FRITZ ENGINEERING LABORATORY

LEHIGH UNIVERSITY

BETHLEHEM, PENNSYLVANIA
Predominant in the new Fritz Engineering Laboratory is the world's largest universal testing machine, capable of applying both tensional and compressional loads up to 5,000,000 pounds. Designed and built by the Baldwin - Lima - Hamilton Corporation, it extends 60 ft. above the test floor and 16 ft. below.
CURRENT RESEARCH PROJECTS

Fritz Engineering Laboratory
Department of Civil Engineering
Lehigh University
Bethlehem, Pa.

October 1961
<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title</th>
<th>Research Personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>205</td>
<td>WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS (PLASTIC DESIGN)</td>
<td>L. S. Beedle T. V. Galambos G. C. Driscoll</td>
</tr>
<tr>
<td>205A</td>
<td>COLUMNS IN CONTINUOUS FRAMES</td>
<td>T. V. Galambos J. Prasad M. Lay</td>
</tr>
<tr>
<td>205C</td>
<td>CORNER CONNECTIONS</td>
<td>G. C. Driscoll</td>
</tr>
<tr>
<td>205E</td>
<td>INELASTIC INSTABILITY</td>
<td>T. V. Galambos</td>
</tr>
<tr>
<td>205H</td>
<td>LATERAL BRACING REQUIREMENTS</td>
<td>T. V. Galambos A. Ferrara</td>
</tr>
<tr>
<td>220A</td>
<td>RESIDUAL STRESS &amp; COMPRESSIONAL PROPERTIES OF STEEL</td>
<td>L. Tall F. Estuar F. Nishino</td>
</tr>
<tr>
<td>223</td>
<td>PRESTRESSED CONCRETE BRIDGE MEMBERS</td>
<td>C. L. Hulsbos J. M. Hanson F. Ople D. Kocaoglu R. M. Miller</td>
</tr>
<tr>
<td>248</td>
<td>BUILT-UP MEMBERS IN PLASTIC DESIGN</td>
<td>A. Ostapenko R. Rampetsreiter J. Kondo</td>
</tr>
<tr>
<td>249</td>
<td>RESIDUAL STRESSES AND WELDED COLUMNS</td>
<td>L. Tall F. Estuar F. Nishino</td>
</tr>
<tr>
<td>251</td>
<td>WELDED PLATE GIRDERS</td>
<td>L. S. Beedle B. T. Yen P. B. Cooper</td>
</tr>
<tr>
<td>256</td>
<td>CONTINUOUS CONCRETE PAVEMENTS</td>
<td>I. J. Taylor</td>
</tr>
<tr>
<td>268</td>
<td>ROTATION CAPACITY REQUIREMENTS</td>
<td>G. C. Driscoll</td>
</tr>
<tr>
<td>269</td>
<td>RESIDUAL STRESSES AND A242 STEEL COLUMNS</td>
<td>L. Tall F. Estuar</td>
</tr>
<tr>
<td>271</td>
<td>LARGE BOLTED JOINTS</td>
<td>L. S. Beedle J. L. Rumpf J. W. Fisher S. Dlugosz</td>
</tr>
<tr>
<td>272</td>
<td>HIGH-STRENGTH STEEL &quot;T-1&quot;</td>
<td>T. V. Galambos Y. Ueda</td>
</tr>
<tr>
<td>273</td>
<td>MULTI-STOREY FRAMES</td>
<td>G. C. Driscoll V. Levi W. C. Hansell</td>
</tr>
<tr>
<td>276</td>
<td>FRAME STABILITY</td>
<td>G. C. Driscoll L. W. Lu Y. C. Yen J. A. Yura</td>
</tr>
<tr>
<td>277</td>
<td>DREDGE PUMP EFFICIENCY</td>
<td>J. B. Herbich R. M. Sorensen H. R. Vallentine R. Warnock</td>
</tr>
<tr>
<td>278</td>
<td>RESTRAINED COLUMNS</td>
<td>T. V. Galambos M. Lay</td>
</tr>
<tr>
<td>279</td>
<td>COMPOSITE DESIGN FOR BUILDINGS</td>
<td>G. C. Driscoll R. G. Slutter D. C. King</td>
</tr>
<tr>
<td>280</td>
<td>SPUR DIKES FOR BRIDGE ABUTMENTS</td>
<td>J. B. Herbich H. R. Vallentine A. Haque</td>
</tr>
<tr>
<td>281</td>
<td>POZZOLANIC REACTIONS ON COMMON SOIL MINERALS</td>
<td>R. J. Leonard J. D. Baldino J. B. Herbich</td>
</tr>
<tr>
<td>283</td>
<td>DREDGE PUMP DESIGN</td>
<td>S. J. Errera H. Reemsnyder C. P. Heins</td>
</tr>
<tr>
<td>284</td>
<td>FATIGUE OF USS &quot;T-1&quot; STEEL</td>
<td>G. C. Driscoll R. G. Slutter D. C. King</td>
</tr>
<tr>
<td>285</td>
<td>FATIGUE OF COMPOSITE BEAMS</td>
<td>L. Tall N. R. N. Rao</td>
</tr>
<tr>
<td>286</td>
<td>COLUMNS REINFORCED BY WELDING COVER PLATES</td>
<td>L. S. Beedle T. V. Galambos Y. Fukumoto</td>
</tr>
<tr>
<td>287</td>
<td>DESIGN OF BEAM COLUMNS</td>
<td>L. S. Beedle J. L. Rumpf J. W. Fisher S. Dlugosz P. O. Ramseneier</td>
</tr>
<tr>
<td>289</td>
<td>BAR-MAT LAP FAILURES IN PAVEMENTS</td>
<td></td>
</tr>
<tr>
<td>290</td>
<td>WELDED AND ROLLED &quot;T-1&quot; COLUMNS</td>
<td></td>
</tr>
<tr>
<td>291</td>
<td>COMPOSITION OF SHIP STEELS</td>
<td></td>
</tr>
<tr>
<td>292</td>
<td>BEARING CAPACITY OF CAISSONS</td>
<td></td>
</tr>
<tr>
<td>293</td>
<td>GRAVITY WAVES IN CONSTRUCTIONS</td>
<td></td>
</tr>
</tbody>
</table>
Since its founding in 1909 Fritz Engineering Laboratory has served industry through its research programs and its industrial testing facilities. Modernization in 1954-55 enabled the University to continue to provide the finest facilities for research in the fields of structures, materials, hydraulics, and structural model analysis. In addition, modern laboratories in soils and sanitation are provided. Fritz Laboratory is a part of the Department of Civil Engineering.

The laboratory facilities are housed in two large structures directly connected with one another, to which heavy equipment may be delivered by truck. Testing machines and other facilities provide the means whereby the largest structures may be tested statically or dynamically. A research library is maintained where current reports from laboratories throughout the world are available for study.

Through its Institute of Research, Lehigh University contracts with research councils, industrial concerns, or associations to undertake cooperative research. The sponsor pays all costs plus a reasonable percentage for overhead. At least a one-year duration is expected on such projects, and publication of results in technical magazines is normally anticipated. About half of the research is sponsored by industry and half by government agencies.

Investigations have ranged from studies of material properties and characteristics up to tests of full-size structures for buildings and bridges. Structural steel research programs have improved design procedures by this approach. Specifications of the AISE, AISC, and AREA have been revised as a direct result of research projects.

In the following pages are described current research projects. Not only are they providing a better understanding of Civil Engineering, but they are supplying the engineer with simpler design techniques and the consumer with more economical structures and systems.
Project 205: WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS (PLASTIC DESIGN)

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
Navy Department (Bureau of Ships, Bureau of Yards and Docks, Office of Naval Research)
Welding Research Council

The general objectives of this research are to develop methods for predicting the ultimate load-carrying capacity of continuous steel structures and to develop practical design procedures for utilizing the reserve plastic strength. Such procedures must take into account such additional factors as fatigue, deflections, brittle fracture, local buckling, lateral buckling, etc., and this is being done on the project.

Results to date have shown that the plastic theory may be applied to the design of continuous beams and single-story industrial frames. Manuals and commentaries have been prepared to assist the designer of these structures. Research has also shown that the plastic theory shows promise for application to the design of other classes of structures, such as multi-story buildings and component parts of ships. Other aspects of this comprehensive program are explained in the descriptions for projects 205A, 205C, 205E, 205H, 248, 268, 273, 276, 278, and 287.

Project 205A: COLUMNS IN CONTINUOUS FRAMES

Sponsors: See 205

In the plastic design of steel rigid frames it is intended to utilize each member to its maximum carrying capacity. The primary purpose of the particular project on columns is to determine the maximum strength of those members in a rigid frame which are subjected to a combination of axial force and end-bending moments. The work required an evaluation of the effect of residual stresses and the various possible combinations of end-bending moments. In addition, the influence of lateral-torsional buckling must be evaluated and the rotation capacity at column ends is being investigated.

Solutions are being obtained by analytical and experimental means. The findings are intended to provide specification writers with aid in writing rational design rules, some parts already having been incorporated in the AISC Manual on plastic design.
Project 205C:  CORNER CONNECTIONS

Sponsors:  See 205

Connections transmit forces from one member to the next, enabling the members to share in supporting the loads placed upon the structure. Studies have been made to obtain information on how to proportion corner connections for portal frames in order that they may meet the requirements imposed by their use in plastically designed structures. Tests of square, tapered, and curved corner connections have verified that they can be designed to have the proper strength, stiffness, and rotation capacity to serve their purpose.

Project 205E:  INELASTIC INSTABILITY

Sponsors:  See 205

The problem of the local buckling of rolled wide-flange shapes in the plastic region has been solved insofar as the requirements of plastic design are concerned. Based on this work, design procedures have been set up to control the geometry of cross-section so that local failure does not prevent the formation of plastic hinges.

The second phase of this investigation is concerned with the post buckling strength and rotation capacity of beams subjected to uniform plastic moments or to a moment gradient. Experimental and theoretical research has shown that the member will develop a plastic hinge if the lateral bracing is spaced at forty-five times its minor radius of gyration or less. Current studies involve the determination of the critical spacing under moment gradient.
Project 205H: LATERAL BRACING REQUIREMENTS

Sponsors: See 205

In a plastically designed structure, a member must undergo large inelastic rotations within the region of a "plastic hinge" so that the moments may be redistributed to develop the full strength of the structure. To achieve these large rotations, provision must be made to prevent the member from failing prematurely due to lateral-torsional buckling.

The purpose of this project is to determine practical means for bracing a member so that it can fully develop its ultimate strength. Currently experimental and theoretical studies are being conducted to evaluate the required strength and stiffness of lateral bracing such that the braced beam will deliver a plastic hinge. Various practical beam-purlin assemblies are studied experimentally.

Project 220A: RESIDUAL STRESS AND THE COMPRESSIVE PROPERTIES OF STEEL

Sponsors: Bureau of Public Roads
          Column Research Council
          National Science Foundation
          Pennsylvania Department of Highways

This program of research is aimed at answering fundamental questions about the behavior of steel columns. These are problems that have been of concern to designers and to specification-writing bodies ever since the advent of rolled and welded steel sections. When the research is completed, the design of steel columns will be based on a much more complete knowledge of their behavior, assuring safety with maximum possible economy.

The results have already been used in the writing of the Column Research Council Specification Guide and in the 1961 AISC specifications. Thus, they will become available to every designer of bridges, buildings and other structures. For related studies see projects 249 and 269.
Project 223: **PRESTRESSED CONCRETE BRIDGE MEMBERS**

**Sponsors:**
- Pennsylvania Department of Highways
- Bureau of Public Roads
- Reinforced Concrete Research Council
- American Steel & Wire Division
- United States Steel Corporation
- American-Marietta Company
- Concrete Products Division

This investigation includes two phases of work:
1. **The Investigation of the Fatigue Failure of Prestressed Concrete Beams.**
   
   The objective of this phase is to develop a method for determining the fatigue resistance of prestressed concrete flexural members under repeated cycles of loading of either constant or varied magnitude.

2. **The Ultimate Strength of Prestressed Concrete Beams Under the Combined Action of Bending and Shear.**
   
   The objective of this phase is to develop a procedure for design of web reinforcement.

Project 248: **BUILT-UP MEMBERS IN PLASTIC DESIGN**

**Sponsor:**
- Navy Department (Bureau of Ships)

Built-up members are very often used in practice, especially in ship structures. Typical examples are deck girders with openings, Vierendeel girders, and the like. The application of plastic design to such members offers some new problems. One of these is the inelastic stability of stiffened plate panels.

The purpose of this program is to investigate the effect of some important parameters, such as the intensity of lateral pressure and the distribution of residual stresses, on the stability of stiffened plate panels under axial compression. The results of experimental investigation will be analyzed in conjunction with theoretical studies and recommendations will be made for the design of ship bottom plating based on ultimate strength.
Project 249: WELDED BUILT-UP COLUMNS

Sponsors: See 220A

When columns are built up from separate plates by welding, they will not necessarily have the same strength as a similar rolled column. After a plate is welded, and allowed to cool, there will remain in the plate residual stresses which are due to the uneven cooling. Because of these stresses, certain portions of the cross section of a column have a decreased capacity for load, whereas other portions have an increased capacity. The residual stresses and their distribution in the cross section play a very important part in the strength of the column.

The position of the weld relative to the plates can either increase or decrease the effect of the residual stresses. It is the purpose of this project to show how plates should be welded together to produce a column with the maximum possible strength.

Project 251: WELDED PLATE GIRDERS

Sponsors: American Institute of Steel Construction
Bureau of Public Roads
Pennsylvania Department of Highways
Welding Research Council

Present design practice for plate girders is based on a theory that is inadequate in two respects. First, girders do not fail by sudden buckling as indicated in this theory. Second, the load-carrying capacity is considerably higher than that predicted by the theory currently in use. It is the aim of this project to study the stability and load-carrying capacity of welded plate girders and to provide information to be used to formulate more progressive design rules, thus permitting the use of more efficient and economical girders.

