SEISMIC PERFORMANCE OF CORNER NON-DUCTILE BEAM COLUMN JOINTS IN GRAVITY LOAD DESIGNED REINFORCED CONCRETE BUILDINGS

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Outline

- Part 1: Background & Review of Available Relevant Literature
  1- Background, past Earthquake Joint Failures
  2- Tests on Non-Ductile Exterior Joints
  3- Tests on Non-Ductile Corner Simulated Joints
  4- Tests on Non-Ductile Corner Joints
  5- General Experimental Conclusions
  6- Joint Shear Strength Degradation Trends

- Part 2: Full Scale Corner Joint Tentative Test
  1- Suggested Test Parameters
  2- Suggested Test Matrix & Specimen Design
  3- Test Setup 4- Work Schedule

PART 1

REVIEW OF AVAILABLE LITERATURE

BACKGROUND

PAST EARTHQUAKE Corner & Exterior BEAM COLUMN JOINT FAILURES

Severe Joint Damage

BACKGROUND

PAST EARTHQUAKE Corner & Exterior BEAM COLUMN JOINT FAILURES




Partial Building Collapse

BACKGROUND

PAST EARTHQUAKE Corner & Exterior BEAM COLUMN JOINT FAILURES

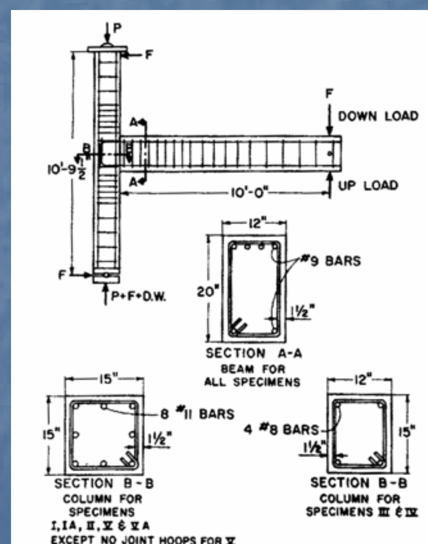
Complete Building Collapse

TEST ON EXTERIOR BEAM COLUMN JOINTS

1- Hanson & Conner 1965 (PCA, Illinois)

TEST PARAMETERS

-Axial Load Level 0.54 fc'Ag to 0.86 fc'Ag. Constant Axial Load
-Joint Concrete Strength (matching either column or beam strength).
-Isolated Joint versus Joint with transverse stubs both sides.

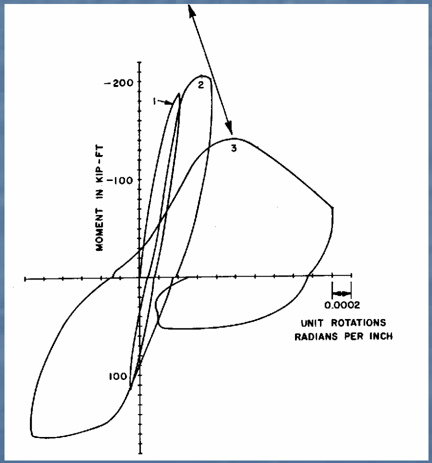


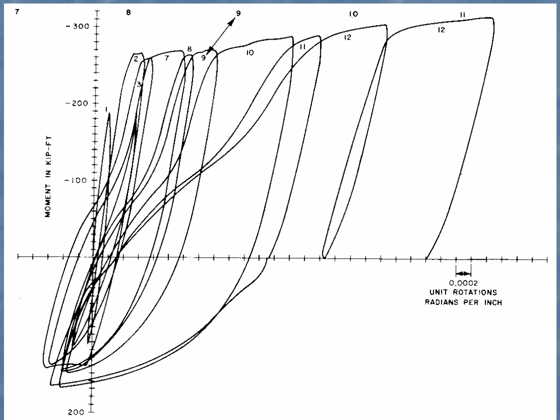
1- Hanson & Conner 1965 (PCA, Illinois)

TEST RESULTS

-Isolated Exterior Joint, with joint fc' = Beam fc' :
Totally inadequate & Brittle, causing joint failure at γ=11.3, without beam yielding.

-Exterior Joint with transverse stub & joint fc'=column fc':
Performed very satisfactorily, ductility index μ=17, joint failure at γ=11.3 after beam yielding. No need for joint hoops (sic).





TESTS ON EXTERIOR BEAM COLUMN JOINT

2- Uzumeri 1977 (U of Toronto)

TEST PARAMETERS

-Axial Load Level constant 0.51 f_c'A_g . Constant Axial Load

-Loading History

-Isolated Joint versus Joint with transverse stub on one side (simulated corner joint).

TESTS ON EXTERIOR BEAM COLUMN JOINT

2- Uzumeri 1977 (U of Toronto)

TEST RESULTS

-Axial Load is Helpful in Early Loading Stages & Detrimental at Later Stages.

-Loading History doesn't Affect the Response

-Simulated corner joint showed similar performance to isolated one

TESTS ON EXTERIOR BEAM COLUMN JOINT

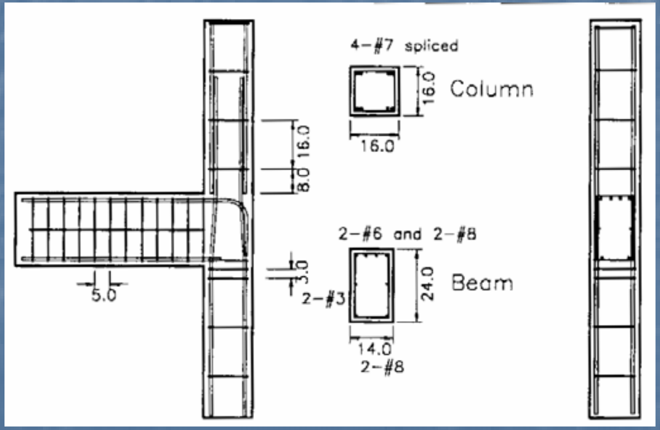
3- Beres et al 1990 (Cornell University)

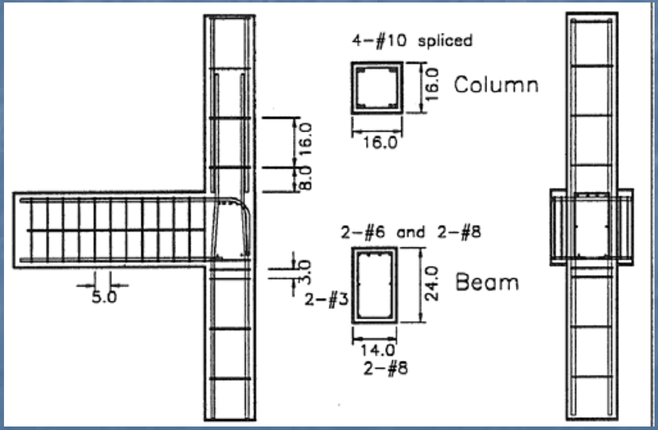
TEST PARAMETERS

-Axial Load Level 0.11 $f_c'A_g$ vs 0.39 $f_c'A_g$ Constant Axial Load.

-Column to Beam Flexural Capacities

-Isolated Joint versus Joint with transverse stubs on both side (Prestressed stubs)





Realistic Pre 1971 Construction with all deficiencies

TESTS ON EXTERIOR BEAM COLUMN JOINT

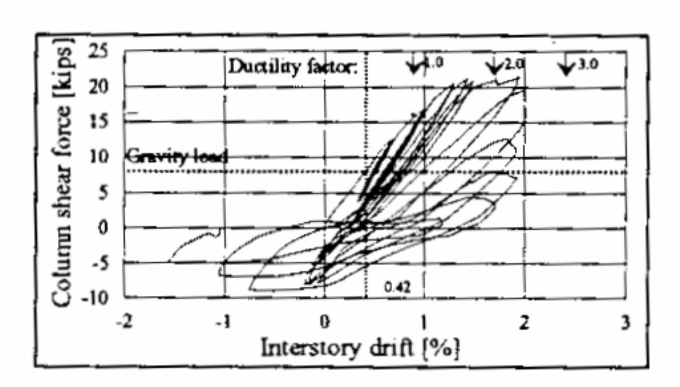
3- Beres et al 1990 (Cornell University)

TEST RESULTS

-Failure mode generally is joint shear failure accompanied or followed by upper column splice failure. Joint shear strength ranges from γ=5.3 - γ=8.3

-Higher Axial Load: Increase joint strength by 20%, more gradual strength degradation, but sudden failure at the end.

-Transverse stubs: Nothing to the strength at high axial load- 25% joint strength gain at low axial. & generally less severe cracking & more gradual degradation.

