Failure Characterization of GFRP-Reinforced Concrete Walls

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National Center for Transportation Infrastructure Durability & Life-Extension

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Introduction

Background

- Shear walls are indispensable for a building structure to accommodate lateral loads. Improper designs accelerate the deterioration of load-bearing members and bring about serviceability problems

- Depending upon aspect ratio (h_w/l_w, where h_w and l_w are the height and length of a wall, respectively), shear walls are categorized as squat and slender; however, no absolute demarcation is available from a behavioral perspective

- On the use of GFRP reinforcement for shear walls, a consensus was not yet made. Some researchers argue that technical evidence is insufficient for field application; by contrast, others claim that the non-yielding nature of GFRP with a low elastic modulus improves the seismic performance of concrete members

Introduction

Need for research

- The design of shear walls is empirical and heavily relies on practitioners' experience without systematic derivations

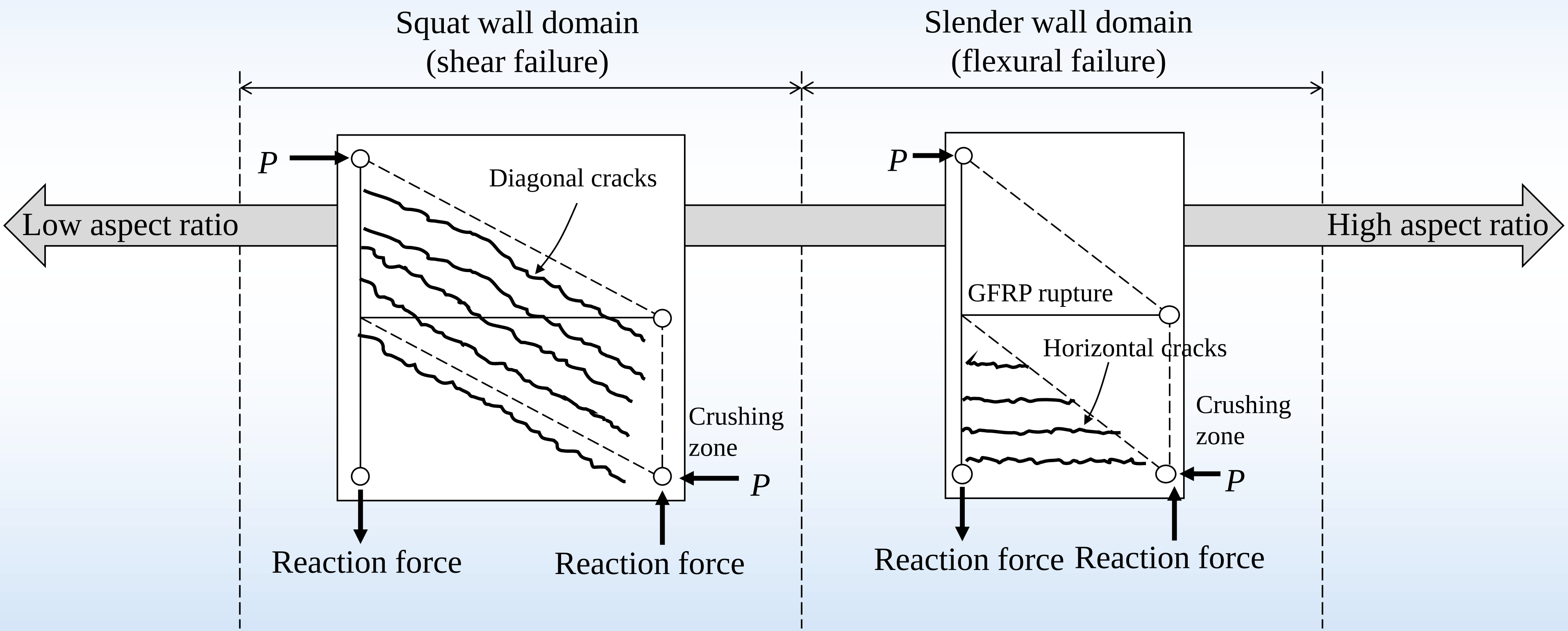
- As far as GFRP-reinforced squat walls are concerned, limited research has been reported and only a few experimental papers are available

