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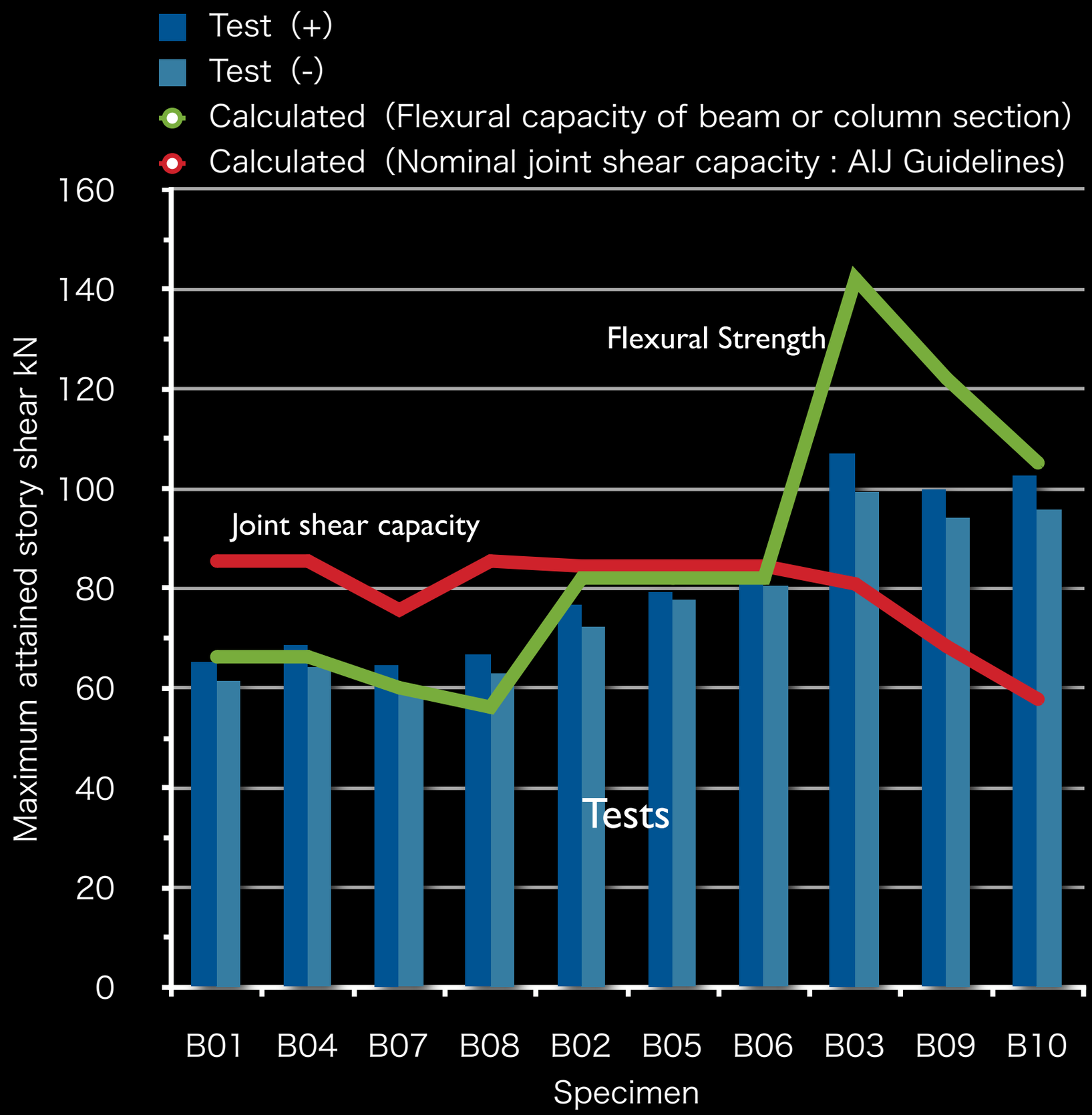

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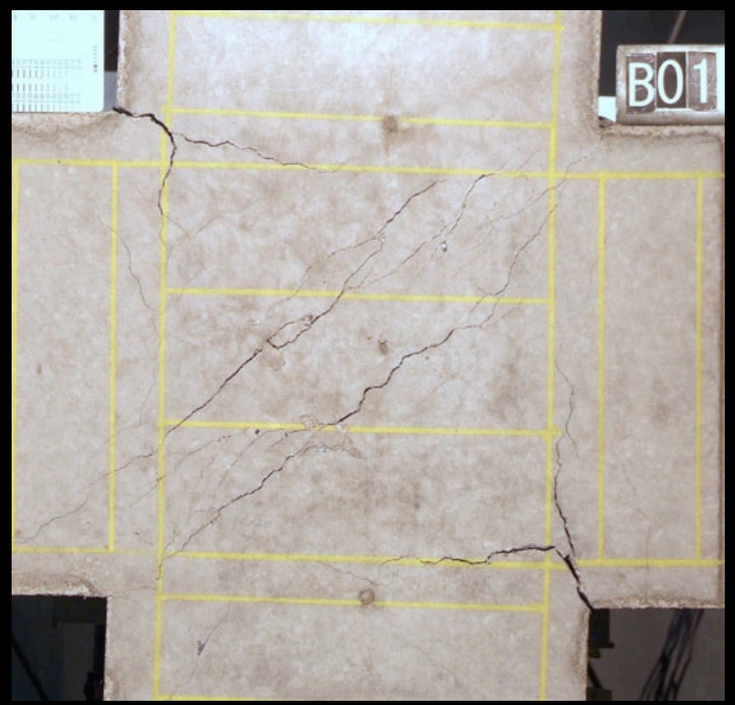

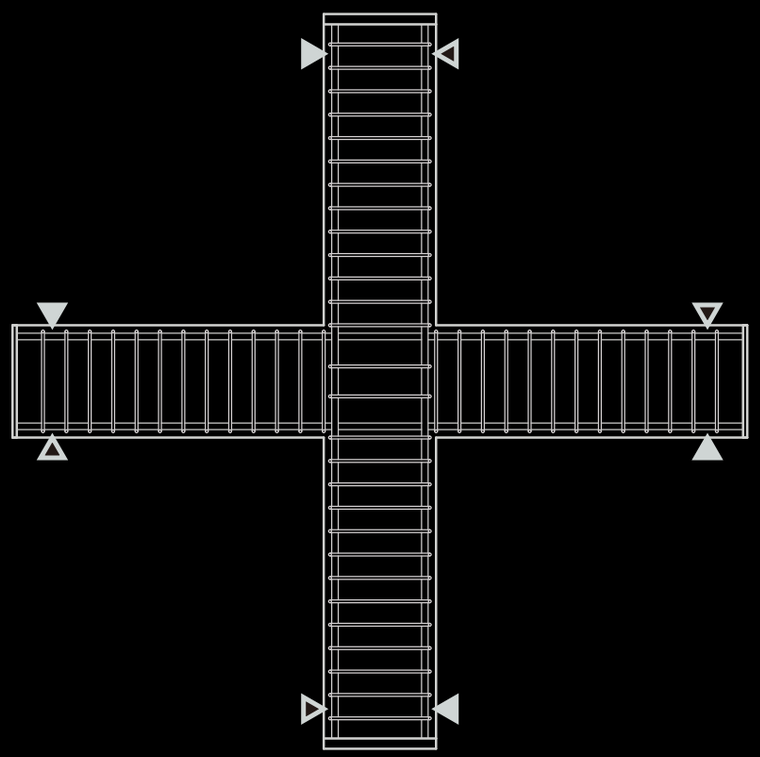

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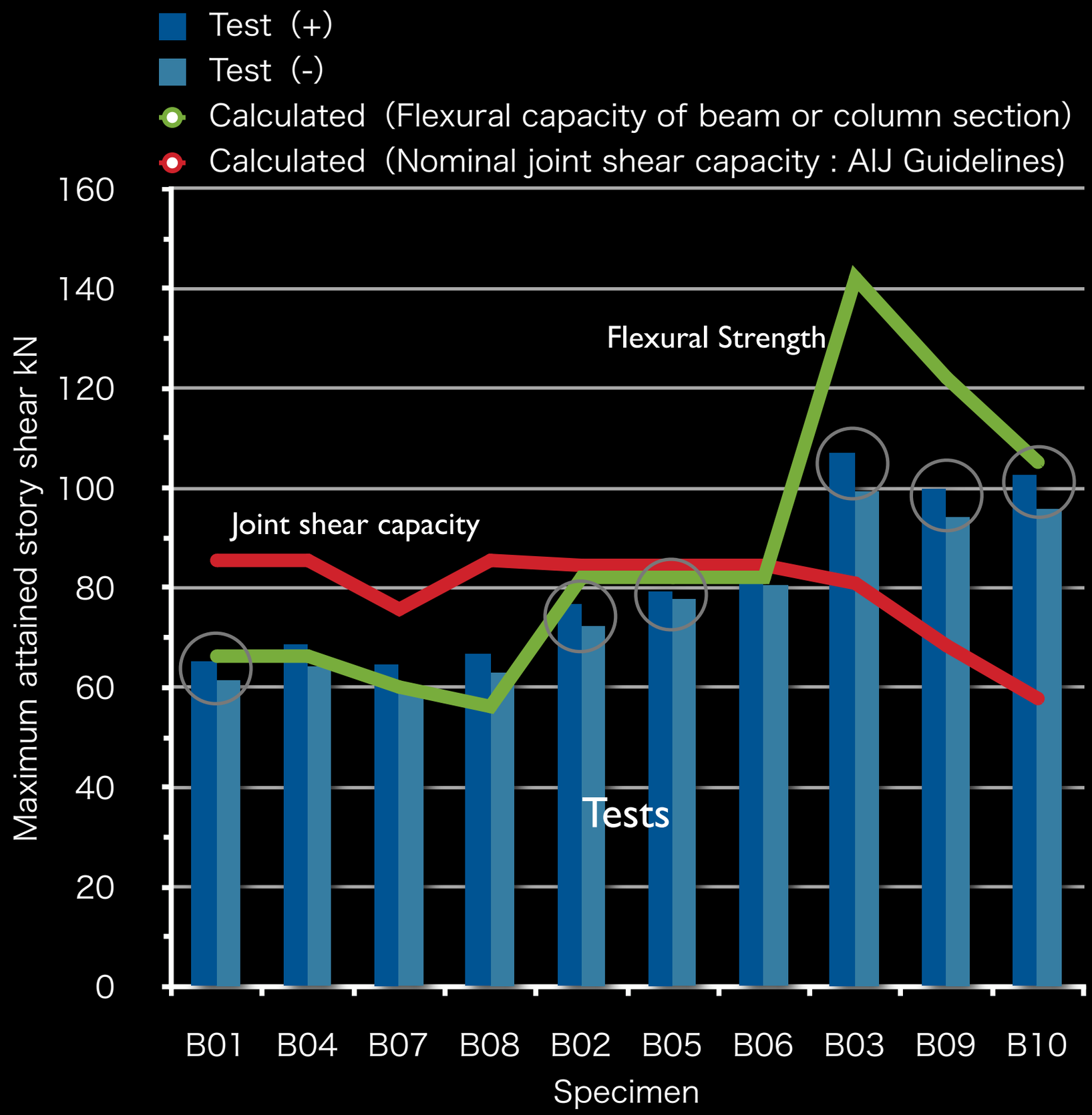

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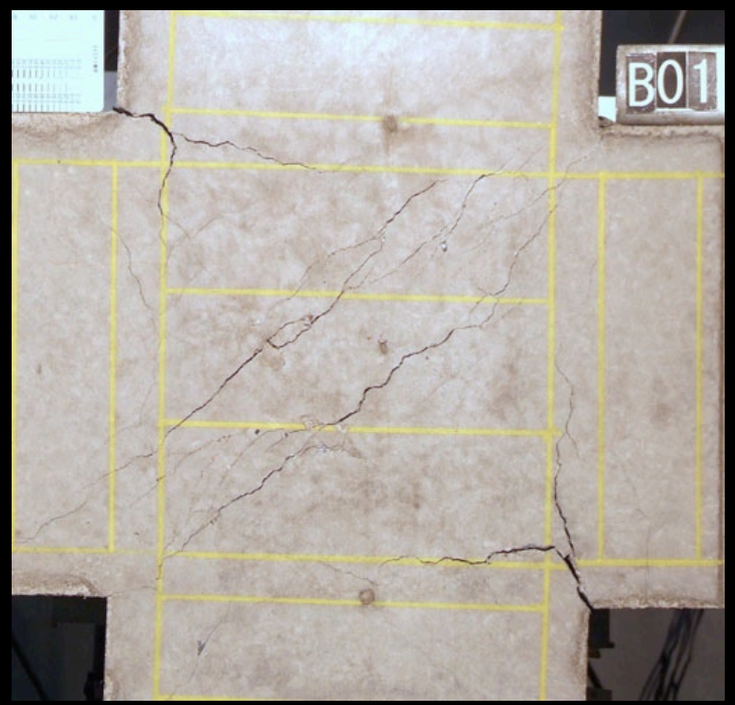

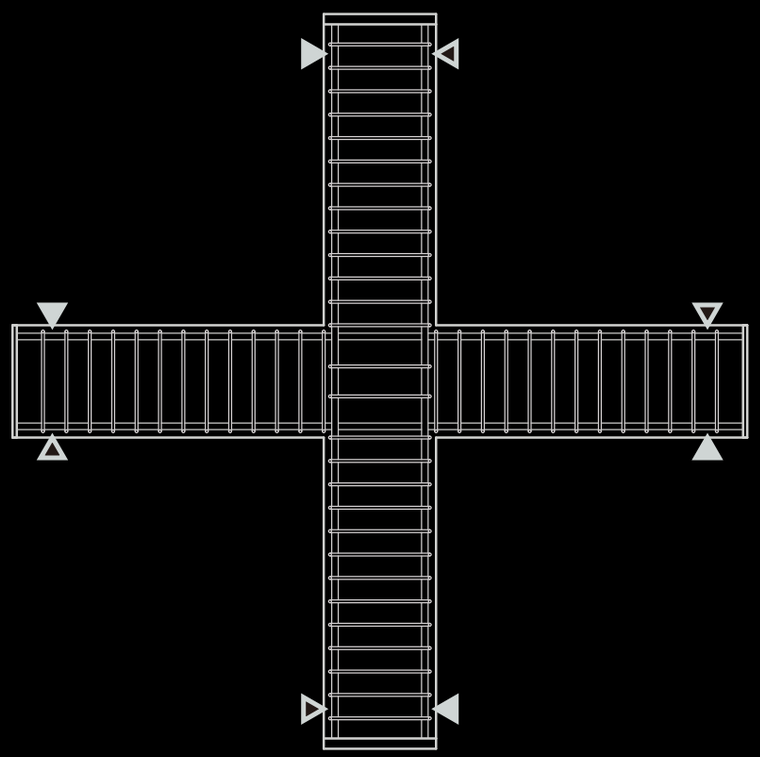

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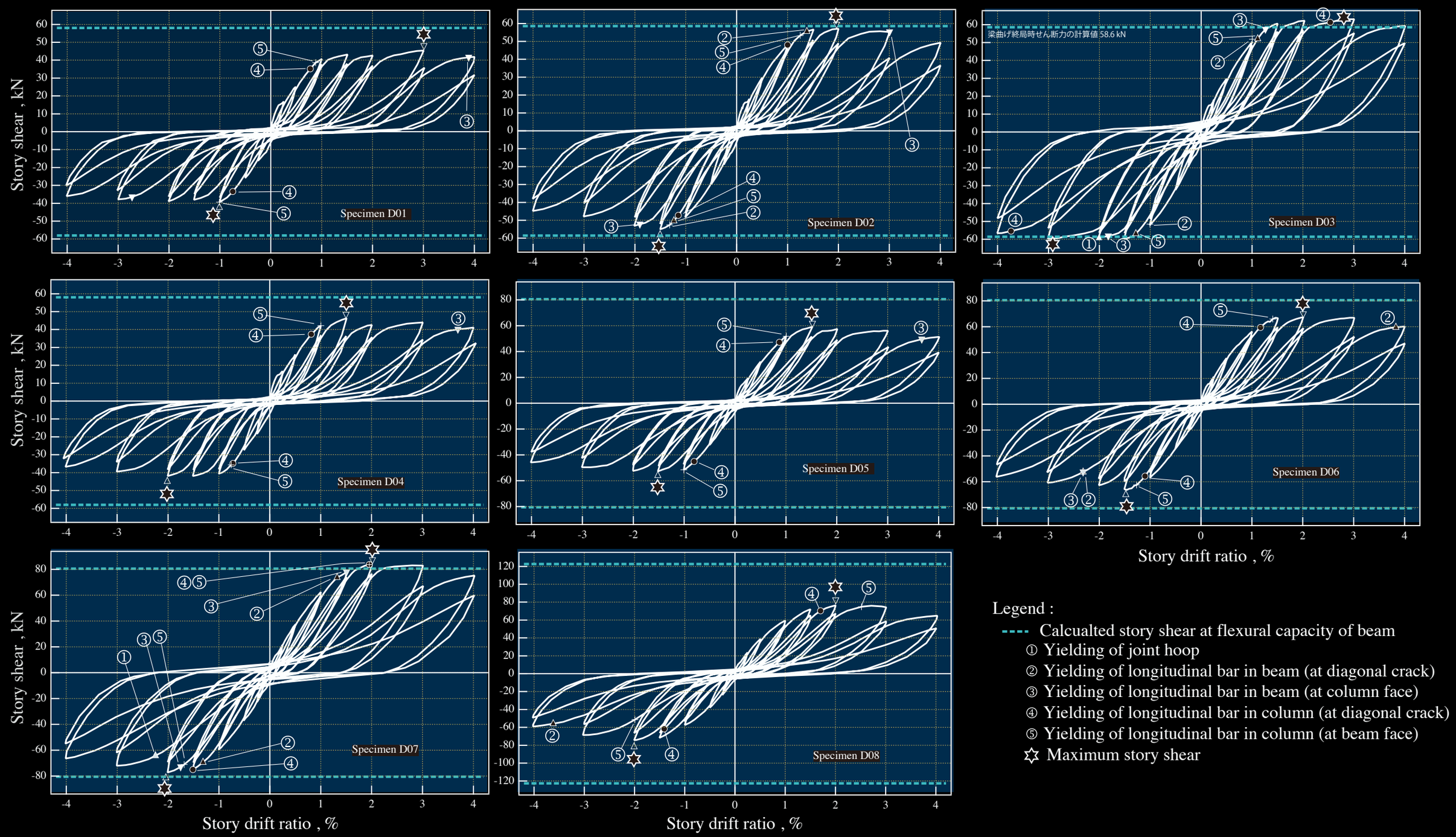
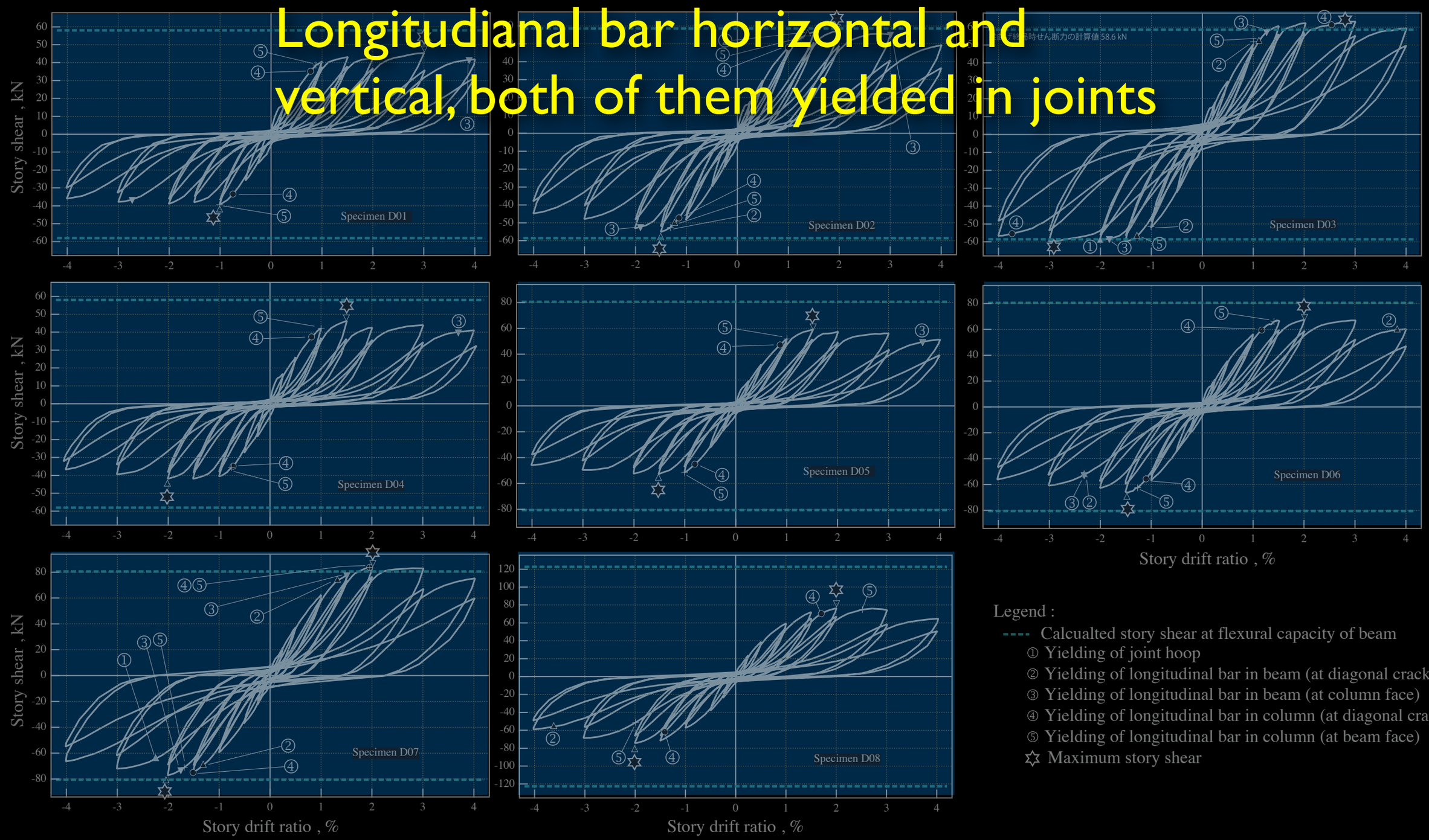


Series D

Story shear-story drift relationships

Longitudianal bar horizontal and vertical, both of them yielded in joints



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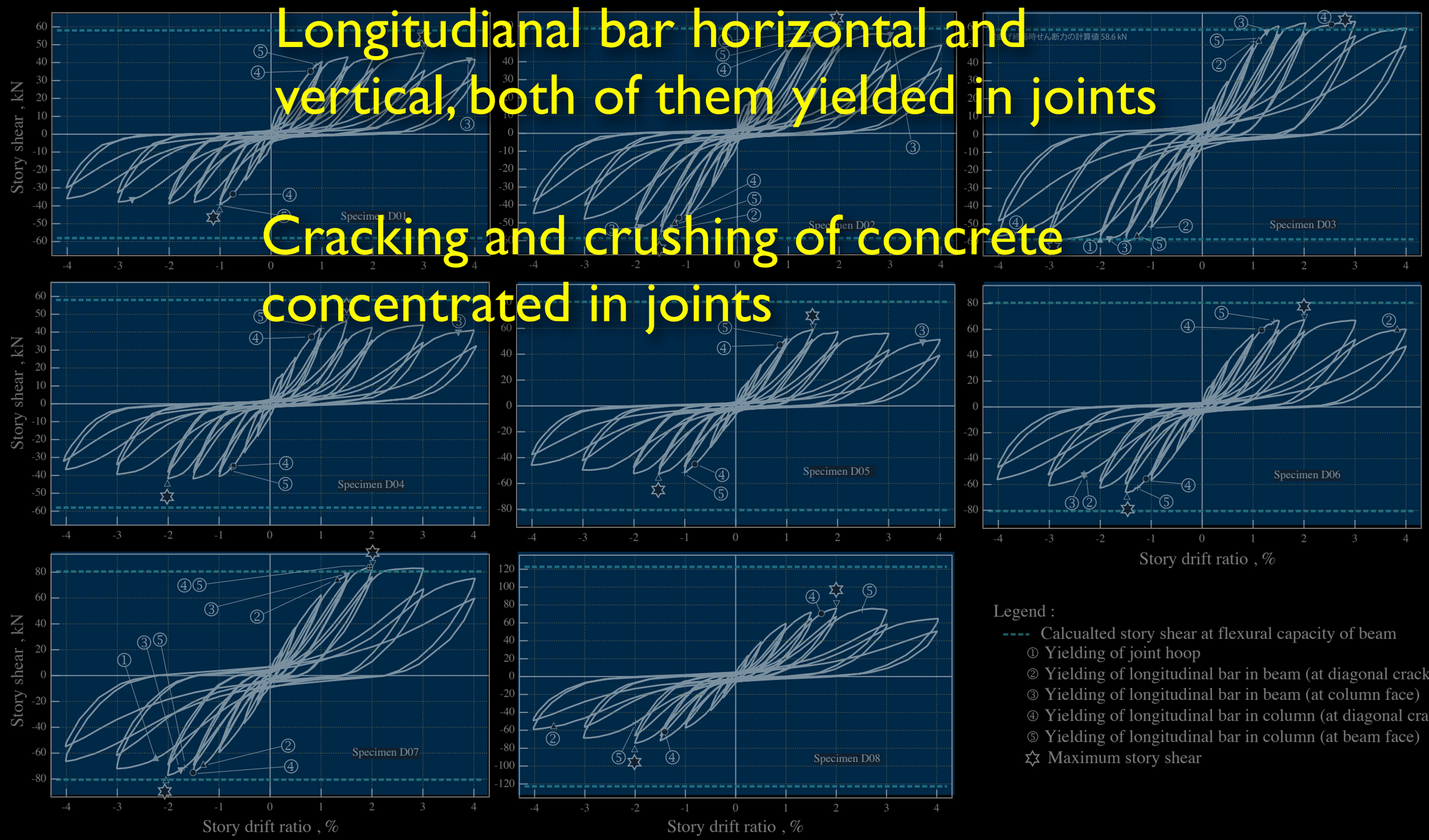

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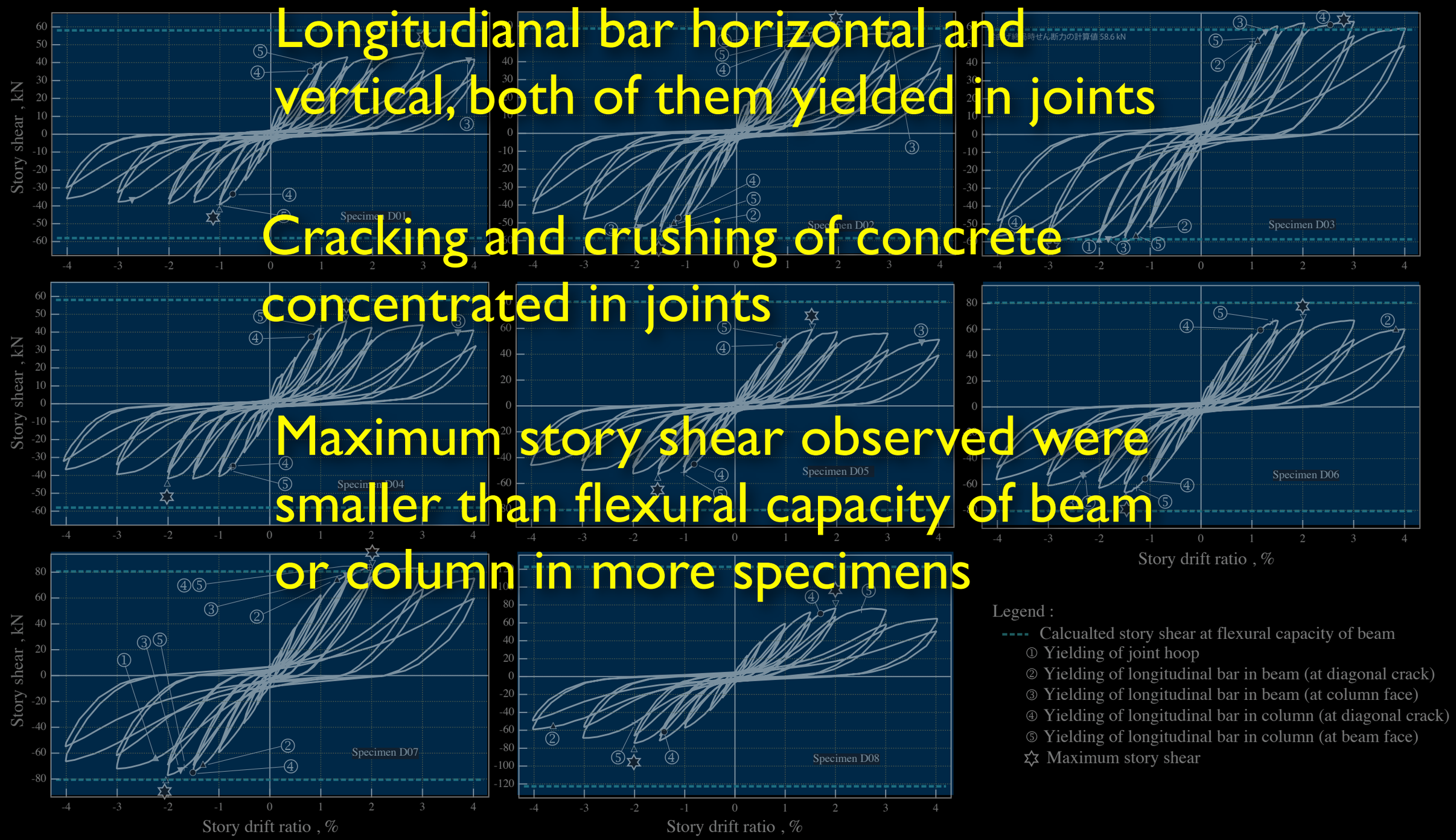