The results of an experimental investigation of the static behavior of girders subjected to bending, shear and combined bending and shear has been presented. A parallel theoretical investigation including design recommendations has recently been completed.

A program of fatigue study on welded plate girders has been started. Pilot tests show that girders built according to proposed design recommendations perform satisfactorily. These tests will be used in planning further investigations.

Other new areas of investigation include girders built of high strength steel and the effectiveness of longitudinal stiffeners.
Project 256: CONTINUOUS CONCRETE PAVEMENTS

Sponsors: Pennsylvania Department of Highways
           Bureau of Public Roads

The objective of this research is to develop a jointless concrete pavement with continuous longitudinal reinforcement which will control the width of transverse shrinkage cracks. Instrumentation has been developed to measure the stress, strain, temperature, deflection, etc. in service pavements constructed as experimental projects.

Results to date have permitted the establishment of some design limitations in pavement thickness, percentage of reinforcement, and sub-base construction.

Many people believe that this type of construction will provide a smooth, low maintenance pavement with a very long service life. Several states have installed these pavements during the past five years (Pennsylvania, Maryland, Texas, for example) and the experience to date has been encouraging.

Project 268: ROTATION CAPACITY REQUIREMENTS

Sponsors: See 205

Plastic analysis of steel structures depends on the ability of the members to form "plastic hinges" and to redistribute moments. In order for redistribution of moment to take place, certain plastic hinges must sustain their plastic moment through a certain angle of rotation. The amount of rotation required may affect the geometry of the structural shapes selected and the spacing of lateral bracing.

This project consists of theoretical studies predicting how much rotation capacity is required of plastic hinges in structures. Comparison of the theoretical requirements with the experimentally determined values assures that the required rotation can take place for the structures that have been studied up to the present time.
Project 269: COMPRESSION PROPERTIES OF LOW-ALLOY STEELS

Sponsors: See 220A

In the drive for economy, the strength of structural members should be exploited to the highest possible degree. This means that all of the influencing factors must be well known in order to assure the needed safety. One factor which only recently has come into the picture is the influence of stresses present in the unloaded member. These "locked-in" or residual stresses originate from temperature differences during the cooling process after rolling. They have been shown to influence the carrying capacity of mild steel columns. Theory predicts that in the low-alloy steels (yield point about 55 ksi) the residual stresses have relatively less influence than in ordinary structural steel (yield 33 ksi).

This project is intended to check these predictions. The positive results obtained so far suggest this additional advantage of using high-strength steel.

Project 271: LARGE BOLTED JOINTS

Sponsors: Bureau of Public Roads
Pennsylvania Department of Highways
Research Council on Riveted and Bolted Structural Joints

In recent years the High Strength Bolt has become the major fastener for field assembled structural connections. This rapid advance has been accelerated even more by recent changes (1960) in the design specification which allow higher shear stresses in bolts than in rivets. A big share of the necessary research was carried out at Fritz Laboratory. Tests were conducted on butt splices using 7/8", 1", and 1-1/8" A325 bolts. One inch plates were used in most of the tests. Theoretical studies showed good correlation with the tests. Continuing work on higher strength steels is being done as part of project 288.
Project 272: **HIGH-STRENGTH STEELS "T-1"**

**Sponsor:** United States Steel Corporation

The current investigation is limited to determining the influence of residual stresses on the strength of solid round sections. Their magnitude and distribution for different manufacturing processes such as quenching, tempering, air cooling, stress relieving and straightening will be determined. In addition, compression tests on short stub columns are conducted. Finally, column buckling tests are made. The results were compared to theoretical predictions considering the influence of residual stresses, and good correlation was obtained.

Project 273: **MULTI-STORY FRAMES**

**Sponsor:** See 205

In applying plastic theory to the design of multi-story building frames, the basic principles involved are the same as for single-story frames. However, certain factors such as frame stability and column behavior take on additional importance in multi-story frames. Also design techniques and procedures tend to become more complicated and should be simplified.

The general objective of this project is to obtain practical methods for the analysis and design of multi-story frames.
Project 276: FRAME STABILITY

Sponsors: See 205

For simple frames, the load to cause formation of a mechanism is easily predicted by simple plastic theory. However, it is possible that "frame instability" may occur before attainment of the predicted ultimate load. By frame instability is meant that phenomenon in which a frame, unrestrained against sidesway at the column tops, will buckle as a unit. The columns which buckle in this form of failure are subjected to restraints at their connections and bases which have not been evaluated heretofore for the plastic range. This problem is of particular interest in the lower stories of multi-story buildings where the columns are most heavily loaded.

The purpose of this project is to determine, both theoretically and experimentally, the extent to which the simple plastic theory requires modification. The project will also develop methods for proportioning columns to assure the needed stability.

Project 277: DREDGE PUMP EFFICIENCY

Sponsors: United States Army Engineers

The immediate purpose of the study is to improve design of a hopper dredge centrifugal pump silt-clay-water mixtures. The long-term objective is to determine the effect of Bingham Body-type of fluid on pumping characteristics. The project has been divided into four phases:

1. Model tests of the existing dredge pump
2. Recommendations for design changes of the dredge pump
3. Model investigation of the modified design of the dredge pump
4. Analysis of the investigation and final recommendations

Phase 1 involved installation in the hydraulic laboratory of a 1.8 scale model of the dredge pump now used on the United States Corps of Engineers dredge ESSAYONS. Water as well as silt-clay-water mixtures (Bingham Body-type of fluid) were pumped and complete characteristics of the pump obtained for capacity of 0 to 1200 gallons per minute, speed of 1150 to 1900 revolutions per minute, and liquid concentrations of 1000 to 1380 grams per liter. Phases 2 and 3 involve modifications in the shape of vane and changes in the exit vane angle of the impeller. Experimental tests indicate considerable improvement in pump efficiency.
Project 278:  

**RESTRAINED COLUMNS**

Sponsors:  
See 205

Individual columns in continuous frames are always restrained by beams and other columns. The effect of this restraint is to make the column in a frame stronger than it would be if no restraint existed. The purpose of this project is to determine the strength of restrained columns, and to develop design procedures for the design of columns in multi-story frames. The theoretical phases of this work have been completed. An experimental program is being planned.

---

Project 279:  

**COMPOSITE DESIGN FOR BUILDINGS**

Sponsor:  
American Institute of Steel Construction

Floor systems for buildings consisting of a concrete slab supported by steel beams have been improved in recent years by providing shear connectors between concrete slab and steel beams. These connectors, which are welded to the top flange of the steel beam, cause the concrete slab and steel beam to act together as a single unit in supporting live loads. This reduces vibrations and deflections in the floor system.

Studies of this type of construction have revealed that the strength of the concrete slab can be considered as reinforcing the steel beam, and the size of the steel beam can then be reduced as compared to non-composite construction. Considerable savings in the amount of steel required for a given building may be achieved in this way. Further studies of shear connectors for composite construction are being made to determine the maximum economy which can be obtained while maintaining adequate safety.
Project 280:  SPUR DIKES FOR BRIDGE ABUTMENTS

Sponsor:  Lehigh University Institute of Research
           Modjeski and Masters, Consulting Engineers

Analytical and Experimental - The project has been divided into four phases: (A) Literature Survey; (B) Analytical Study; (C) Experimental study in a fixed-bed model to determine the desired lengths and shapes of spur dikes to provide uniform velocity distributions in the waterway between bridge abutments; (D) Experimental study in a movable-bed model to verify findings in part (C). A spur dike has been defined as a projection extending upstream from the bridge abutment.

Preliminary investigation indicates that a properly designed spur dike can produce a fairly uniform velocity distribution between the abutments.

Project 281:  POZZOLANIC REACTION OF COMMON SOIL MINERALS

Sponsor:  National Science Foundation

The supply of adequate base course material for pavements and slabs has been depleted, or is being rapidly depleted in many areas of the United States. In order to meet the needs for this vital material many states are importing this material to the critical areas, or looking for more economical means of providing a sub-base material that will be adequate for the climatic and traffic effects that will be imposed on it. Lime has been widely considered as an economical material capable of stabilizing most soils to produce an adequate base course material.

Although there have been many laboratory and field tests of soils stabilized with lime, there have been very few studies of the fundamental chemical and physical aspects of the process. This project deals with the chemical reaction of the lime with the various species of minerals that occur in soils and with the influence of the reaction product on the strength properties of the lime stabilized soil. Theoretically, if the mechanism of the reaction and the nature of the reaction products were better known, it might be possible to predict strength properties and to improve the results of the reaction.
Project 285:  **FATIGUE OF COMPOSITE BEAMS**

Sponsor:  American Institute of Steel Construction

This project is an outgrowth of Project 279, "Composite Beams for Buildings". In Project 279, the composite steel beam and concrete floor slab were subject to static loads. In this project the composite floor is subject to fatigue loadings in order to determine the ultimate strength of the shear connectors under fatigue loading.

Results of this project may provide a new basis for the design of bridge members and other composite members subjected to fatigue loading.

---

Project 286:  **COLUMNS REINFORCED BY WELDING**

**COVER PLATES**

Sponsor:  American Institute of Steel Construction

Quite often in modern building construction it is desirable to load columns above the working loads which were the basis of the original design. Reinforcement becomes necessary to utilize such columns.

This investigation is concerned with the strength characteristics, during and after welding, of a steel H-column reinforced under load by the welding of cover plates to the flanges. The pilot program includes tests of stub columns and several actual columns together with the necessary residual stress measurements and other control tests. The results will show whether a major investigation is warranted to improve design procedures for such stub members.
Project 283: DREDGE PUMP DESIGN

Sponsor: National Bulk Carriers, Inc.

Suction-type dredging is an important method employed in dredging operations and other civil engineering works. The efficiency of a suction dredge pump depends on such variables as impeller and voluble design, and the mechanical analysis and concentration of material being pumped.

The National Bulk Carriers, Incorporated, have recently built in Japan a hopper dredge, S. S. "ZULIA". This vessel has four dredge pumps very similar to that of the United States Army Corps of Engineers dredge "ESSAYONS" except for certain modifications of the impeller, particularly the vane exit angle. No efficiency or head capacity curves are available for this particular pump.

The objective of the investigation is to obtain the efficiency and head capacity curves, to check the effect of the reduced vane exit angle, and to prove the efficiency of the dredge pump. Phases of the program include (1) 1:8 Model test with one concentration of silt-clay-water mixture, (2) A Model test with a modified impeller and using three concentrations of silt-clay-water mixtures, and (3) A Model test with previously established best impeller with three concentrations of sand-water mixtures.

Project 284: FATIGUE OF USS "T-l" STEEL

Sponsor: United States Steel Corporation

The useful life of a structure or a machine can be shortened considerably by a fracture phenomenon known as fatigue, the breaking of a material at a stress considerably less than its ultimate stress. Since the fatigue resistance of a material is a function of many variables, metallurgical structure, stress-state and -history, residual stresses, etc., it is not possible at present to predict the fatigue life or strength of a structural or machine part unless the stress-fatigue life relationship for that particular part has been experimentally determined.

This project will determine the fatigue resistance of "T-l" steel, a quenched and tempered high-strength constructional steel, when fillet-welds are present.
Project 287: **DESIGN OF BEAM-COLUMNS**

Sponsor: American Institute of Steel Construction

The purpose of this project is to coordinate research results from other projects on inelastic instability (such as 205A, Columns in Continuous Frames; 278, Restrained Columns; etc.) and to explore uses for this information in practical design. The specific aim of the work is to broaden the scope of present beam-column specifications to include the latest research results. Design methods are being developed for beam-columns of various types of rolled and welded built-up shapes manufactured from structural carbon and high-strength steels.

Project 288: **LARGE BOLTED JOINTS - HIGH STRENGTH STEELS**

Sponsors: Bureau of Public Roads  
Pennsylvania Department of Highways  
Research Council on Riveted and Bolted Structural Joints  
American Institute of Steel Construction  
(Fort Pitt Bridge Works)

With increased use of high strength steels in construction during recent years the necessity to investigate their behavior when used with high strength bolts became apparent.

Current and future research at Lehigh will include investigations of high strength steels fastened with ASTM A325 bolts. Also, plans are being formulated for tests of high strength steel plate connected with ASTM A354 bolts.

This work is an outgrowth of Project 271. The initial studies on high strength steel determined the proper tension-shear ratio for "balanced design" when steel of 50,000 psi yield point was used with ASTM A325 bolts. The current project will involve experimental work utilizing half a butt joint, together with control tests to determine material properties. Also the theoretical aspects governing the joint performance will be investigated.

The purpose of this project is to develop methods of predicting the strength and performance of bolted joints. The project will also help to evolve design stresses for high strength steels (50,000 and 100,000 yield) and the two grades of high strength bolts.
Project 289:  BAR-MAT LAP FAILURES IN PAVEMENTS

Sponsors:  Pennsylvania Department of Highways
           Bureau of Public Roads

The objective of this project is to determine the optimum method for the placement of reinforcement in concrete pavement.

Several failures have occurred in service pavements where bar-mat reinforcement was lapped to maintain longitudinal continuity. Laboratory tests with short pavement slabs and simulated field conditions are used to compare the bond strength and tensile strength of the concrete and the reinforcement during the early life of a pavement.

These tests should also result in a better understanding of the shrinkage phenomena in long reinforced concrete structures.

Project 290:  WELDED AND ROLLED "T-1" COLUMNS

Sponsor:  United States Steel Corporation

The overall purpose of the research is to develop design information for welded box and H-sections (fabricated from "T-1" plates) and for rolled heat-treated angle and wide flange sections of "T-1" steel used in compression.