- Because the failure mechanism of squat walls differs from that of slender walls, archetypal methods that are predicated upon ductile responses cannot be applied

- A refined mechanics-based model should be developed to elucidate the intrinsic behavior of squat walls with GFRP rebars, leading to the proposal of practical design equations

Introduction

Potential failure modes



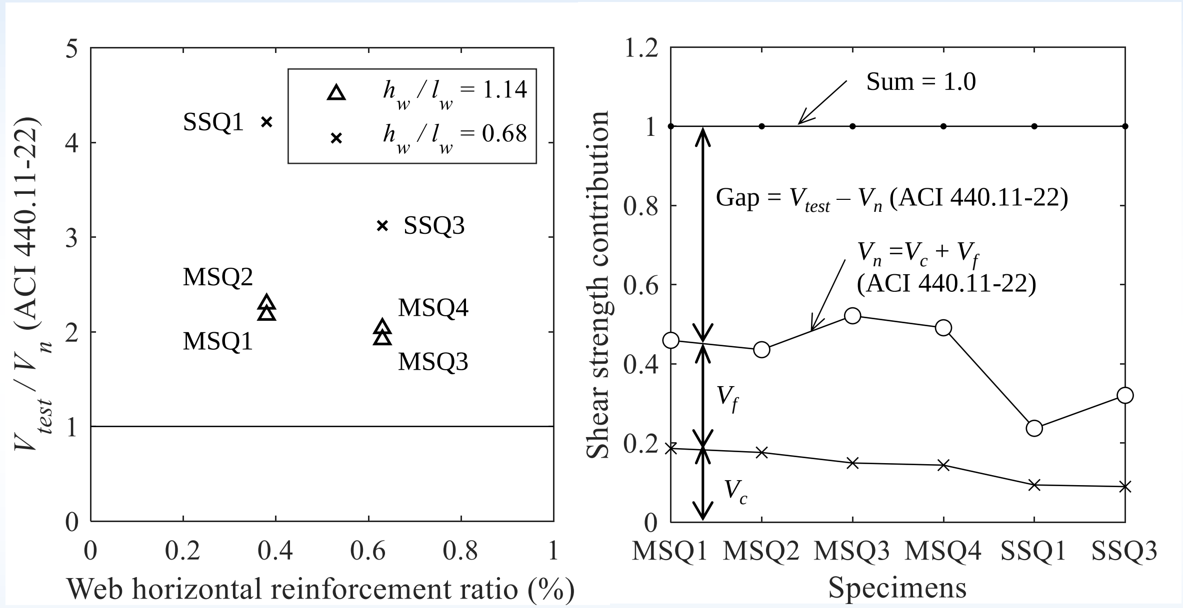
Introduction

Existing design methods (ACI 440.11-22)