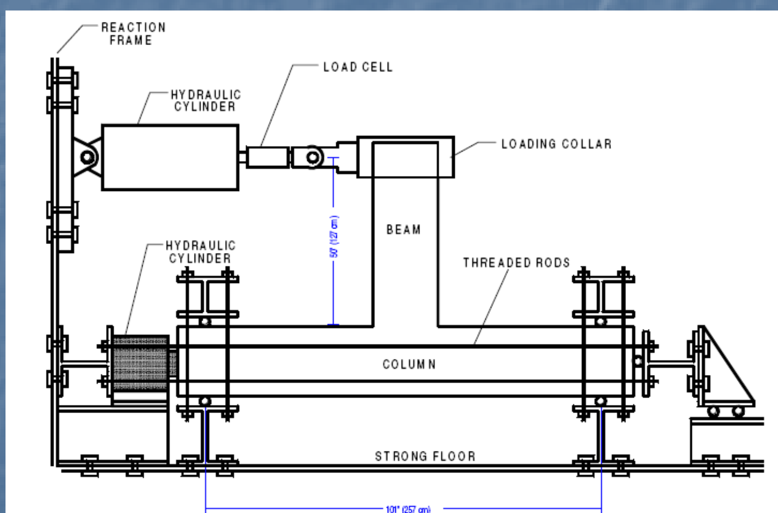


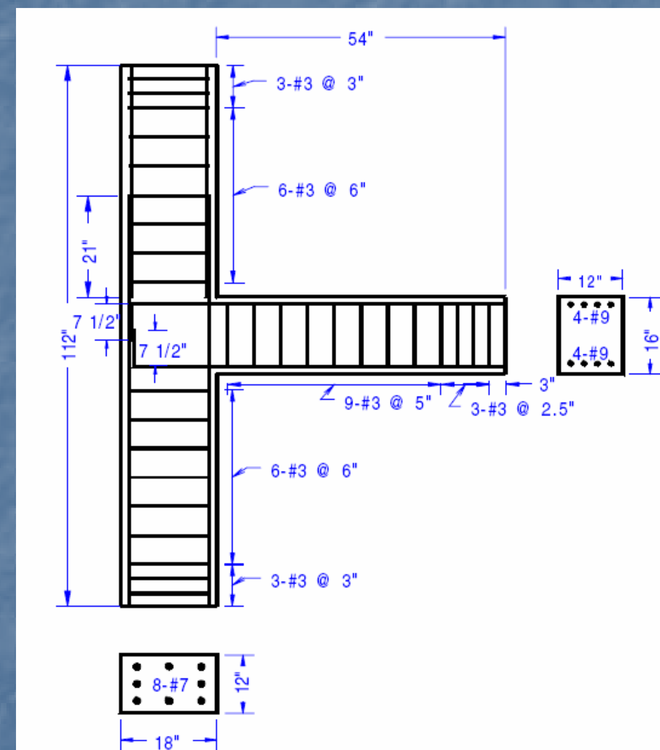
TESTS ON EXTERIOR BEAM COLUMN JOINT

4- Clyde et al 2000 (U of Utah)

TEST PARAMETER

-Axial Load Level 0.10 $f_c'A_g$ vs 0.25 $f_c'A_g$
Randomly varied Axial Load.





TESTS ON EXTERIOR BEAM COLUMN JOINT

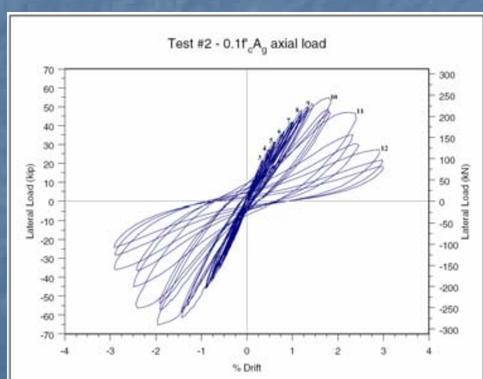
4- Clyde et al 2000 (U of Utah)

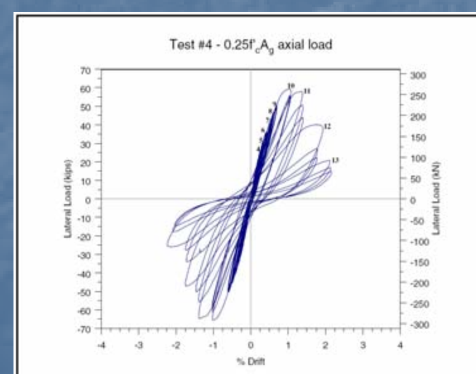
TEST RESULTS

-Failure mode generally is joint shear failure after initial beam yielding. Joint shear strength coeff. ranges from γ=11.5 – γ=14

-Higher Axial Load: Slight increased joint strength by 8%, tendency to more brittle failure, reduced the deformational capacity by 40% & energy dissipation by 20%

-Residual Axial Capacity: 18% drop in axial capacity at joint shear failure



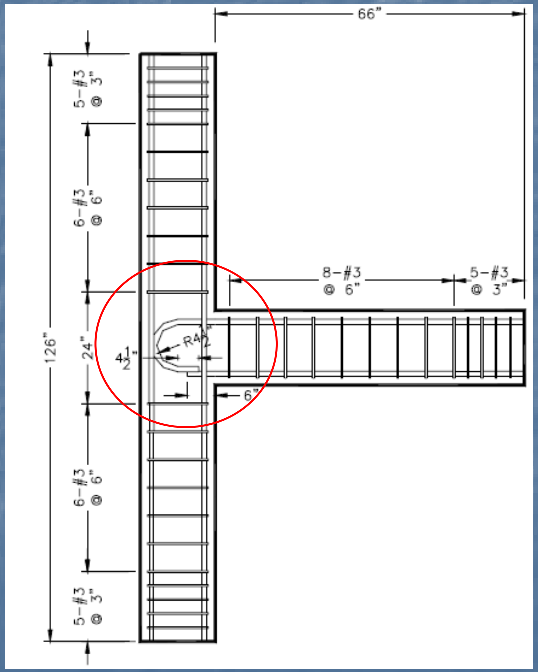


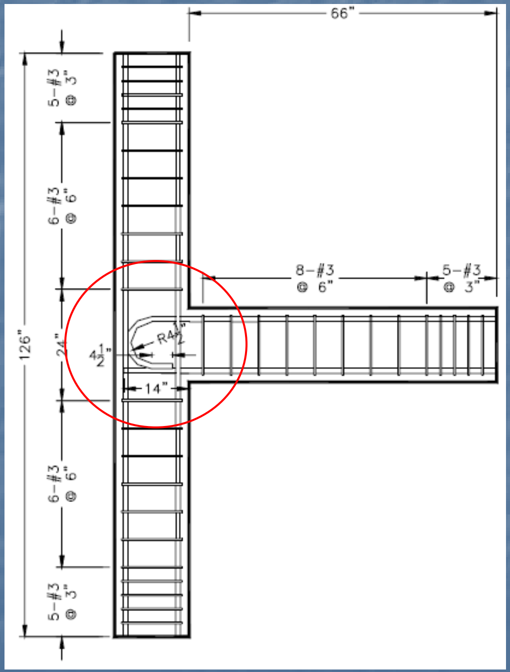
TESTS ON EXTERIOR BEAM COLUMN JOINT

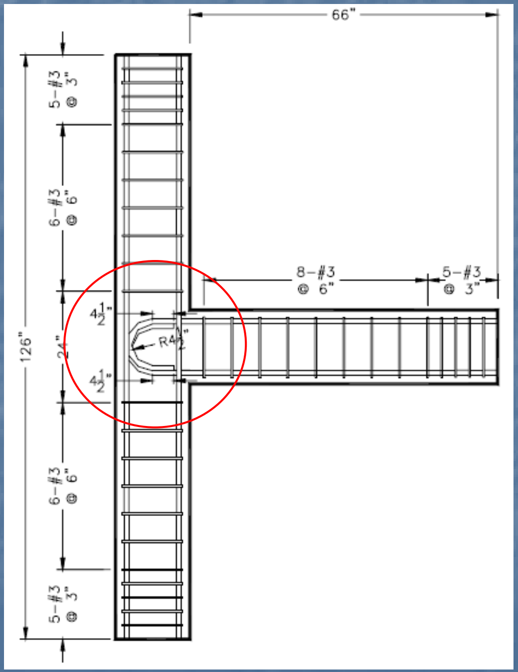
5- Pantelides et al 2002 (U of Utah)

TEST PARAMETERS

-Axial Load Level 0.10 $f_c'A_g$ vs 0.25 $f_c'A_g$ -Bottom Beam Rft Anchorage Detail







