ALEXANDER C. SCORDELIS: LEGACY IN FINITE ELEMENT ANALYSIS OF REINFORCED CONCRETE

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Reference: *Alexander C. Scordelis*

His Legacy: *Finite Element Analysis of Reinforced Concrete*

Open Issues: *Post-Peak Performance Evaluation*

ALEXANDER C. SCORDELIS [1923-2007]

Professor= Scholar+Educator, Structural Engineer, PhD-Advisor=Doktor Vater

Foto taken from ACI-SP 205 [2002], ASCE/ACI 447 Committee on FEARCS
Includes Biographical Summary of A. Scordelis (eds. Kaspar Willam, T. Tanabe)

ALEXANDER C. SCORDELIS
BIOGRAPHICAL SUMMARY

Alexander C. Scordelis is the Bryon L. and Elvira E. Nishkian Professor Emeritus of Structural Engineering at the University of California at Berkeley, where he has been a member of the faculty since 1949. He has taught a large number of undergraduate and graduate courses in analysis and design of structures.

He has been actively engaged in research in a variety of fields throughout his career, including analytical and experimental investigations of reinforced and prestressed concrete beams, slabs, folded plates, and thin shell and bridge structures. The major research contributions of Professor Scordelis have been on three principal topics: concrete thin shells, box girder bridges, and the nonlinear finite element analysis of reinforced and prestressed systems.

For concrete thin shells during the 1950s and the 1960s, he developed linear methods of analysis that could be utilized effectively with digital computers to analyze shell structures of all shapes and types. In recent years he has extended this work, using nonlinear finite element analysis to simulate the structural response of arbitrary reinforced concrete shell structures through their elastic, cracking, inelastic, and ultimate loads ranges, taking into account nonlinear materials, geometry, and the time-dependent effects of creep and shrinkage.

For many years he has conducted a continuing research program on concrete box girder bridges to study successively straight, simple, and continuous bridges, curved bridges, and skew bridges. Results of this research have been used widely in the United States and abroad. This work was then, and is now, being extended to prestressed concrete segmental box girder bridges and cable-stayed bridges. In these studies, the effects of prestressing, sequence of construction, and time-dependent effects are included in the analytical procedure.

He also has conducted a continuing research program on the finite element analysis of reinforced and prestressed concrete structures. His original papers on this subject in 1967 were the first to open up this new area of research, which is now being studied by researchers throughout the world. Results of research in this field of study have been used in the analysis and design of bridges, buildings, nuclear containment structures, and offshore platforms.

Professor Scordelis has always had interest in applying the results of his research to practical engineering problems. During the past 40 years, he has been a consultant to various structural engineering firms and governmental agencies on more than forty major projects involving shell structures, bridge structures, reinforced and prestressed concrete structures, and computer solutions for complex structural systems.

Professor Scordelis is an Honorary Member of the American Society of Civil Engineers and a Fellow of the American Concrete Institute. He is an Honorary Member of the Association for Shell and Spatial Structures. He is also a member of the Structural Engineers Association of Northern California and the American Segmental Bridge Institute. He is a registered Civil Engineer in the State of California.

He has received many awards, including the ASCE Moissieff Award three times, in 1976, 1981, and 1992; the Western Electric Award for Excellence in Engineering Teaching in 1978; the Best Paper Award from the Canadian Society of Civil Engineers in 1982; the K. B. Woods Award of the Transportation Research Board, National Academy of Sciences in 1982; the ASCE Howard Award in 1989; and the University of California "Berkeley Citation" in 1990. In 1987 he was awarded the Bryon L. and Elvira E. Nishkian Chair as Professor of Structural Engineering, and in 1989 he was appointed by Governor Deukmejian to the Governor's Board of Inquiry on the 1989 Loma Prieta Earthquake. He is a Member of the Caltrans Seismic Advisory Board and the Chairman of the Golden Gate Bridge Seismic Instrumentation Advisory Panel. In 1994 he was appointed to the Blue Ribbon Panel for the review of the structural evaluation of the Kingdome in Seattle.

He was elected into the National Academy of Engineering in 1978 with a citation for "pioneering the development and application of advanced structural analysis to the design of record breaking and unique structural systems." In 1993 he received the highest honor of the ASBI, the Leadership Award, for "outstanding contributions in research and computer program development for analysis of segmental concrete bridges." In 1993 he received the Berkeley Engineering Alumni Society Distinguished Engineering Alumnus Award, which stated: "...who by his contributions to elegant structures and devotion to educating generations of Berkeley engineers has brought distinction to the College of Engineering and its alumni." In 1994 he received the highest honor, awarded only every three or four years, by two separate international organizations: first from IASS, the Torroja Medal, "for his contributions to the analysis and design of thin shell concrete structures"; and second from FIP, the Freyssinet Medal, "for his contribution in prestressed concrete structures."

ALEXANDER C. SCORDELIS

Three Computational Milestones:

1. Scordelis, A.C. and Lo, K.S.: Computer analysis of cylindrical shells ACI Journal, 61, 1964, 539-562.

2. Scordelis, A.C. and Ngo, De: Finite element analysis of reinforced concrete beams, ACI Journal 64, 1967, 152-163.

3. Scordelis, A.C., Nilson, A.H. and Gerstle, K.: Finite Element Analysis of Reinforced Concrete, ASCE State-of-the Art Report, New York, 1982.

Early Finite Element/Finite Strip/Layered Frame Dissertations:

K.S. Lo [1964], Abu Gazaleh [1965], Art Nilson [1967], Larry Selna [1967], Kaspar Willam [1969], Andy Franklin [1970], Christian Meyer [1970], W. Knudsen [1972], C.S. Lin [1973], De Ngo [1975], A.F. Kabir [1976], Y.J. Kang [1977], Günter Müller [1977], Frieder Seible [1982], Mark Ketchum [1986], et al..

STATE-OF-THE-ART REPORT ON FEARC

ASCE-SP, New York [1982], ASCE/ACI 447 publ. by Committee on FEARCS

State-of-the-Art Report on

FINITE ELEMENT ANALYSIS OF REINFORCED CONCRETE

Prepared by the Task Committee on Finite Element Analysis of Reinforced Concrete Structures of the Structural Division Committee on Concrete and Masonry Structures

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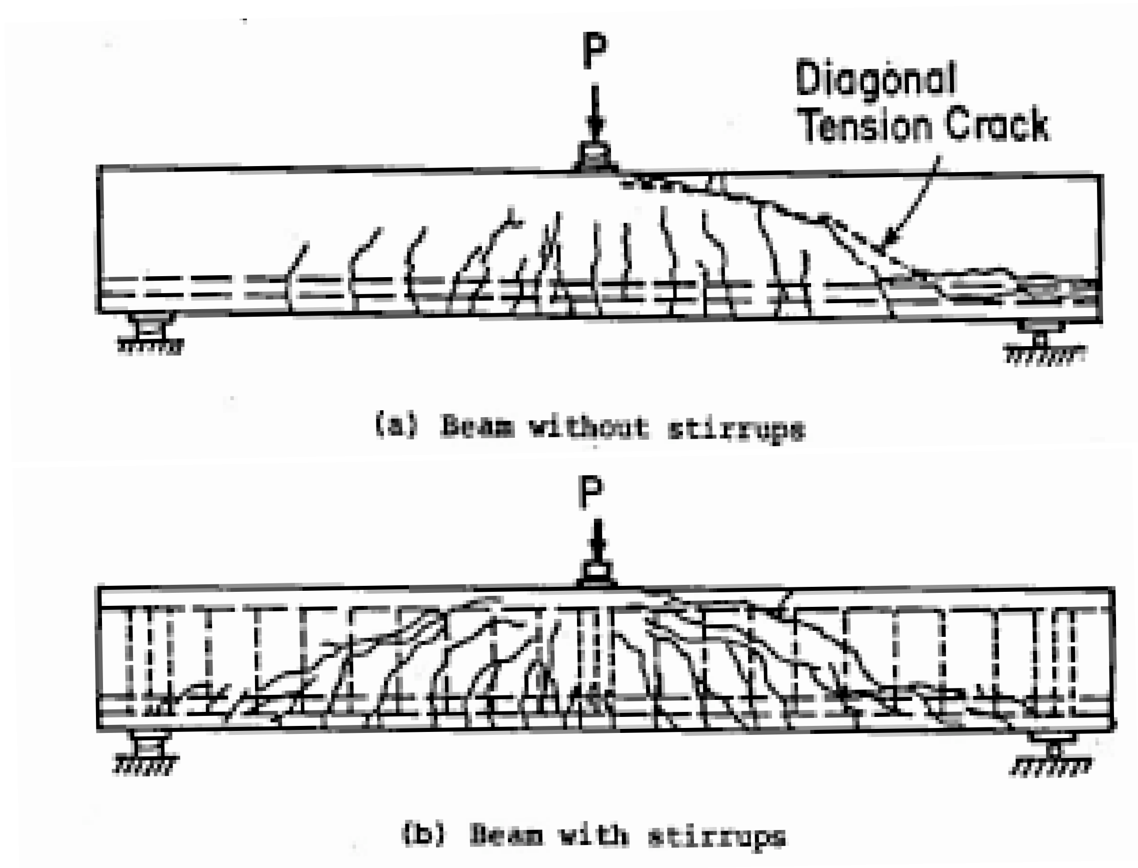
Chapter 1. Introduction: A.C. Scordelis, A.H. Nilson and K. Gerstle
Reinforced Concrete Beams, B. Bresler, V. Bertero [1968]



