Experimental Study on the Damage Evolution of Re-bar Concrete Interface

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Abstract

- A new type of bond-slip test is developed in this study
- Constitutive relationship of bond is obtained for the test
- FEA using this constitutive relationship
- Result analysis and comparing

General Overview

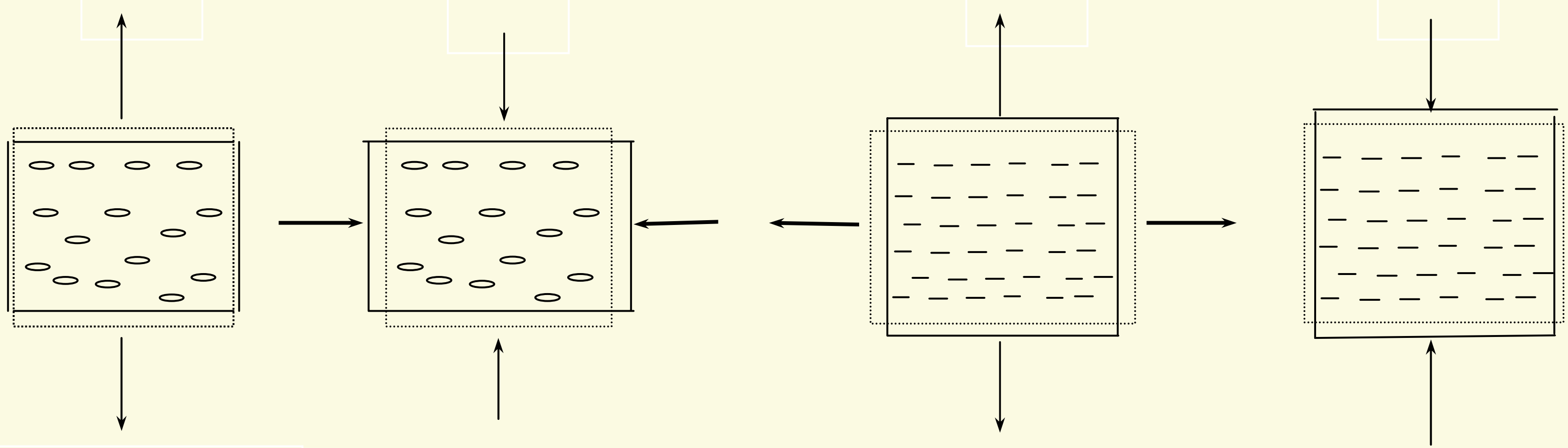
- Introduction and Literature Review
- Experiment Procedure
- Experimental Data Analysis
- Numerical Computation Study
- Conclusion and Discussion

1.1 Introduction

- Liu Yu's Concrete Model

$$\tilde{D}_i = \begin{cases} D_i & \text{when } \sigma_{ii} \geq 0 \quad or \quad \varepsilon_{ii} \geq 0 \\ 0 & \sigma_{ii} < 0 \; and \quad \varepsilon_{ii} < 0 \end{cases}$$

$$\tilde{D} = \begin{Bmatrix} \tilde{D}_1 \\ \tilde{D}_2 \\ \tilde{D}_3 \end{Bmatrix}$$



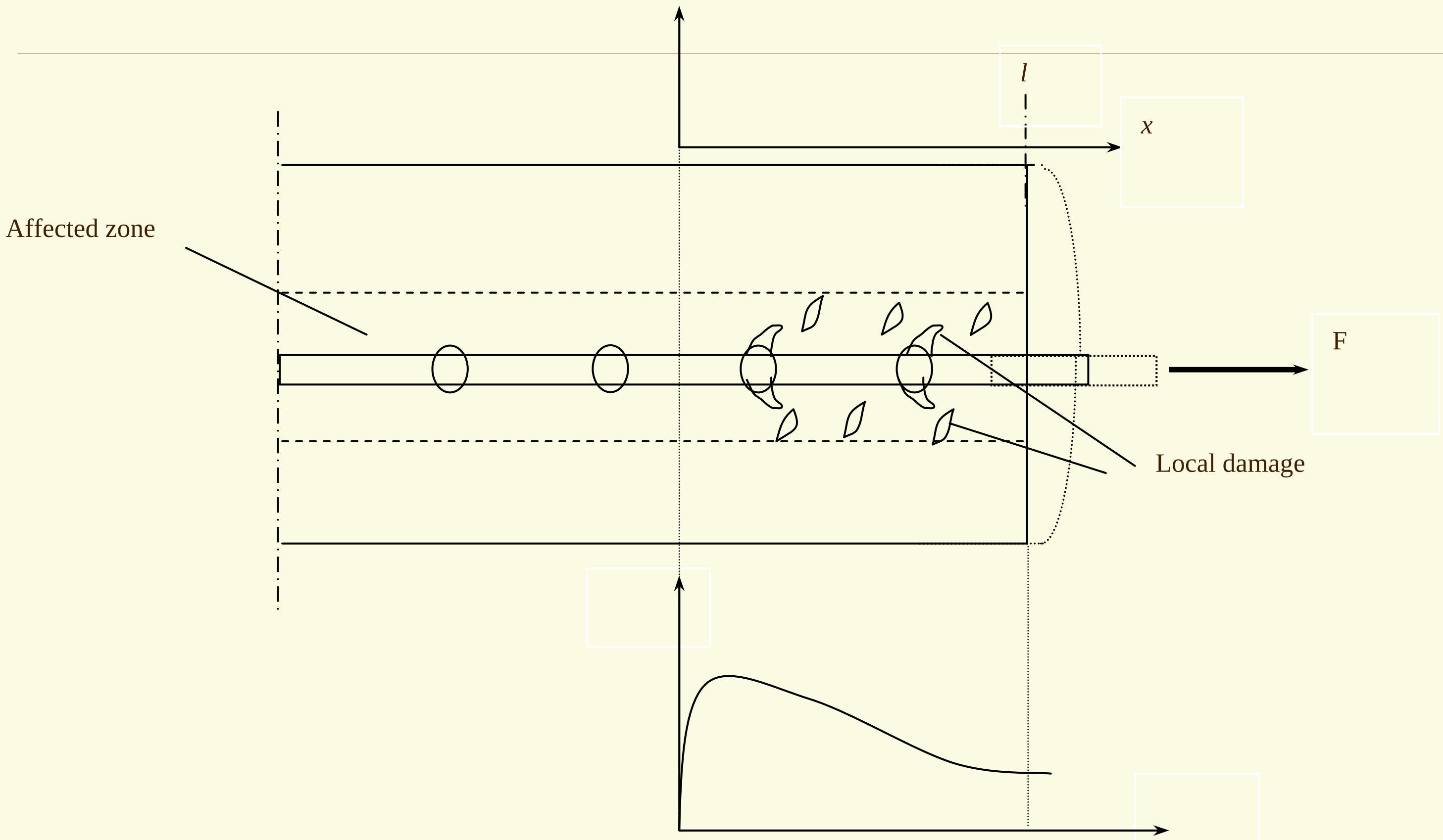
(a). (b). (c). (d).

RCED Model (RC Element Damage Model)

- Damage in the reinforced concrete

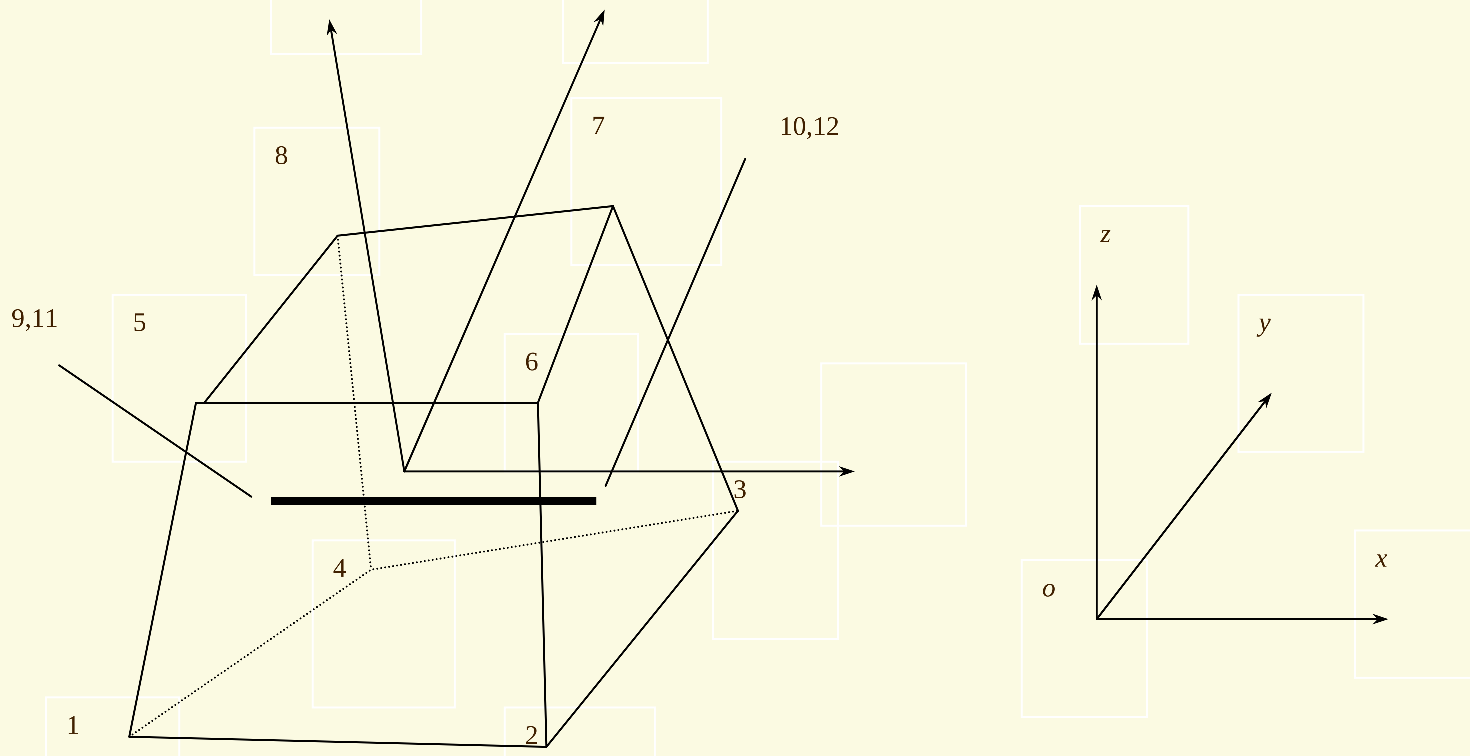
  1. Effective damage in concrete
  2. Slip between concrete and re-bar
  3. Local damage in concrete due to slip

RCED Model (RC Element Damage Model)



Local damage zone in RCED Model

RCED Model (RC Element Damage Model)



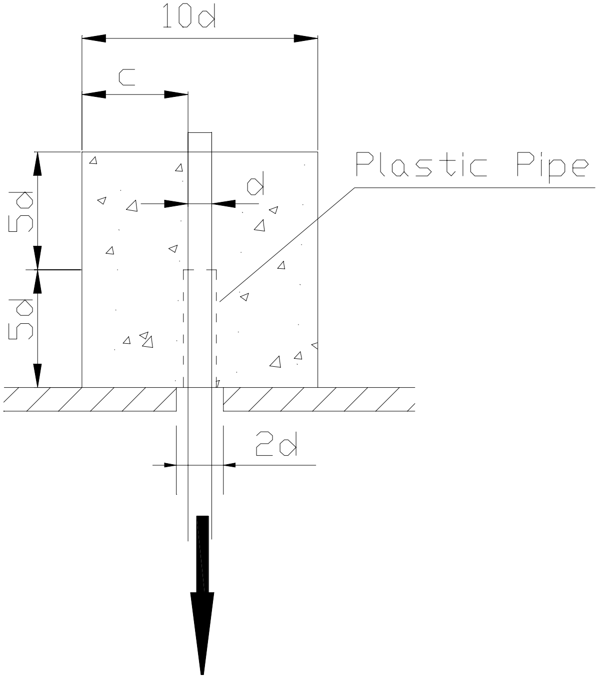
Element in RCED Model

1.2 Literature Review

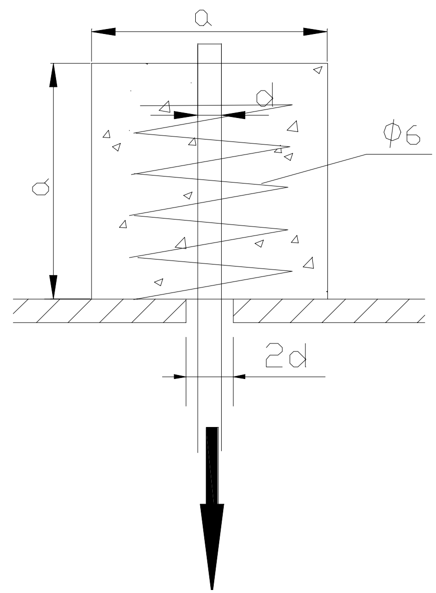
- Bond Test Method

1. Pull-out Test
2. Beam-type Test
3. Uniaxial-tension Test

Pull-out Test

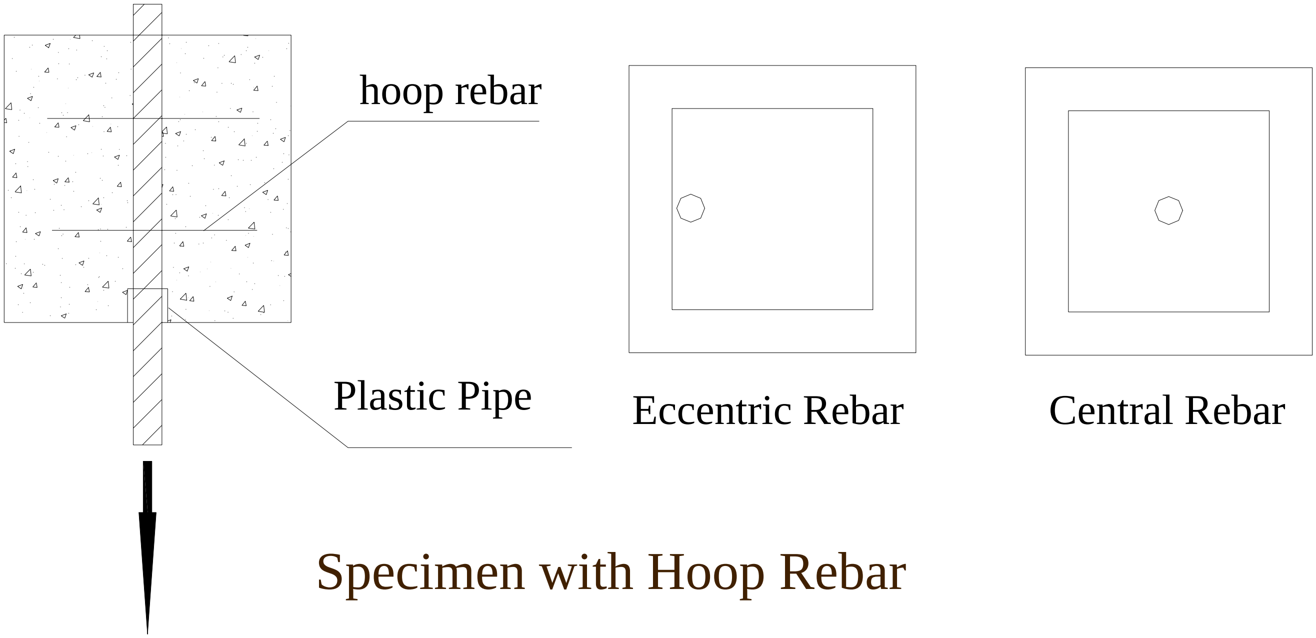


No-transverse bar pull-out test



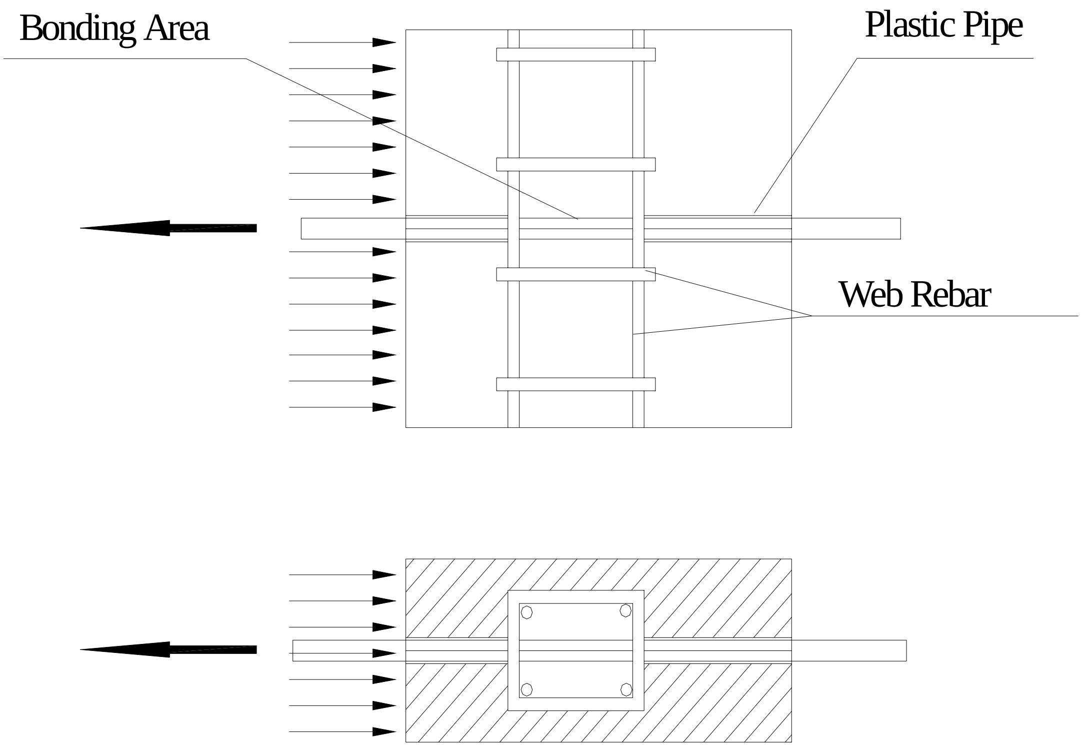
With transverse bar pull-out test

Pull-out Test



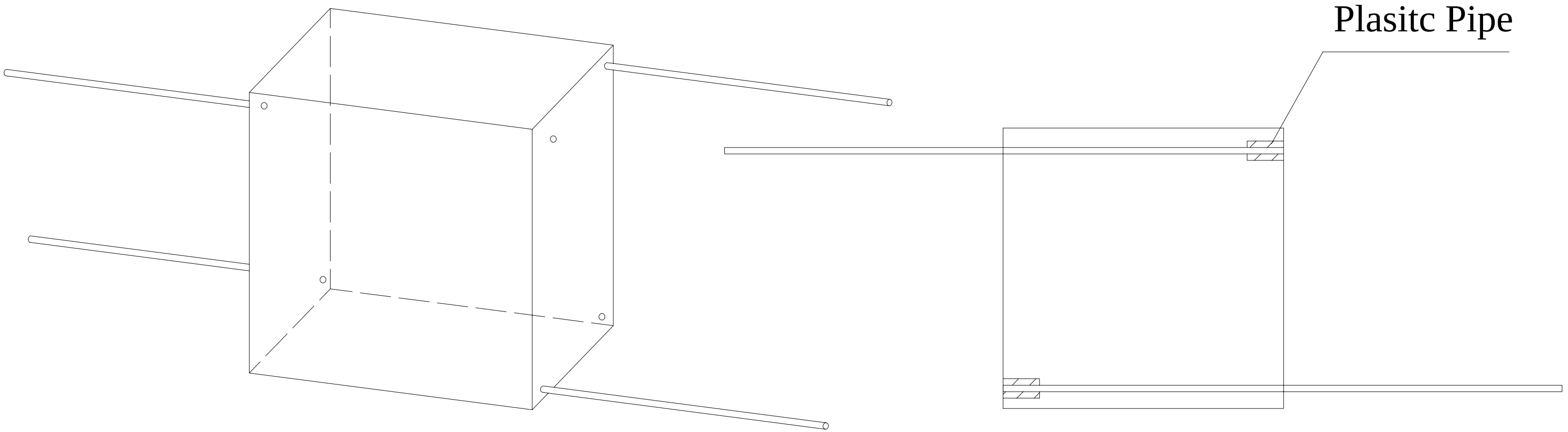
Specimen with Hoop Rebar

Pull-out Test



Specimen with Web Rebar

Pull-out Test



Rebar in Different places

Feature of Pull-out Test

- Strongpoint

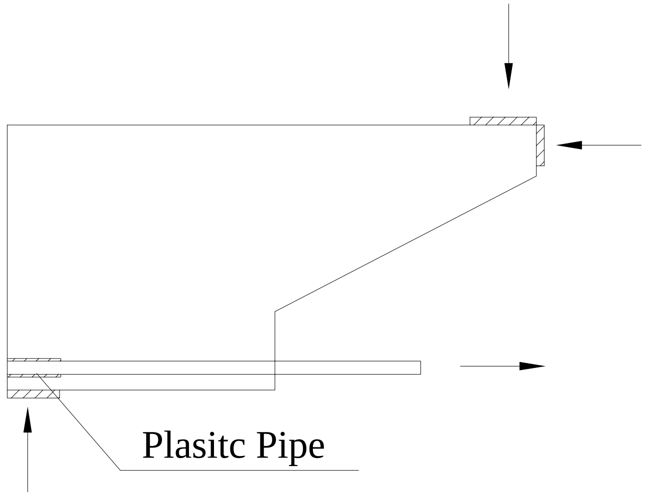
  1. Can determine the anchoring strength of bond