TESTS ON EXTERIOR BEAM COLUMN JOINT

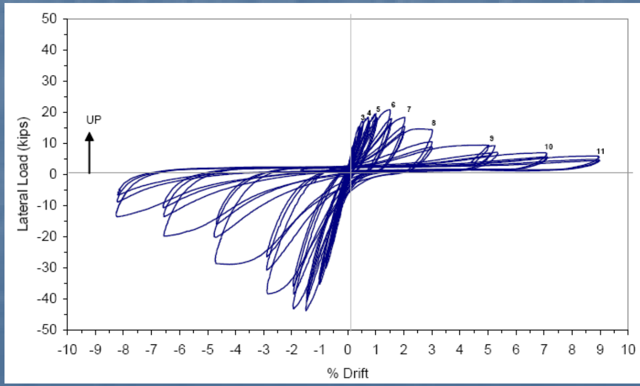
5- Pantelides et al 2002 (U of Utah)

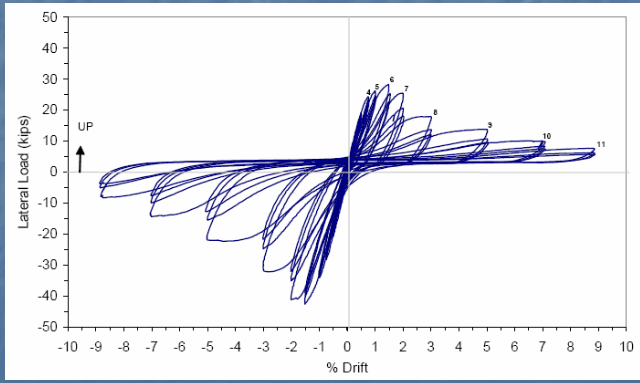
TEST RESULTS (Bond Slip Failure Specimens)

-Failure modes : Bond slip in short embedded length bottom bars with Loss of lateral load Capacity

-Joint shear strength coefficient γ=5.2 - γ=7

-Higher Axial Load: Increase joint strength by 35%, tendency to more brittle failure, 25% reduction in displacement ductility & 32% reduction in energy dissipation





TESTS ON EXTERIOR BEAM COLUMN JOINT

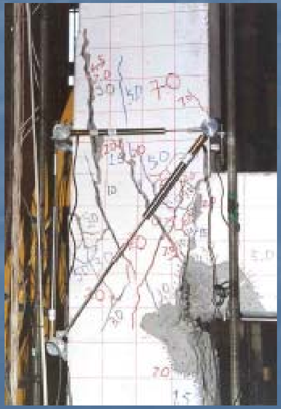
5- Pantelides et al 2002 (U of Utah)

TEST RESULTS (Joint Shear Failure Specimens)

-Failure modes : Joint Shear Failure with Loss of Gravity Load Capacity , more brittle (35% less ductility) than bond slip failure

-Joint shear strength coefficient γ=10.3 - γ=11.8 (77% higher than bond slip joints)

-Higher Axial Load: Increase joint strength by 15%, tendency to more brittle failure, 5% reduction in displacement ductility & 15% reduction in energy dissipation



TESTS ON EXTERIOR BEAM COLUMN JOINT

6- Pampanin et al 2002 (Italy)

TEST SPECIMENS

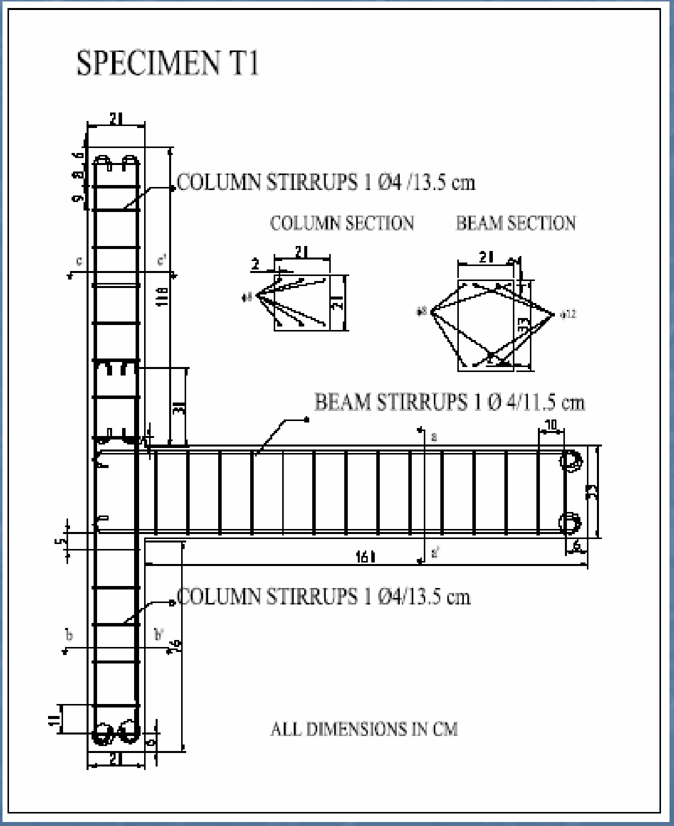
-Deficient 1960 Joints:
1- Plain (Smooth) Rebars
2- Beam Rebars Anchorage Deficient (Unhooked)
3- Absence of Capacity Design
4- Low Characteristic Strength of Materials

Axial Load

Low level 0.10 $f_c'A_g$
Varied with lateral load bilinear

Test Parameter

Effect of Beam Flexural Strength



TESTS ON EXTERIOR BEAM COLUMN JOINT

6- Pampanin et al 2002 (Italy)

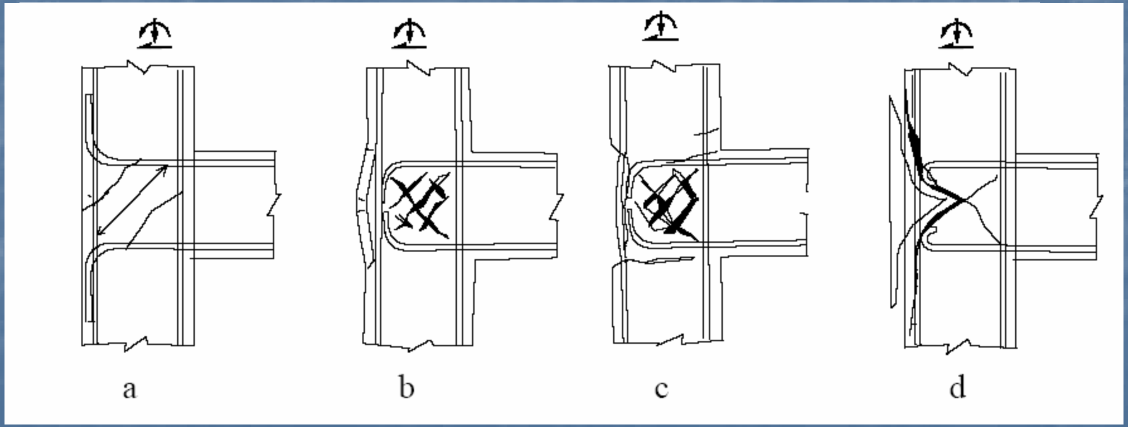
TEST RESULTS

-Failure modes : Brittle hybrid failure mechanism: sudden and severe joint shear damage after the first diagonal crack combined with slip failure of beam rebars. (Joint Wedge)

-Final Failure: By loss of Axial load capacity

-Joint shear strength coefficient γ=4.3 (Diagonal Strut not developed), Displacement Ductility μ=2.67

-Similar Performance to Bent out Beam Rebars Joints



TESTS ON SIMULATED CORNER BEAM COLUMN JOINT

1- Hanson & Conner 1972 (PCA, Illinois)

TEST SPECIMEN

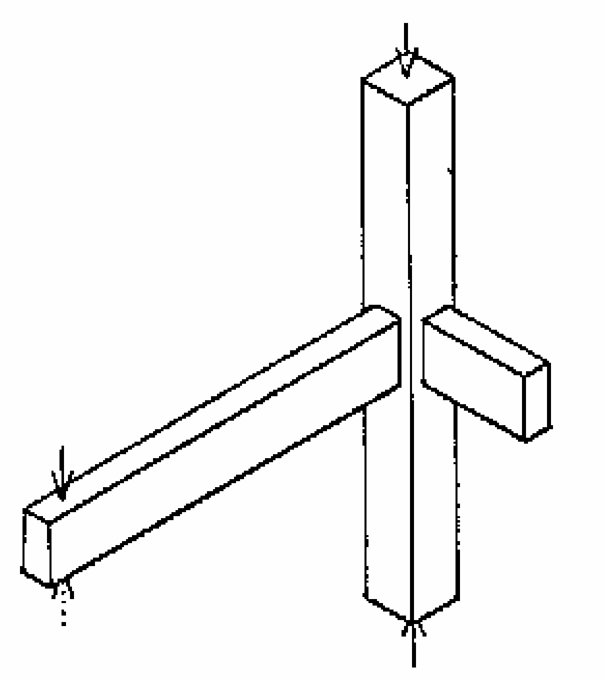
-One preloaded Transverse Stub until cracking
-Preloading removed before test