The phases of the research program are:
I.  Basic Studies
   (a) Experimental and theoretical investigation of the magnitude and distribution of residual stresses in sections fabricated by welding heat-treated plates and in rolled heat-treated sections. The effect of stress relieving welded sections will also be investigated.
   (b) Experimental and theoretical investigation of local buckling for the study of the effect of residual stresses on local buckling.

II.  Axially Loaded Columns

   Experimental and theoretical studies of axially loaded columns which include investigation of the effects of (1) residual stresses and (2) small amounts of out-of-straightness.

III.  Beam Columns

   Experimental and theoretical investigations of columns subjected to both axial force and intentional bending moment.
Project 291:  COMPOSITION OF SHIP STEELS

Sponsor:    Bureau of Ships

The initial stage of this program which is currently being conducted consists of a study of the influence of dimensional changes in test specimens on brittle fracture transition temperature. The testing methods to be used are the Van der Veen test, the Bagsar test, and the drop-weight test. Initial tests will use a heat of ABS Class C normalized steel plate in 1, 2, and 3-inch thicknesses.

In the Van der Veen test, which is presently being conducted, the plate thickness serves as the width of the bend specimen while the height is normally constant at 2.76". However, the specimen height will be another variable in this investigation including 1/2 and 1/4 the standard height for all three plate thicknesses. Several series with other span lengths will also be tested. Both ductility and fracture transition temperatures will be determined.

Project 292:  BEARING CAPACITY OF CAISSONS

Sponsor:    Lehigh University Institute of Research

The purpose of this research project is to investigate aspects of the bearing capacity of caissons under different base conditions. The base conditions to be investigated will be for a caisson bearing directly on rock, and caissons socketed into rock with several socket designs.

The research will be divided into two phases. The first phase will be theoretical in nature and will consist of mathematical and photoelastic analyses. The second phase will consist of scale model tests of caissons to determine the validity of the analytical results.
Project 293:  GRAVITY WAVES IN CONSTRUCTIONS

Sponsor: Lehigh University Institute of Research

The problem of wave propagation in river estuaries is exceedingly complex. Present methods of estimating the wave characteristics in vertical and horizontal transitions are not very accurate.

The purpose of this project is to study the transformation of gravity waves. The test will be performed under simplified conditions in a 70 foot long, 2 feet wide and 2 feet deep wave channel. The investigation is a theoretical and experimental study of the effects of gradual changes in the depth and width in a channel along with the effects of both shallow and deep water waves. It is hoped to extend the results of this study to more complicated geometrical systems in order to provide a method for predicting wave transitions in river estuaries.
<table>
<thead>
<tr>
<th>TITLE</th>
<th>PROJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Column Design</td>
<td>287</td>
</tr>
<tr>
<td>Bolted Joints</td>
<td>271, 288</td>
</tr>
<tr>
<td>Caissons, Bearing Capacity of</td>
<td>292</td>
</tr>
<tr>
<td>Columns Reinforced with Welded Cover Plates</td>
<td>286</td>
</tr>
<tr>
<td>Columns, Restrained</td>
<td>278</td>
</tr>
<tr>
<td>Columns, Welded - Built-up</td>
<td>249</td>
</tr>
<tr>
<td>Columns, Welded - Built-up and Rolled &quot;T-1&quot;</td>
<td>290</td>
</tr>
<tr>
<td>Composite Beams, Fatigue of</td>
<td>285</td>
</tr>
<tr>
<td>Composite Design for Buildings</td>
<td>279</td>
</tr>
<tr>
<td>Concrete Pavements, Continuous</td>
<td>256</td>
</tr>
<tr>
<td>Concrete, Prestressed Bridge Members</td>
<td>223</td>
</tr>
<tr>
<td>Connections, Corner</td>
<td>205C</td>
</tr>
<tr>
<td>Dredge Pump Design</td>
<td>283</td>
</tr>
<tr>
<td>Dredge Pump Efficiency</td>
<td>277</td>
</tr>
<tr>
<td>Fatigue of Composite Beams</td>
<td>285</td>
</tr>
<tr>
<td>Fatigue of USS &quot;T-1&quot; Steel</td>
<td>284</td>
</tr>
<tr>
<td>Frames, Columns in Continuous</td>
<td>205A</td>
</tr>
<tr>
<td>Frames, Lateral Bracing Requirements</td>
<td>205H</td>
</tr>
<tr>
<td>Frames, Multi-Story</td>
<td>273</td>
</tr>
<tr>
<td>Frame Stability</td>
<td>276</td>
</tr>
<tr>
<td>Frames, Welded - Continuous and Their Components</td>
<td>205</td>
</tr>
<tr>
<td>Girders, Plate Welded</td>
<td>251</td>
</tr>
<tr>
<td>Gravity Waves in Constrictions</td>
<td>293</td>
</tr>
<tr>
<td>High-Strength Steel</td>
<td>269, 272, 284</td>
</tr>
<tr>
<td>Instability, Inelastic</td>
<td>205E</td>
</tr>
<tr>
<td>Pavements, Bar-Mat Lap Failure in</td>
<td>289</td>
</tr>
<tr>
<td>Plastic Design, Built-up Members in</td>
<td>248</td>
</tr>
<tr>
<td>Plastic Design, Welded Continuous Frames and Their Components</td>
<td>205</td>
</tr>
<tr>
<td>Plate Girders, Welded</td>
<td>251</td>
</tr>
<tr>
<td>Pozzolanic Reaction on Common Soil Minerals</td>
<td>281</td>
</tr>
<tr>
<td>Residual Stress</td>
<td>220A, 249, 290</td>
</tr>
<tr>
<td>Rotation Capacity Requirements</td>
<td>268</td>
</tr>
<tr>
<td>Ship Steel</td>
<td>291</td>
</tr>
<tr>
<td>Spur Dikes</td>
<td>280</td>
</tr>
<tr>
<td>Steel, Composition for Ship</td>
<td>291</td>
</tr>
<tr>
<td>Steel, Compressive Properties of Low-Alloy</td>
<td>269</td>
</tr>
<tr>
<td>Steel, Fatigue of USS &quot;T-1&quot; Steel</td>
<td>284</td>
</tr>
<tr>
<td>Steel, High Strength &quot;T-1&quot;</td>
<td>272</td>
</tr>
<tr>
<td>&quot;T-1&quot; Steel</td>
<td>272, 284, 290</td>
</tr>
</tbody>
</table>
## SPONSOR INDEX

<table>
<thead>
<tr>
<th>SPONSOR</th>
<th>PROJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMERICAN INSTITUTE OF STEEL CONSTRUCTION</td>
<td>205, 205A, 205C, 205E, 205H, 251, 268, 273, 276, 278, 279, 285, 286, 287, 288</td>
</tr>
<tr>
<td>AMERICAN IRON AND STEEL INSTITUTE</td>
<td>205, 205A, 205C, 205E, 205H, 268, 273, 276, 278</td>
</tr>
<tr>
<td>AMERICAN-MARIETTA COMPANY</td>
<td>223</td>
</tr>
<tr>
<td>Concrete Products Division</td>
<td></td>
</tr>
<tr>
<td>AMERICAN STEEL &amp; WIRE DIVISION</td>
<td>223</td>
</tr>
<tr>
<td>United States Steel Corporation</td>
<td></td>
</tr>
<tr>
<td>BUREAU OF PUBLIC ROADS</td>
<td>220A, 223, 249, 251, 256, 269, 271, 288, 289</td>
</tr>
<tr>
<td>COLUMN RESEARCH COUNCIL</td>
<td>220A, 249, 269</td>
</tr>
<tr>
<td>FORT PITT BRIDGE WORKS</td>
<td>288</td>
</tr>
<tr>
<td>LEHIGH UNIVERSITY</td>
<td>280, 292, 293</td>
</tr>
<tr>
<td>Institute of Research</td>
<td></td>
</tr>
<tr>
<td>MODJESKI &amp; MASTERS</td>
<td>280</td>
</tr>
<tr>
<td>Consulting Engineers</td>
<td></td>
</tr>
<tr>
<td>NATIONAL SCIENCE FOUNDATION</td>
<td>220A, 249, 269, 281</td>
</tr>
<tr>
<td>NATIONAL BULK CARRIERS INC</td>
<td>283</td>
</tr>
<tr>
<td>NAVY DEPARTMENT</td>
<td>205, 205A, 205C, 205E, 205H, 248, 268, 273, 276, 278, 291</td>
</tr>
<tr>
<td>Bureau of Ships</td>
<td></td>
</tr>
<tr>
<td>Bureau of Yards and Docks</td>
<td></td>
</tr>
<tr>
<td>Office of Naval Research</td>
<td></td>
</tr>
<tr>
<td>PENNSYLVANIA DEPARTMENT OF HIGHWAYS</td>
<td>220A, 223, 249, 251, 256, 269, 271, 288, 289</td>
</tr>
<tr>
<td>REINFORCED CONCRETE RESEARCH COUNCIL</td>
<td>223</td>
</tr>
<tr>
<td>RESEARCH COUNCIL ON RIVETED &amp; BOLTED STRUCTURAL JOINTS</td>
<td>271, 288</td>
</tr>
<tr>
<td>UNITED STATES ARMY ENGINEERS</td>
<td>277</td>
</tr>
<tr>
<td>WELDING RESEARCH COUNCIL</td>
<td>205, 205A, 205C, 205E, 205H, 251, 268, 273, 276, 278</td>
</tr>
</tbody>
</table>
CURRENT RESEARCH PROJECTS

Fritz Engineering Laboratory
Department of Civil Engineering
Lehigh University
Bethlehem, Pa.

October 1961
<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title</th>
<th>Research Personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>205</td>
<td>WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS (PLASTIC DESIGN)</td>
<td>L. S. Beedle, T. V. Galambos, G. C. Driscoll</td>
</tr>
<tr>
<td>205A</td>
<td>COLUMNS IN CONTINUOUS FRAMES</td>
<td>T. V. Galambos, J. Prasad, M. Lay</td>
</tr>
<tr>
<td>205C</td>
<td>CORNER CONNECTIONS</td>
<td>G. C. Driscoll</td>
</tr>
<tr>
<td>205E</td>
<td>INELASTIC INSTABILITY</td>
<td>T. V. Galambos</td>
</tr>
<tr>
<td>205H</td>
<td>LATERAL BRACING REQUIREMENTS</td>
<td>T. V. Galambos, A. Ferrara</td>
</tr>
<tr>
<td>220A</td>
<td>RESIDUAL STRESS &amp; COMPRESSIVE PROPERTIES OF STEEL</td>
<td>L. Tall F. Estuar, F. Nishino, C. L. Hulsbos, J. M. Hanson, F. Ople, D. Kocaoglu, R. M. Miller</td>
</tr>
<tr>
<td>223</td>
<td>PRESTRESSED CONCRETE BRIDGE MEMBERS</td>
<td>A. Ostapenko, R. Rampetsreiter, J. Kondo</td>
</tr>
<tr>
<td>248</td>
<td>BUILT-UP MEMBERS IN PLASTIC DESIGN</td>
<td>L. Tall F. Estuar, F. Nishino</td>
</tr>
<tr>
<td>249</td>
<td>RESIDUAL STRESSES AND WELDED COLUMNS</td>
<td>L. S. Beedle, B. T. Yen, P. B. Cooper</td>
</tr>
<tr>
<td>251</td>
<td>WELDED PLATE GIRDERs</td>
<td>I. J. Taylor</td>
</tr>
<tr>
<td>256</td>
<td>CONTINUOUS CONCRETE PAVEMENTS</td>
<td>G. C. Driscoll</td>
</tr>
<tr>
<td>258</td>
<td>ROTATION CAPACITY REQUIREMENTS</td>
<td>L. Tall F. Estuar</td>
</tr>
<tr>
<td>271</td>
<td>LARGE BOLTED JOINTS</td>
<td>T. V. Galambos, Y. Ueda, G. C. Driscoll, V. Levi, W. C. Hansell</td>
</tr>
<tr>
<td>272</td>
<td>HIGH-STRENGTH STEEL &quot;T-1&quot;</td>
<td>G. C. Driscoll, L. W. Lu, Y. C. Yen, J. A. Yura</td>
</tr>
<tr>
<td>273</td>
<td>MULTI-STORY FRAMES</td>
<td>J. B. Herbich, R. M. Sorensen, H. R. Vallentine, R. Warnock</td>
</tr>
<tr>
<td>276</td>
<td>FRAME STABILITY</td>
<td>T. V. Galambos, M. Lay</td>
</tr>
<tr>
<td>277</td>
<td>DREDGE PUMP EFFICIENCY</td>
<td>G. C. Driscoll, R. G. Slutter, D. C. King</td>
</tr>
<tr>
<td>278</td>
<td>RESTRAINED COLUMNS</td>
<td>J. B. Herbich, H. R. Vallentine, A. Haque</td>
</tr>
<tr>
<td>279</td>
<td>COMPOSITE DESIGN FOR BUILDINGS</td>
<td>R. J. Leonard, J. D. Baldino</td>
</tr>
<tr>
<td>280</td>
<td>SPUR DIKES FOR BRIDGE ABUTMENTS</td>
<td>J. B. Herbich, S. J. Errera, R. D. Stout</td>
</tr>
<tr>
<td>281</td>
<td>POZZOLANIC REACTIONS ON COMMON SOIL MINERALS</td>
<td>G. C. Driscoll, C. P. Heins</td>
</tr>
<tr>
<td>282</td>
<td>DREDGE PUMP DESIGN</td>
<td>S. J. Errera, H. Reemsnyder</td>
</tr>
<tr>
<td>283</td>
<td>FATIGUE OF USS &quot;T-1&quot; STEEL</td>
<td>G. C. Driscoll, H. R. Vallentine</td>
</tr>
<tr>
<td>284</td>
<td>FATIGUE OF COMPOSITE BEAMS</td>
<td>L. Tall N. R. N. Rao</td>
</tr>
<tr>
<td>285</td>
<td>COLUMNS REINFORCED BY WELDING COVER PLATES</td>
<td>L. S. Beedle, T. V. Galambos, Y. Fukumoto</td>
</tr>
<tr>
<td>287</td>
<td>DESIGN OF BEAM COLUMNS</td>
<td>L. S. Beedle, J. L. Rumpf, J. W. Fisher, S. Dlugosz, P. O. Ramseier</td>
</tr>
<tr>
<td>288</td>
<td>LARGE BOLTED CONNECTIONS - HIGH STRENGTH STEELS</td>
<td>I. J. Taylor, D. Kocaoglu, L. Tall F. Nishino, Y. Ueda</td>
</tr>
<tr>
<td>289</td>
<td>BAR-MAT LAP FAILURES IN PAVEMENTS</td>
<td>S. J. Errera, R. D. Stout, C. R. Roper, E. L. Yordy</td>
</tr>
<tr>
<td>290</td>
<td>WELDED AND ROLLED &quot;T-1&quot; COLUMNS</td>
<td>R. J. Leonard</td>
</tr>
<tr>
<td>291</td>
<td>COMPOSITION OF SHIP STEELS</td>
<td>J. B. Herbich, R. M. Sorensen, J. Willenbrock</td>
</tr>
<tr>
<td>292</td>
<td>BEARING CAPACITY OF CAISSONS</td>
<td></td>
</tr>
<tr>
<td>293</td>
<td>GRAVITY WAVES IN CONSTRUCTIONS</td>
<td></td>
</tr>
</tbody>
</table>
Since its founding in 1909 Fritz Engineering Laboratory has served industry through its research programs and its industrial testing facilities. Modernization in 1954-55 enabled the University to continue to provide the finest facilities for research in the fields of structures, materials, hydraulics, and structural model analysis. In addition, modern laboratories in soils and sanitation are provided. Fritz Laboratory is a part of the Department of Civil Engineering.