$$V_n = V_c + V_f \leq V_{n,\max}$$

$$V_c = k_3 f_c'^{0.5} t_w kd = k_4 f_c'^{0.5} k l_w t_w$$

$$V_f = A_{fv} f_{fv} d / s = \rho_h f_{fv} l_w t_w$$

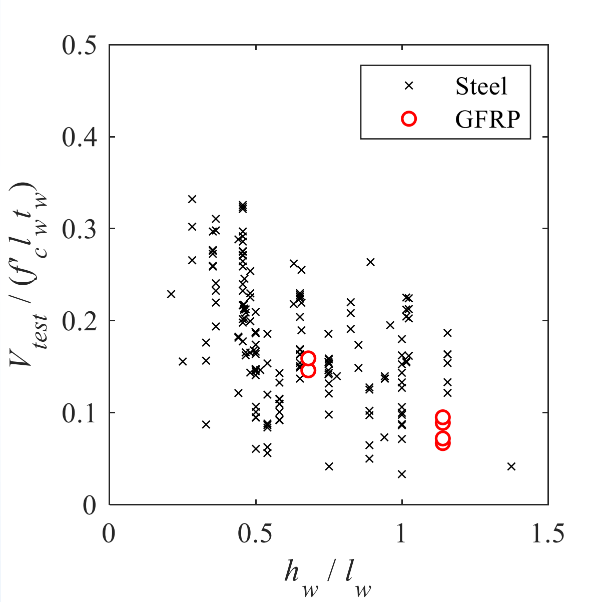


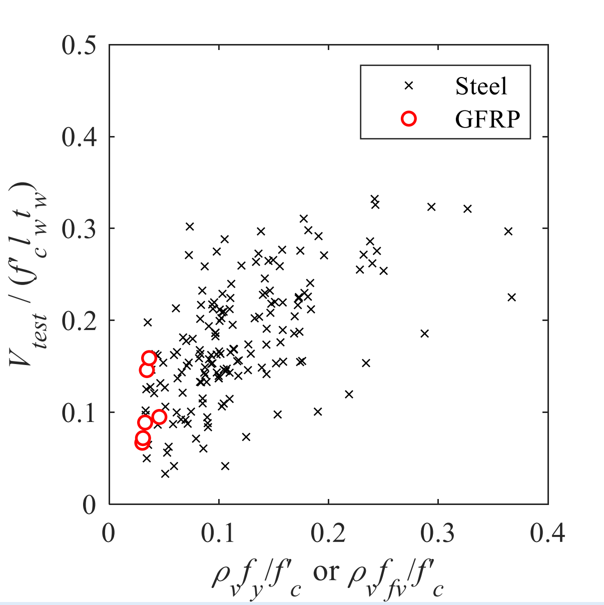
Design approach of ACI 440.11-22 does not cover GFRP-reinforced concrete squat walls