Axial Load

High Ratio 0.86 f_c'A_g Constant Load

Test Parameter

Effect of Transverse Stub Confinement on Joint Strength



TESTS ON SIMULATED CORNER BEAM COLUMN JOINTS

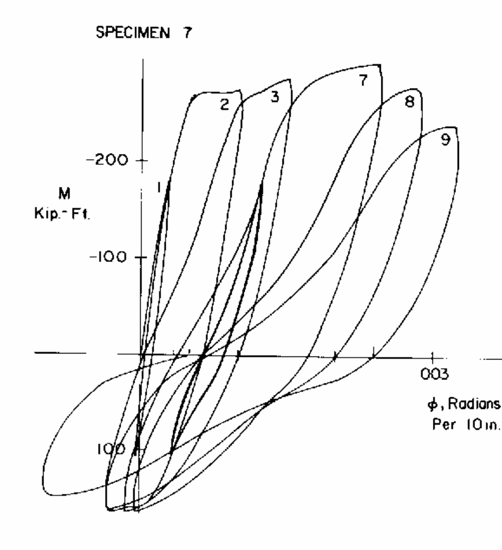
1- Hanson & Conner 1972 (PCA, Illinois)

TEST RESULTS

-Failure mode : Joint Shear Failure After Beam Yielding. Adequate response up to μ=2.67 Followed by severe cracking

-Joint shear strength coefficient γ=12, Displacement Ductility μ=4

-Very Slight Strength gain over the isolated joint,
-Some improvement in ductility

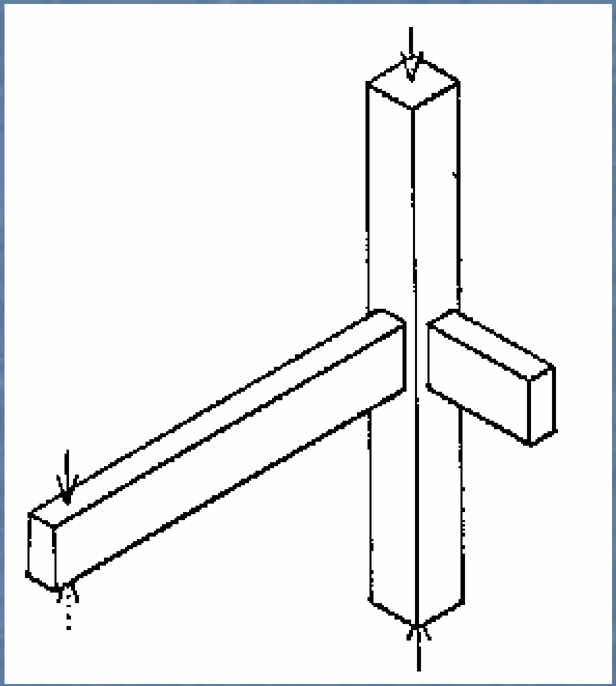


TESTS ON SIMULATED CORNER BEAM COLUMN JOINT

2- Uzumeri 1977 (U of Toronto)

TEST SPECIMEN

-One preloaded Transverse Stub until cracking
-Preloading persists during test



Axial Load

High Ratio $0.51\ f_c'A_g$ Constant Load

Test Parameter

Effect of Transverse Stub Confinement on Joint Strength

TESTS ON SIMULATED CORNER BEAM COLUMN JOINTS

2- Uzumeri 1977 (U of Toronto)

TEST RESULTS

-Failure mode : Joint Shear Failure. Beam & Column Intact

-Joint shear strength coefficient γ=11.2, Displacement Ductility μ=3

-Generally behaved similar to isolated exterior joint.

-No additional confinement effect strength gain due to transverse stubs.

-Slight increase in ductility (15%)

-Stub slightly increased the anchorage capacity of beam reinforcement

TESTS ON CORNER BEAM COLUMN JOINT

1- Preistley 1994 (UCSD)

TEST SPECIMENS

- -One Unreinforced Corner Joint
- -One reinforced Corner Joint
- -No Slab
- -Unrealistic Boundary Conditions

Axial Load

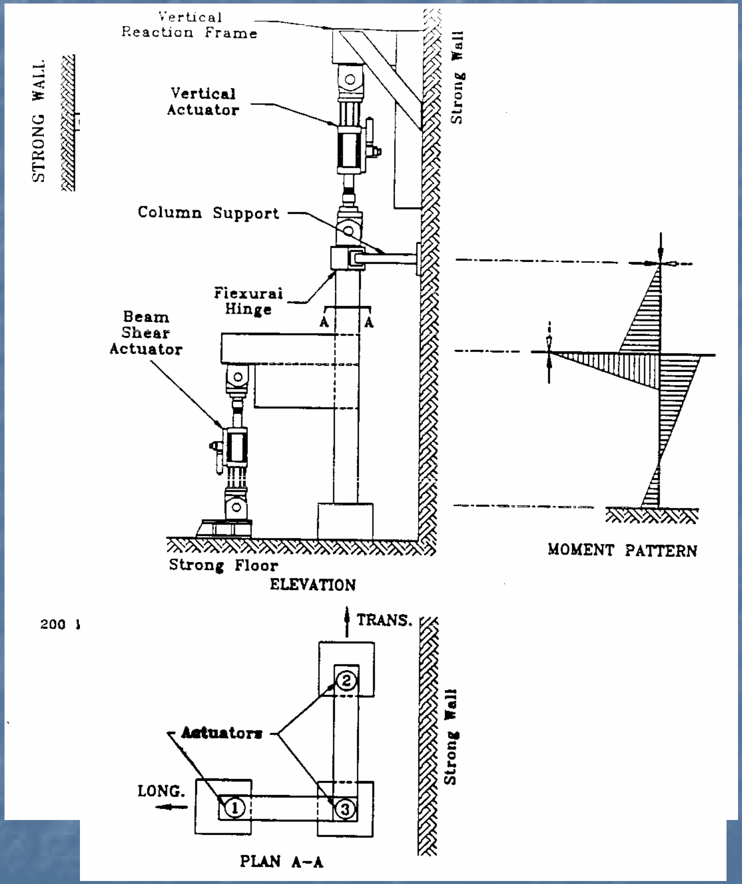
Axial Load Ratio 0.15 f_c'A_g Varied with Lateral (Dynamic Analysis)

Test Parameter

Evaluate Unreinforced Joint Shear Strength

Load History

Uniaxial Loading followed By diagonal Biaxial



TESTS ON CORNER BEAM COLUMN JOINTS

1- Preistley 1994 (UCSD)

TEST RESULTS (Unreinforced Joint)

-Failure mode : Joint Shear Failure After Beam Yielding

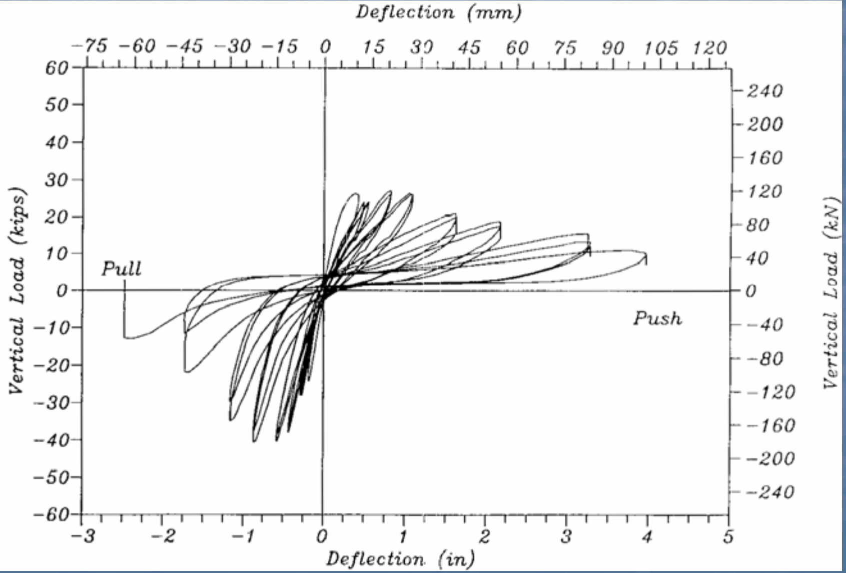
-Final Failure : Loss of Gravity Load Capacity

-Generally Very Poor Performance

-Joint shear strength coefficient:

γ=5.61 for Uniaxial Loading,
γ=8.11 Diagonal Loading.