The laboratory facilities are housed in two large structures directly connected with one another, to which heavy equipment may be delivered by truck. Testing machines and other facilities provide the means whereby the largest structures may be tested statically or dynamically. A research library is maintained where current reports from laboratories throughout the world are available for study.

Through its Institute of Research, Lehigh University contracts with research councils, industrial concerns, or associations to undertake cooperative research. The sponsor pays all costs plus a reasonable percentage for overhead. At least a one-year duration is expected on such projects, and publication of results in technical magazines is normally anticipated. About half of the research is sponsored by industry and half by government agencies.

Investigations have ranged from studies of material properties and characteristics up to tests of full-size structures for buildings and bridges. Structural steel research programs have improved design procedures by this approach. Specifications of the AISE, AISC, and AREA have been revised as a direct result of research projects.

In the following pages are described current research projects. Not only are they providing a better understanding of Civil Engineering, but they are supplying the engineer with simpler design techniques and the consumer with more economical structures and systems.

Head of Department of Civil Engineering and Fritz Engineering Laboratory          W. J. Eney
Director of Fritz Engineering Laboratory                                          Lynn S. Beedle
Structural Metals                                                                 George C. Driscoll (Acting)
Concrete                                                                         C. L. Hulsbos
Hydraulics                                                                       J. B. Herbich
Soils Laboratory                                                                 R. J. Leonard
Structural Models                                                               W. J. Eney
Engineer of Tests                                                              S. J. Errera
Project 205: WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS (PLASTIC DESIGN)

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
Navy Department (Bureau of Ships, Bureau of Yards and Docks, Office of Naval Research)
Welding Research Council

The general objectives of this research are to develop methods for predicting the ultimate load-carrying capacity of continuous steel structures and to develop practical design procedures for utilizing the reserve plastic strength. Such procedures must take into account such additional factors as fatigue, deflections, brittle fracture, local buckling, lateral buckling, etc., and this is being done on the project.

Results to date have shown that the plastic theory may be applied to the design of continuous beams and single-story industrial frames. Manuals and commentaries have been prepared to assist the designer of these structures. Research has also shown that the plastic theory shows promise for application to the design of other classes of structures, such as multi-story buildings and component parts of ships. Other aspects of this comprehensive program are explained in the descriptions for projects 205A, 205C, 205E, 205H, 248, 268, 273, 276, 278, and 287.

Project 205A: COLUMNS IN CONTINUOUS FRAMES

Sponsors: See 205

In the plastic design of steel rigid frames it is intended to utilize each member to its maximum carrying capacity. The primary purpose of the particular project on columns is to determine the maximum strength of those members in a rigid frame which are subjected to a combination of axial force and end-bending moments. The work required an evaluation of the effect of residual stresses and the various possible combinations of end-bending moments. In addition, the influence of lateral-torsional buckling must be evaluated and the rotation capacity at column ends is being investigated.

Solutions are being obtained by analytical and experimental means. The findings are intended to provide specification writers with aid in writing rational design rules, some parts already having been incorporated in the AISC Manual on plastic design.
Connections transmit forces from one member to the next, enabling the members to share in supporting the loads placed upon the structure. Studies have been made to obtain information on how to proportion corner connections for portal frames in order that they may meet the requirements imposed by their use in plastically designed structures. Tests of square, tapered, and curved corner connections have verified that they can be designed to have the proper strength, stiffness, and rotation capacity to serve their purpose.

Project 205C: CORNER CONNECTIONS

Sponsors: See 205

The problem of the local buckling of rolled wide-flange shapes in the plastic region has been solved insofar as the requirements of plastic design are concerned. Based on this work, design procedures have been set up to control the geometry of cross-section so that local failure does not prevent the formation of plastic hinges.

The second phase of this investigation is concerned with the post buckling strength and rotation capacity of beams subjected to uniform plastic moments or to a moment gradient. Experimental and theoretical research has shown that the member will develop a plastic hinge if the lateral bracing is spaced at forty-five times its minor radius of gyration or less. Current studies involve the determination of the critical spacing under moment gradient.
In a plastically designed structure, a member must undergo large inelastic rotations within the region of a "plastic hinge" so that the moments may be redistributed to develop the full strength of the structure. To achieve these large rotations, provision must be made to prevent the member from failing prematurely due to lateral-torsional buckling.

The purpose of this project is to determine practical means for bracing a member so that it can fully develop its ultimate strength. Currently experimental and theoretical studies are being conducted to evaluate the required strength and stiffness of lateral bracing such that the braced beam will deliver a plastic hinge. Various practical beam-purlin assemblies are studied experimentally.

Project 220A: RESIDUAL STRESS AND THE COMpressive ProperTIES OF STEEL

Sponsors: Bureau of Public Roads
Column Research Council
National Science Foundation
Pennsylvania Department of Highways

This program of research is aimed at answering fundamental questions about the behavior of steel columns. These are problems that have been of concern to designers and to specification-writing bodies ever since the advent of rolled and welded steel sections. When the research is completed, the design of steel columns will be based on a much more complete knowledge of their behavior, assuring safety with maximum possible economy.

The results have already been used in the writing of the Column Research Council Specification Guide and in the 1961 AISC specifications. Thus, they will become available to every designer of bridges, buildings and other structures. For related studies see projects 249 and 269.
Project 223: PRESTRESSED CONCRETE BRIDGE MEMBERS

Sponsors: Pennsylvania Department of Highways
Bureau of Public Roads
Reinforced Concrete Research Council
American Steel & Wire Division
United States Steel Corporation
American-Marietta Company
Concrete Products Division

This investigation includes two phases of work:
1. The Investigation of the Fatigue Failure of Prestressed Concrete Beams.
   The objective of this phase is to develop a method for determining the fatigue resistance of prestressed concrete flexural members under repeated cycles of loading of either constant or varied magnitude.

2. The Ultimate Strength of Prestressed Concrete Beams Under the Combined Action of Bending and Shear.
   The objective of this phase is to develop a procedure for design of web reinforcement.

Project 248: BUILT-UP MEMBERS IN PLASTIC DESIGN

Sponsor: Navy Department (Bureau of Ships)

Built-up members are very often used in practice, especially in ship structures. Typical examples are deck girders with openings, Vierendeel girders, and the like. The application of plastic design to such members offers some new problems. One of these is the inelastic stability of stiffened plate panels.

The purpose of this program is to investigate the effect of some important parameters, such as the intensity of lateral pressure and the distribution of residual stresses, on the stability of stiffened plate panels under axial compression. The results of experimental investigation will be analyzed in conjunction with theoretical studies and recommendations will be made for the design of ship bottom plating based on ultimate strength.
Project 249: WELDED BUILT-UP COLUMNS

Sponsors: See 220A

When columns are built up from separate plates by welding, they will not necessarily have the same strength as a similar rolled column. After a plate is welded, and allowed to cool, there will remain in the plate residual stresses which are due to the uneven cooling. Because of these stresses, certain portions of the cross section of a column have a decreased capacity for load, whereas other portions have an increased capacity. The residual stresses and their distribution in the cross section play a very important part in the strength of the column.

The position of the weld relative to the plates can either increase or decrease the effect of the residual stresses. It is the purpose of this project to show how plates should be welded together to produce a column with the maximum possible strength.

Project 251: WELDED PLATE GIRDERS

Sponsors: American Institute of Steel Construction
Bureau of Public Roads
Pennsylvania Department of Highways
Welding Research Council

Present design practice for plate girders is based on a theory that is inadequate in two respects. First, girders do not fail by sudden buckling as indicated in this theory. Second, the load-carrying capacity is considerably higher than that predicted by the theory currently in use. It is the aim of this project to study the stability and load-carrying capacity of welded plate girders and to provide information to be used to formulate more progressive design rules, thus permitting the use of more efficient and economical girders.

The results of an experimental investigation of the static behavior of girders subjected to bending, shear and combined bending and shear has been presented. A parallel theoretical investigation including design recommendations has recently been completed.

A program of fatigue study on welded plate girders has been started. Pilot tests show that girders built according to proposed design recommendations perform satisfactorily. These tests will be used in planning further investigations.

Other new areas of investigation include girders built of high strength steel and the effectiveness of longitudinal stiffeners.
Project 256: CONTINUOUS CONCRETE PAVEMENTS

Sponsors: Pennsylvania Department of Highways
           Bureau of Public Roads

The objective of this research is to develop a jointless concrete pavement with continuous longitudinal reinforcement which will control the width of transverse shrinkage cracks. Instrumentation has been developed to measure the stress, strain, temperature, deflection, etc. in service pavements constructed as experimental projects.

Results to date have permitted the establishment of some design limitations in pavement thickness, percentage of reinforcement, and sub-base construction.

Many people believe that this type of construction will provide a smooth, low maintenance pavement with a very long service life. Several states have installed these pavements during the past five years (Pennsylvania, Maryland, Texas, for example) and the experience to date has been encouraging.

Project 268: ROTATION CAPACITY REQUIREMENTS

Sponsors: See 205

Plastic analysis of steel structures depends on the ability of the members to form "plastic hinges" and to redistribute moments. In order for redistribution of moment to take place, certain plastic hinges must sustain their plastic moment through a certain angle of rotation. The amount of rotation required may affect the geometry of the structural shapes selected and the spacing of lateral bracing.

This project consists of theoretical studies predicting how much rotation capacity is required of plastic hinges in structures. Comparison of the theoretical requirements with the experimentally determined values assures that the required rotation can take place for the structures that have been studied up to the present time.
Project 269:  **COMPRESSIVE PROPERTIES OF LOW-ALLOY STEELS**

Sponsors:  See 220A

In the drive for economy, the strength of structural members should be exploited to the highest possible degree. This means that all of the influencing factors must be well known in order to assure the needed safety. One factor which only recently has come into the picture is the influence of stresses present in the unloaded member. These "locked-in" or residual stresses originate from temperature differences during the cooling process after rolling. They have been shown to influence the carrying capacity of mild steel columns. Theory predicts that in the low-alloy steels (yield point about 55 ksi) the residual stresses have relatively less influence than in ordinary structural steel (yield 33 ksi).

This project is intended to check these predictions. The positive results obtained so far suggest this additional advantage of using high-strength steel.

Project 271:  **LARGE BOLTED JOINTS**

Sponsors:  Bureau of Public Roads  
Pennsylvania Department of Highways  
Research Council on Riveted and Bolted Structural Joints

In recent years the High Strength Bolt has become the major fastener for field assembled structural connections. This rapid advance has been accelerated even more by recent changes (1960) in the design specification which allow higher shear stresses in bolts than in rivets. A big share of the necessary research was carried out at Fritz Laboratory. Tests were conducted on butt splices using 7/8", 1", and 1-1/8" A325 bolts. One inch plates were used in most of the tests. Theoretical studies showed good correlation with the tests. Continuing work on higher strength steels is being done as part of project 288.
The current investigation is limited to determining the influence of residual stresses on the strength of solid round sections. Their magnitude and distribution for different manufacturing processes such as quenching, tempering, air cooling, stress relieving and straightening will be determined. In addition, compression tests on short stub columns are conducted. Finally, column buckling tests are made. The results were compared to theoretical predictions considering the influence of residual stresses, and good correlation was obtained.

Project 273:  **MULTI-STORY FRAMES**

Sponsor:  See 205

In applying plastic theory to the design of multi-story building frames, the basic principles involved are the same as for single-story frames. However, certain factors such as frame stability and column behavior take on additional importance in multi-story frames. Also design techniques and procedures tend to become more complicated and should be simplified.