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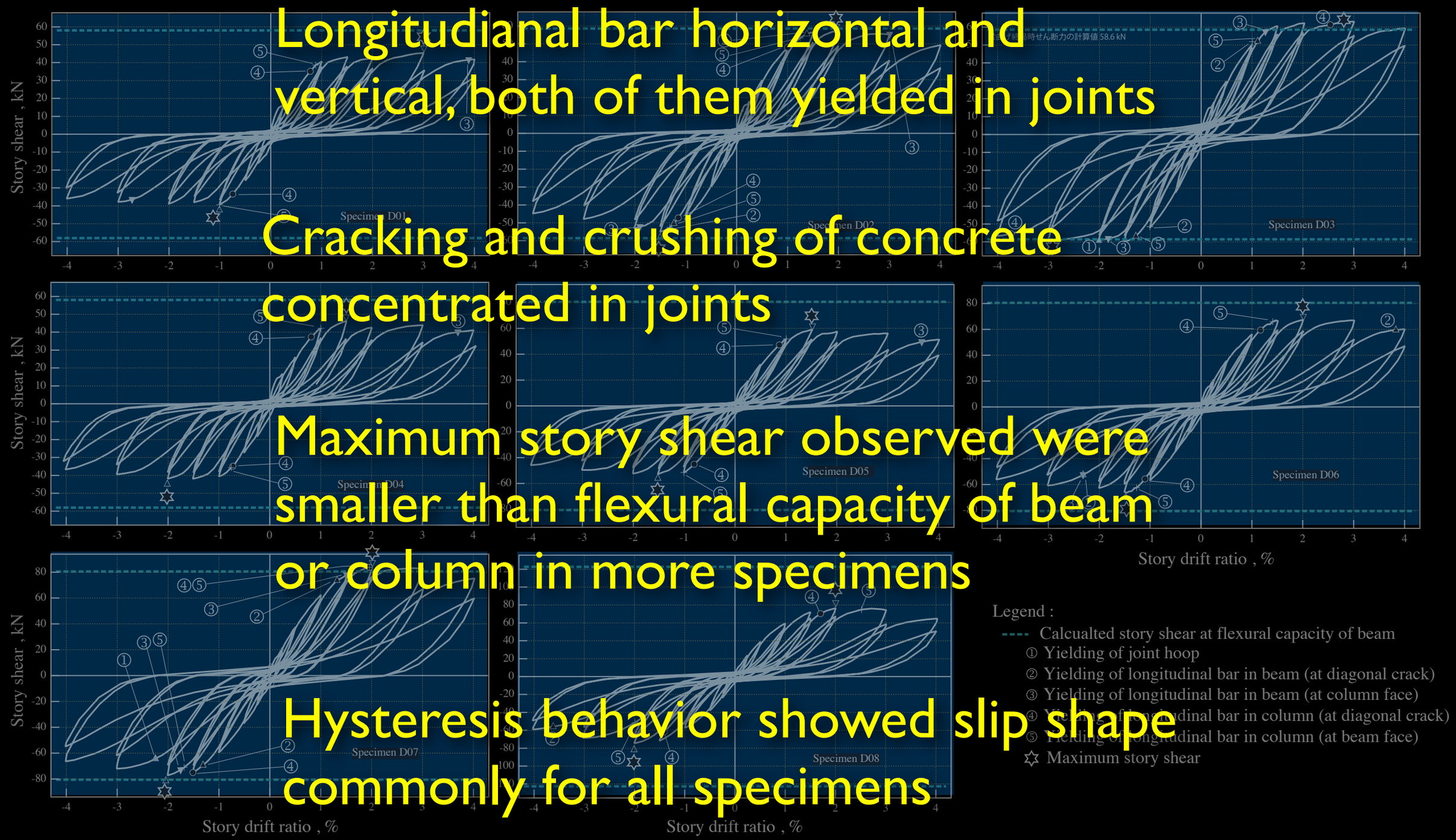

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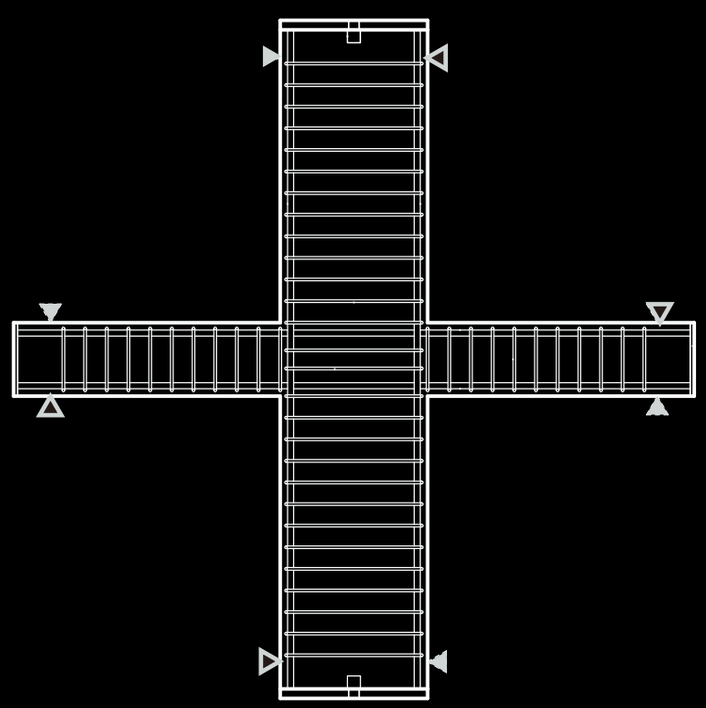

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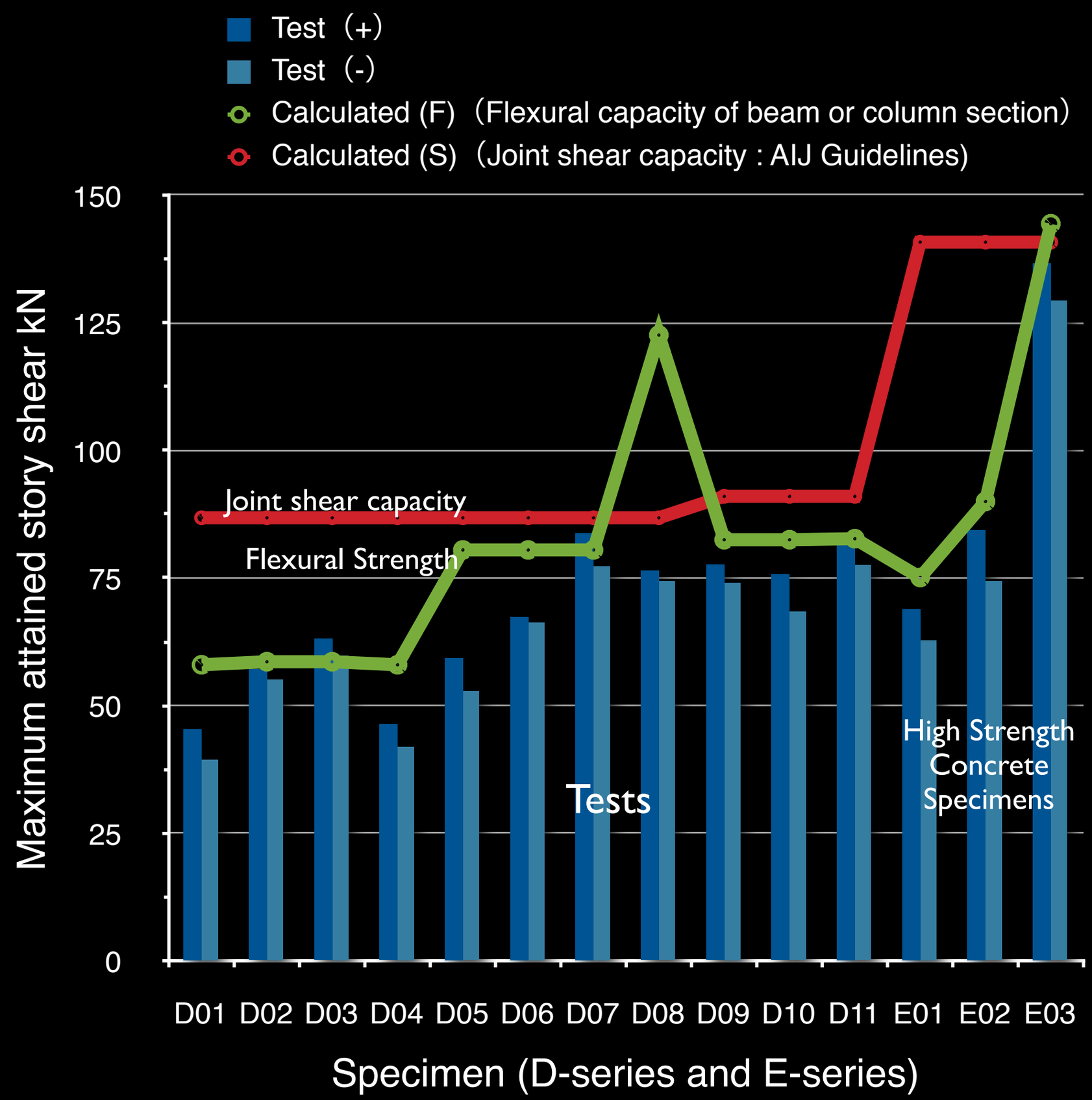

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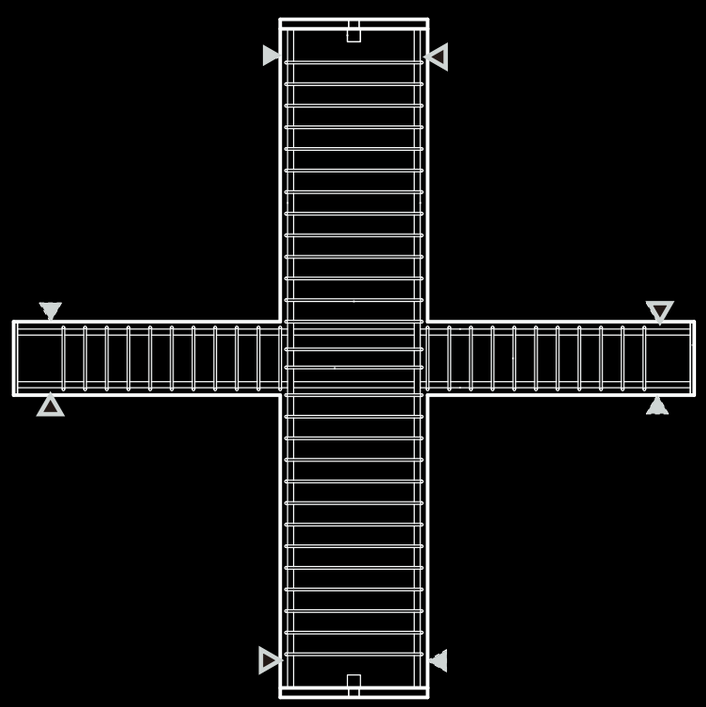

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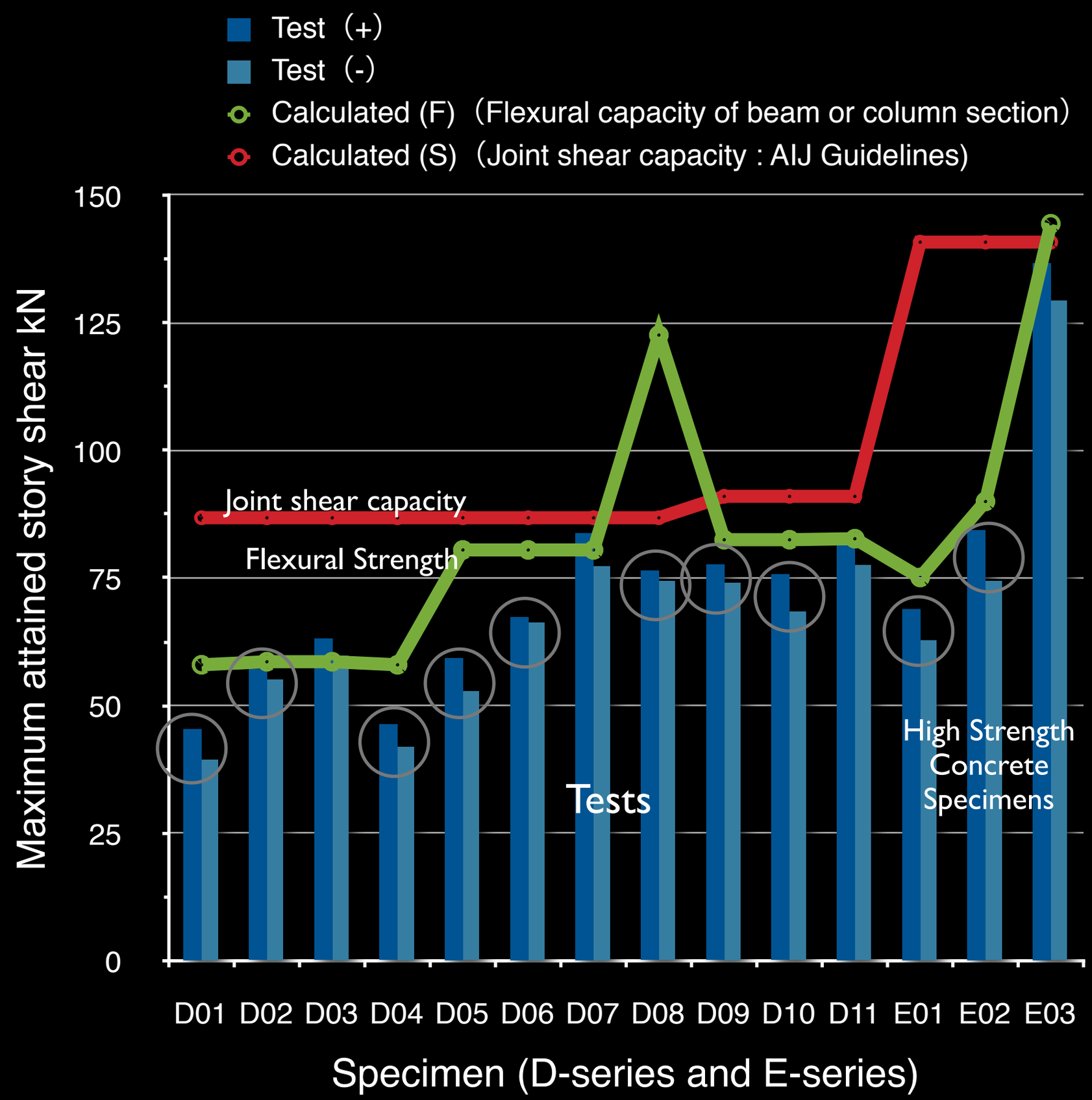

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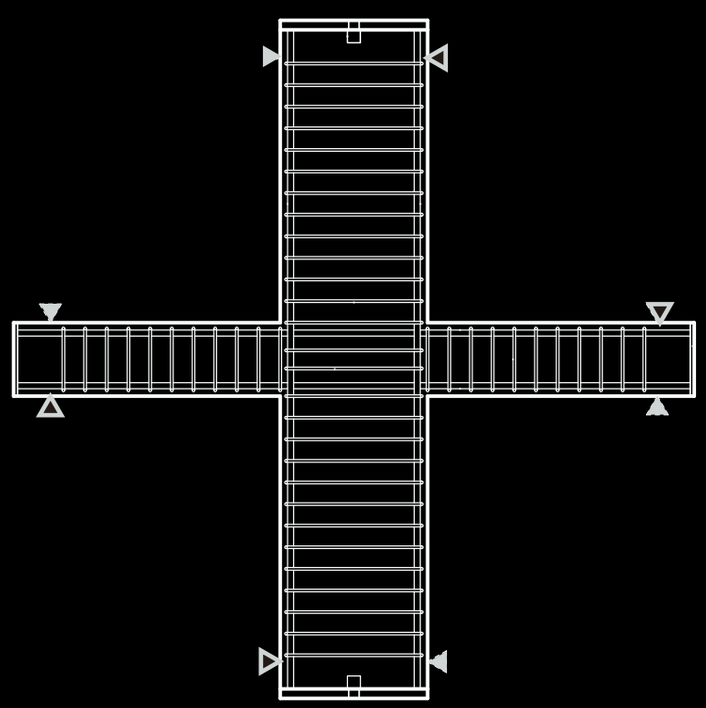

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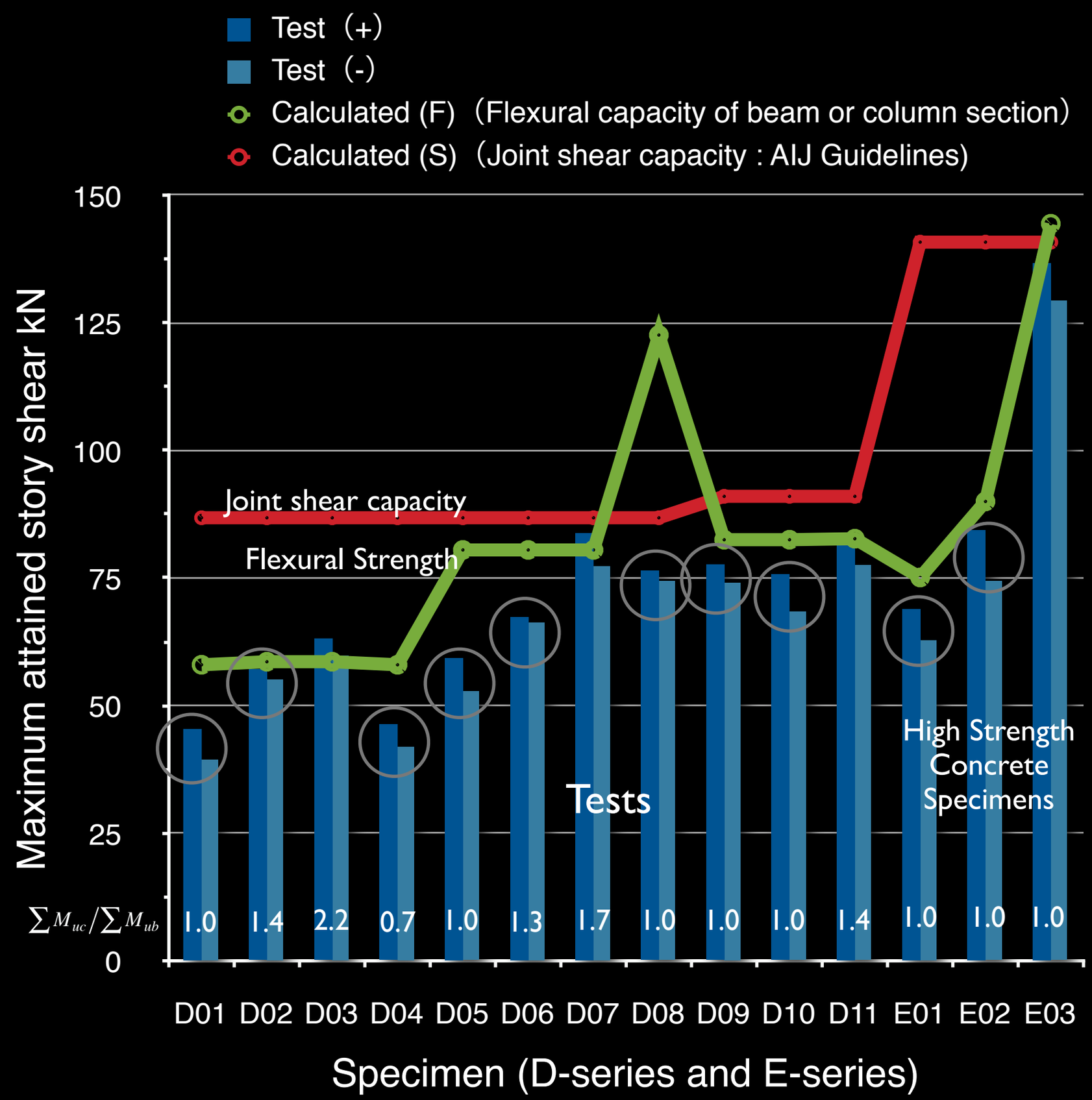
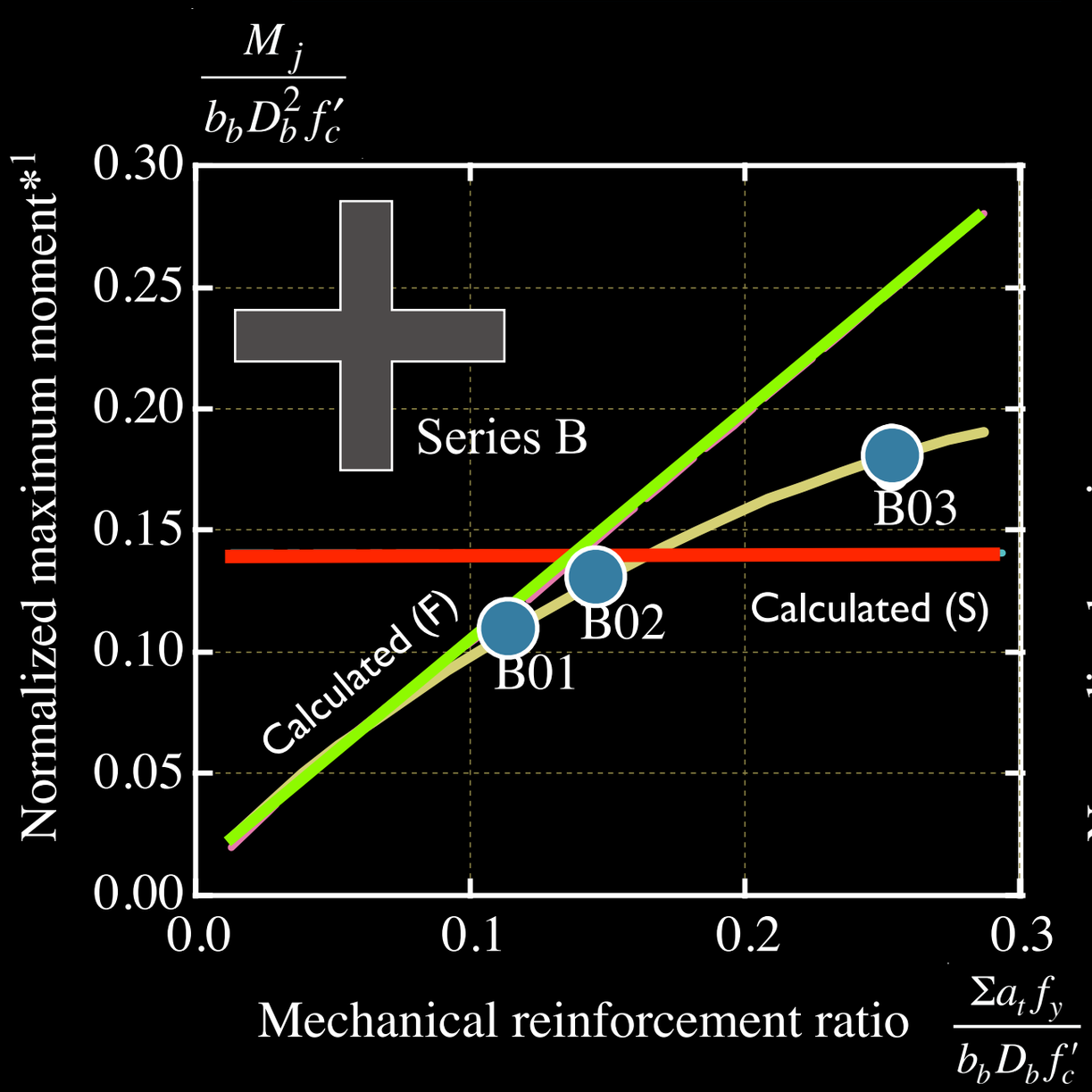
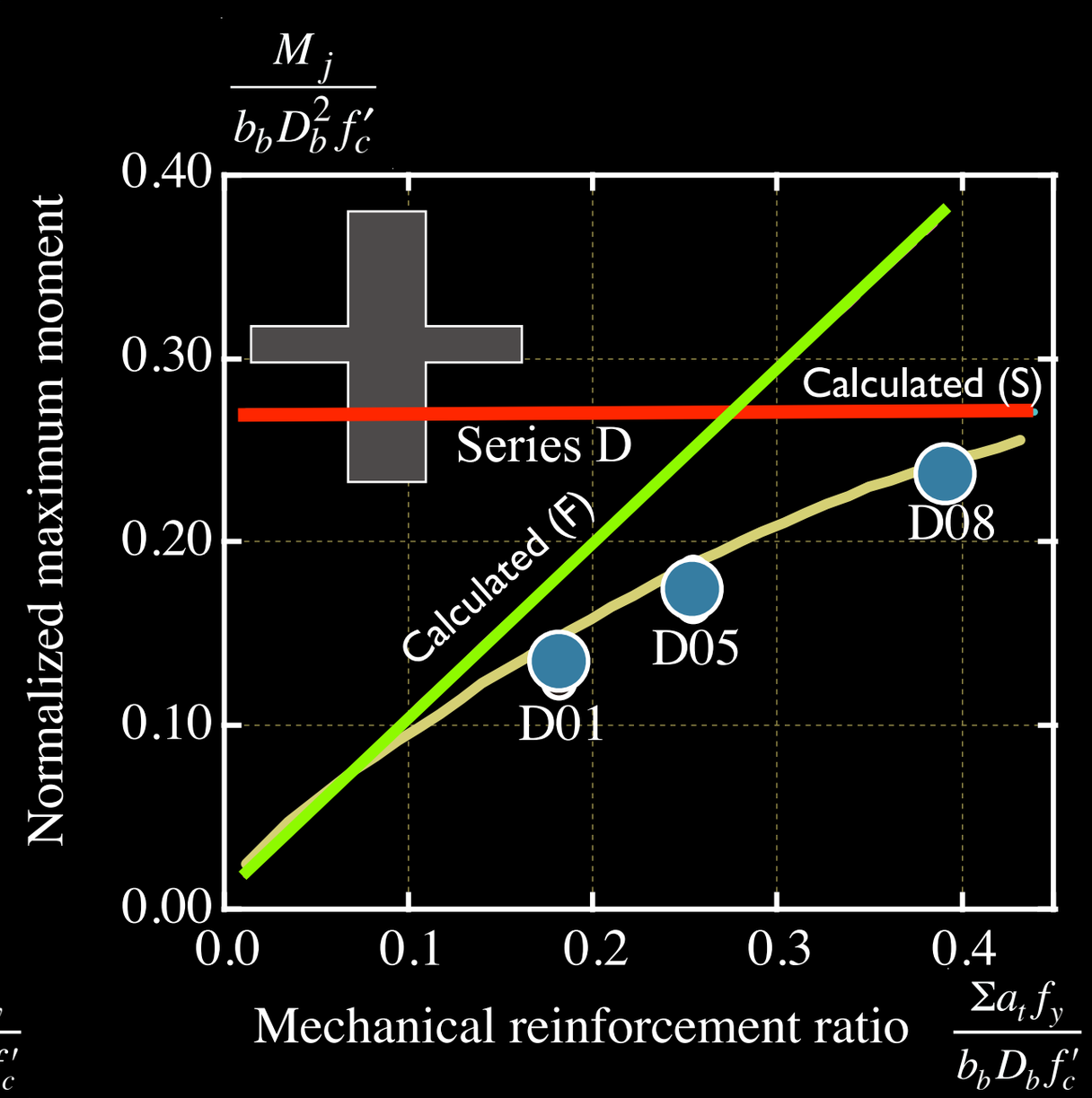


Mechanical Reinforcement Ratio and Strength

$$\sum M_{uc} / \sum M_{ub} = 1.0$$

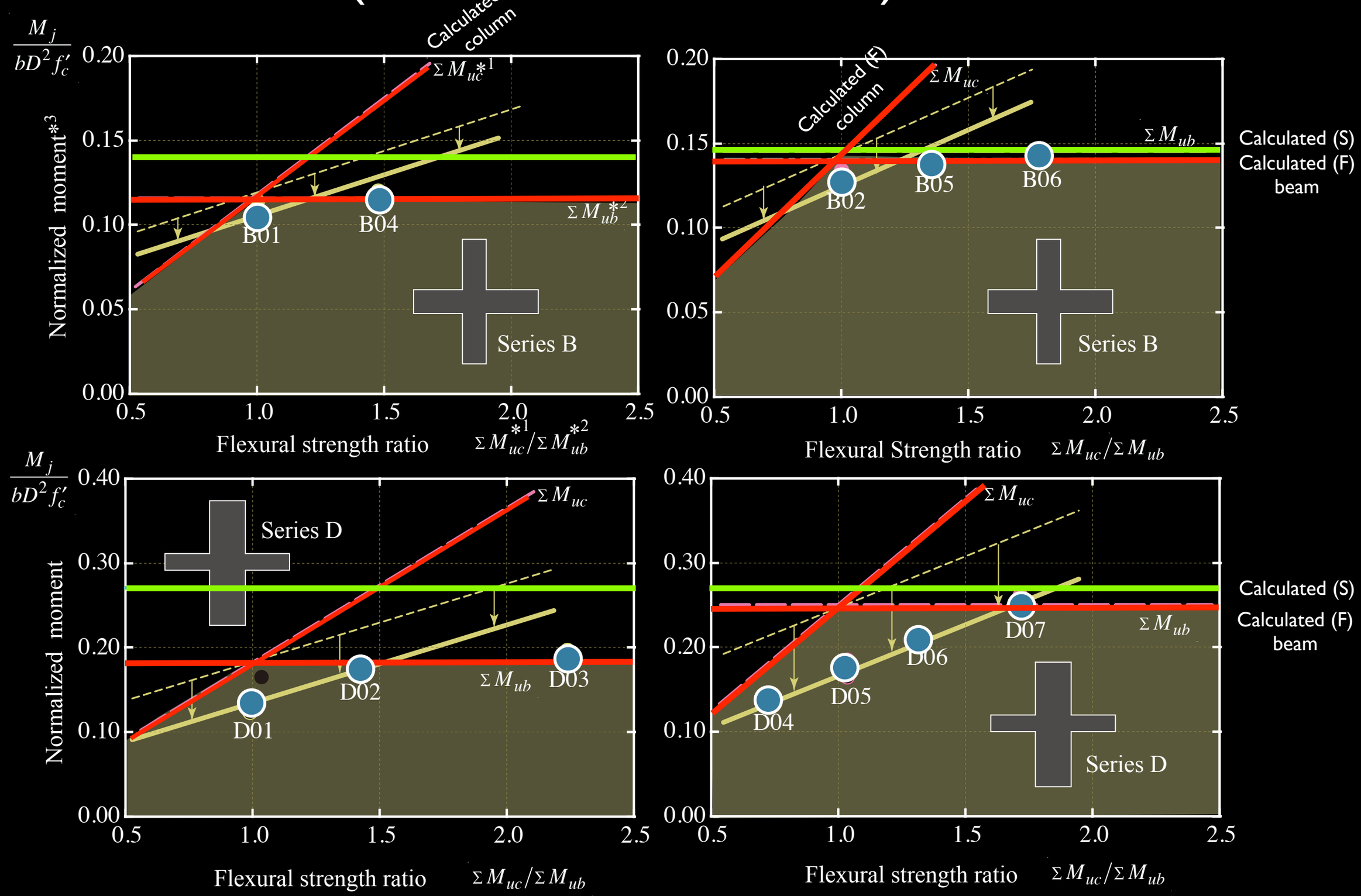




Nominal joint shear strength

Flexural strength of section

Flexural Strengths Ratio (Beam vs. Column)



Summary of Test Results

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- Maximum story shear of some specimens are smaller 5% to 30% than the story shear calculated by the flexural strength of the beam or the column

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- Those joints are conformed to current seismic provision, i.e. they have safety margin of the nominal joint shear strength by 0% to 50%.