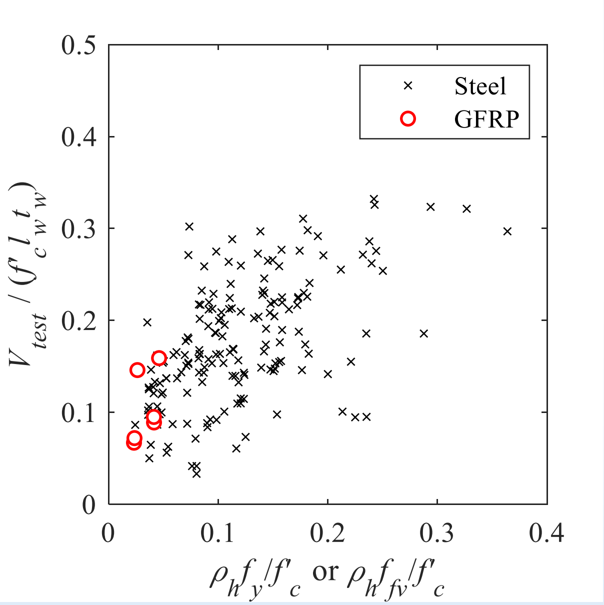
Introduction

Steel vs. GFRP

Experimental database



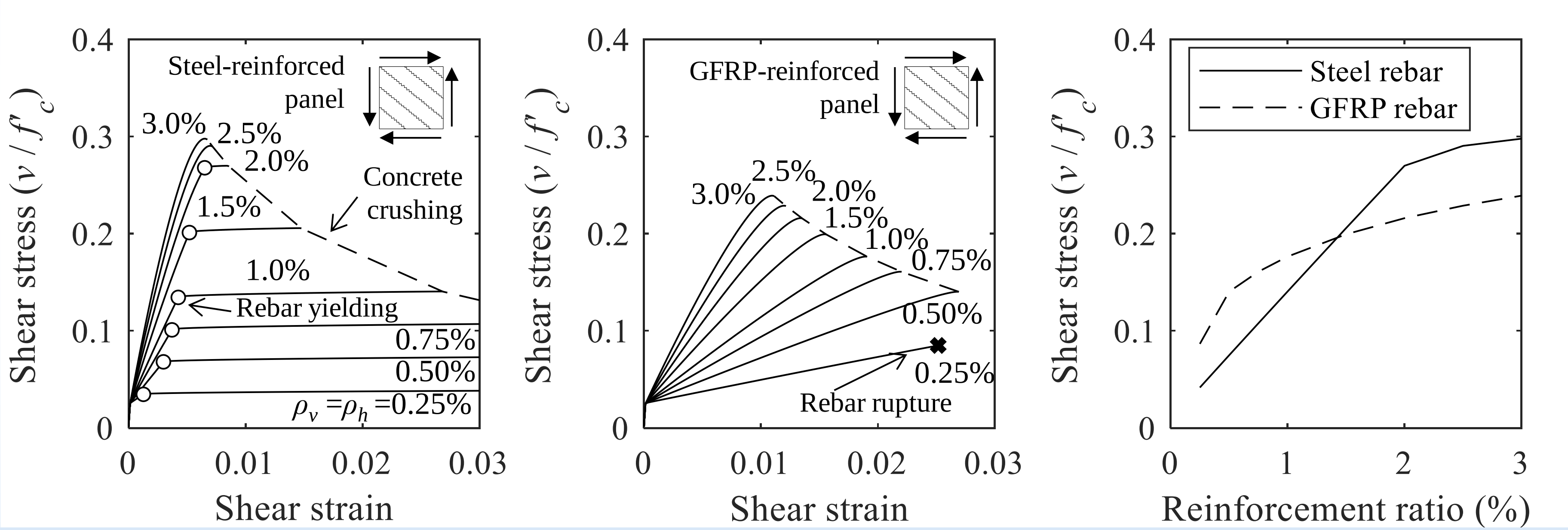




Introduction

Steel vs. GFRP