-Displacement Ductility Factor μ=2.39



GENERAL EXPERIMENTAL CONCLUSIONS

EFFECT OF AXIAL LOAD

On Strength

-Opinion 1 : Slightly increases Joint shear strength (8%-20%)
-Opinion 2 : No Effect at All
-Opinion 3 : Helpful in early stages of loading, Detrimental in inelastic stages

On Ductility

-More pronounced effect than on strength
-More tendency to brittle failure with higher axial load
-15% -32% Reduction in Drift and Displacements Ductility
-20% drop in Energy Dissipation

GENERAL EXPERIMENTAL CONCLUSIONS

EFFECT OF SLAB PRESENCE

Non-Ductile Joints

No Data Available

Ductile Exterior Joints

-Increasing Beam Plastic Capacity, Imposes Higher Demand on Joint

-Reduces Spandrels Confining Effect on Joint due to Imposed Torsional Stresses, more rapid Joint Strength Deterioration

GENERAL EXPERIMENTAL CONCLUSIONS

EFFECT OF LOADING HISTORY

1- No Effect on Joint Shear Strength (Uni. vs Diagonal)

2- More Pronounced Deterioration in Stiffness with Biaxial Loading

3- Quasi-Static is more Conservative than Dynamic Loading (Apparent Strength Increase with Rapid Dynamic)

GENERAL EXPERIMENTAL CONCLUSIONS

EFFECT OF TRANSVERSE SPANDREL CONFINEMENT

1- Opinion 1: Tremendous Strength Improvement (Questionable Result)

2- Opinion 2: No or Very Slight Strength Improvement

3- Slight Increase in Beam Rebar Anchorage Capacity

4- Decrease Severity of Cracking & Strength Degradation

5- Minor Ductility Improvement (15%)

GENERAL EXPERIMENTAL CONCLUSIONS

EFFECT OF BEAM REBAR ANCHORAGE DETAIL IN JOINT

1- Detail 1: Bent-Out Rebars: Entirely inadequate, very low Joint Shear Strength, Can't Develop Diagonal Strut, $\gamma < 4$

2- Detail 2: Bent-In Rebars : Better Performance, still inadequate, γ up to 11-12

3- Detail 3: Short Bottom Rebar Embedded : Certain Bond Slip Failure, γ=5 -7, Little More Ductile

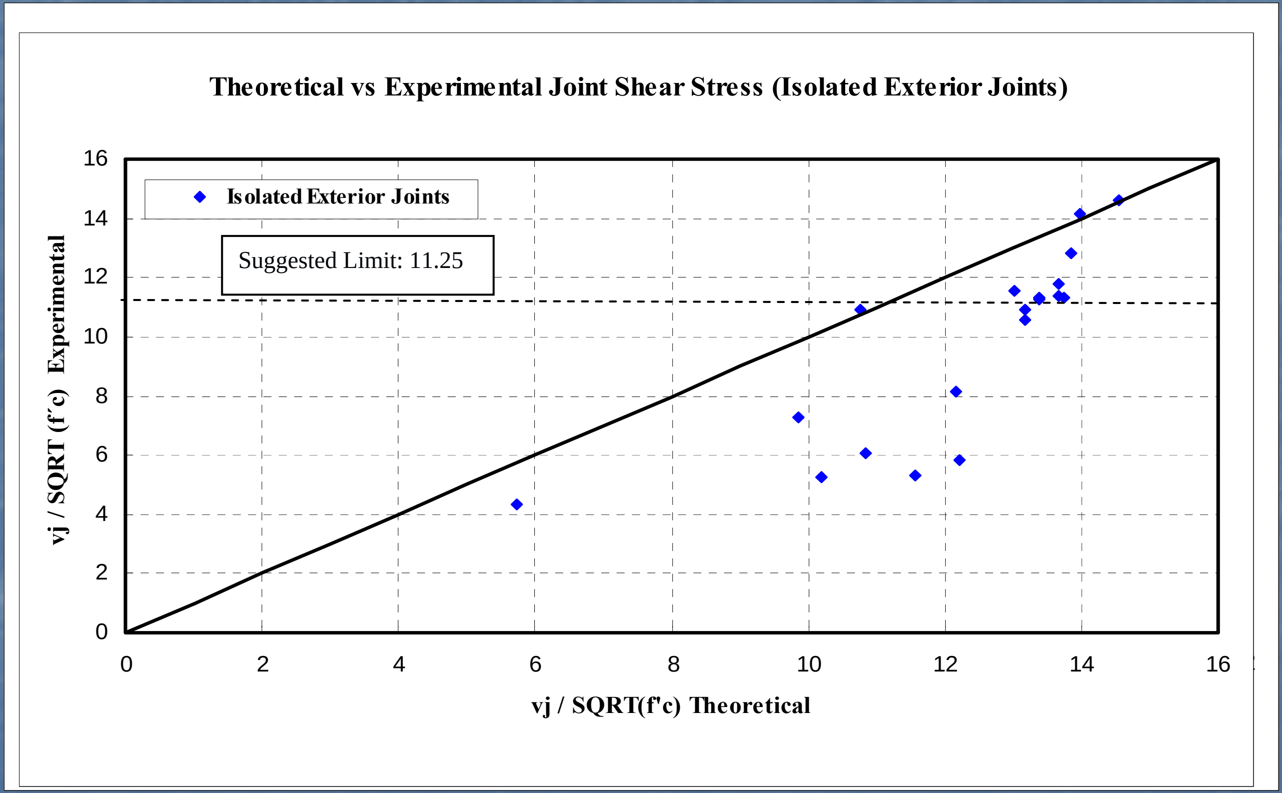
4- Detail 4: Smooth Unhooked Rebars: Similar Performance to Detail 1, No Strut Developed, γ=4.2