  2. Easy to procedure

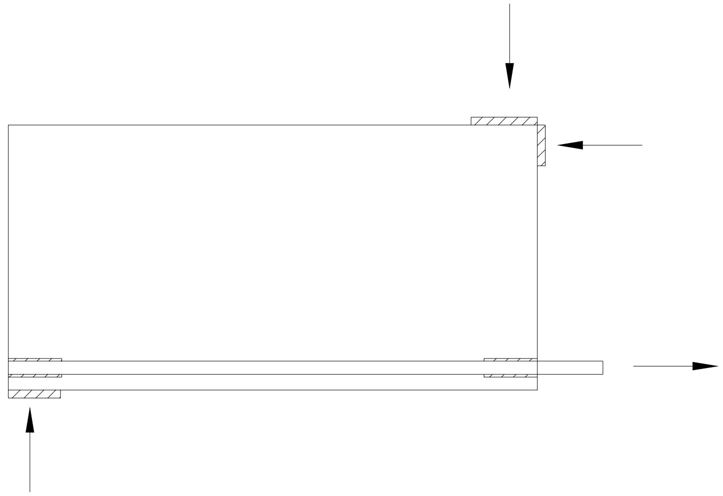
- Shortage

  Complex stress state around the surface

Beam-type Test

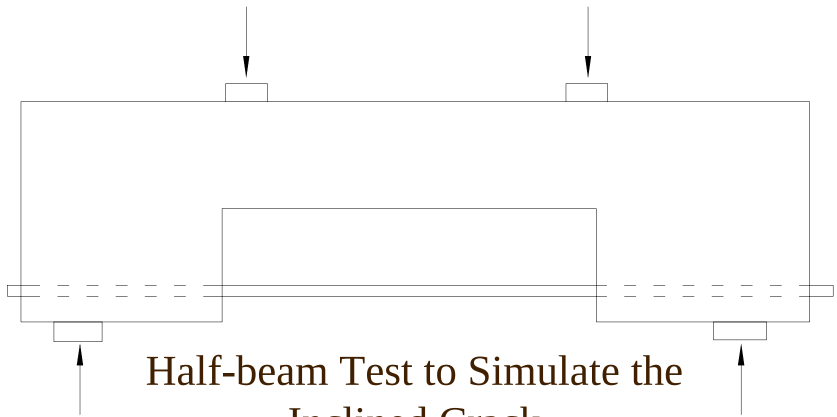


Half-beam Test to Simulate the Inclined Crack

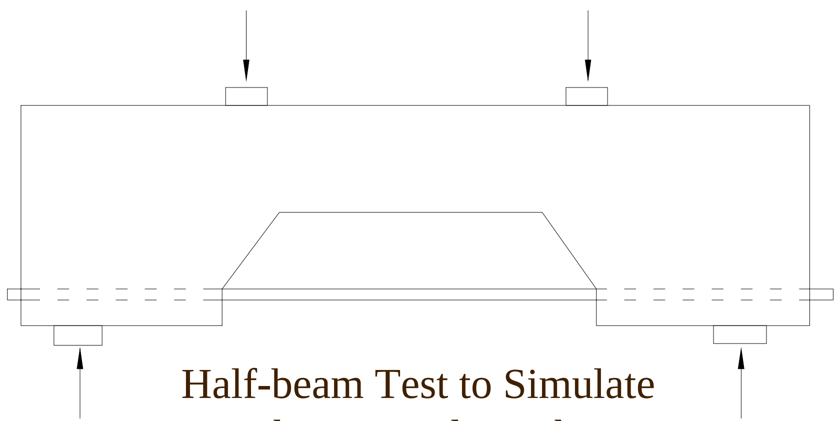


Half-beam Test to Simulate the Vertical Crack

Beam-type Test

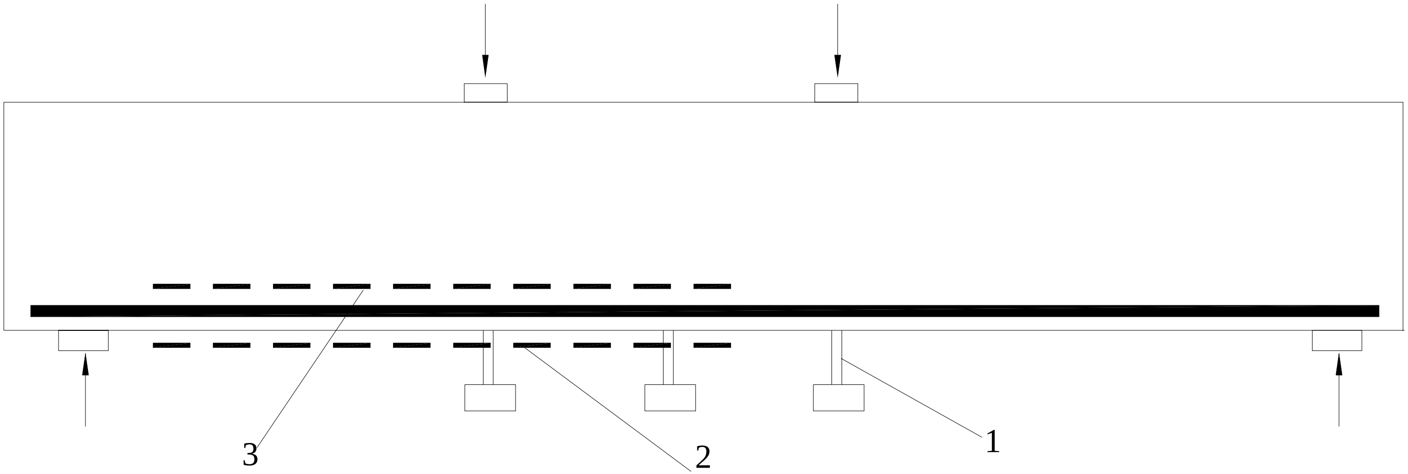


Half-beam Test to Simulate the Inclined Crack



Half-beam Test to Simulate the Vertical Crack

Beam-type Test



Simply Supported Beam Test

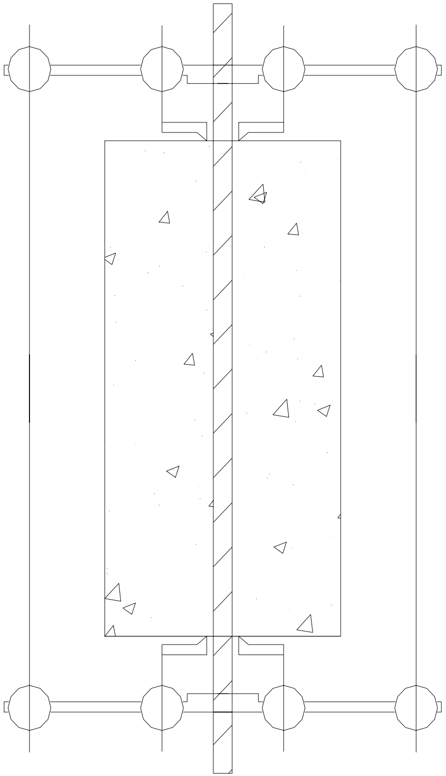
1: Lever-type Strain Gauge 2: Strain Gauge On the Bottom
3: Strain Gauge on the Side

Feature of Beam-type Test

- Strongpoint
  1. Very close to the real state
  2. Can determine bond strength of both anchoring zone and between cracks
- Shortage

  Complex and Expensive

Uniaxial-tension Test



Uniaxial-tension Test

Feature of Uniaxial-tension Test

- Strongpoint

  1. Can determine the bond stress between cracks

  2. Easy to Procedure

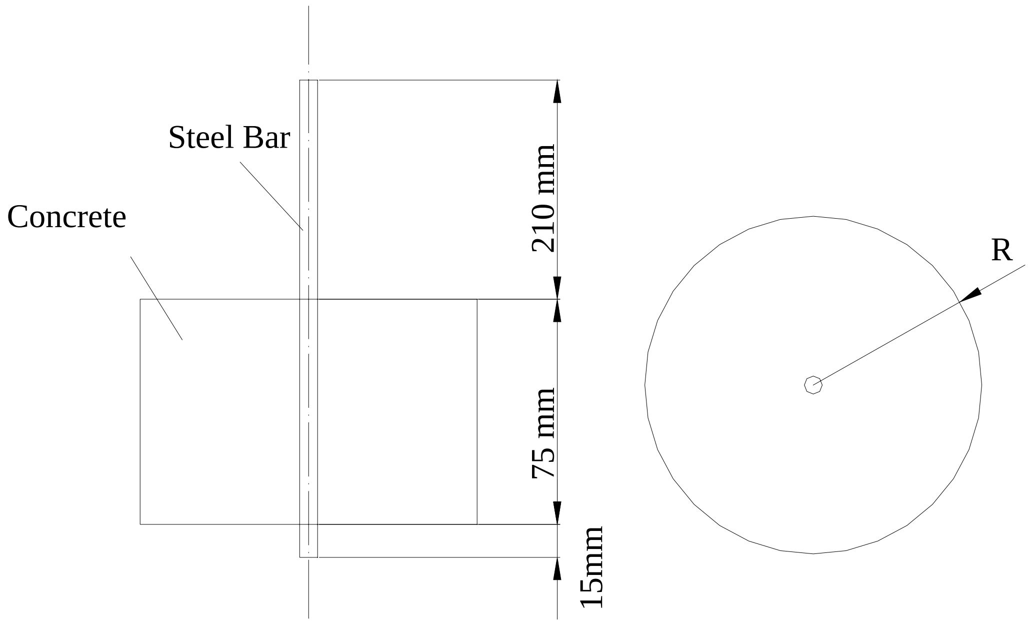
- Shortage

  Complex distribution of bond stress

2. Procedure of Test

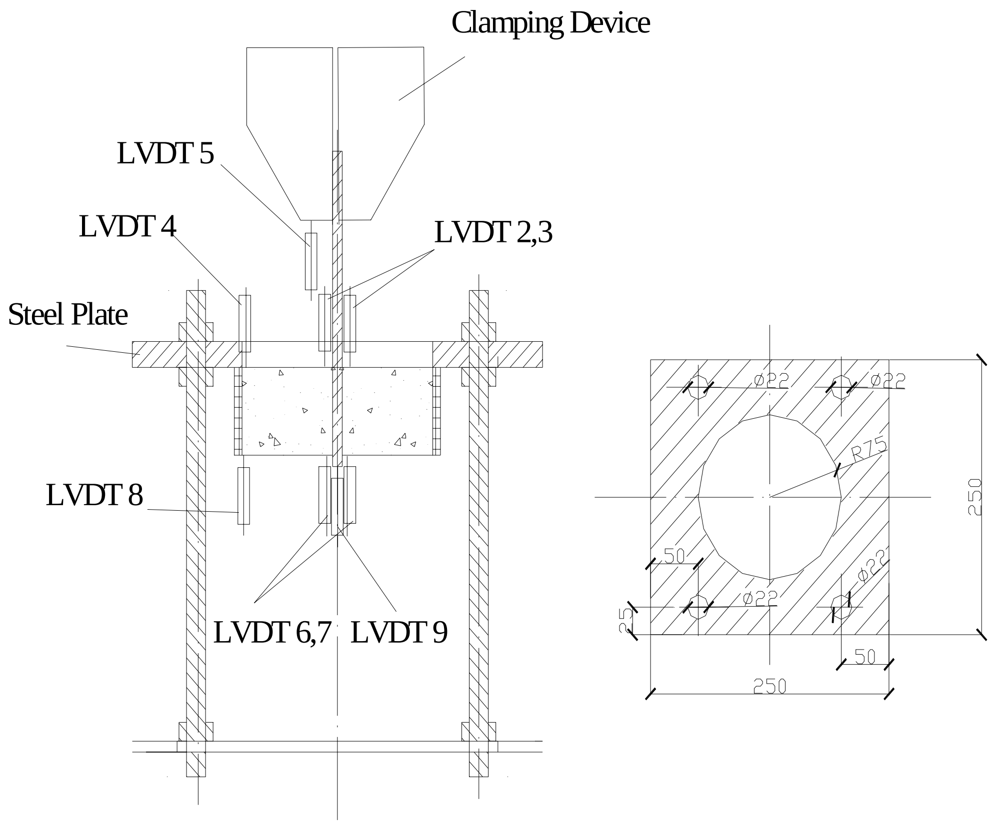
1. Assumption in RCED Model
   a. Pure shear deformation in the bond zone
   b. Linear slip field
2. Test purpose
   a. Determine the evolution of D_s
   b. Determine the rational size of RCED element
   c. Determine the parameter of a_1, a_2

Test Device and Method



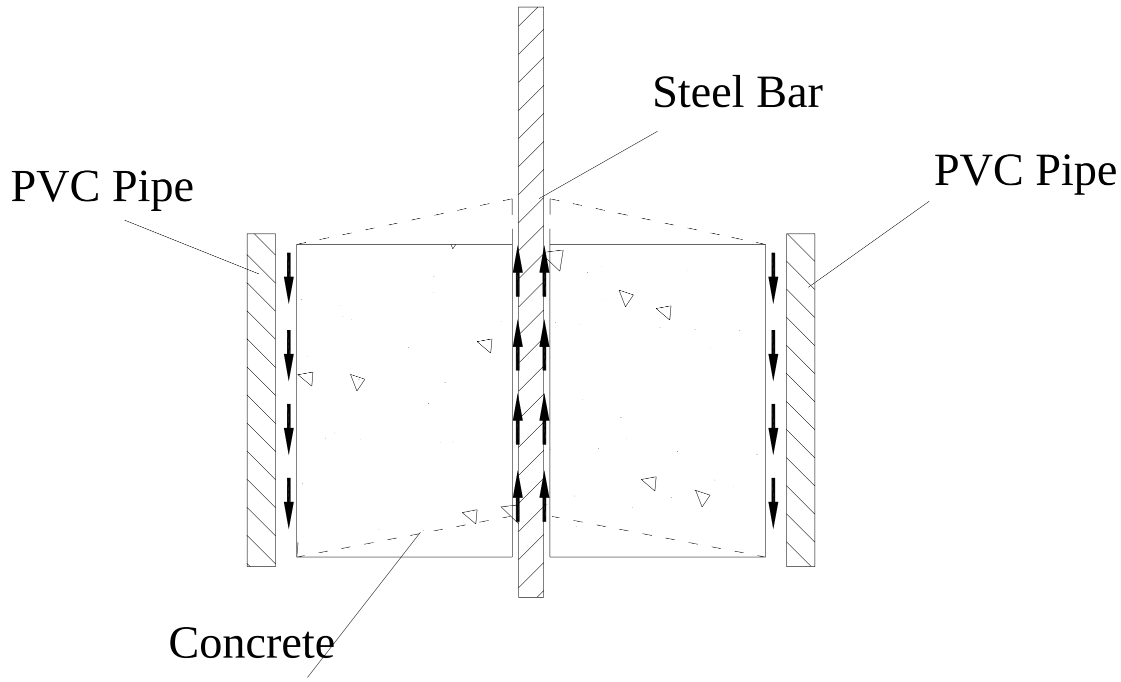
RC Specimen

Test Device and Method



Loading Device

Test Device and Method



Stress State of the Specimen

Test Device and Method

- Assumption in RCED Model

  1. Shear deformation in bond zone

  2. Linear slip field

- Feature of the Test

  1. Constraint force is applied through PVC pipe and glue. Concrete is under pure shear stress condition

  2. Specimen is as thin as possible

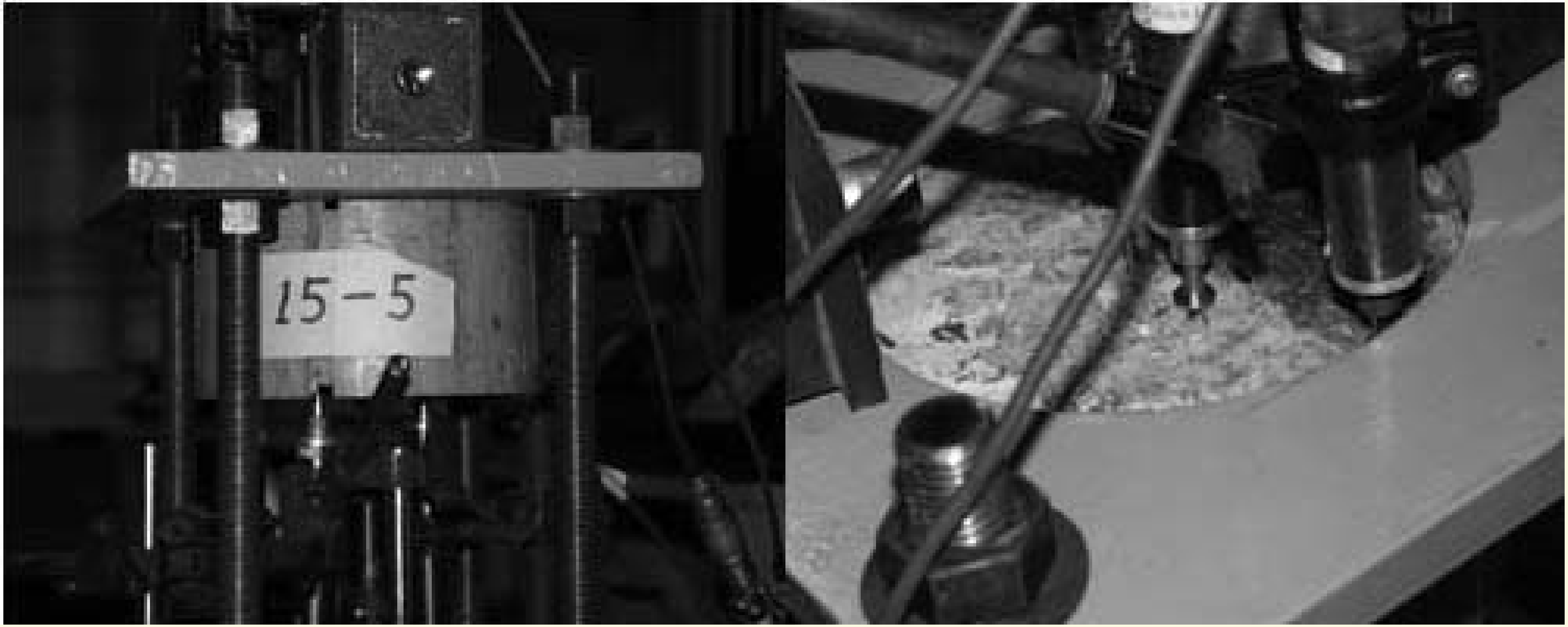
Conclusion: This test can satisfy RCED model

Test Device and Method

(a) Concrete Specimen before Test

(b) PVC Pipe before Test

Test Device and Method



(c, d) During the Test

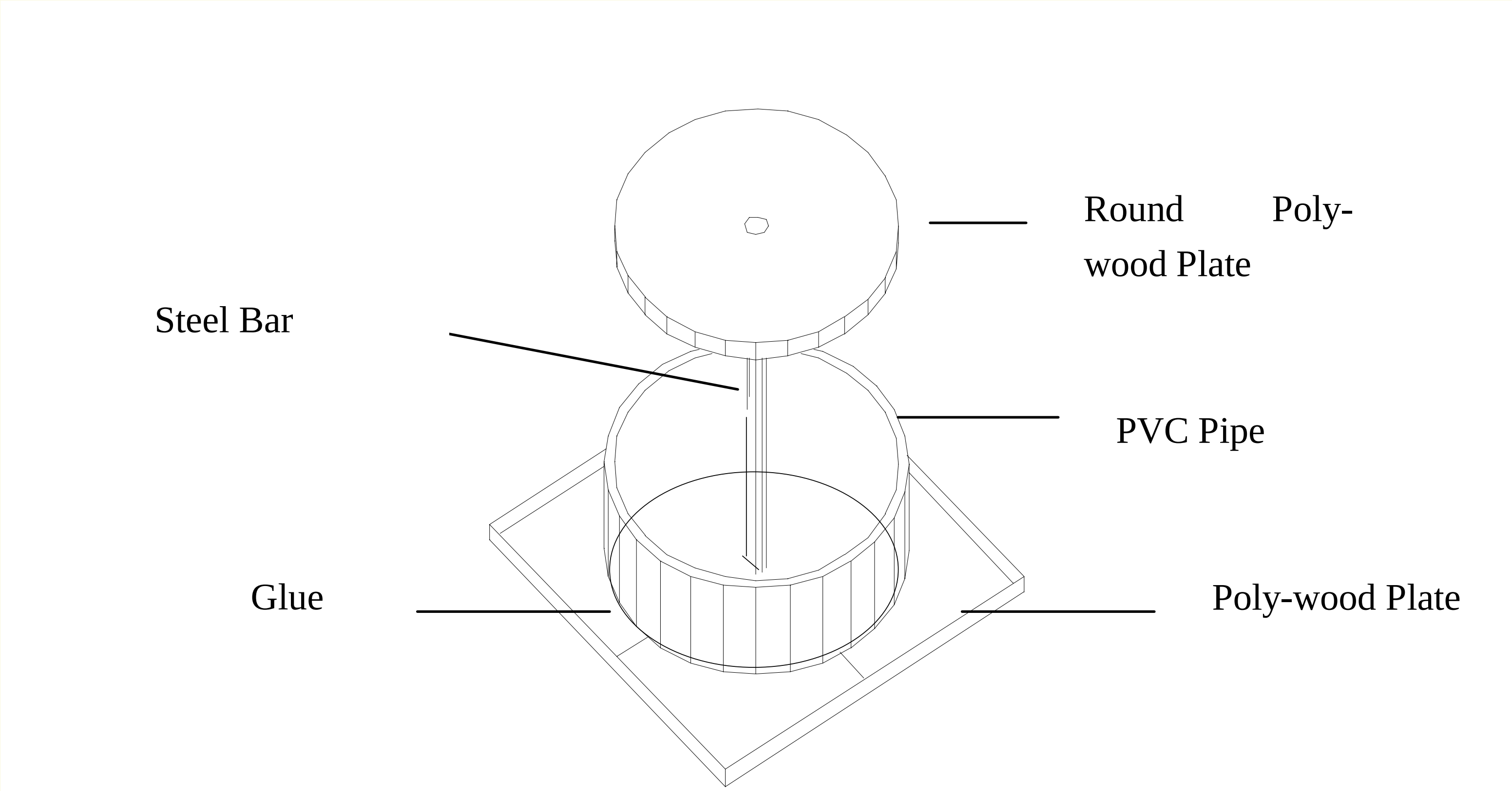
Test Device and Method

Test Device Setup

Test Procedure

- Design the Mold
- Test of Steel Bar
- Casting of Concrete
- Design of Loading Device
- Specimen Analysis before Test
- Trial Loading and Analysis of Failure
- Improving Method
- Formal Loading
- Standard Specimen Test