(a) Beam without stirrups

(b) Beam with stirrups

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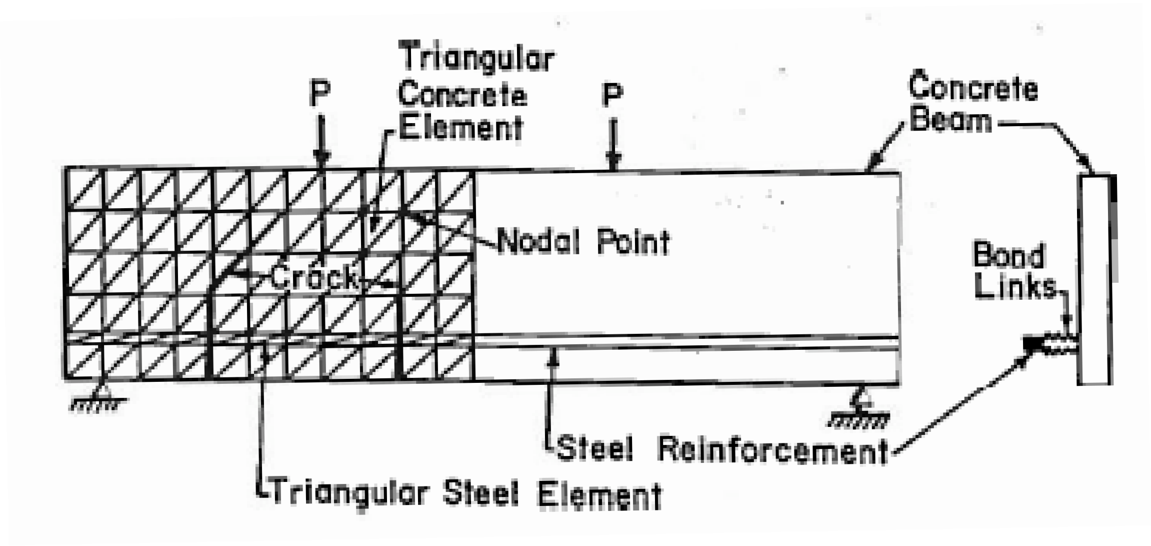
Chapter 1. Introduction: A.C. Scordelis, A.H. Nilson and K. Gerstle

RC Beam, De Ngo and A.C. Scordelis [1967]



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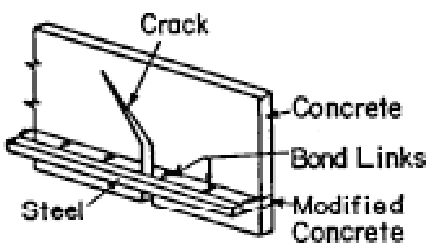
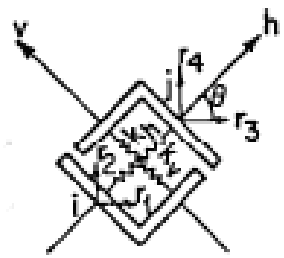
Chapter 1. Introduction: A.C. Scordelis, A.H. Nilson and K. Gerstle

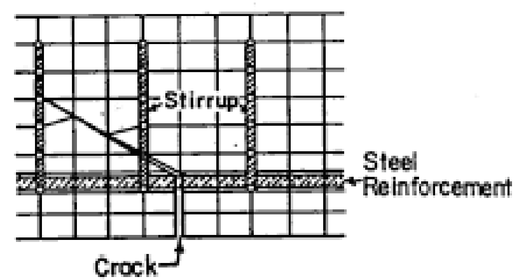
RC Finite Elements, De Ngo and A.C. Scordelis [1967]



