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Committee Survey

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SURVEY OF CURRENT STRUCTURAL RESEARCH: DISCUSSION-CLOSURE

by

Survey Committee

and

Research Committee of ASCE Structural Division

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SURVEY OF CURRENT STRUCTURAL RESEARCH

Discussion and Summary by Survey Committee and Research Committee of the ASCE Structural Division

This report serves as an addendum to the main text of the "Survey of Current Structural Research", second edition, which was published as ASCE Manual 51 in early 1970. The purpose of the report is to list the additional structural research projects that were received after the closing date for the manual, and to revise the tabulations so that they summarize all of the projects submitted. A total of 147 such projects are included herein.

The general arrangement of the material is according to the administrative and task committees of the ASCE Structural Division. A complete list of the main category and subcategory headings is given in Table 1. The task committees (or subtopics) are listed beneath the appropriate administrative grouping as subcategories. Additional subcategories have been added where project descriptions are not within the scope of any ASCE task committee.

The format used for listing data for the research projects is identical with that of Manual 51. The sequence for listing this information is as follows. The data is characterized as to its main interest area and is assigned to one of the twelve main categories. The individual research projects are then assigned to the appropriate subcategory or task committee.

The information supplied by each individual project includes its title, institution where the work is performed, principal investigator(s), sponsor(s), and the abstract. The first item of each individual project

is its title. The second item begins with the institution where the investigation is being performed, followed by the principal investigator(s) listed in parenthesis. Next comes the sponsor designation (the word "same" has been used in the last item to indicate that the sponsor and the institution where the work is performed are the same). The abstract for each project is the final item in the project description. The description of the project is the same as has been furnished by each investigator except for minor editing.

The sequence used for listing all projects within a particular subcategory is alphabetical according to the institution. When there are several projects in a particular subcategory being undertaken by the same research institution, they are then arranged alphabetically according to the last name of the first investigator. Several projects having the same institution and investigator would then be arranged alphabetically according to each project title.

As with the previous survey, tables and indexes have been revised to summarize and locate project data. The tables listed have been revised to include all material submitted. The inclusion of the additional projects herein have brought to 1877 the total number of projects reported for this second survey. The author, institution, and subject indexes listed herein refer only to those projects listed in this report.

Table 1 contains the number of projects listed in each subcategory and the total for the main category, including both those in Manual 51 and in this supplement. The total is more than twice the number of projects listed in the 1965 survey in which 789 projects were reported by 15 countries.

Table 2 indicates that replies were received from 28 countries--nearly twice the number of countries represented in the first survey. There were six countries reporting 50 projects or more. The United States, Japan, England, India, Canada and Australia constitute this group, and this covers 85% of the projects reported. The remaining 15% were contributed by the other 22 countries.

Table 3 delineates the distribution and number of projects which have been supported by principal sponsoring organizations. This tabulation includes only those projects which have provided this information. As expected the federal, state, and local governments both in the United States and abroad sponsored approximately half of these projects.

Table 4 lists the institutions where research is being performed and the type of research as delineated by the main categories. Almost 70% of the reported research is being conducted at universities.

Table 5 gives the financial description of the research projects within each main category. (For 40% of the projects no financial data were supplied). An estimate of the total financial expenditure for the 60% of the reported research is about 18 million dollars, a figure that seems low.

This survey was conducted at the Fritz Engineering Laboratory, Lehigh University, through the Research Committee of the ASCE Structural Division. The Survey Committee gratefully acknowledges the interest and financial sponsorship provided by the Office of Science Information Service, National Science Foundation. The Science Information Exchange was particularly helpful in supplying data on a number of projects.

Appreciation is extended to all those who contributed to the survey by submitting completed questionnaires. It is the intent of the Structural Division Research Committee to provide for a periodic updating of the survey.

Respectfully submitted,

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TABLE 1: ASCE STRUCTURAL DIVISION COMMITTEES AND INTEREST CATEGORIES

1.	Analysis and Design of Structures		
	1.1 Bridges		85
	1.2 Factor of Safety		15
	1.3 Methods of Analysis		111
	1.4 Special Building Problems		20
	1.5 Tower Design		4
	1.6 Esthetics in Design		2
	1.7 Suspended Structures		17
	1.8 Models		32
	1.9 Behavior & Design of Structural Systems		87
	1.10 Shell Structures		95
		Total	468
2.	Dynamic Forces		
	2.1 Seismic Forces		59
	2.2 Wind Forces		22
	2.3 Blast Forces		
	1. Air Blast (incl. sonic boom)		15
	2. Ground Shock		14
	2.4 Others		16
		Total	126
3.	Electronic Computation		29
4.	Masonry & Reinforced Concrete		
	4.1 Composite Const. (concrete-concrete)		4
	4.2 Design of Reinforced Concrete Slabs		23
	4.3 Engineered Masonry		14
	4.4 Folded Plate Construction		6
	4.5 Limit Design		32
	4.6 Precast Structural Concrete Design and Construction		21
	4.7 Prestressed Concrete		44
	4.8 Reinforced Concrete Columns		20
	4.9 Reinforced Masonry Design & Practice		5
	4.10 Shear & Diagonal Tension		37
	4.11 Lateral Load Distribution		8
	4.12 Corrosion		12
	4.13 Creep		29
	4.14 Dams		13
	4.15 Concreting Materials		73
	4.16 Reinforcing Materials & Methods		23
	4.17 Deflection Predictions		9
	4.18 Torsion of Reinforced Concrete		20
	4.19 Cracking		20
	4.20 Bond & Anchorage Reinforcement		18
	4.21 Others		73
		Total	504

Table 1 Continued

5.	Metals	
	5.1 Composite Const. (concrete-steel)	40
	5.2 Compression Members (incl. buckling and instability)	60
	5.3 Flexural Members	
	1. Hybrid Beams and Girders	6
	2. Box Girders	6
	3. Prestressed Steel	2
	4. Curved Girders	12
	5. Castellated Beams	2
	6. Plate Girders	15
	7. Cover Plates	-
	8. Beams with Web Openings	3
	9. Others	3
	5.4 Light Gage Metals	9
	5.5 Lightweight Alloys	5
	5.6 Orthotropic Plate Bridges	14
	5.7 Plastic Design	47
	5.8 Structural Connections	
	1. Bolted Joints	50
	2. Riveted Joints	2
	3. Welded Joints	34
	4. Bonded Joints	3
	5.9 Structural Fatigue	
	1. Fatigue Analysis & Theories	10
	2. Fatigue of Members & Details	21
	3. Loading History & Cumulative Damage	7
	4. Design	-
	5.10 Tubular Structures	16
	5.11 Special Structures	22
	5.12 Fracture	26
	5.13 Fabrication Techniques	5
	5.14 Corrosion	21
	5.15 Others	37
	Total	478
6.	Nuclear Structures & Materials	
	6.1 Shielding	3
	6.2 Containment Vessels	13
	Total	16
7.	Plastics	
	7.1 Design Criteria for Adhesives & Connections	3
	7.2 Design Criteria for Plastic Structural Components	3
	7.3 Properties of Selected Structural Plastics and Systems	5
	7.4 Structural Applications	4
	Total	15
8.	Wood	
	8.1 Composite Construction	4
	8.2 Laminated Elements	11

Table 1 Continued

	8.3 Flexural Members		9
	8.4 Plywood Panels		5
	8.5 Wood Shell Roofs		2
	8.6 Buckling and Stability		7
	8.7 Fire Retardant Treatment		7
	8.8 Connections		13
	8.9 Others		36
		Total	94
9.	Response of Full Scale Structures		
	9.1 In-Service Performance		37
	9.2 Controlled Load & Destruction Tests		12
	9.3 Damage Evaluation		2
		Total	51
10.	Other Structural Materials		
	10.1 Ceramics		1
	10.2 New Structural Materials		8
		Total	9
11.	Structures in Other Environments		
	11.1 Outer Space		7
	11.2 Underwater		8
	11.3 Buried Structures		25
		Total	40
12.	Others		47
		TOTAL PROJECTS	1877

TABLE 2: PARTICIPATING COUNTRIES

Australia	59	Mexico	21
Belgium	11	Netherlands	8
Brazil	11	Norway	3
Canada	83	Portugal	11
Chile	3	Scotland	9
Denmark	8	South Africa	1
England	136	Sweden	23
France	14	Switzerland	17
Hungary	2	Turkey	1
India	88	United States	968
Ireland	5	Venezuela	1
Israel	3	West Germany	29
Italy	29	Yugoslavia	14
Japan	307	Not Specified	11
Kenya	1	TOTAL PROJECTS	1,877
		TOTAL COUNTRIES	28

TABLE 3: SPONSORS AND PROJECTS

Sponsor	United States		Foreign Countries		U.S.	Others
	Number of Sponsors	Number of Projects	Number of Sponsors	Number of Projects	Percent of Projects	Percent of Projects
Industry	23	42	33	74	3	5
Institutes & Associations	16	95	18	35	6	2
Professional Societies	3	12	4	7	1	—
Research Councils	9	36	16	155	2	10
Private Foundations	3	9	4	11	1	1
Local & State Governments	37	191	5	13	13	1
Federal, Non-Defense	16	210	29	160	14	11
Federal, Defense	33	184	4	7	12	—
Universities	48	140	38	112	9	7
Others	1	1	10	24	—	2
Total	189	920	161	598	61	39

TABLE 4: INSTITUTIONS WHERE RESEARCH IS BEING PERFORMED

Category		Analysis & Design of Structures	Dynamic Forces	Electronic Computation	Masonry & Reinforced Concrete	Metals	Nuclear Structures & Materials	Plastics	Wood	Response of Full Scale Structures	Other Structural Materials	Structures in Other Environments	Others	Total
Universities	U.S.	190	48	14	164	157	7	1	45	18	3	8	18	673
	Foreign	179	48	9	169	164	3	5	16	11	1	12	9	626
Research Organizations[a]	U.S.	9	2	1	6	10	2	-	5	4	2	2	4	47
	Foreign	20	7	2	14	32	-	-	1	2	-	2	4	84
Industries	U.S.	2	2	-	18	18	3	-	4	3	3	-	-	53
	Foreign	11	6	1	22	19	1	-	1	5	-	-	4	70
Governments	U.S.	30	7	1	85	27	-	9	17	7	-	14	6	203
	Foreign	20	6	1	18	31	-	-	5	1	-	2	2	86
Not Specified		7	-	-	8	20	-	-	-	-	-	-	-	35
TOTAL		468	126	29	504	478	16	15	94	51	9	40	47	1877

[a]Research councils, institutions, associations, and private foundations.

TABLE 5: DISTRIBUTION OF FINANCIAL SUPPORT

Category	Number of Projects for Various Amounts of Support, in dollars							Total
	None	0 to 1,000	1,000 to 10,000	10,000 to 25,000	25,000 to 50,000	Over 50,000	Not Specified	
1. Analysis & Design of Structures	74	37	81	58	48	29	141	468
2. Dynamic Forces	8	4	25	11	13	16	49	126
3. Electronic Computation	4	1	5	6	3	6	4	29
4. Masonry Reinforced Concrete	38	44	80	44	29	43	226	504
5. Metals	29	11	118	58	37	27	198	478
6. Nuclear Structures & Materials	2	-	1	2	2	8	1	16
7. Plastics	2	-	1	2	2	4	4	15
8. Wood	3	3	17	9	4	1	57	94
9. Response of full Scale Structures	-	1	10	11	7	8	14	51
10. Other Structural Materials	-	-	2	-	2	-	5	9
11. Structures in Other Environments	1	2	4	5	6	8	14	40
12. Others	2	1	8	7	6	4	19	47
TOTAL	168	104	352	213	159	154	732	1877

1. ANALYSIS AND DESIGN OF STRUCTURES

1.1 Bridges

(1) SHORT SPAN STEEL BRIDGES
BHP Melbourne Research Laboratories (M. G. Lay and M. McCormick); BHP Co. Ltd.

The aim of the project is to study the optimization and rationalization of design, fabrication and erection of short span steel bridges. (MRL project 19)

(2) BEHAVIOR OF SKEW PLATES
Jadavpur University (P. Som and G. Chakravorty); same

Theoretical analysis of skew plates with different end conditions and different degrees of skew is done by several methods, and results are compared with experimental data. Influence surfaces for bending and shear are developed. Dimensions of the plate and the loading are selected to suit the requirements for bridge design.