Element-level shear behavior



Model Development and Discussion

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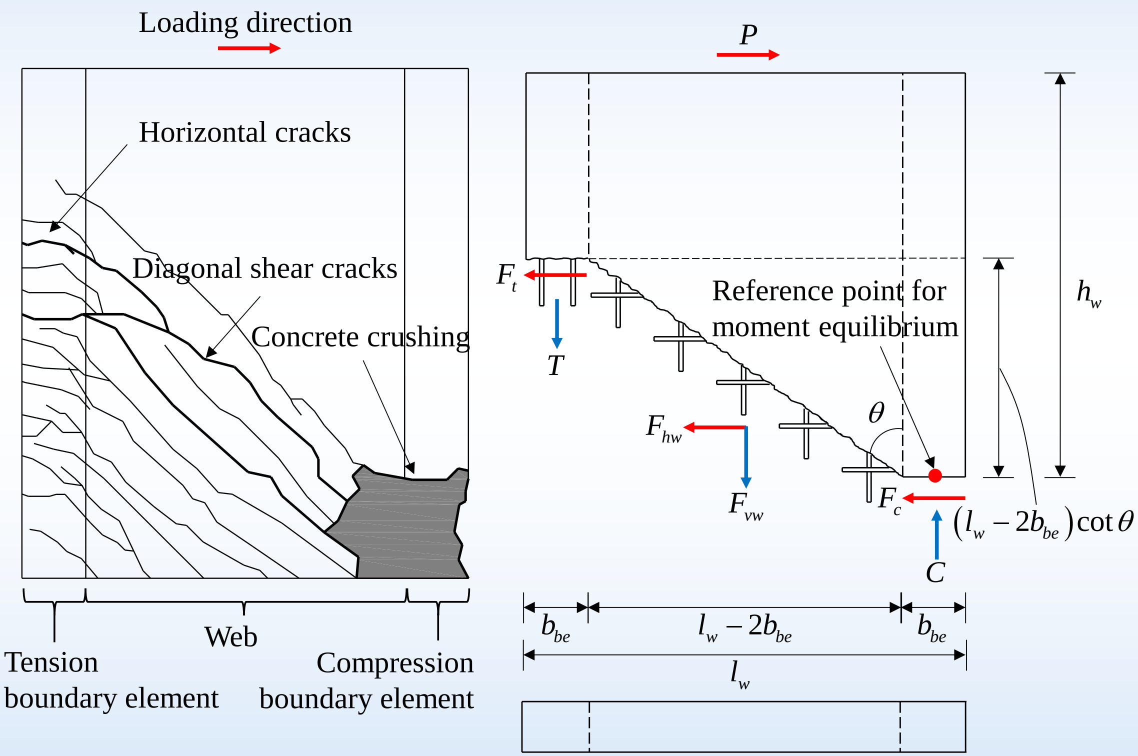
Model Development and Discussion