1. Design the Mold



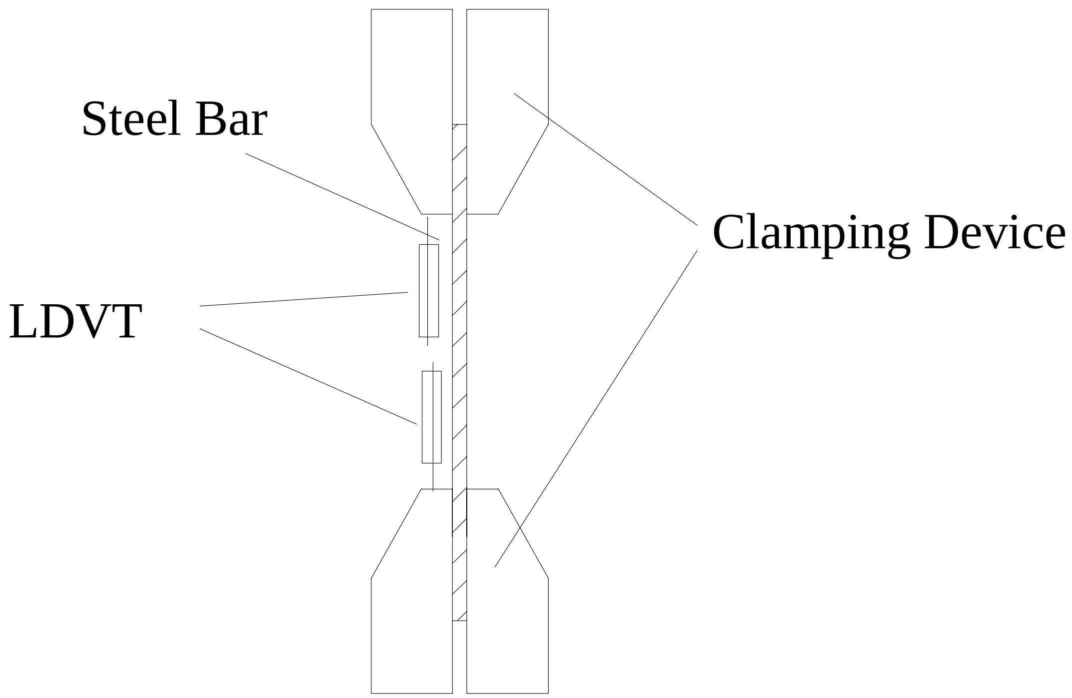
Specimen Mold

2. Test of Steel Bar

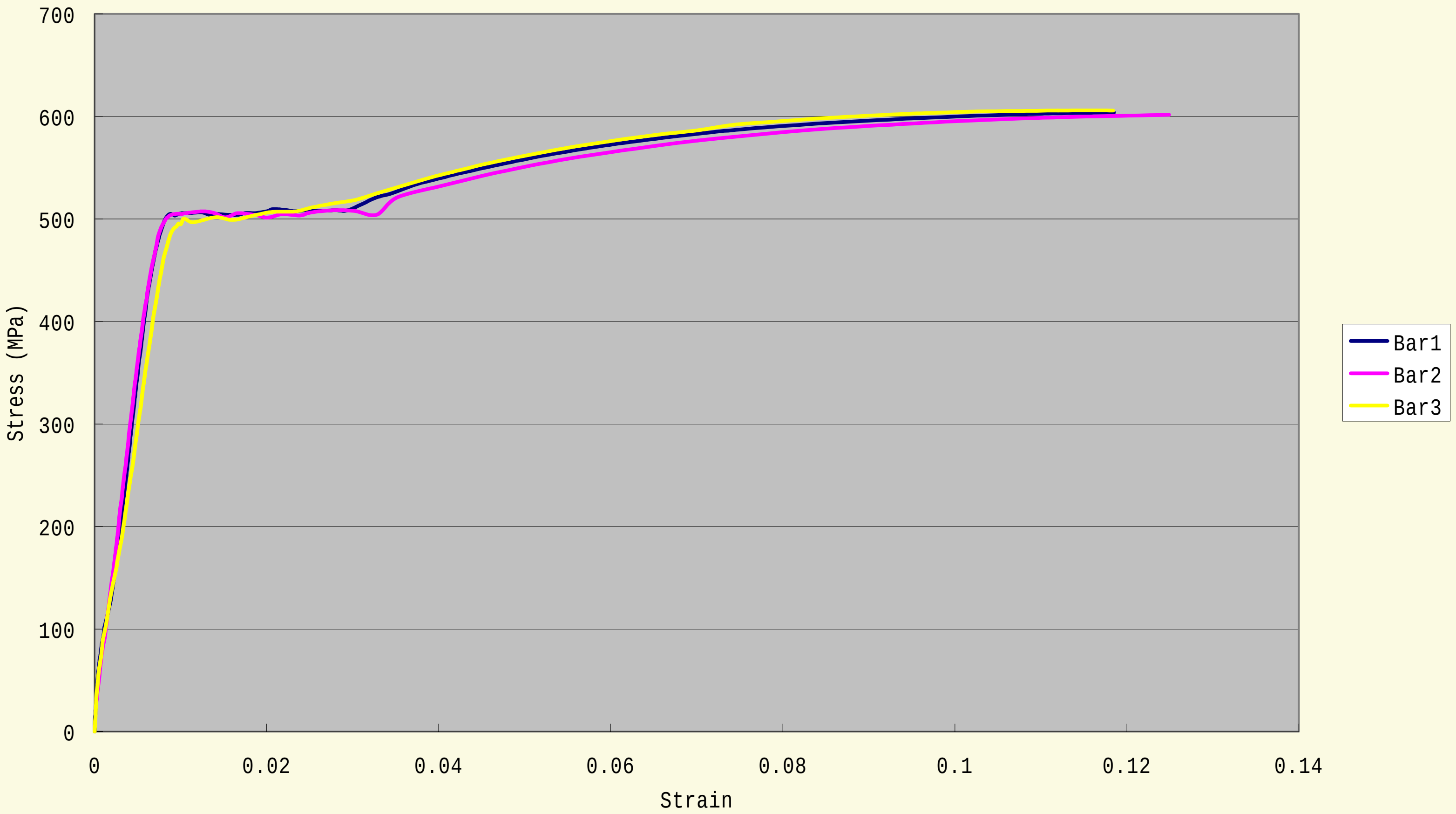
Displacement Determined By LVDT 5

- Slip Between Steel Bar and Concrete
- Elongation of the Free Part of Steel Bar
- Slip Between Steel Bar and Clamping Device

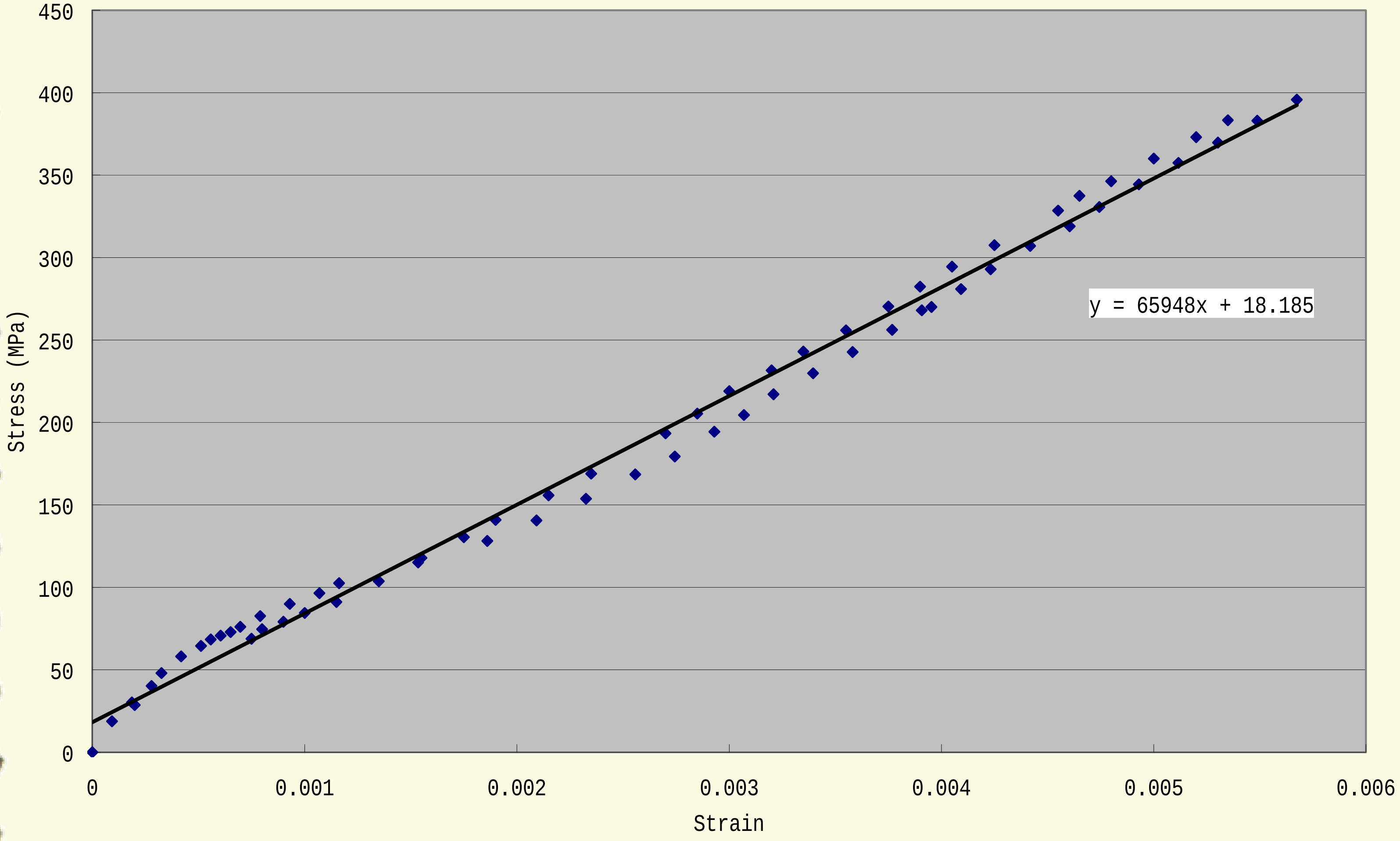
2. Test of Steel Bar



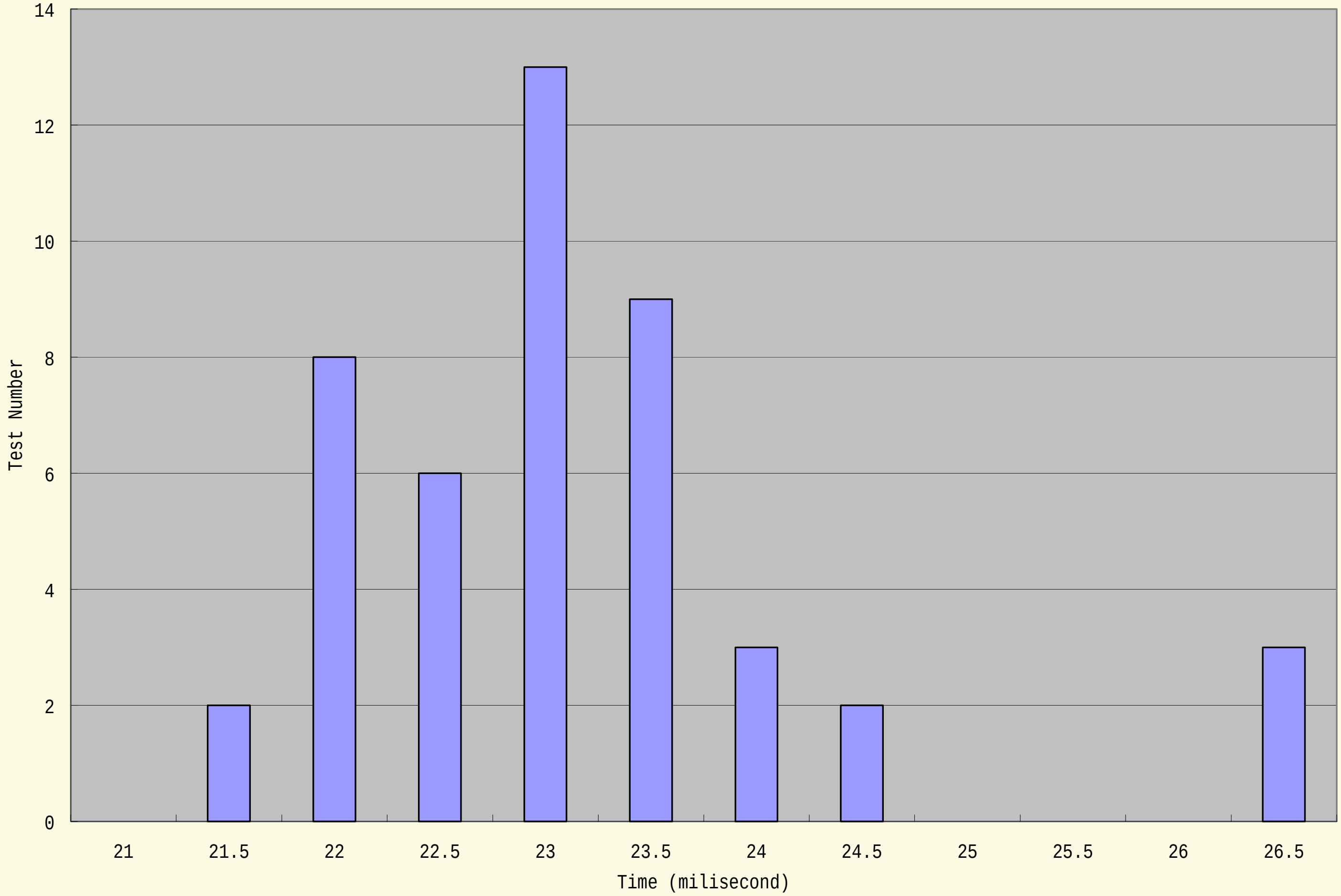
2. Test of Steel Bar



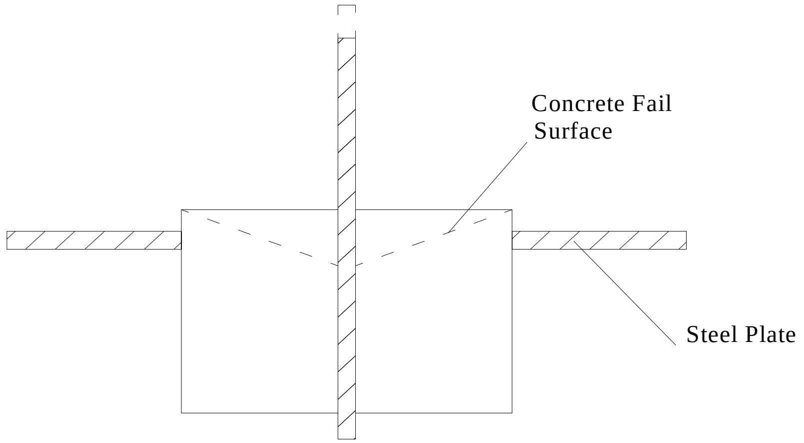
2. Test of Steel Bar



5. Specimen Analysis before Test



6. Trial Loading and Analysis of Failure

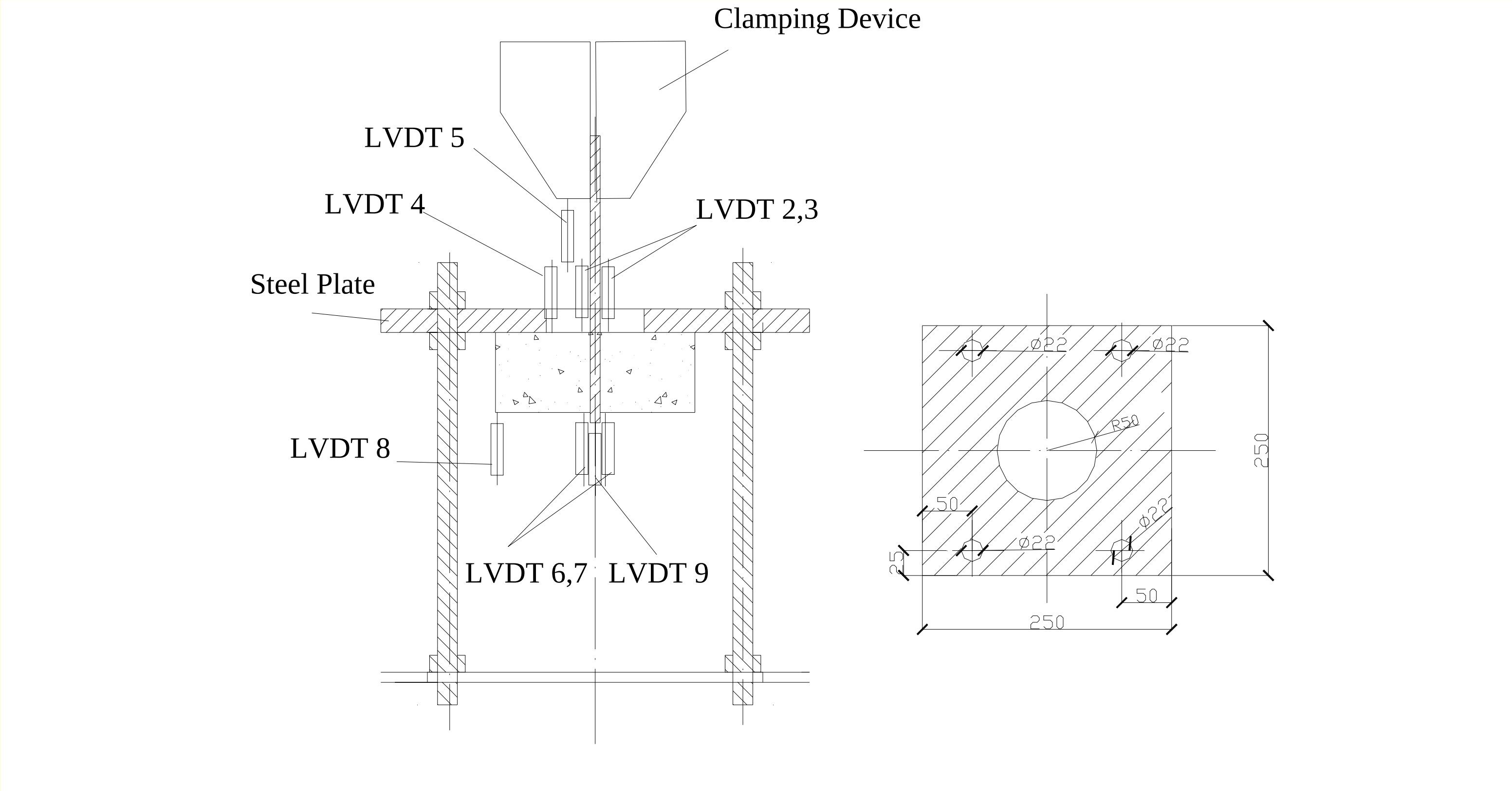


Fail Surface of 10-7

6. Trial Loading and Analysis of Failure

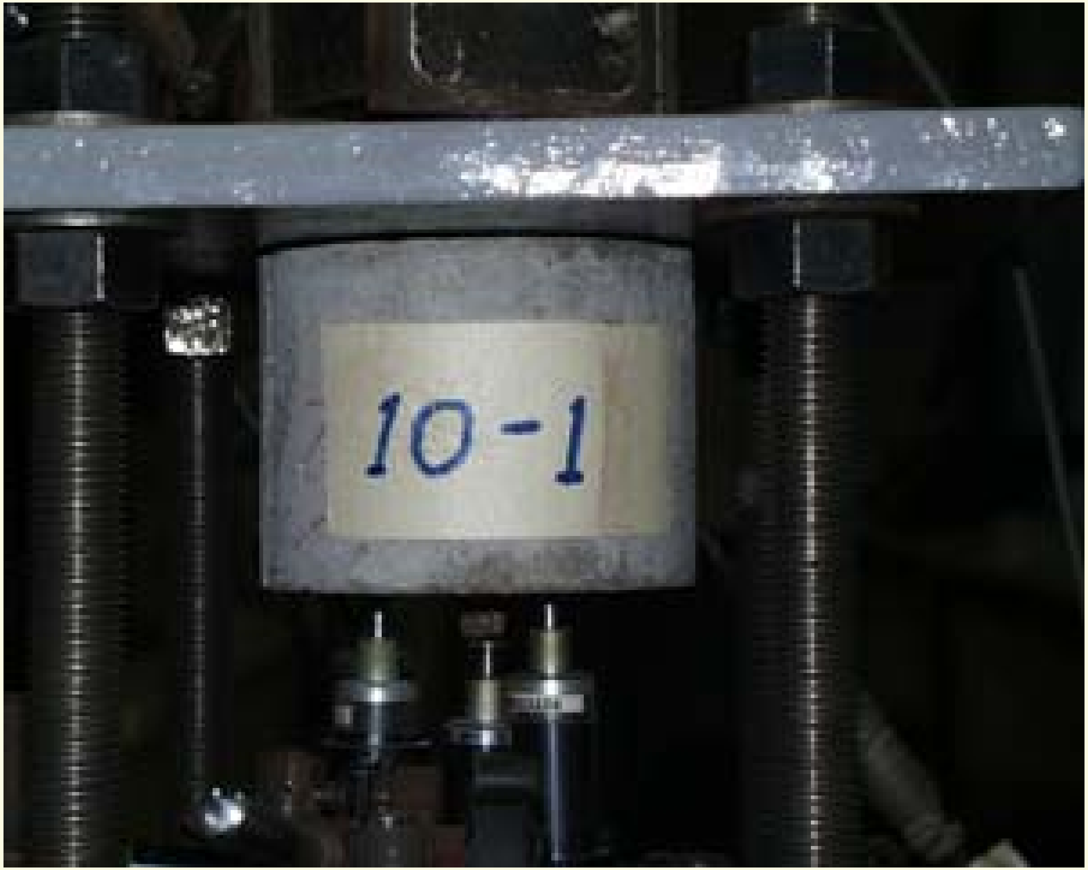
Test Result of 10-7

6. Trial Loading and Analysis of Failure



Load Applied directly without PVC Pipe

6. Trial Loading and Analysis of Failure



Load Applied directly without PVC Pipe

6. Trial Loading and Analysis of Failure

- Conclusion obtained from trial loading

  1. The adhesive isn’t process properly
  2. The confinement is still large

7. Improving the Method

- Roughen the adhesive interface deeper
- Split the PVC pipe finely

8. Formal Loading

Test Result of 10-1

8. Formal Loading

Test Result of 15-5

8. Formal Loading

Test Result of 10-5

8. Formal Loading

Test Result of 10-4

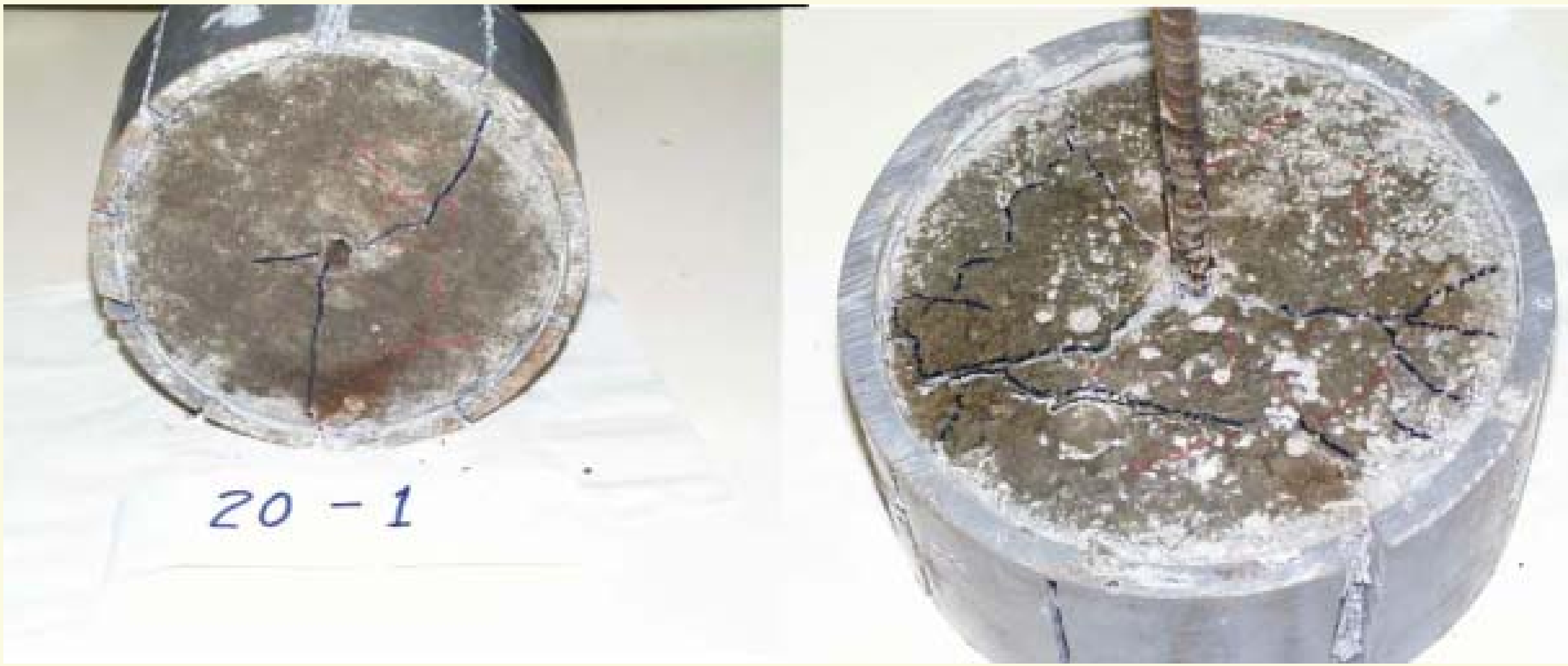
8. Formal Loading

Test Result of 15-1

8. Formal Loading

Test Result of 15-6

8. Formal Loading



Test Result of 20-1

8. Formal Loading

Test Result of 20-5

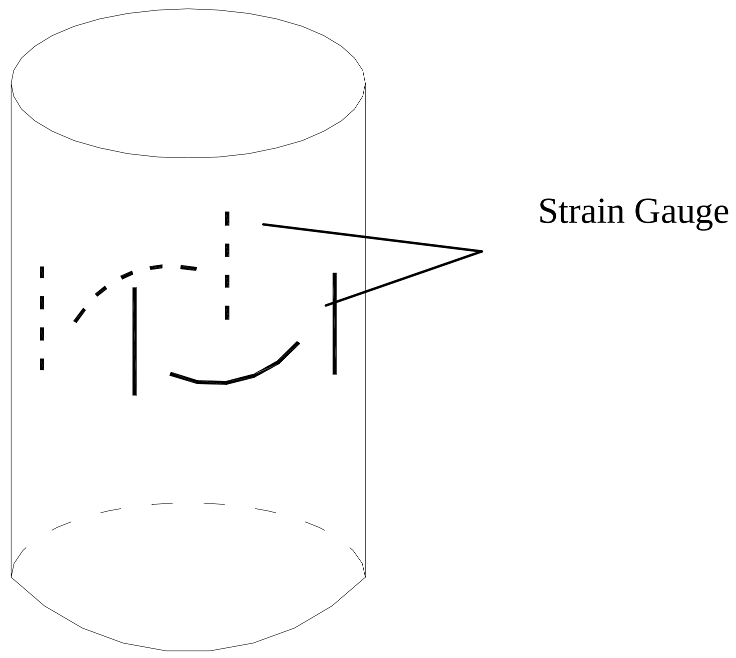
9. Standard Specimen Test

Standard Tube Specimen

- Size: 15×15×15cm
- Result:

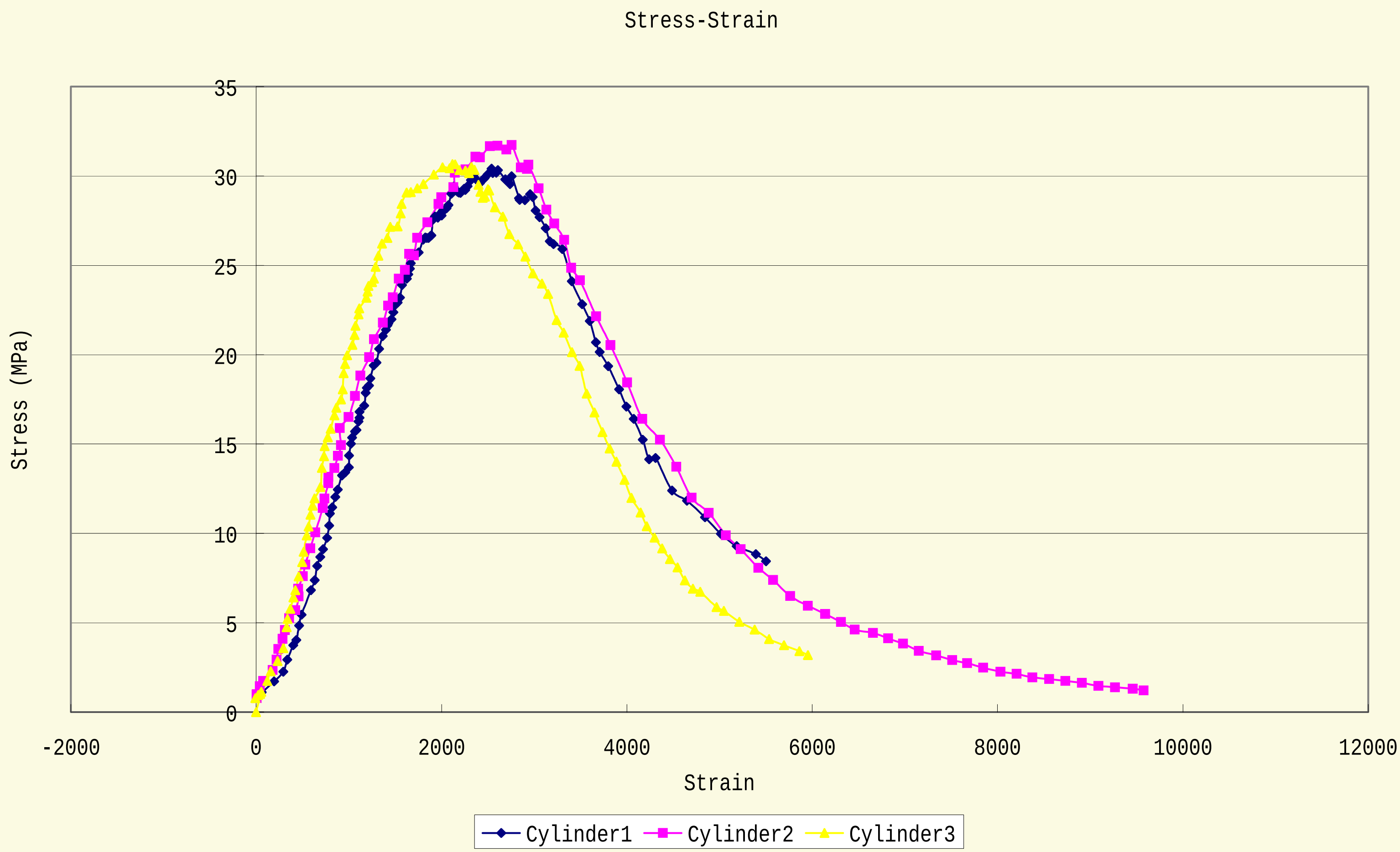
Specimen Number	1	2	3
Max Load (KN)	953	1061	959
Max Strength (MPa)	42.36	47.16	42.62

9. Standard Specimen Test



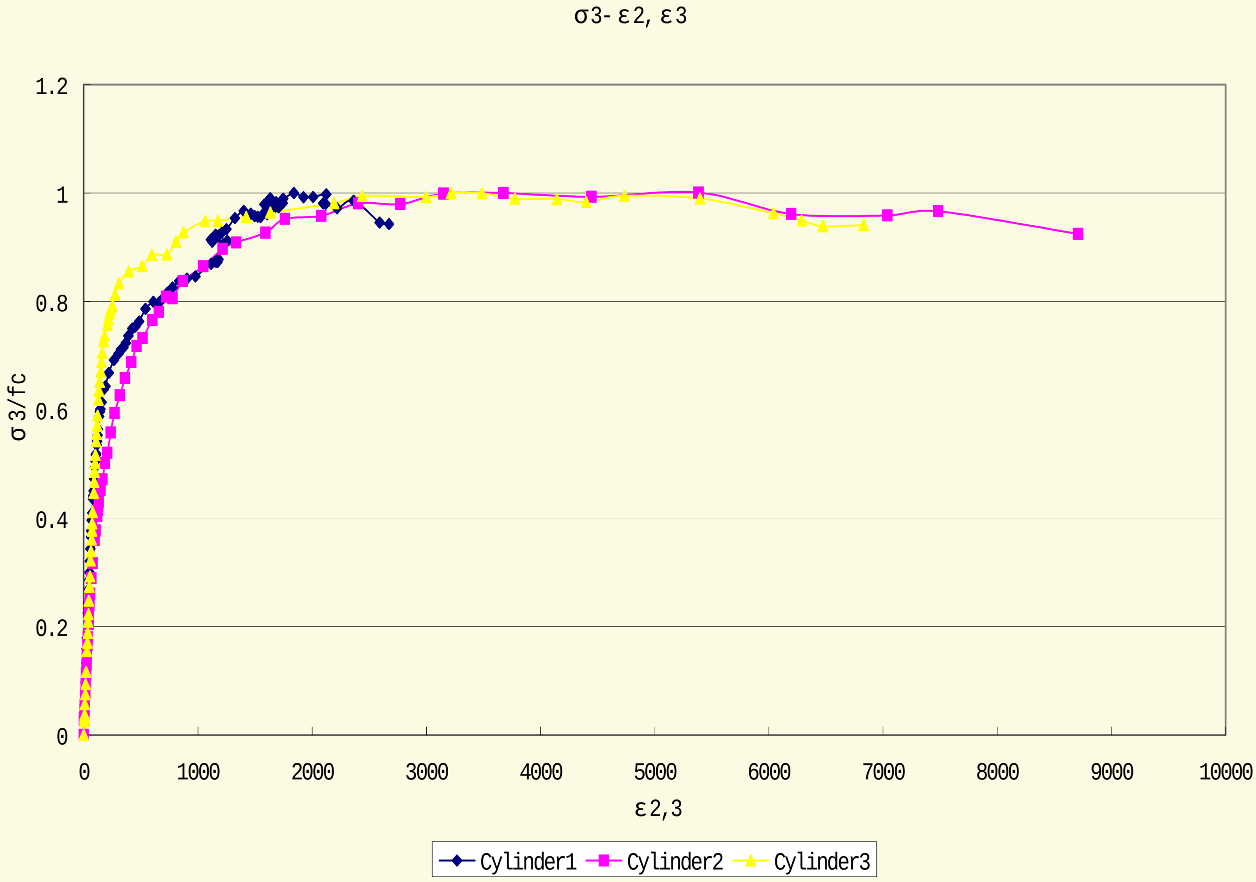
Six Strain Gauges on Standard Cylinder Specimen

9. Standard Specimen Test



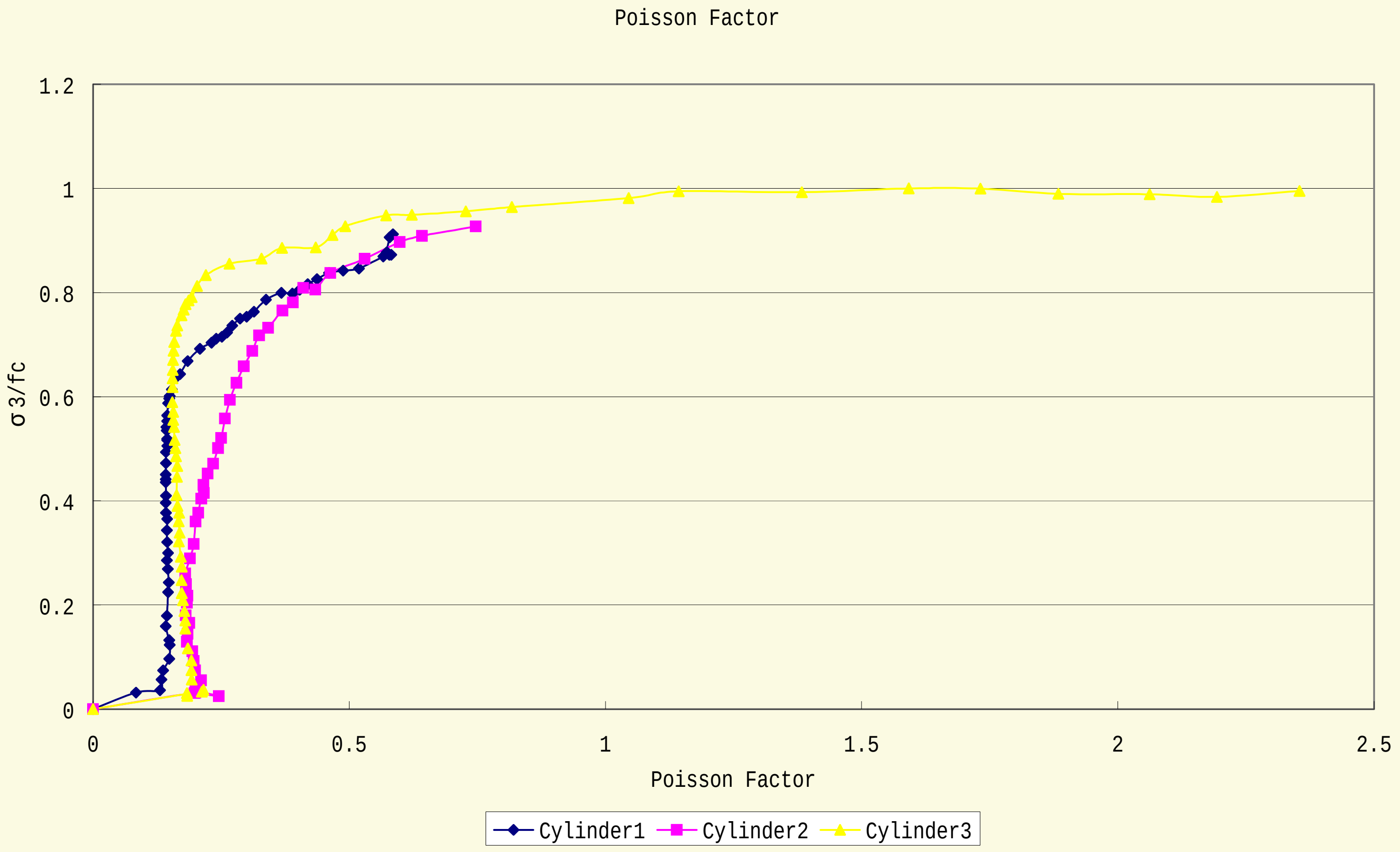
Lognitudinal-stress-strain Curve

9. Standard Specimen Test



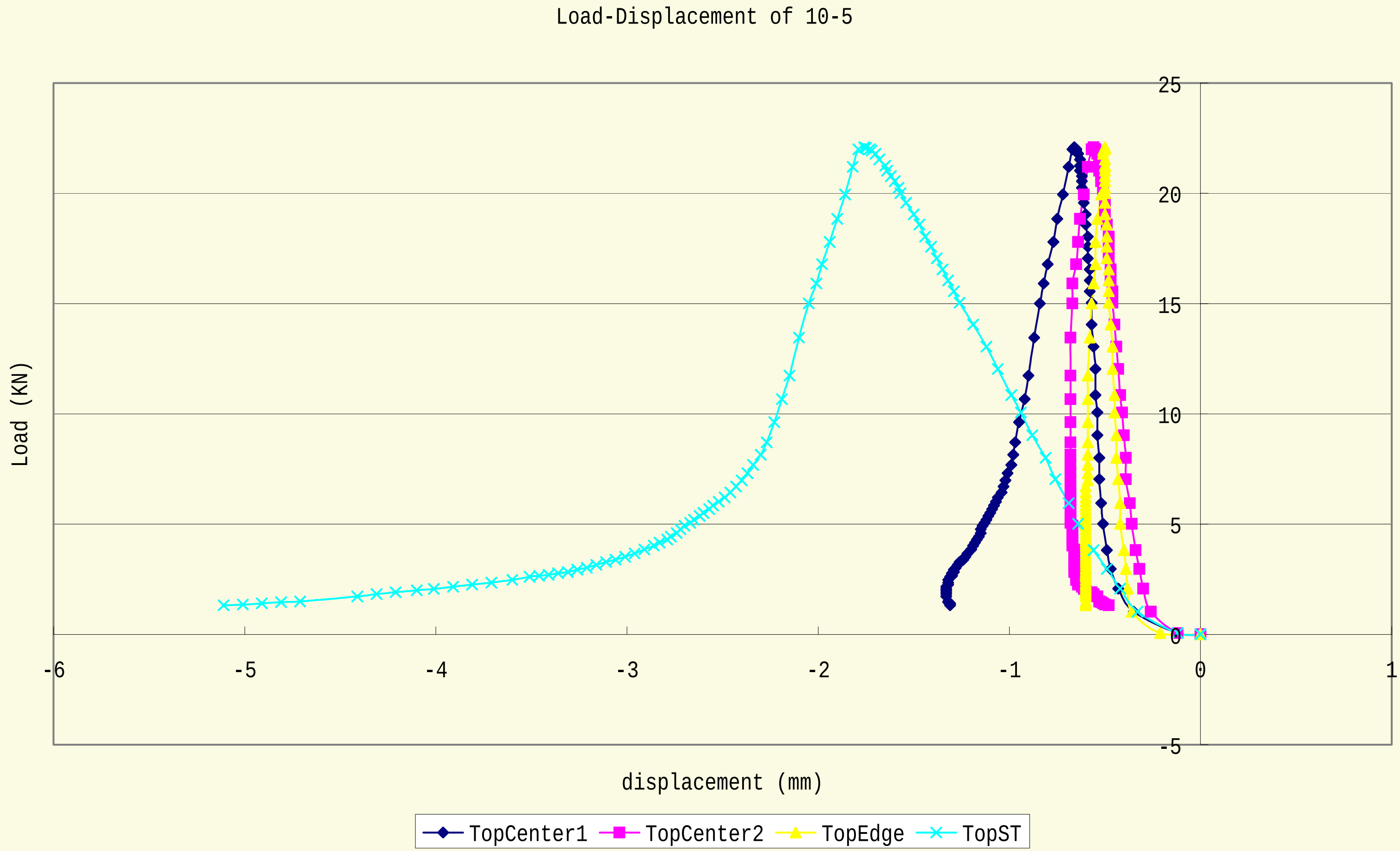
Side-stress-strain Curve

9. Standard Specimen Test



Stress- Poisson Ratio

3. Experimental Data Analysis



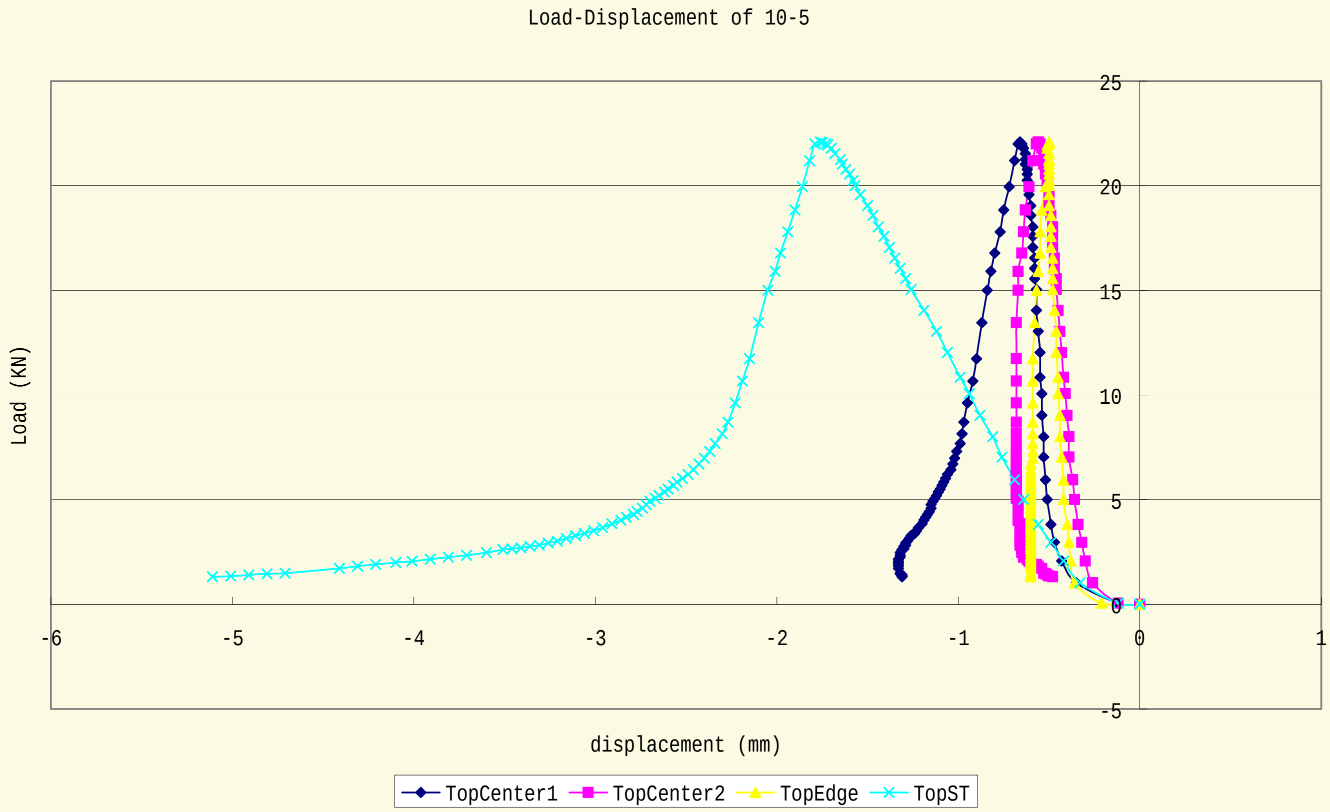
Topical Experiment Original Data

3. Experimental Data Analysis

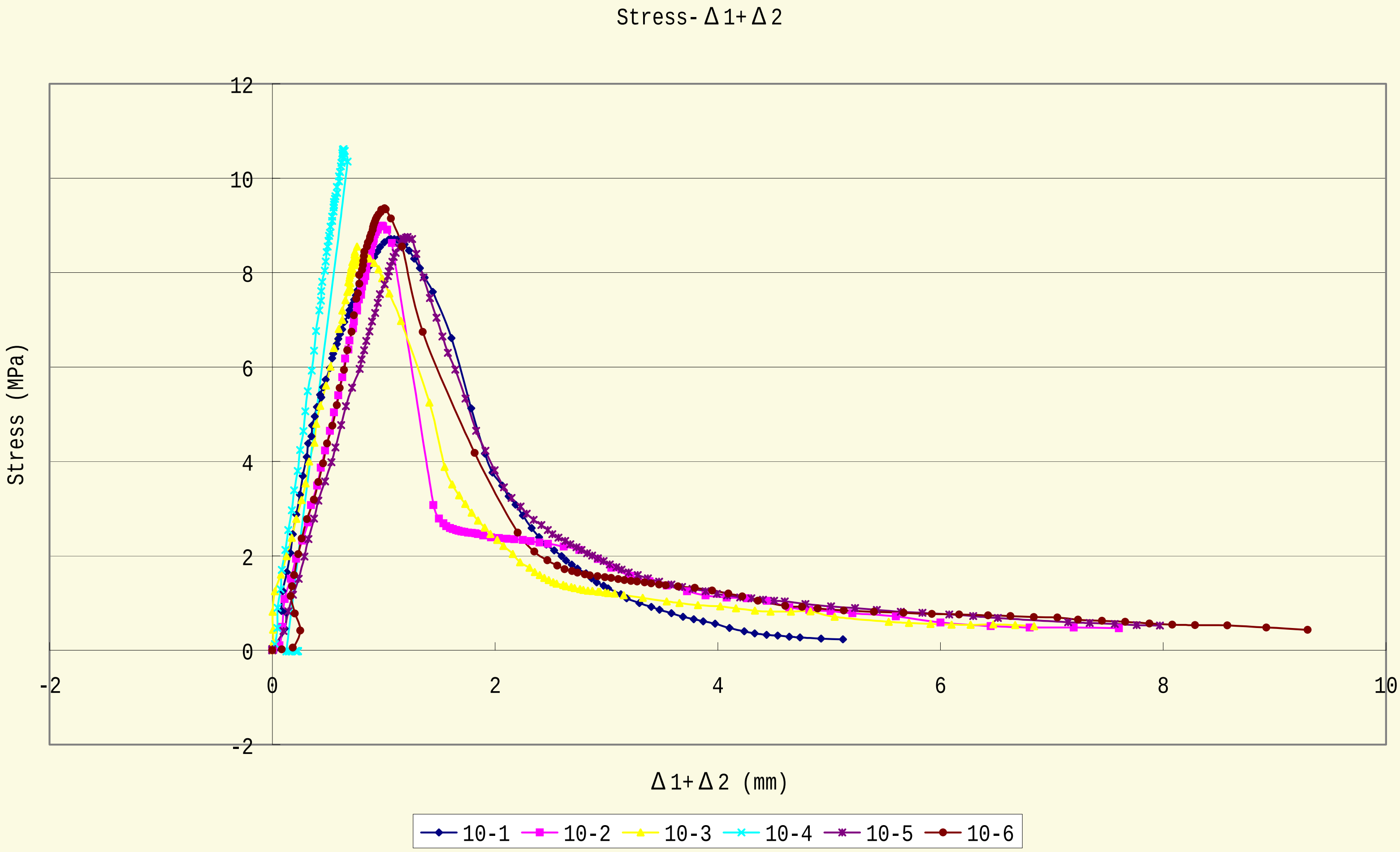
The following information can be obtained from the experimental data:

1. τ-Δ_1+Δ_2 Curve
2. Influence of Height and Radius of Specimen
3. Shear Stress Distribution of Steel Bar and Deformation of Concrete
4. Slip Damage Zone

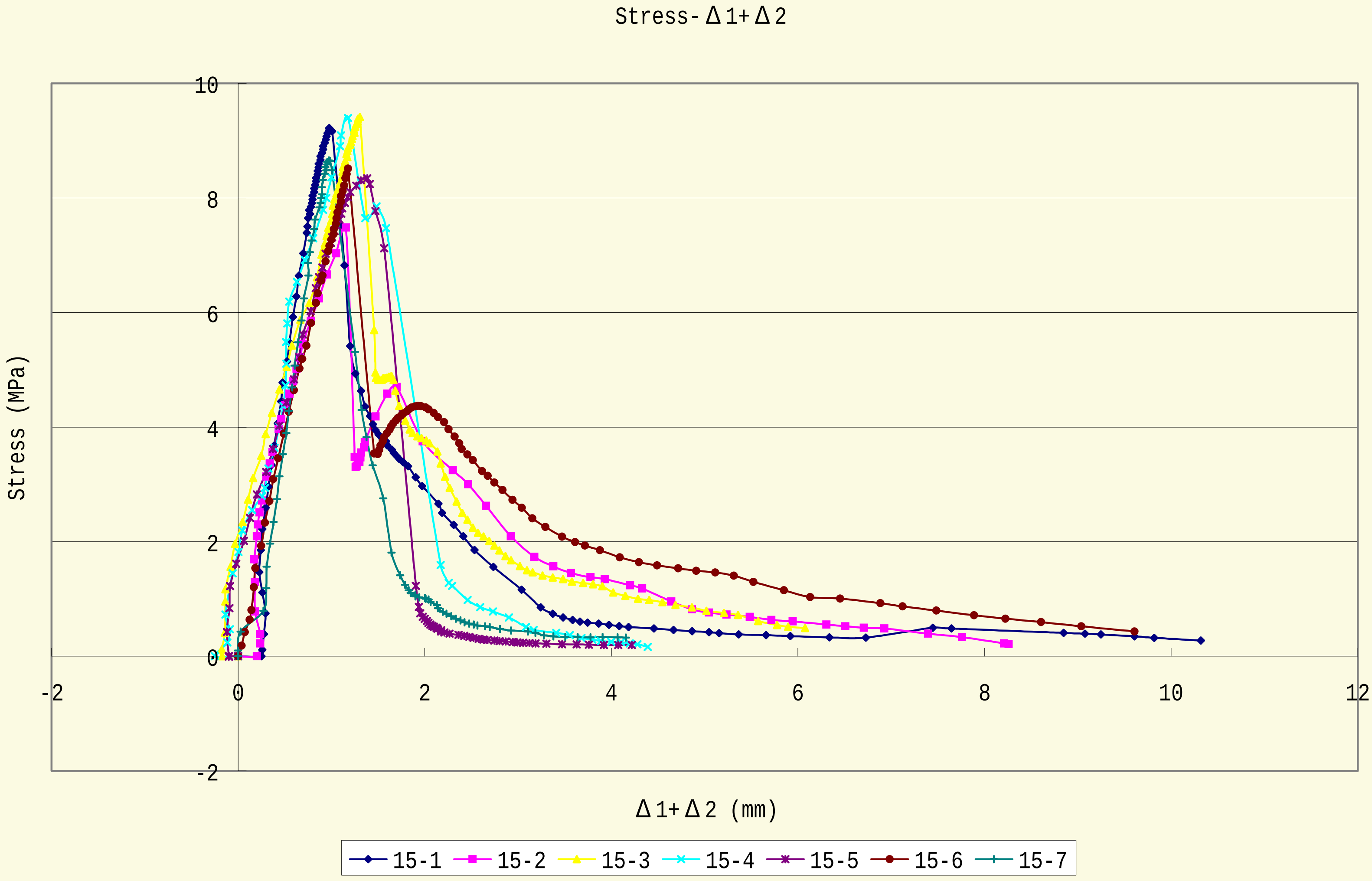
Original Data



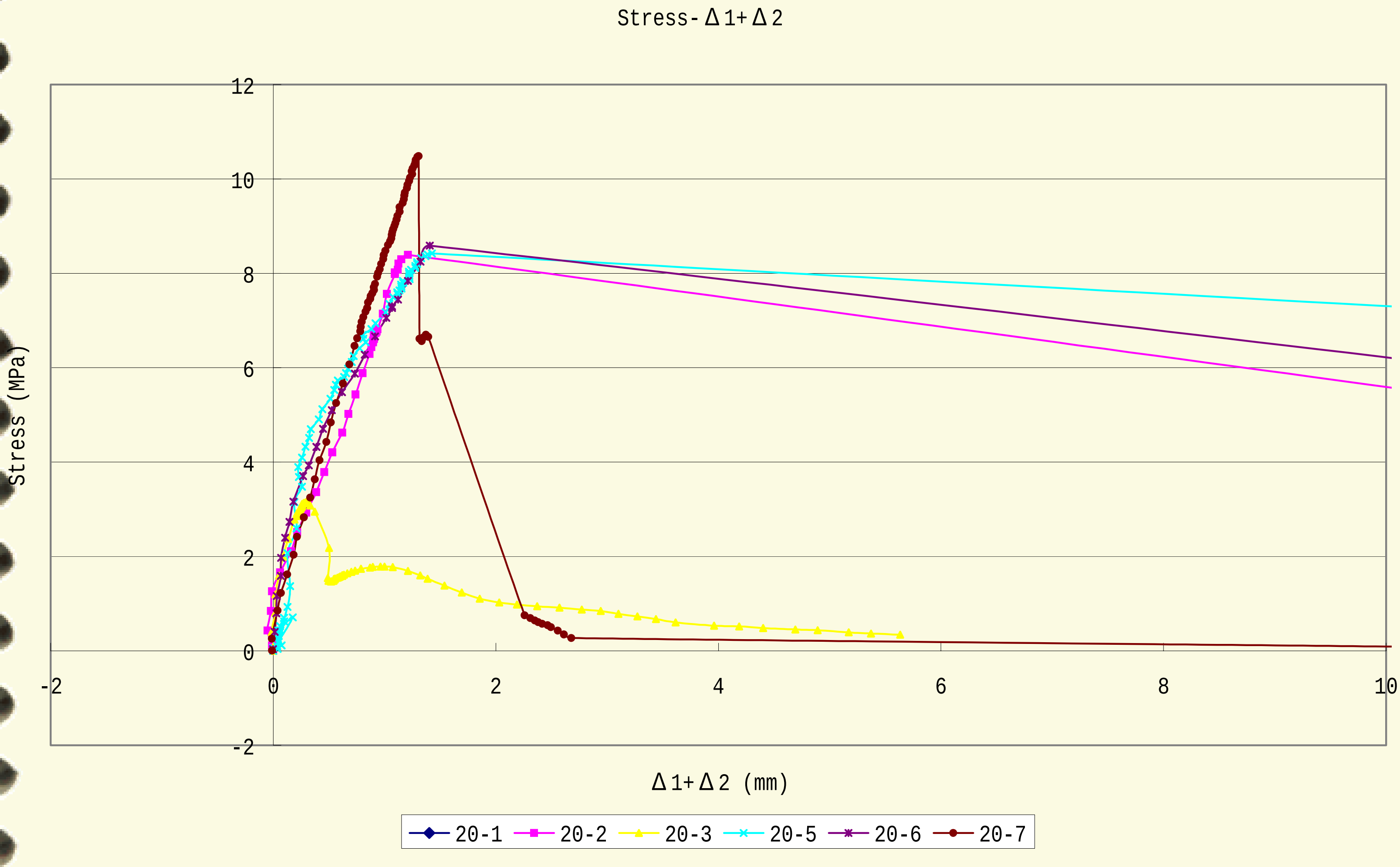
τ-$\Delta_1+\Delta_2$ Curve



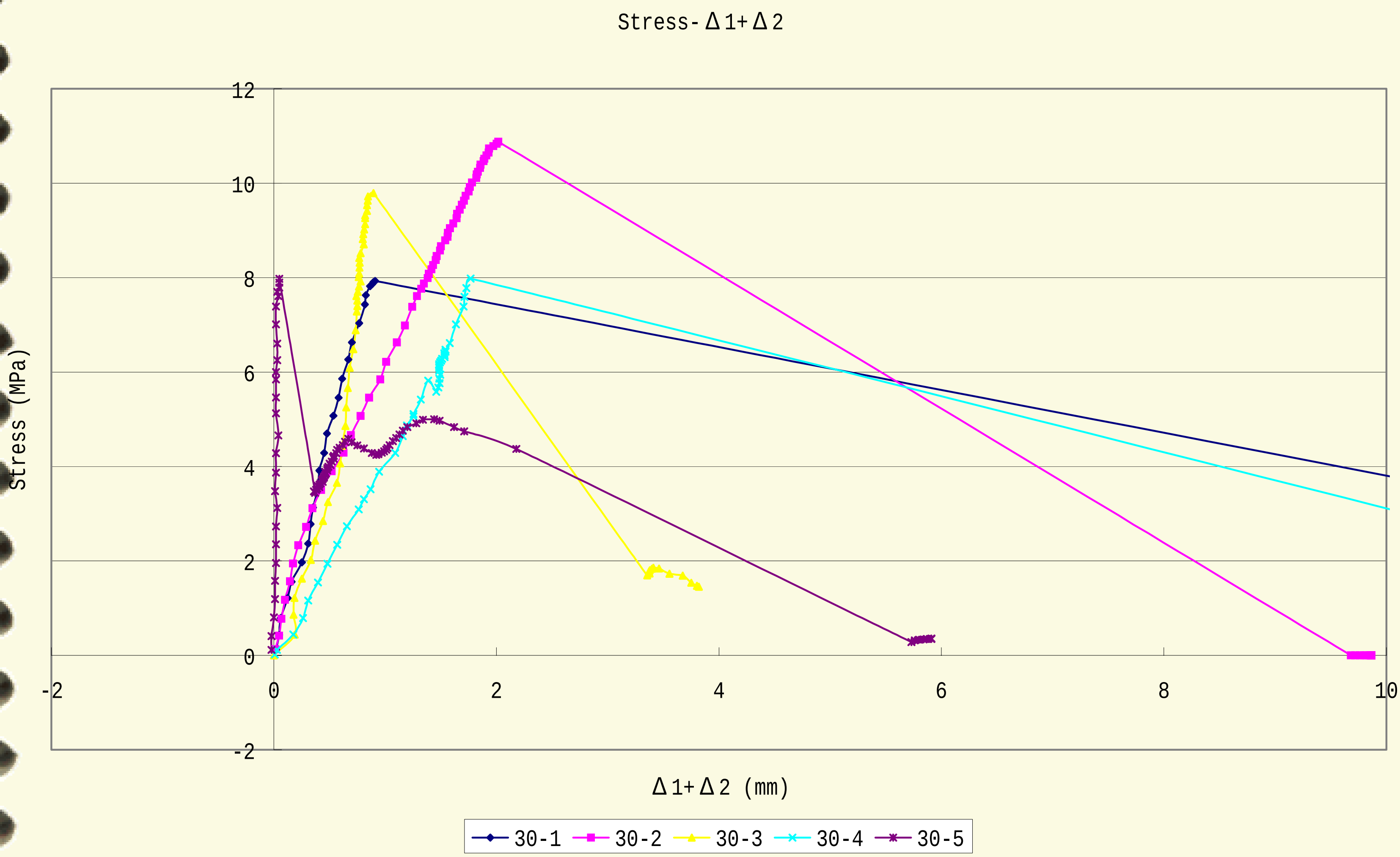
τ-$\Delta_1+\Delta_2$ Curve



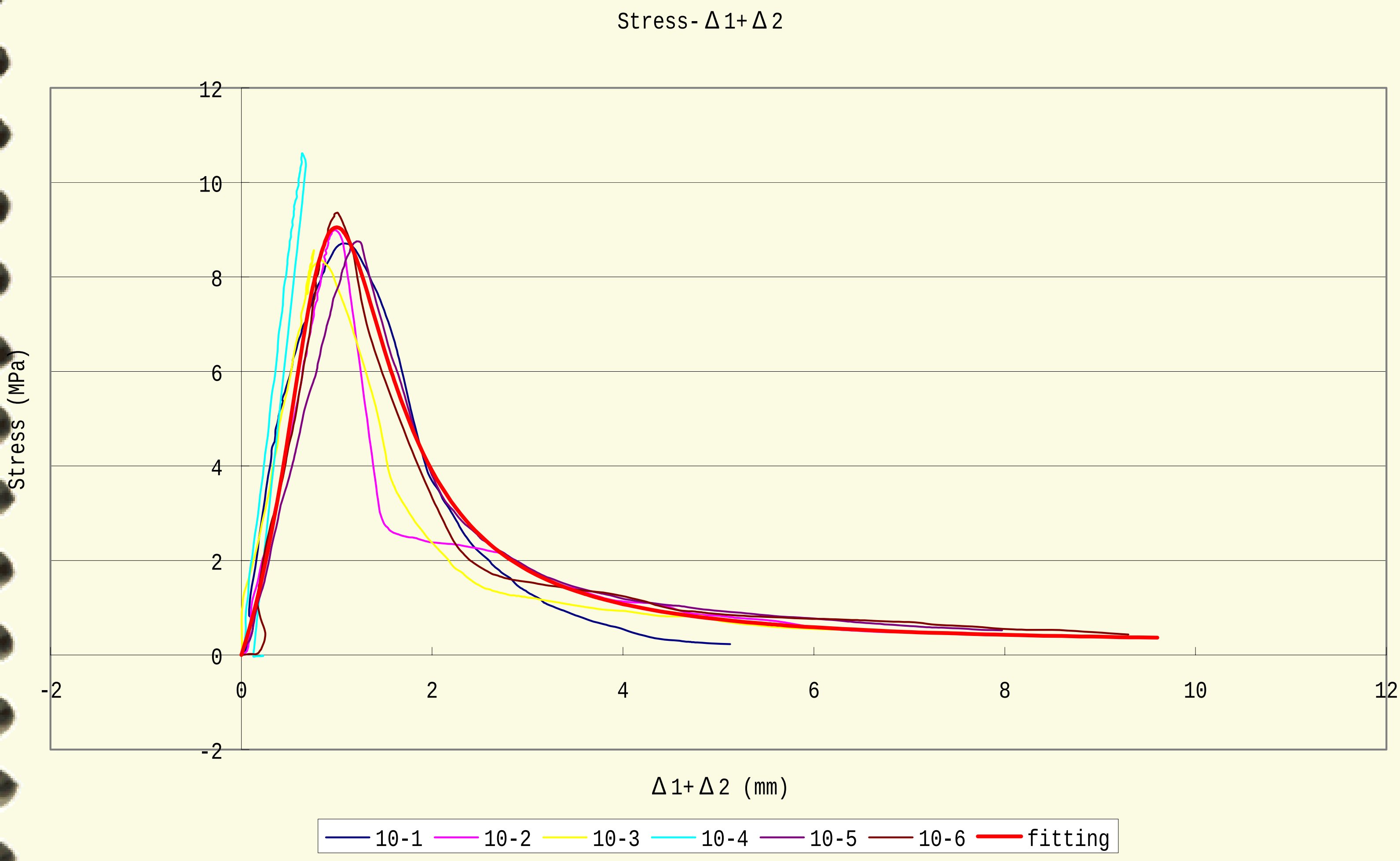
τ-$\Delta_1+\Delta_2$ Curve



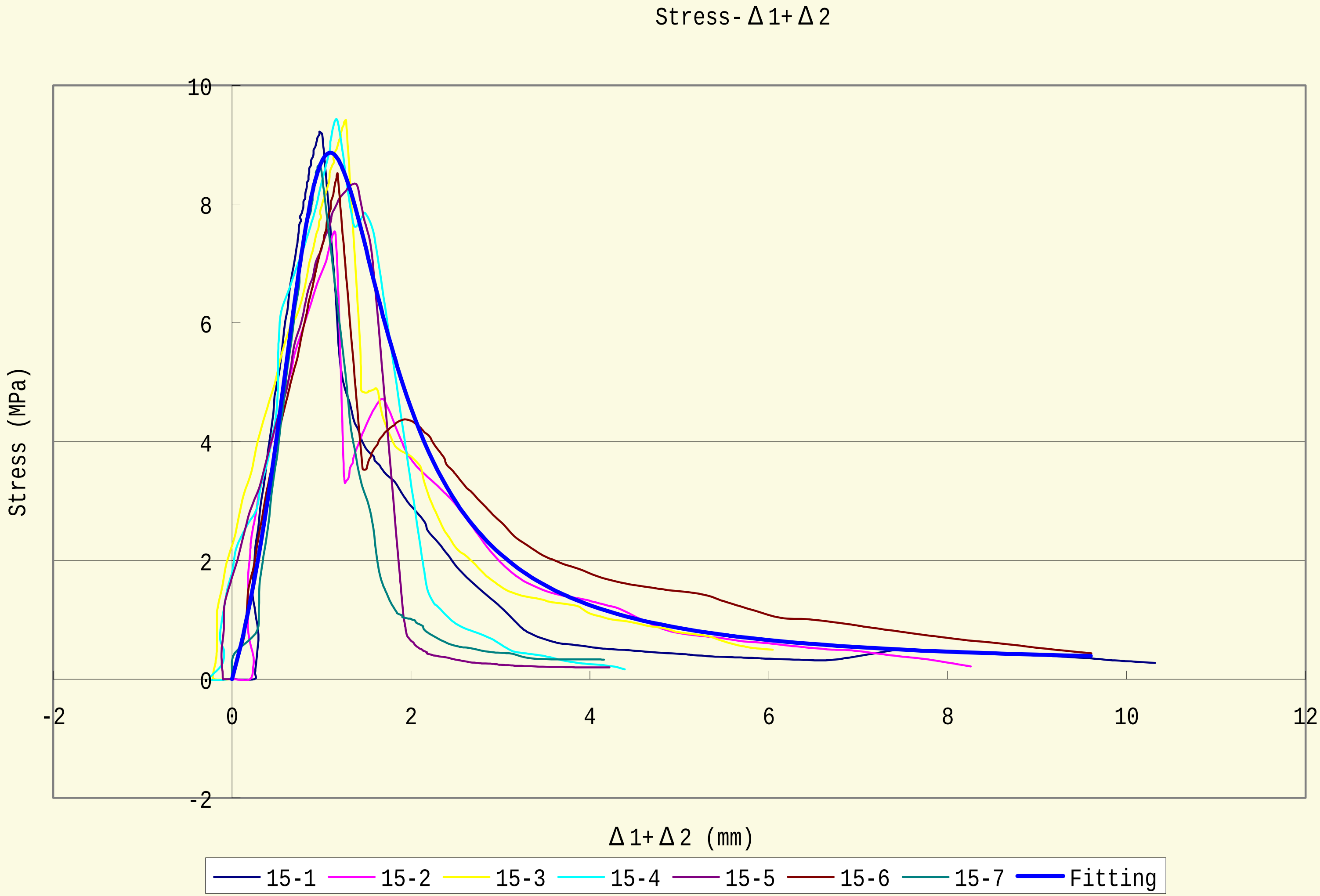
τ-Δ_1+Δ_2 Curve



τ-$\Delta_1+\Delta_2$ Curve Fitting



τ-Δ_1+Δ_2 Curve Fitting



Empirical Formula

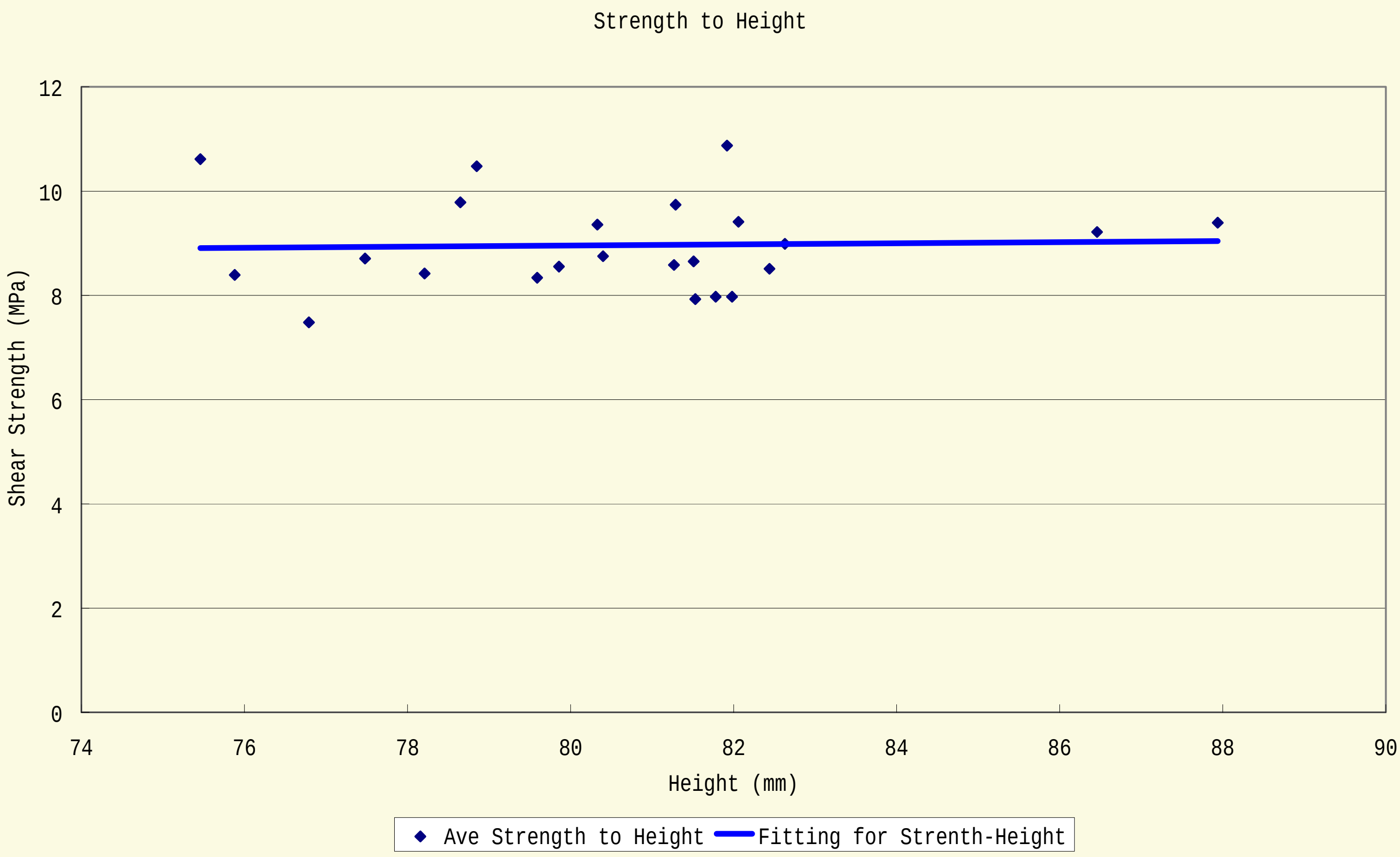
$$\tau = \frac{0.7260\tau_{max}(\frac{\xi}{\xi_0}) + 0.061(\frac{\xi}{\xi_0})^{3.2}}{1 - 0.916(\frac{\xi}{\xi_0}) + 0.642(\frac{\xi}{\xi_0})^{2.87}}$$