(3) ANALYSIS OF INTERCONNECTED BEAMS
Regional Engineering College, Durgapur (M. M. Basole and P. K. Das); Central Mechanical Engineering Research Institute

The objective is to develop methods of analysis for bridge decks of grid type subjected to abnormal wheel loads under different conditions of support and members.

1.2 Factor of Safety

(1) ADAPTIVE SYSTEMS FOR EARTHQUAKE RESISTANT STRUCTURES
New Mexico, University of (J.T.P. Yao); National Science Foundation

The object of this research is to study the dynamic response and reliability of adaptive structural systems subjected to deterministic as well as probabilistic loads. Special applications will be made to the design and analysis of earthquake resistant structures.

1.3 Methods of Analysis

(1) FINITE ELEMENT METHOD FOR SHEAR WALLS
Indian Institute of Technology, Kanpur (P. Dayaratnam, T. Sethuratnam and R. S. Bhagwat); Council of Scientific and Industrial Research

A finite element stiffness matrix for each panel is developed as an element stiffness matrix. A computer program for the analysis of tall structures which includes the shear walls, frames, and built-in panels as elements of the structure is developed. Some experimental work is also undertaken.

ANALYSIS AND DESIGN OF STRUCTURES

(2) THERMOELASTIC DEFORMATION OF SKEW PLATES
Osaka Prefecture, University of (T. Katayama); none

Many reports on thermal deformations of rectangular plates have been published. But, there are few reports about skew plates. The fundamental equations of the thermoelastic deformations of skew plates are derived from the first and second law of thermodynamics by the variational method on the basis of the stationary theorem of the total potential energy. It is shown that the fundamental equations derived by the above-mentioned procedure agrees with the equations obtained by the direct transformation of the Cartesian coordinate system.

(3) THERMOELASTIC PROBLEMS IN A SYMMETRICAL REGION UNDER ASYMMETRICAL TEMPERATURE DISTRIBUTION
Osaka Prefecture, University of (T. Sekiya); none

This research presents an analog procedure for determining the thermal stress distribution in the doubly-connected symmetrical region under an asymmetrical temperature distribution. The distribution of thermal stress was obtained for the square region with a circular hole or a slot-shaped hole under asymmetrical temperature distribution. Furthermore, the agreement between the analog result and the theoretical result and the agreement between the analog result and the thermal stress under the actual thermal load were quite good.

(4) THERMAL STRESSES IN A PLATE DUE TO RADIANT HEATING
Osaka Prefecture, University of (Y. Sugiyama); none

Thermal stresses in a clamped rectangular plate due to radiant heating through the utilization of quartz infrared lamps are investigated and a comparison is made between the experimental and theoretical results. The temperature distributions and the strains of the test plate with the effective dimensions of 400mm x 200mm x 1.57mm were first measured by means of C-C thermocouples and temperature compensated strain gages. The thermoelastic equations were solved by both finite difference method and Galerkin's method, two cases, i.e. for a coarse net and a finer net, were calculated. In the latter method, two terms in the approximation were carried out. Stress distributions which were obtained from the direct measurements and those from the numerical calculations showed fairly good agreement considering difficulties.

(5) UNSTEADY THERMAL STRESS IN HOLLOW CIRCULAR REGIONS
Osaka Prefecture, University of (S. Sumi); none

A mechanical analog procedure for solving two-dimensional thermoelastic problems is developed and conducted in the transient stress problem of a hollow circular region with heat transfer at the inner surface. The analog solution shows an excellent agreement with analytically determined values.

(6) EXPERIMENTAL VERIFICATION OF COMPUTER SIMULATION METHODS FOR SLAB AND GIRDER BRIDGES
Texas at Austin, University of (J. E. Breen, J. V. Repa, J. Kaczmarek, N. Barboza, and N. Bakir); Texas Highway Department and U. S. Bureau of Public Roads

The purpose of this project is the documentation and experimental verification of a number of comprehensive computer programs for highway bridge design. The principal aim is to provide information on the proper values of design parameters such as stiffness, rotational restraints, etc., to be used with the programs based on previously reported experimental studies. Further experimental research will be performed to fill in gaps apparent from research surveys.

(7) DEVELOPMENT OF METHODS FOR COMPUTER SIMULATION OF BEAM COLUMNS AND GRID BEAMS AND SLAB SYSTEMS
Texas at Austin, University of (H. Matlock and W. R. Hudson); Texas Highway Department and U. S. Bureau of Public Roads

Current design practices for bridge form systems and pavement slabs do not account for all the variables which exist in nature. Furthermore, closed form solutions are extremely difficult to obtain for even simpler cases of discontinuous orthotropic plates and slabs. In this project discrete element theories and methods have been adopted and extended to provide computer programs for the solution of orthotropic pavement slabs and complex floor slab systems. These solutions are being used to analyze bridges and pavements, and will subsequently be used in the development of new design techniques.

1.4 Special Building Problems

(1) MONORIAL STRESSES IN WIDE-FLANGE BEAMS
BHP Melbourne Research Laboratories (M. G. Lay and P. Foden); same

The project examined the stresses produced in wide-flange beams by monorail-type loads applied at the flange tips and recommended design rules for the same.

(2) THE EFFECT OF OPENINGS ON THE LATERAL STRENGTH OF INFILLED FRAMES
Indian Institute of Technology, New Delhi (D. V. Mallick and R. P. Garg); same

For infilled frames, in which the infill is not connected to the frame, the lateral strength depends upon the length of contact between the frame and the infill. If an infilled frame is subjected to cyclic loading, the infill rocks inside the frame between the support corners, thus, the diagonal of the infill which was in compression during the first half cycle changes to a tension member in the second half cycle

and vice versa. It is thus obvious that the position of an opening near the corner will affect the lateral strength of the infilled frame during vibration. In the present paper, attention is given to these topics.

(3) DESIGN OF ECONOMIC STEEL STRUCTURES
Regional Engineering College, Durgapur (M. M. Basole and P. K. Das); Central Mechanical Engineering Research Institute

The objective is to use lattice type of construction for design of medium industrial structures with or without gantry girders.

(4) RESEARCH AND DEMONSTRATION PROGRAM COVERING LOW-INCOME HOUSING
Texas at Austin, University of (J. Neils Thompson and F. B. Johnson); U. S. Department of Housing and Urban Development

Ten different construction and material systems for housing construction are being built by ten different companies for the purpose of research and demonstration techniques in low-cost construction. The purposes for the research studies are to determine the effectiveness of each innovative design in serving the needs of the occupants, determination of projected costs for large numbers of units and the performance of each house structurally, its livability, its functionality, etc. This project encompasses the structural, architectural, materials, mechanical, and electrical engineering phases, as well as the architectural and sociological disciplines.

(5) DRILLED SHAFT FOOTINGS FOR HIGHWAY SERVICE STRUCTURES
Texas A & M University (D. L. Ivey); Texas Highway Department and U. S. Bureau of Public Roads

The object of this research is to develop an analytical procedure which will determine the actual resistance of these footings to the three major loading conditions; static or pull-over loads, sustained or long-term loads, dynamic loads. The approach to the problem is through development of theory and testing. At the present time, a basic theory has been developed and 70% of the testing has been completed. Pull-over tests on models have been successfully correlated with the theory. Limited full-scale tests (four model and five full scale) are currently underway. Tests during the final study year will involve approximately ten dynamic tests.

1.7 Suspended Structures

(1) CABLE SUSPENDED ROOFS: STATIC BEHAVIOR
Cornell University (D. P. Greenbern and G. Winter); American Iron and Steel Institute

The objectives are to develop precise methods of analysis, including the non-linear effects of materials behavior and of change under load, of cable-suspended roof systems, including the determination of deflections under service loads and of the actual ultimate loads and to formulate, if possible, simplified design methods of satisfactory accuracy.

1.8 Models

(1) SMALL MODEL STUDIES FOR REINFORCED CONCRETE DESIGN
Purdue University (R.C. Siclen, M. J. Gutzwiller and R. H. Lee); Indiana State Highway Commission

This research project was an experimental study on the feasibility of using small scale models to represent reinforced concrete beams. The specific objectives were: 1.) to establish model techniques and materials applicable to small scale beams, 2.) to compare model test results with standard theory and previous test results from larger scale beams. In order to accomplish the objectives of the research, fifty-three model beams of different sizes and shapes were used. Cylinders were used to determine model concrete properties.

1.9 Behavior and Design of Structural Systems

(1) PERFORMANCE OF BEAMS AND COLUMNS CONTINUOUSLY BRACED WITH DIAPHRAGMS
Cornell University (S. J. Errera); American Iron and Steel Institute

The objectives are to determine by theory and test the bracing effect of shear-rigid diaphragms on flexural and torsional-flexural buckling strength of columns and beams continuously or intermittently connected to such diaphragms (wall-sheathing, rood-decking, floor-panels) and to develop design methods for taking advantage of this effect.

(2) OPTIMAL DESIGN OF STRUCTURES
Indian Institute of Technology, Kanpur (P. Dayaratnam and S. N. Patnaik); same

The objective is to develop an iterative method which considers full stress and minimum weight criteria as the main basis of design. Plane and space trusses are essentially discussed.

(3) STABILITY FUNCTIONS OF CONCRETE MEMBERS
Indian Institute of Technology, New Delhi (B. M. Ahuja and K. K. Nayar); same

Theoretical and experimental built up of stability function for concrete members and hence the stiffness of concrete structures are studied.

(4) LATERAL INSTABILITY OF THE COMPRESSION FLANGE OF CRANE GANTRY GIRDERS
Jadavpur University (P. Som); same

A simplified approach to the estimation of critical compressive stress in built-up girders with unequal flange areas has been made. Tests to verify the formula are being done on perspex models and welded steel girders with various end conditions.

(5) BRACING REQUIREMENTS WITH STEEL DIAPHRAGMS
Cornell Univesity (G. Winter); American Iron and Steel Institute

The objectives are to analyze by theory and test the restraint against twist and lateral deflection provided by shear-rigid diaphragms to channel- and Z-beams loaded in the plane of the web, and to formulate pertinent design rules.

(6) APPLICATION OF STATISTICS IN CIVIL ENGINEERING
Melbourne, University of (L. K. Stevens, A. M. Hasofer and D. S. Mansell); Australian Research Grants Committee

The aim of project is to establish bases for adoption of a rational probabilistic approach to structural design.
Statistical methods have been applied to problems in structural engineering including the mechanisms of brittle fracture, distribution of floor line loadings and dynamic effects of wind.

(7) BEHAVIOR AND ULTIMATE STRENGTH OF REINFORCED CONCRETE THIN WALLED PRISMATIC STRUCTURAL ELEMENTS
P. S. G. College of Technology (V. Ramakrishnan and Y. Ananthanarayana); Council of Scientific and Industrial Research, India and University Grants Commission

Thin walled reinforced concrete members are being increasingly used in view of the efficiency of their structural action and the economy of materials. However, for lack of systematic test information regarding the behavior and the ultimate strength of these sections, no specific recommendations have been made in the codes regarding their analysis and design. The analysis and design of these structural elements present problems quite different from the behavior of conventional solid sections. The behavior and reliability should be investigated with a view to maximize the usefulness of such sections as a primary building component for all types of structures. More research is needed on all aspects of this problem. The recent progress made in the fields of ultimate strength design and limit design makes a knowledge of the ultimate load carrying capacity, and the deformation characteristics of these members, a prerequisite for an optimum design of them. As thin walled reinforced concrete members are highly susceptible to torsional loads, their ultimate strength and behavior under combined bending and torsion is of utmost practical importance. The following aspects are in this investigation being studied both theoretically and experimentally: 1.) the ultimate strength, 2.)

deformation characteristics, load deflection relationships, torque-twist relationships, crack pattern and crack width, 3.) mode of failure, 4.) interaction between bending and torsion of reinforced initially concrete thin walled structural members. It is proposed to study the behavior of box beams with or without openings.

1.10 Shell Structures

(1) DYNAMIC RESPONSE OF THIN SHELLS TO SUDDENLY APPLIED LOADS
California, University of (W. Nachbar); U. S. Air Force

The objective of this research is to conduct fundamental studies on the dynamic response of shallow arches and thin shells of elastic and anelastic materials to suddenly applied loads. The results to be expected include general principles leading to a more complete understanding of the processes involved and development of efficient methods of analysis and computation. Particular attention will be paid to the optimization problems of minimizing the weight or cost of a structure for a given class of loadings or maximizing the damage inflicted on a given structure at a given cost in energy.