Mechanics-based model

$$P = F_t + F_{hw} + F_c$$
$$C = T + F_{vw}$$



$$F_{hw} = \rho_h E_f \varepsilon_h (l_w - 2b_{be}) t_w \cot\theta = \rho_h E_f \varepsilon_h A_{web} \cot\theta$$

$$F_{hv} = \rho_v E_f \varepsilon_v (l_w - 2b_{be}) t_w = \rho_v E_f \varepsilon_v A_{web}$$

$$T = \rho_{be} E_f \varepsilon_{be} b_{be} t_w = \rho_{be} E_f \varepsilon_{be} A_{be} = \rho_{be} E_f \varepsilon_v A_{be}$$

Failure modes:

1) Rupture of GFRP rebars in the web

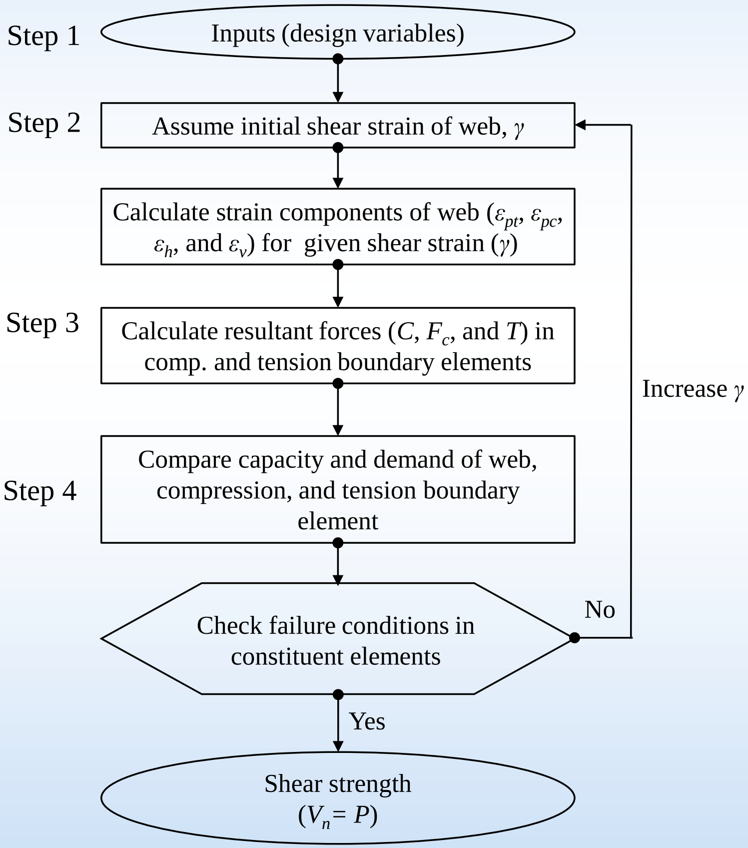
2) Web-crushing

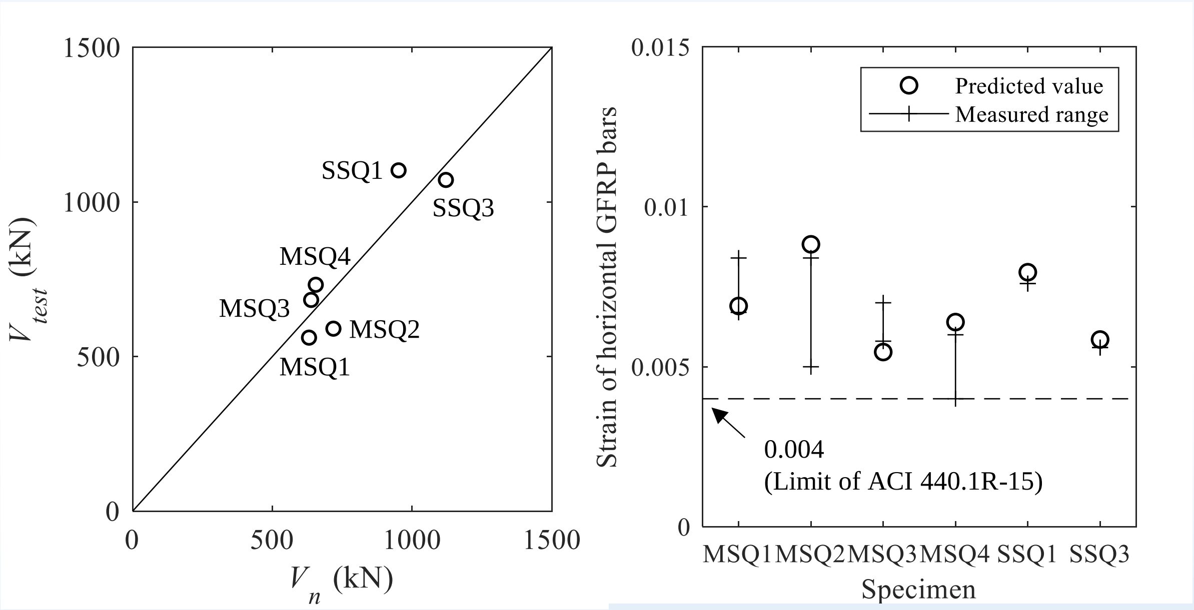
3) Rupture of GFRP rebars in the tension boundary element

4) Concrete crushing in the compression boundary element

Model Development and Discussion

Mechanics-based model





Validation

Design Recommendations

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Design Recommendation

Proposed revision

$$V_n = V_c + V_f = 0.3 f_c^{'} \beta l_w t_w + \left(0.004 E_f\right) A_{fv} d / s \le k_2 f_c^{'0.5} l_w t_w$$

(0.004E_f from ACI 440.1R-15)