The general objective of this project is to obtain practical methods for the analysis and design of multi-story frames.
For simple frames, the load to cause formation of a mechanism is easily predicted by simple plastic theory. However, it is possible that "frame instability" may occur before attainment of the predicted ultimate load. By frame instability is meant that phenomenon in which a frame, unrestrained against sidesway at the column tops, will buckle as a unit. The columns which buckle in this form of failure are subjected to restraints at their connections and bases which have not been evaluated heretofore for the plastic range. This problem is of particular interest in the lower stories of multi-story buildings where the columns are most heavily loaded.

The purpose of this project is to determine, both theoretically and experimentally, the extent to which the simple plastic theory requires modification. The project will also develop methods for proportioning columns to assure the needed stability.

Project 276: FRAME STABILITY

Sponsors: See 205

Project 277: DREDGE PUMP EFFICIENCY

Sponsors: United States Army Engineers

The immediate purpose of the study is to improve design of a hopper dredge centrifugal pump silt-clay-water mixtures. The long-term objective is to determine the effect of Bingham Body-type of fluid on pumping characteristics. The project has been divided into four phases:

1. Model tests of the existing dredge pump
2. Recommendations for design changes of the dredge pump
3. Model investigation of the modified design of the dredge pump
4. Analysis of the investigation and final recommendations

Phase 1 involved installation in the hydraulic laboratory of a 1.8 scale model of the dredge pump now used on the United States Corps of Engineers dredge ESSAYONS. Water as well as silt-clay-water mixtures (Bingham Body-type of fluid) were pumped and complete characteristics of the pump obtained for capacity of 0 to 1200 gallons per minute, speed of 1150 to 1900 revolutions per minute, and liquid concentrations of 1000 to 1380 grams per liter. Phases 2 and 3 involve modifications in the shape of vane and changes in the exit vane angle of the impeller. Experimental tests indicate considerable improvement in pump efficiency.
Project 278: **RESTRAINED COLUMNS**

Sponsors: See 205

Individual columns in continuous frames are always restrained by beams and other columns. The effect of this restraint is to make the column in a frame stronger than it would be if no restraint existed. The purpose of this project is to determine the strength of restrained columns, and to develop design procedures for the design of columns in multi-story frames. The theoretical phases of this work have been completed. An experimental program is being planned.

Project 279: **COMPOSITE DESIGN FOR BUILDINGS**

Sponsor: American Institute of Steel Construction

Floor systems for buildings consisting of a concrete slab supported by steel beams have been improved in recent years by providing shear connectors between concrete slab and steel beams. These connectors, which are welded to the top flange of the steel beam, cause the concrete slab and steel beam to act together as a single unit in supporting live loads. This reduces vibrations and deflections in the floor system.

Studies of this type of construction have revealed that the strength of the concrete slab can be considered as reinforcing the steel beam, and the size of the steel beam can then be reduced as compared to non-composite construction. Considerable savings in the amount of steel required for a given building may be achieved in this way. Further studies of shear connectors for composite construction are being made to determine the maximum economy which can be obtained while maintaining adequate safety.
Project 280: **SPUR DIKES FOR BRIDGE ABUTMENTS**

**Sponsor:** Lehigh University Institute of Research
Modjeski and Masters, Consulting Engineers

**Analytical and Experimental** - The project has been divided into four phases: (A) Literature Survey; (B) Analytical Study; (C) Experimental study in a fixed-bed model to determine the desired lengths and shapes of spur dikes to provide uniform velocity distributions in the waterway between bridge abutments; (D) Experimental study in a movable-bed model to verify findings in part (C). A spur dike has been defined as a projection extending upstream from the bridge abutment.

Preliminary investigation indicates that a properly designed spur dike can produce a fairly uniform velocity distribution between the abutments.

Project 281: **POZZOLANIC REACTION OF COMMON SOIL MINERALS**

**Sponsor:** National Science Foundation

The supply of adequate base course material for pavements and slabs has been depleted, or is being rapidly depleted in many areas of the United States. In order to meet the needs for this vital material many states are importing this material to the critical areas, or looking for more economical means of providing a sub-base material that will be adequate for the climatic and traffic effects that will be imposed on it. Lime has been widely considered as an economical material capable of stabilizing most soils to produce an adequate base course material.

Although there have been many laboratory and field tests of soils stabilized with lime, there have been very few studies of the fundamental chemical and physical aspects of the process. This project deals with the chemical reaction of the lime with the various species of minerals that occur in soils and with the influence of the reaction product on the strength properties of the lime stabilized soil. Theoretically, if the mechanism of the reaction and the nature of the reaction products were better known, it might be possible to predict strength properties and to improve the results of the reaction.
Project 283: DREDGE PUMP DESIGN

Sponsor: National Bulk Carriers, Inc.

Suction-type dredging is an important method employed in dredging operations and other civil engineering works. The efficiency of a suction dredge pump depends on such variables as impeller and voluble design, and the mechanical analysis and concentration of material being pumped.

The National Bulk Carriers, Incorporated, have recently built in Japan a hopper dredge, S. S. "ZULIA". This vessel has four dredge pumps very similar to that of the United States Army Corps of Engineers dredge "ESSAYONS" except for certain modifications of the impeller, particularly the vane exit angle. No efficiency or head capacity curves are available for this particular pump.

The objective of the investigation is to obtain the efficiency and head capacity curves, to check the effect of the reduced vane exit angle, and to prove the efficiency of the dredge pump. Phases of the program include (1) 1:8 Model test with one concentration of silt-clay-water mixture, (2) A Model test with a modified impeller and using three concentrations of silt-clay-water mixtures, and (3) A Model test with previously established best impeller with three concentrations of sand-water mixtures.

Project 284: FATIGUE OF USS "T-l" STEEL

Sponsor: United States Steel Corporation

The useful life of a structure or a machine can be shortened considerably by a fracture phenomenon known as fatigue, the breaking of a material at a stress considerably less than its ultimate stress. Since the fatigue resistance of a material is a function of many variables, metallurgical structure, stress-state and history, residual stresses, etc., it is not possible at present to predict the fatigue life or strength of a structural or machine part unless the stress-fatigue life relationship for that particular part has been experimentally determined.

This project will determine the fatigue resistance of "T-l" steel, a quenched and tempered high-strength constructional steel, when fillet-welds are present.
Project 285: FATIGUE OF COMPOSITE BEAMS

Sponsor: American Institute of Steel Construction

This project is an outgrowth of Project 279, "Composite Beams for Buildings". In Project 279, the composite steel beam and concrete floor slab were subject to static loads. In this project the composite floor is subject to fatigue loadings in order to determine the ultimate strength of the shear connectors under fatigue loading.

Results of this project may provide a new basis for the design of bridge members and other composite members subjected to fatigue loading.

Project 286: COLUMNS REINFORCED BY WELDING COVER PLATES

Sponsor: American Institute of Steel Construction

Quite often in modern building construction it is desirable to load columns above the working loads which were the basis of the original design. Reinforcement becomes necessary to utilize such columns.

This investigation is concerned with the strength characteristics, during and after welding, of a steel H-column reinforced under load by the welding of cover plates to the flanges. The pilot program includes tests of stub columns and several actual columns together with the necessary residual stress measurements and other control tests. The results will show whether a major investigation is warranted to improve design procedures for such stub members.
Project 287: DESIGN OF BEAM-COLUMNS

Sponsor: American Institute of Steel Construction

The purpose of this project is to coordinate research results from other projects on inelastic instability (such as 205A, Columns in Continuous Frames; 278, Restrained Columns; etc.) and to explore uses for this information in practical design. The specific aim of the work is to broaden the scope of present beam-column specifications to include the latest research results. Design methods are being developed for beam-columns of various types of rolled and welded built-up shapes manufactured from structural carbon and high-strength steels.

Project 288: LARGE BOLTED JOINTS - HIGH STRENGTH STEELS

Sponsors: Bureau of Public Roads
Pennsylvania Department of Highways
Research Council on Riveted and Bolted Structural Joints
American Institute of Steel Construction
(Fort Pitt Bridge Works)

With increased use of high strength steels in construction during recent years the necessity to investigate their behavior when used with high strength bolts became apparent.

Current and future research at Lehigh will include investigations of high strength steels fastened with ASTM A325 bolts. Also, plans are being formulated for tests of high strength steel plate connected with ASTM A354 bolts.

This work is an outgrowth of Project 271. The initial studies on high strength steel determined the proper tension-shear ratio for "balanced design" when steel of 50,000 psi yield point was used with ASTM A325 bolts. The current project will involve experimental work utilizing half a butt joint, together with control tests to determine material properties. Also the theoretical aspects governing the joint performance will be investigated.

The purpose of this project is to develop methods of predicting the strength and performance of bolted joints. The project will also help to evolve design stresses for high strength steels (50,000 and 100,000 yield) and the two grades of high strength bolts.
Project 289: BAR-MAT LAP FAILURES IN PAVEMENTS

Sponsors: Pennsylvania Department of Highways
          Bureau of Public Roads

The objective of this project is to determine the optimum method for the placement of reinforcement in concrete pavement.

Several failures have occurred in service pavements where bar-mat reinforcement was lapped to maintain longitudinal continuity. Laboratory tests with short pavement slabs and simulated field conditions are used to compare the bond strength and tensile strength of the concrete and the reinforcement during the early life of a pavement.

These tests should also result in a better understanding of the shrinkage phenomena in long reinforced concrete structures.

Project 290: WELDED AND ROLLED "T-1" COLUMNS

Sponsor: United States Steel Corporation

The overall purpose of the research is to develop design information for welded box and H-sections (fabricated from "T-1" plates) and for rolled heat-treated angle and wide flange sections of "T-1" steel used in compression.

The phases of the research program are:
I. Basic Studies
   (a) Experimental and theoretical investigation of the magnitude and distribution of residual stresses in sections fabricated by welding heat-treated plates and in rolled heat-treated sections. The effect of stress relieving welded sections will also be investigated.
   (b) Experimental and theoretical investigation of local buckling for the study of the effect of residual stresses on local buckling.
II. Axially Loaded Columns
    Experimental and theoretical studies of axially loaded columns which include investigation of the effects of (1) residual stresses and (2) small amounts of out-of-straightness.
III. Beam Columns
    Experimental and theoretical investigations of columns subjected to both axial force and intentional bending moment.
Project 291: COMPOSITION OF SHIP STEELS

Sponsor: Bureau of Ships

The initial stage of this program which is currently being conducted consists of a study of the influence of dimensional changes in test specimens on brittle fracture transition temperature. The testing methods to be used are the Van der Veen test, the Bagsar test, and the drop-weight test. Initial tests will use a heat of ABS Class C normalized steel plate in 1, 2, and 3-inch thicknesses.

In the Van der Veen test, which is presently being conducted, the plate thickness serves as the width of the bend specimen while the height is normally constant at 2.76". However, the specimen height will be another variable in this investigation including 1/2 and 1/4 the standard height for all three plate thicknesses. Several series with other span lengths will also be tested. Both ductility and fracture transition temperatures will be determined.

Project 292: BEARING CAPACITY OF CAISSONS

Sponsor: Lehigh University Institute of Research

The purpose of this research project is to investigate aspects of the bearing capacity of caissons under different base conditions. The base conditions to be investigated will be for a caisson bearing directly on rock, and caissons socketed into rock with several socket designs.

The research will be divided into two phases. The first phase will be theoretical in nature and will consist of mathematical and photoelastic analyses. The second phase will consist of scale model tests of caissons to determine the validity of the analytical results.
The problem of wave propagation in river estuaries is exceedingly complex. Present methods of estimating the wave characteristics in vertical and horizontal transitions are not very accurate.

The purpose of this project is to study the transformation of gravity waves. The test will be performed under simplified conditions in a 70 foot long, 2 feet wide and 2 feet deep wave channel. The investigation is a theoretical and experimental study of the effects of gradual changes in the depth and width in a channel along with the effects of both shallow and deep water waves. It is hoped to extend the results of this study to more complicated geometrical systems in order to provide a method for predicting wave transitions in river estuaries.
## SUBJECT INDEX