(2) SHELL ROOF STRUCTURES
Cornell University (P. Gergely and G. Winter); American Iron and Steel Institute

The objectives are to analyze by theory and test the behavior, deformations, and carrying capacity (including instability) of hyperbolic-paraboloid steel shells consisting of orthotropic, ribbed light-gage steel panels and appropriate edge members, and to formulate design methods.

(3) ANALYSIS OF DOUBLY-CURVED ARCH DAMS ON ELASTIC FOUNDATIONS
Indian Institute of Technology, Bombay (J. Panikar, C. Suryanarayana Rao, P. Murthy and M. Joshi); same

The initial attempt in applying shell theory to doubly-curved arch dams has been made using shells of revolution. Solutions were made for obtaining the stresses. The second part of the investigation included a plaster celite model study using strain gauges. The second phase of the work was continued using the Viassov's equations for shallow shells on a arbitrary shape, which was modified to include the affect of transverse forces. The shell was imagined as a static-model, developed as a plate resting on an elastic base. The resulting equations of equilibrium was solved by using Finite-difference techniques and the results for deflections and stresses were obtained by electronic computation.

ANALYSIS AND DESIGN OF STRUCTURES

The third phase of the work was based on an approximate analysis to include the enlargement of the boundary and foundation deformation and attempts were made to compute the necessary constants using a computer. A model study on a scale of 1 in 250 (the Morrow Point dam) was used.

(4) ANALYSIS OF THICK HYPERBOLIC PARABOLOID SHELLS
Indian Institute of Technology, Kanpur (P. Dayaratnam and S. K. Lahiri); none

The total potential energy of shallow thick hyperbolic paraboloid shell is developed by using thick shell theory using Reisners variational approach. A force deformation relation is obtained. Solutions to simple boundary conditions are obtained on computer.

(5) EFFECTS OF SPACING TRANSVERSE DIAPHRAGM ON ULTIMATE STRENGTH OF CYLINDRICAL SHELLS
Indian Institute of Technology, Kanpur (P. Dayaratnam and P. N. Mehta); none

A set of prestressed micro-concrete cylindrical shells are cast taking prestressing force and spacing of the transverse diaphragms as parameters. Their behavior and ultimate strength are studied.

(6) SIMPLIFIED METHODS OF ANALYSIS OF SHELLS
Indian Institute of Technology, New Delhi (B. M. Ahuja and S. S. Bhatia); same

The object of the tests is to ascertain experimentally the stiffness of an element of Hyperbolic paraboloid shell and compare it with one obtained analytically using finite element technique and using and ignoring different compatibilities. This will establish the relative importance of different compatibilities and influence of cracks in these.

(7) SIMPLIFIED METHODS OF SHELL DESIGN
Indian Institute of Technology, New Delhi (B. M. Ahuja and S. S. Bhatia); same

Physical verification of the stiffness matrix of a Hyperbolic Paraboloid shell at different cracked stages is studied. The model is prestressed where its intensity can be reduced at will. The edges have controlled displacements, and means for measuring the restraint is provided. Theoretical work by finite elements shall then be compared and inferences drawn on possible approximations about compatibilities and stress or strain distributions along junction of elements.

(8) ULTIMATE STRENGTH OF DOUBLY CURVED SHELLS
Jadavpur University (P. Som and B. Ghosh); same

Conoidal shells are tested to destruction for observing the ultimate load and crack pattern of the shell in order to evolve a method of ultimate design of such shells on the basis of possible extension of yield-line theory. Shells are made of sand-cement mortar. One

model of plaster of paris has also been tested. Dimensions of the shell are such that within the elastic range the shell may be assumed to be subjected to membrane forces only.

(9) THIN ELASTIC SHELLS
Stanford University (W. A. Flugge); U. S. Army Office of Research

The objective is to investigate the properties of extremely thin elastic shells. Investigations include: 1.) Large deformation of thin elastic toroidal shells, 2.) A linearized membrane theory for prestressed shells of revolution, 3.) A study of inflated thin shells, 4.) The membrane theory of the toroidal shell (a singular perturbation problem). All four investigations consider very thin, inflated ballons. Item (1) contains general equations for large-strain deformation of axisymmetric shells, solutions for the inflation and deflation of a toroid, the occurrence of wrinkle zones in the latter case. Item (2) treats prestressed (inflated) shells under a small additional load. Item (3) studies a similar problem for unsymmetric loads and deals with the influence of the bending stiffness upon the action of point and line roads.

(10) APPLICATION OF FINITE ELEMENT METHODS TO NON-LINEAR STRUCTURES
University College of South Wales and Monmouthshire (D. Ashwell); none listed

The objective is to consider the application of finite element methods to the nonlinear behavior of plate and shell structures.

(11) INEXTENSIONAL SHELL THEORY
University College of South Wales and Monmouthshire (D. Ashwell); none

The objective is to investigate implications of an assumed inextensibility on the behavior of shells, particularly with reference to their instability.

(12) APPLICATION OF FINITE ELEMENT METHOD TO SHELL STRUCTURES
University College of South Wales and Monmouthshire (A. B. Sabir); none listed

The analogy between a plate on elastic foundation and a shell with double curvature is used to obtain a stiffness matrix for a shallow curved element. The matrix is used to obtain solutions to structural problems.

2. DYNAMIC FORCES

2.1 Seismic Forces

(1) INELASTIC BEHAVIOR OF BEAM-COLUMN SUBASSEMBLIES UNDER REPEATED LOADING

California, University of, Berkeley (E. Popov and V. Bertero); Committee of Structural Steel Producers and the Committee of Steel Plate Producers

The objective is to determine the inelastic behavior of beam-to-column subassemblages under repeated actions (loading or imposed deformations). The investigation was planned to be carried out in two phases. In the first phase, preliminary studies were done in order to plan a systematic program of tests and analytical studies which form the second phase. The first phase which has been completed included: (1) review of current methods for reinforcing panel zone of beam-to-column connections, (2) evaluation of present practice for designing such panel zone, (3) selection of specimen to be tested and, (4) development of testing set-up.

(2) DYNAMIC ANALYSIS OF SHEAR BUILDING WITH AND WITHOUT OPENINGS

Indian Institute of Technology, New Delhi (D. V. Mallick and V. Prakash); same .

The inplane theoretical natural frequencies of the shear walls are calculated using the finite element method. Experimental investigations of natural frequencies and associated mode shapes will be made and results compared with the theory. This project is a part of the investigation of finding response of structure to earthquakes.

2.2 Wind Forces

(1) WIND EFFECTS ON BUILDINGS AND OTHER STRUCTURES

The Electrical Research Association, United Kingdom (R. Harris); Construction Industry Research and Information Association

There are four areas of research in this project. Measurements of hourly average wind speeds involve long term measurements of wind data to examine the effects of site topography on the mean wind flow, calibration of the readings of various standard wind-measuring instruments against those of a more accurate instrument, development of a method for conducting a site wind survey. Measurements of winds on structures involve the recording of detailed wind measurements, and the computation from these wind records of the spatial and temporal properties of gusts. At present measurements are being made at twelve positions up to 600 ft. above ground level on a radio mast, and on a line of masts, each 10 meters high, on an airfield. Later, another radio mast on a site having significantly different topography, will be instrumented. Wind effects on structures involve simultaneous measurements of gusts, and the strains and displacements of a number of structures, so that calculated structural behavior can be compared with

experimental measurements. This work is being carried out on some small structures and on a 200 ft. high lattice tower. Theoretical studies involve investigations of the properties of wind and its interaction with structures including coherence, the aerodynamic admittance of lattice structures, and the dynamic response of simple structures.

3. ELECTRONIC COMPUTATION

(1) THE DEVELOPMENT OF A PROBLEM-ORIENTED COMPUTER LANGUAGE FOR SIMULATION OF ENVIRONMENTAL CONDITIONS IN BUILDINGS
Pennsylvania State University (L. O. Degelman, L. O. Sinkey and J. A. Simon); National Science Foundation

This project is intended for the development of a "problem-oriented" computer language for the evaluation and design of building wall, roof and air conditioning systems. In order to accomplish this objective the research project will include (1) extensions to some mathematical models for air conditioning simulation, (2) development of a vocabulary and instruction commands for the problem-oriented language, (3) development of cost optimization models for the integration of building environmental systems, (4) programming and testing of the language and integrating it into an existing programming system, and (5) developing a user's manual for the use of the language.

(2) COMPUTER METHODS FOR NONLINEAR STRUCTURAL ANALYSIS
St. Louis University (J. Sobieszczanski) National Aeronautics and Space Administration

The structure under consideration is composed of finite elements. Force-deformation relationships for all the elements are derived from the known material properties and element geometry. They include full stress-strain properties with strain hardening, Bauschinger effect, creep, temperature influence on mechanical properties, etc. without any simplifications other than those required by digitalization. Load and temperature are given as functions of time. Analysis is performed by incremental method with a new technique of subordinated time step. Output gives stresses and displacements as functions of time. Provision for a member fracture, total collapse, loading, unloading cycles is included. Programming is carried out in FORTRAN IV.

4. MASONRY AND REINFORCED CONCRETE

4.1 Composite Construction

(1) DESIGN OF REINFORCED CONCRETE GIRDER BRIDGES
Kyoto University (K. Okada); none listed

In order to obtain a rational design method for a reinforced concrete multi-web bridge, both experimental and theoretical studies have been carried out on the following items: (1) the load distribution, (2) effective width of the floor slab both in elastic and plastic state, (3) the ultimate strength and yield condition. Reinforced mortar bridge models are tested under some vertical eccentric load conditions, and the analytical method adopted is as follows: (1) folded plate theory regarding a concrete girder bridge as a folded plate structure (2) yield line theory and finite element method regarding the bridge as a orthogonal anisotropic plate.

4.2 Design of Reinforced Concrete Slabs

(1) EXPERIMENTAL STUDY OF YIELD PATTERN AND ANALYSIS OF CIRCULAR SLABS WITH AND WITHOUT OPENINGS
Birla Institute of Technology & Science (M.L. Samaiya and H.S. Moondra); same

All slabs were tested for simply supported condition and for uniformly distributed load. The slabs were provided mesh reinforcement and radial-ring reinforcement to study their effectiveness. Yield patterns obtained are as expected with theoretical considerations. Ultimate loads obtained are 2 to 3 times the theoretical ultimate loads.

(2) ULTIMATE STRENGTH OF REINFORCED CONCRETE SLABS
Kyoto University (K. Okada); none listed

Studies are made on the ultimate strength of reinforced concrete slabs using mortar model slabs having two varying reinforcement ratios, slab depths and orthogonal and diagonal arrangements of slab reinforcement. Test slabs have free ends or fixed ends along all four edges, and are loaded with various areas. Applicability of the yield line theory to slabs and the behavior of the slab at failure, especially in punching shear, have been examined. It appears that Johansen's yield line theory can predict the ultimate strength of slabs if the slab fails in bending. In the case where the slab fails in shear, a empirical ultimate strength design formula is proposed which is determined by modifying Moe's equation. Characteristics of the frustum of a cone or a pyramid formed in the slab due to a column load are examined in detail.

4.3 Engineered Masonry

(1) HIGH BOND MORTAR RESEARCH
National Bureau of Standards (L.E. Cattaneo and E.O. Pfrang); U.S. Department of Commerce

The objectives are to purchase expendable supplies and equipment and to provide technical support in carrying out research on the structural properties of masonry using high bond mortars and the establishment of satisfactory design and performance criteria for such masonry. Studies will be initiated in an effort to develop procedures for the engineered design of masonry constructed with high bond mortars. Engineering data will be accumulated on the performance and strength of masonry walls which have been constructed with the use of high bond and ordinary masonry mortars. Theoretical and laboratory investigations will be initiated into the mechanism of failure of masonry structural systems.

(2) MASONRY WALL SYSTEMS
National Bureau of Standards(L.E. Cattaneo); U.S. Department of Commerce

The objective is to assist in carrying out the mission of developing needed information on the structural properties of structural clay masonry products by providing the necessary support activities. The approach is to determine the strength of clay brick masonry and develop analytical equations describing the strength. Tests are being conducted in which the parameters include brick, mortar, brick masonry, and the end restraint. New test methods may be developed for testing the strength of clay brick masonry. One of the important objectives of this program is to determine the effect of the various mechanical, elastic and strength properties of the brick on the integrity of structural clay masonry. Other areas of study of masonry include creep, fatigue, non destructive testing, mechanism of load transfer in cavity walls, effect of eccentricity of loads on masonry walls, and field measurements of differential building movements.