JOINT SHEAR STRENGTH DEGRADATION TRENDS

NON-DUCTILE ISOLATED EXTERIOR JOINTS

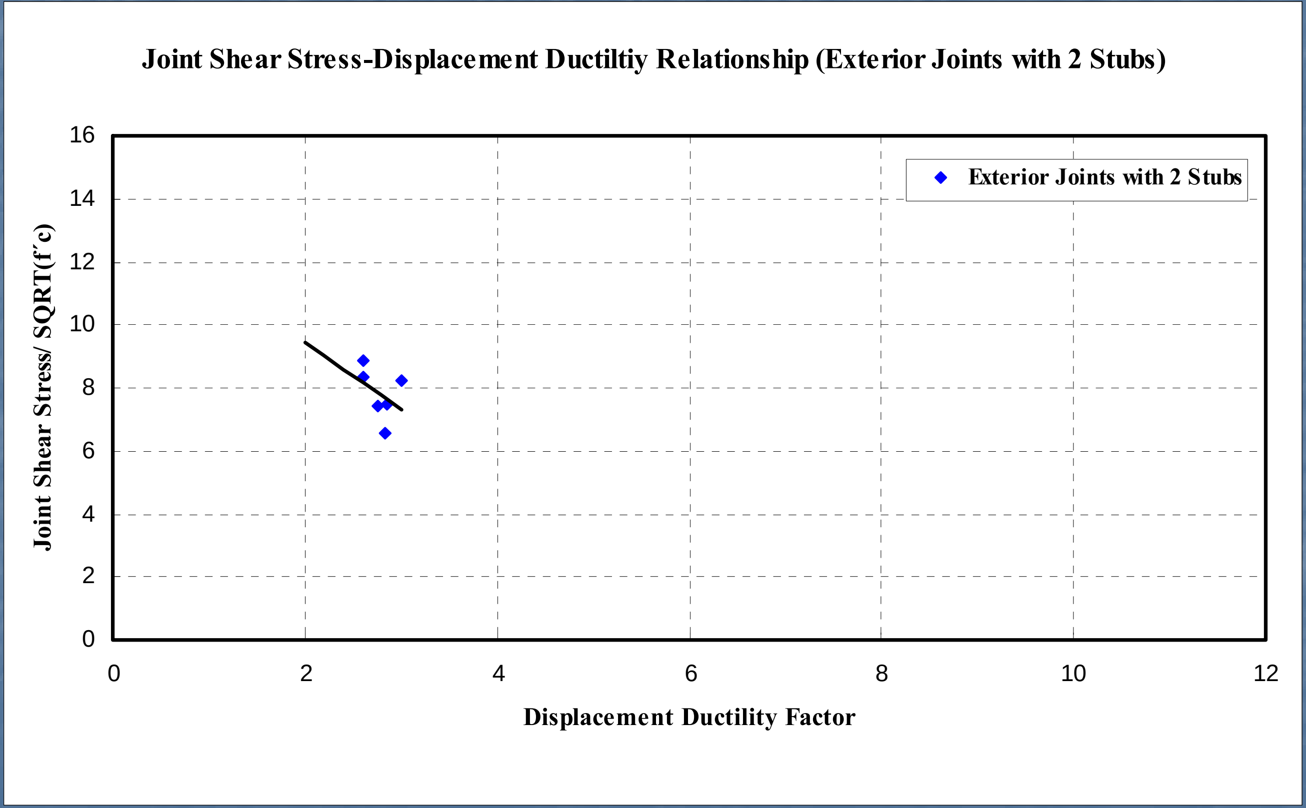
Suggested γ= 11.25

Suggested μ= 2.7



JOINT SHEAR STRENGTH DEGRADATION TRENDS

NON-DUCTILE EXTERIOR JOINT with TWO SPANDRELS

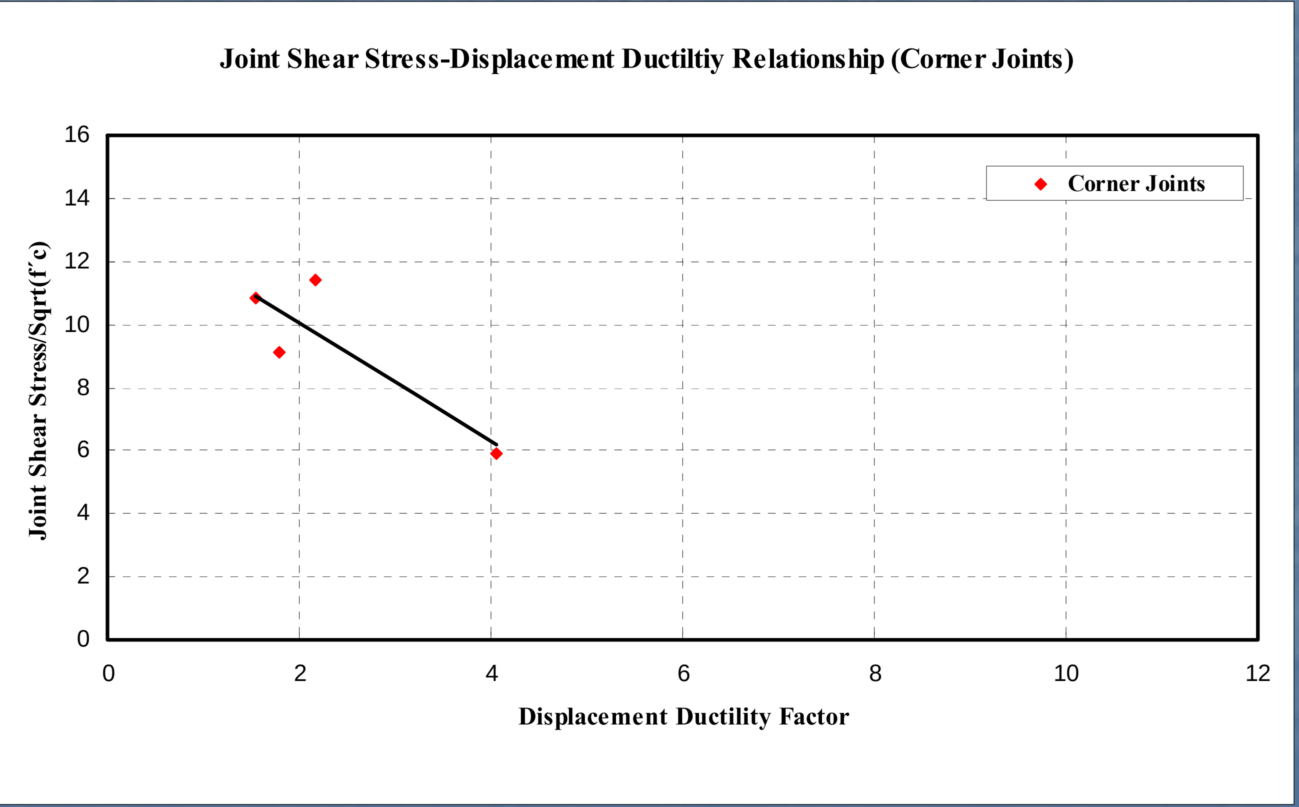


JOINT SHEAR STRENGTH DEGRADATION TRENDS

CORNER NON-DUCTILE JOINTS

Suggested γ= 11.50

Suggested μ= 3.5



PART 2

TENTATIVE FULL SCALE CORNER BEAM COLUMN JOINT TEST

Drawbacks & Unanswered Questions in Previous Tests

1- Definite Result about the Effect of High Axial load

2- Distinction of Joint Strength for Different Failure Scenarios,

3- Reliable Shear Strength Degradation Models for Non-ductile Joints

4- Corner Joint Shear Strength Coeff. γ, and Corresponding μ

5- Non-ductile Joint Shear Strength, for varying Joint Aspect Ratio

6- Effect of Beam to Column Width Ratio, (Joint Masking Area)

7- Effect of Slab Presence for non-ductile joints

8- Realistic Representation of Biaxial Loading

9- Assessment of Joint capability to support Gravity Axial Load after severe inelastic loading

SUGGESTED TEST PARAMETERS

1- Axial Load Level, 0.15 fc'Ag vs 0.30 fc'Ag

2- Failure Mechanism, Joint Shear failure vs Joint Shear Failure after Beam Yielding

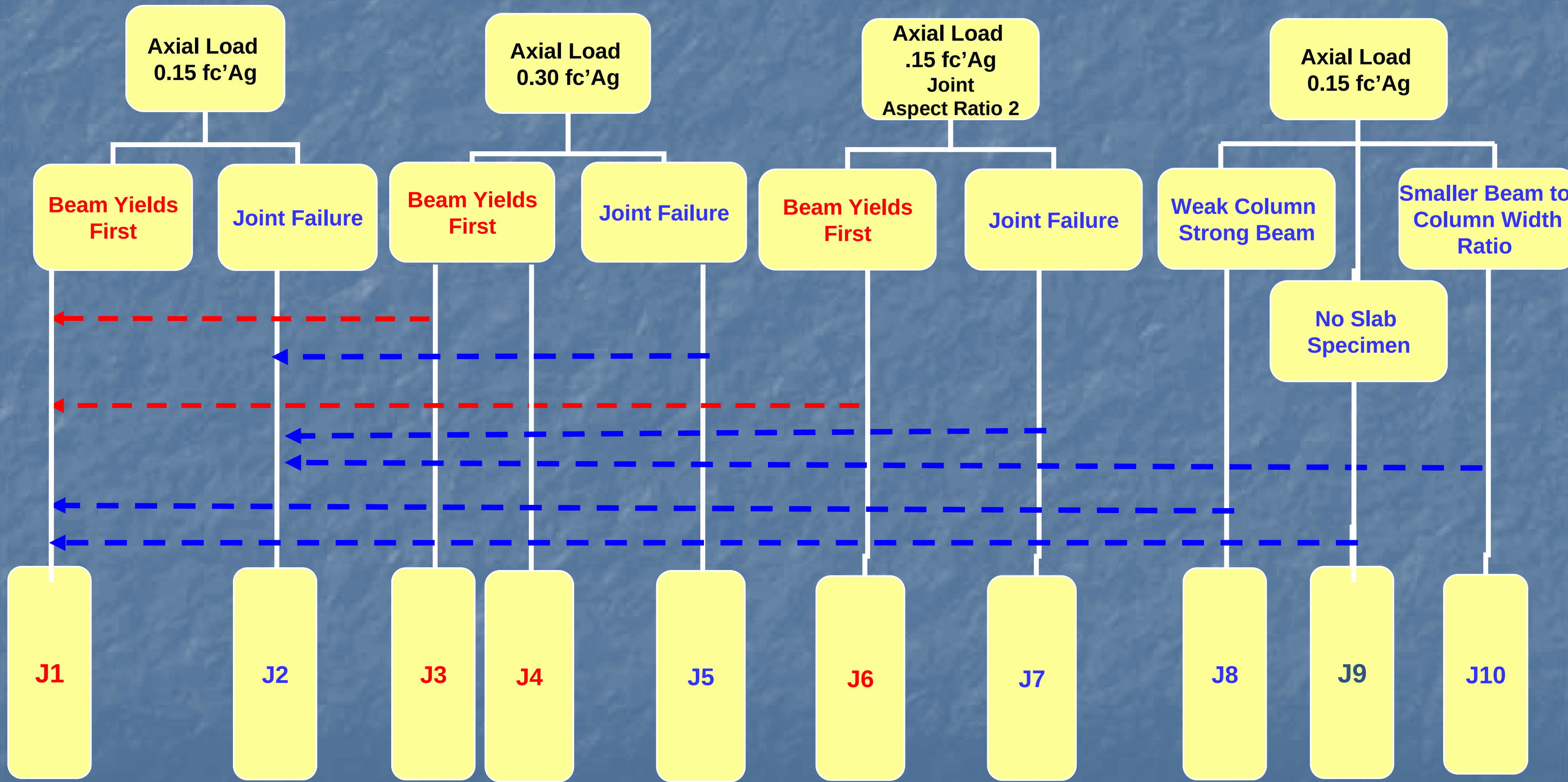
3- Beam to Column Flexural Strength $\sum M_c / \sum M_b$, Strong Column Weak Beam vs Strong Beam Weak Column Conditions.