<table>
<thead>
<tr>
<th>TITLE</th>
<th>PROJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Column Design</td>
<td>287</td>
</tr>
<tr>
<td>Bolted Joints</td>
<td>271, 288</td>
</tr>
<tr>
<td>Caissons, Bearing Capacity of</td>
<td>292</td>
</tr>
<tr>
<td>Columns Reinforced with Welded Cover Plates</td>
<td>286</td>
</tr>
<tr>
<td>Columns, Restrained</td>
<td>278</td>
</tr>
<tr>
<td>Columns, Welded - Built-up</td>
<td>249</td>
</tr>
<tr>
<td>Columns, Welded - Built-up and Rolled &quot;T-1&quot;</td>
<td>290</td>
</tr>
<tr>
<td>Composite Beams, Fatigue of</td>
<td>285</td>
</tr>
<tr>
<td>Composite Design for Buildings</td>
<td>279</td>
</tr>
<tr>
<td>Concrete Pavements, Continuous</td>
<td>256</td>
</tr>
<tr>
<td>Concrete, Prestressed Bridge Members</td>
<td>223</td>
</tr>
<tr>
<td>Connections, Corner</td>
<td>205C</td>
</tr>
<tr>
<td>Dredge Pump Design</td>
<td>283</td>
</tr>
<tr>
<td>Dredge Pump Efficiency</td>
<td>277</td>
</tr>
<tr>
<td>Fatigue of Composite Beams</td>
<td>285</td>
</tr>
<tr>
<td>Fatigue of USS &quot;T-1&quot; Steel</td>
<td>284</td>
</tr>
<tr>
<td>Frames, Columns in Continuous</td>
<td>205A</td>
</tr>
<tr>
<td>Frames, Lateral Bracing Requirements</td>
<td>205H</td>
</tr>
<tr>
<td>Frames, Multi-Story</td>
<td>273</td>
</tr>
<tr>
<td>Frame Stability</td>
<td>276</td>
</tr>
<tr>
<td>Frames, Welded - Continuous and Their Components</td>
<td>205</td>
</tr>
<tr>
<td>Girders, Plate Welded</td>
<td>251</td>
</tr>
<tr>
<td>Gravity Waves in Constrictions</td>
<td>293</td>
</tr>
<tr>
<td>High-Strength Steel</td>
<td>269, 272, 284, 288, 290</td>
</tr>
<tr>
<td>Instability, Inelastic</td>
<td>205E</td>
</tr>
<tr>
<td>Pavements, Bar-Mat Lap Failure in</td>
<td>289</td>
</tr>
<tr>
<td>Plastic Design, Built-up Members in</td>
<td>248</td>
</tr>
<tr>
<td>Plastic Design, Welded Continuous Frames and Their Components</td>
<td>205</td>
</tr>
<tr>
<td>Plate Girders, Welded</td>
<td>251</td>
</tr>
<tr>
<td>Pozzolanic Reaction on Common Soil Minerals</td>
<td>281</td>
</tr>
<tr>
<td>Residual Stress</td>
<td>220A, 249, 290</td>
</tr>
<tr>
<td>Rotation Capacity Requirements</td>
<td>268</td>
</tr>
<tr>
<td>Ship Steel</td>
<td>291</td>
</tr>
<tr>
<td>Spur Dikes</td>
<td>280</td>
</tr>
<tr>
<td>Steel, Composition for Ship</td>
<td>291</td>
</tr>
<tr>
<td>Steel, Compressive Properties of Low-Alloy</td>
<td>269</td>
</tr>
<tr>
<td>Steel, Fatigue of USS &quot;T-1&quot; Steel</td>
<td>284</td>
</tr>
<tr>
<td>Steel, High Strength &quot;T-1&quot;</td>
<td>272</td>
</tr>
<tr>
<td>&quot;T-1&quot; Steel</td>
<td>272, 284, 290</td>
</tr>
<tr>
<td>SPONSOR</td>
<td>PROJECT</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>AMERICAN INSTITUTE OF STEEL CONSTRUCTION</td>
<td>205, 205A, 205C, 205E, 205H, 251, 268, 273, 276, 278, 279, 285, 286, 287, 288</td>
</tr>
<tr>
<td>AMERICAN IRON AND STEEL INSTITUTE</td>
<td>205, 205A, 205C, 205E, 205H, 268, 273, 276, 278</td>
</tr>
<tr>
<td>AMERICAN-MARIETTA COMPANY</td>
<td></td>
</tr>
<tr>
<td>Concrete Products Division</td>
<td>223</td>
</tr>
<tr>
<td>AMERICAN STEEL &amp; WIRE DIVISION</td>
<td></td>
</tr>
<tr>
<td>United States Steel Corporation</td>
<td>223</td>
</tr>
<tr>
<td>BUREAU OF PUBLIC ROADS</td>
<td></td>
</tr>
<tr>
<td>COLUMN RESEARCH COUNCIL</td>
<td>220A, 223, 249, 251, 256, 269, 271, 288, 289</td>
</tr>
<tr>
<td>FORT PITT BRIDGE WORKS</td>
<td>220A, 249, 269</td>
</tr>
<tr>
<td>LEHIGH UNIVERSITY</td>
<td></td>
</tr>
<tr>
<td>Institute of Research</td>
<td>280, 292, 293</td>
</tr>
<tr>
<td>MODJESKI &amp; MASTERS</td>
<td></td>
</tr>
<tr>
<td>Consulting Engineers</td>
<td>280</td>
</tr>
<tr>
<td>NATIONAL SCIENCE FOUNDATION</td>
<td>220A, 249, 269, 281</td>
</tr>
<tr>
<td>NATIONAL BULK CARRIERS INC</td>
<td>283</td>
</tr>
<tr>
<td>NAVY DEPARTMENT</td>
<td></td>
</tr>
<tr>
<td>Bureau of Ships</td>
<td>205, 205A, 205C, 205E, 205H, 248, 268, 273, 276, 278, 291</td>
</tr>
<tr>
<td>Bureau of Yards and Docks</td>
<td></td>
</tr>
<tr>
<td>Office of Naval Research</td>
<td></td>
</tr>
<tr>
<td>PENNSYLVANIA DEPARTMENT OF HIGHWAYS</td>
<td>220A, 223, 249, 251, 256, 269, 271, 288, 289</td>
</tr>
<tr>
<td>REINFORCED CONCRETE RESEARCH COUNCIL</td>
<td>223</td>
</tr>
<tr>
<td>RESEARCH COUNCIL ON RIVETED &amp; BOLTED</td>
<td>271, 288</td>
</tr>
<tr>
<td>STRUCTURAL JOINTS</td>
<td></td>
</tr>
<tr>
<td>UNITED STATES ARMY ENGINEERS</td>
<td>277</td>
</tr>
<tr>
<td>WELDING RESEARCH COUNCIL</td>
<td>205, 205A, 205C, 205E, 205H, 251, 268, 273, 276, 278</td>
</tr>
</tbody>
</table>
CURRENT RESEARCH PROJECTS

Description
and
Bibliography

Fritz Engineering Laboratory
Department of Civil Engineering
Lehigh University
Bethlehem, Pa.

March 1964

237.17 (64)
<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>205</td>
<td>WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS</td>
</tr>
<tr>
<td>205A</td>
<td>COLUMNS IN CONTINUOUS FRAMES</td>
</tr>
<tr>
<td>205H</td>
<td>LATERAL BRACING REQUIREMENTS</td>
</tr>
<tr>
<td>223</td>
<td>PRESTRESSED CONCRETE BRIDGE MEMBERS</td>
</tr>
<tr>
<td>248</td>
<td>BUILT-UP MEMBERS IN PLASTIC DESIGN</td>
</tr>
<tr>
<td>249</td>
<td>WELDED BUILT-UP COLUMNS</td>
</tr>
<tr>
<td>273</td>
<td>MULTI-STORY FRAMES</td>
</tr>
<tr>
<td>276</td>
<td>FRAME STABILITY</td>
</tr>
<tr>
<td>278</td>
<td>RESTRAINED COLUMNS</td>
</tr>
<tr>
<td>284</td>
<td>FATIGUE OF USS &quot;T-1&quot; STEEL</td>
</tr>
<tr>
<td>285</td>
<td>FATIGUE OF COMPOSITE BEAMS</td>
</tr>
<tr>
<td>288</td>
<td>LARGE BOLTED CONNECTIONS</td>
</tr>
<tr>
<td>289</td>
<td>BAR-MAT LAP FAILURES IN PAVEMENTS</td>
</tr>
<tr>
<td>290</td>
<td>WELDED AND ROLLED &quot;T-1&quot; COLUMNS</td>
</tr>
<tr>
<td>291</td>
<td>COMPOSITION OF SHIP STEELS</td>
</tr>
<tr>
<td>296</td>
<td>HOLLOW STRUCTURAL TUBING</td>
</tr>
<tr>
<td>297</td>
<td>PLASTIC DESIGN IN HIGH STRENGTH STEELS</td>
</tr>
<tr>
<td>301</td>
<td>DREDGE PUMPS AND DREDGING SYSTEMS</td>
</tr>
<tr>
<td>302</td>
<td>BIBLIOGRAPHY ON BOLTED AND RIVETED STRUCTURAL JOINTS</td>
</tr>
<tr>
<td>303</td>
<td>FATIGUE STRENGTH OF WELDED PLATE GIRDERDS</td>
</tr>
<tr>
<td>304</td>
<td>LONGITUDINALLY STIFFENED PLATE GIRDERDS</td>
</tr>
<tr>
<td>305</td>
<td>HYBRID STEEL COLUMNS</td>
</tr>
<tr>
<td>306</td>
<td>HORIZONTAL SHEAR CONNECTION IN COMPOSITE BEAMS</td>
</tr>
<tr>
<td>307</td>
<td>IMPACT TESTS OF BRIDGE RAIL</td>
</tr>
<tr>
<td>308</td>
<td>NON-CIRCULAR CYLINDRICAL SHELLS</td>
</tr>
<tr>
<td>309</td>
<td>BOND BETWEEN CONCRETE AND PRESTRESSING STRAND</td>
</tr>
<tr>
<td>310</td>
<td>GAS REMOVAL ASSOCIATED WITH DREDGE PUMPS</td>
</tr>
<tr>
<td>311</td>
<td>FRACTURE MODE TRANSITION OF MILD STEEL</td>
</tr>
<tr>
<td>312</td>
<td>SURVEY OF CURRENT STRUCTURAL RESEARCH</td>
</tr>
<tr>
<td>313</td>
<td>MODELS FOR THREE-DIMENSIONAL STRUCTURES</td>
</tr>
</tbody>
</table>

BIBLIOGRAPHY

PROJECTS LISTED BY DIVISION

AUTHOR INDEX

SUBJECT INDEX

SPONSOR INDEX
Since its founding in 1909 Fritz Engineering Laboratory has advanced knowledge and techniques in the field of Civil Engineering through its research programs and industrial testing facilities. Modernization of the Laboratory in 1954-55 enabled the University to continue to provide the finest facilities for research in the fields of structures, materials, hydraulics, structural model analysis, soil mechanics and sanitation. Fritz Laboratory is a part of the Department of Civil Engineering.

The laboratory facilities are housed in two inter-connected units—a four-story unit and a seven-story unit. Ready access to the main testing areas is provided to facilitate the delivery of large and heavy equipment. With the available testing machines and special accessories, large structural members can be tested statically or dynamically. A research library is maintained where current reports from laboratories throughout the world are available for study.

Through its Institute of Research, Lehigh University contracts with research councils, industrial concerns, or associations to undertake cooperative research. The sponsor is expected to pay all costs plus a reasonable percentage for overhead. At least a one-year duration is expected on such projects, and publication of results in technical magazines is normally anticipated. About half of the research is sponsored by industry and half by government agencies.

Investigations have ranged from studies of material properties and characteristics up to tests of full-size structures for buildings and bridges. Structural steel research programs have improved design procedures by this approach. Specifications of the American Association of State Highway Officials, American Institute of Steel Construction, Association of Iron and Steel Engineers, and American Railway Engineering Association have been revised as a direct result of research projects.

In the following pages, the current research projects are described. A bibliography of reports on these projects is also included.

Head of Department of Civil Engineering and Fritz Engineering Laboratory
W. J. Eney
Director of Fritz Engineering Laboratory
Lynn S. Beedle
Engineer of Tests
R. G. Slutter
Hydraulics
J. B. Herbich
Sanitary
W. P. Isaacs
Soil Mechanics
R. J. Leonard
Structural Concrete
C. L. Hulsbos
Structural Metals
George C. Driscoll
Structural Models
L. W. Lu (Acting)
Project 205: WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS
(PLASTIC DESIGN)

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
United States Navy Department
Welding Research Council

The general objectives of this research are to develop methods for predicting the ultimate load-carrying capacity of continuous steel structures and to develop practical design procedures for utilizing the reserve plastic strength. Such procedures must take into account such additional factors as fatigue, deflections, brittle fracture, local buckling, lateral buckling, etc., and this is being done on the project.

Results to date have shown that the plastic theory may be applied to the design of continuous beams and single-story industrial frames. Manuals and commentaries have been prepared to assist the designer of these structures. Research has also shown that the plastic theory shows promise for application to the design of other classes of structures, such as multi-story buildings and component parts of ships.

Test of full-size frame verifies plastic design theory
Project 205A: **COLUMNS IN CONTINUOUS FRAMES**

Sponsor: American Institute of Steel Construction  
American Iron and Steel Institute  
Column Research Council (Advisory)  
United States Navy Department  
Welding Research Council

In the plastic design of steel rigid frames it is intended to utilize each member to its maximum carrying capacity. The primary purpose of the particular project on columns is to determine the maximum strength of those members in a rigid frame which are subjected to a combination of axial force and end-bending moments. The work requires an evaluation of the effect of residual stresses and the various possible combinations of end-bending moments. In addition, the influence of lateral-torsional buckling must be evaluated and the rotation capacity at column ends is being investigated.

Solutions are being obtained by analytical and experimental means. The findings are intended to provide specification writers with aid in writing rational design rules, some parts already having been incorporated in the AISC Manual on plastic design.
Project 205H: LATERAL BRACING REQUIREMENTS

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
United States Navy Department
Welding Research Council

In a plastically designed structure, a member must undergo large inelastic rotations within the region of a "plastic hinge" so that the moments may be redistributed to develop the full strength of the structure. To achieve these large rotations, provision must be made to prevent the member from failing prematurely due to lateral-torsional buckling.

The purpose of this project is to determine practical means for bracing a member so that it can fully develop its ultimate strength. Currently experimental and theoretical studies are being conducted to evaluate the required strength and stiffness of lateral bracing such that the braced beam will deliver a plastic hinge. Various practical beam-purlin assemblies are studied experimentally.

Static test of beam laterally supported at the third points
Project 223: PRESTRESSED CONCRETE BRIDGE MEMBERS

Sponsors: Pennsylvania Department of Highways
Scientific Research Council

This project was established to develop fundamental information for evaluating the behavior of prestressed concrete beams. Work has consisted primarily of studies in three areas:

1. Bond characteristics of steel strand.
2. Fatigue resistance of strand and concrete.
3. Ultimate strength under combined moment and shear.

Studies of the bond characteristics and the fatigue resistance have been completed. The study of bond characteristics between strand and concrete resulted in the establishment of design criteria for insuring adequate safety against a bond failure, and contributed to the acceptance of the larger sized 7/16 in. diameter strand in prestressing work. The study of fatigue resistance resulted in development of procedures for predicting the flexural fatigue life of prestressed beams.