4.4 Folded Plate Construction

(1) EFFECTS OF SPACING TRANSVERSE DIAPHRAGMS ON ULTIMATE STRENGTH OF PRESTRESSED FOLDED PLATES
Indian Institute of Technology, Kanpur (P. Dayaratnam and P. Indubhushan); none

A set of prestressed micro-concrete folded plates are cast taking prestressing force and spacing of transverse diaphragms as parameters. The folded plates are tested for ultimate load and their behavior is studied.

(2) SHORT FOLDED PLATES
Indian Institute of Technology, New Delhi (K. Seetharamulu and S. C. Rajkumar); same

It is being attempted to present a rationalized method of analysis for bunkers, the investigation includes: (1) analysis of short folded plates continuous over movable and rigid diaphragms, (2) finite openings in such folded plates, and (3) end diaphragms which may be vertical or inclined are considered to have finite stiffness. The experimental investigations consist of aluminium and photoelastic models.

4.5 Limit Design

(1) EFFECTS OF VARIABLE REPEATED LOAD ON REINFORCED CONCRETE STRUCTURES
California, Berkeley, University of (V. Bertero); same

The objective is to investigate effects of different loads on reinforced concrete structures designed according to limit design theory. To achieve this end a computer program is being developed. The structure is discretized by the finite element procedure. Integration of the stiffness differential equations is carried out numerically by the step-by-step displacement method.

(2) STABILITY FUNCTIONS OF CONCRETE MEMBERS
Indian Institute of Technology, New Delhi (B. M. Ahuja, K. K. Nayar and K. K. Gupta); same

Stability calculations of reinforced concrete frames depend on functions valid only for a homogeneous elastic material. Due to redistribution of stresses and different elastic properties in different parts of stress-strain curve, these functions change drastically. An attempt is being made to see this analytically, and then these shall be verified experimentally.

(3) LIMIT DESIGN OF REINFORCED CONCRETE CONTINUOUS BEAMS
Kyoto University (K. Okada); same

Experimental studies were made on the rotation capacity of a section and the yield of plastic hinges in reinforced and prestressed concrete beams. This study aims at investigating the yield "mechanism" of continuous reinforced concrete beams in relation to the relative strengths of sections at the mid-span and the supports. Several reinforced concrete multi-span beams are tested, and variables involved in this study are as follows: span ratio, loading condition and cross sectional constants. Deflections along the spans of the continuous beams in the elastic and plastic stage are also observed.

(4) BEHAVIOR AND ULTIMATE STRENGTH OF REINFORCED CONCRETE PORTAL FRAMES
P.S.G. College of Technology (V. Ramakrishnan, R. Krishnamoorthy D. Jagannathan); Council of Scientific and Industrial Research, India and P.S.G. College of Technology, Coimbatore

Analysis and experimental investigations have been carried out on the behavior and strength of the following: (1) single-bay single story portal frames with a constant section, under and over - reinforced, (2) single-bay single story portal frames with a variable section, (3) single-bay two story portal frames with constant section. The main points investigated were behavior of frames in elastic and inelastic stages, formation of plastic hinges and failure mechanism, moment-rotation characteristics, etc. The variables considered were strength of concrete, sectional properties, percentage of reinforcement, both longitudinal and transverse, degree of redundancy. While rigorous analysis is in progress, a limit design procedure suggested by A. L. L. Baker has been verified. It has been observed that the general behavior of the under-reinforced frames was in agreement with

Baker's assumptions. The study also revealed that the permissible hinge rotations recommended by Baker are on the conservative side, except in the case of portal frames having inadequate shear reinforcement. Elastic analysis predicts the behavior of portal frames until the formation of first plastic hinge, and hence elastic analysis can confidently be used as a check.

(5) BEHAVIOR AND ULTIMATE STRENGTH OF REINFORCED CONCRETE SPACE FRAMES
P.S.G. College of Technology (V. Ramakrishnan); same

Work both experimental and analytical has been initiated on the behavior and strength of reinforced concrete space frames. A limit design procedure has been successfully extended to the case of corner lintels, which are among the simplest of these space frames. Experimental values show good correlation with the theoretical predictions.

(6) ULTIMATE FLEXURAL STRENGTH OF SHALLOW REINFORCED CONCRETE BEAMS
Regional Engineering College (R. C. Ganguli and M. L. Arora); Burdwan, University of

The ultimate flexural strength of reinforced concrete beams is predicted. The accepted works by Mattock, Kriz & Hognestad and that by the senior investigator under-estimate the strength. A over strength factor based on Multiple Regression Analysis was computed. Special emphasis on the deflection prediction was made as the ultimate load of shallow beam to a large extent, was controlled by deflection.

4.6 Precast Structural Concrete Design and Construction

(1) DESIGN PROCEDURES FOR LONG SPAN PRESTRESSED CONCRETE BRIDGES OF SEGMENTAL CONSTRUCTION
Texas, Austin, University of (J. Breen, G. Lacey, T. Komura and R. Brown); Texas Highway Department, U. S. Bureau of Public Roads

This project has as its objective the development of a new construction system for long span highway bridges using precast segments. It will consist of a determination of the present state of the art in this area, the adaptation of cellular analysis procedures to segmental construction, the development and verification of design criteria, and a study of the economic feasibility of the procedures developed. Preliminary studies indicate spans in the 150 to 300 foot range are feasible.

4.7 Prestressed Concrete

(1) EFFECT OF CRACK SPACING ON ULTIMATE STRENGTH OF PRESTRESSED CONCRETE I-BEAMS
Indian Institute of Technology, Kanpur (P. Dayaratnam and P. N. Parghi); Council of Scientific and Industrial Research, India

A series of beams, each beam made of several precast beam blocks are constructed. Width of each block, amount of prestressing force and effective eccentricity are taken as parameters in the testing program. Artificial cracks are automatically developed at the ultimate strength of prestressed concrete beams.

(2) INVESTIGATION OF STRESS DISTRIBUTION IN THE ANCHORAGE ZONE OF POST-TENSIONED PRESTRESSED CONCRETE BEAMS
Indian Institute of Technology, New Delhi (Rasheeduzzafar and M. Raghupati); same

Objectives are: (1) a study of the qualitative and quantative distribution of stresses in the anchorage zone, location of critical planes, suggestions of reinforcement scheme and design, study of failure characteristics under combined stresses, and (2) theoretical investigation of the possible stress distribution between aggregate and paste, possibilities of thrust rings, modes of failure under direct and complex loadings.

(3) ANCHOR ZONE STRESSES IN POST-TENSIONED AND PRE-TENSIONED SYSTEM S
Jadavpur University, Calcutta (P. Som, K. Ghosh, and B. Sengupta); same

Theoretical and experimental studies of the anchor zone stresses are made. Two and three dimensional stress analysis of anchor zone stresses in post-tensioned system are studied and experimental verification of theoretical results are made. In the pre-tensioned system, beams of various sections are tested with different design parameters to check the development of bond and bursting stress within the anchor zone.

(4) YIELD LINE THEORY FOR TWO-WAY PRESTRESSED CONCRETE SLABS
P.S.G. College of Technology, Coimbatore (V. Ramakrishnan and T. S. Ramakrishnan); same

Methods of analysis and design for reinforced concrete slabs based on Johansen's yield line theory are now well established. But, a similar study for prestressed concrete slabs does not appear to have caught the attention of research workers. Work is in progress to study analytically and experimentally the behavior of two-way concrete slabs with post-tensioned steel under point loads both in the elastic and plastic stages. The yield lines will be observed and analysed with a view to arrive at a possible yield criterion for their failure. It is also proposed to rationalize an ultimate load analysis for economical design of prestressed slabs. Slabs with different breadth to length ratios and with different end conditions are proposed to be studied. The results will be compared with those of plain reinforced concrete slabs.

(5) USE OF PRECAST-PRESTRESSED CONCRETE FOR BRIDGE DECKS
Purdue University (C. F. Scholer, M. J. Gutzwiller and R. Lee); Indiana State Highway Commission and Bureau of Public Roads

The overall purpose of the proposed research is to develop and field test a precast bridge deck. In order to accomplish this objective, several stages of research will be required. A preliminary study developing the technical and economic feasibility of the precast deck was required. During the preliminary phase, alternate designs of the deck sections, connections and prestressing systems were evaluated. While concrete is the primary material under consideration, application of other materials will be investigated. Further development of the most promising preliminary designs is in progress, using instrumented test specimens subjected to simulated traffic loads. Monitoring of deck response, continuity and smoothness will permit selection of the most feasible design. Fabrication methods and connection details will be developed in agreement with the test program. Following the laboratory development, the construction and field testing of a full scale bridge using a precast deck will be accomplished. The intent is to use a bridge planned for construction in the local area for this phase of the work. A report on the feasibility study has been completed and the laboratory study phase of the research is continuing.

(6) PRESTRESSED CELLULAR CONCRETE STRUCTURES
U.S. Naval Civil Engineering Laboratory (P. J. Rush and F. E. Brink); U. S. Navy

The objective is to investigate precast concrete blocks assembled into structural shapes. This includes but not limited to sizes, shapes, dimensions, and properties of elemental blocks, appropriate prestressing systems, shear connections, adhesives for concrete, and mechanical connections for continuity. The approach is to conduct a literature study, beam tests in first year, and analytical (theoretical) studies, develop hardware and techniques, and report results. Progress will be dependent on available technical mass power and requisite hardware, materials, and equipment. A series of beam tests (each assembled from ten cellular blacks) were performed with variables being; concrete formulations, individual block reinforcement, joint fillers, prestress force, and prestress methods. In every beam test, failure was initiated by cracking in the web sections of certain blocks other than those directly under the loading plate or over the end support. In all cases, failure occurred as center beam deflection reached or slightly exceeded 0.60 inches which for the 54 inch span, gave a deflection span ratio of 1 to 900.

4.8 Reinforced Concrete Columns

(1) ULTIMATE STRENGTH OF RECTANGULAR REINFORCED CONCRETE COLUMNS
Kyoto University (K. Okada); none listed

Only limited information is available regarding the ultimate strength of rectangular reinforced concrete columns subjected to a biaxially eccentric load that may be caused due to earthquake forces in the structure. Experimental tests are made using two types of model specimens, one has 18 cm square section and the other, 12 cm X 18 cm rectangular section. The effects of arrangement of reinforcement on the location of neutral axis and on the ultimate strength of column are to be investigated both theoretically and experimentally.

REINFORCED CONCRETE COLUMNS

(2) BEHAVIOR AND ULTIMATE STRENGTH OF REINFORCED CONCRETE HOLLOW COLUMNS

P.S.G. College of Technology (V. Ramakrishnan and S. Alexander); University Grants Commission and P.S.G. College of Technology

The behavior and ultimate strength of reinforced concrete hollow columns under axial load and uni-axially eccentric loads have been investigated with the following variables: 1) percentage area of hollow portion, 2) strength of concrete 3) percentage of reinforcement, 4) length of column, and 5) eccentricity of loading. The general behavior of hollow columns was observed to be similar to that of solid columns. Ultimate strength of reinforced concrete axially loaded hollow columns may very well be predicted by the solid column formula duly accounting for the hollow area. Ultimate strength of eccentrically loaded hollow columns failing by tension mode can be estimated by Hognestad's method. But, the same method under-estimates the load carrying capacity of eccentrically loaded hollow columns failing by compression mode. The reason for such disparity are being investigated.

(3) ULTIMATE STRENGTH OF REINFORCED CONCRETE COLUMNS SUBJECT TO ECCENTRIC LOADING

P.S.G. College of Technology (V. Ramakrishnan and S. Alexander); University Grants Commission and P.S.G. College of Technology

The project consists of analytical and experimental investigations on eccentrically loaded columns, the object being to arrive at rigorous methods of analysis for the behavior and strength of such columns. As a basis for the formulation of such rigorous methods, the stress-strain curve of concrete has been expressed in terms of a continuous function containing sufficient parameters which can be adjusted for variations in the quality of concrete. Based on this, rigorous analysis has been developed for sections under bending and extended to include the effect of axial thrust. The analysis has been computerized. Besides, systems of curves have been provided which facilitate easy solution of complicated results of analysis. Experiments have been conducted on columns loaded with eccentricities ranging from 0 to 1 1/2 the diameter to verify the validity of the analysis.