τ, Average bond stress

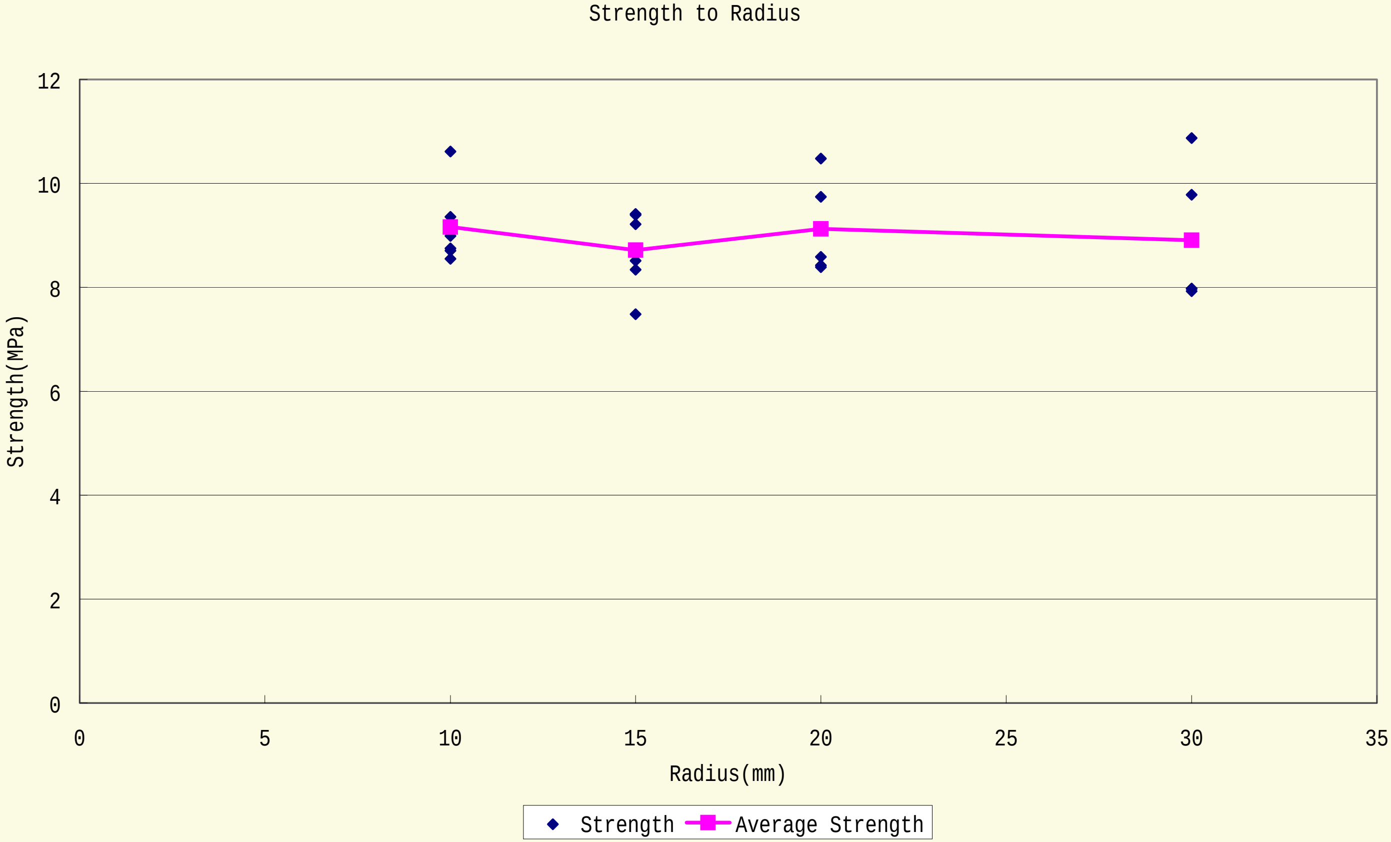
ξ, Value of $\Delta_1+\Delta_2$

ξ_0, Value of $\Delta_1+\Delta_2$ at peak point

Influence of Height of Specimen



Influence of Radius of Specimen

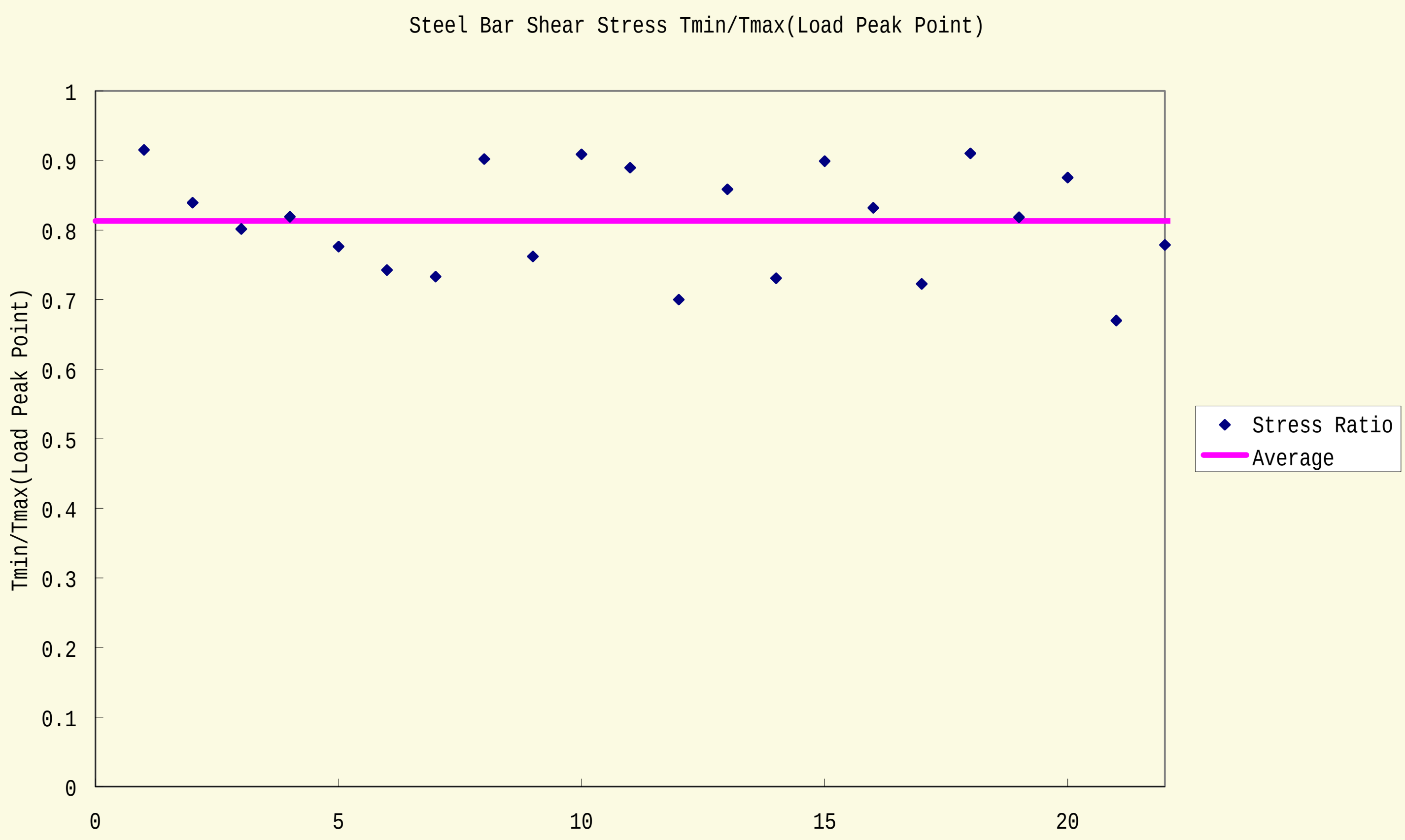


Shear Stress Distribution along Steel Bar

- Obtain the Shear Stress Distribution from the following conditions

1. Elongation of the steel bar
2. Relationship between τ and Δ
3. Linear assumption in RCED model

Shear Stress Distribution along the Steel Bar



Slip Damage Zone

In this test, there is no obvious slip damage zone founded with UPV. So we consider that the slip damage zone is very small, which appears just around the interface of concrete and re-bar.

Numerical Study

- Objectives

1. Whether the empirical relationship of bond-slip obtained from the test can be used directly in finite element analysis
2. To verify the assumption in RCED model

Numerical Study

- Finite Element Analysis Software

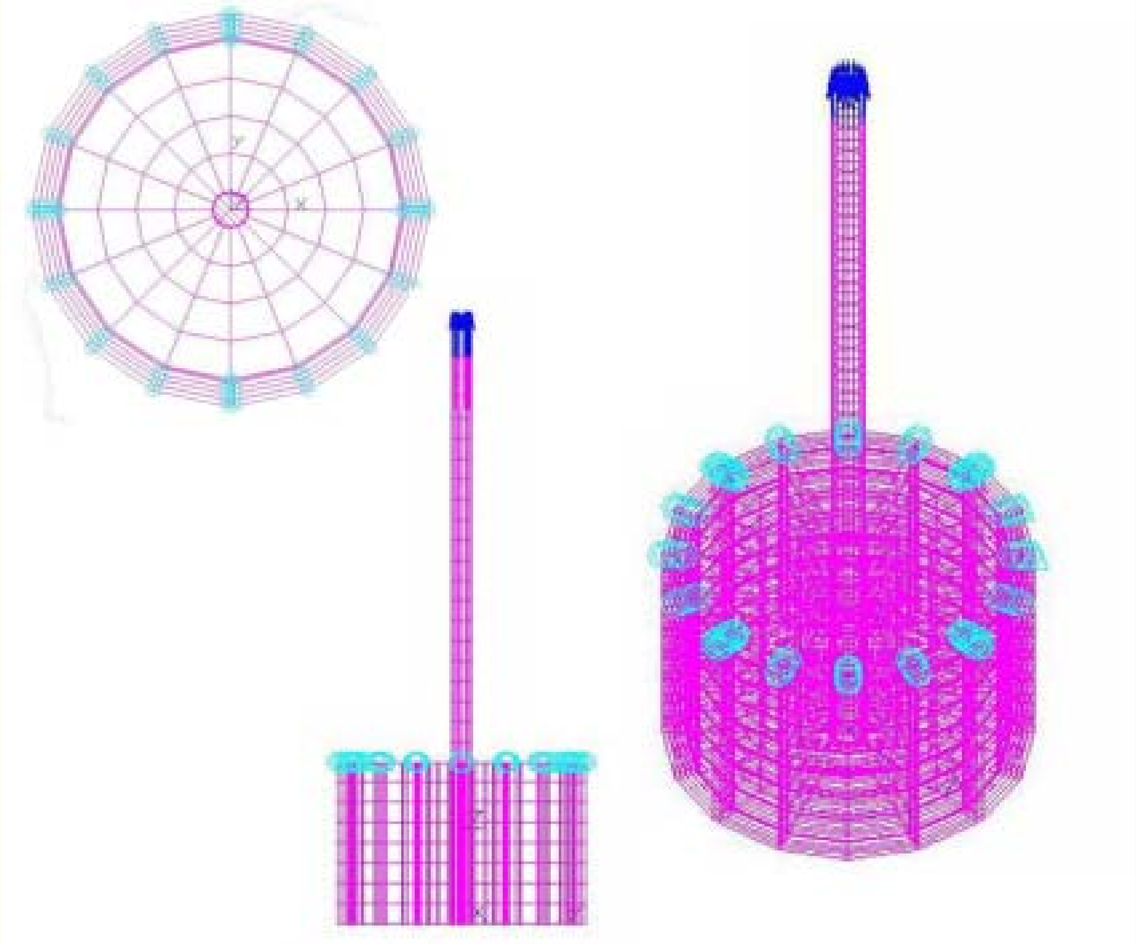
1. Linear analysis: MARC k 7.3.2
2. Non-linear analysis: Sap 91

- Element Type and Mesh

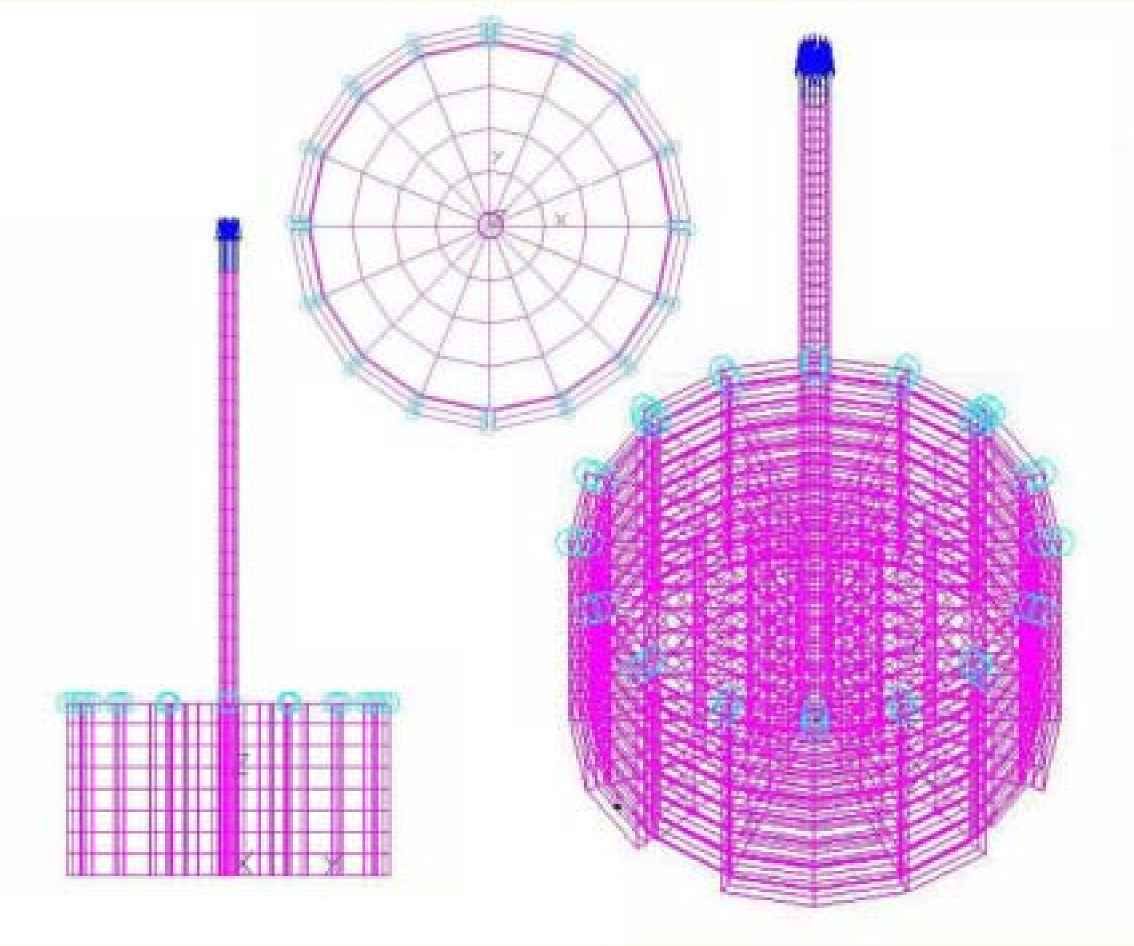
Concrete, Steel bar, Glue and PVC pipe: 20 nodes 3D element.