4- Joint Shear Strength, through Joint Aspect Ratio, 1 vs 1.67

5- Beam to Column Width Ratio, (Joint Masking Area), 0.9 vs 0.55

6- Effect of Slab Presence

SUGGESTED TEST MATRIX



SUGGESTED SPECIMENS

Specimen 1: Low Axial Load, Aspect Ratio 1, Beam Yield→Joint Failure

Specimen 2: High Axial Load, Aspect Ratio 1, Beam Yield →Joint Failure

Specimen 3: Low Axial Load, Aspect Ratio 1, Joint Failure

Specimen 4: High Axial Load, Aspect Ratio 1, Joint Failure

Specimen 5: Low Axial Load, Aspect Ratio 2, Beam Yield→ Joint Failure

Specimen 6: Low Axial Load, Aspect Ratio 2, Joint Failure

Specimen 7: High Axial Load, Aspect Ratio 2, Joint Failure

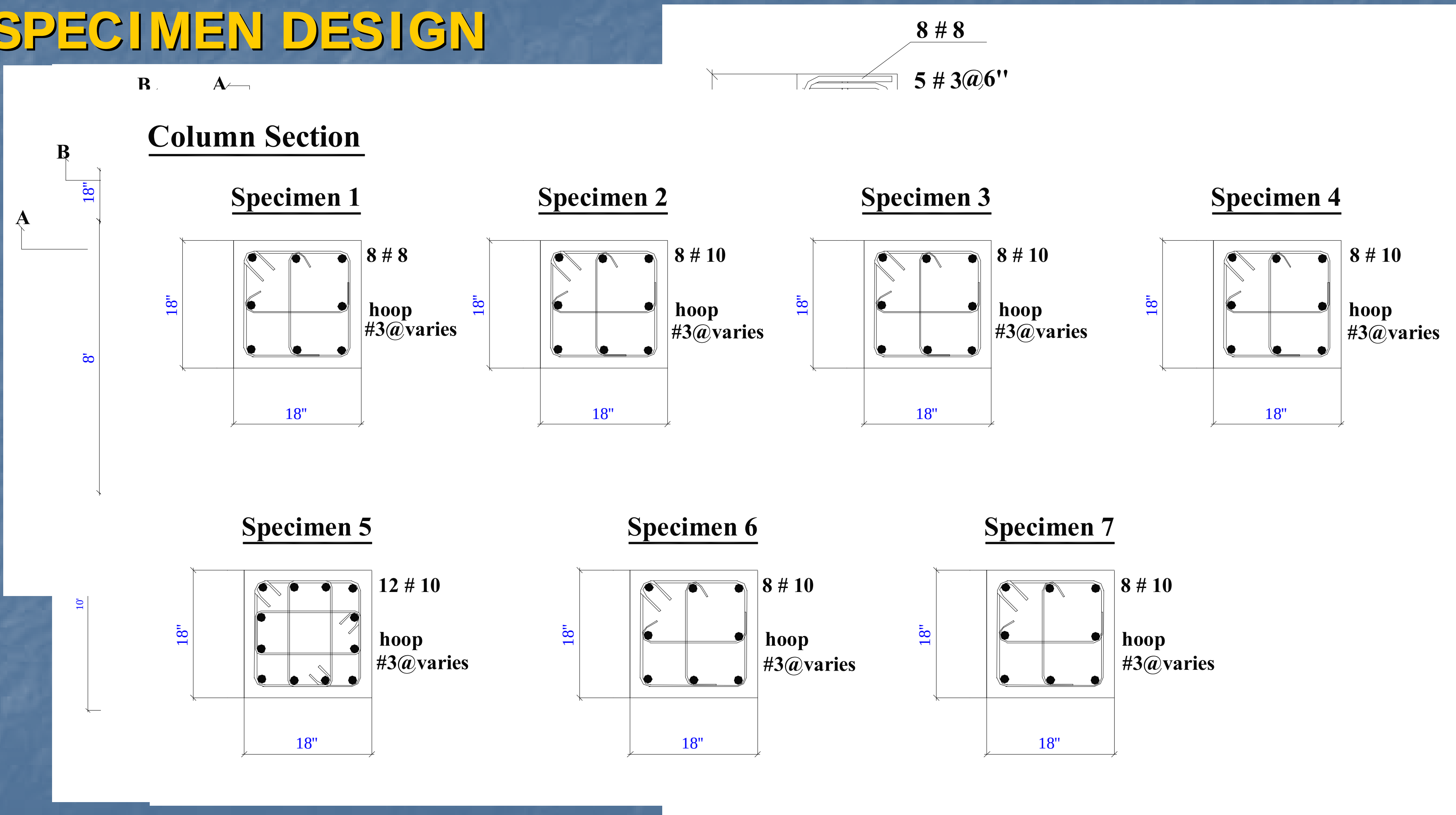
Specimen 8: Low Axial Load, Aspect Ratio 1, Lower Beam Rft, Beam Yield→ Joint Failure

Specimen 9: Low Axial Load, Aspect Ratio 1, Weak Column Strong Beam, Beam Yield→Joint Failure

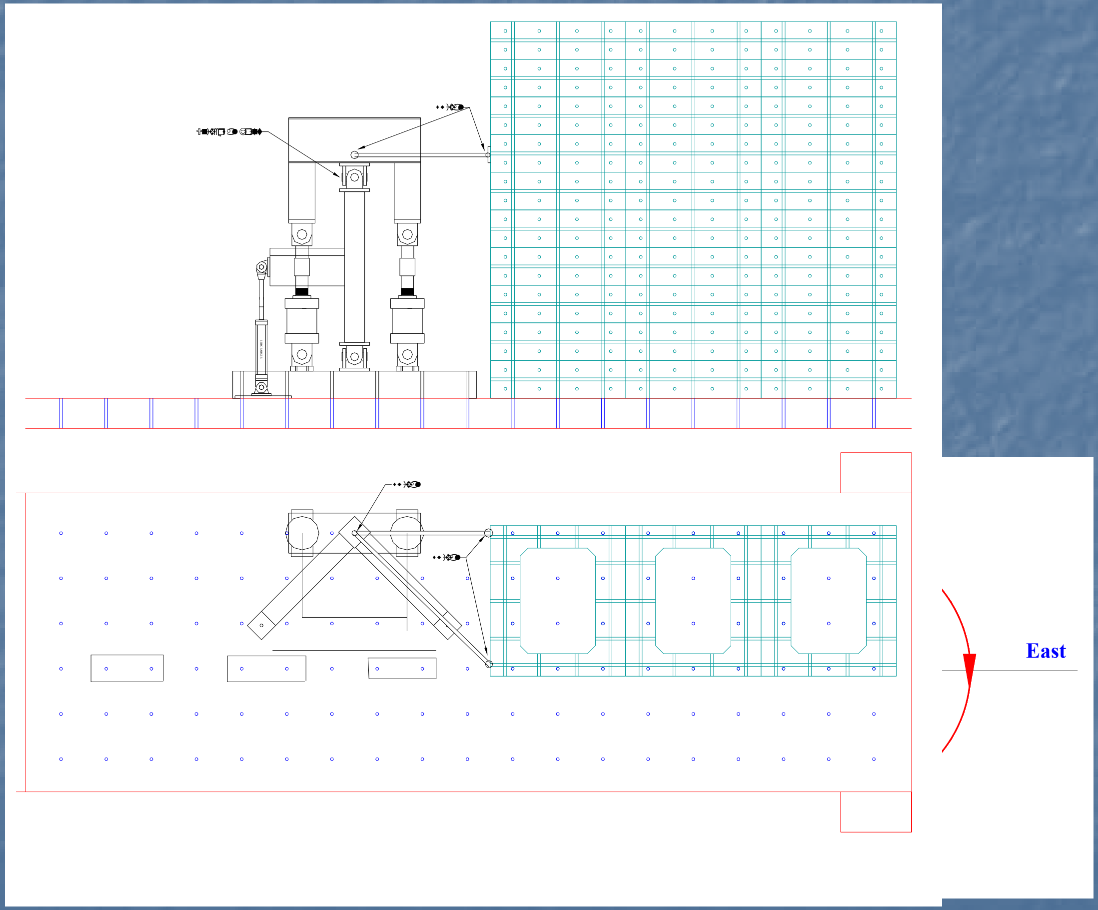
Specimen 10: Low Axial Load, Aspect Ratio 1, Smaller Beam to Column Width Ratio, Joint Failure