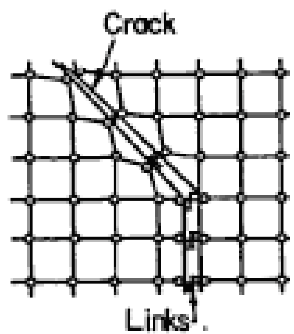
(a) Analytical model



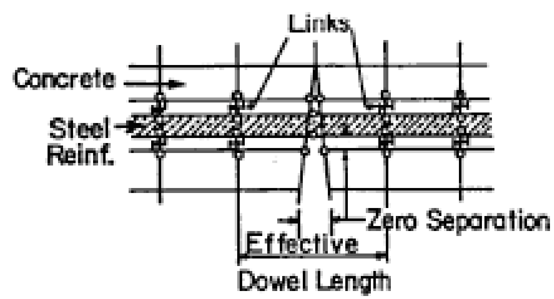
(b) Linkage element



(c) Reinforcement representation



(d) Crack and aggregate interlock



(e) Effective dowel length

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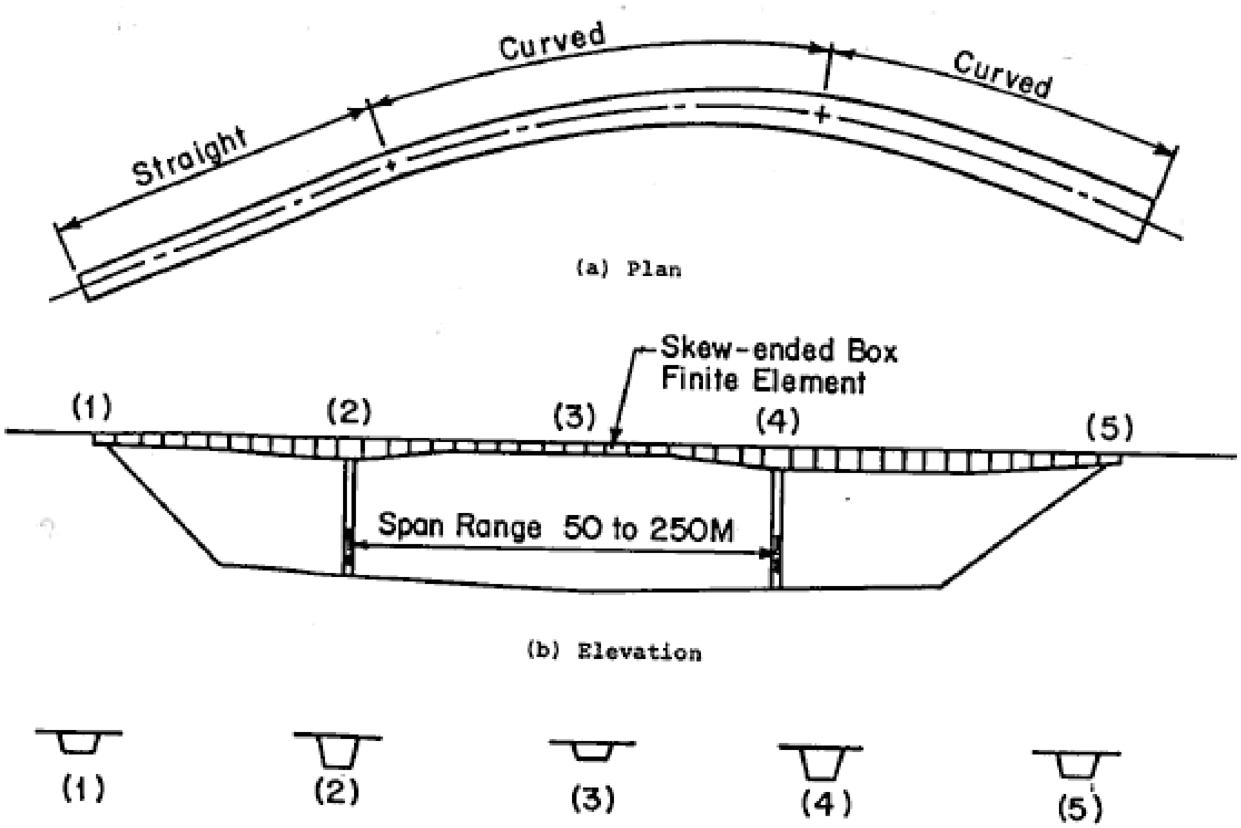
Chapter 1. Introduction: A.C. Scordelis, A.H. Nilson and K. Gerstle

Box Girder Bridge, A.C. Scordelis [1978]



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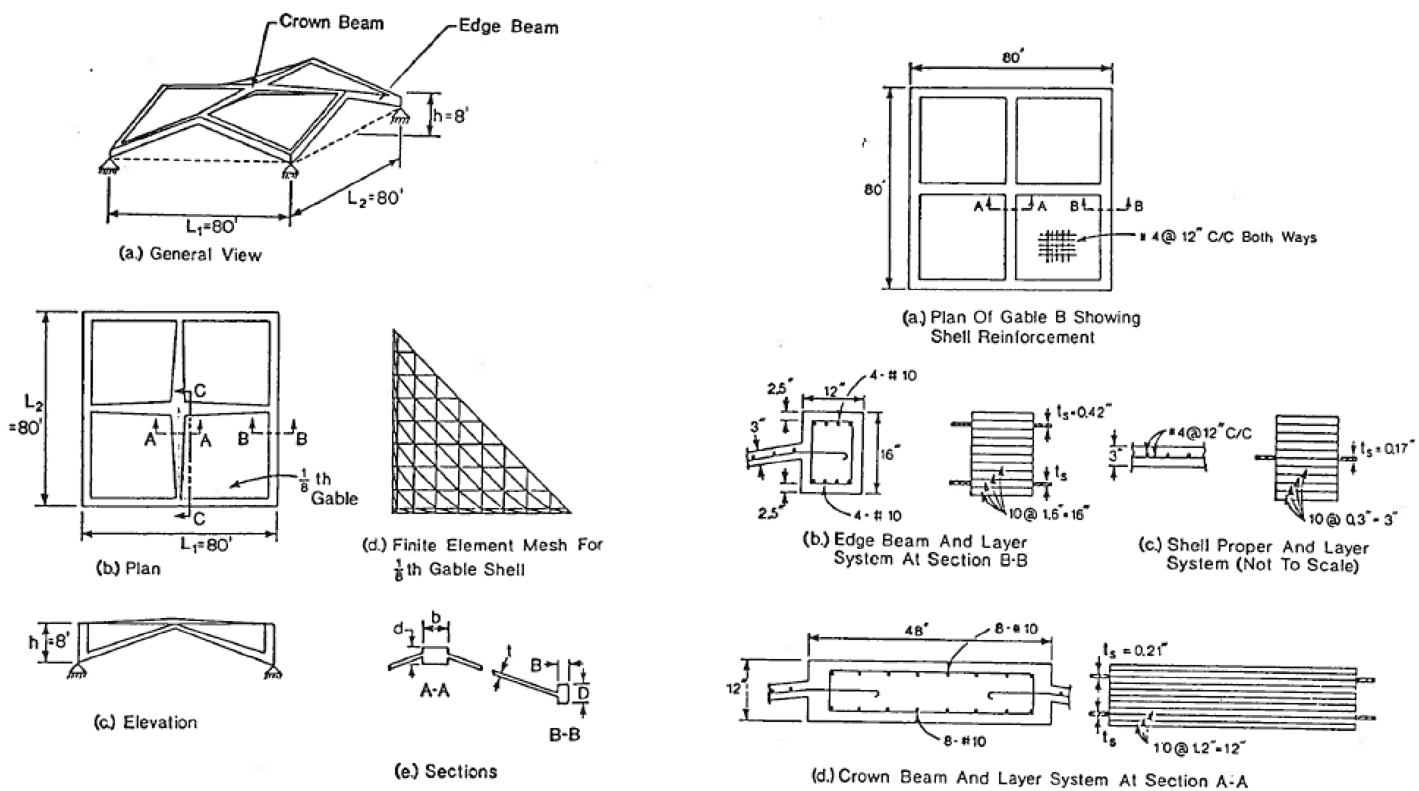
Chapter 8. Numerical Examples and Applications: A.C. Scordelis et al.

Hypar Gable Roof, A.F. Kabir and A.C. Scordelis [1979]



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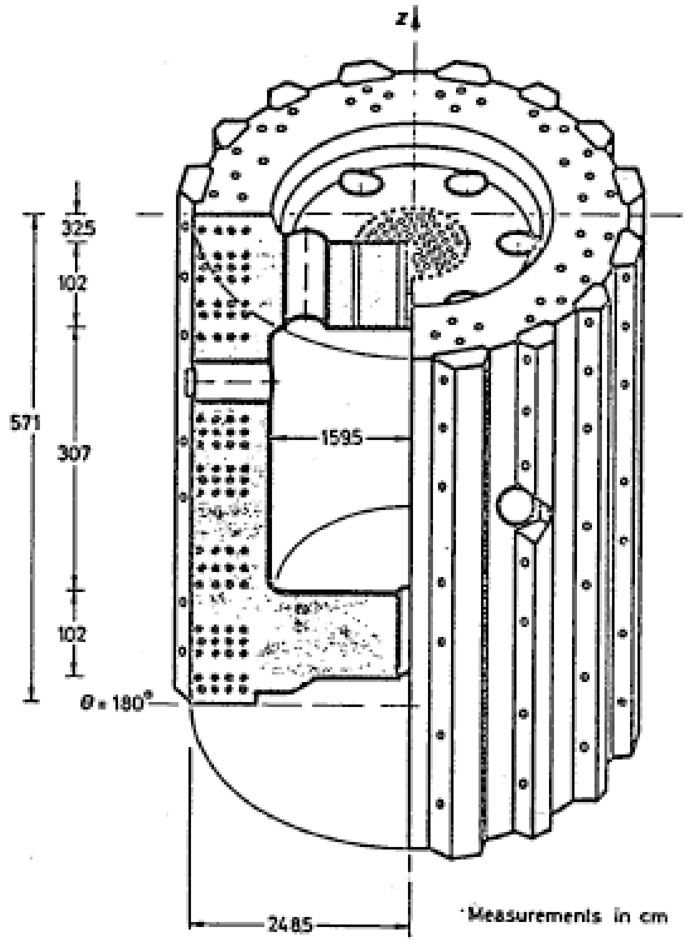
Chapter 8. Numerical Examples and Applications: A.C. Scordelis et al.