Currently under study is the ultimate strength of prestressed beams under the combined action of moment and shear, i.e. shear strength. Earlier work on prestressed beams without web reinforcement evaluated such specific variables as the effect of variation in magnitude of the prestressing force and size of the prestressing elements, length of bearing at the reaction, and the effect of existing inclined cracks. From this work an analytical method for determining the shear compression strength of prestressed beams without web reinforcement was developed. At the present time tests are being carried out on prestressed I-beams with web reinforcement to determine and evaluate the significant factors causing inclined cracking, and to determine the variation in ultimate shear strength with amount of web reinforcement and length of shear span. The objective of this work is to develop criteria for design of web reinforcement.
Project 248: **BUILT-UP MEMBERS IN PLASTIC DESIGN**

Sponsors: United States Navy Department

Built-up members are very often used in practice, especially in ship structures. Typical examples are deck girders with openings, Vierendeel girders, and the like. The application of plastic design to such members offers some new problems. One of these is the inelastic stability of stiffened plate panels.

The purpose of this program is to investigate the effect of some important parameters, such as the intensity of lateral pressure and the distribution of residual stresses, on the stability of stiffened plate panels under axial compression. The results of experimental investigation will be analyzed in conjunction with theoretical studies and recommendations will be made for the design of ship bottom plating based on ultimate strength.

[Diagram of ship bottom panel with labels for Longitudinal Stiffener and Transverse Frame, showing loading on the ship bottom panel due to wave action - Hoggings]
Project 249: WELDED BUILT-UP COLUMNS

Sponsors: Pennsylvania Department of Highways
Bureau of Public Roads
Column Research Council

Columns used in tall multi-story buildings carry extremely high axial loads. These loads far exceed the carrying capacity of the largest available rolled shape so that a need for welded columns arises. The fabrication of column sections by welding sets up residual stresses different from the stresses found in rolled shapes. This results in a difference between the load carrying capacity of the welded shape and the rolled shape. The object of this research is to study the behavior of welded built-up columns as influenced by cross-sectional shape, thickness of component plates, weld size, use of hybrid shapes, and different methods of fabrication.

Early tests on small and medium-size welded shapes indicate that at medium range of slenderness ratios these shapes exhibit a column strength which is considerably less than that of a corresponding rolled shape. The investigation has been extended to welded shapes made up of thick plates (one to three inches or more).

Stub column test of a built-up member
Project 273: **MULTI-STORY FRAMES**

Sponsors: American Institute of Steel Construction  
American Iron and Steel Institute  
Column Research Council (Advisory)  
United States Navy Department  
Welding Research Council

In order to apply plastic theory to the design of multi-story building frames, the assumptions implied in the existing plastic theories must be studied in detail. The effect of axial forces and secondary moments due to deflections cannot be neglected as in the analysis and design of single-story frames. The instability of restrained columns and of entire frames becomes the overriding concern. It is known that only in cases where the combination of compressive forces and deflections results in negligible effects can the simplifying assumptions of simple plastic theory be used.

The general purpose of this project is to develop methods for 1) Predicting the ultimate strength of multi-story frames subjected to various combinations of loads and 2) Designing such frames based on their ultimate strength. Both braced and unbraced frames are being studied. To verify the developed theories, experiments involving full-scale multi-story, multi-bay frames will be conducted.
Project 276: FRAME STABILITY

Sponsors: American Institute of Steel Construction
          American Iron and Steel Institute
          Column Research Council (Advisory)
          United States Navy Department
          Welding Research Council

For simple frames, the load to cause formation of a mechanism is easily predicted by simple plastic theory. However, it is possible that "frame instability" may occur before attainment of the predicted ultimate load. Frame instability is that phenomenon by which a frame, unrestrained against sidesway at the column tops, buckles as a unit. The columns which buckle in this form of failure are subjected to restraints at their connections and bases which have not been evaluated heretofore for the plastic range. This problem is of particular interest in the lower stories of multi-story buildings where the columns are most heavily loaded.

The purpose of this project is to determine, both theoretically and experimentally, the extent to which the simple plastic theory requires modification. The project will also develop methods for proportioning columns to assure the needed stability.

Test of scale model multi-story frame
Project 278: RESTRAINED COLUMNS

Sponsors: American Institute of Steel Construction
          American Iron and Steel Institute
          Column Research Council (Advisory)
          United States Navy Department
          Welding Research Council

Individual columns in continuous frames are always restrained by beams and other columns. The behavior of individual columns has been extensively investigated. However, in order to determine the strength of the structure as a whole, the structure may be broken down into typical units. These units may then be analyzed and combined to give a good indication of the strength. A theoretical solution to the restrained column problem has been completed including the effect of sidesway action.

A typical test unit is shown below consisting of a column restrained by beams framing into it at top and bottom.
Project 284: FATIGUE OF USS "T-1" STEEL

Sponsors: United States Steel Corporation

The useful life of a structure or a machine can be shortened considerably by fatigue. In recent years, with the introduction of the constructional quenched and tempered alloy steel "T-1", studies have been made on the fatigue resistance of plain specimens with various surface conditions, specimens butt-welded by various processes and plate specimens cyclically loaded in the plastic range.

The objective of the test program is to study the fatigue resistance of non-load-carrying longitudinal fillet welds such as the flange-to-web fillet weld in the pure moment region of a welded built-up girder. Instead of testing only built-up beams under cyclic loading, it was decided to test small axially loaded welded specimens which simulated the critical region of the beam. Similitude would then be verified by testing beams of similar geometric proportions.
Project 285: **FATIGUE OF COMPOSITE BEAMS**

Sponsors: American Institute of Steel Construction

The purpose of this project is to determine the fatigue strength of the shear connectors due to repeated loading of the composite section, and to investigate various aspects concerning the spacing of shear connectors.

Results of this project may provide a new and more economical basis for the design of bridge members and other composite members subjected to fatigue loading.
Phase I:

In order that the behavior of a structural joint under load may be predicted, the properties of the individual bolts must be determined. A series of standard tests are carried out on a representative sample of bolts from a given bolt lot to determine the mean load-elongation characteristics for the lot. These include direct tension tests, torqued tension tests, and tests to determine the double shear strength of the bolts.

In the direct tension tests the bolt is simply pulled apart. Calibration in torqued tension requires turning the nut against a specified grip resistance until the bolt fractures in combined tension and shear. The double shear strength of a single bolt is determined by loading the bolt in the "jig" (shown below) until it shears at either, or both, ends.

Torqued Tension
Direct Tension
Double shear test of single bolt
Phase II:

With the increased use of high strength steels in construction during recent years, the necessity to investigate their behavior when used in joints connected with high strength bolts became apparent. Consequently the work at Lehigh is now concerned with the behavior of A440 and T-1 steel joints fastened with A325 or A490 high strength bolts. The results from the tests are being used to verify a theoretical method of predicting the strength and performance of any joint.
Project 289: REINFORCEMENT LAP FAILURES IN CONTINUOUSLY REINFORCED CONCRETE PAVEMENTS

Sponsors: Pennsylvania Department of Highways
Bureau of Public Roads

Several failures in some of the first experimental continuously reinforced concrete pavements were observed in the region of the laps in the reinforcement, suggesting the need for more information concerning the structural behavior of continuous pavements in the lap region. In this project, two series of slabs will be investigated experimentally in an attempt to prevent failures from occurring in the lap regions. Two different types of steel reinforcement will be used in the test specimens. One series will be reinforced with bars, the other with welded wire fabric.

The test specimens will be axially loaded during a three-day period in a loading sequence designed to simulate the effects of critical atmospheric temperature changes in the early life of a pavement slab. Judgment of the lap adequacy will be based on the performance during the three-day loading period and on an ultimate load test.
The overall purpose of this research is to develop design criteria for welded box and H sections as well as for rolled heat-treated angle and wide flange sections, of "T-1" steel used in compression.

Phase I: BASIC STUDIES

Preceding the investigation of the compression strength of specific members it is necessary, and important, to obtain more basic knowledge on material properties. The most important of these are the stress-strain relationships, yield stress level and modulus of elasticity. The magnitude and distribution of residual stresses which exist in the members are also of importance.

Figure 1, below, shows typical residual stress patterns for welded plates, sections fabricated by welding, and rolled heat-treated sections.
Because of the high yield stress of "T-1" steel, local instability plays a more important role in the failure mechanism of compression members fabricated from the steel than it does in structural mild steel. This phase includes experimental and theoretical studies with emphasis placed on the effect of residual stresses on local buckling. Preliminary analysis shows that these residual stresses do have a significant effect on the buckling strength of the member, both in the elastic and inelastic range.

Design recommendations for the width-thickness ratio of the component plates used in the fabrication of the member will be the final result of this phase.
Project 290: WELDED AND ROLLED HEAT-TREATED "T-l" COLUMNS

Phase III: CENTRALLY LOADED COLUMNS

Experimental and theoretical studies of centrally loaded columns are carried out to determine the effect of residual stresses and small amounts of out-of-straightness on their behavior. Preliminary study has shown the effects of residual stress on the strength of the column was rather small compared with columns of constructional mild steel. This is especially true for rolled heat-treated sections.

The theoretical analysis includes a study of the possible torsional buckling modes in addition to the failure by flexure buckling. It is expected that torsional behavior will play an important role in the failure mode of angle or tee sections which are axially loaded.

The analysis will be extended to the strength of beam columns subjected to axial force and bending.
Phase I:

Specimen geometry was studied to determine what effect specimen dimensions would have on determining transition temperatures. It was found that increasing plate thickness was a definite factor in raising the transition temperature of plates up to two inches thick, but had little effect on plates thicker than two inches.

This was found to be true on a variety of tests run. These tests were the van der Veen (see fig. 3), the modified Naval Drop-Weight test (see fig. 1), and the Bagsar test (see fig. 2). All three tests gave similar results as to the effect of specimen geometry on transition temperature.
Project 291: BRITTLE FRACTURE INVESTIGATIONS ON SHIP STEEL COMPOSITION

Phase II:

With the van der Veen test being selected as a suitable brittle fracture test, investigations are continuing with tests on a variety of steels to select an "optimum" steel.

Bethlehem Steel "ABS-Class C" normalized, United States Steel "T-1", and Lukens Steel "LT-75" in the normalized, quenched, and quenched and tempered conditions have been tested to determine the effect of heat treatment as well as specimen geometry. Metallurgical effects of the various plates have also been investigated.

Weldability tests will be run as well as an investigation concerning variables of the van der Veen test.

Van der Veen Test

Fig. 3
Project 296: HOLLOW STRUCTURAL TUBING

Sponsors: National Tube Division, United States Steel

The purpose of the investigation is to study the behavior of columns made of hot-rolled structural tubing (square and rectangular cross-section) of A36 steel, particularly in relation to the strength of equivalent rolled H-shapes and of similar columns fabricated by welding.

The program includes the testing of ten columns with slenderness ratios varying from 30 to 100. The material and cross-sectional properties are determined through preliminary tests which include tensile coupon tests, residual stress measurements, and stub column tests.

Preliminary results indicate that the hot-rolled box shapes have negligible residual stresses and, therefore, exhibit better column characteristics than the WF or welded shapes.
Project 297: PLASTIC DESIGN IN HIGH STRENGTH STEELS

Sponsors: American Institute of Steel Construction
          American Iron and Steel Institute
          Column Research Council (Advisory)
          United States Navy Department
          Welding Research Council

With the wide acceptance of high strength steels, it was found desirable to also investigate the inelastic behavior of members and frames made out of higher strength steels, notably steels in the 50 ksi yield strength range.

The purpose of this project is to investigate the applicability of available research information to high strength steels and to provide new results where these are necessary.

Current work consists of the determination of the material properties and an investigation of local and lateral buckling problems. The work is being performed by means of experiments and also through theoretical investigation.

Bending test of high strength steel beam laterally supported
Project 301: DREDGE PUMP RESEARCH

Sponsor: Ellicott Machine Corporation

A contract between the Lehigh University Institute of Research, the Fritz Engineering Laboratory Hydraulics Division, and the Ellicott Machine Corporation provided for a performance study of a model dredge pump one sixth of actual size.

The objective of this investigation is to determine experimentally the operating characteristics of a one to six model dredge pump and the performance of a dredging system as it is influenced by the materials handled, suction head losses, size of impeller diameter, and impeller speeds.

The centrifugal pump and suction line assembly is a one to six scale model of the operating dredge "Alaska". The pump test stand assembly consists of a storage tank, suction pipeline, pump, and discharge line, all connected in a continuous flow loop. Exterior to this flow system is the motor which drives the model pump.

The experimental program enables investigators to construct characteristic curves (Head in feet of water Vs. Flow in gallons per minute, Efficiency Vs. Flow, and Brake Horsepower Vs. Flow) and cavitation curves (Total Head in feet of water Vs. Suction Head in feet of water). It is hoped these curves will lead to proper selection of pumps and design improvements.

Scale model dredging system
Since the Research Council on Riveted and Bolted Structural Joints was formed in 1947 much research has been conducted and reported. It is evident from the review of publications, and in light of the continuing program of research, that a comprehensive bibliography should be prepared on the subject of bolted and riveted structural joints.

The objective of this project is to provide informative abstracts of the work on bolted and riveted joints which was done between De Jorge's survey (up to 1944) and the initiation of the ASCE Information Retrieval Program in January 1963.