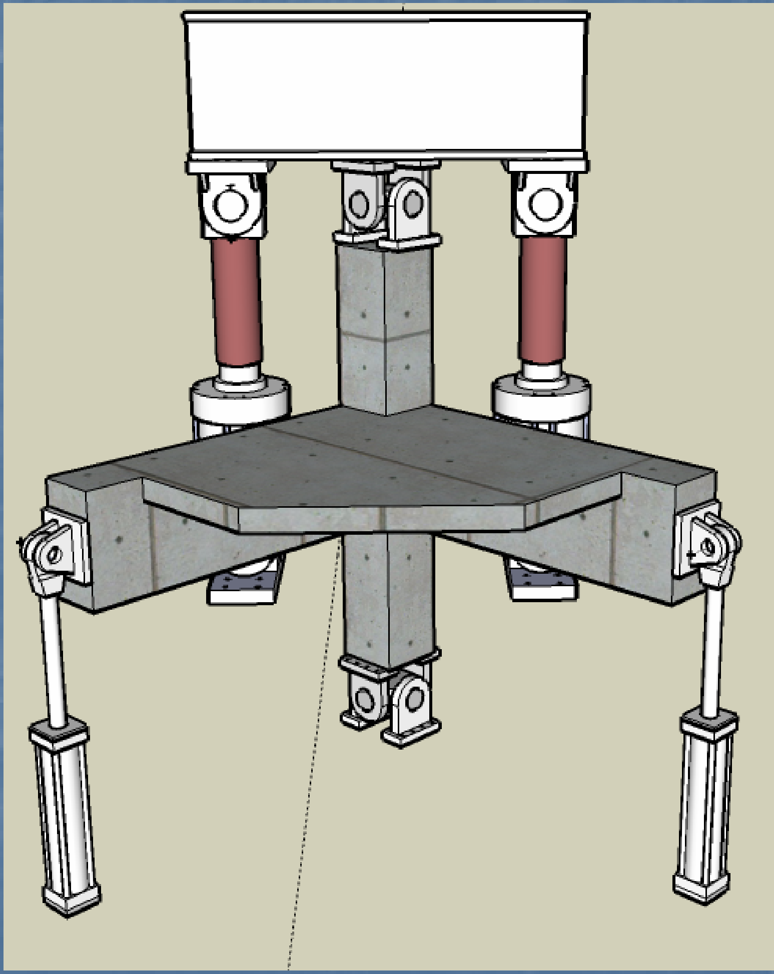
Specimen 11: Low Axial Load, Aspect Ratio 1, No Slab, Beam Yield→Joint Failure

SPECIMEN DESIGN



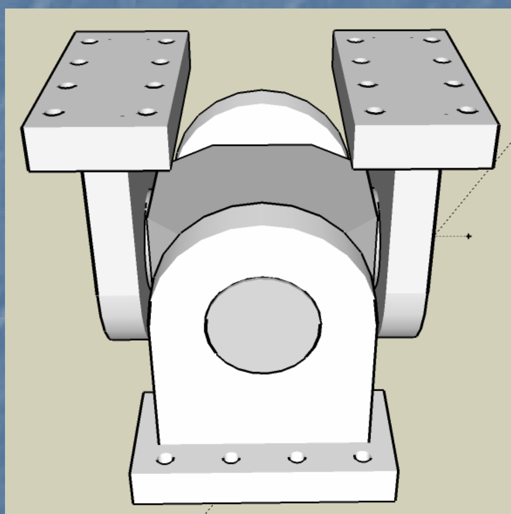
Test Setup

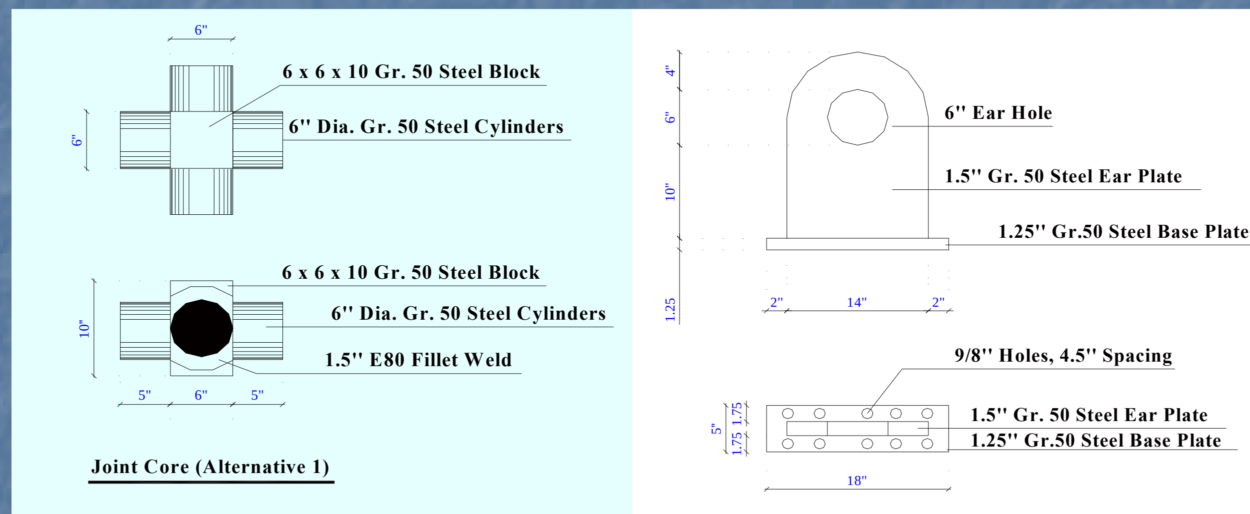




Test Attachments

3D Universal Joint

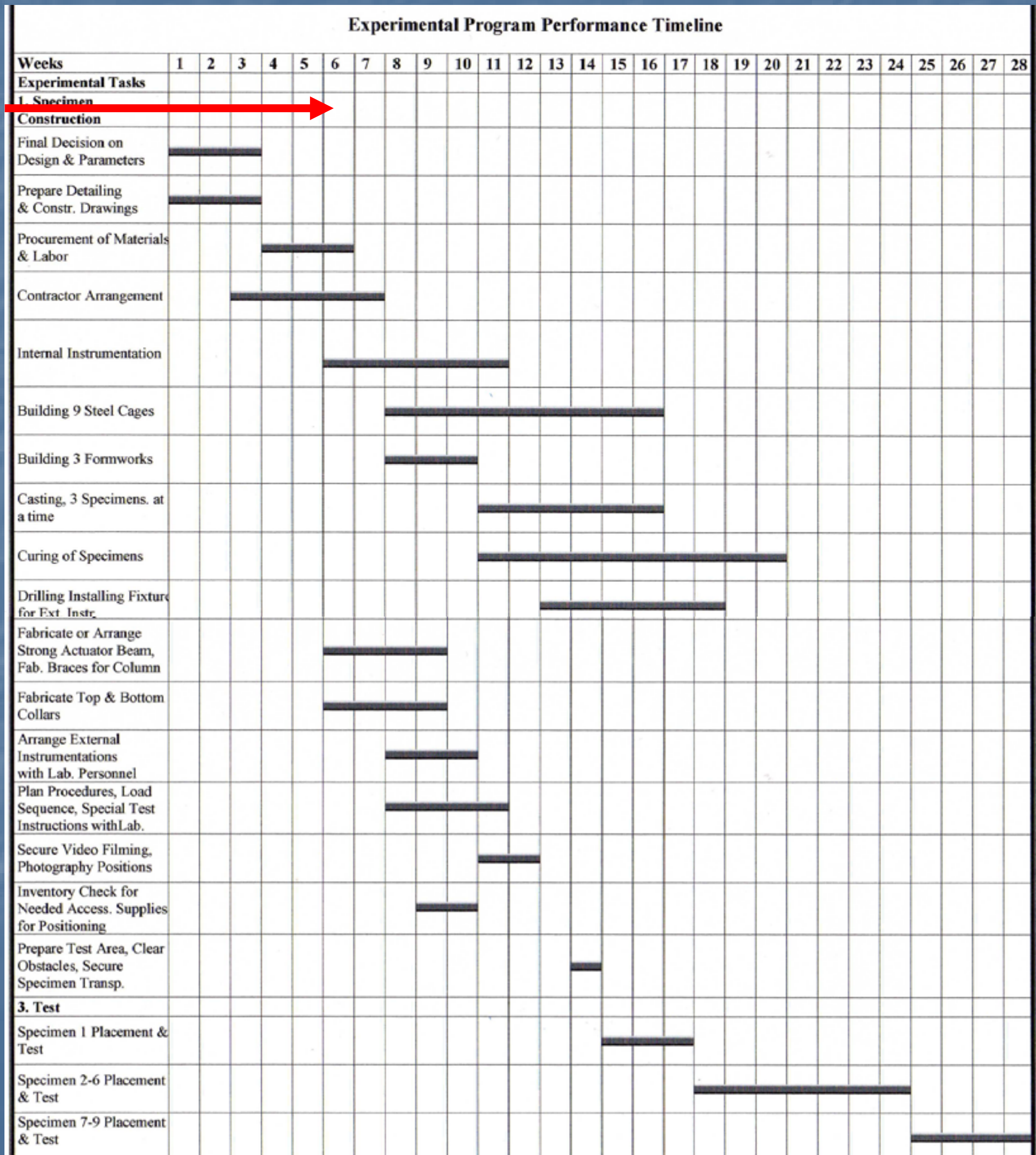




800 Kips Compression, 350 Kips Tension Capacities

Work Schedule

Tentative First Test End of Oct 2008



Thank You