Bond: Spring element

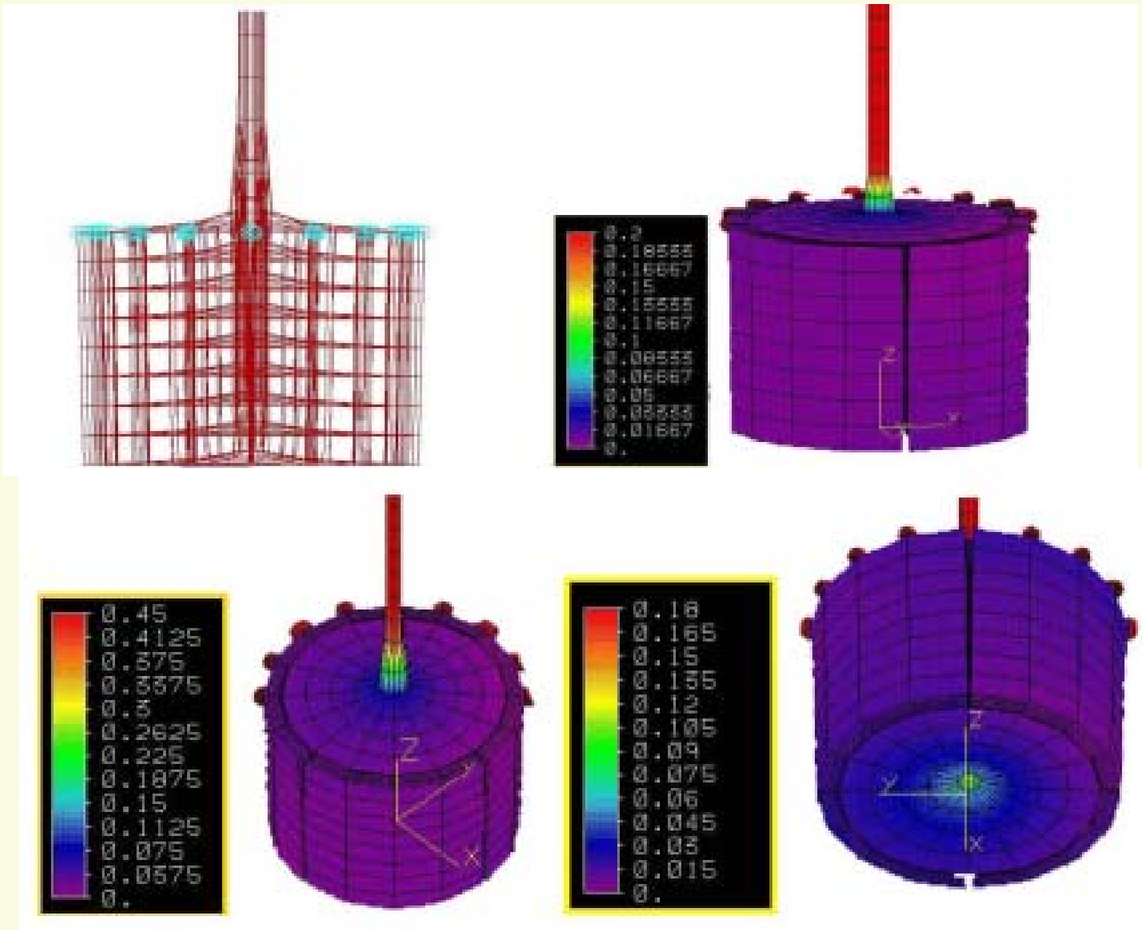
Mesh of Specimen Series 10



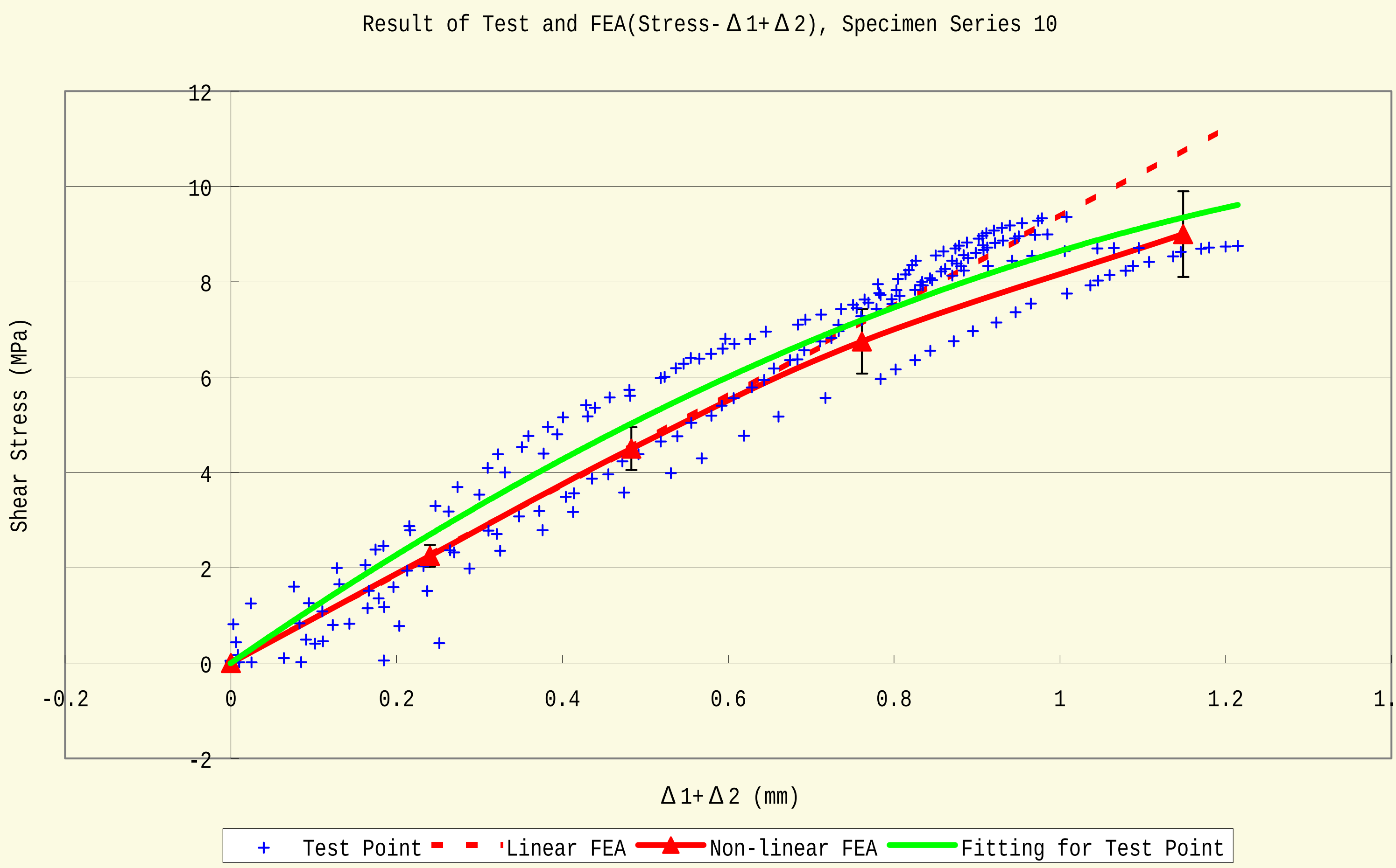
Mesh of Specimen Series 15



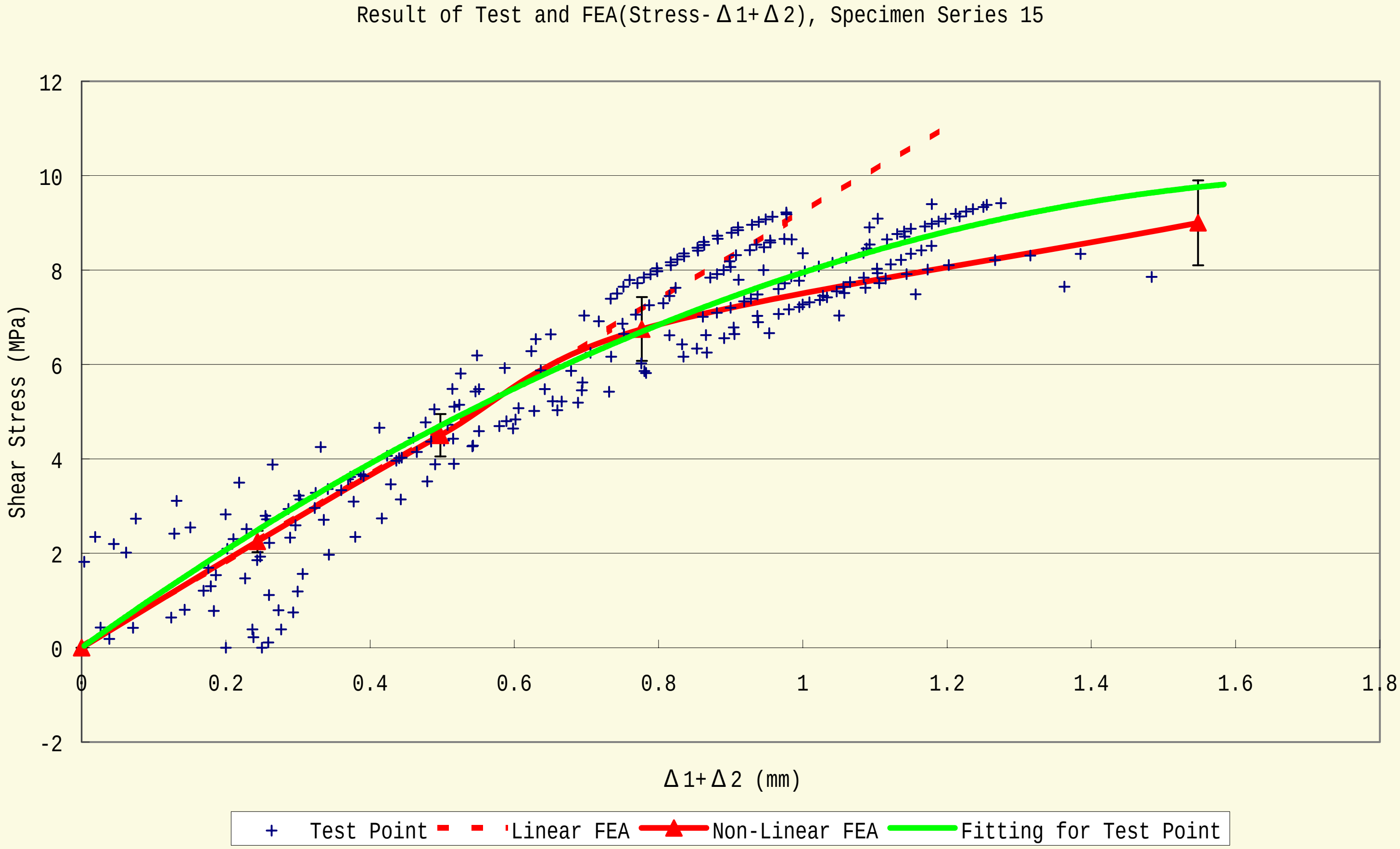
Numerical Result



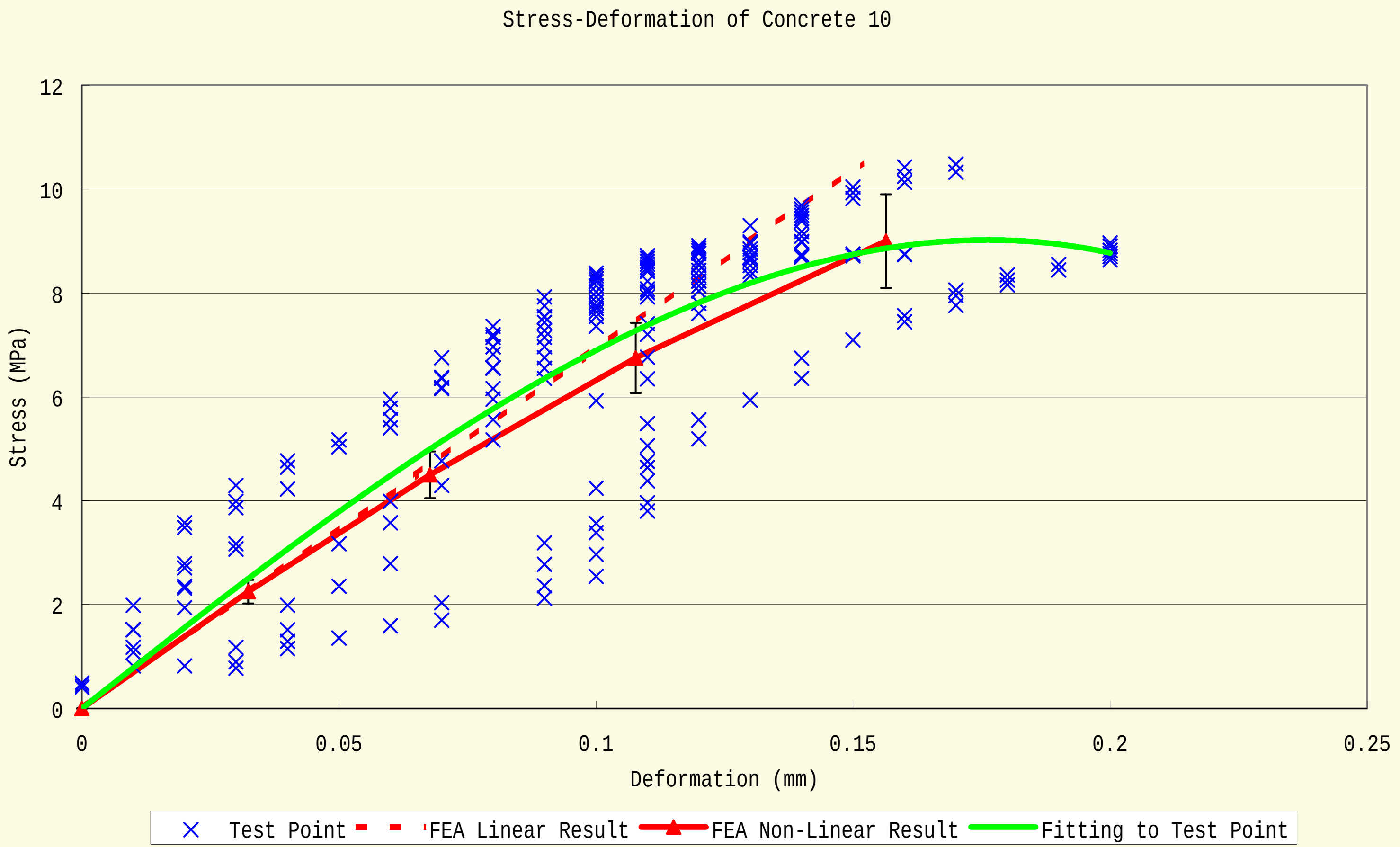
Comparison with Test Results



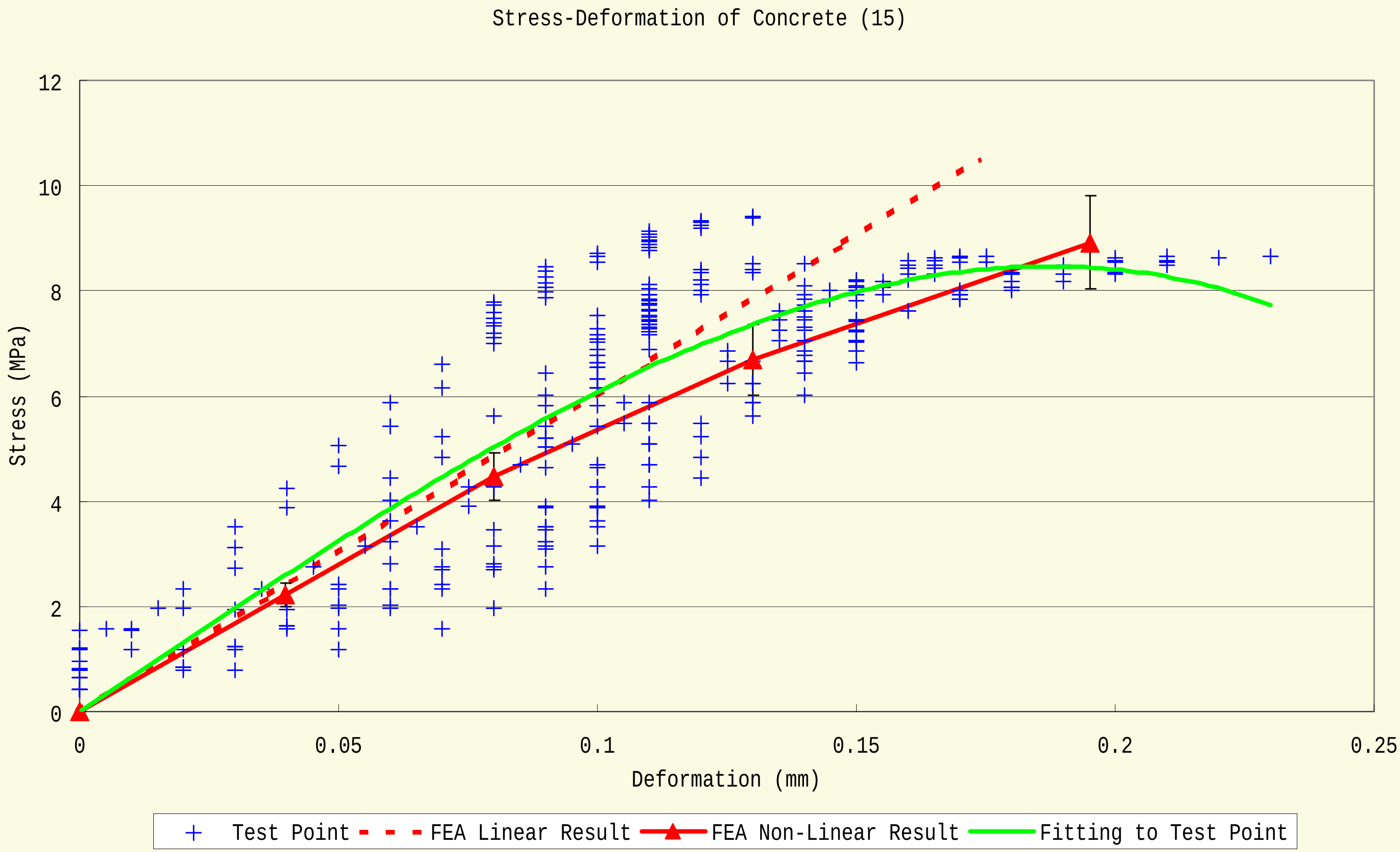
Comparison with Test Result



Comparison with Test Result



Comparison with Test Result

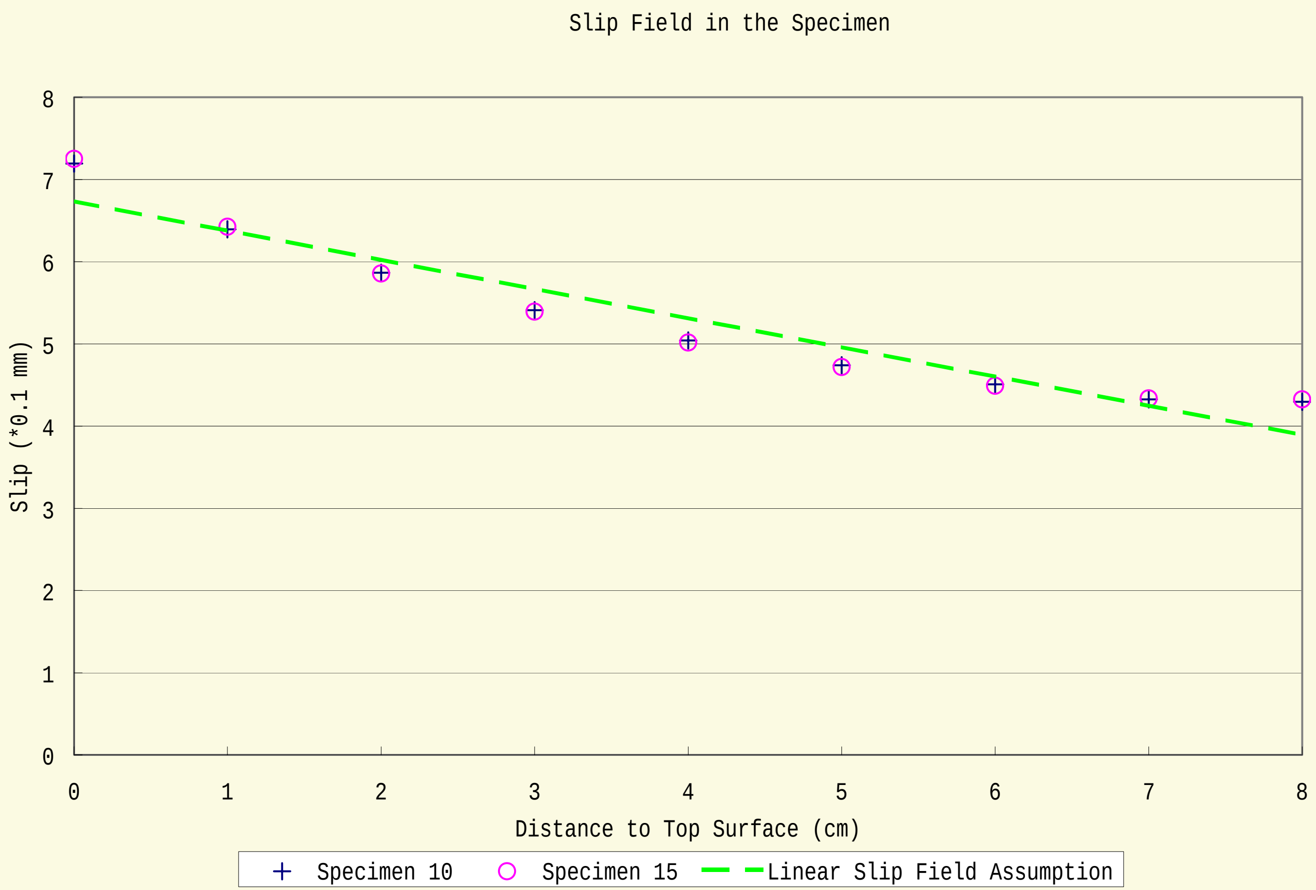


Comparison with Test Result

The errors between the test results and numerical results are smaller than 10%.

Hence, the bond-slip relationship obtained from the test can be directly used in finite element analysis.

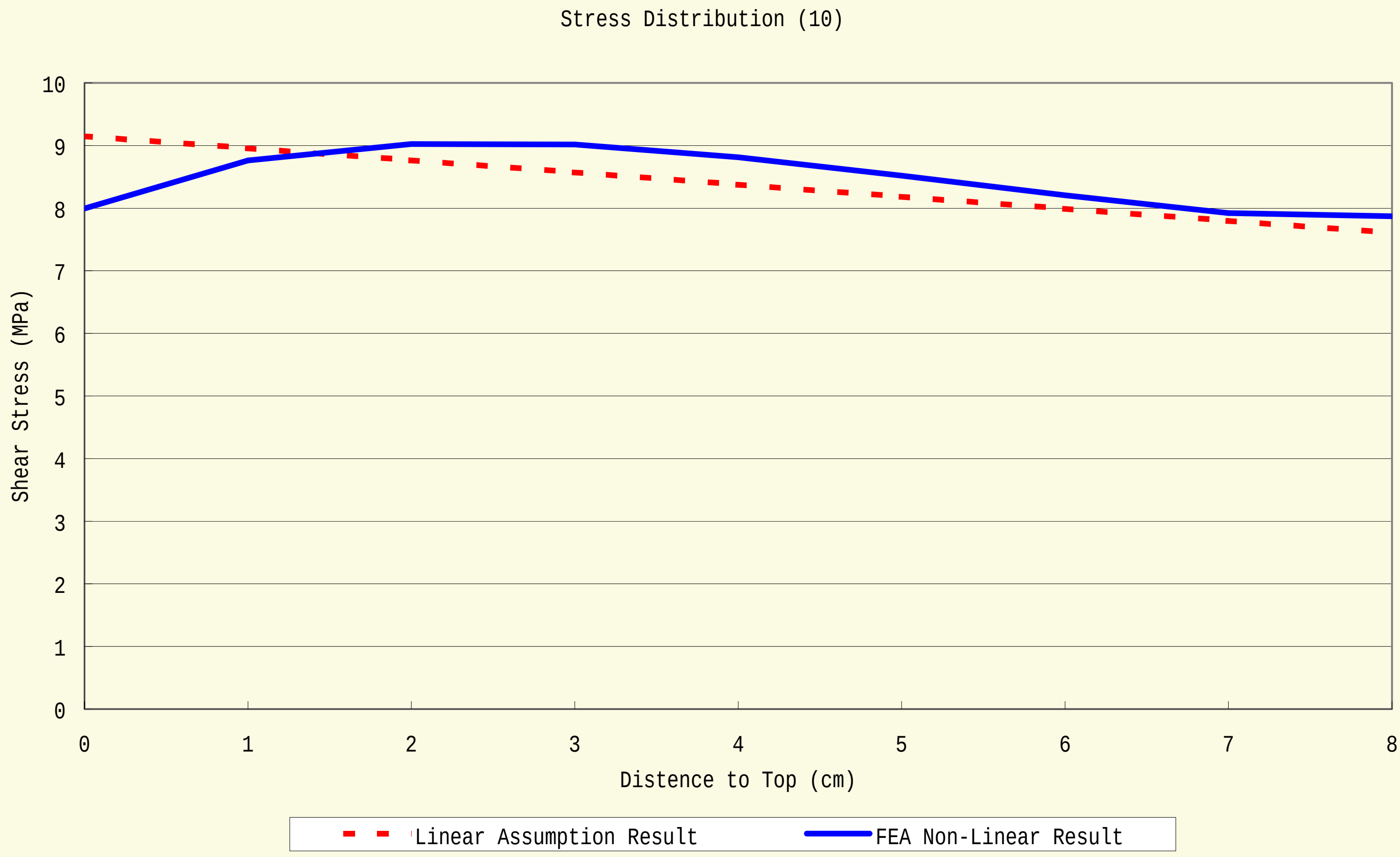
Slip Field in the Specimen



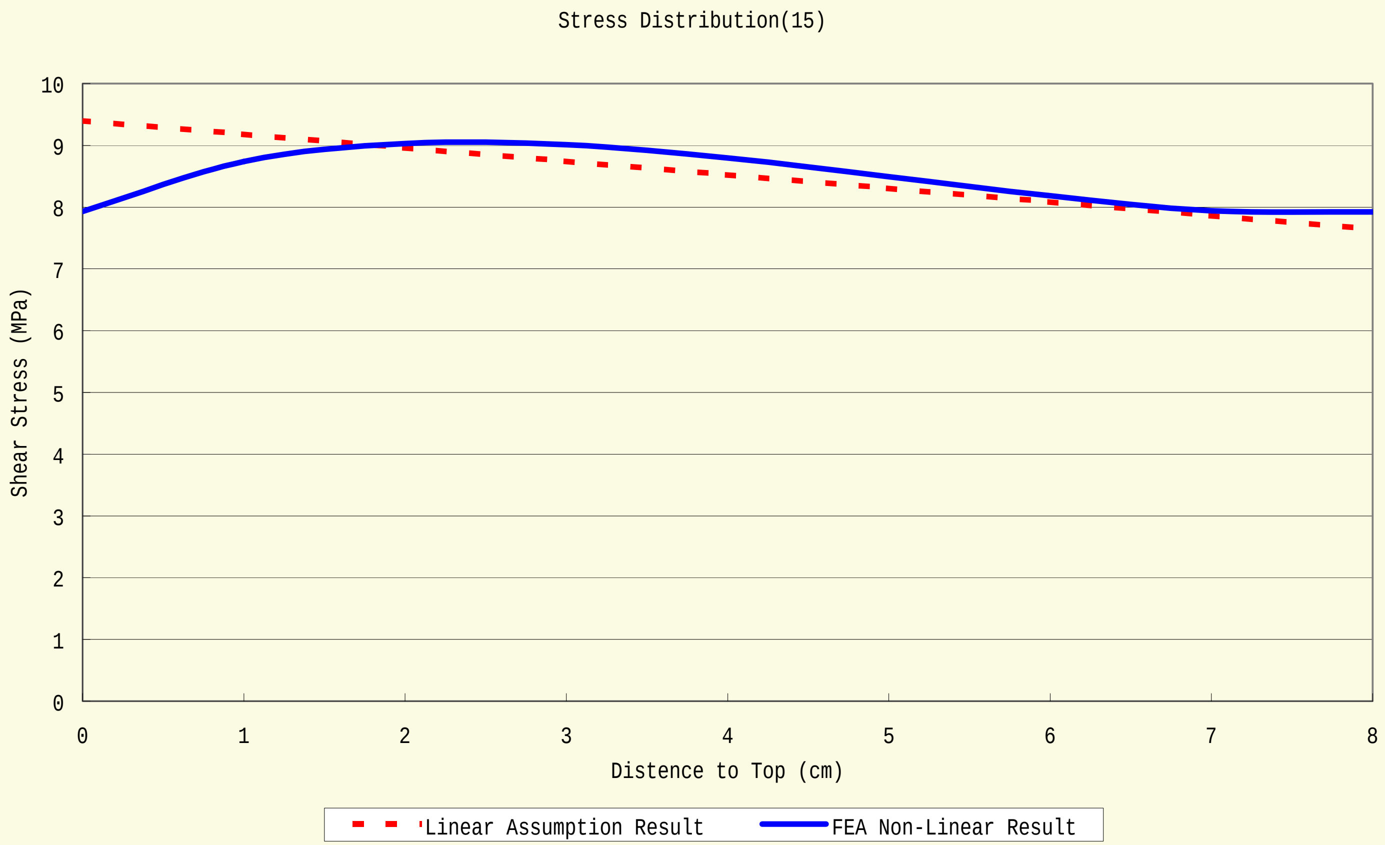
Slip Field in the Specimen

- The linear degree of slip field is 0.925. The assumption of linear slip field in RCED model is rational.
- The size of the specimen influences the slip field lightly.