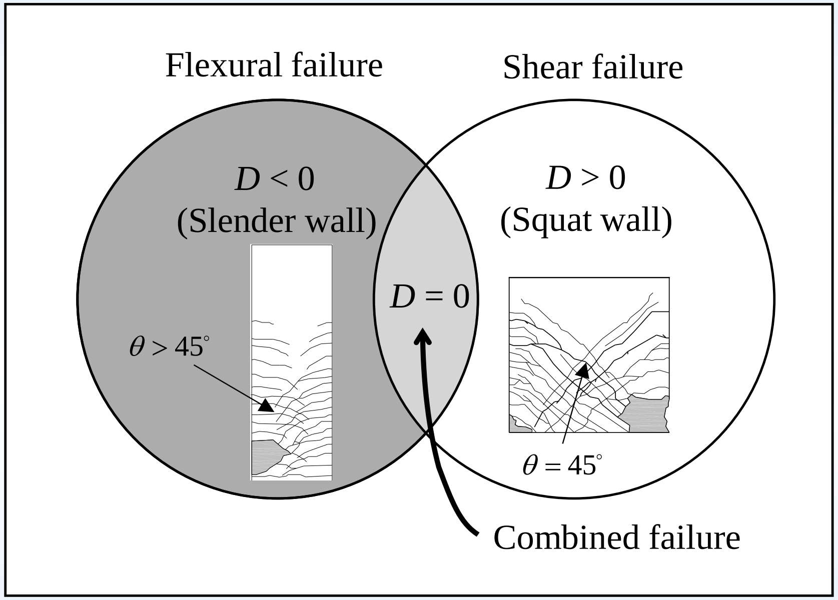
Determination of failure modes

$$D = \frac{F_c}{f_{fu} A_w} = 0.25 \left(\rho_{be} \frac{A_{be}}{A_w} \frac{l_w - b_{be}}{h_w} + \rho_v \frac{A_{web}}{A_w} \frac{l_w - b_{be}}{2h_w} + \rho_h \frac{A_{web}}{A_w} \left(\frac{l_w - 2b_{be}}{2h_w} - 1 \right) \right)$$

(D = failure determinant index, instead of simple aspect ratios)

Design Recommendation

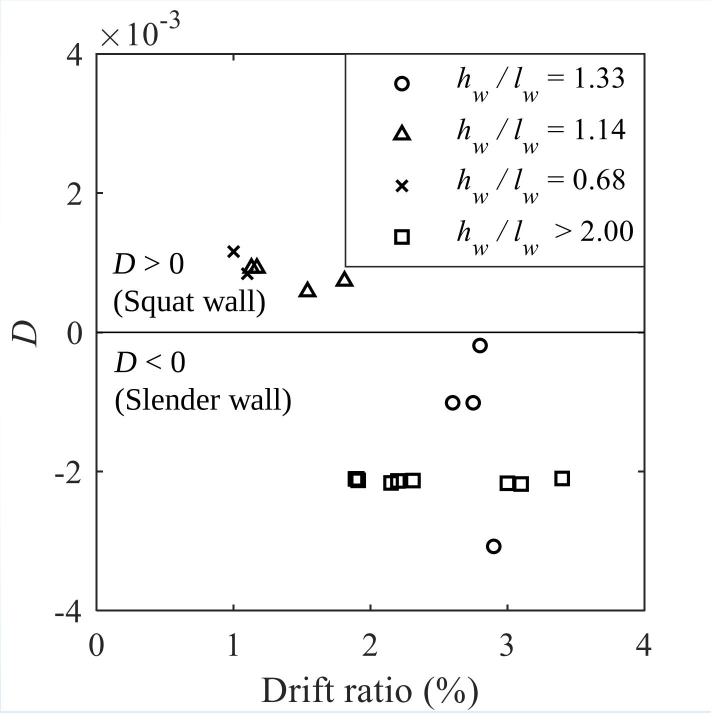
Application of proposed determinant index



$D > 0 \rightarrow$ squat walls with shear failure

$D = 0 \rightarrow$ trantision with combined shear-flexural failure

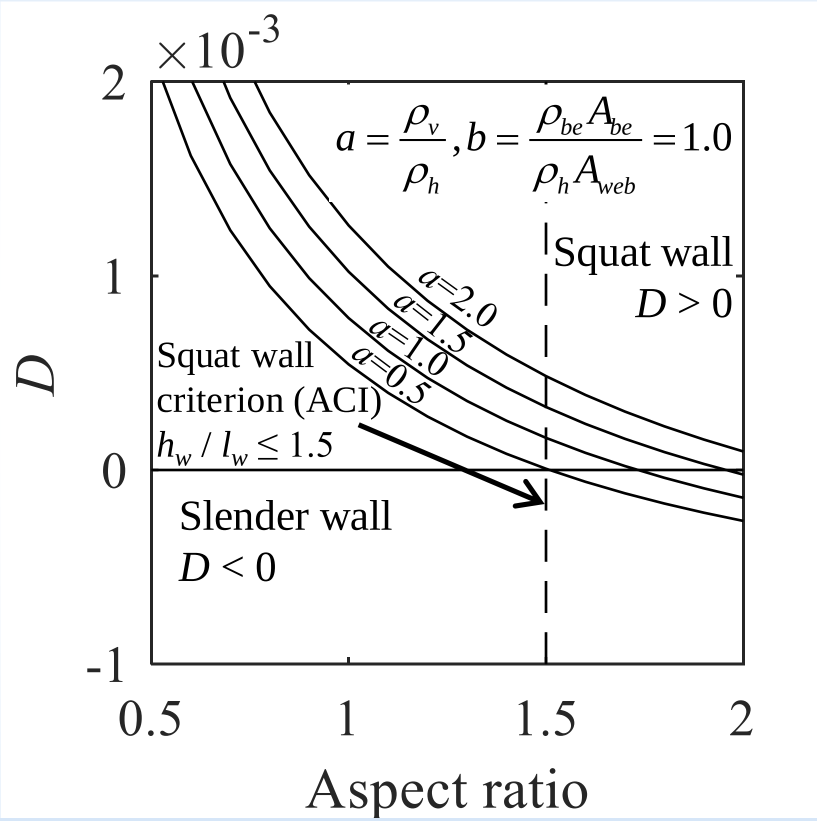
$D < 0 \rightarrow$ slender walls with flexural failure