- The extent of insufficiency in the story shear is larger

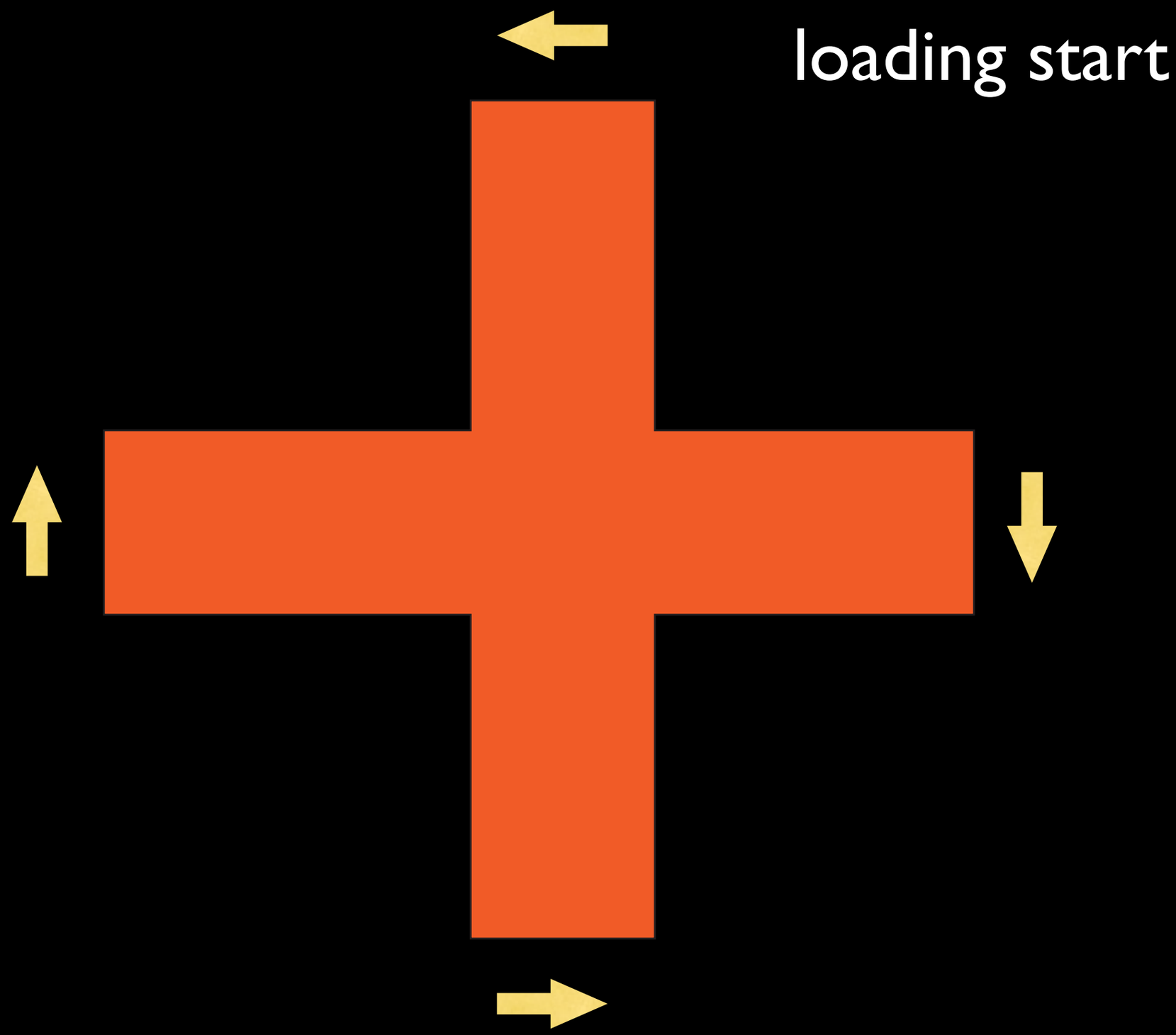
  a. if the flexural strength of the column is equal or nearer to the flexural strength of the beam, and

  b. if the depth of the column is larger than that of the beam.

Modeling of yielding of longitudinal bars in a beam-column joint

To understand the reason why the flexural theory overestimates strengths

Modeling of yielding of longitudinal bars in a beam-column joint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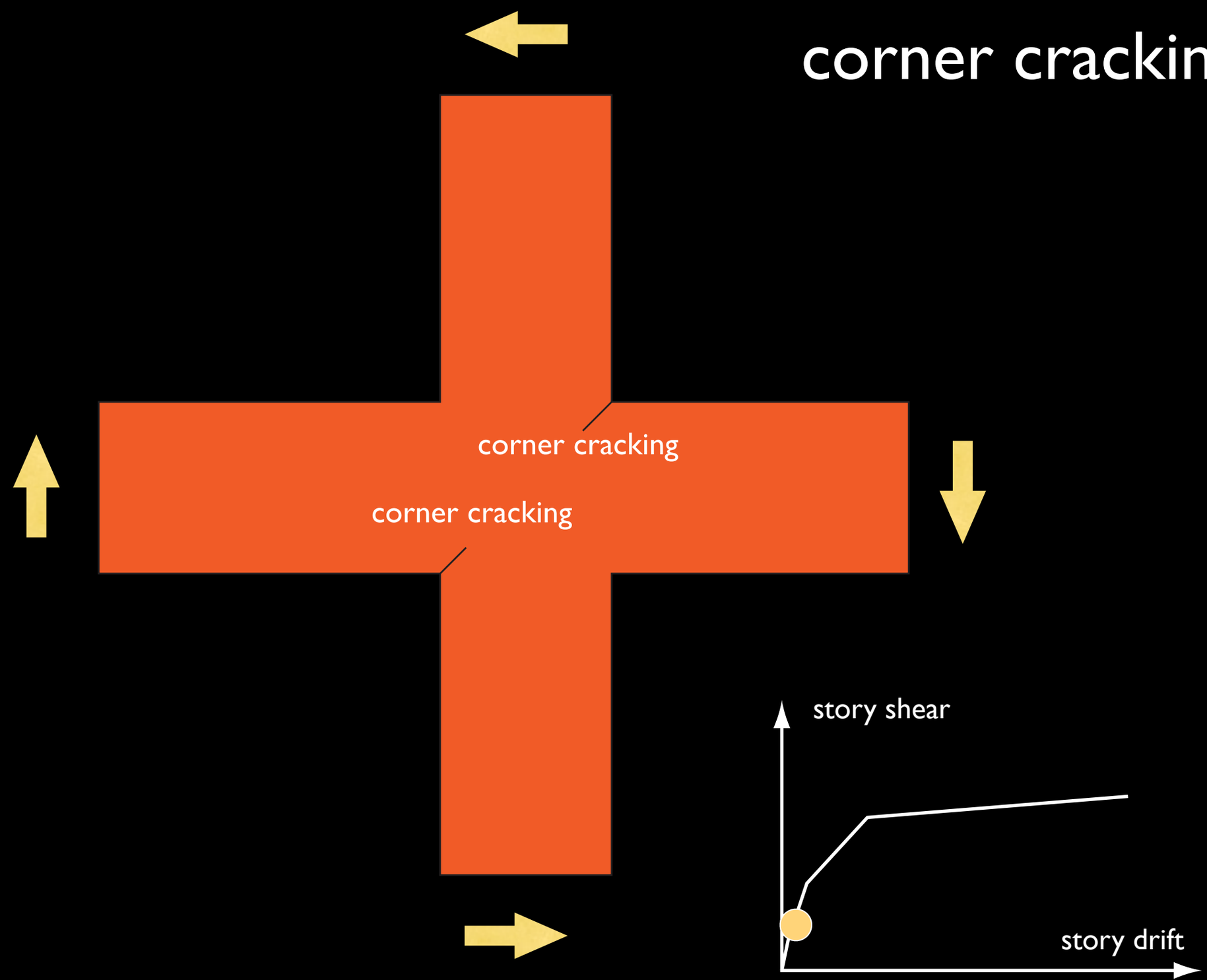
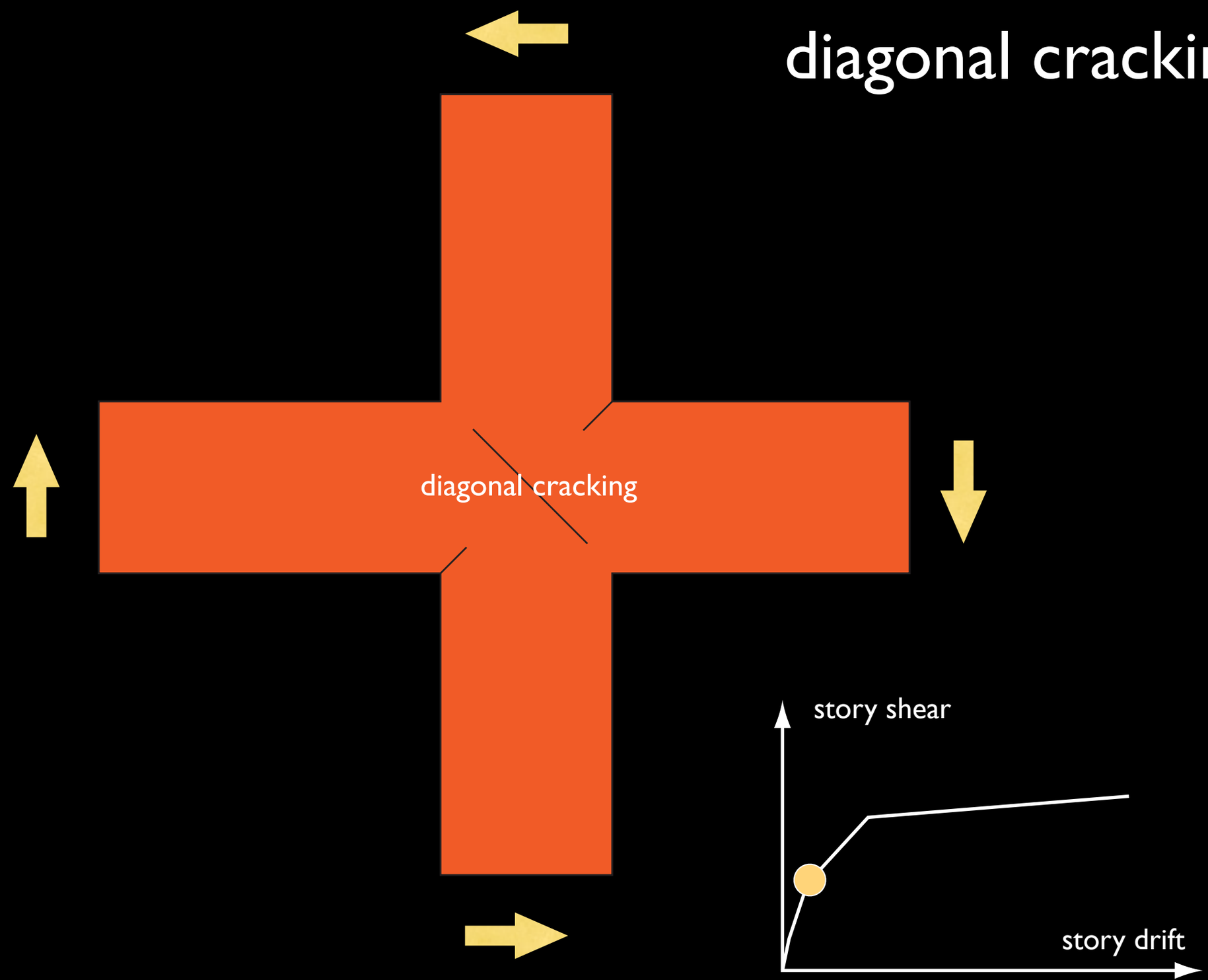
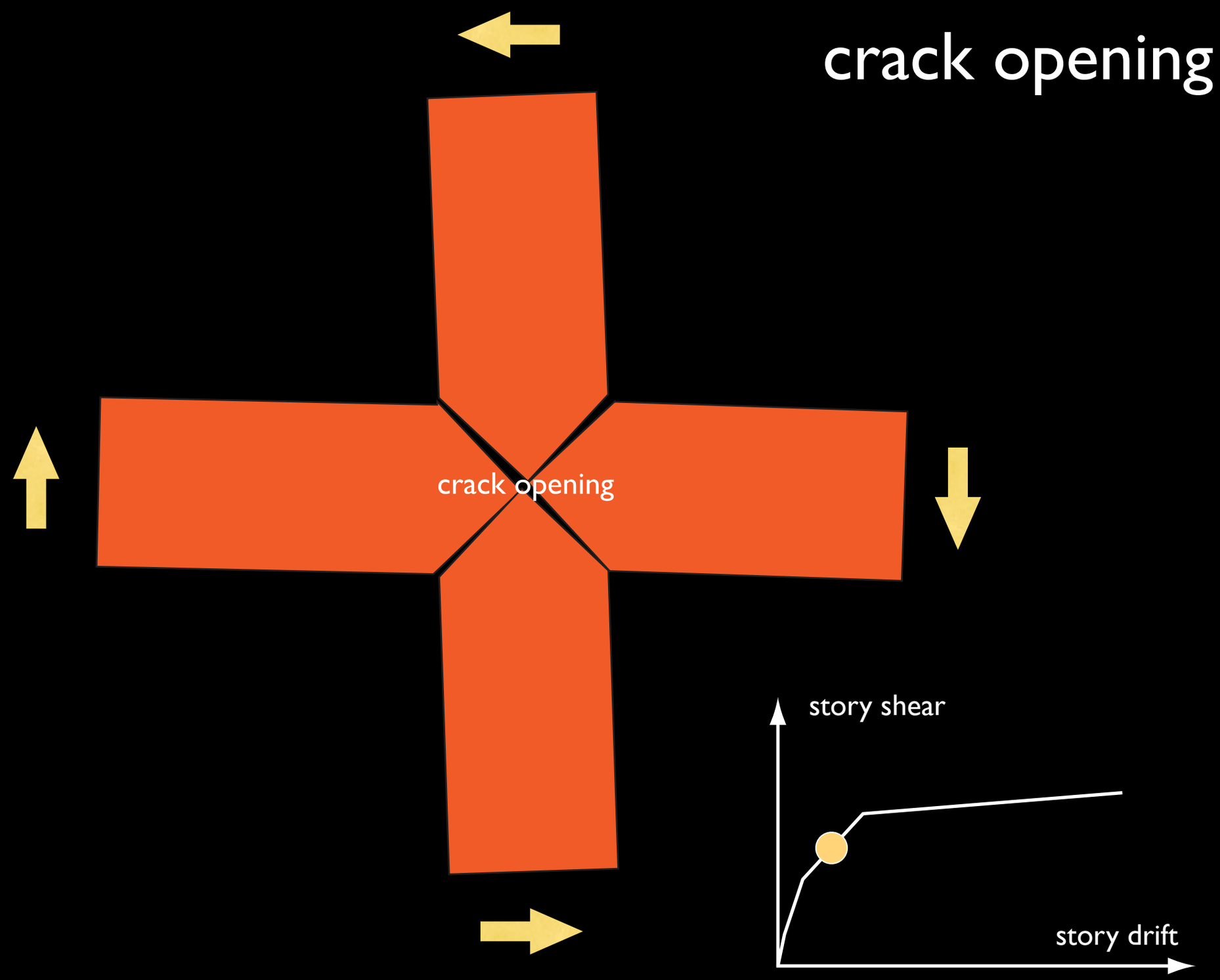
corner cracking

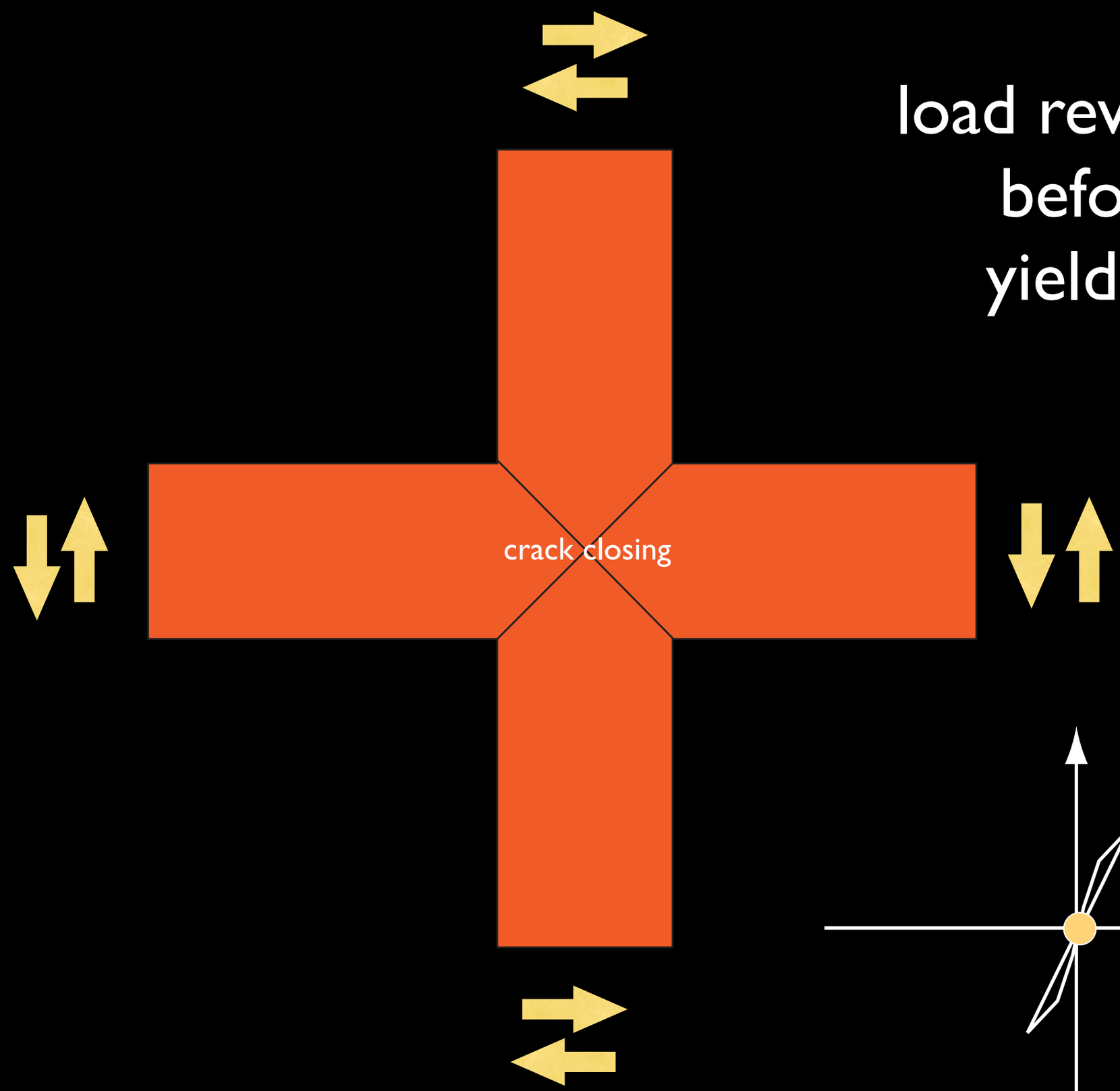


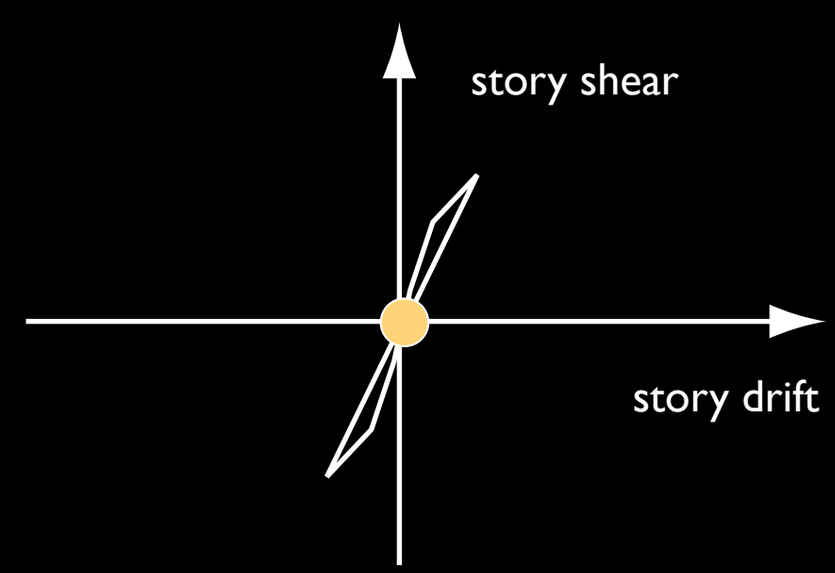
diagonal cracking

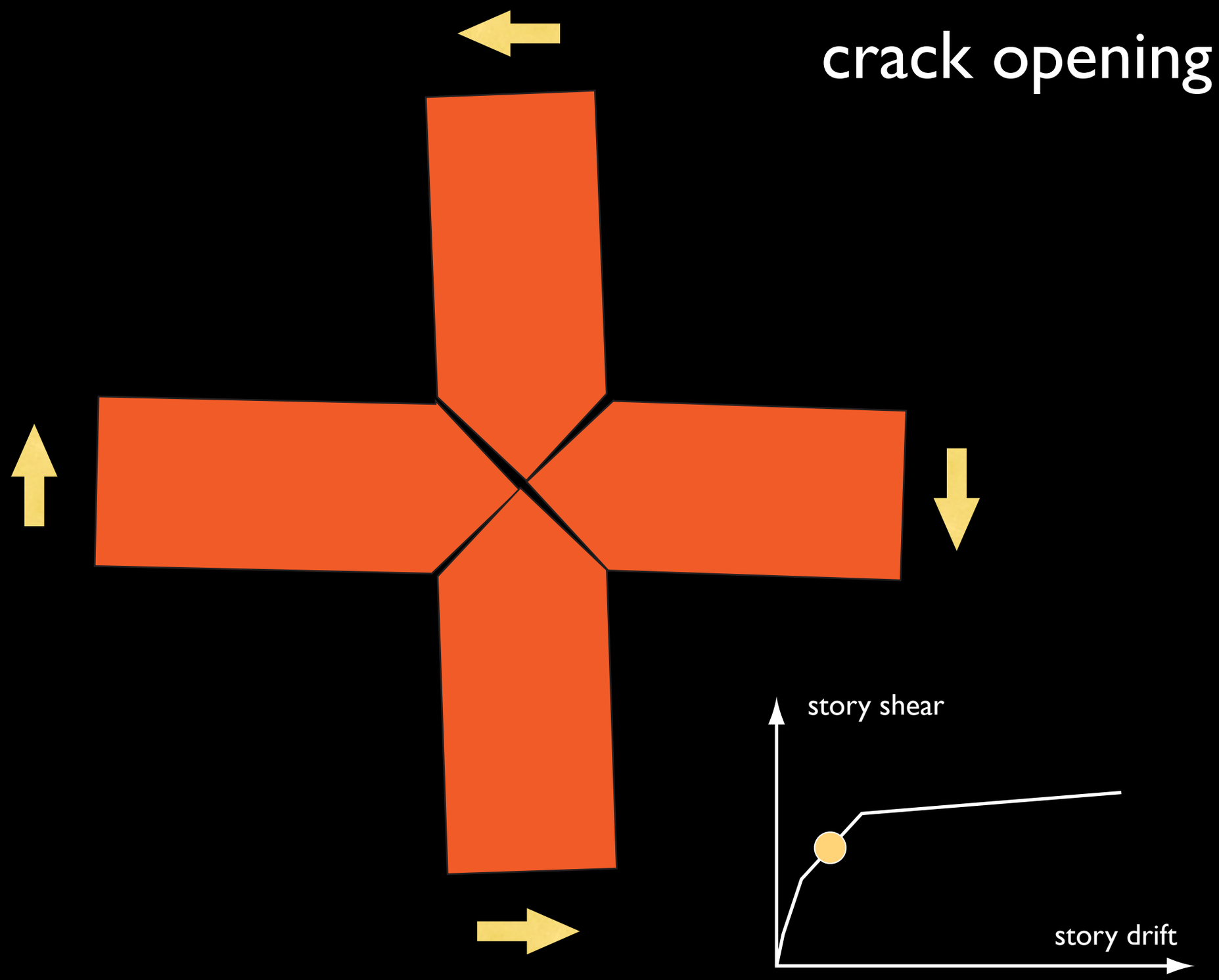



crack opening
crack opening
story shear
story drift

load reversals
before
yielding



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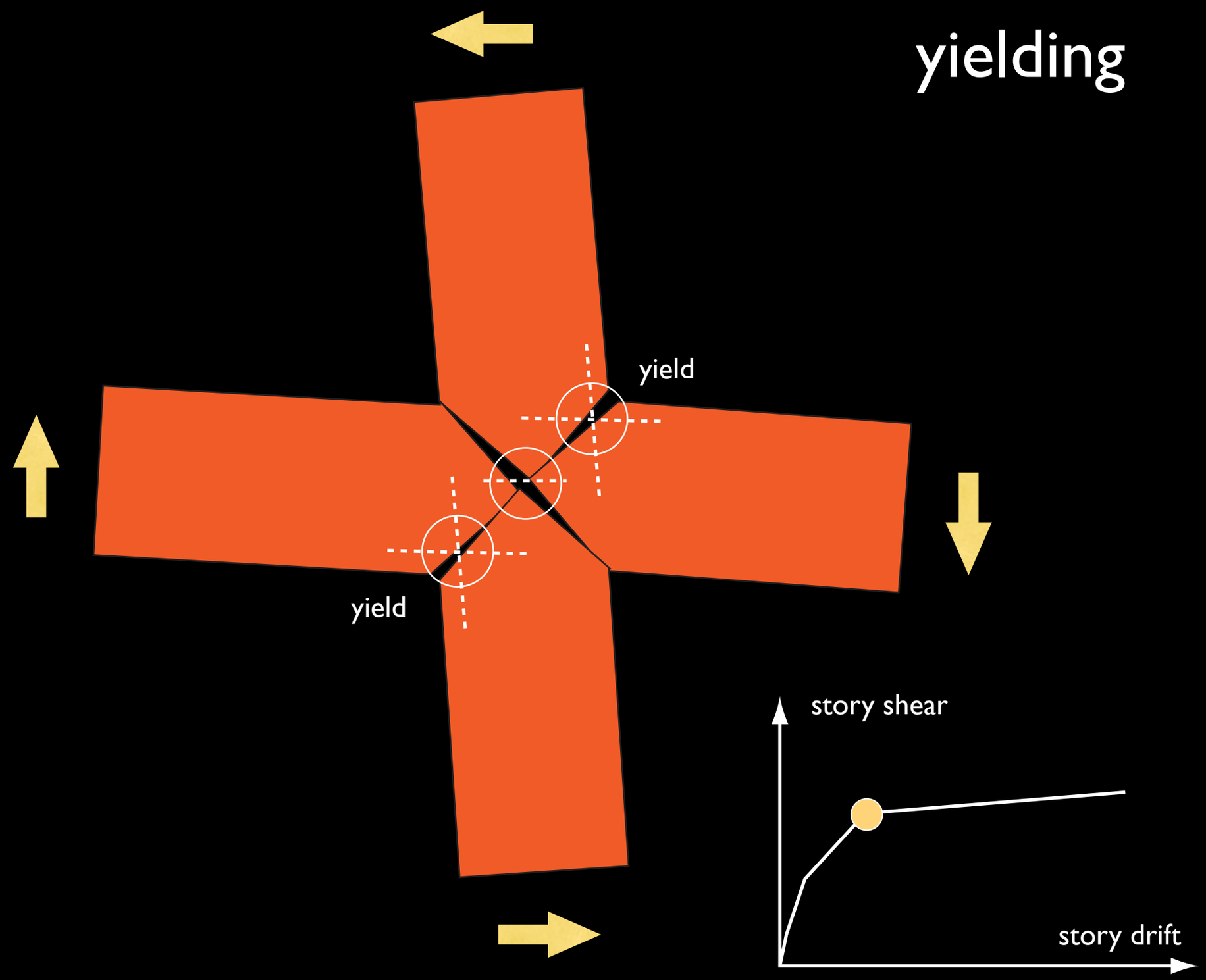