(4) MICROCRACKING AS A FACTOR IN ULTIMATE STRENGTH OF LONG REINFORCED CONCRETE COLUMNS

Texas, Austin, The University of (P. M. Ferguson, J. E. Breen, and S. R. Guntur); National Science Foundation

Test investigations of cantilever columns are proposed as an extension to work which has been under way for seven years. Computer analyses, verified by tests, have been developed for various frames without sidesway. Similar analyses for columns as parts of frames under lateral loading seem, consistently and significantly (more than 20%), overestimate the strengths obtained under small eccentricities. It appears that microcracking occurring quickly at high concrete stresses is particularly significant here, adds important curvature and deflection, and leads to early instability or failure. At present, creep data

largely stops at 65 percent of f'_c, approximately where such microcracking becomes important. This investigation proposes to evaluate the effect of this microcracking in terms of the curvature and stiffness of model-size cantilever columns (4" by 6") under small eccentricities of loading. This data will be incorporated into existing computer analyses of frames, and sample frames will be tested to verify such analyses.

4.9 Reinforced Masonry Design and Practice

(1) MASONRY RESEARCH
National Bureau of Standards (L.E. Cattaneo); U.S. Department of Commerce

The objectives are to purchase expendable supplies and equipment and to provide for technical support in carrying out research on the structural properties of masonry and the establishment of satisfactory design and performance criteria for structural clay masonry. Studies will be initiated in an effort to develop non-destructive test methods for the determination of the physical properties of clay masonry. Procedures will be developed for the measurement of the differential movement between various elements of individual structural systems incorporating clay masonry. Theoretical and laboratory investigations will be initiated into the distribution and compressive strain in masonry bonded hollow walls systems.

4.10 Shear and Diagonal Tension

(1) SHEAR IN REINFORCED CONCRETE MEMBERS
Assam Engineering College (N. K. Chaudhury); Govt. of India

The object of this research project is to study the behavior of reinforced concrete members in shear under ultimate load conditions and to obtain additional information to supplement the existing knowledge on this problem so that a rational method for design can be evolved.

(2) ULTIMATE LOAD BEARING CAPACITY OF REINFORCED CONCRETE DEEP BEAM WITH WALL TYPE REINFORCEMENT
Birla Institute of Technology and Science (G.V. Joshi, T. K. Rao and S.C. Agarwal); same

It is proposed to analyse deep beams by a photoelastic method for a single span under two point loading and simply supported at the base with different depth to span ratio. It is further proposed to investigate the effect of wall type reinforcement on the load bearing capacity.

(3) DIAGONAL TENSION FAILURE OF T-BEAMS
Birla Institute of Technology and Science (T.K. Rao and S. Jerath); same

Generally the strength of a T-Beam in diagonal tension is taken that of a rectangular beam whose width is equal to the rib width of T-Beam and depth is the same as that of the T-Beam. Thus the resistance of the flange is ignored in resisting diagonal tension. But it

has been observed that the flange of the T-beam also adds to the strength of a T-beam. It is intended to find the effect of the flange of a T-beam to its shear capacity for different types of shear failures. Thirty six beams were cast to study the effect of flange width, web reinforcement and flange reinforcement for three different shear span-depth ratios of 1.5, 2.5 and 3.5. The effective span of beams was four feet, and concrete of an average compressive cube strength of 3000 psi was used.

(4) SHEAR IN FLAT-PLATE CONSTRUCTION UNDER UNIFORM LOADING
Commonwealth Experimental Building Station (H. Tasker and M. Sekhon); Cement and Concrete Association of Australia, and A.R.C. Industries Limited.

From a series of half-scale tests on connections between a flat-plate floor, with negative reinforcement in the column strip stressed at working load to either 24,000 psi or 30,000 psi and a steel column, it is concluded that: (1) the calculated values of the factor of safety for all specimens are in excess of two (CA2-1963), (2) the calculated values of the factor of safety for all but two specimens are in excess of two (ACI-318-63), and (3) the ultimate strength analyses in ACI-318-63 (ϕ = 1) and Equation 6 of CEBS Special Report No. 23 predict the failure loads of the specimens with an acceptable and comparable accuracy. ACI 318-63 (ϕ = 0.85) is over-conservative. Significant increases in deflection, creep, and widths and number of cracks at working load result from increases in flexural stresses in reinforcement at working load. Shear cages are effective in reducing deflection and creep. While the average values of included angles formed by the planes of failure exceed 90° for all specimens, there is a significant reduction in the included angle where the flexural stresses in the negative reinforcement exceed 22,000 psi at working load. Shear cages are not as effective as column brackets in the transfer of shear stresses, and in one case the shear cage of the experimental 0.6% type was not as effective as the shear cage of the 0.8% type specified in CA2-1968. The shear characteristics in the vicinity of eccentrically loaded columns is studied in stage 2 of the project.

(5) EFFECT OF WEB REINFORCEMENT ON THE SHEAR STRENGTH OF REINFORCED CONCRETE BEAMS
Jalpaiguri Government Engineering College, (N. C. Sinha); Govt. of India

The problem of shear in reinforced concrete is being investigated. Many investigations have been carried out for determining the effect of parameters like: (a) quality of concrete, (b) percentage of steel, (c) bond between the reinforcement and concrete, (d) curtailment of flexural reinforcement, (e) cross section and shape, (f) type of loading, and (g) shear span ratio. In the course of the investigations it has been observed that particular sections are critical from the point of view of shear. Positions of such critical sections have been reported to depend on the span, a/d or M/Vd. No appreciable work has been done on the effect of the web reinforcement placed around such critical sections. The purpose of the project is to investigate the effect of web reinforcement placed around critical sections on the shear strength of beams

(6) DEEP BEAMS
P.S.G. College of Technology (V. Ramakrishnan and Y. Ananthanarayana): same

Beams whose depths are comparable to their spans have shown an elastic behavior different from the more common flexural members. This difference in behavior is mainly attributed to the significant effects of vertical normal stresses and shear deformations in these members. Such members are often designated as deep beams. As reinforced concrete structural members are increasingly designed on the basis of their ultimate strength, there is a need to know the behavior and ultimate strength (both flexural and shear) of deep beams as well. To fill the above gap, a series of research projects on deep beam is in progress. So far about 30 single-span, simply supported, reinforced concrete, deep beams having different depth to span ratios, different amount of reinforcement and subjected to different types of loading (central concentrated load, eccentric load, two point load and uniformly distributed load) have been tested. Based on the observed behavior and strength, an equation is evolved for predicting the ultimate shear strength of deep beams. Headway has been made in the ultimate flexural strength of deep beams as well.

(7) THE EFFECT OF SHEAR REINFORCEMENT AND TENSION BAR CUTOFF ON THE SHEAR STRENGTH OF CONCRETE BEAMS
Purdue University(J. G. Borchelt, M. Gutzwiller and R. Lee); Indiana State Highway Commission

This was an experimental study of the ultimate behavior of reinforced concrete beams which fail in shear. The objectives of this investigation were: (1) to repeat certain beam tests of earlier studies in order to clarify and supplement their investigation, (2) to determine the effect of concrete strength upon the behavior and failure mode of beams with different shear span to depth ratios, (3) to use all of the data available in order to draw conclusions. Nine beams from the earlier reports were retested in accordance with the original procedure. Ten additional beams were cast to complete the study of the concrete strength. All specimens had a 6" x 13" rectangular cross-section and were loaded to simulate a portion of a continous girder. The beams were designed to restrict failure to a shear type failure in the length between maximum negative moment and zero moment, commonly called the shear span. Failure occurred in two modes, shear compression and diagonal tension. It was found that the type of failure depended upon the position of the diagonal crack when it crossed the neutral axis. The location of the critical crack depended upon the shear span to depth ratio and the concrete strength. Detailed discussion of individual beam behavior and the failure patterns are presented along with the summary of test results.

(8) STUDIES OF THE BEHAVIOR OF REINFORCED CONCRETE T-BEAMS SUBJECTED TO REPEATED LOADS
Purdue University (R. Platoni, M. Gutzwiller and R. Lee); Indiana State Highway Commission

This investigation is a continuation of a study of restrained reinforced concrete members. The purpose of the investigation is to observe the behavior of T-beams subjected to repeated loadings. The major variable under investigation is the ratio of shear span to depth. Recent studies have indicated flexural failures under repeated loading, whereas similar members exhibited shear failures due to static loading. Fatigue of the reinforcing steel was more prevalent than progressive failure in shear. T-beams under study in the present investigation will add breadth to the previous work.

(9) STUDIES OF THE BEHAVIOR OF REINFORCED CONCRETE BEAMS SUBJECTED TO REPEATED LOADS
Purdue University (W. Rogers, M. Gutzwiller and R. Lee); Indiana State Highway Commission

Sixteen beams of 6" x 13" rectangular cross-section were subjected to repeated loading in such a manner as to simulate a portion of a continous girder subjected to concentrated loads. The beams were designed so that the critical region for failure with respect to shear was the length between the point of zero moment and the point of maximum negative moment , commonly called the shear span. The objective of this study was to observe the behavior of beams of different shear span-to-depth ratio with varying amounts of web reinforcement. The magnitude of the repeated load was taken as a percentage of the predicted ultimate load and was varied to determine the effect on the behavior of the specimens. The specimens, which were weak with respect to shear, failed in one of three modes: shear-compression, diagonal tension, or brittle fracture of the reinforcement. It was found that the fatigue life of the member increased when the magnitude of the repeated load was reduced. The presence of stirrups was observed to increase the endurance of a member when compared to the behavior of a similar specimen without web reinforcement. Detailed discussion of the failure patterns and individual beam behavior are presented along with the summary of test results.

(10) SHEAR STRENGTH OF REINFORCED CONCRETE T-BEAMS
Regional Engineering College, Durgapur (R.C. Ganguli and M. Banerjee); University of Burdwan, India

The tests on 20 T-Beams without web reinforcement were conducted. An equation for ultimate shear strength of Reinforced Concret T-Beams was evolved. Reflections on Code recommendations by (ACI-318-1963) and (IS-456-1964), show that while the former is mostly safe, the latter one at times yields unsafe designs.

4.11 Lateral Load Distribution

(1) LOAD DISTRIBUTION IN BRIDGE DECKS
Melbourne, University of (L. K. Stevens and G. D. Base); Australian Road Research Board

Studies of load distributions in beam and slab bridges have been completed. Various analytical methods have been checked against results obtained from model tests and from a test to destruction of a full scale 60 ft. span prestressed concrete beam and slab bridge.

Effectiveness of diaphragms and interaction of hand rails and curbing were studied over the whole range of behavior, and impact factors were obtained for a range of vehicle speeds.

(2) LATERAL STIFFNESS OF CONCRETE HOLLOW GIRDERS
Pant College of Technology (S. Ojha); same

The exact lateral distribution of deck loads in the various ribs of a concrete hollow griders is still a subject of much controversy. Research material and design coefficients are available for T-beam and slab construction but these cannot necessarily be applied to hollow girders. The object of the project is to make an analytical and experimental study of the problem and to devise design charts for for practical use.

4.12 Corrosion

(1) PRESTRESSED CONCRETE DURABILITY AND CORROSION AS AFFECTED BY SOLUBLE SALTS
Montana State University (M. Moss); Montana State Highway Commission and U. S. Bureau of Public Roads

Small prestressed and non-prestressed slabs having ponded salt solutions on one side were evaluated with respect to spalling, sulfate attack, freeze-thaw durability and strand corrosion. The corrosive effect of sulfate ions on exposed prestressing wires was investigated. A study was made of the extent of strant corrosion due to salt ions penetrating structural elements.

(2) CRACK WIDTH DUE TO CORROSION
Texas, University of (P. Ferguson); Texas Highway Department and Bureau of Public Roads

This past year studies have established the relationship between the crack width at a reinforcing bar and that at the surface of the concrete for varying amounts of cover and varying steel stresses. Now a number of beams and slabs have been made and will be kept under stress for a period of several years. Various covers and various theoretical stresses will be represented, as well as varying concrete strengths. The loaded beams will be sprayed daily with a salt water solution, dried under natural atmospheric conditions, and thus be exposed to a fairly severe corrosive situation. The specimens will be observed for two or more years to establish degree of corrosion which develops and to establish whether this corrosion develops more through the cracks or by penetration of the salt through the concrete itself.

4.13 Creep

(1) LONG-TERM STUDY OF CREEP DEFLECTION IN REINFORCED CONCRETE STRUCTURES
Commonwealth Experimental Building Station, Australia (J. Heiman); same

Metal plugs have been inserted in the top surface of a deck of a

flat-plate car park, where normal weight concrete was used and in some of the floors of a high-rise office building of beam-and-slab construction where lightweight concrete was used. Relative deflections at midspans are being measured with relation to the adjacent columns by means of a precise level. The measurements have been carried out for periods of four and three years respectively and the results obtained to date suggest that the values of the long term multipliers given in the Australian design code and used to predict total deflections may be low.