1:5 Scale THTR Vessel, J.H. Argyris and K. Willam et al. [1974]



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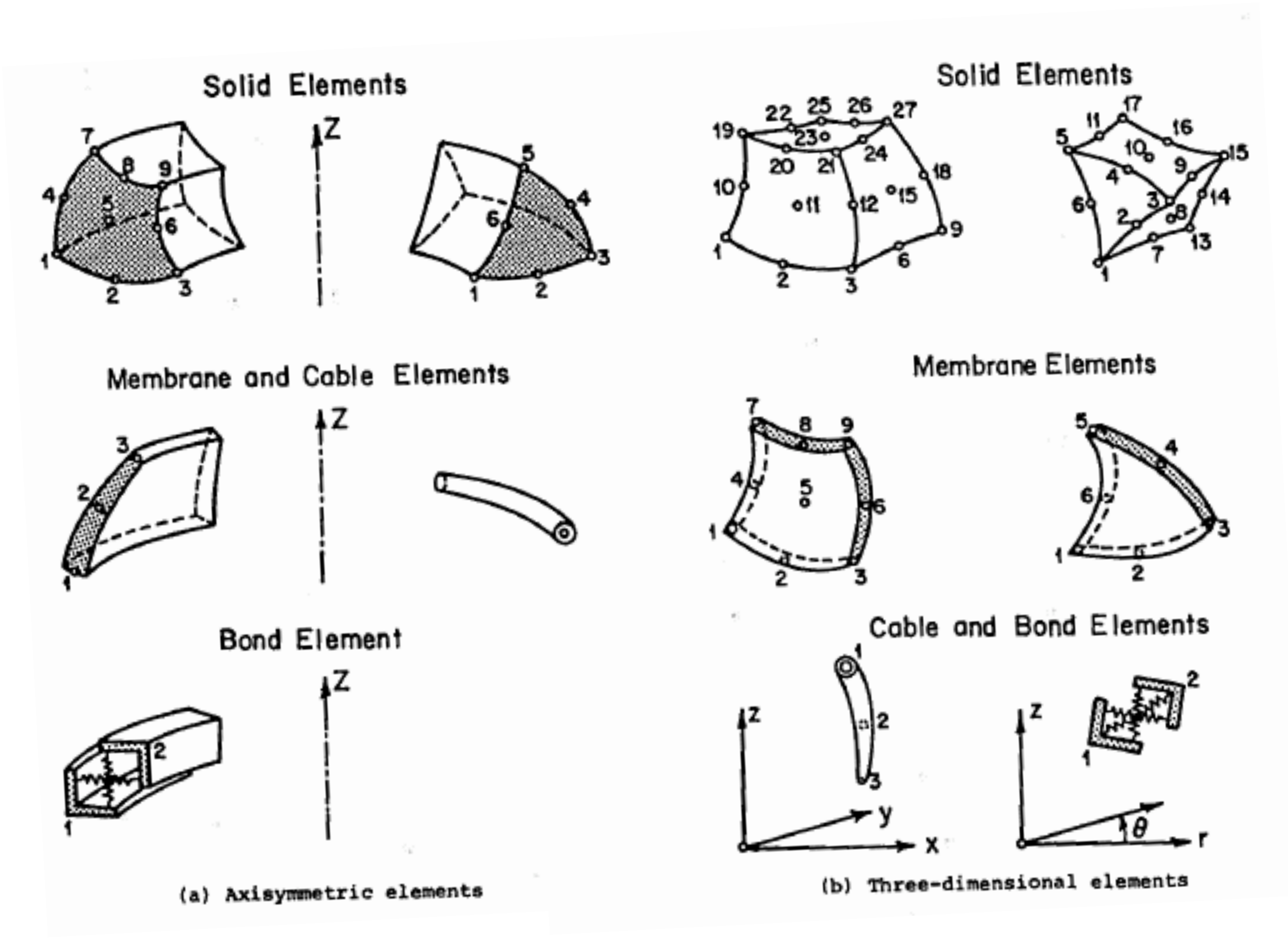
Chapter 8. Numerical Examples and Applications: A.C. Scordelis et al.

RC Elements, J.H. Argyris and K. Willam et al. [1974]



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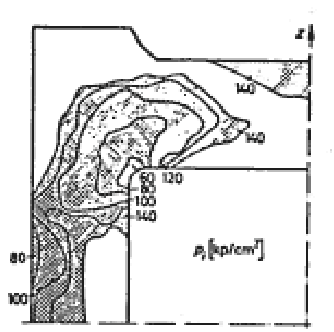
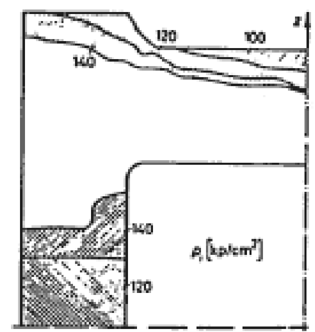
Chapter 8. Numerical Examples and Applications: A.C. Scordelis et al.

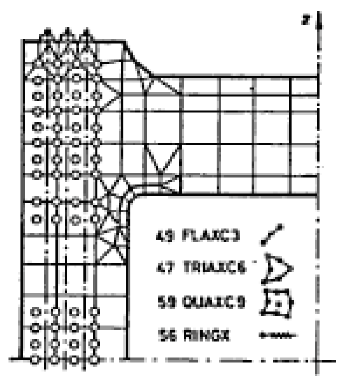
PV Proof Test, J.H. Argyris and K. Willam et al. [1974]



Circumferential Crack Zones



Radial Crack Zones



751 Degrees of Freedom

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Chapter 2. Constitutive Relations and Failure Theories: W.F. Chen et al.

Multiple Approaches to 2D and 3D Concrete Models:

1. Elasticity-Based: K-G, Orthotropic (PA), Continuum Damage
2. Plasticity-Based: Isotropic Hardg/Softg, Ass. vs Non-Associative
3. Endochronic: Internal Variable Format (Generalized Standard Solids)

Issues: material stability, uniqueness, well-posedness

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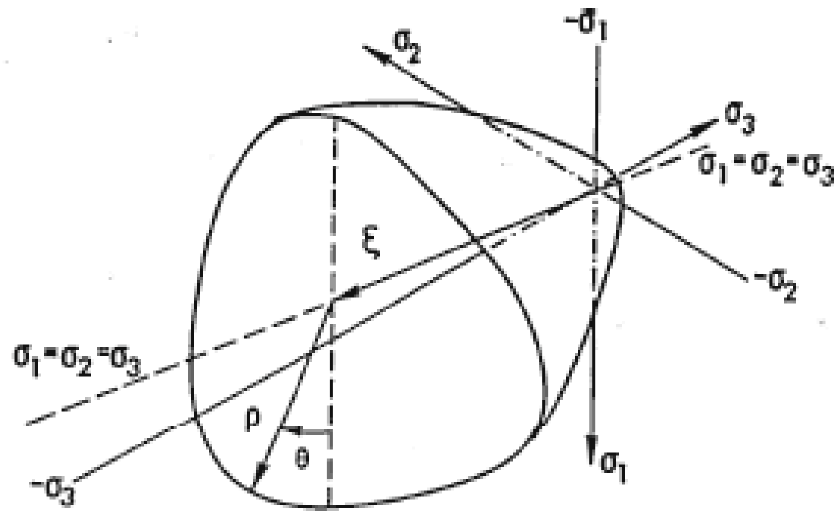
Chapter 2. Constitutive Relations and Failure Theories: W.F. Chen et al.