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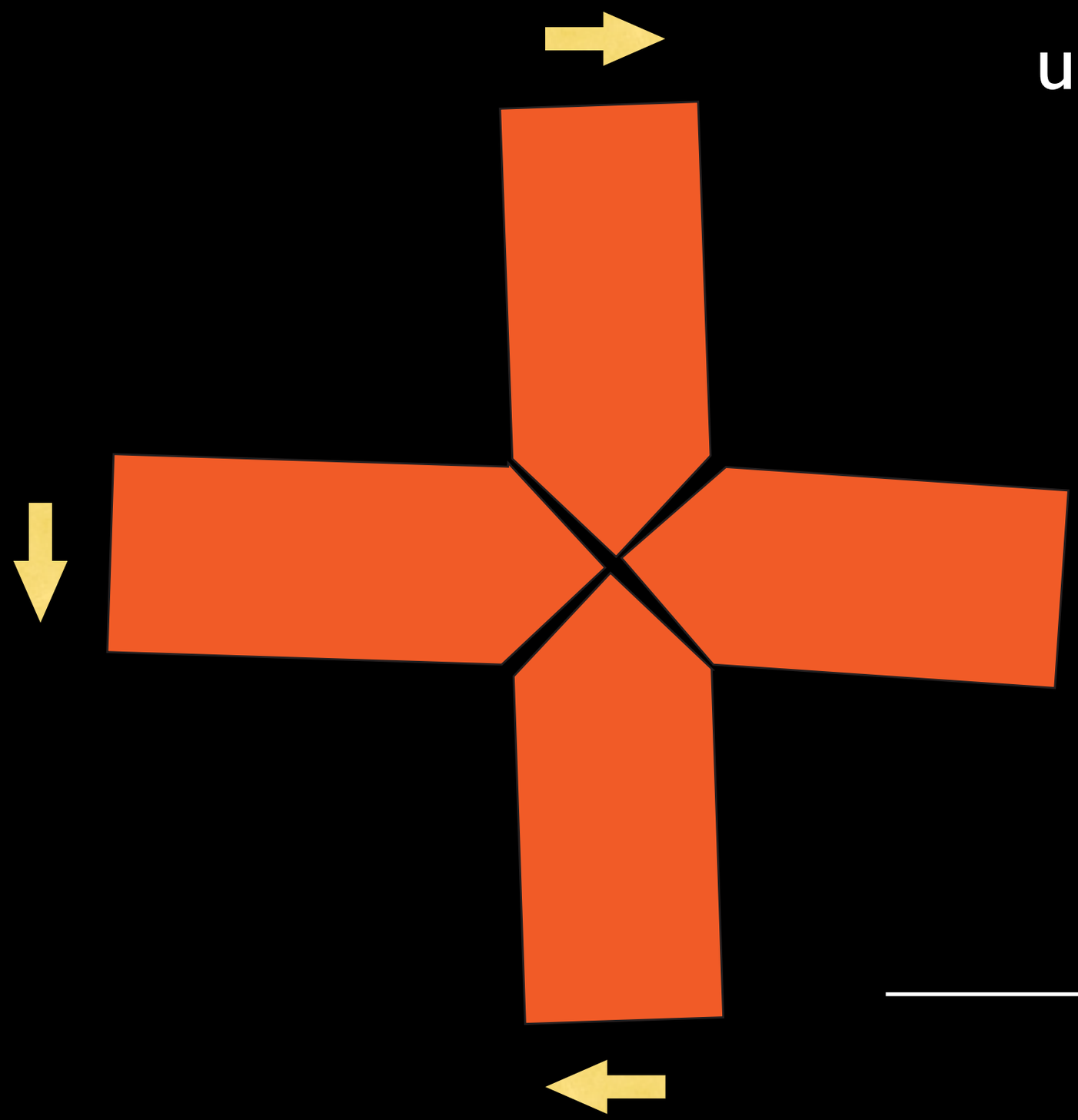
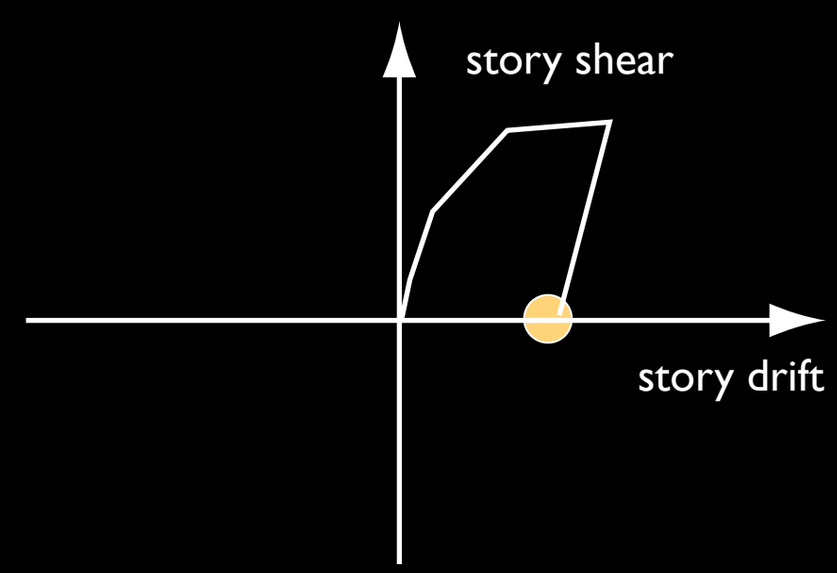
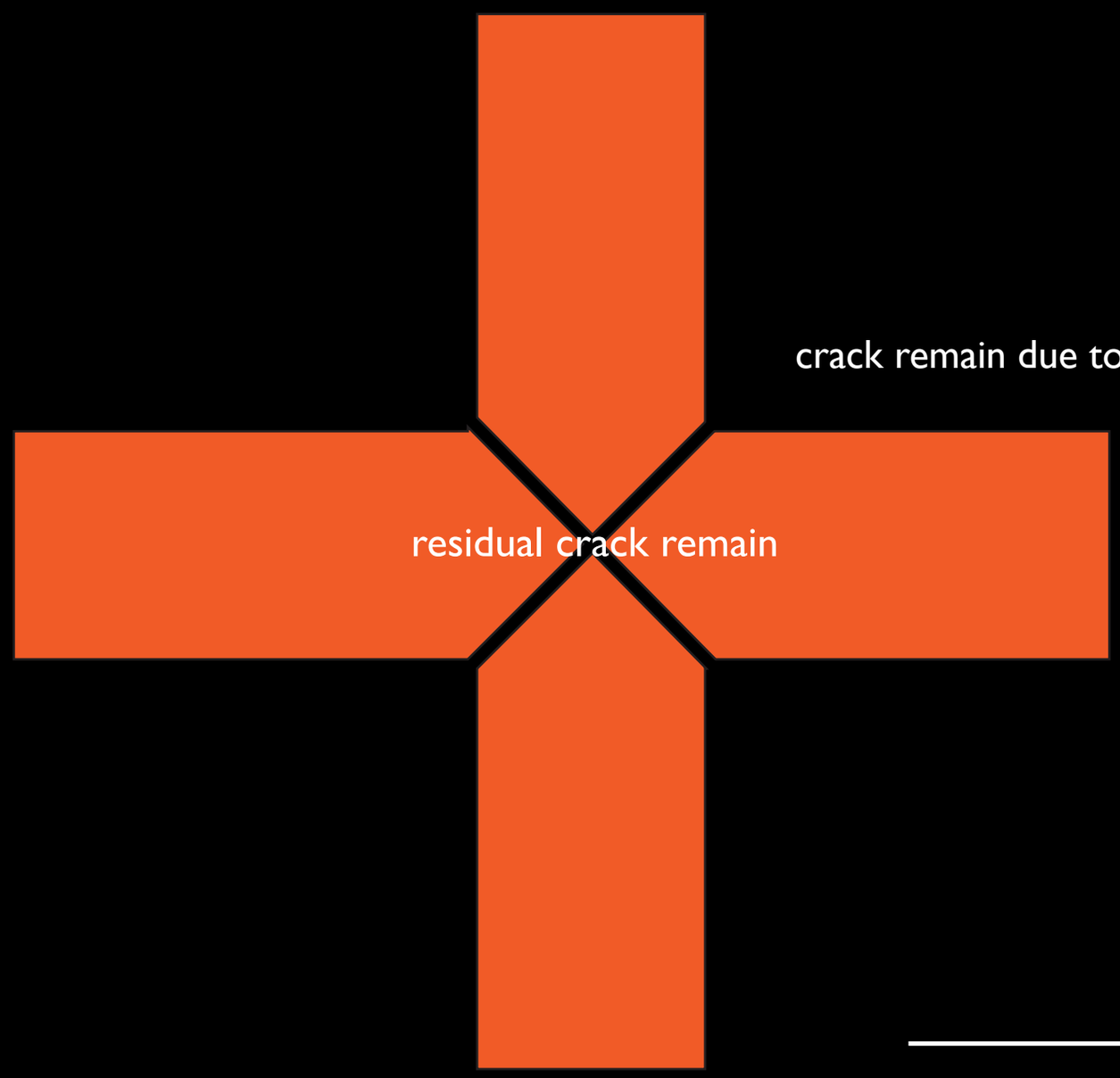
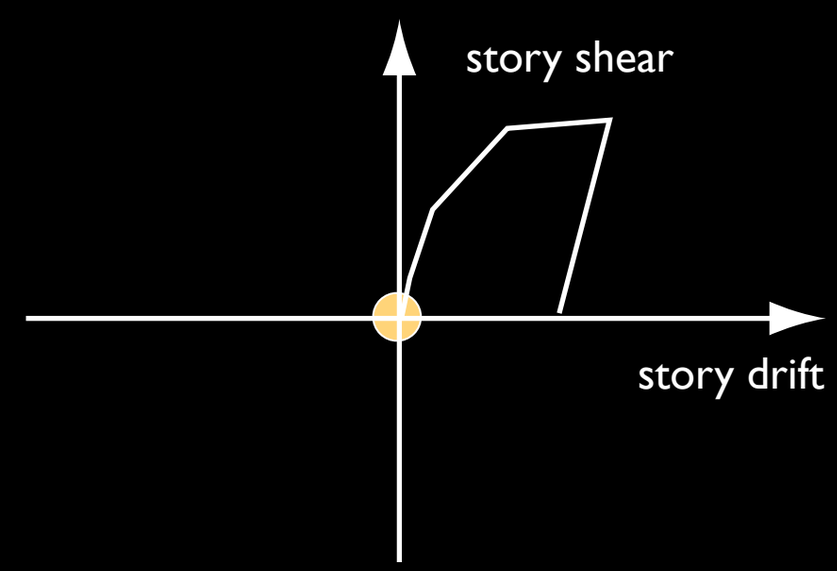




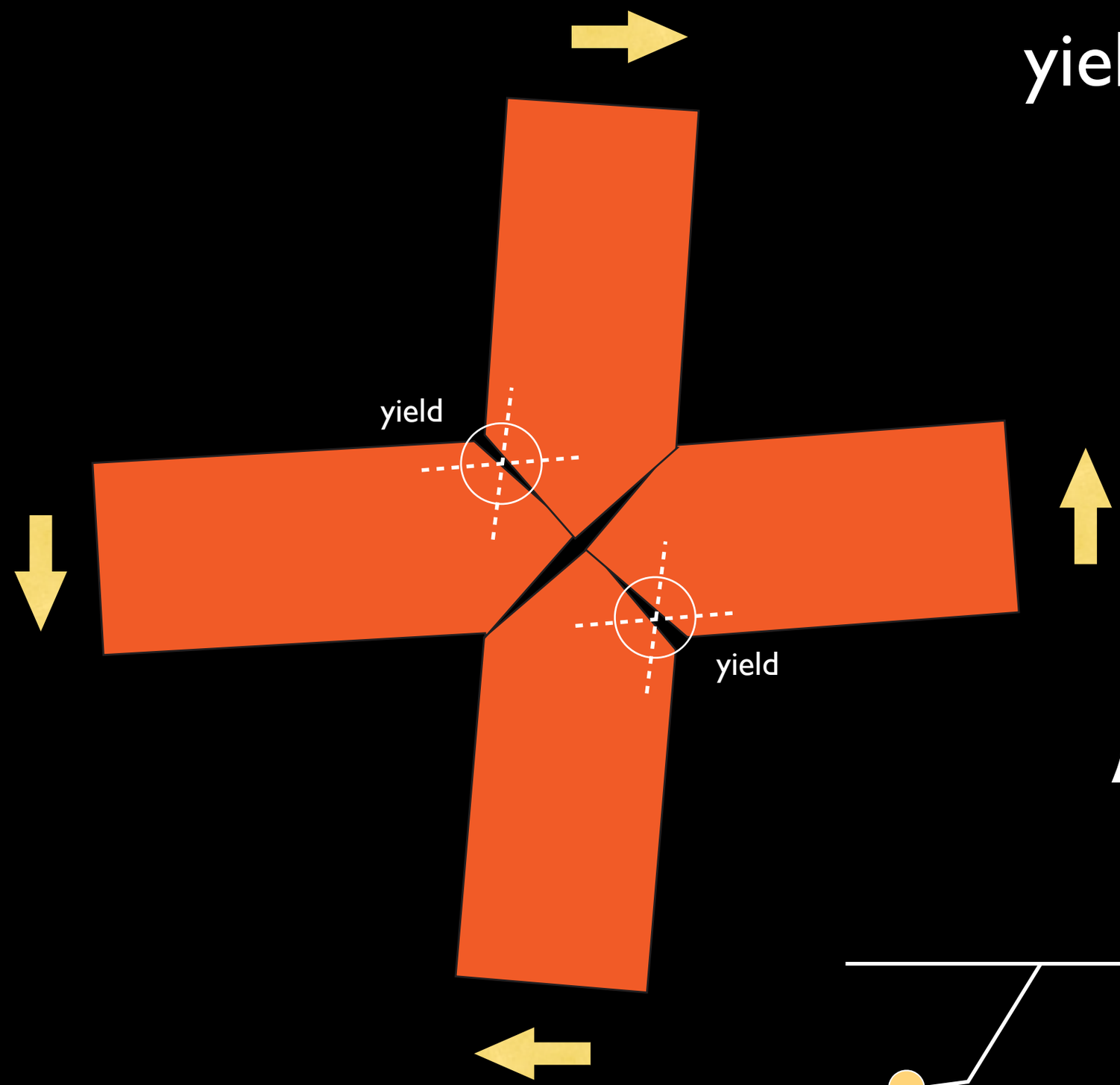
load reversals after yielding

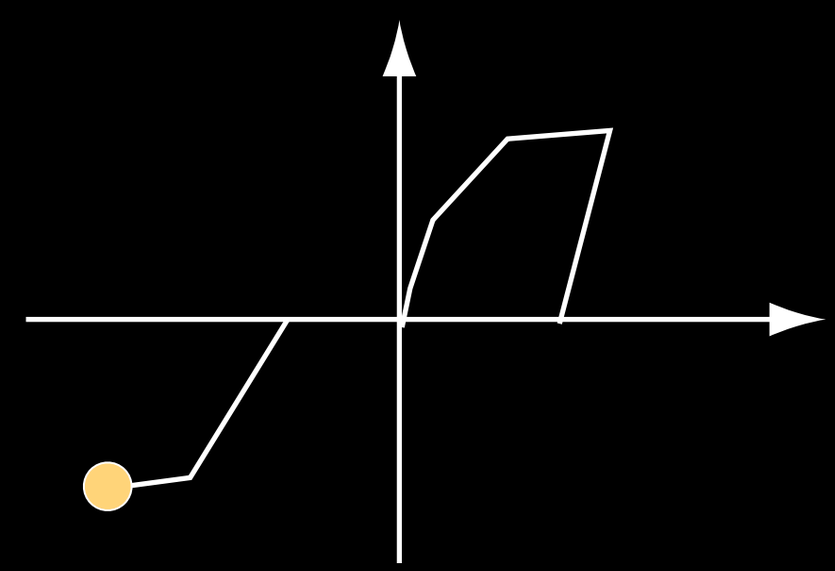
crack remain due to residual stain after tensile yielding





yielding





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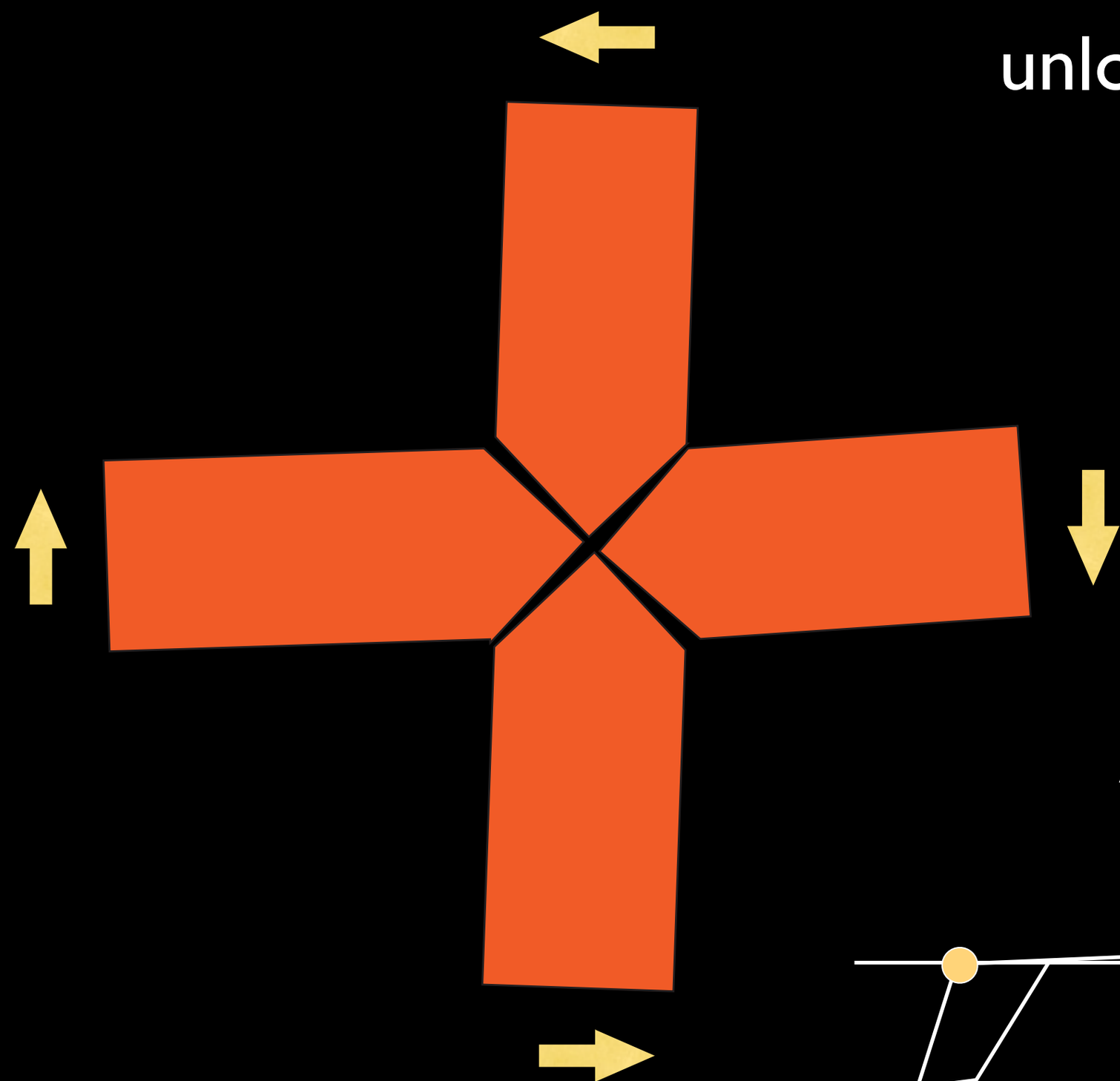
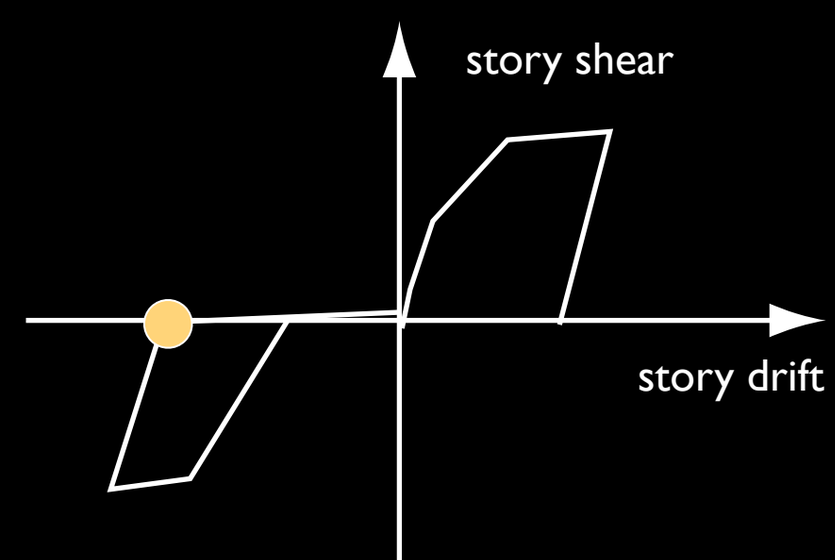
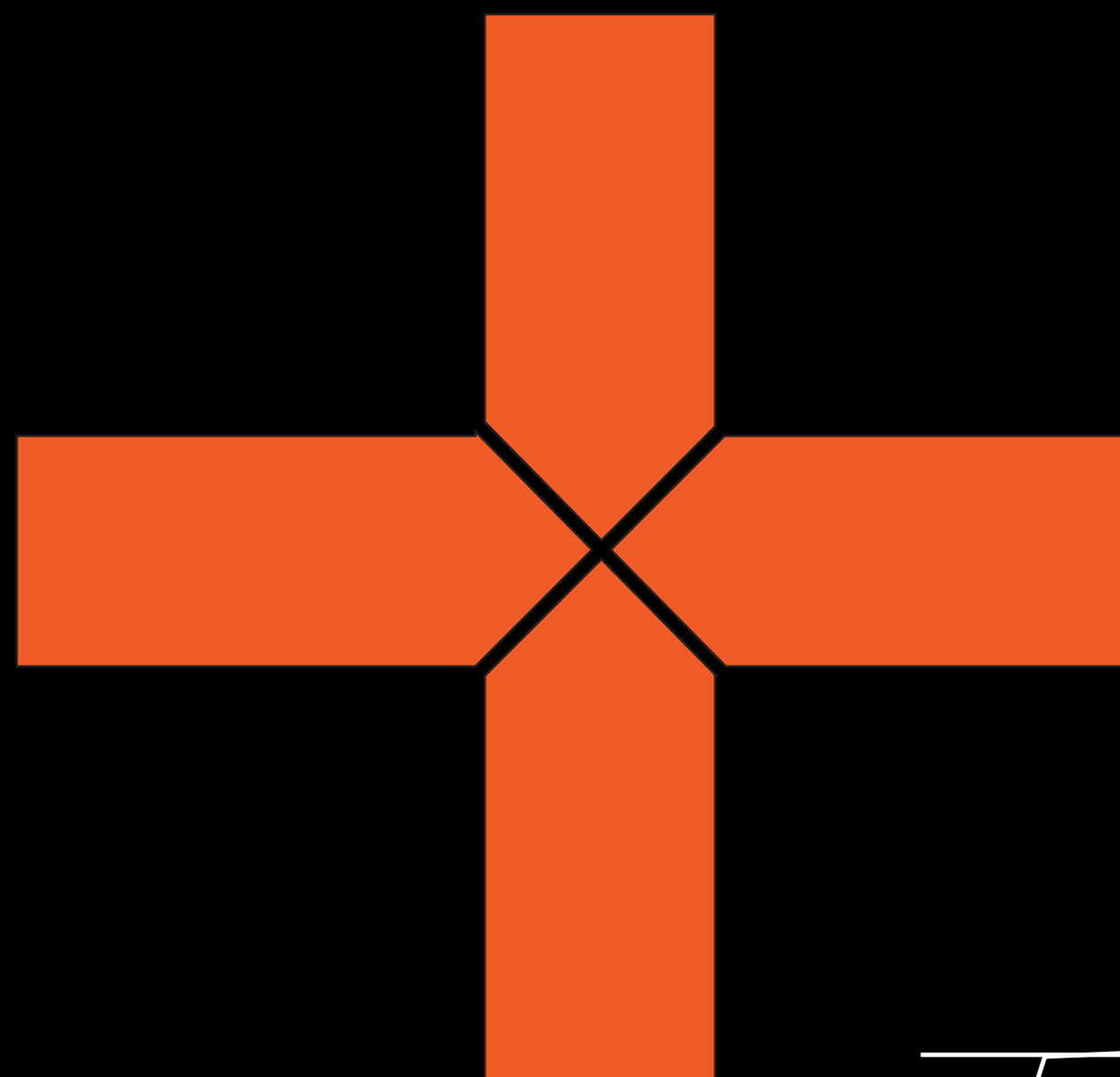
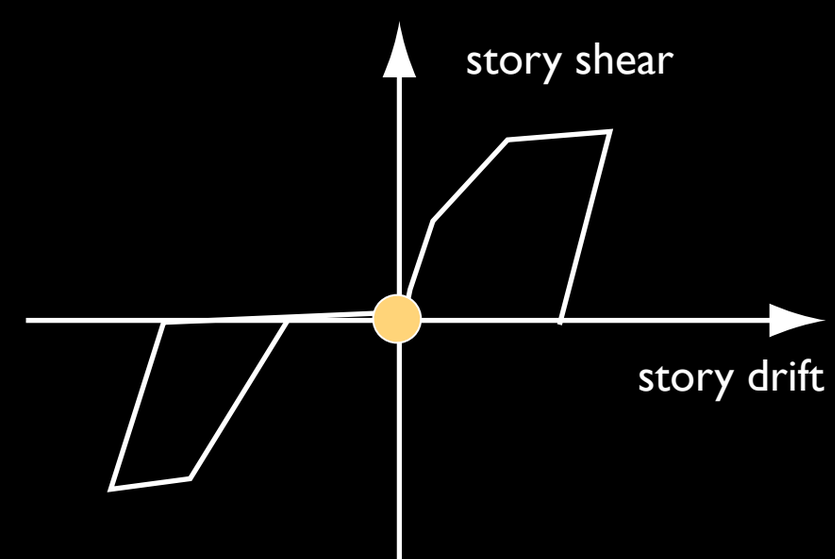
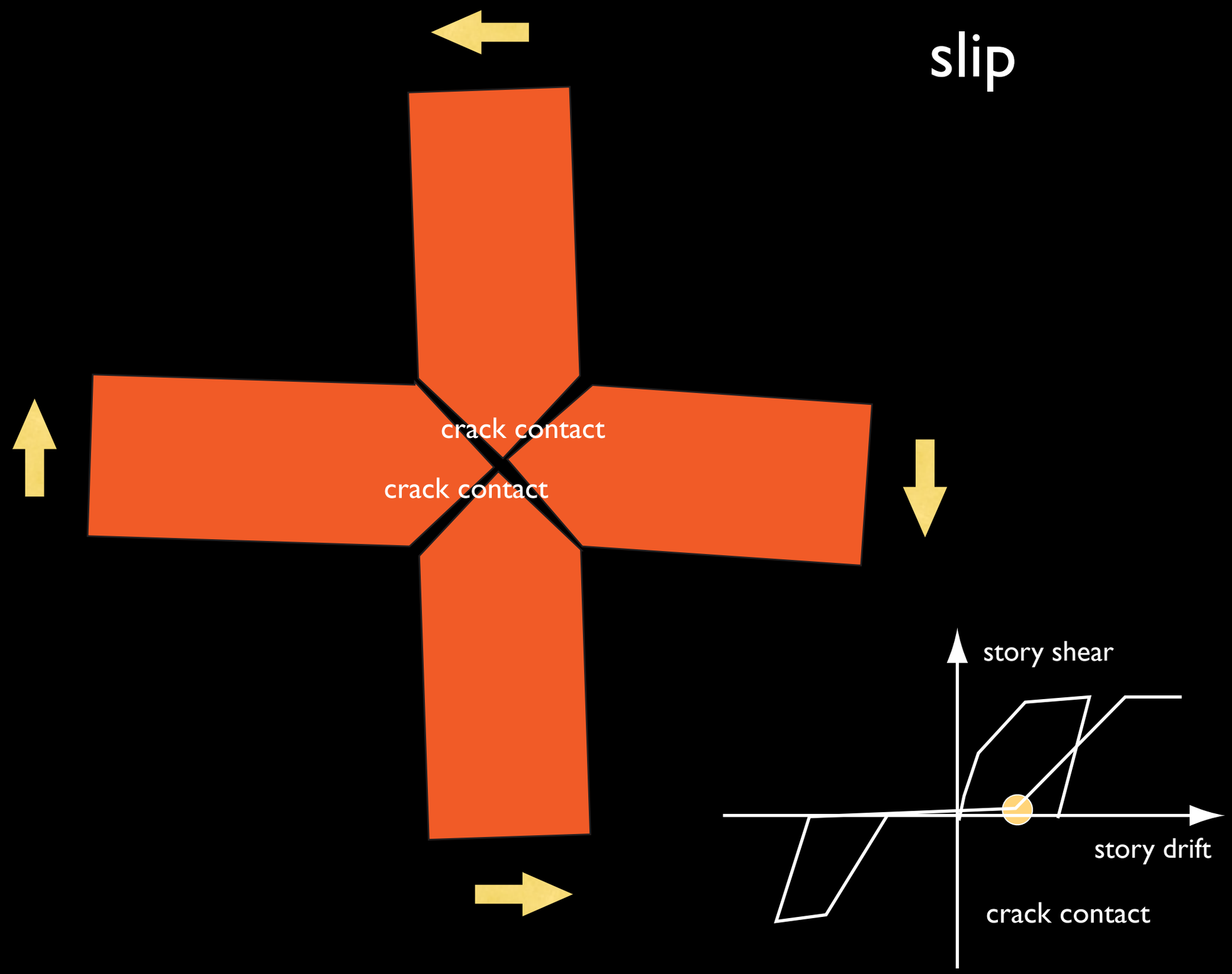