(2) CREEP CHARACTERISTICS OF CONCRETE
Kyoto University (K. Okada); none listed

Creep characteristics are tested both of normal aggregate and artificial light weight aggregate concretes under three moisture conditions (R.H. of 50%, 80% and 100%), and various sustained-stress levels. To investigate the effects of properties of aggregate and amount of coarse aggregate on the creep of concrete, creep tests of mortar are also made for reference. Creep under compression, tensile and flexural tension are compared in the lightweight aggregate concrete. The creep and creep-recovery under high stress level are to be studied further.

(3) AN INVESTIGATION OF THE TIME-DEPENDENT DEFORMATION OF CONCRETE UNDER TRIAXIAL-STRESS CONDITIONS
Texas, The University of (E. S. Perry, T. Kennedy and J. Thompson); Union Carbide Corporation

The purpose of this investigation is to obtain information on the creep behavior of concrete when loaded at room temperature and elevated temperatures under multiaxial loading conditions. The specimens consist of both 6 in x 12 in and 6 in x 16 in specimens. Vibrating wire gages embedded in the specimens are used to determine strain in the axial and radial directions. The information obtained in this study will be used in the design of prestressed concrete reactor vessels.

4.15 Concreting Materials

(1) EXPANSIVE CEMENT CONCRETE
California, Berkeley, University of (V. Bertero, D. Pirtz, and M. Polivka); National Science Foundation

The objective is to investigate physico-chemical characteristics of expansive cements and mechanical behavior of expansive cement concrete structural elements.

(2) EFFECT OF SPECIMEN SHAPE ON CONCRETE STRENGTH
Indian Institute of Technology, Kanpur (P. Dayaratnam and C. Kameswara Rao); none

Failure of a concrete specimen by distortion energy is developed based on some experimental assumptions. The results are compared with experimental results of various investigations.

(3) RESIN CONCRETE FOR STRUCTURAL USE
Kyoto University (K. Okada); same

Resin concrete means concrete in which resin such as epoxy or polyester is used as binder instead of cement in the ordinary concrete. To utilize resin concrete for structural components, the mechanical properties of epoxy and polyester resin concretes such as compressive and tensile strength, modulus of elasticity, creep and shrinkage characteristics are investigated. For polyester resin concrete a compressive strength of about 100 kg/cm^2, and a flexural strength of about 180 kg/cm^2 are obtained. Creep at 20°C seems to be very small compared with conventional concrete. Acceleration tests for waterproofness of resin concrete under boiling water are also made and effectiveness of reinforcement with steel or glass fiber in resin concrete beams are now being investigated.

(4) INVESTIGATION OF CONCRETE ADMIXTURE
Pennsylvania Department Highways, Materials Bureau (P. D. Stewart); same

A silicone-base, Portland cement concrete admixture was tested. The compound, when added in a proportionate amount to the cement, reportedly strengthened the hydrated matrix thus making the concrete more resistant to freeze-thaw action and deicing chemicals. The experiment batches consisted of a bridge deck concrete designed at standard slump and at a high-slump consistencies. Test specimens were made for compressive and flexural strengths and for freeze-thaw evaluation.

(5) AIR ENTRAINMENT IN CONCRETE
Texas A & M University (D. L. Ivey); Texas Highway Department and U. S. Bureau of Public Roads

The major factors which were investigated in this study were Mixing methods, Chemical retarders, Air entraining agents. Another primary area of research was the development of a field test for the adequacy of the entrained air system. The void spacing indicator (VSI) was developed in this study to fulfill this need.

4.16 Reinforcing Materials & Methods

(1) BENDS IN TENSION REINFORCEMENT
Commonwealth Experimental Building Station (M. S. Sekhon); same

In order to determine safe radii for the bends in bars of various sizes under different conditions and intensities of stress, the Commonwealth Experimental Building Station has been conducting an investigation into the effects of right-angle bends of small internal radius in fully stressed reinforcement in flexural members. The work completed to date has been devoted to the study of the case of negative bending (tension on the outer face of the specimen). The project has now been extended to the case of positive bending (bending on the inner or re-entrant angle of the members).

(2) SPLICES OF LARGE BARS IN REINFORCED CONCRETE
Texas at Austin, The University of (P. M. Ferguson, E. Briceno, and I. O. Erbug); Texas Highway Department and U. S. Bureau of Public Roads

Closely spaced splices of any bar size tend to split more readily than widely spaced splices. This is particularly true for large bars such as are used at the base of a retaining wall. Tests will check the available strength and the required lap for closely spaces splices of #11 bars. At present, splicing of #18S and #14S bars by laps is not permitted by the ACI Building Code. However, mechanical and various fusion splices are not always satisfactory. The project will establish how to splice these very large bars by lapping them and the degree to which the lap length may be reduced by using spirals around the bars or closely spaced ties.

(3) STRENGTH EFFECT OF CUTTING OFF TENSION BARS IN CONCRETE BEAMS
Texas at Austin, The University of (P. M. Ferguson, R. J. Tatikonda, S. I. Husain, and D. W. Lee); Texas Highway Department and U. S. Bureau of Public Roads

This second series of 22 beam tests was developed to correct weaknesses found in most of the 41 beams with bar cutoffs tested earlier. Nominal dimensions were 9 in x 18 in and 9 in x 24 in, and concrete strength varied from 2368 to 4480 psi. Longitudinal reinforcing bars met the specifications of ASTM A15 and A432. Various types of web reinforcement were used as follows: no web reinforcement, vertical stirrups, bent bars, and stirrups with bent bars. Because of variations in bar cutoff points, it is difficult to list types of web reinforcement in the proper order of shear strength. Extra vertical stirrups recaptured some of the shear strength lost by cutting off bars, but the amount required was larger than anticipated. In general, the substitution of bent bars for cutoff bars restored most of the strength and the use of both bent bars and stirrups tended to give beams greater strength than beams with full length straight bars.

(4) FLUCTUATING LOADS ON REINFORCED CONCRETE STRUCTURES
University College of South Wales and Monmouthsire (J. L. Bannister); none

The objective is to study a series of beams reinforced with steels of varying tensile strength and notch ductility. The reinforcement is continuous, welded, or lapped. The object is to study the limiting range of stress to sustain ten million repetitions, using realistic live to dead load ratios.

4.18 Torsion of Reinforced Concrete

(1) ULTIMATE TORSIONAL STRENGTH OF RECTANGULAR REINFORCED CONCRETE BEAMS
Birla Institute of Technology and Science (G. V. Joshi and G. V. Shankar); same

The principal object of the investigation is to determine the ultimate strength of plain and reinforced concrete sections and to give an approach for predicting the strength of the reinforced concrete section under pure torsion. Eighteen beams were cast with different percentage of longitudinal and transverse steel and tested under pure torsion. The results are yet to be analyzed.

(2) EFFECT OF COMBINED BENDING, TORSION, AND SHEAR IN REINFORCED CONCRETE

Jalpaiguri Government Engineering College (S. P. K. Gayen); University Grants Commission

At present there is no satisfactory method for design of a reinforced concrete member subject to combined bending, torsion, and shear. In fact, very little is known about the behavior of a reinforced concrete element subject to such combination of loadings. There are three distinctly different types of crack patterns and modes of failure under the three types of loadings while acting separately, but while acting simultaneously it is not easy to predict how a member will behave due to the interaction between bending, torsion, and shear. Previous investigations in this field are very limited. The scope of the present investigation is to study the interaction between bending, torsion, and shear, the effect of combined loadings on ultimate strength, crack pattern, and mode of failure.

(3) COMBINED BENDING AND TORSION IN REINFORCED CONCRETE STRUCTURAL ELEMENTS AND SPACE FRAMES

P. S. G. College of Technology (V. Ramakrishnan and B. Vijayarangan); Council of Scientific and Industrial Research, India

Experimental and analytical investigations have been carried on the behavior and strength in combined bending and torsion of reinforced concrete rectangular, "T", and Hollow beams with and without web reinforcements. Factors investigated were (1) influence of concrete properties, (2) percentage of tensile and compression reinforcement, (3) influence of web reinforcement (spiral, vertical, inclined), (4) torque-twist relationship, and (5) torsion to bending moment ratio. Interaction of bending and torsion has been studied in detail. Equations have been suggested for predicting ultimate strength. Analysis and experimental work are in progress with a view to suggest a unified theory.

(4) COMBINED TORSION, SHEAR, AND MOMENT IN T-BEAMS

Texas at Austin, The University of (P. M. Ferguson, U. Behera, and K. S. Rajagopalan); National Science Foundation

L-shaped and T-beams under torsion combined with flexure and shear are being investigated with emphasis on the influence and value of stirrups, the extra stress produced by torsion in longitudinal reinforcement, and the stiffness of such members. Cases where the ultimate capacity is limited by the longitudinal reinforcement are receiving special attention. Various percentages of longitudinal steel are being used.

4.19 Cracking

(1) CRACKING OF PORTLAND CEMENT CONCRETE PAVEMENTS
National Crushed Stone Association (I. V. Kalcheff, F. P. Nichols, Jr., and F. A. Renninger); same

Relatively new concrete pavements in several midwestern states are showing early signs of distress known as "D" cracking and believed due to a freeze-thaw phenomenon. "D" cracking normally occurs first at the intersection of the longitudinal and transverse joints or at any random cracks in the slab. As the deterioration progresses, crumbling and pull-out occurs in the cracked areas necessitating undue early maintenance. The causative factors seem to be questionable quality coarse aggregate subjected to adverse environmental conditions. None of the standard or normally used quality test procedures define or delineate those combinations apt to "D" crack in the field. The problem, therefore, resolves to one of developing adequate laboratory procedures and determining the mechanism of failure. No formal report as yet has been published.

(2) TENSION MEMBERS IN REINFORCED CONCRETE ROOF TRUSSES
P. S. G. College of Technology (V. Ramakrishnan and C. N. Balasubramanian); same

Analytical and experimental investigations are being carried out to study the behavior and ultimate strength of tension members in rigid joint and pin joint roof trusses. Effect of end conditions for optimum steel requirements, crack formation and propagation, width and distribution of cracks, and design criteria for strength assessment of reinforced concrete tension members are studied in detail.

4.20 Bond and Anchorage Reinforcement

(1) MECHANISM OF STIFFNESS DETERIORATION IN REINFORCED CONCRETE MEMBERS
California, Berkeley, The University of (V. Bertero and B. Bresler); same

The objective of this study is to investigate the mechanism of stiffness deterioration that has been observed in reinforced concrete structures when they are subjected to repeated reversal actions such as those induced by severe wind or extreme earthquake ground motions. The formulation of a realistic mechanism of stiffness deterioration is essential for understanding of the observed behavior and for future research in this field. The method of attack are analytical and experimental with emphasis in the formulation of a realistic mechanism of stiffness deterioration based on evaluation of experimental results that are already available with particular attention to bond deterioration and slippage of steel relative to concrete. Few tests will be carried out to obtain some basic properties of materials, especially concrete under reversal strains and then to check validity of the analytical prediction.

(2) DESIGN CRITERIA FOR OVERHANGING ENDS OF BENT CAPS
Texas at Austin, The University of (P. M. Ferguson, J. E. Breen, and D. Victor); Texas Highway Department, U. S. Bureau of Public Roads

This investigation was made to establish safe shear and bond stresses for highway bridge bent caps. Depth at column face was 36 in. for all specimens, while depth at outer end decreased to a minimum of 24 in. Widths varied from 8 in. to 31 in. for the 36 specimens tested. Concrete strengths varied from 2860 to 6170 psi. Reinforcing bars used compiled with ASTM designations. It was found that ultimate shear stress much higher than allowed by current specifications was feasible for loads placed between 0.5D and 1.2D from the support. Vertical stirrups added no perceptible strength, but horizontal web bond stress was effective. It was found that the nomial bond stress in the length between load and support was not important, but that an anchorage distance beyond the load was essential.

(3) SHEAR STRENGTH OF BENT CAPS BETWEEN COLUMNS
Texas at Austin, The University of (S. T. Chen, M. S. Cheng, J. James, and H. M. Liao); Texas Highway Department, U. S. Bureau of Public Roads

Permissible shear and bond design stresses for the interior portion of bend caps having shear spans between 0.5D and 1.2D from load to support were established. Nine full size two column bent caps were cast such that the two halves of each would provide 18 tests. Concrete strengths varied from 3050 to 4700 psi and reinforcing bars met the specifications of ASTM-A432. Various types of shear reinforcement were used as follows: vertical, horizontal, spiral, over tension bars, and web reinforcing. High shear stresses were found to be permissible, almost in line with those previously recommended for the cantilever ends of bent caps. Although bond stresses must be considered, higher allowable values are permissible than those in general use.