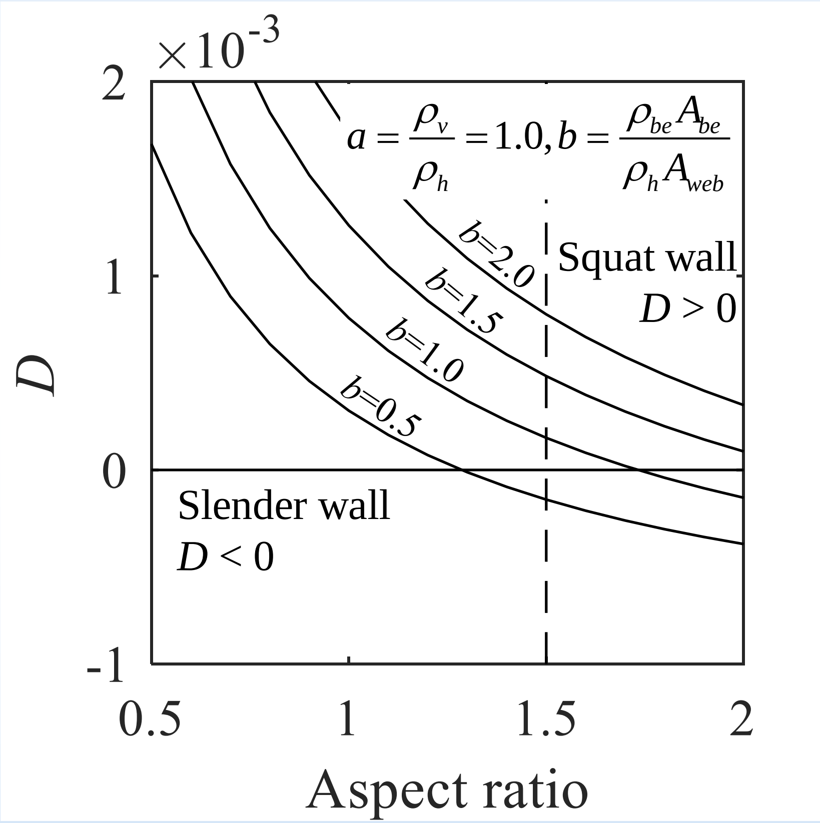
Experimental assessment

Design Recommendation

Parametric analysis



Vertical reinforcement ratio in web



Longitudinal reinforcement ratio in boundary elements

Conclusions

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Conclusions

- The provisions of ACI 440.11-22 underestimated the shear capacity of GFRP-reinforced squat walls, owing to the empirical nature of the equations originating from flexure-shear-combined responses
- The behavioral differences of squat walls with steel and GFRP rebars were evident in terms of failure characteristics and shear stress developments. The source of these discrepancies was reinforcing amounts, tension-stiffening mechanisms, and material properties
- Contrary to the prevalent methodologies relying on ambiguous aspect ratios, the determinant index demystified the classification of squat walls by utilizing the geometric and reinforcing attributes of the walls

Acknowledgements

- **Thank-you to:**

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