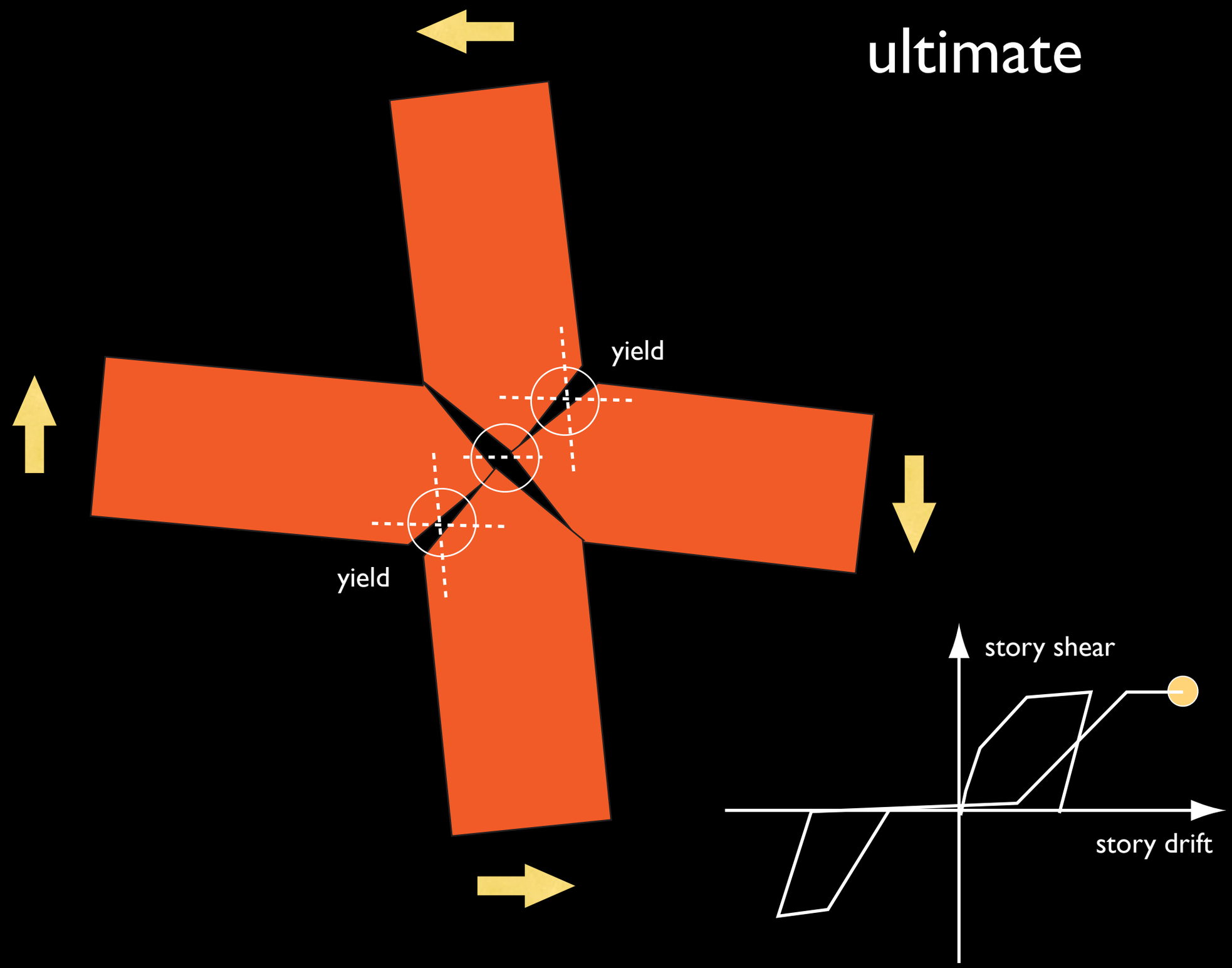
load reversals
after
yielding



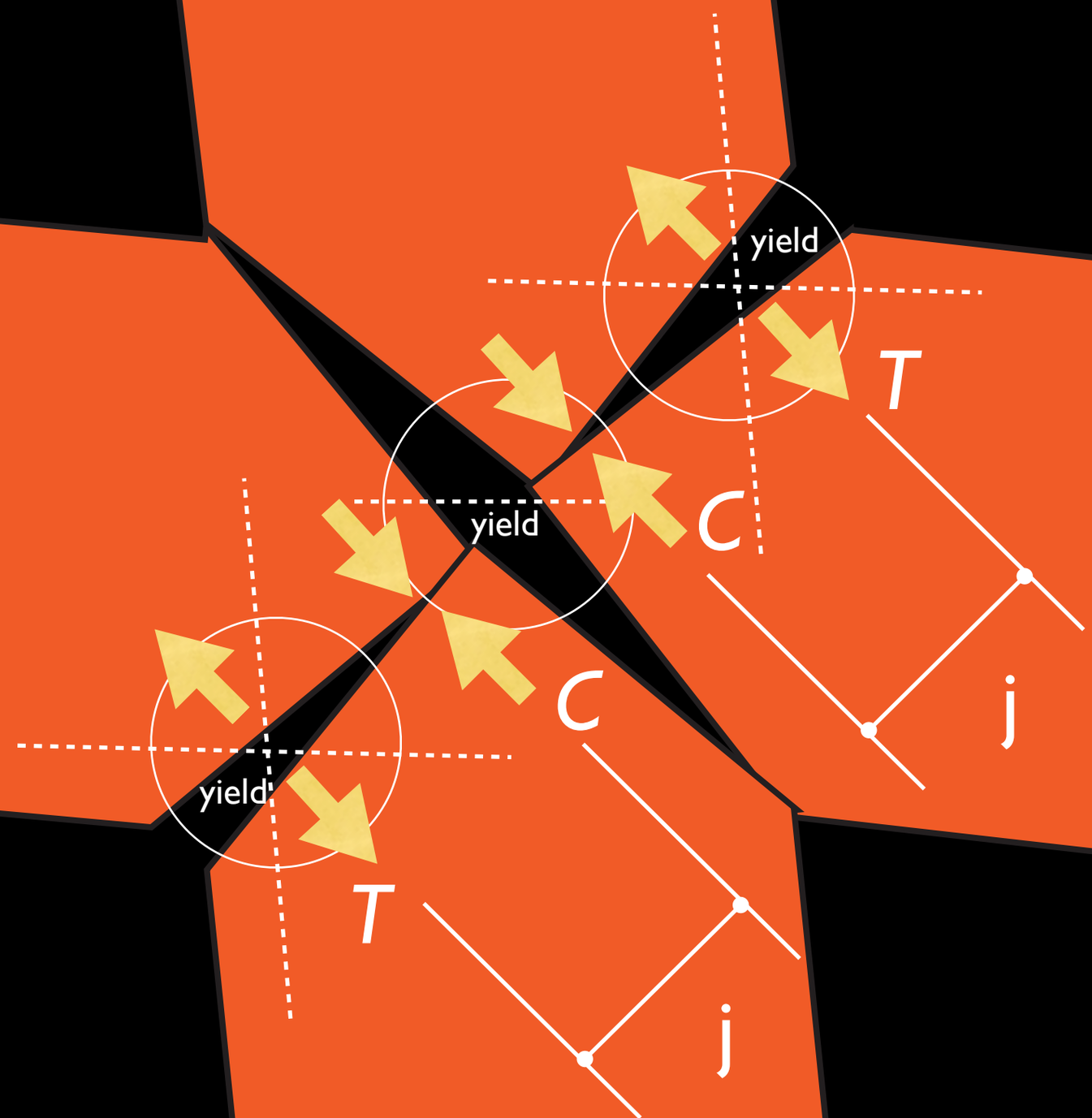



slip
crack contact
crack contact
story shear
story drift
crack contact

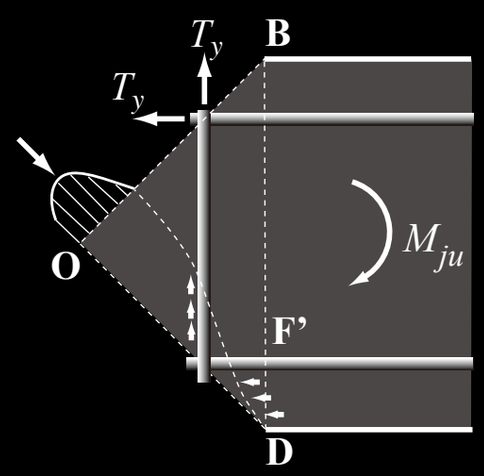
ultimate

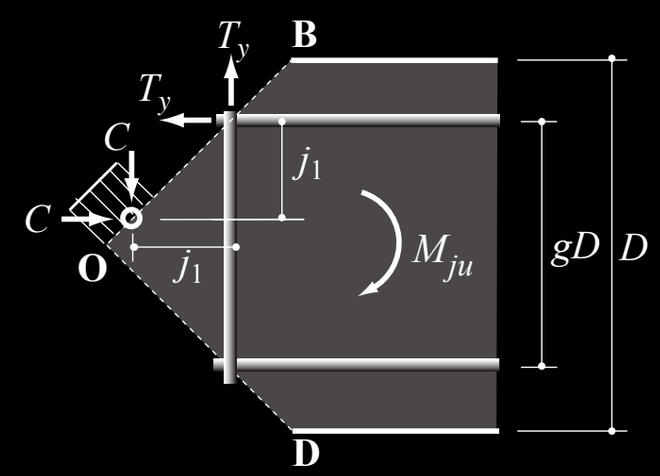


Definition of Ultimate Moment Capacity of Joint



Proposed Equations for Ultimate Moment Capacity of Joint (by Shiohara et al. : Nine Parameter Model)

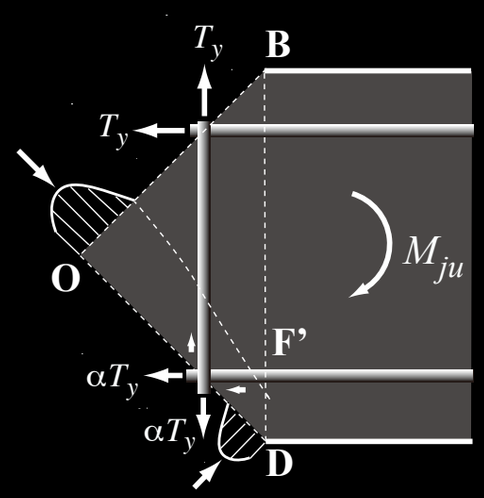


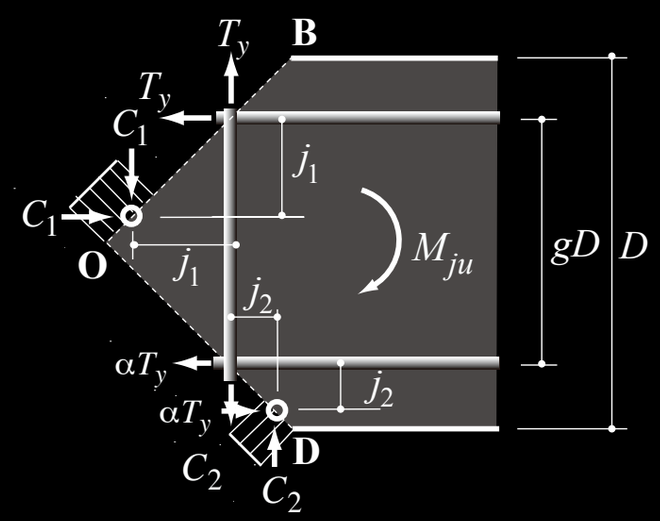


$$C = T_y$$

$$j_1 = \frac{1}{2} D \left\{ g - \frac{T_y}{bD\beta_3 f_c'} \right\}$$

$$M_{ju} = 2 j_1 T_y = 2 j_1 C$$





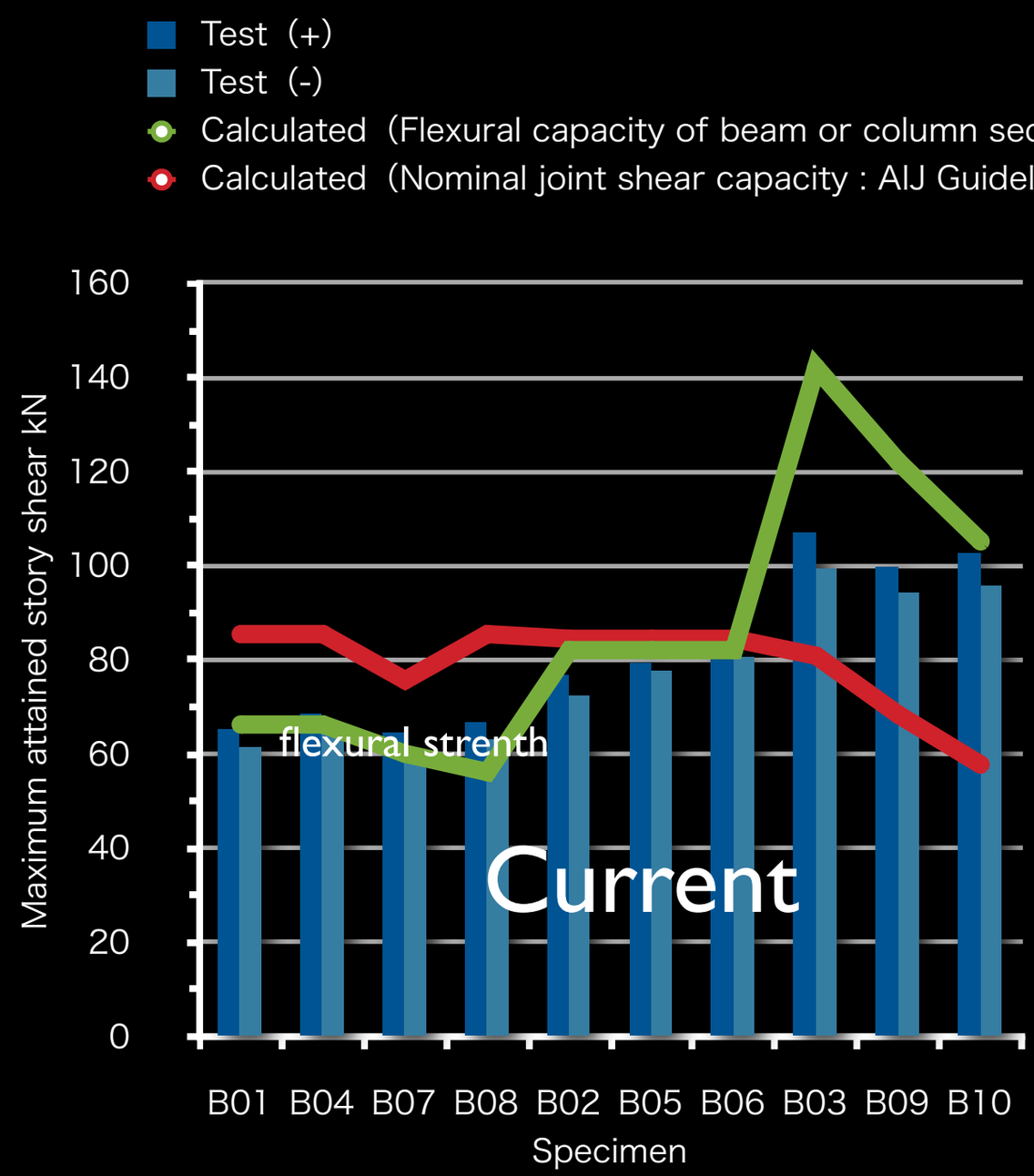
$$C_1 = T_y \qquad C_2 = \alpha T_y$$

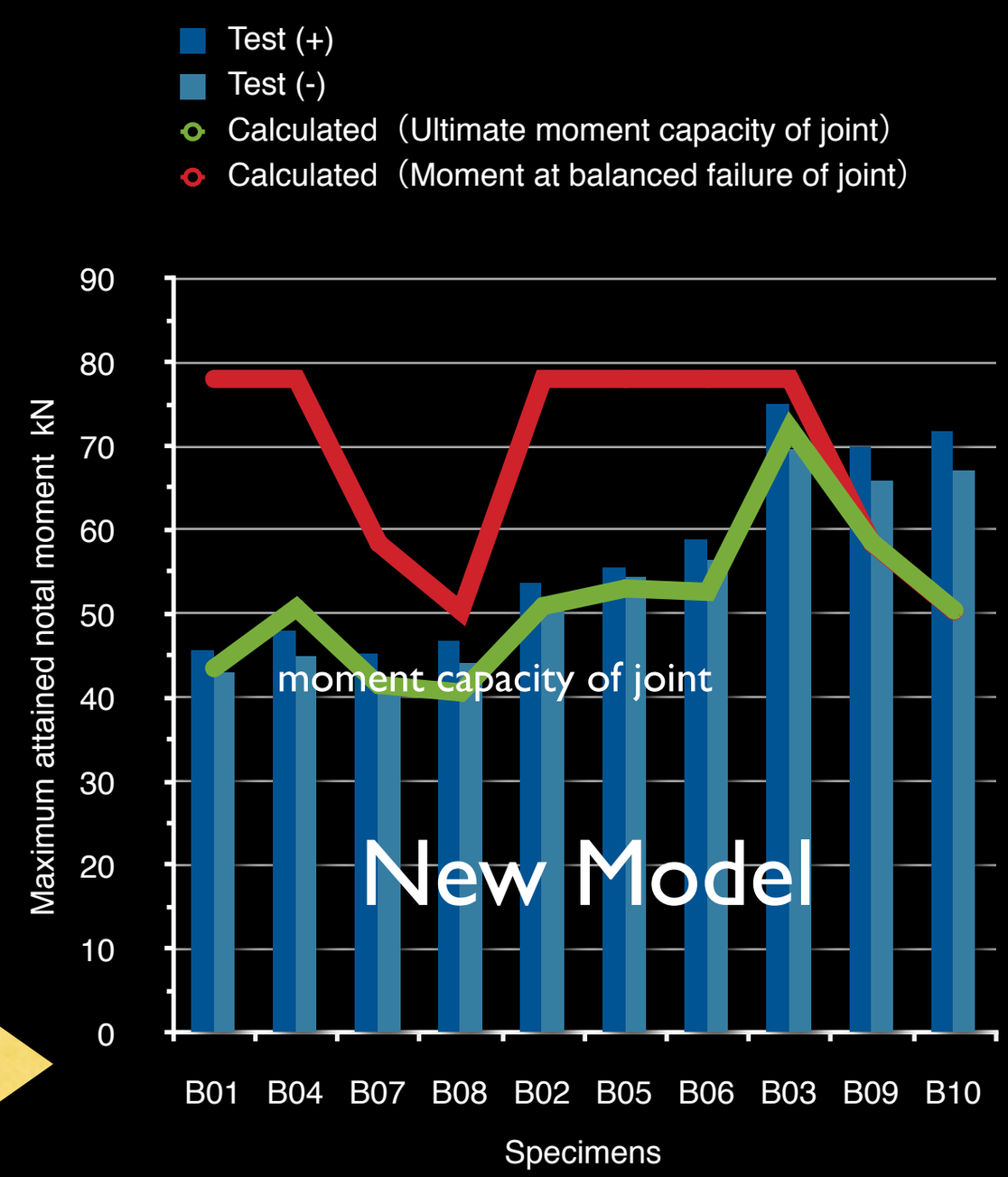
$$j_1 = \frac{1}{2} D \left\{ g - \frac{C_1}{bD\beta_3 f_c'} \right\} \quad j_2 = \frac{1}{2} D \left\{ (1-g) - \frac{C_2}{bD\beta_3 f_c'} \right\}$$

$$M_{ju} = 2\left(j_1 T_y + j_2 \alpha T_y \right) = 2\left(j_1 C_1 + j_2 C_2 \right)$$

Prediction of Maximum Story Shear

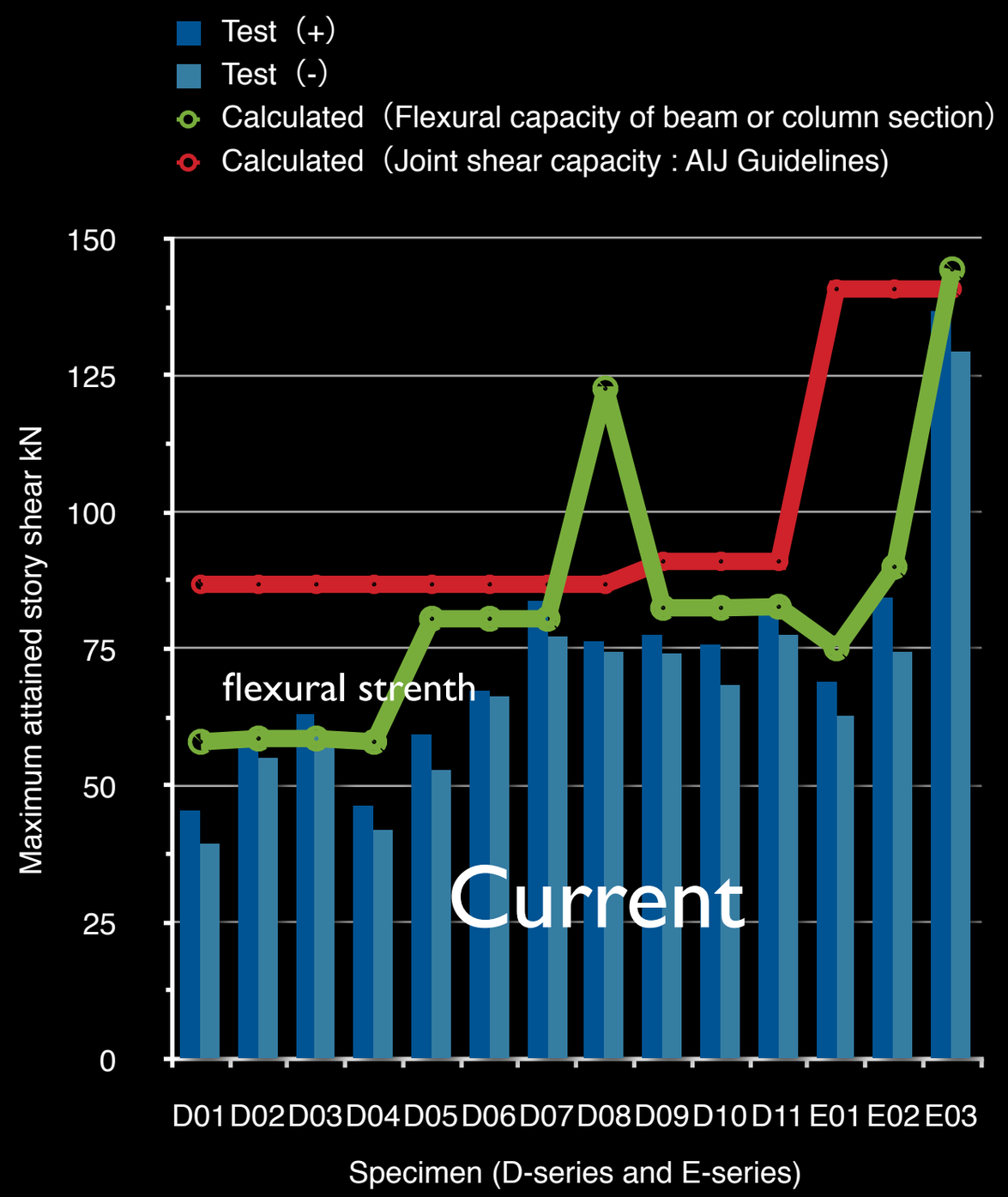
(by New Model)

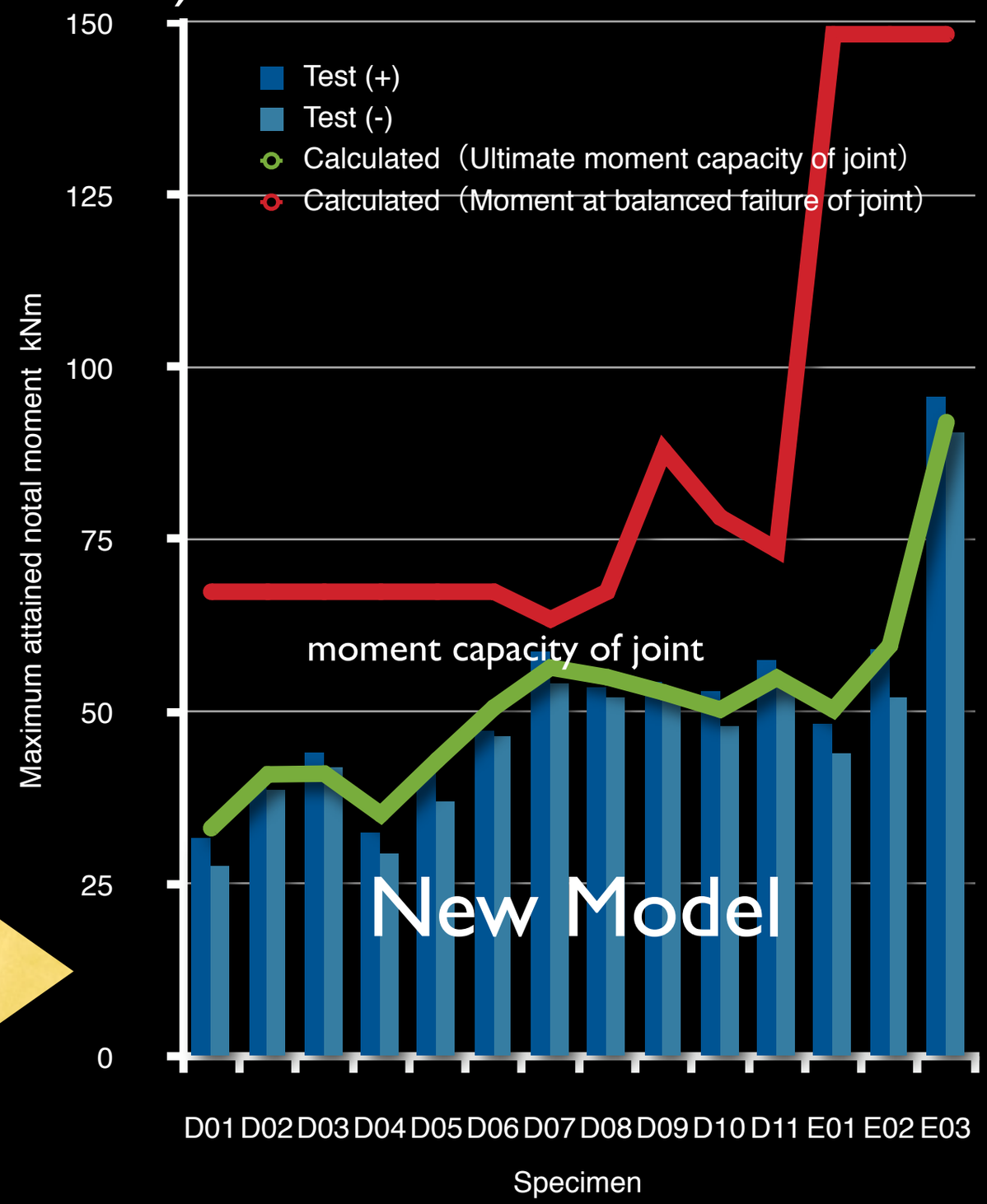




Prediction of Maximum Story Shear

(by New Model)





Conclusions

- Current seismic provisions for RC beam-column joints are deficient and can not secure the lateral strength of moment resisting frames predicted by the flexural theory of RC sections.
- The design parameters considered is not a rare feature but is rather seen frequently in existing reinforced concrete buildings.
- Hence a large number of existing RC moment resisting frame structures may be more vulnerable than we expected.

Recommendation

- Serious consideration on the impacts of this test dataset on huge stock of RC building in the world should be addressed by structural engineers, researchers and code writers.