4.21 Others

(1) STRENGTH RELATIONSHIP OF CONCRETE UNDER DIFFERENT CURING CONDITIONS
P. S. G. College of Technology (V. Ramakrishnan and M. D. Chielo Kitchley); Council of Scientific and Industrial Research

An experimental program has been created in this field where there has been a dearth of data and lack of understanding on the development of strength in concrete with respect to time and temperature under different curing conditions. The concept of maturity as it exists now has been shown to be of very limited use. Equations for strength at any age have been suggested for each curing condition and temperature. An experimental investigation was conducted on the influence of different methods of curing, like water curing, steam curing, air oven curing, and pressure curing on the compressive

strength of concrete. Tests were conducted at different temperatures and different ages on about a thousand and four hundred cubes. Equations relating strength and maturity have been suggested for the particular quality of constitutents and size and shape of specimens chosen. Using these equations in conjunction with a correction curve, it is possible to predict the strength of concrete subjected to immersion or humid curing for any given maturity at any particular temperature between 80°F to 208°F. Effect of use of fly ash with various percentages in concrete when subjected to various curing conditions has been investigated.

(2) TENSILE STRENGTH OF CONCRETE
P. S. G. College of Technology (V. Ramakrishnan and S. K. C. Gopal); Council of Scientific and Industrial Research

A series of tests were conducted to standardise a test procedure to find out the tensile strength of concrete. A total of thirty-eight batches of specimens were cast to study the different aspects of the problems. A review of the work done by other research workers on the tensile tests for concrete, and a comparative study of the different methods of test were also undertaken. The factors influencing the test results such as size and shape of the specimen, packing materials, and rate of loading have been analyzed. In the light of the findings of this investigation, the cylinder split test has been suggested as the standard test for finding the tensile strength of concrete. The standard testing procedure for this test has also been suggested. In addition, the relationship of tensile strength with compressive strength and modulus of rupture has been discussed.

(3) CONSTRUCTION AND BEHAVIOR OF TWO-WAY REINFORCED CONCRETE CELLULAR FLOOR SLABS
University College of South Wales and Monmouthshire (D. M. Porter); same

The work to date concerns primarily construction problems for: (1) Determining range of concrete mixes with necessary flow characteristics, (2) Organization of placing a compaction process to ensure 100% complete soffit, and (3) Fixing and holding down requirements for void forms.

5. METALS

5.1 Composite Construction

(1) BEHAVIOR OF CONTINUOUS COMPOSITE BEAMS
Alberta, The University of (J. Longworth); National Research Council of Canada

The object of the project is to formulate design criteria for ultimate strength design of composite steel and concrete sections. Although considerable information is available concerning behavior in positive bending, not nearly as much attention has been paid to behavior in negative bending. Presently an intensive study is being conducted into behavior in an isolated negative moment region considered such problems as effective slab width, contribution of longitudinal and transverse steel, lateral and local buckling effects. Load tests are being conducted on full scale specimens. Once this phase has been completed, studies will begin on continuous spans.

(2) COMPOSITE BEAMS (STEEL AND CONCRETE)
P. S. G. College of Technology (V. Ramakrishnan and S. Rajasekaran); Council of Scientific and Industrial Research

This research program investigates the extension of steel concrete composite beams to buildings. Spiral and stud shear connectors are being studied varying the amount of shear connection, so that the optimum quantity of shear connection needed to develop the ultimate strength of the beam may be established. Slip, unlift, moment-curvature relationship and deflection under static loading are studied in greater detail.

5.2 Compression Members

(1) LATERAL BUCKLING OF ROLLED STEEL BEAMS
Birla Institute of Technology and Science (S. Kumar and U. K. Bhatia); same

To study the lateral buckling of rolled steel beams with ends restrained from rotation about the longitudinal axis, freely supported two point load system, in the elastic and the inelastic ranges.

(2) TORSIONAL-FLEXURAL BUCKLING
Cornell University (G. Winter); American Iron and Steel Institute

The objectives are to determine by theory and test the torsional-flexural buckling strength of concentrically loaded, singly-symmetrical open thin-walled compression members, and the complete behavior including failure either by instability or by yielding of similar members eccentrically loaded, and to formulate simplified equations for design use.

(3) BUCKLING OF SHELLS SUBJECT TO BENDING
Illinois at Urbana, The University of (R. E. Miller); same

An initially straight cylindrical shell, subject to bending, may collapse by local ovaling of the cross-section. Cylinders constructed of a low modulus material and having a relatively large thickness to radius ratio have this property. It is desired to determine the critical bending moment for such failure for various geometric properties of cylinders. Equations derived for thin shells are employed in the analysis and since large deflections are likely to occur, non-linear terms will be retained. The complexity of the non-linear shell equations suggests an inverse solution, and assumptions on the radial, tangential, and axial displacements are made. The equations resulting from this substitution are evaluated by computer to determine the critical bending moment.

(4) THERMAL DEFORMATION OF PARALLELOGRAM PLATES UNDER RADIANT HEATING
Osaka Prefecture, The University of (E. Matsumoto); Ministry of Education, Japan

The deformation of a parallelogram plate clamped along its edges and subjected to uniform radiant heating on one surface was studied experimentally and theoretically. The temperature rise, deflection, and strains on the surface of the plate were measured continuously during heating. The thermal buckling phenomenon was clearly observed. The fundamental differential equations for the thermal deformation of the parallelogram plate were solved by the finite difference method, using the measured temperature distribution and considering the effect of the deformation of the clamping frame. The critical temperature and the mode of thermal buckling were obtained.

(5) LOCAL BUCKLING OF THIN COMPRESSION PLATES SUBJECTED TO EDGE LOADS
Pant College of Technology, Pantnagar (U. P. Eihence); Uttar Pradesh Agricultural University

The investigation deals with a theoretical analysis for developing expressions for computing the buckling load for thin plates subjected to partial edge loads on one edge in the plastic region.

(6) ELASTIC AND INELASTIC STABILITY OF STRUCTURAL ELEMENTS
Western Australia, The University of (C. Massey); same

All aspects of the stability, both elastic and inelastic, of common structural elements are studied.

5.3.9 Flexural Members: Others

(1) PROPERTIES OF STEEL ANGLES
B. H. P. Melbourne Research Laboratories (M. G. Lay and J. Leigh); B. H. P. Company Limited

The aim of the project is to obtain data on the behavior of angles in bending and when laterally unsupported.

5.4 Light Gage Metals

(1) INFLUENCE OF DUCTILITY
Cornell University (S. J. Errera and G. Winter); American Iron and Steel Institute

The objectives are to determine the role of both general and local ductility in the performance of thin-walled steel members under substantially static loading, to review critically presently specified ductility requirements, and to determine quantitatively the minimum ductilities needed for satisfactory performance and the methods by which to determine such ductilities for sheet, strip, and thin plate steels.

(2) EFFECTS OF COLD FORMING ON STRUCTURAL BEHAVIOR
Cornell University (G. Winter); American Iron and Steel Institute

The objectives are to study the mechanism of strain hardening in steel, to determine the strength increase obtained in cold-forming of structural shapes and components, and to develop methods for taking advantage of such strengthening in design.

(3) STAINLESS STEEL DESIGN
Cornell University (G. Winter); American Iron and Steel Institute

The objectives are to determine the structural behavior of members formed from austenitic stainless steels, either annealed or tempered, as influenced by the inelastic and strongly anisotropic characteristics of these stainless steels, and to formulate design methods for members formed of such material.

5.7 Plastic Design

(1) OPTIMAL PLASTIC DESIGN OF UNBRACED MULTI-STORY FRAMEWORKS
CSIRO Division of Building Research (A. R. Toakley); same

This project is concerned with the optimal design of two-dimensional multi-story sway frameworks, based on a consideration of elastic-plastic behavior. Considerable progress has already been made, in that a design method has been found which takes into consideration the effect of overall frame instability and the effect of axial load on the fully plastic moments. It is intended to extend the method to cope with restrictions on working load deflections, column instability, and dynamic behavior. An investigation is also being made into suitable means of handling the necessarily large linear programming problem involved.

(2) INELASTIC BEHAVIOR OF MULTI-STORY STEEL FRAMES
Illinois at Urbana, The University of (E. H. Gaylord and E. W. Wright); same

A procedure for preliminary design and a mathematical model which permits a detailed analysis of the inelastic behavior of steel frames not braced against sidesway have been developed. Remarkable agreement between theory and test values was found for three frames tested at another university.

5.8.4 Structural Connections: Bonded Joints

(1) CRACK PROPAGATION IN ADHESIVE JOINTS
University College of South Wales and Monmouthshire (B. H. Williams); University Grants Committee

The objectives are to determine the fracture toughness of structural adhesives and to examine the parameters, such as temperature, shape of the structural joint, and nature of the adhesive, upon which the fracture toughness depends.

5.11 Special Structures

(1) ANALYSIS OF AN ANCHORED SHEET PILE WALL OF VARYING SECTION MODULUS
Fuji Iron and Steel Company, Limited (K. Ishiguro); same

In deep water anchored sheet pile construction, steel sheet pilings of composite section which have double the section moduli as that of as-rolled sections have been utilized to withstand the earth pressure moment. The sheet pilings have varying section moduli, the wall portion above dredge level being composite section, while the embedded portion being ordinary section. Theoretical studies on the basis of beam theory on elastic foundations were made to analyze the effects of varying section on the magnitude of maximum bending moment at the wall portion and embedded portions. It is noted that the maximum bending moment at wall portion is not very much affected by stiffness of embedded portion of sheet piles, whereas the maximum bending moments at the embedded portion are considerably affected by the stiffness. Loading tests on a beam model were conducted to check the stress distribution in vicinity of varying point of the sheet pilings section. Also measurements of wall deflection by means of inclinometre at stages of backfill procedure are included in the scheme.

5.12 Fracture

(1) ENGINEERING ASPECTS OF PIPELINES
B. H. P. Melbourne Research Laboratories (M. G. Lay and J. Collam); B. H. P. Company Limited

The aim of the project is to study the effects of cold deformation of steel on pipeline behavior and the relevance of the various

approaches currently in use for crack initiation predictions in pipelines.

(2) CRACK PROPAGATION
University College of South Wales and Monmouthshire (D. G. Ashwell); none

The objective is to develop experimental methods for determination of the fracture toughness of various materials.

5.14 Corrosion

(1) DETERIORATION OF MATERIALS IN TROPICAL ENVIRONMENTS
Office of Naval Research (A. L. Alexander); U. S. Navy

The objectives are to measure corrosion, determine corrosion rates of metals and alloys exposed to seawater and inland tropical environments, and determine the natural resistance of tropical woods to marine borers, fungi, and termites. Experimental work has already begun, and exposures of most metal specimens have been completed. Samples of 52 most commonly used structural metals and alloys have been carefully prepared, weighed, and measured and placed on long-term exposure to three marine and two atmospheric environments in Panama. At intervals of 1, 2, 4, 8, and 16 years, duplicate samples have been removed and corrosion effects determined by measurement of weight loss, pit depths, and reduction in tensile strength. Corrosion losses are being converted to commonly used units and compared with corrosion of similar metals in more temperate latitudes. Specimens of 167 tropical wood species have been collected, botanically identified, and placed in three tropical degrading environments in the Panama Canal Zone.

6. NUCLEAR STRUCTURES AND MATERIALS

6.2 Containment Vessels

(1) CONCRETE NUCLEAR REACTOR VESSELS
California, Berkeley, The University of (V. Bertero and M. Polivka); Union Carbide

The project purports to determine experimentally a stress-strain law and strength criteria which would account for time and temperature effects useful for stress analysis of prestressed concrete reactor vessels. The initial phase of the investigation will be concerned with influence of elevated temperature and temperature cycling on strength and deformation of concrete under short-time loading.

7.2 Design Criteria for Plastic Structural Components

(1) FIBER RESIN CONSTRUCTION
University College of South Wales and Monmouthshire (J. O. Doley); Ministry of Technology (United Kingdom)

The project undertakes an investigation, both theoretical and experimental, into the stress concentrations around cut-outs in structural items manufactured from fibers/resin composites (e.g. holes for branch pipes in the walls of filament wound pressure vessels) and into methods of reinforcement to reduce these stress concentrations.