Concrete Failure Envelope, K. Willam and E.P. Warnke [1974]



Triaxial strength surface in principal stress space

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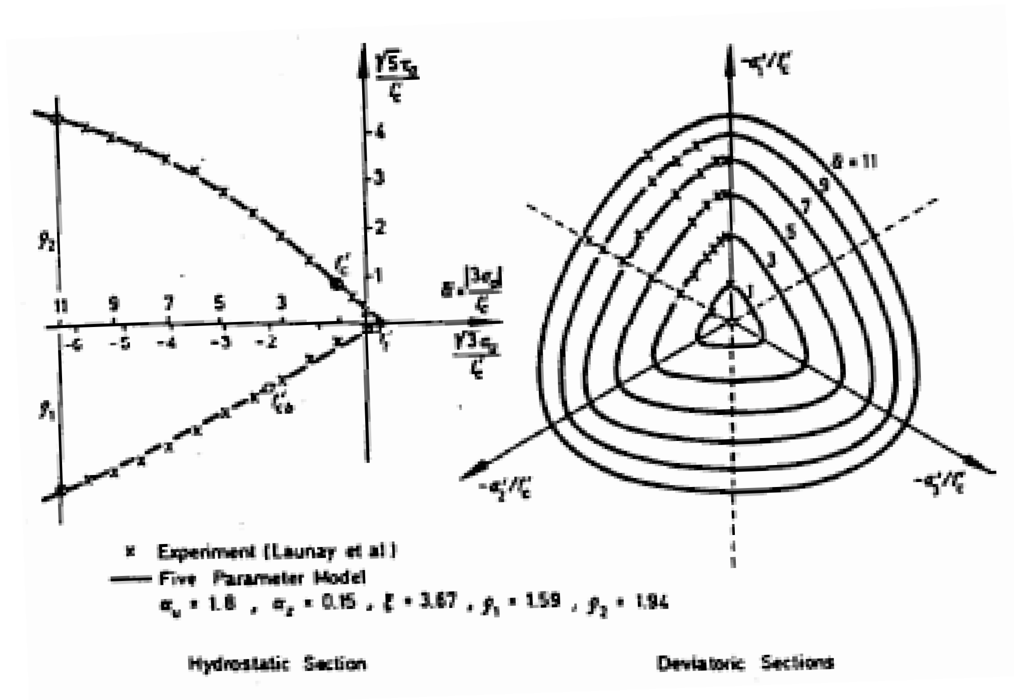
Chapter 2. Constitutive Relations and Failure Theories: W.F. Chen et al.

5 Parameter Model, K. Willam and E.P. Warnke [1974]



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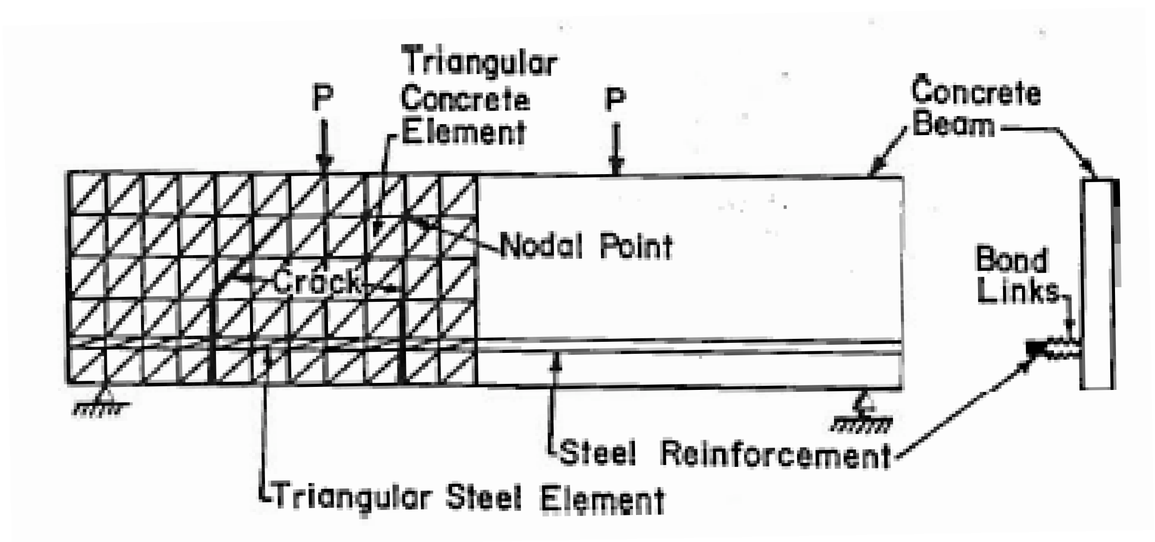
Chapter 3. Modeling of Reinforcement and Bond: M.S. Mirza et al.

RC Beam, De Ngo and A.C. Scordelis [1967]



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Chapter 3. Modeling of Reinforcement and Bond: M.S. Mirza et al.

Layered RC Plate, A.C. Scanlon [1971]

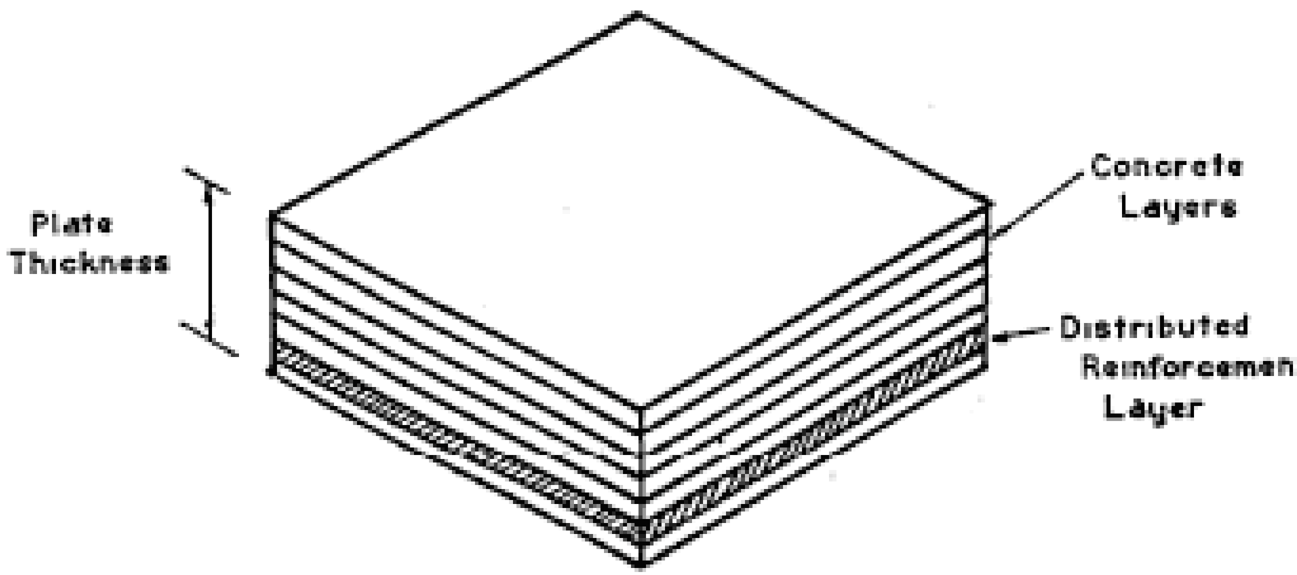

FIG 3.11 LAYERED PLATE BENDING ELEMENT

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Chapter 3. Modeling of Reinforcement and Bond: M.S. Mirza et al.

Multiple Approaches to Composite Action of RCS:

1. Full Bond: Embedded vs Discrete Reinforcement
2. Contact Models: Nodal Links vs Cohesive Interface Elements
3. Reduced Material Models: Traction-Separation Relations (fracture energy basis)

Issues: elastic penalty stiffness, numerical conditioning

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Chapter 3. Modeling of Reinforcement and Bond: M.S. Mirza et al.