Let’s challange !

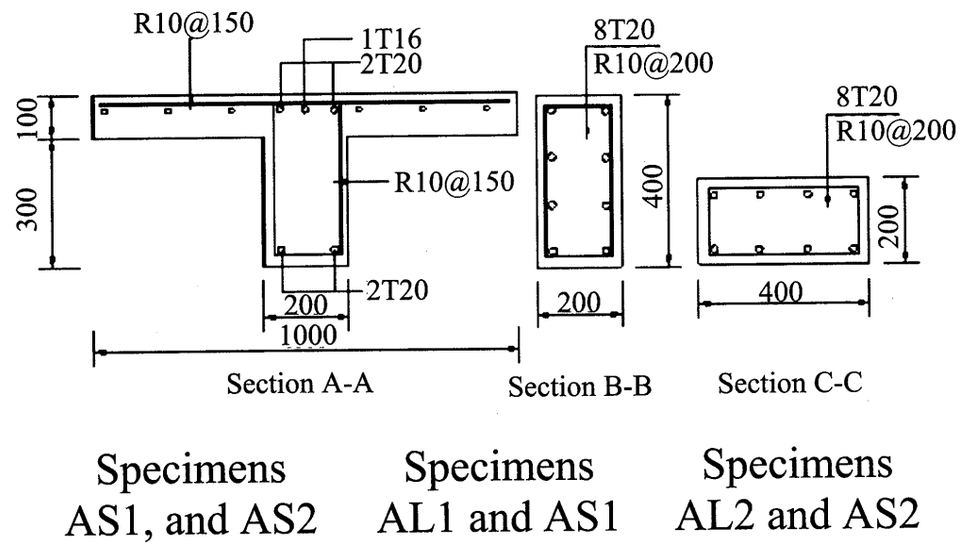
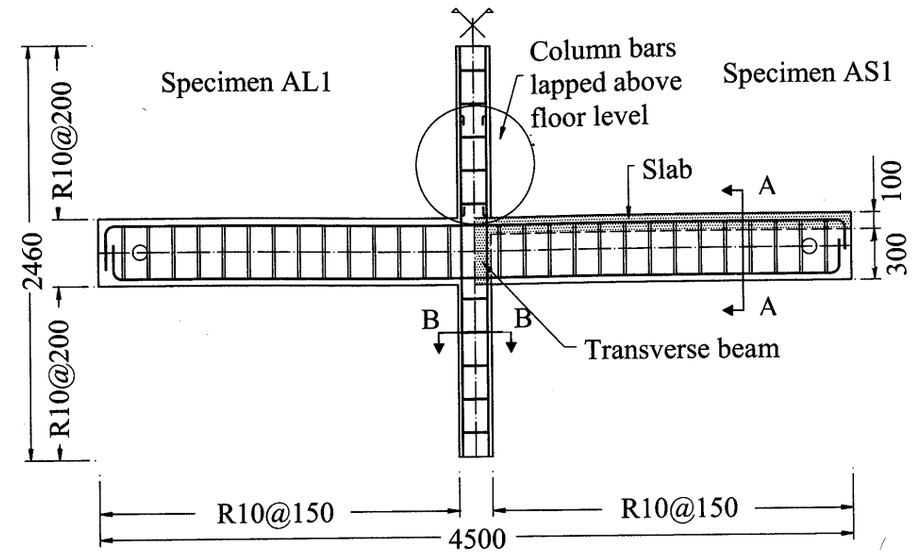
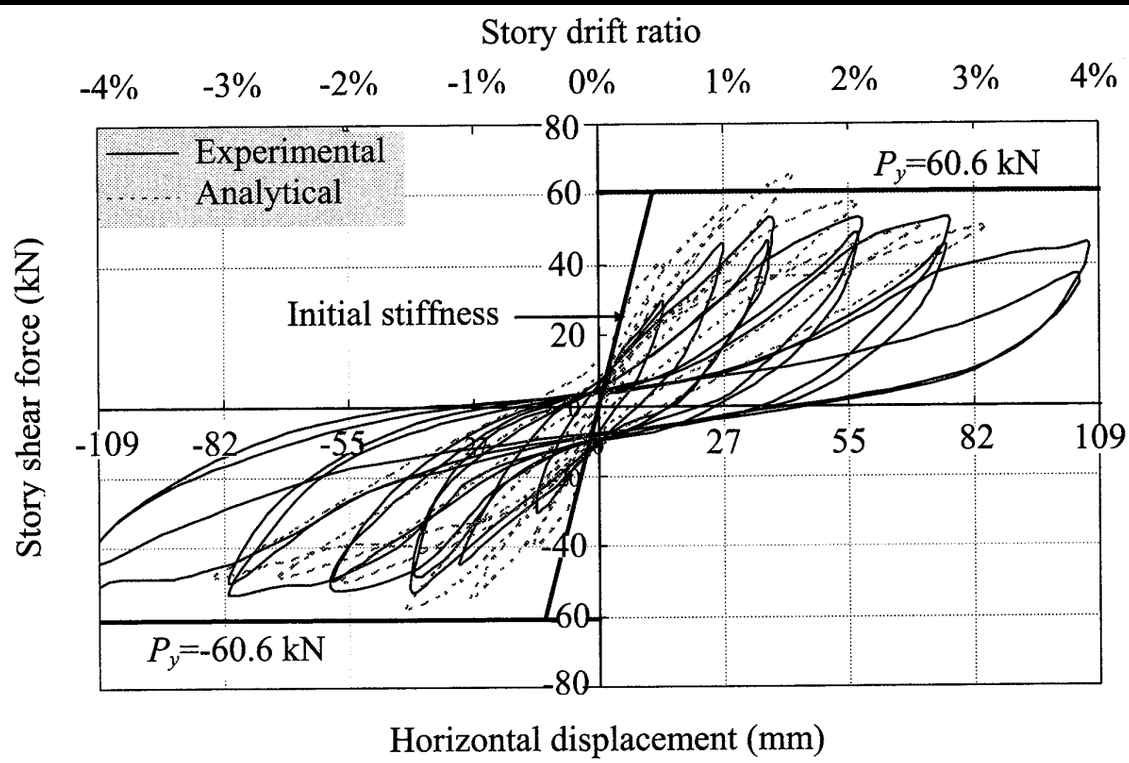


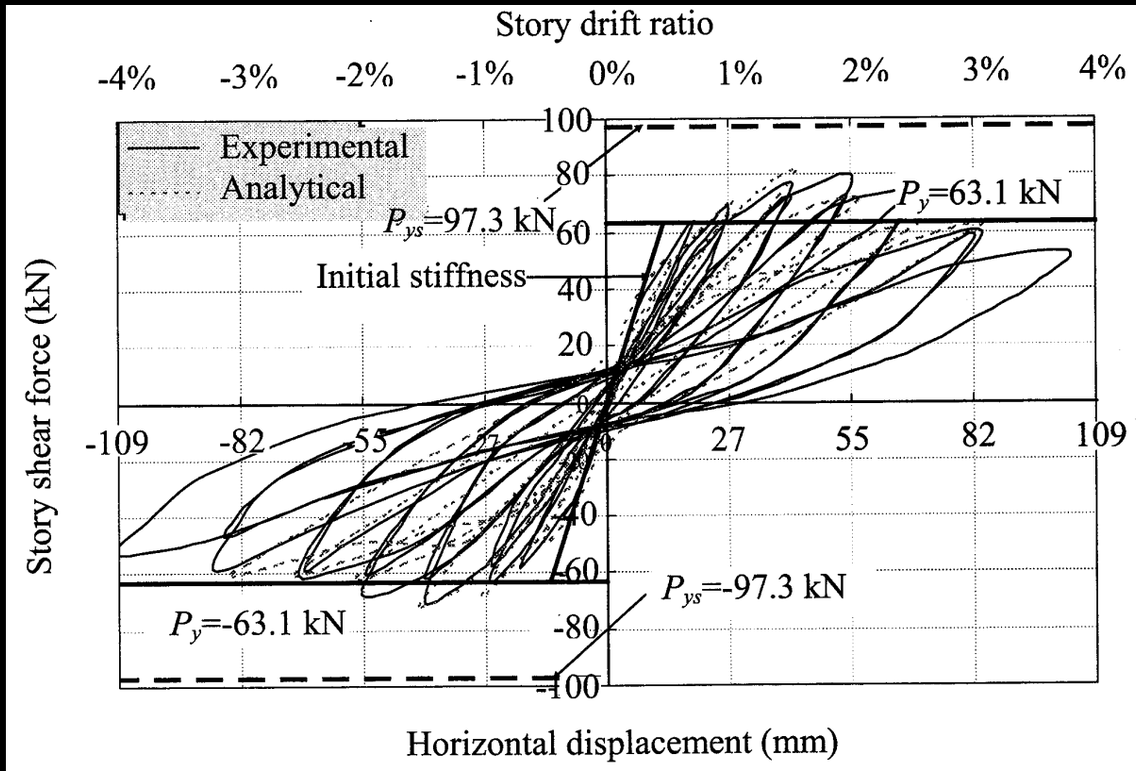
Fig. 1. Dimensions and details of Specimens AL1, AS1, AL2, and AS2 (in mm)



(a) Specimens AL1 and AS1



a) Specimen AL1



b) Specimen AS1

Bin Li (2009). Experimental and numerical Investigations on the Seismic Behavior of Lightly Reinforced Concrete Beam-column Joint. Journal of Structural Engineering, ASCE, Sept. 2009.

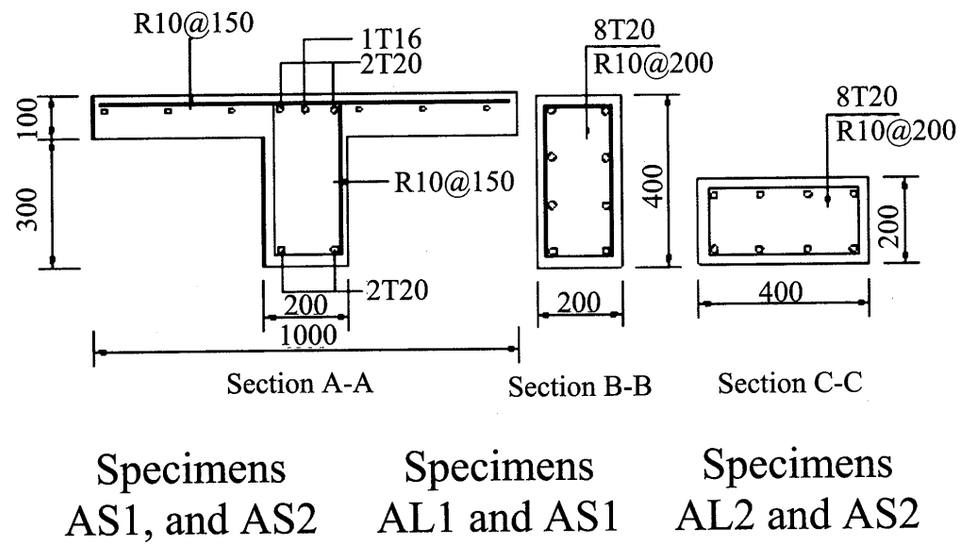
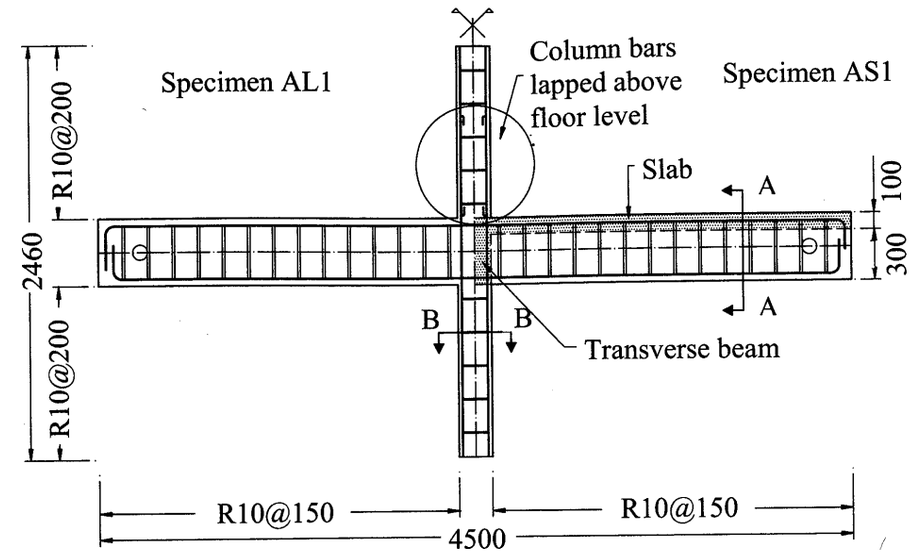
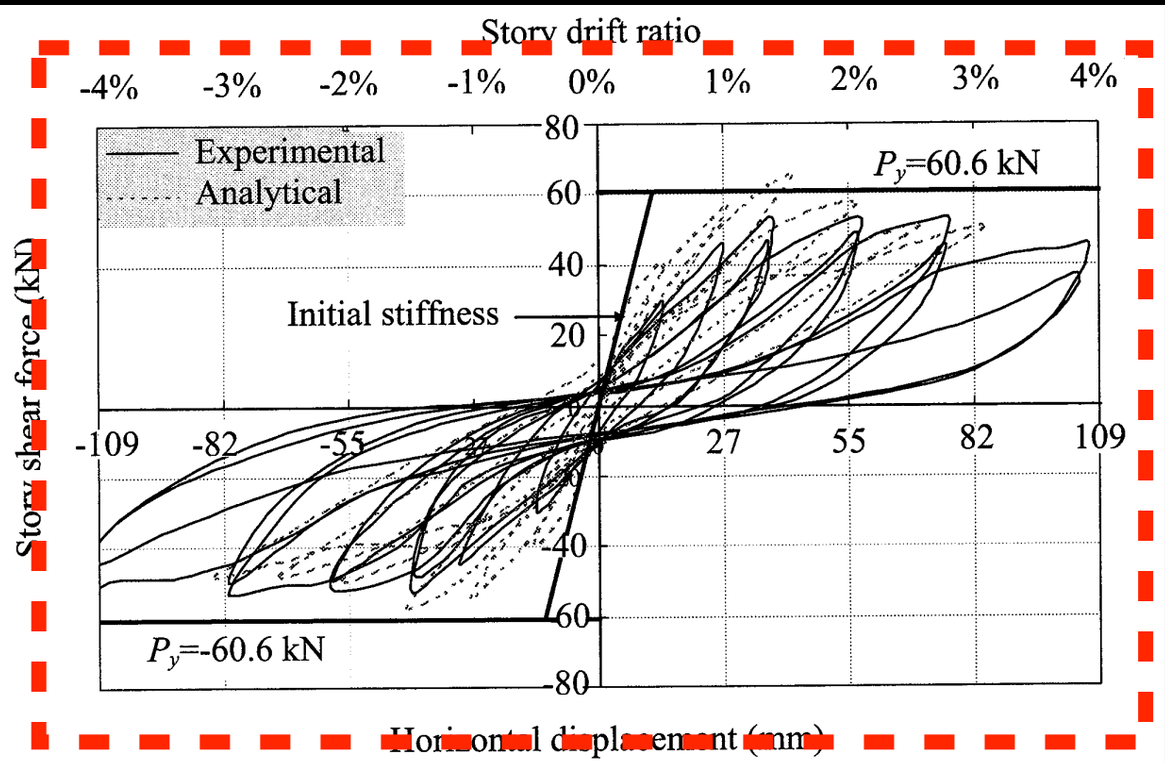


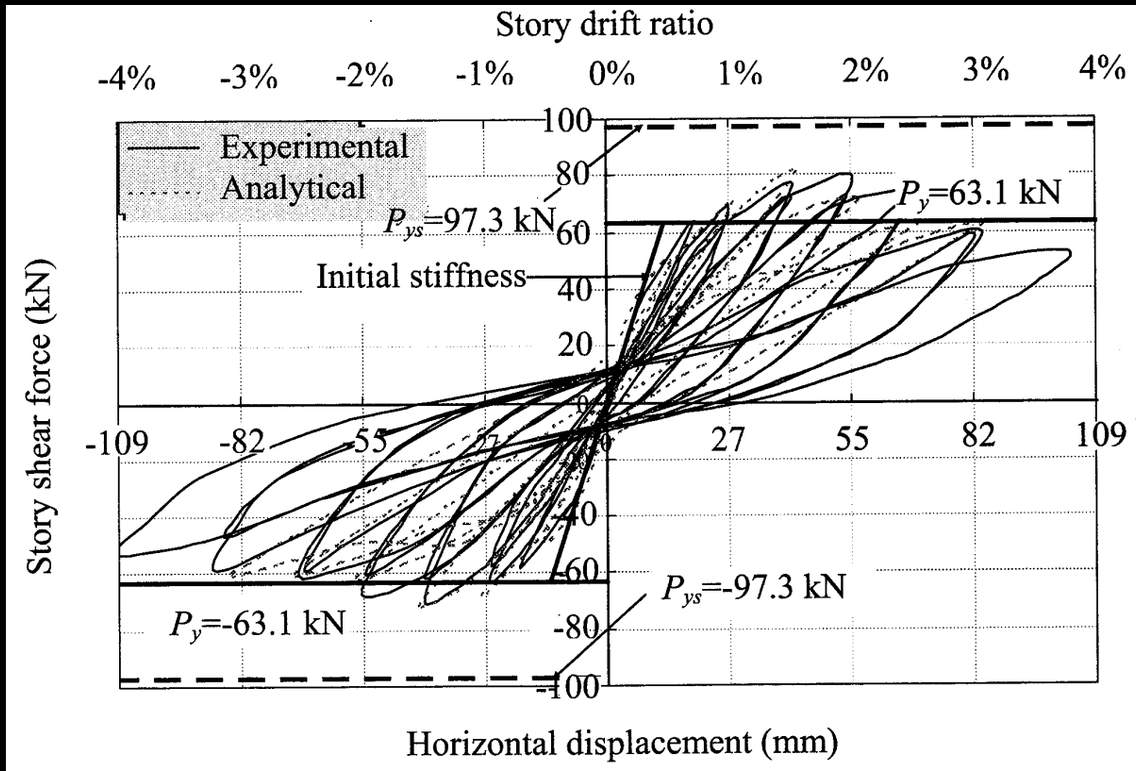
Fig. 1. Dimensions and details of Specimens AL1, AS1, AL2, and AS2 (in mm)



(a) Specimens AL1 and AS1

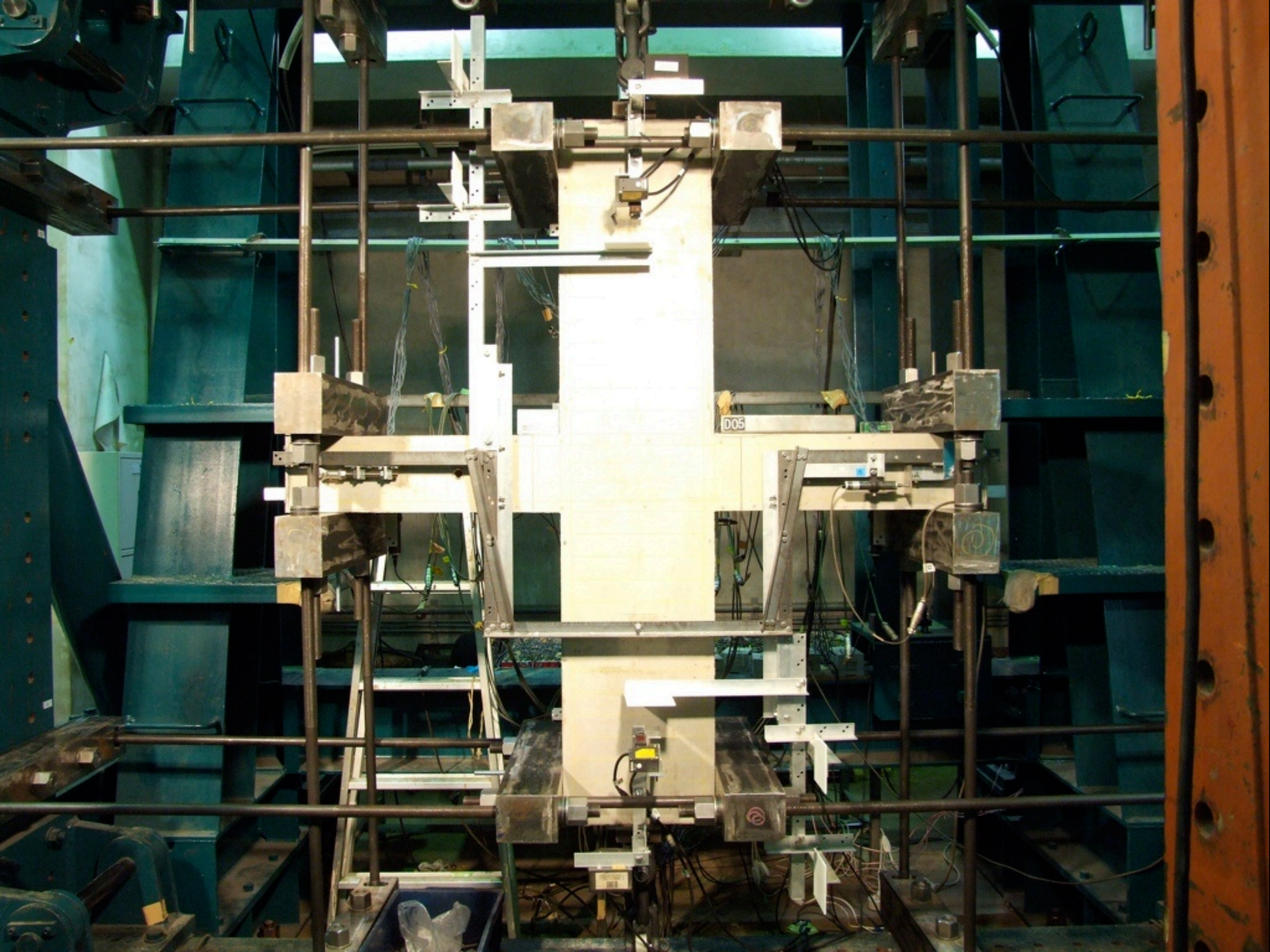


a) Specimen AL1



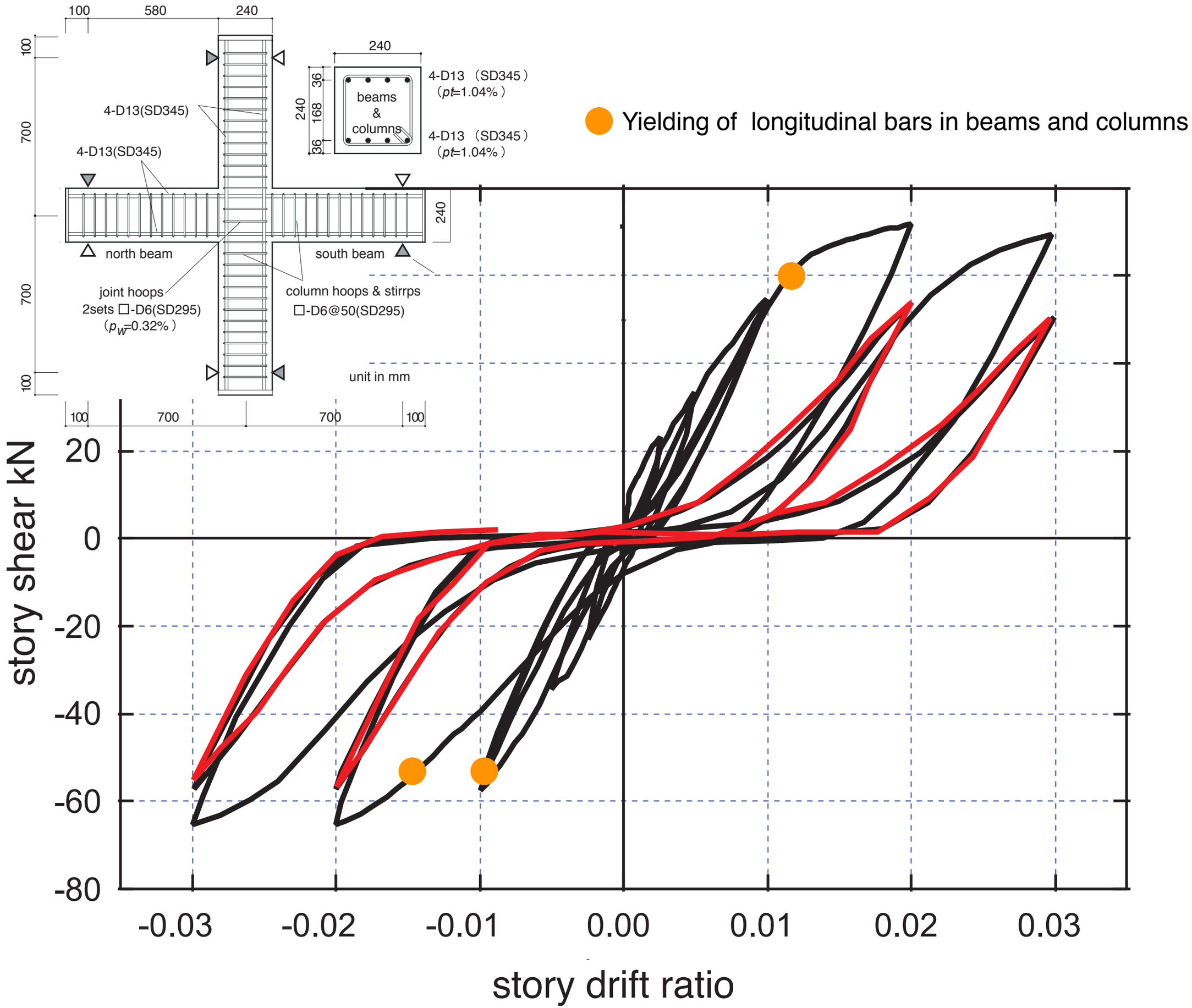
b) Specimen AS1

Bin Li (2009). Experimental and numerical Investigations on the Seismic Behavior of Lightly Reinforced Concrete Beam-column Joint. Journal of Structural Engineering, ASCE, Sept. 2009.


D05

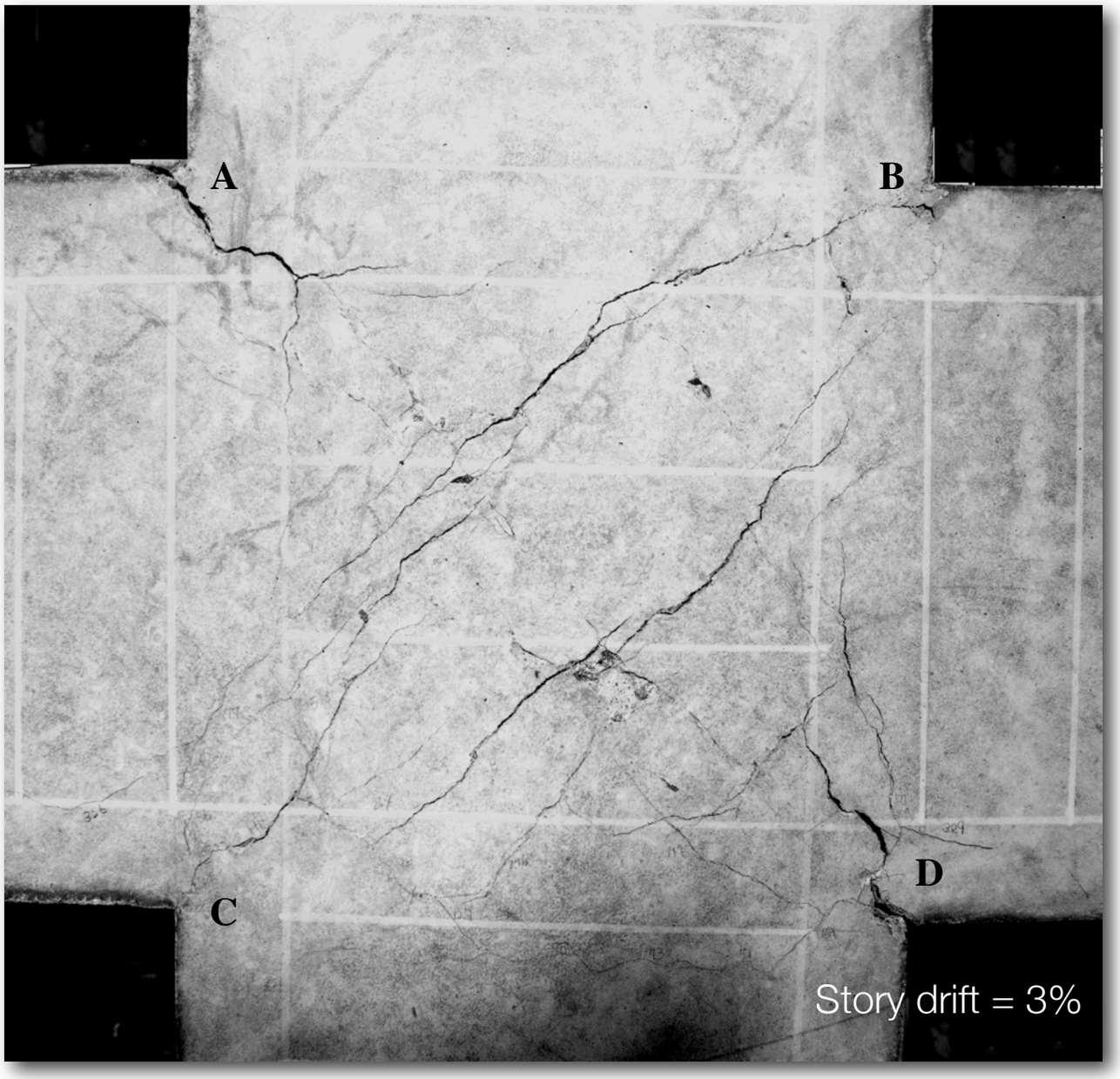
Acknowledgment

- The authors acknowledge the supports by the Grant-in-aid for researches on the building codes improvement by Ministry of Land, Infrastructure, Transport and Tourism, Japan, awarded to a research proposal entitled "Research on design parameters of RC reinforced concrete beam-column joint necessary for ductile behavior of building structures (PI: Hitoshi Shiohara)," FY2008.