7.4 Structural Applications

(1) STRUCTURAL PLASTICS
U. S. Naval Civil Engineering Laboratory (R. A. Breckenridg); U. S. Navy Bureau of Yards and Docks

The objective is to determine to what extent plastics are being used as structural materials and propose further studies regarding their applicability. A literature survey has been conducted of existing knowledge regarding the use of various plastics. As structural materials, the properties and design of reinforced plastics have been studied and a technical note is completed.

8. WOOD

8.1 Composite Construction

(1) DESIGN OF IMPROVED WOOD FLOORS
Forest Products Laboratory (D. M. Onysko); same

The composite action of subflooring, finish flooring, and ceilings with the supporting floor joists is not accounted for in present design practice. A composite design approach with existing design criteria may lead to unacceptable limber floors. Currently acceptable deflection and vibration characteristics of floors in homes need to be ascertained to serve as guidelines in composite floor design.

8.2 Laminated Elements

(1) EVALUATION OF DESIGN TECHNIQUES FOR GLULAM BEAMS
Forest Products Laboratory (E. N. Aplin); same

The strength of glued-laminated structural timber beams is being studied. Working stresses assigned to glulam beams by the Candian Standards Association Code of Recommended Practice for Engineering Design in Timber are based in part on the so-called I_k/I_g concept which related the presence of knots in laminations to reduction of beam strength. The ratio I_k/I_g was found in tests performed at the Ottawa Laboratory on 56 commercially manufactured laminated beams to be rather inaccurate in predicting beam strength. The goal of this research is to determine how to increase the "useful beam strength" as expressed by the lower exclusion limit for strength. This may be achieved either by increasing the mean strength or by reducing the variability of strength, or both. It is expected that improving the means of selecting high strength lumber for use in the most highly stressed laminations will be the major step in achieving the goal.

(2) WOOD FACTORS AFFECTING THE ADHESION PROCESS
Michigan at Ann Habor, The University of, School of Natural Resources (A. A. Marra); U. S. Department of Agriculture

The objectives to study relationships of wood factors are: (1) extractives and anatomical elements influencing adhesion, (2) tree growth and wood processing conditions, and (3) adhesion qualities and "gluability" criteria. Initial research will develop techniques of analysis of lipids (fatty acids) and phenolics (lower molecular weight) in extractives of wood of: a) sugar maple, a high-fat content standard substrate for evaluating adhesives, and b) red oak, a high phenolic content potential furniture wood of variable gluability. Treatments will include varied temperature, duration, air-water media, and pH of water.

(3) THE USE OF WEST AUSTRALIAN HARDWOODS FOR GLULAM BEAMS AND NON-DESTRUCTIVE TESTS FOR EVALUATION OF BOND
Western Australia, The University of (B. G. Smith); none

Glue bond failures have occurred in structures fabricated from local hardwoods (eucalypts). An investigation has been carried out into the gluability of important species considering the effects of moisture content, surface condition, assembly time, and direction of sawing of laminae. Non-destrictuve evaluation of glue bond quality has been explored, in particular vibration methods. A testing procedure including both flexural and torsional tests is suggested. The former were tested uniformly across the section but non-uniformly along the member; the latter produces a glue-line stress varying across the section but with all sections along the member similarly stressed. Indications are that deficient glue bond quality will be revealed by the discrepancy between the measured moduli of the beam and that computed from the moduli of component laminae.

8.3 Flexural Members

(1) EVALUATION OF MECHANICAL LUMBER GRADING
Forest Products Laboratory (K. E. Leach); same

Analysis of the results of static bending tests carried out on 312 white spruce 2 in. x 6 in. joists has shown the Stress-O-Matic mechanical grading machine to be overly conservative in assigning E and f values to the lumber. A check will be made on proposed modifications to the Stress-O-Matic to see if increased selection efficiency is realized.

(2) LOAD SHARING IN FLEXURAL MEMBERS
Forest Products Laboratory (T. L. Scott and A. P. Jessome); same

In framing systems, recognition is given in design to the fact that loads are shared by adjacent members when the lumber members are repetitive such as in a floor system or in a vertically laminated member. This recognition is in the form of an increase in allowable stresses because it has been realized that it is virtually impossible for lumber members of minimum strength to occur side by side in a load-sharing system. Since the increase in allowable stresses was based primarily on intuitive judgment, there exists a need to substantiate this view in the form of an analysis of existing data from structural-sized members and some comprehensive laboratory testing.

8.4 Plywood Panels

(1) NAIL-GLUING OF STRUCTURAL PLYWOOD MEMBERS
Forest Products Laboratory (S. B. Bellosillo and P. Gaudert); same

Current code requirements accept glued plywood structural assemblies on a performance basis regardless of the manner of their fabrication. There is, however, a pervading prejudice against the acceptability of nail-gluing as a fabrication technique while there is a greater tolerant permissiveness for clamp-glued assemblies. But the present criteria for acceptance of these composite constructions is absent

or vague in many codes. The current block-shear test for determining shear strength of secondary gluelines between plywood and lumber has been found inadequate. By construction, the plywood lap does not present a similar surface for compression loading as solid wood and makes all references to the behavior of solid block-shear specimens erroneous. A search for an adequate shear test, therefore, has taken precedence to any other work contemplated under search of a practical shear test for field evaluation of the structural adequacy of plywood structural assemblies.

8.7 Fire Retardant Treatment

(1) DYNAMIC PROPERTIES OF FIRE RESISTANT WOOD STRUCTURES
U. S. Naval Civil Engineering Laboratory (F. E. Brink); Government Laboratory, Bureau of Yards and Docks

The objective is to determine the effect of pressure impregnation with fire-retardent chemicals on laminated structural timbers and plywood subjected to dynamic loading. The end product will be to provide information necessary for formulation of design criteria applicable to fire-resistant wood structures. Static beam tests were conducted to determine the load-deformation behavior of laminated douglas fir timbers. Both treated and untreated beams will be tested to serve as guidelines for the dynamic tests. Dynamic tests in the NCEL blast simulator will be conducted on approximately 10 beams of structural size. One-half of the number tested will be untreated and will serve as control for evaluating the effects of the fire-retardent treatment. Static and dynamic tests will be conducted on treated and untreated plywood sheets in the NCEL slab loader. Approximately 12 sheets of laminated doublas fir plywood will be loaded to rupture for this phase.

8.8. Connections

(1) IMPROVEMENT OF WOODEN SLEEPERS
Railway Technical Research Institute of Japanese National Railway (K. Shimizu); same

The following items are under investigation: (1) conditioning and impregnating method of green sleepers, (2) resin-impregnated sleepers, (3) spike-holding pluges and chemicals contained pads, (4) new preservatives for bridge sleepers, and (5) performance of foreign grown timbers for sleepers.

8.9 Others

(1) PROTECTION OF WOOD FROM DECAY
Forest and Wood Products Disease Laboratory (R. C. De Groot); U. S. Forest Service

The project aims to (1) study the fungus deterioration of wood from the time of harvesting, through manufacturing processes, storage,

and ultimate use and (2) determine fungi responsible, conditions favoring development, control measures through modifications of handling methods, structural designs, and use of water repellents and preservatives. Research will be continued on decay of exterior woodwork of buildings associated with rain seepage; and work initiated to determine fungi responsible for deterioration of various products under various conditions, including the role of soft rotters. Study will be made of spore dissemination and germination, infection of wood in place, and the relative importance of incipient infections occurring before wood is put in use. Research on log protection will include practical control experiments.

9. RESPONSE OF FULL SCALE STRUCTURES

9.1 In-Service Performance

(1) STRAIN, WIND PRESSURE, AND ACCELERATION MEASUREMENTS IN A FOURTY-STORY BUILDING
B. H. P. Melbourne Research Laboratories (M. G. Lay and P. Foden); B. H. P. Company Limited

The project aims to measure the response of a large multi-story steel building to live, dead, and wind loads by means of instrumentation inserted in the building during construction.

9.2 Controlled Load and Destruction Tests

(1) FIRE RESISTANCE OF STEEL STRUCTURES
B. H. P. Melbourne Research Laboratories (M. G. Lay and D. Knight); B. H. P. Company Limited

The aim of the project is to examine the behavior of actual steel structures (both protected and unprotected) in fire conditions utilizing both experimental studies and extrapolations of small scale tests.

(2) FIELD GEOMETRY OF DEFORMED STRUCTURES
Tasmania, The University of (M. S. Gregory); Australian Research Grants Commission

The objective is to use Moire fringe methods to obtain slopes of deformed flat plates, deformed cylinders, and sheets of material strained in their plane over large fields. Detailed information of the deformed shape is found. This data is useful for investigations of the behavior of plates, including buckled webs, and cylindrical shells. This data can be useful for development of analytical models and for direct design from models.

11. STRUCTURES IN OTHER ENVIRONMENTS

11.1 Outer Space

(1) SPACECRAFT DESIGN SYNTHESIS
Bell Aerosystems Company (R. A. Gellatly); National Aeronautics and Space Administration

The general objectives include study of the problems involved in the development of a large scale synthesis program for use as a basic tool in the optimal design of spacecraft, and to determine the economic feasibility of such a development. The study will cover extension of existing optimization techniques to include cost and reliability as merit criteria.

11.2 Underwater

(1) STRESS CONCENTRATION IN THICK WALLED EXTERNAL VESSELS
U. S. Naval Civil Engineering Laboratory (W. A. Kennan); Government Laboratory, Bureau of Yards and Docks

The objective is to make preliminary investigations of stress concentrations in thick-walled external pressure vellels with T/D ratios less than or equal to 1/10 suitable for use as undersea structures. A mathematical analysis of the problem will be conducted to establish and describe the critical parameters. Photoelastic techniques will probably be used to study selected structural configurations under simple types of loading. Models of selected deep-ocean vessels or sections of the vessels will be fabricated for photoelastic studies. The results of the studies will be used to develop methods for minimizing the deleterious effects of stress concentrations in undersea vessels.

12. OTHERS

(1) THE THEORETICAL BASES AND POSSIBLE EXTENSIONS OF DESIGN CODES FOR STEEL STRUCTURES

B. H. P. Melbourne Research Laboratories (M. G. Lay); B. H. P. Company Limited

The project aims to ensure continual re-examination and improvement of the bases for design rules and to ensure that these rules are maintained in as up-to-date form as possible.

(2) THE EFFECT OF COARSE AGGREGATE PARTICLE SHAPE AND TEXTURE

National Crushed Stone Association (I. V. Kalcheff and F. P. Nichols, Jr.); same

Bituminous concrete base courses employ coarse aggregate up to and including particles of 1 1/2 inch size. No methods of test are presently available by which to measure the structural adequacy or proper design parameters of such mixtures. It is the object of this program to (1) develop such a procedure and (2) document the effect of aggregate shape and surface texture on the structural quality of the resulting mixture. A triaxial testing program has been established and the effect on aggregate charactrristics are being documented.

(3) HIGHWAY PAVEMENT SKID RESISTANCE

National Crushed Stone Association (I. V. Kalcheff, F. P. Nichols, Jr., and F. A. Renninger); same

With the current intensive interest related to highway safety, pavement skid resistance has become an item of critical concern to the highway design and maintenance engineers. Several methods are available to measure the level of skid resistance in the field and recommendations as to adequate levels have been issued. A complete understanding, however, as to those characteristics of highway materials which influence skid resistance levels has not as yet been developed. The skid resistance potential of a proposed pavement mixture would be a desirable property to measure as would the polish susceptibility of the proposed aggregate material. Aggregate polish susceptibility and bituminous mix design are being investigated with the effect toward the development of adequate skid levels the paramount consideration. A 14-foot diameter laboratory test track is being used to subject test pavements to actual rubber tire wear.

(4) THERMAL STRESSES IN INGOT MOLDS

Osaka Prefecture, The University of (S. Sumi); Nissin Steelworks Company, Limited

Although ingot molds of complex shape are usually found in steelworks, there is at present little detailed information to assist the designer to produce molds which will resist cracking due to

the thermal stresses. This investigation determines the temperature changes and the thermal stresses experienced by slab molds. Electrical analog studies of steady and transient temperature distributions are described, and some of the results obtained by an analog simulator are compared with the measured values. A mechanical analog procedure is conducted in the thermal stresses problems. The results obtained show that the maximum stresses occur at the centerline of the minor side in both cases of steady and transient states. Furthermore, the transient tensile stress set-up at the outer face reaches its peak within a few minutes. These results explain why occasional cracking occurs.

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