Link and Interface Elements, De Ngo and Scordelis [1967], Goodman, Taylor and Brekke [1968]

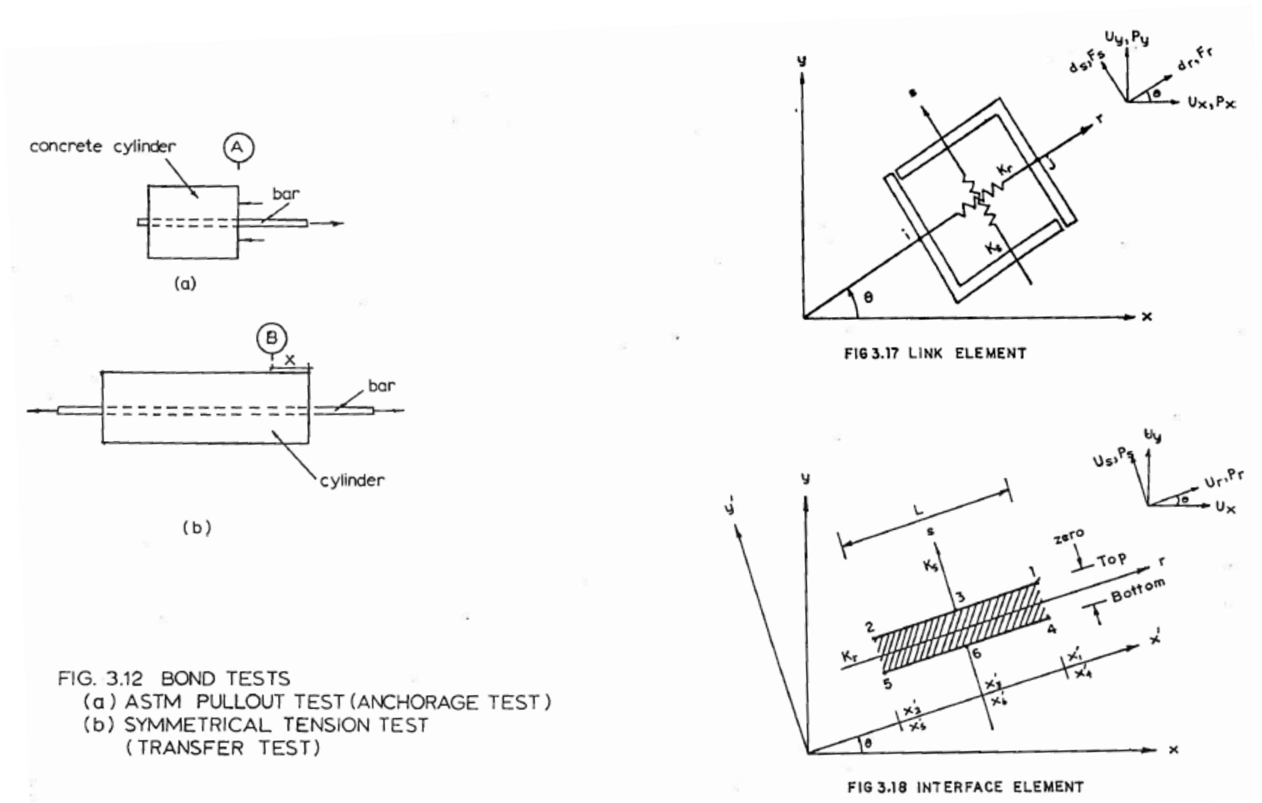

FIG. 3.12 BOND TESTS
(a) ASTM PULLOUT TEST (ANCHORAGE TEST)
(b) SYMMETRICAL TENSION TEST
(TRANSFER TEST)

FIG 3.17 LINK ELEMENT

FIG 3.18 INTERFACE ELEMENT

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Chapter 4. Concrete Cracking: W.C. Schnobrich et al.

Multiple Approaches to Tensile Cracking:

1. Discrete Cracking Models: Nodal Separation (Ngo and Scordelis [1967]), LEFM-fracture basis (Ngo [1975])
2. Smeared Cracking Models: Fixed (orthotropic) vs Rotating (isotropic) Cracking Models (Rashid [1968])
3. Degradation Models: Damage-based (elastic stiffness) vs plastic softening (strength)

Issues: cracking = continuum vs surface phenomenon, fracture mode I vs mode II, mode III cracking, cohesive interface models, tension stiffening vs tension softening in RC.

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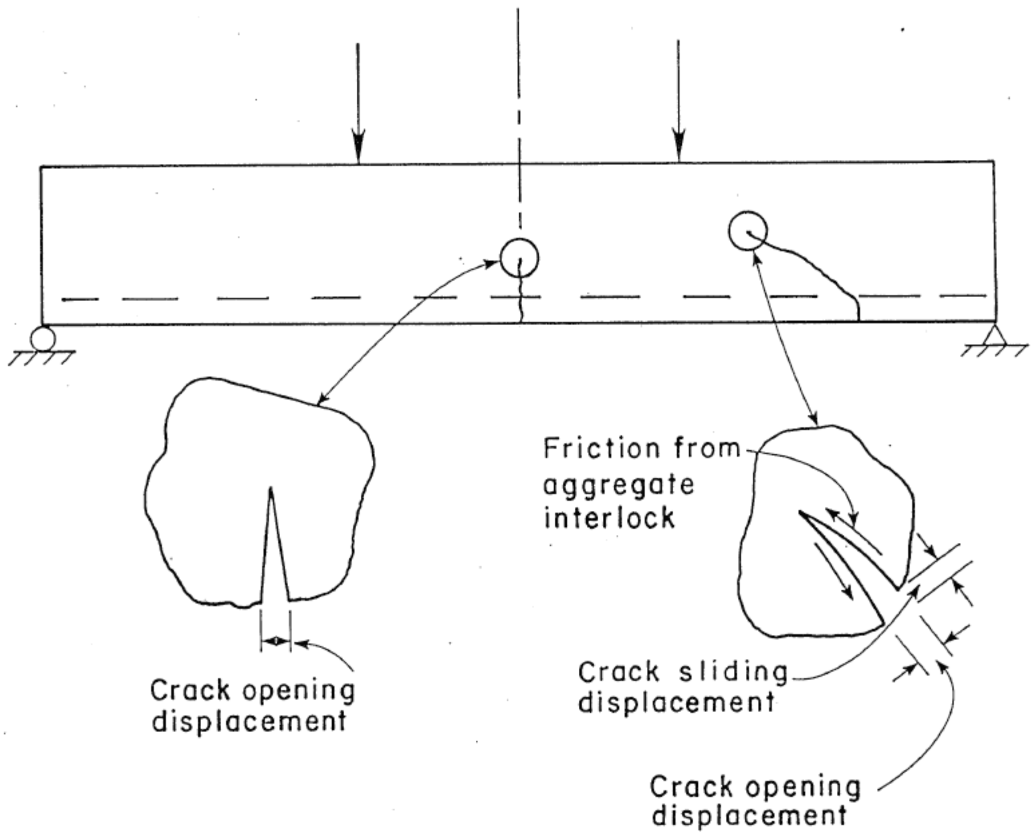
Chapter 4. Concrete Cracking: W.C. Schnobrich et al.

LEFM Fracture Mechanics, Ingraffea [1978]



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Chapter 5. Shear Transfer: O. Buyukozturk et al.

Multiple Approaches to Shear Transfer:

1. Interface Shear Transfer: Aggregate Interlock
2. Dowel Action in RC: Shear Friction
3. Shear Slip Relations: Joint Elements

Issues: dilatancy and locking behavior.