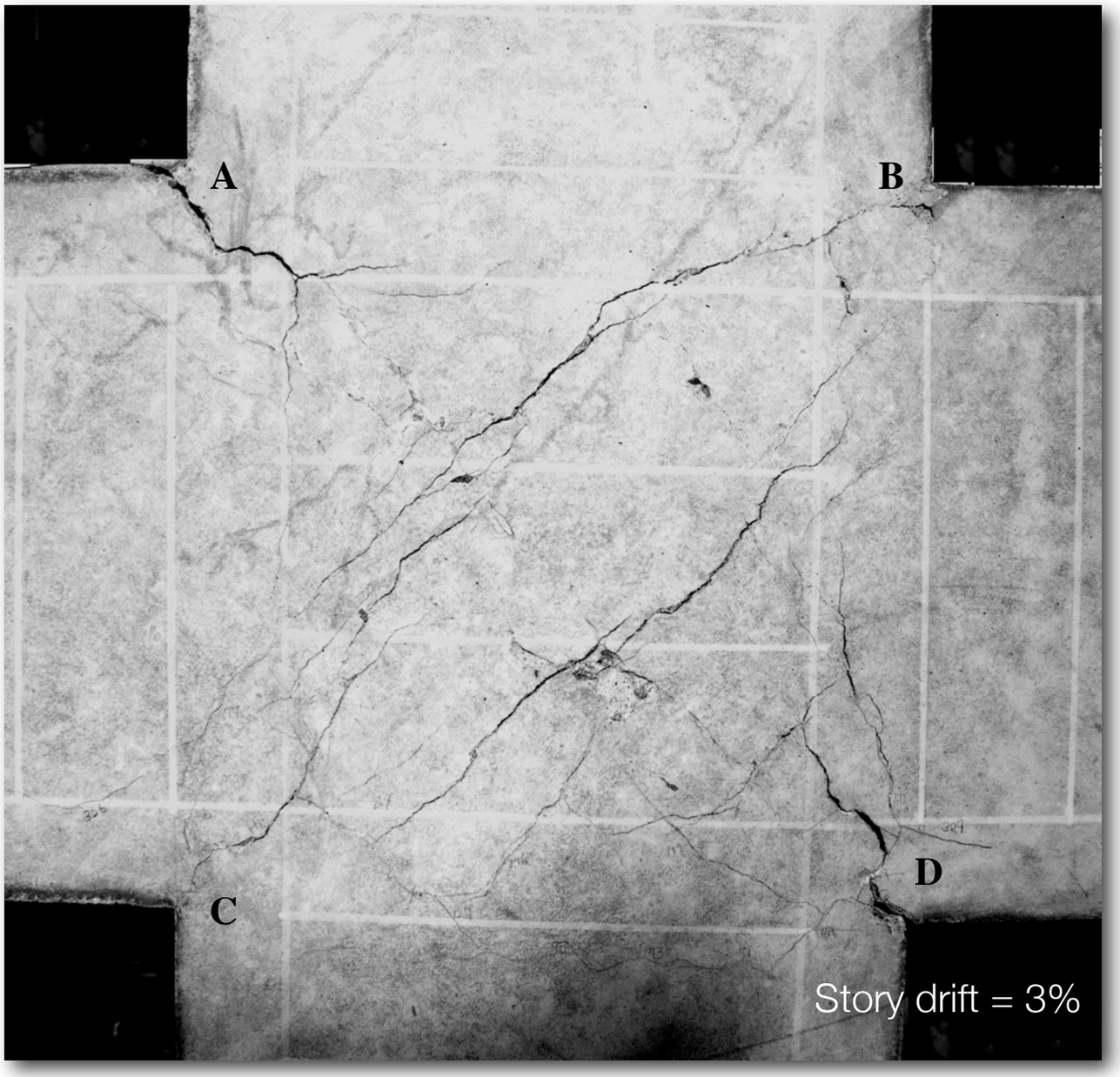

100
580
240
100
700
700
100
4-D13(SD345)
4-D13(SD345)
north beam
south beam
joint hoops
2sets □-D6(SD295)
(pw=0.32%)
column hoops & stirrps
□-D6@50(SD295)
240
240
36
168
36
beams
&
columns
4-D13 (SD345)
(pt=1.04%)
4-D13 (SD345)
(pt=1.04%)
unit in mm
100
700
700
100
Yielding of longitudinal bars in beams and columns
story shear kN
20
0
-20
-40
-60
-80
-0.03
-0.02
-0.01
0.00
0.01
0.02
0.03
story drift ratio

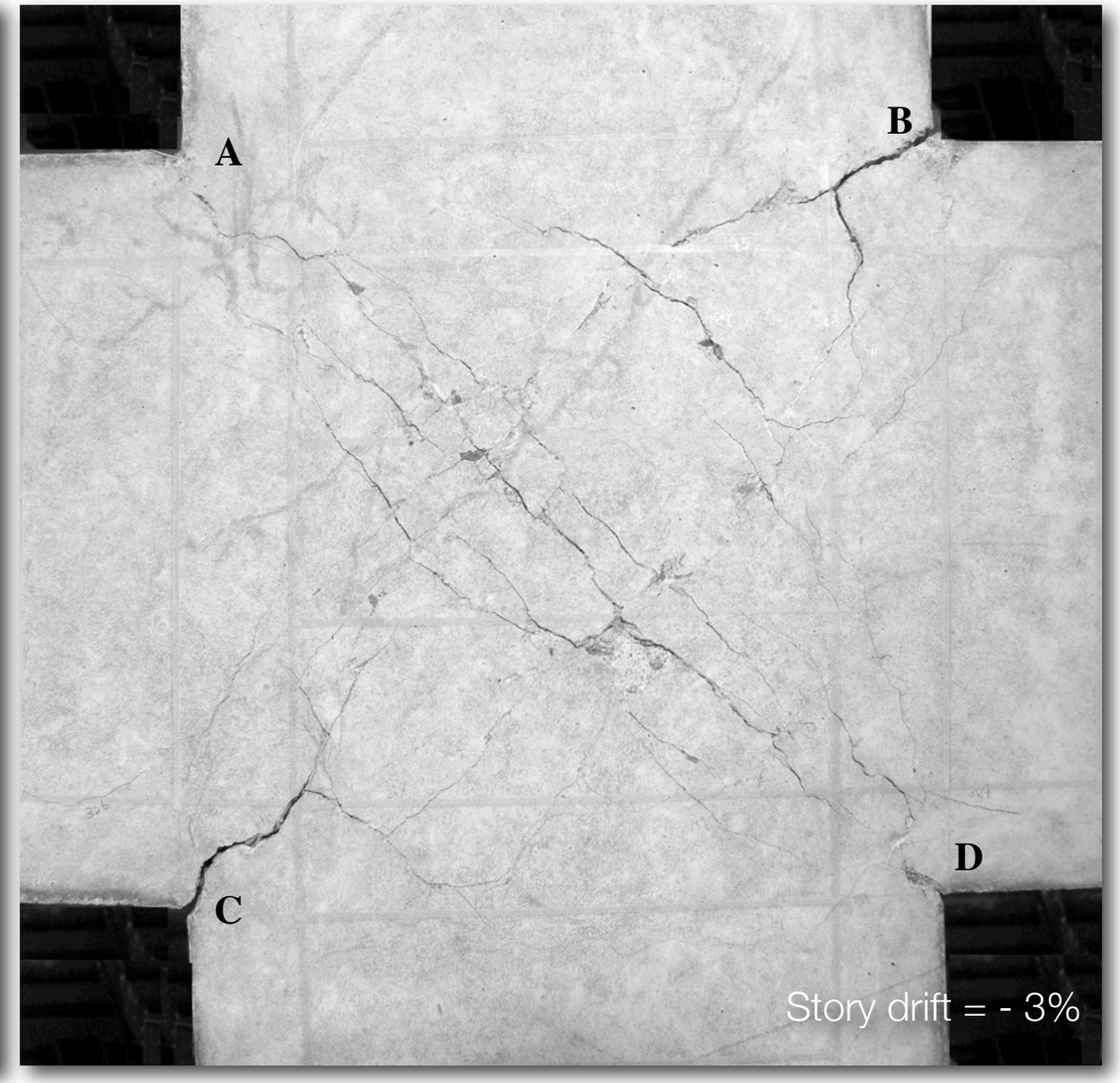
Observed Crack at 3% Story Drift

Observed Crack at 3% Story Drift



Observed Crack at 3% Story Drift





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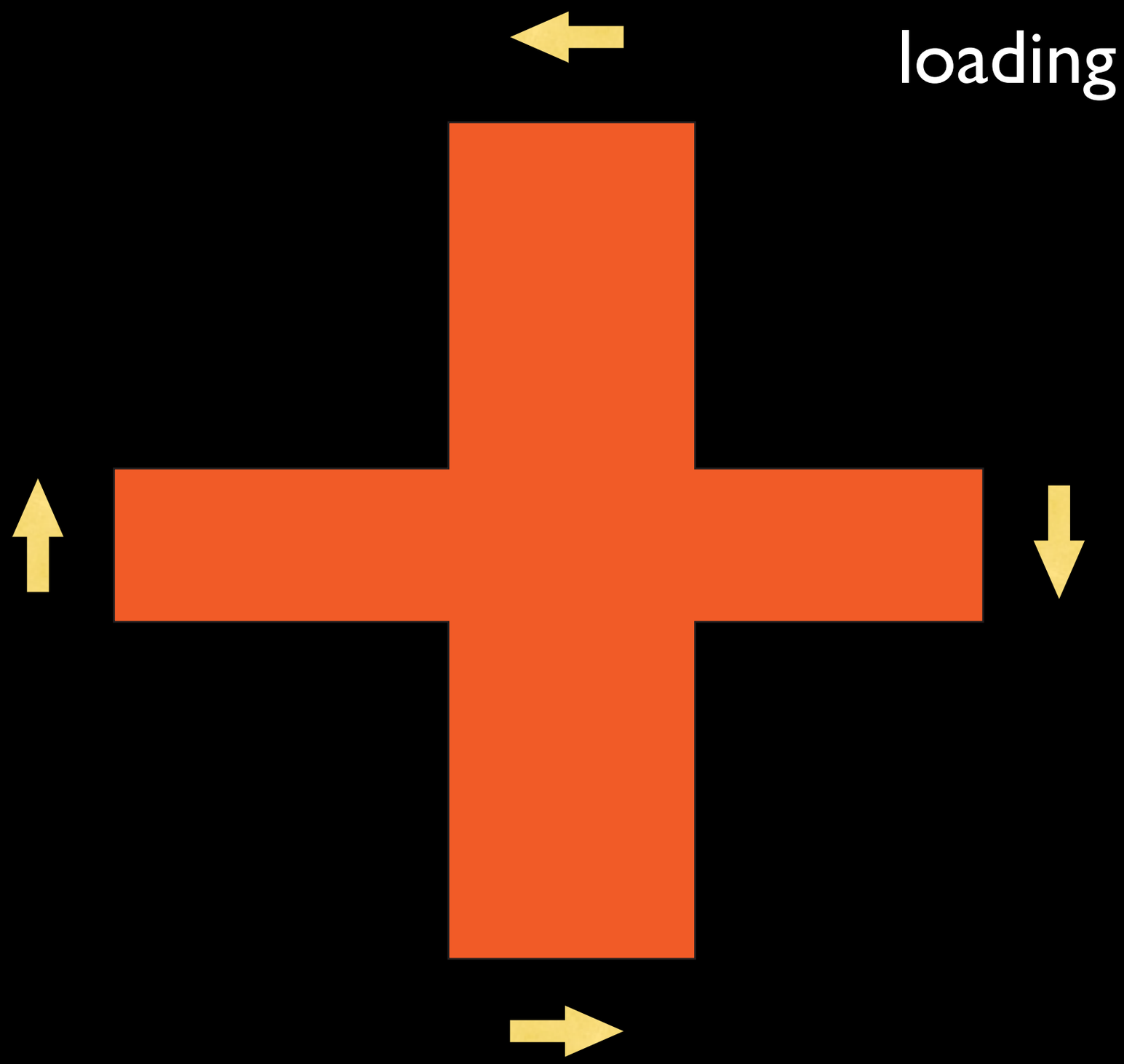
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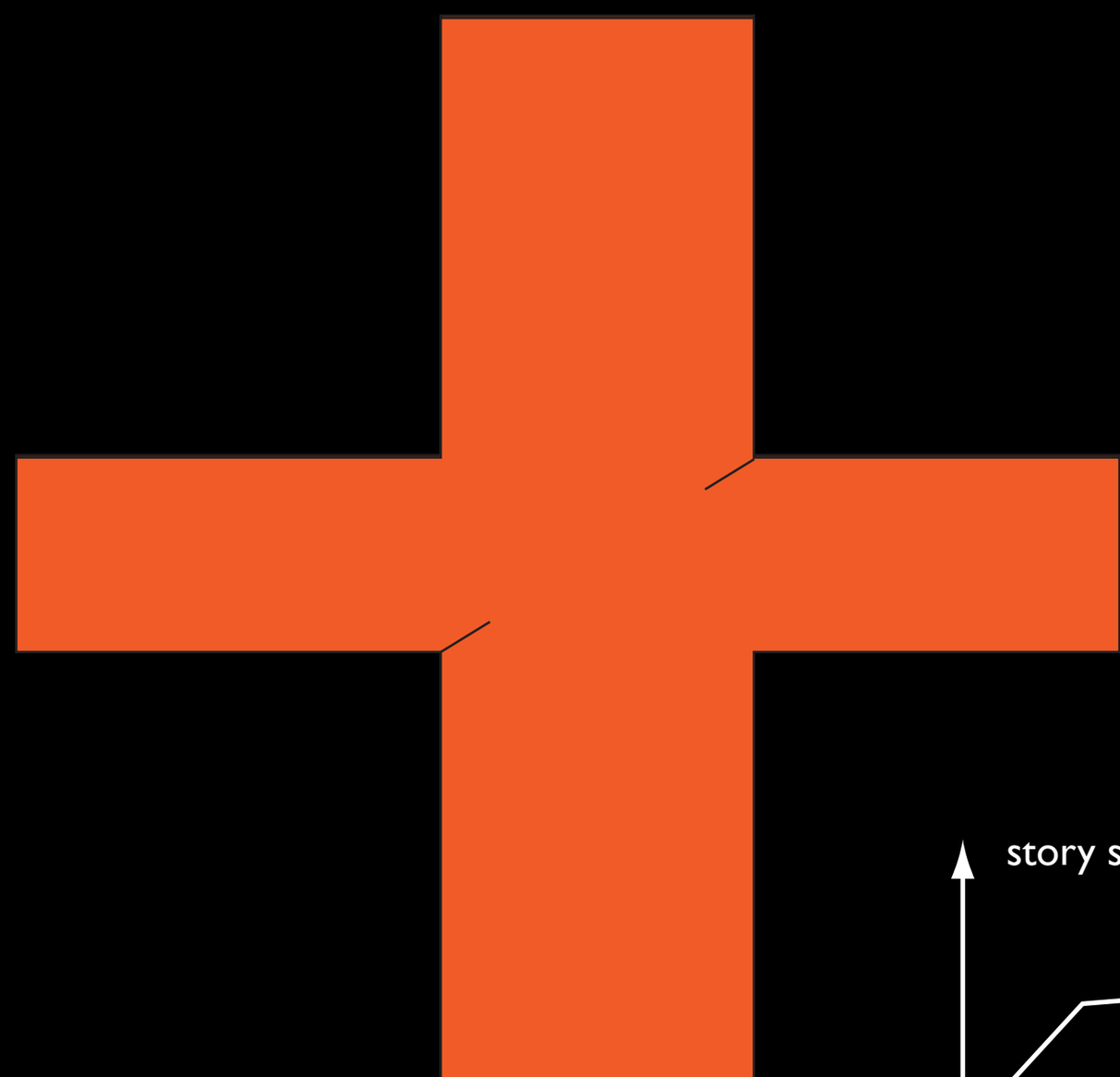
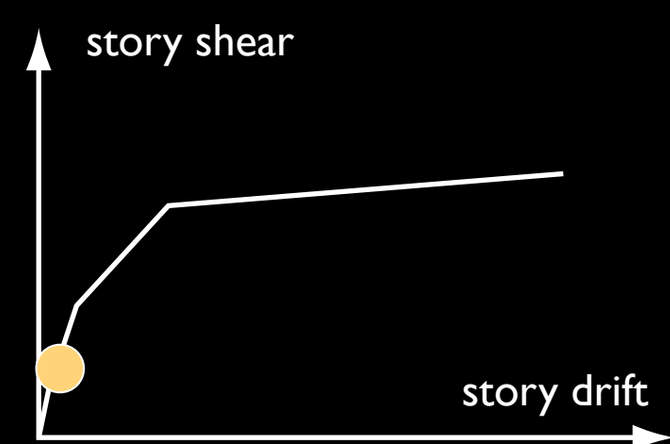
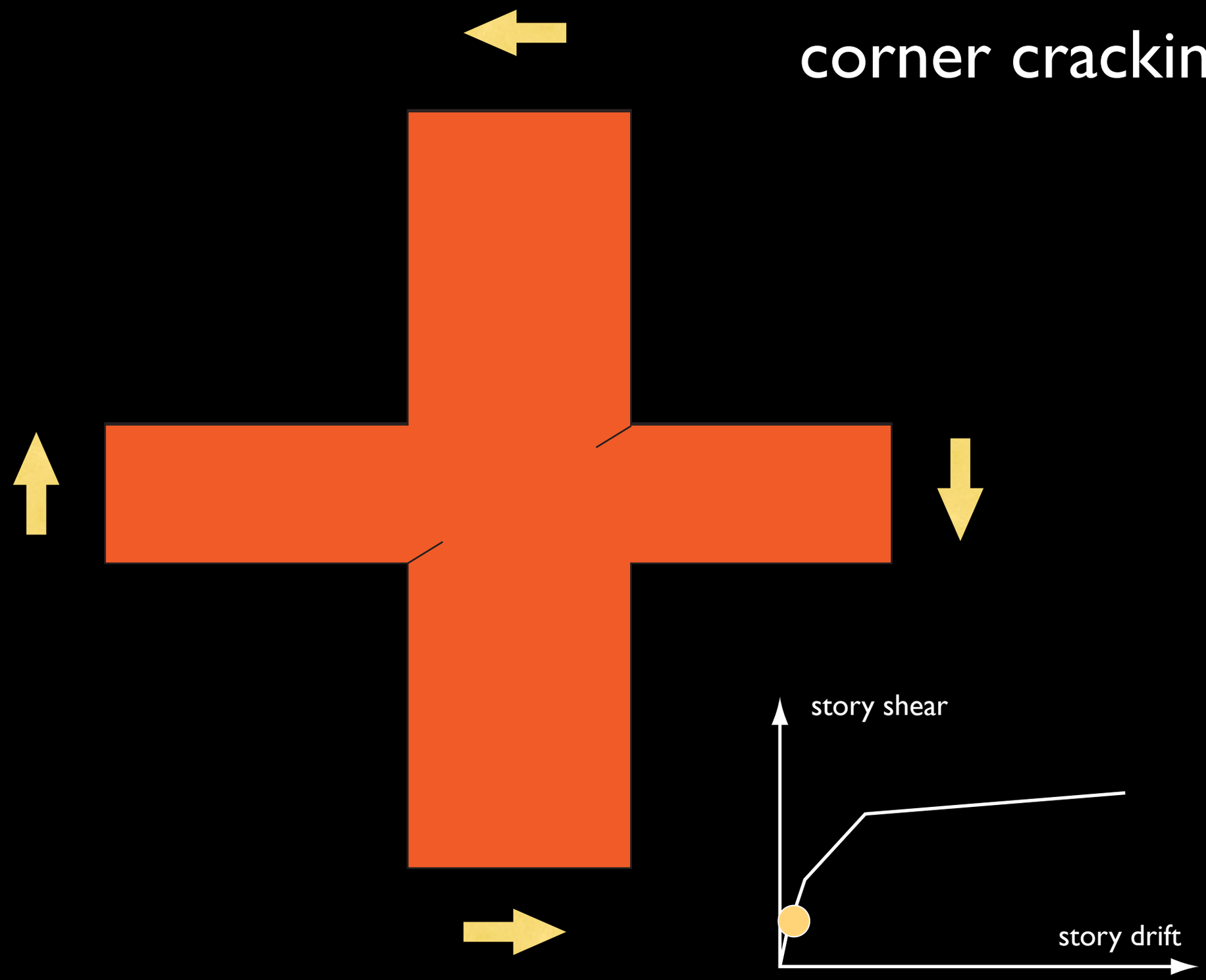
corner cracking