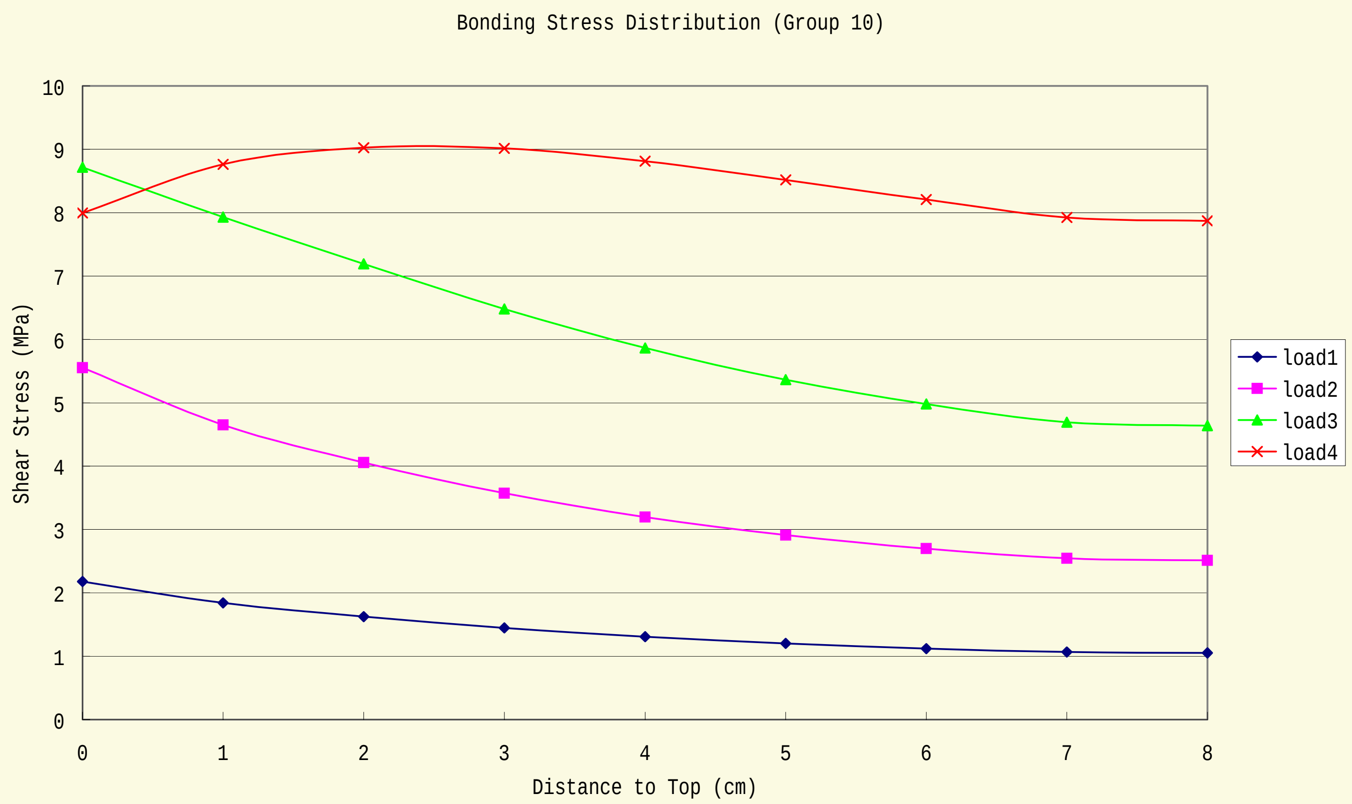
Bond Stress along Steel Bar



Bond Stress along Steel Bar



Change of Bond Stress



Conclusions

- Obtain the full curves of the relationship of τ-Δ_1+Δ_2 . The empirical formula of τ-Δ_1+Δ_2 is obtained for the curves. Numerical study proves that this formula can be used in FEA directly.
- The influence of specimen size to the local damage zone is not obvious.
- The linear slip field in RCED model is rational

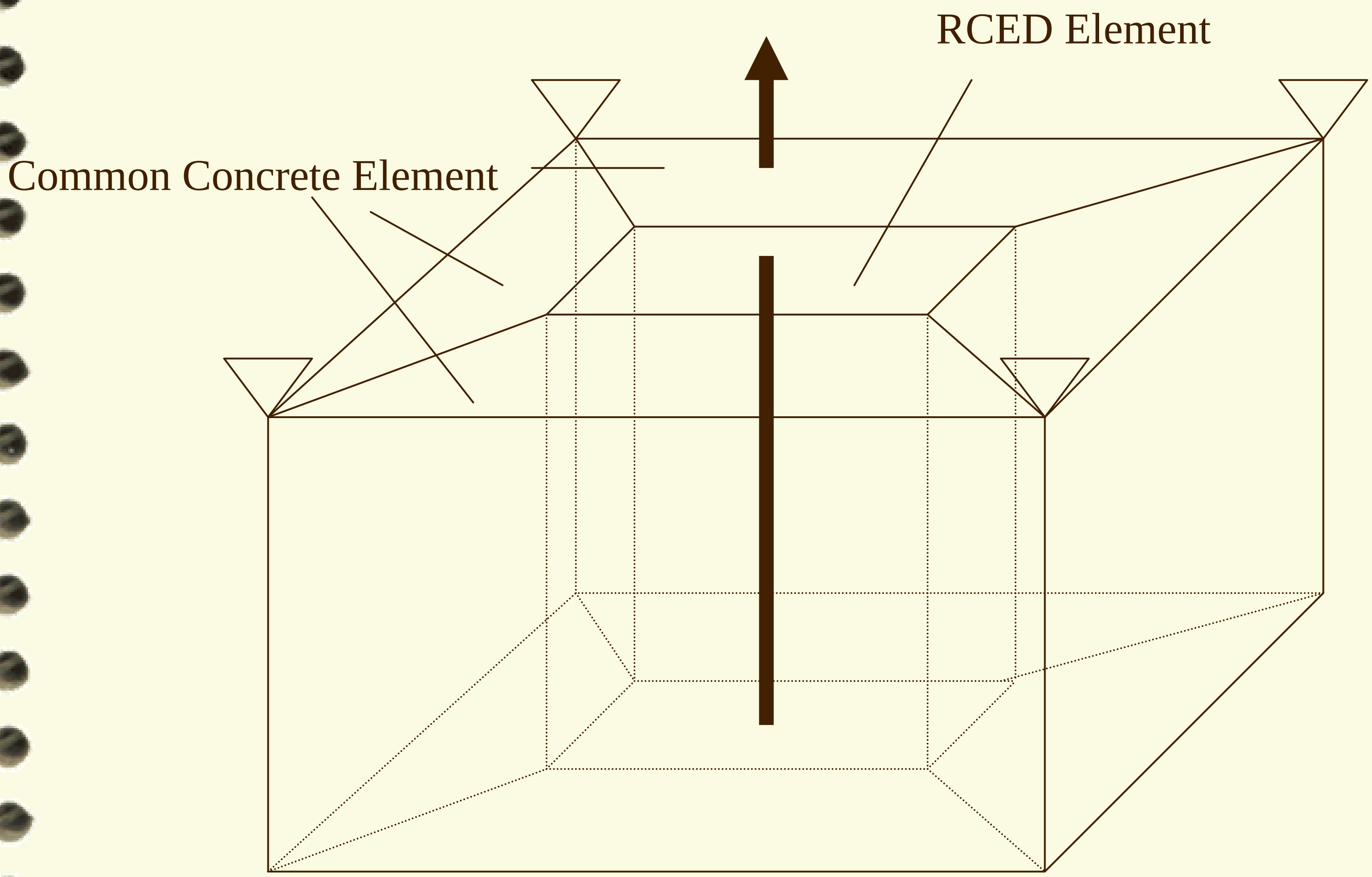
Appendix

To apply the RCED model in real structure analysis.

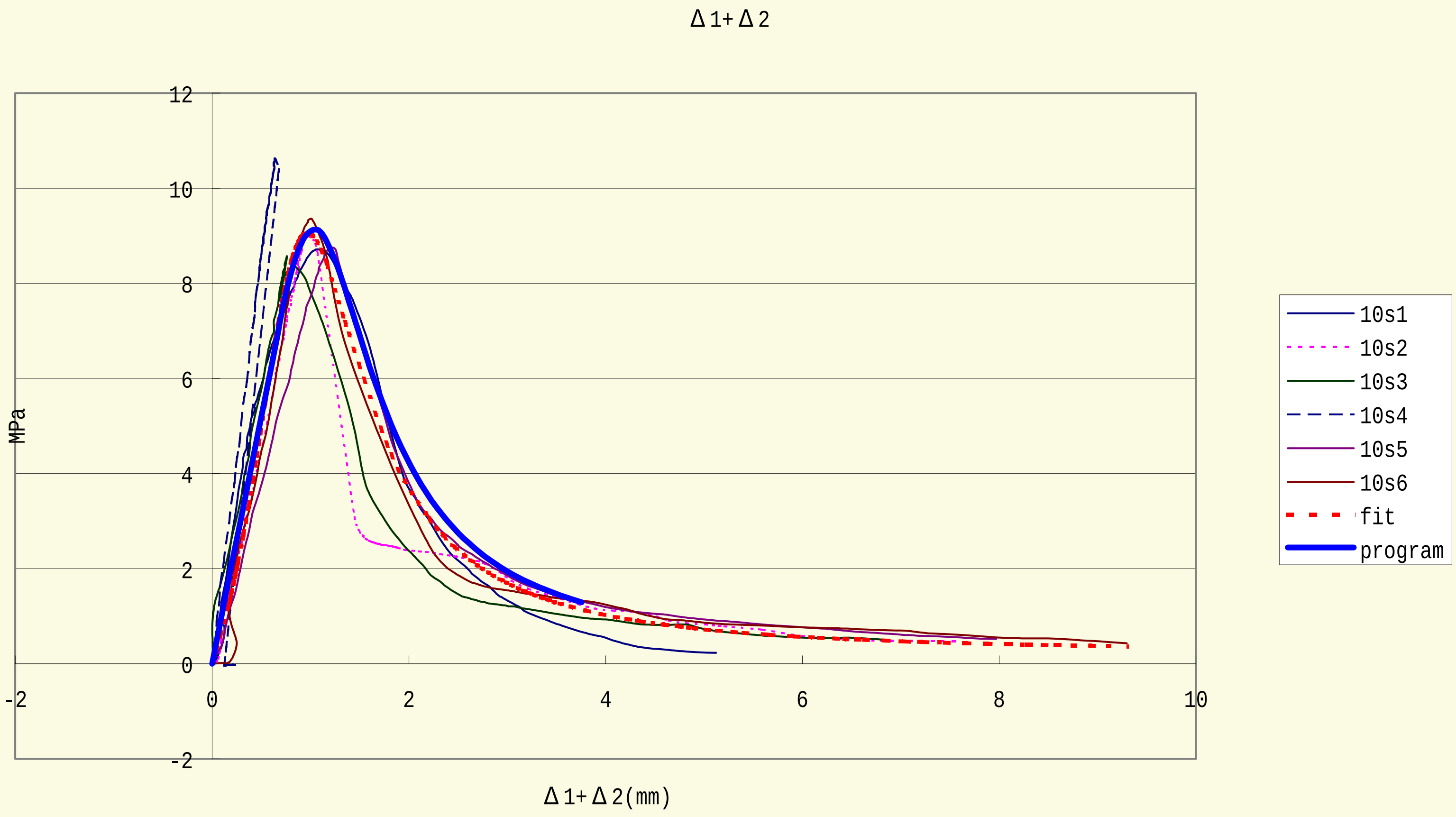
Case 1: Using RCED model to analyze our test.

Case 2: Using RCED model to analyze the Doerr's uniaxial-tension test (ASCE Vol.113, No.10, October, 1987)

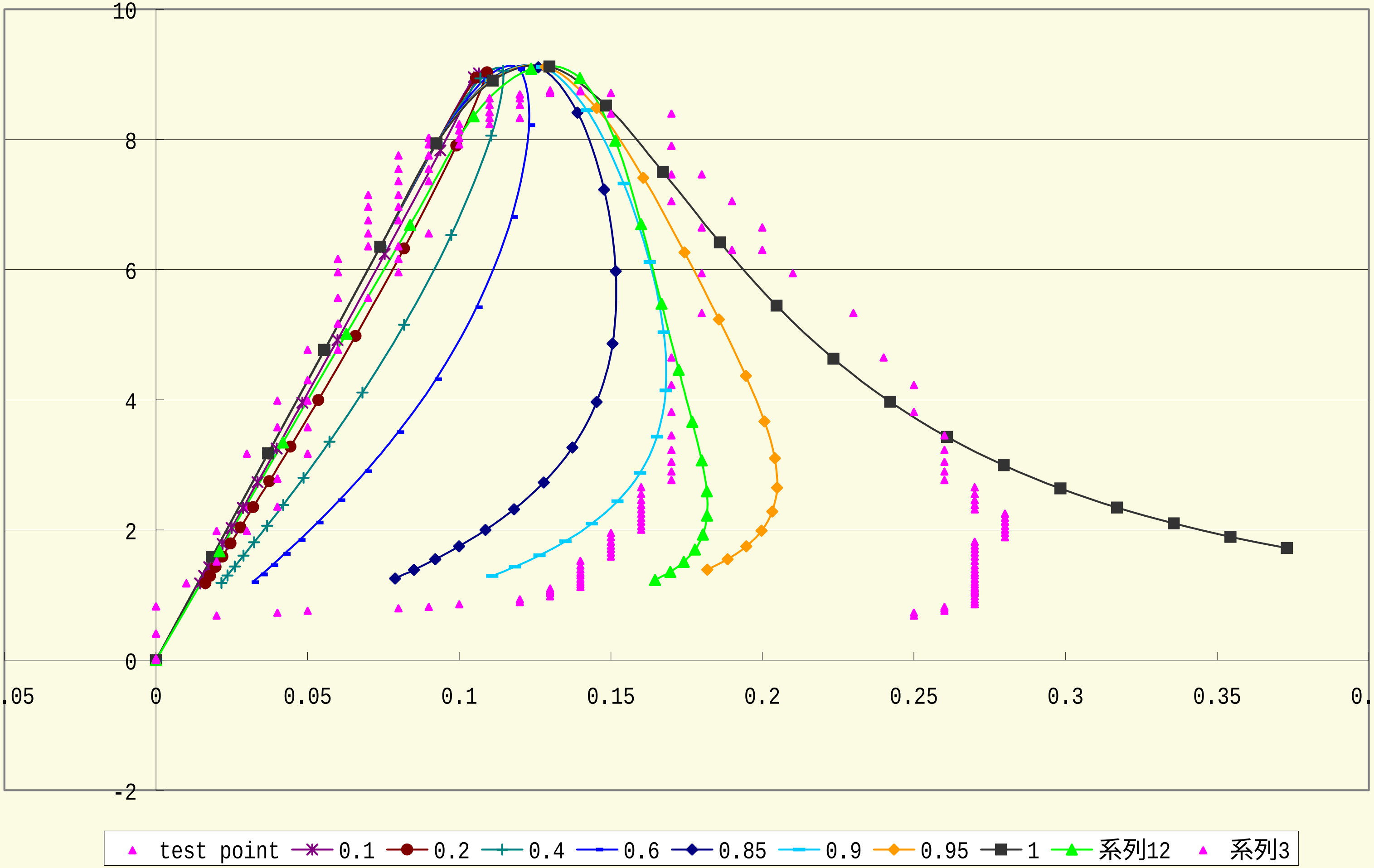
Mesh of Case 1



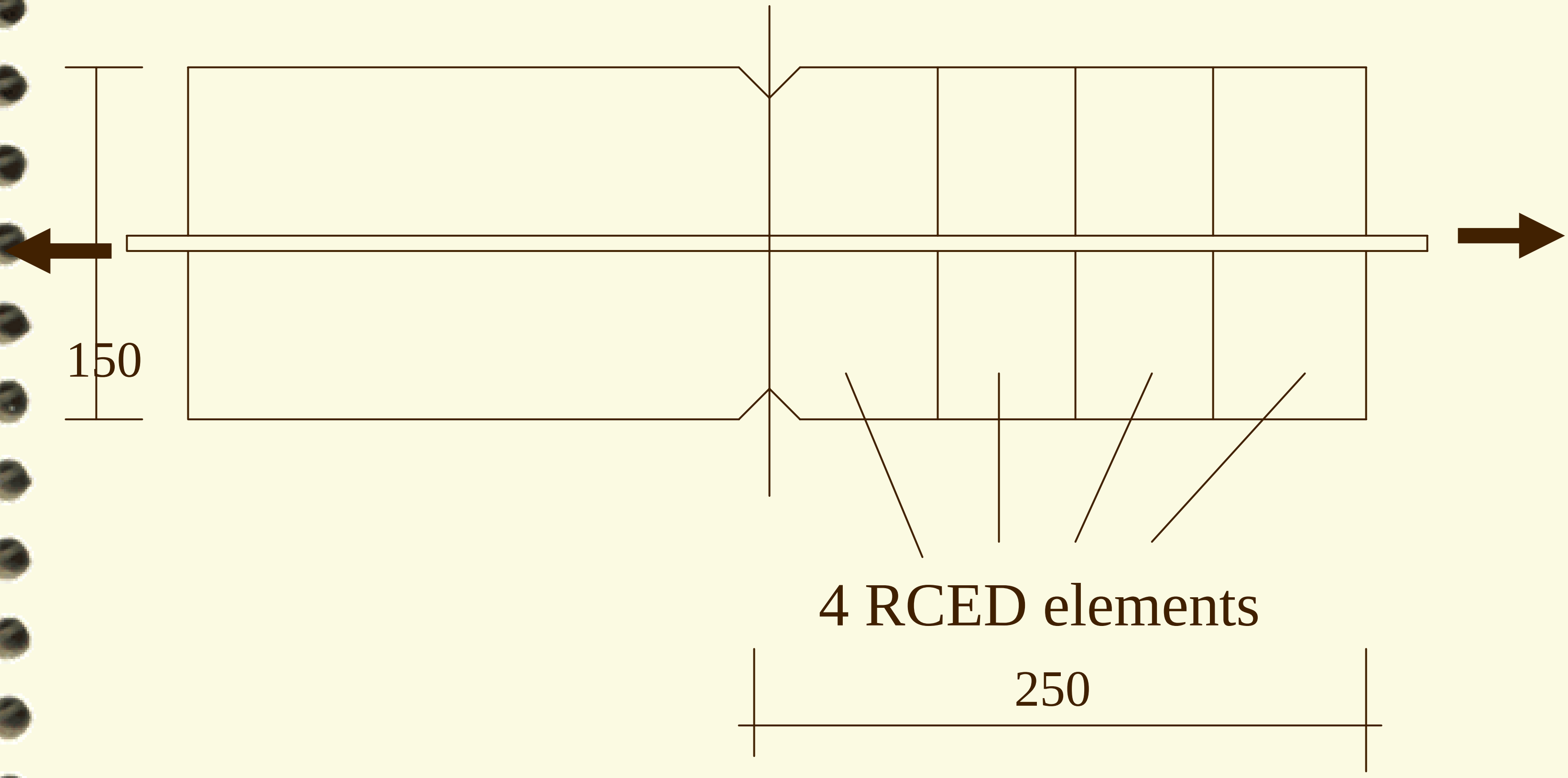
Result (τ-Δ_1+Δ_2)



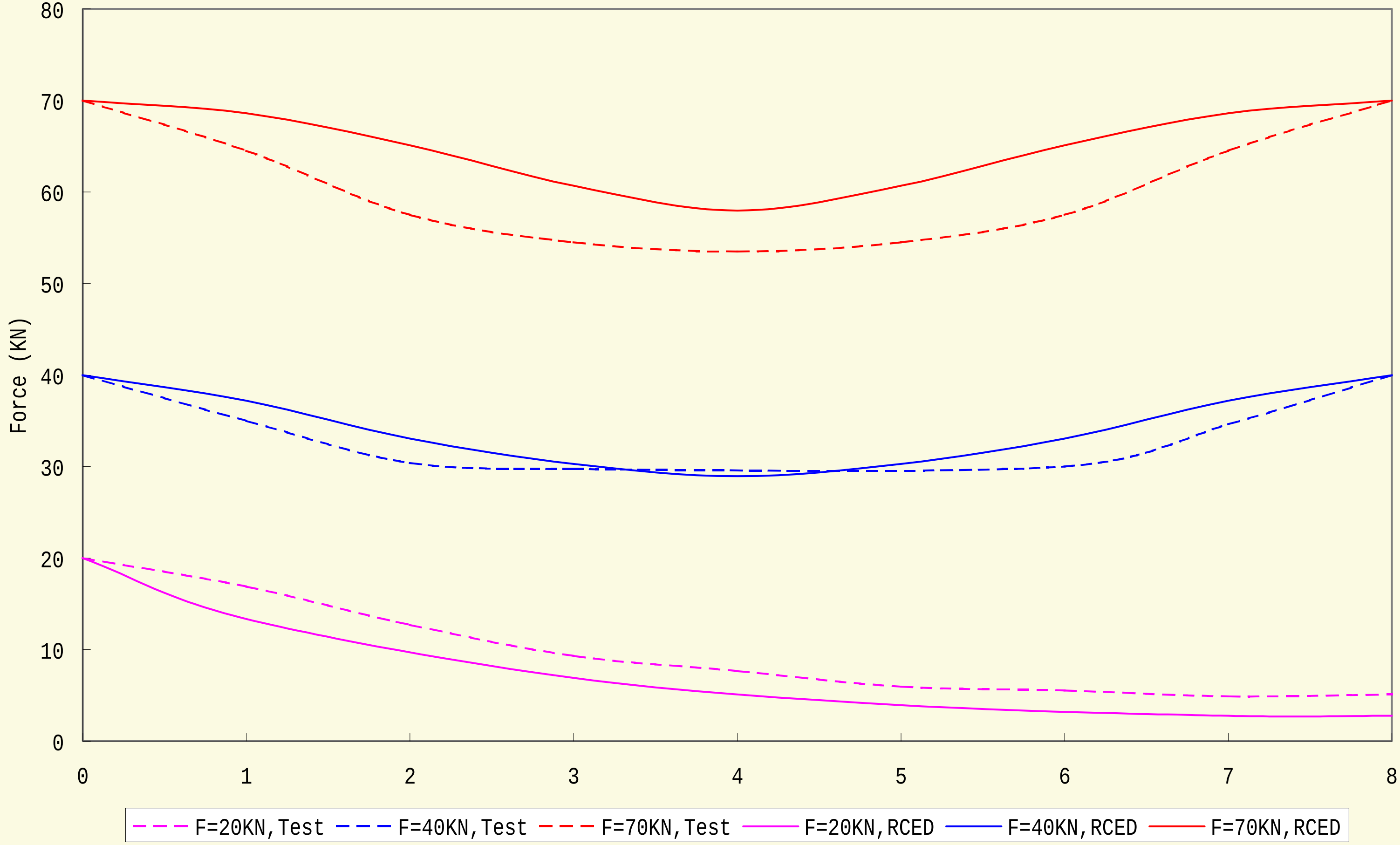
Result (Deformation of Concrete)



Mesh of Case 2



Result (Steel bar axial-force)



Element Number to Obtain the Same Precision

Traditional element	RCED model
Case 1 Element used: 656	Case 1 Element used: 5
Case 2 Element used: 192	Case 2 Element used: 4

Conclusion: the element number RCED model needed is much less than the traditional ones. RCED model is useful in real structure analysis