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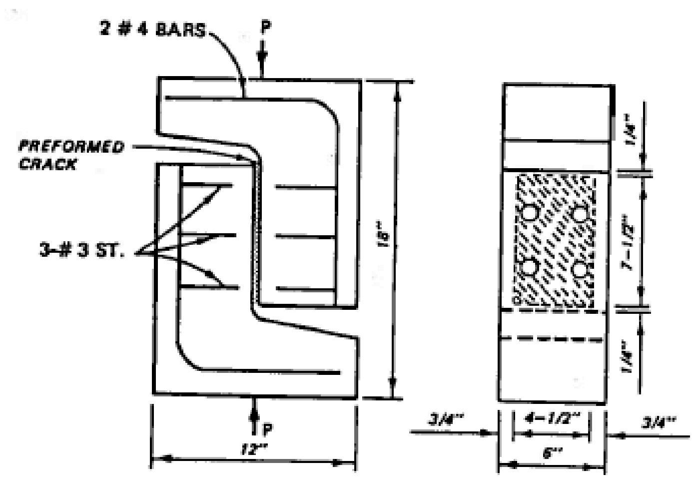
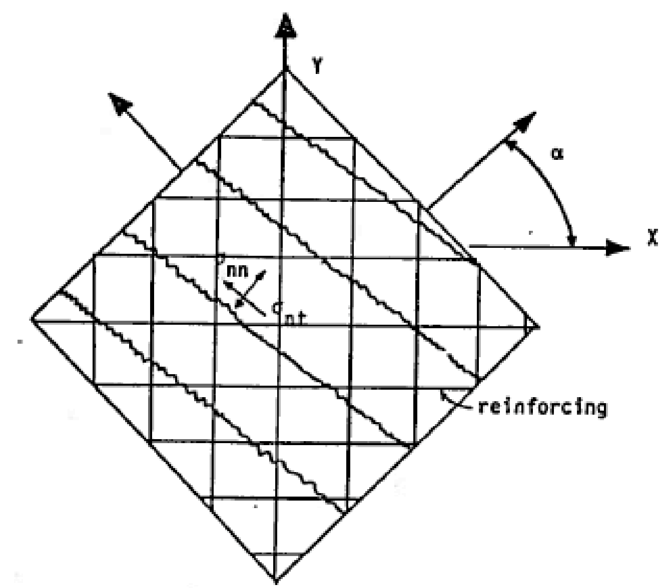
Chapter 5. Shear Transfer: O. Buyukozturk et al.

Aggregate Interlock Pauley and Loeber [1974], Rough Cracks, Bažant and Gambarova [1980]



Specimen Used in Paulay and Loeber's Investigation



Concrete Plate Considered by Bazant and Gambarova

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Chapter 6. Time-Dependent Effects: Z.P. Bažant et al.

Multiple Approaches to Creep and Shrinkage:

1. Creep and Shrinkage: Concrete Rheology and Viscoelasticity
2. Effect of Ageing: History Effects
3. Recursive Algorithms: Maxwell Series Expansion

Issues: drying shrinkage (Pickett effect) and transitional thermal creep.

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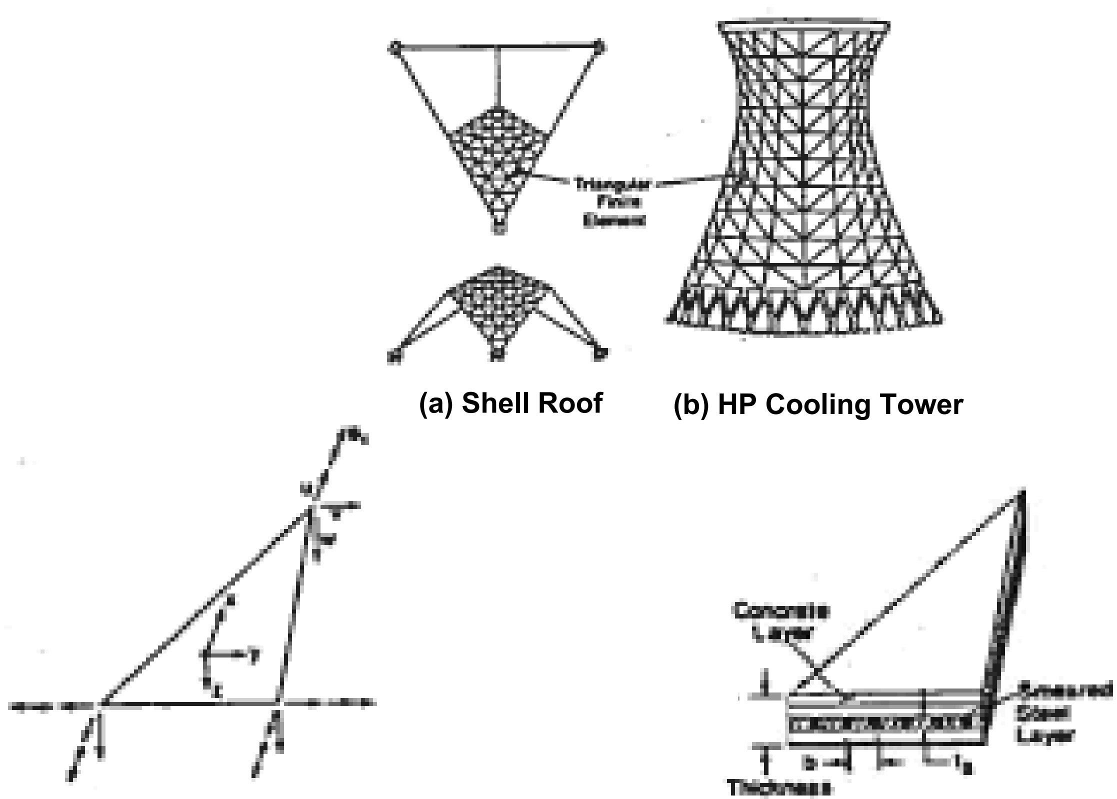
Chapter 6. Time-Dependent Effects: Z.P. Bažant et al.

Cooling Tower, A.F. Kabir and A.C.Scordelis [1979]



(a) Shell Roof (b) HP Cooling Tower

(c) 15 DOF Triangular Finite Element

(d) Layer System

ACI SP-205

Finite Element Analysis of
Reinforced Concrete Structures

Editors
Kaspar Willam
Tada-aki Tanabe

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NLFEARC: 'Look both Ways before Crossing', Frank Vecchio and D. Palermo

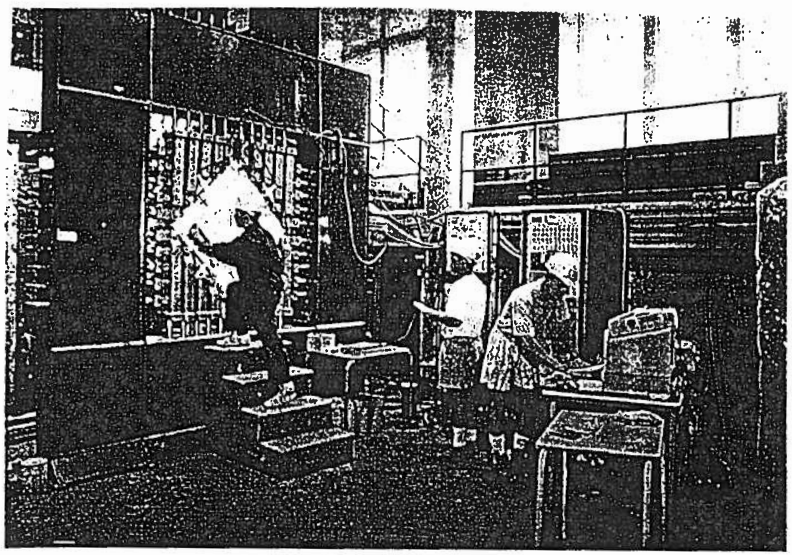


Figure 1: University of Toronto Panel Element Tester, constructed in 1979.