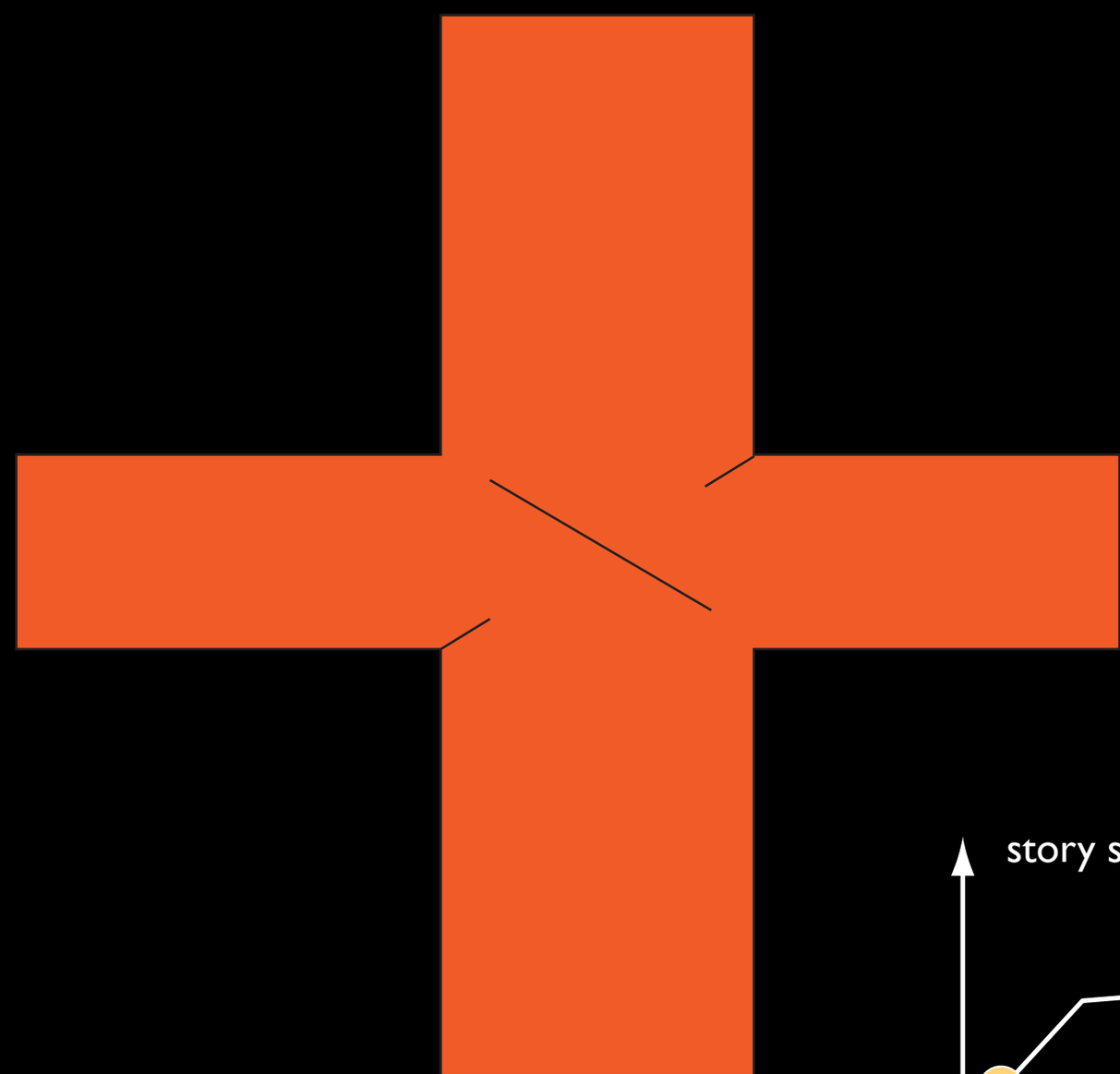


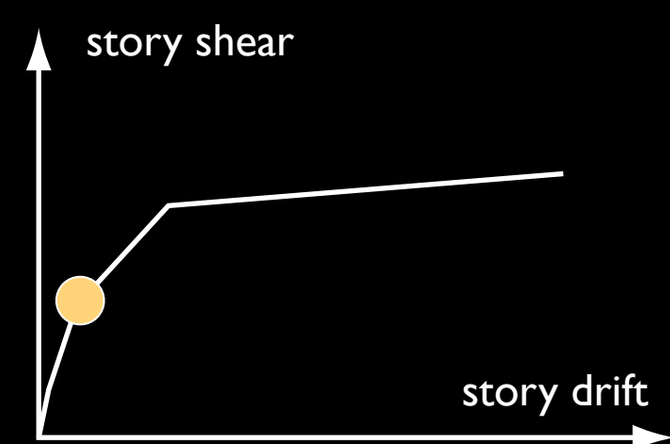


corner cracking

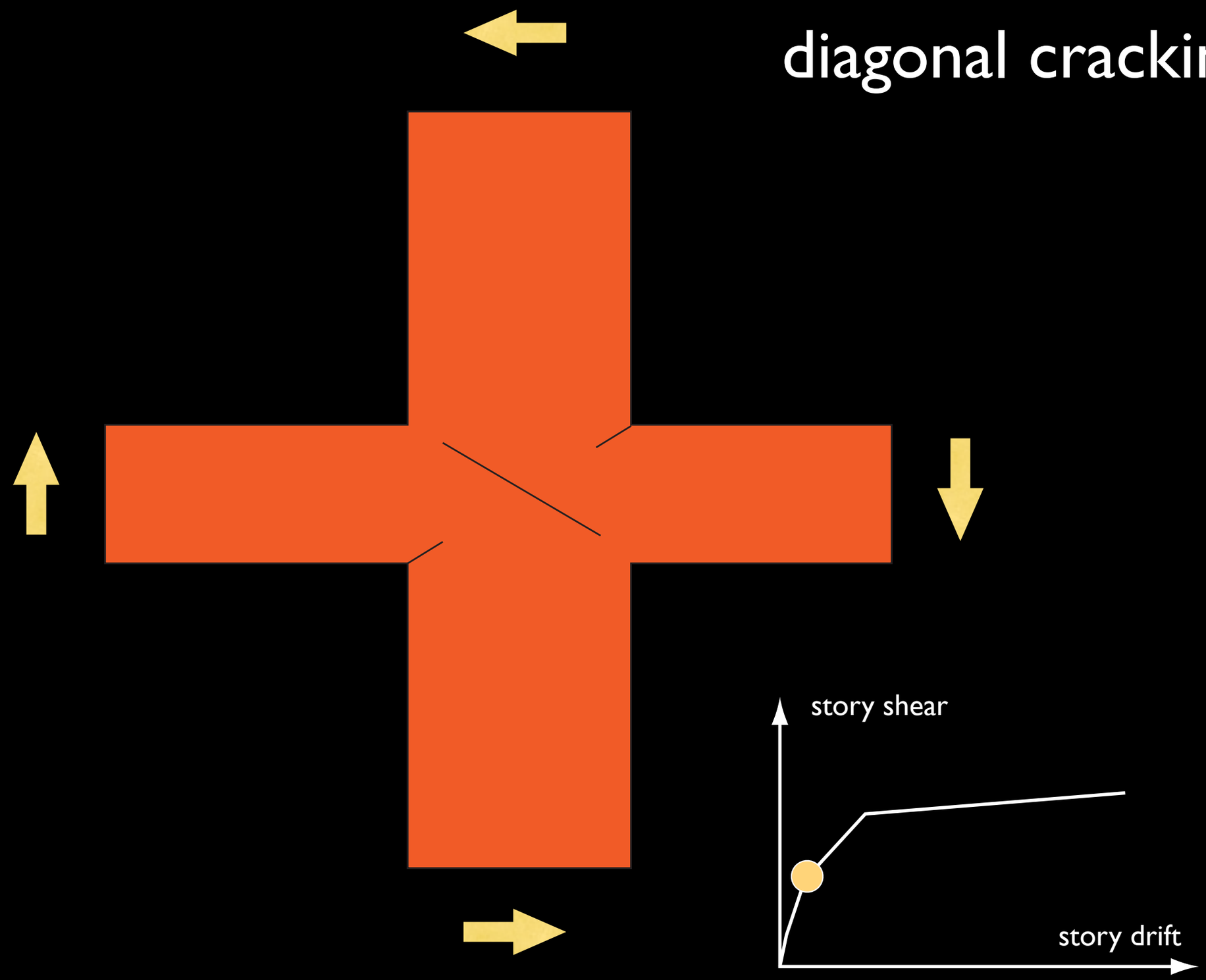


diagonal cracking

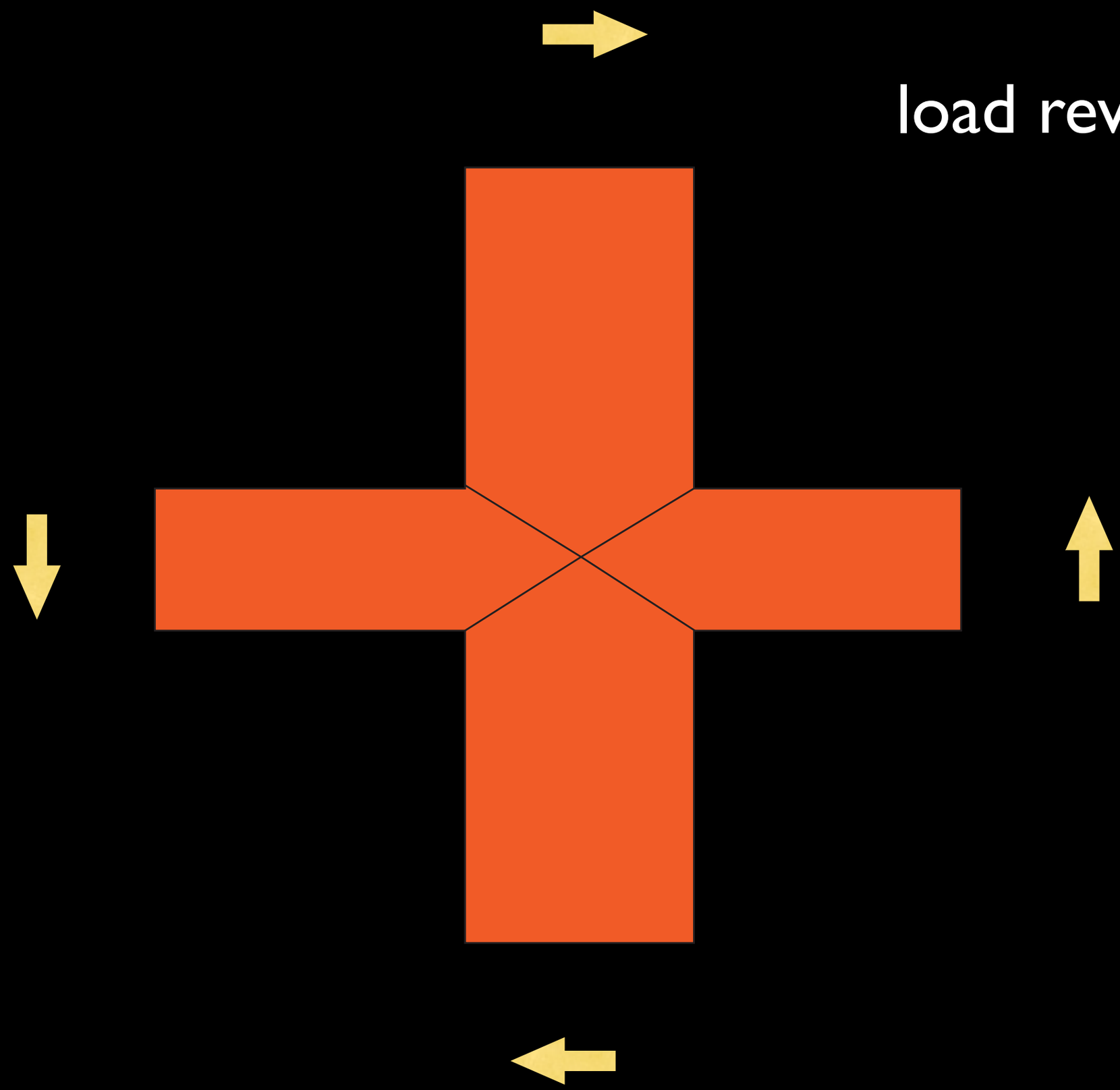




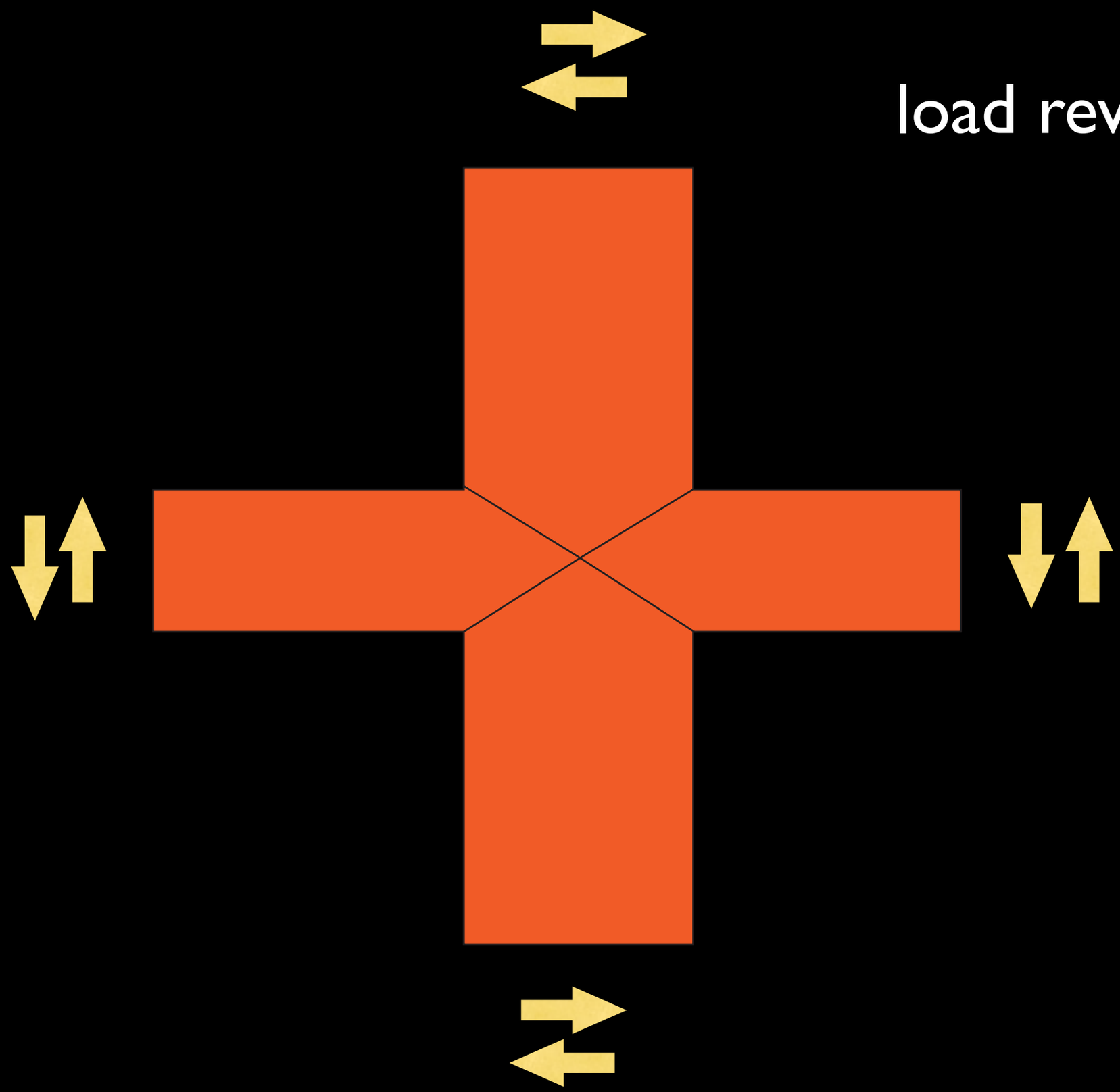
diagonal cracking



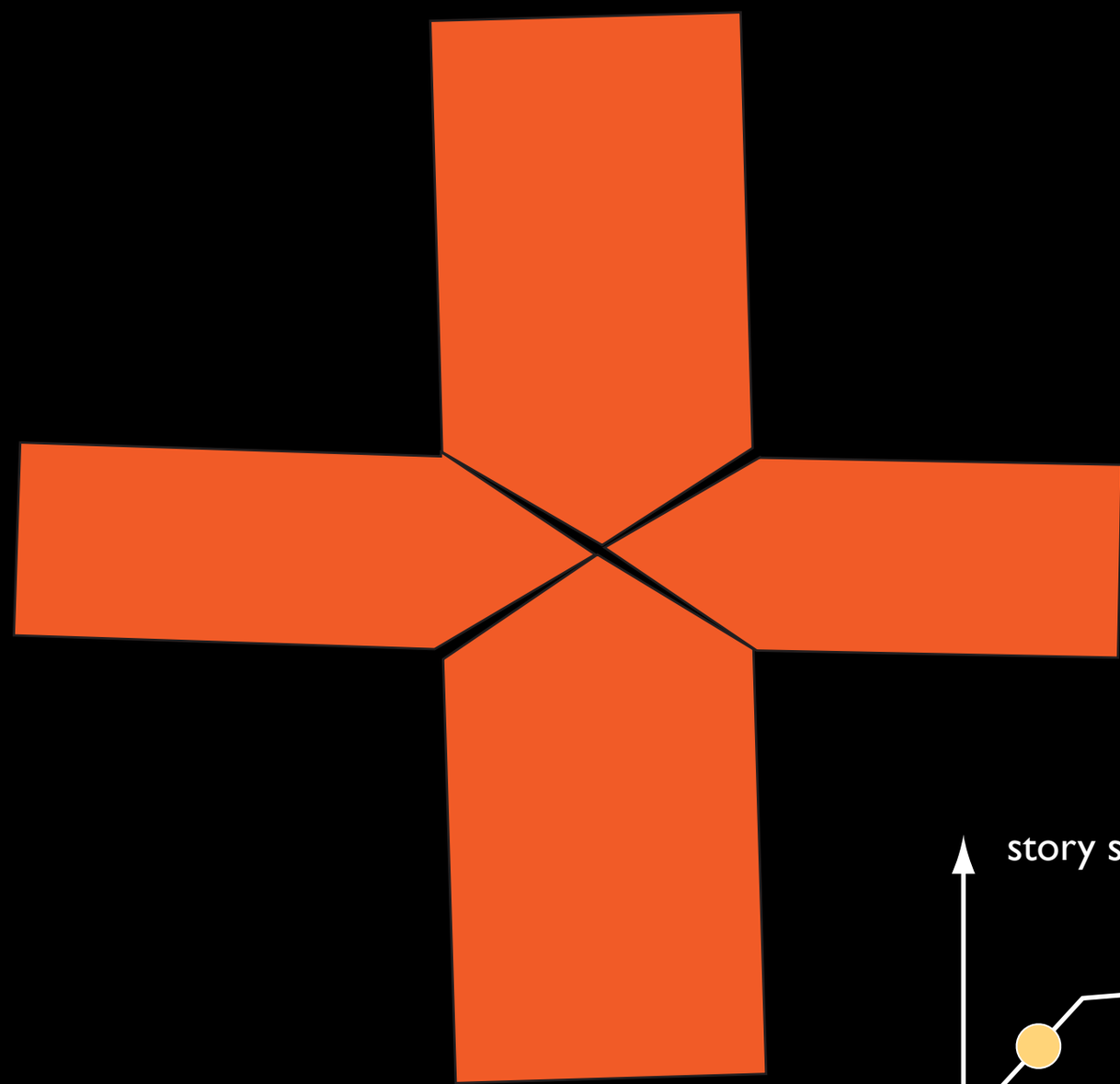
load reversals

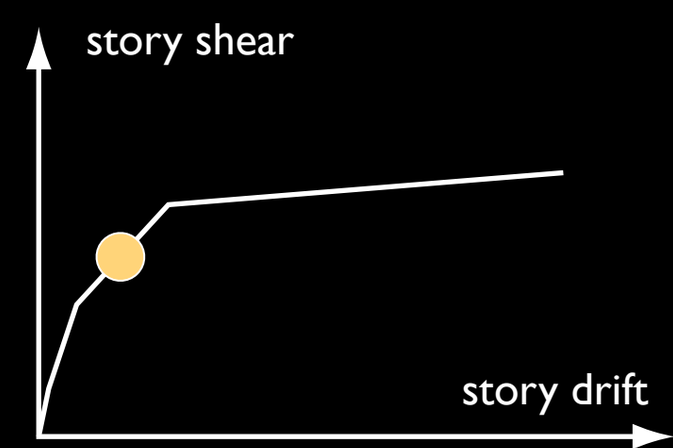


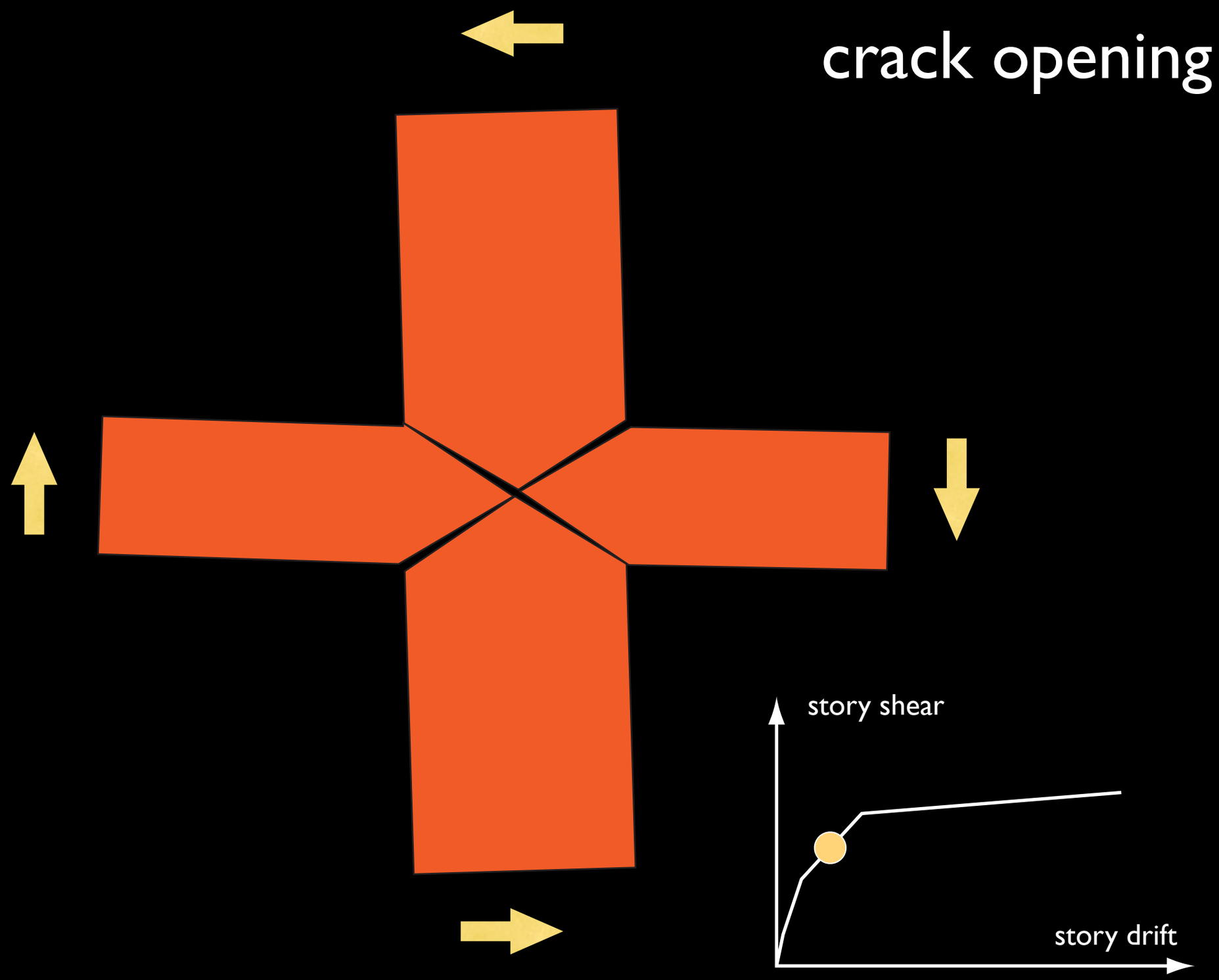
load reversals



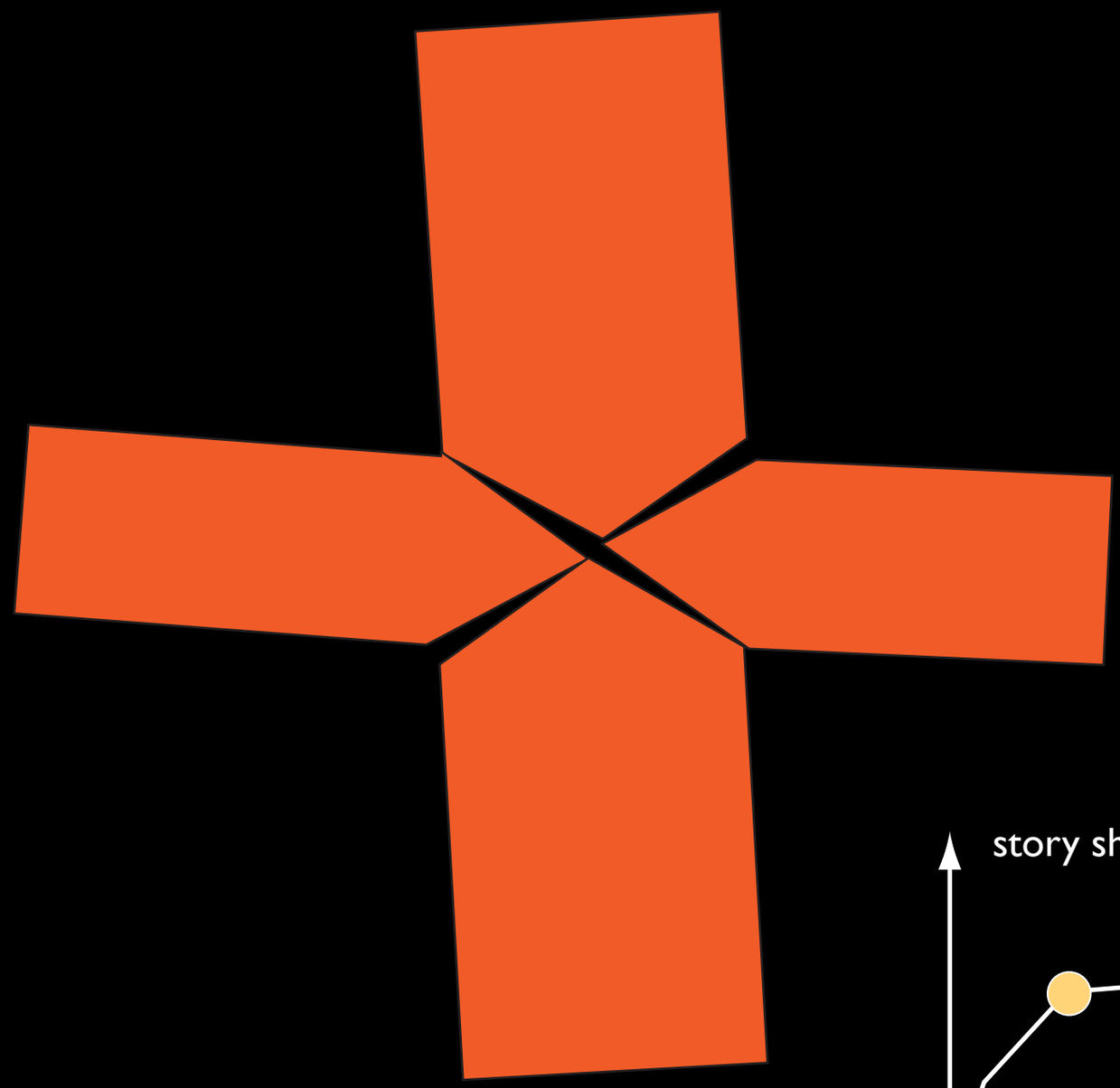
crack opening

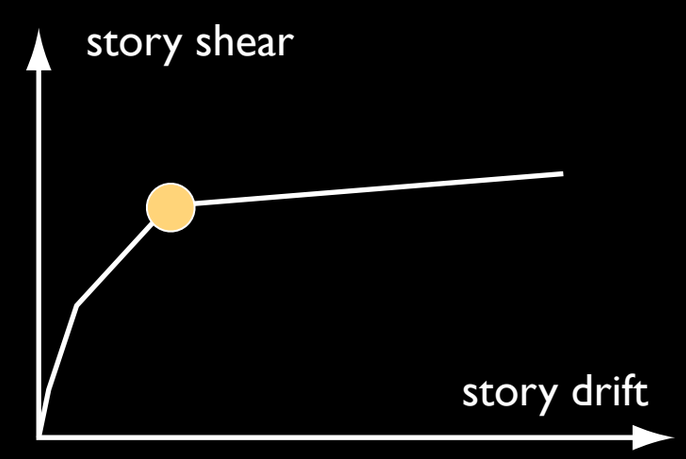




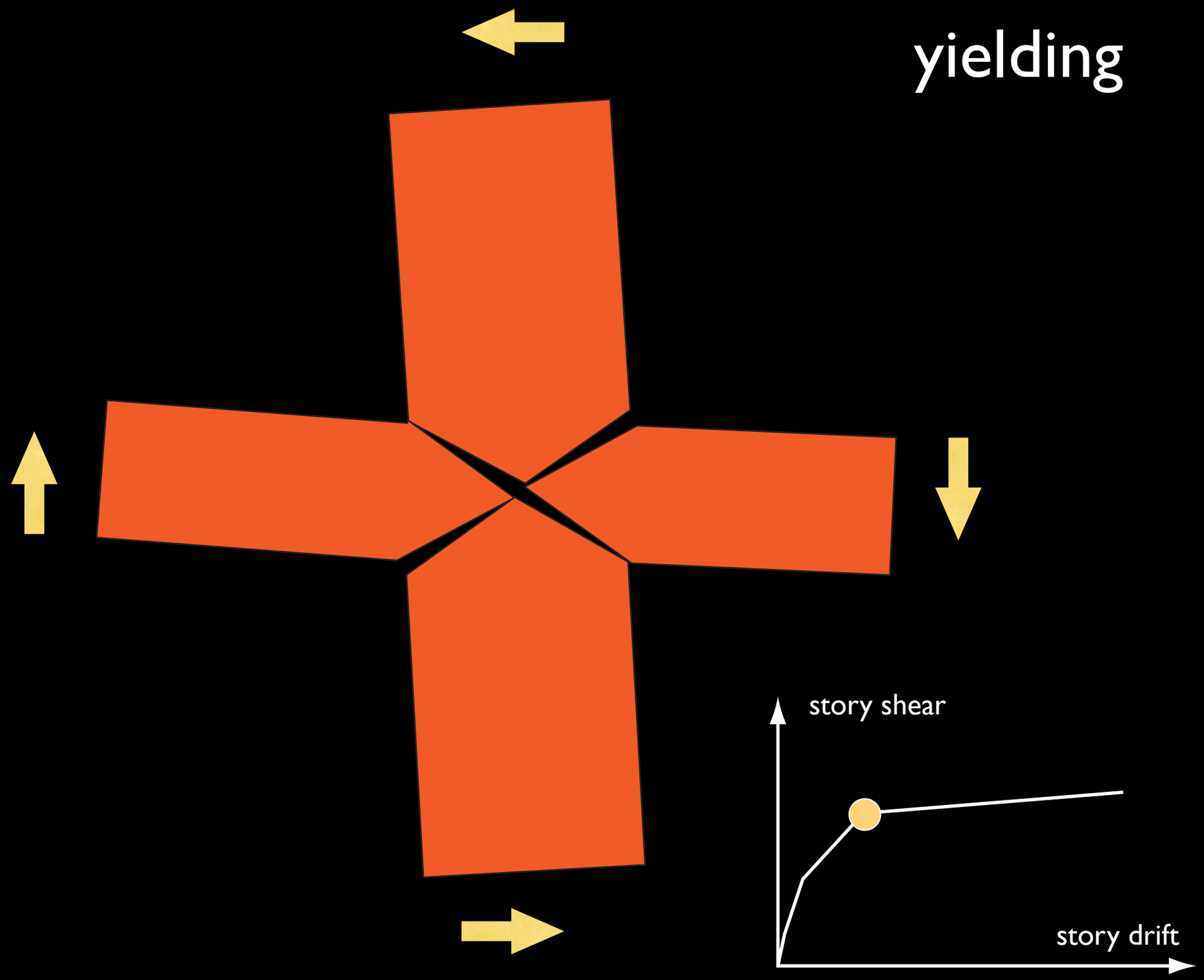

crack opening
story shear
story drift

yielding

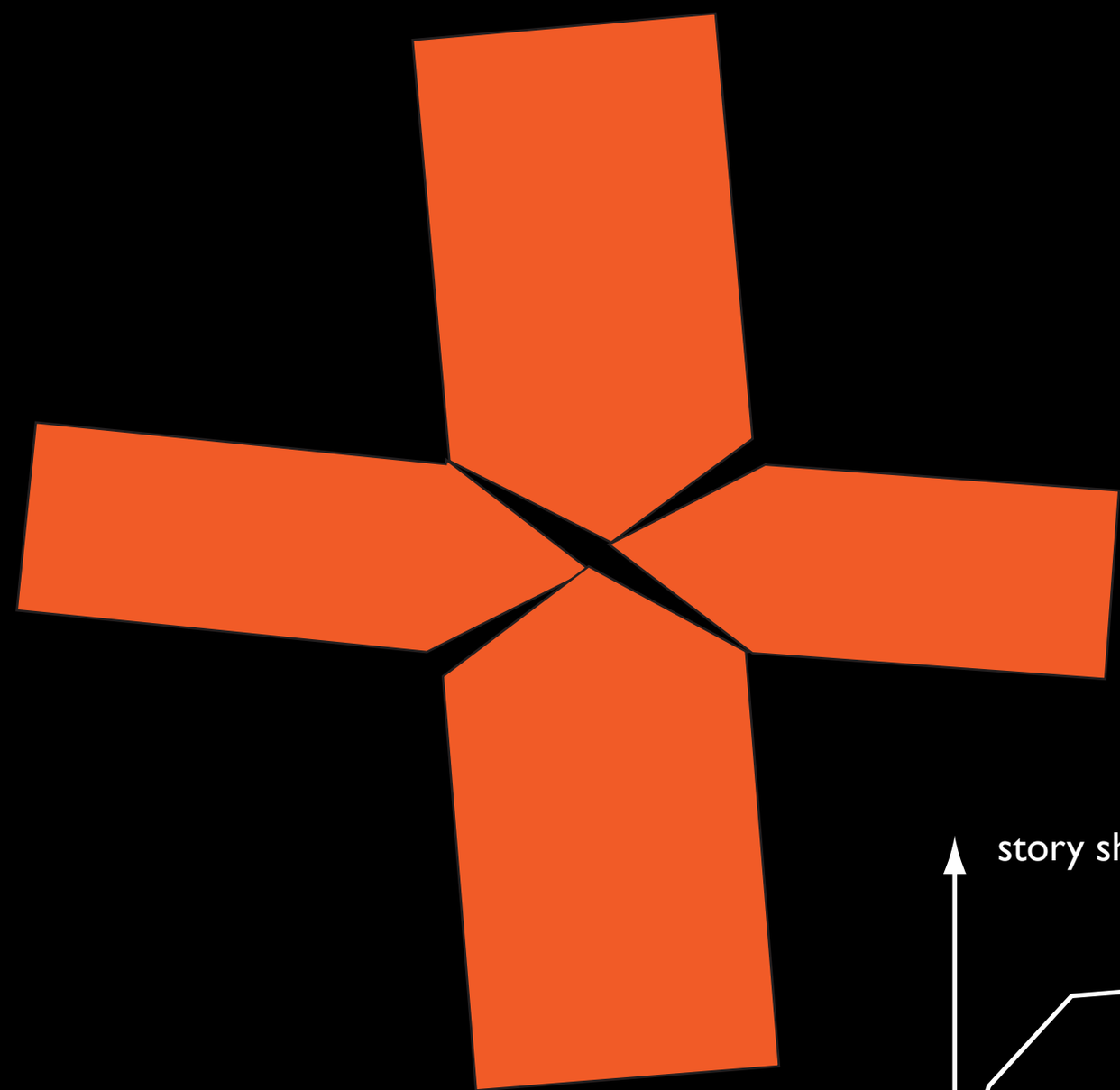


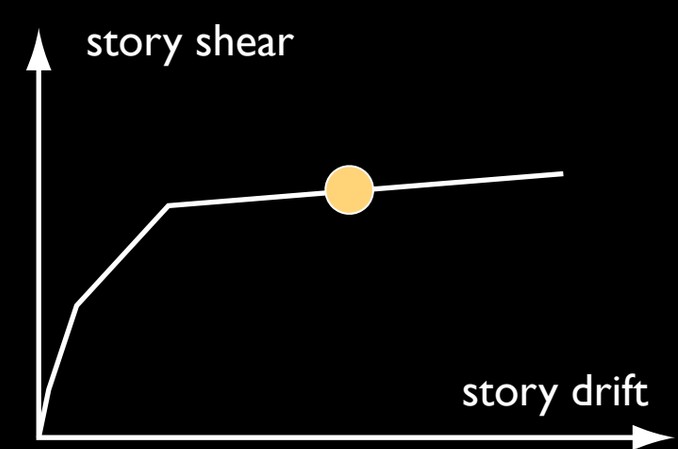


yielding



ultimate





ultimate