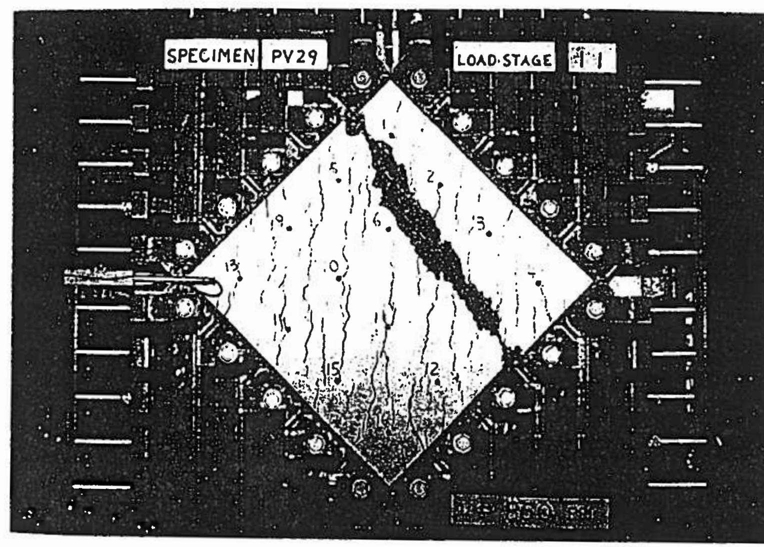
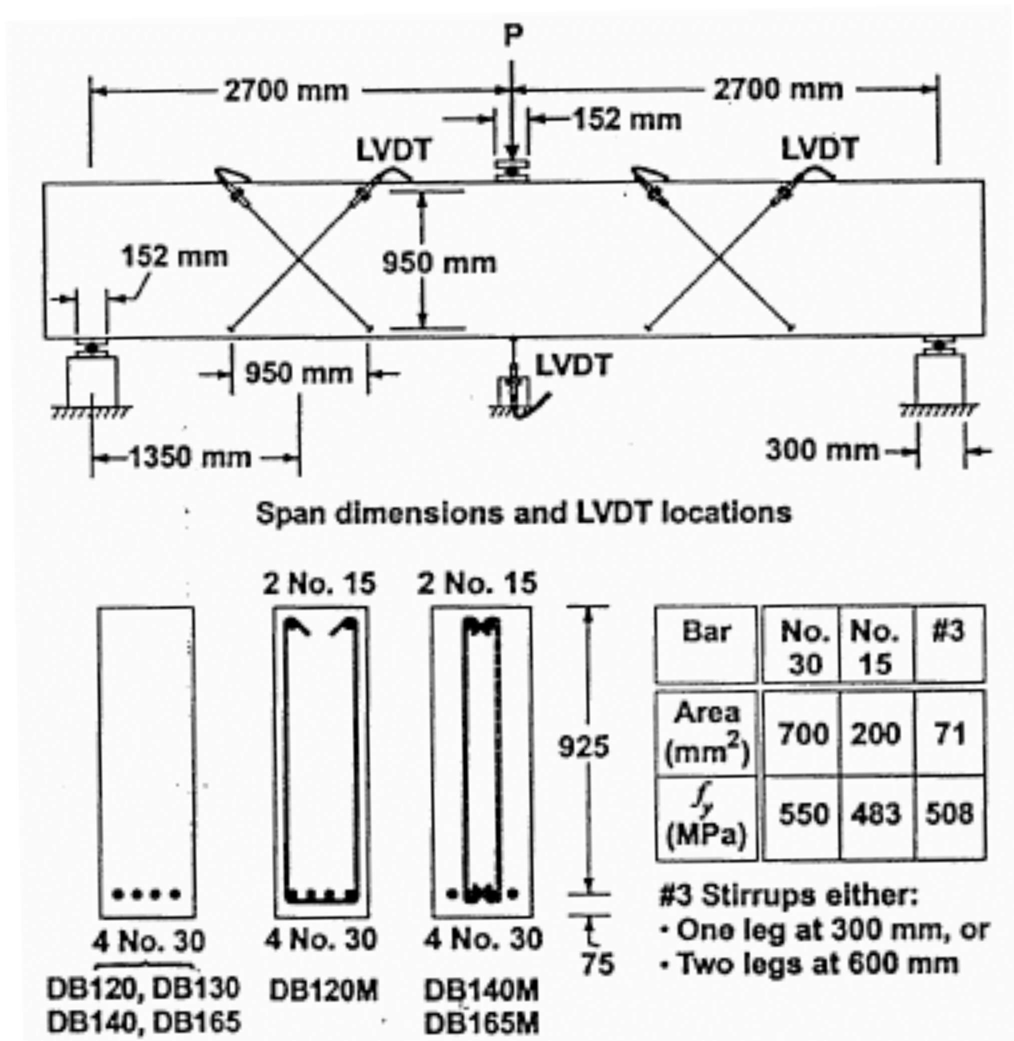


Figure 2: Vecchio's PV29 at failure in the Panel Tester.

ACI SP 205

NLFEARC: Example Deep Beams, Angelakos, Bentz and Collins [2001]



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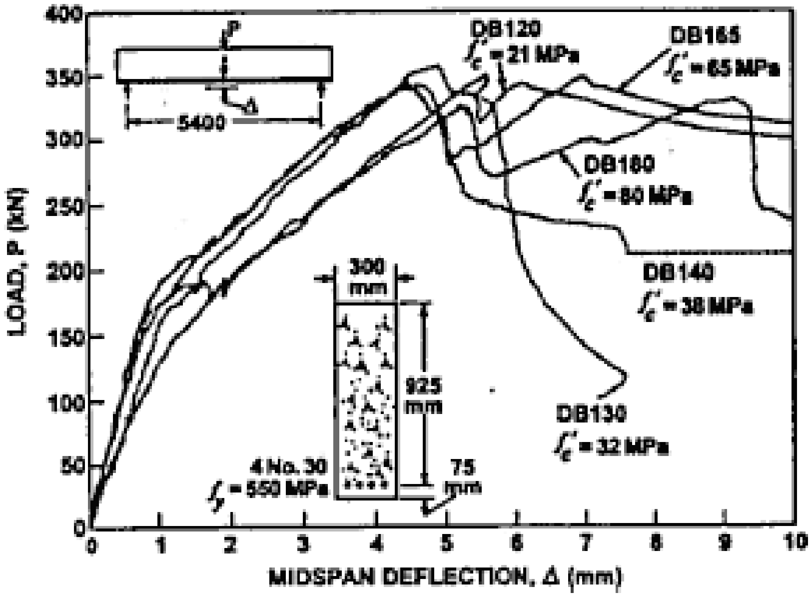
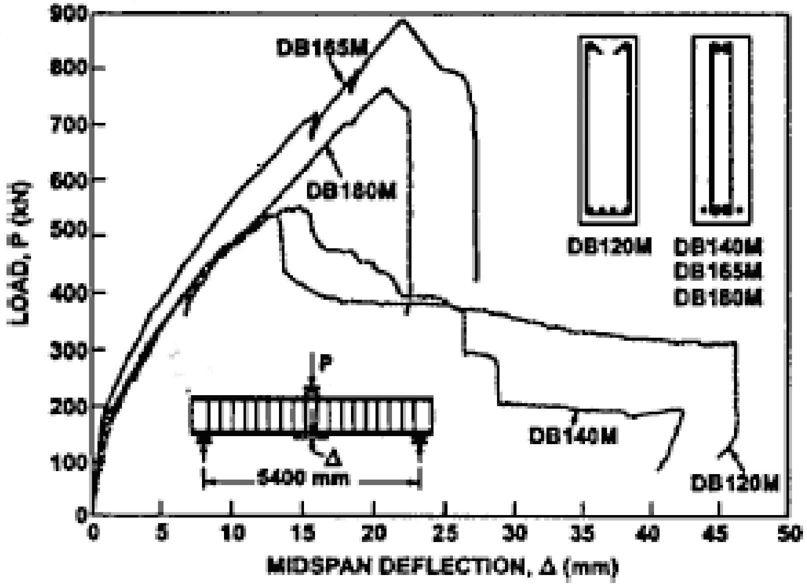
NLFEARC: Example Deep Beams, Angelakos, Bentz and Collins [2001]





CONCLUDING REMARKS

Alexander C. Scordelis: *Legacy in FEARC*

Reinforced Concrete = Composite Action:
Role of Confinement and Bond

Challenge - Robust Prediction of Strength and Especially Ductility:
Internal friction - drop of resistance due to loss of confinement
Internal Cohesion - drop of resistance due to tensile cracking