Below is a typical abstract of a paper written about connections:

**KEY WORDS:** bolts; connections; steel; structural engineering; testing

**ABSTRACT:** Direct tension and torqued tension tests of 170 A325 bolts were carried out to determine the behavior and performance of individual A325 bolts. The major variables studied in the program included the effect of thread length between the thread run-out and the face of the nut, the effect of grip, continuous and incremental torquing, and reserve strength in tension after torquing. The behavior and performance of the bolts is examined, and typical data are presented. The results are related to the current "Specification for Structural Joints Using ASTM A325 Bolts" and have influenced the amount of nut rotation required when the turn-of-nut method of tightening is used. For usual grips, the grip length was found to have no appreciable effect on the load-elongation characteristics when the length of thread under the nut was approximately the same. Nut rotations greater than one-half turn from snug yielded little additional clamping force. Decreasing the amount of exposed thread under the nut results in a decrease in the deformation capacity of the bolt.

Project 303: FATIGUE STRENGTH OF WELDED PLATE GIRDER

Sponsor: American Iron and Steel Institute
American Institute of Steel Construction
U. S. Bureau of Public Roads
Pennsylvania Department of Highways
Welding Research Council

The objective of this project is to investigate the fatigue strength of plate girders. Previous studies indicate that tension field action and redistribution of stresses in webs contribute to girder static strength which can be utilized in the design of building girders. The significance of the static strength for bridge girders is being examined both experimentally and analytically.

Seven slender web plate girders have been tested, five under high shear and two under pure bending. Data obtained are being analyzed. To determine fatigue properties of flange web joints, small tee-shaped specimens are tested in repeated web bending. These and results of other tests will be used in the analytical study.

The ultimate aim is the formulation of design standards for safe and economical bridge girders.
The objective of this project is to investigate the possible contribution of longitudinal stiffeners to the static load-carrying capacity of plate girders and to make recommendations that would be useful in translating the results into design rules.

Previous theoretical and experimental research on transversely stiffened plate girders has indicated that the load-carrying capacity of a girder is not directly related to the theoretical web buckling load. Although current design practice with regard to longitudinal stiffeners is based on a buckling analysis, it is expected that the load-carrying capacity of a longitudinally stiffened girder also is not directly related to the theoretical buckling load.
Project 305: HYBRID STEEL COLUMNS

Sponsor: Pennsylvania Department of Highways
Column Research Council

Hybrid steel shapes are those built up by welding together different types of steels. The availability of a number of constructional steels has enabled the engineer to design a variety of hybrid members. A hybrid shape has the advantage that the stronger material can be utilized in regions of high stress and the material of lower yield can be used in the lower stressed regions.

This project is a pilot study which will explore the feasibility of using hybrid shapes as columns. Column shapes are built up of "T-1", A441 and A36 steels. Residual stress measurements are made; stub column tests and pinned ended column tests are conducted to evaluate the strength of hybrid columns. A theoretical analysis is also made and verified by the results of the tests.

Fabrication of a Hybrid H-shape with "T-1" steel flanges and A441 web
A study of the requirements for the connection between a precast concrete web and a cast-in-place slab under static loading has been completed at the University of Wisconsin. A series of tests will be conducted at Fritz Lab to evaluate the behavior of the horizontal shear connection under repeated loads.

The variables include:

a) Roughness of the contact surface of the beam. A retarding agent is used to enable brushing out the mortar between the pieces of coarse aggregate to obtain a so-called intermediate finish; a rough finish is produced by removing particles of coarse aggregate with boards having nails protruding approximately 3/4".

b) Ratio of shear span to effective depth. Beam spans of 8 feet and 20 feet will be used.

c) Percentage of shear connection reinforcement. Two percentages of steel will be used.

In any test in which a failure under repeated load does not occur with at least 2,000,000 cycles, the beam will be loaded to failure with a static load.

In light of the results of the static investigation, it is felt that the repeated load tests will justify reductions in requirements for shear connections subjected to repeated loads. It is expected that these results will be reflected in specifications for bridge structures.
Opinions throughout the country are divergent concerning the "proper" design of safety railings for highways and highway bridges.

In attempting to select railing designs which are safe, economical, and otherwise acceptable, the effectiveness of presently used and proposed rail configurations has been investigated by subjecting rails to impact tests. These tests are run using radio controlled cars at high speed, and have been conducted, among other places, in California, New York, and here at Lehigh.

Project 307 is a continuation of a previous Lehigh testing program, but with tests being conducted specifically on aluminum bridge railings. Along with the impact tests, a comprehensive survey of designs, specifications and railing test procedures will be conducted in an attempt to evaluate the present state of the bridge and guard rail design problems.
Whereas there are many analytical and tabular methods of analyzing circular cylindrical shells, non-circular shells offer such difficulties that analysis is available only for a few simple shapes. The purpose of this project is to develop a numerical procedure for the analysis of cylindrical shells of a non-circular shape subjected to an arbitrarily distributed loading. The analysis is performed by means of finite differences and a complex force is used as the variable instead of displacements.
Project 309: BOND BETWEEN CONCRETE AND PRESTRESSING STRAND

Sponsors: Pennsylvania Department of Highways
Bureau of Public Roads

The recent development of a new high-strength prestressing strand has created the need for information on the structural behavior of concrete flexural members prestressed with this new strand. One of the main factors which influences flexural behavior is the bond between the concrete and prestressing steel. Knowledge of the transfer bond is important in determining stresses in the early life of the member, and later, in determining the ability of the member to develop anchorage up to the ultimate strength. Flexural bond, which is significant prior to cracking, becomes of major importance when flexural cracking occurs. As the cracks develop, greatly increased bond stresses are produced. These stresses move nearer to the ends of the member as the ultimate load is approached, and have a definite effect on the mode of ultimate failure.

The main objective of this investigation will be the study of flexural bond. To date, the major studies have involved static load tests of members prestressed with strand of normal strength. In this study, 1/2 in. high-strength strand will be investigated. In the first phase, a series of specimens will be subjected to static loading to establish (1) the development of flexural bond stresses, and (2) the effect of this development on overall flexural behavior. A second series of specimens will be used to determine the effect of repeated loads on flexural bond characteristics. All of the specimens will be beams loaded as shown below.

A supplemental phase of the investigation will be a pilot study of the effect of low temperature on the fatigue life of the 1/2 in. high-strength strand.
Project 310: GAS REMOVAL ASSOCIATED WITH DREDGE PUMPS

Sponsor: U. S. Army Engineers

In dredging operations, the pump may encounter mixtures consisting of widely varying amounts of solids, liquids and gases. When materials containing a considerable amount of entrained gas are encountered, some of this gas is liberated in the suction pipe of the dredge and may accumulate in such quantities that the volume of solids discharged by the pump is reduced or completely stopped.

The objective of the project will be to recommend the best type of the gas removal system and its optimum location in the suction assembly of the pump. Various possible gas removal systems will be studied theoretically and several systems will be investigated experimentally in a model dredge pump.

The work will be done in four phases:

Phase A (a) Literature Search (b) Formulation of Test Program
Phase B (a) Formulation of Specific Test Setups (b) Establishment of Test Schedule
Phase C (a) Establishment of Test Setups (b) Performance of Tests with Water Only
Phase D (a) Performance of Tests with Solid-Water mixtures (b) Tests with Physical Equipment Alterations

Project 311: FRACTURE MODE TRANSITION OF MILD STEEL

Sponsor: Faculty Research Program (Institute of Research)

In recent developments in fracture mechanics, the resistance of the material to an unstable propagation of a crack has been characterized by a parameter which measures the energy absorption per unit area of material at the onset of such propagation. For materials in which the crack surface exhibits essentially the same microscopic features, whether in slow or fast cracking, the value of this parameter has been measured in "fracture toughness" tests. In the case of mild steel, a change in metallurgical mode of separation (cleavage) intervenes in this process and precipitates failure. This program will attempt to measure, on slow-bend specimens, the value of the parameter which governs the onset of the cleavage mode of fracture.
Project 312: **SURVEY OF CURRENT STRUCTURAL RESEARCH**

Sponsor: Fritz Engineering Laboratory  
American Society of Civil Engineers

A survey of current research in structures is being conducted in conjunction with the Structural Division Research Committee and various Technical Committees of the American Society of Civil Engineers. The survey covers both domestic and foreign research.

The principal purpose of the survey is to provide information which will assist the various technical committees of ASCE in carrying out their work; another purpose is to inform the Structural Division membership of research that is in progress and to assist the Society in planning further research. Also, it should enable investigators to make direct contact with one another.

The survey is being conducted principally through the use of a questionnaire. The questionnaire collects the following information:

1. Title of the project
2. Sponsor
3. Names, departments and official titles of principal investigators
4. Name and address of the institution
5. Nature of the project according to the current ASCE Structural Division Technical Committees:
   a) Analysis and Design of Structures
   b) Electronic Computation
   c) Masonry and Reinforced Concrete
   d) Metals
   e) Nuclear Structures and Materials
   f) Wood
   g) Plastics
6. Abstract of the project

In addition, the Science Information Exchange and the Engineering College Research Review provide information for the survey.
Architects and structural engineers when designing complex structures such as sports arenas, exhibition halls, and large auditoriums, often strive to support the roof with a minimum number of columns impeding on main floor areas. This has given rise to new structural frames with unusual appearance (mostly shell type structures). Such frames are often complex in nature and become very difficult or impossible to analyze for the internal stresses resulting from dead and live loads. A useful tool which can be effectively used in analyzing these structures is structural models.

The work involved in this project consists of the following phases: 1) A study of the properties of various available materials which can be used to make the models, 2) Development of practical methods of fabricating shell models of constant and variable thickness, 3) Investigation of the reliability of various methods of loading structural models, and 4) Development of methods for interpreting results obtained from models and extrapolating them to prototype structures.
BIBLIOGRAPHY OF REPORTS ON CURRENT PROJECTS
Beedle, L. S. and Johnston, B. G.
PLASTIC BEHAVIOR OF WIDE FLANGE BEAMS,
Welding Journal, 27 (11), p. 538-s, 1948,
Publication No. 63

Yang, C. H.
PLASTIC BEHAVIOR OF CONTINUOUS BEAMS, 1949

Chen, C. H.
STRENGTH OF COLUMNS UNDER COMBINED BENDING AND
COMPRESSION, 1949

Ruzek, J. M. and Topractosoglou, A. A.
TEST OF A RIGID FRAME KNEE, 1949

Beedle, L. S. and Yang, C. H.
DISCUSSION OF "FLEXURE OF I-SECTION ABOVE PLASTIC RANGE",
1950

Beedle, L. S.; Ready, J. A. and Johnston, B. G.
TESTS OF COLUMNS UNDER COMBINED THRUST AND MOMENT,
Proc. SESA, 8 (1), p. 109, 1950, Publication No. 72

Johnston, B. G.; Yang, C. H. and Beedle, L. S.
AN EVALUATION OF PLASTIC ANALYSIS AS APPLIED TO
STRUCTURAL DESIGN, Welding Journal, 32 (5), p. 224-s,
1953, Publication No. 87

Knudsen, K. E.
ABSTRACT TRANSLATION OF MAIER-LEIBNITZ'S "CONTRIBUTION
TO THE PROBLEM OF ULTIMATE CARRYING CAPACITY OF SIMPLE
AND CONTINUOUS BEAMS OF STRUCTURAL STEEL AND TIMBER", 1950

Beedle, L. S.
RESEARCH ON RIGID FRAMES, Proc. AISC National Engineering
Conference, p. 21, 1952, Publication No. 79

Beedle, L. S. and Johnston, B. G.
RULES OF PRACTICE IN PLASTIC DESIGN, 1954

Beedle, L. S.
RECENT TESTS OF RIGID FRAMES, Proc. AISC National Engineering
Conference, p. 13, 1954, Publication No. 97

Beedle, L. S.
PLASTIC STRENGTH OF STEEL FRAMES, Trans. ASCE, 122, p. 1139,
1957, Publication No. 102

Ketter, R. L. and Thurlimann, B.
CAN DESIGN BE BASED ON ULTIMATE STRENGTH?
Civil Engineering, 25 (1), p. 59, January 1955,
Publication No. 100

* Published Report
205.29 Thurlimann, B.
ANALYSIS OF FRAMES FOR ULTIMATE STRENGTH, 1955

*205.31 Ketter, R. L.

*205.32 Beedle, L. S.; Thurlimann, B. and Ketter, R. L.
PLASTIC DESIGN IN STRUCTURAL STEEL, Summer Course Lecture Notes, Lehigh University, AISC Publication, 1955
Publication No. 106

*205.34 Beedle, L. S.
PRACTICAL APPLICATIONS OF PLASTIC DESIGN IN STRUCTURAL STEEL, Proc. SEAOC, October 1955

*205.36 Driscoll, G. C., Jr. and Beedle, L. S.

*205.41 Ketter, R. L. and Beedle, L. S.

*205.42 American Institute of Steel Construction
Proc. AISC National Engineering Conference, 1956,
Publication No. 110

Thurlimann, B.
SIMPLE PLASTIC THEORY, p. 13

Ketter, R. L.
ANALYSIS AND DESIGN EXAMPLES, p. 19

Beedle, L. S.
EXPERIMENTAL VERIFICATION OF PLASTIC THEORY, p. 36

Thurlimann, B.
MODIFICATIONS TO "SIMPLE PLASTIC THEORY", p. 50

Driscoll, G. C., Jr.
TEST OF TWO-SPAN PORTAL FRAME, p. 74

205.45 Beedle, L. S.
EXPERIMENTAL VERIFICATION AND MODIFICATIONS TO THE SIMPLE PLASTIC THEORY, 1956

*205.47 Beedle, L. S.
GRADUATE STUDIES IN PLASTIC ANALYSIS AND DESIGN, ASEE
Civil Engineering Bulletin 22 (1), p. 8, December 1956,
Publication No. 114

* Published Report
Ketter, R. L.
PLASTIC DESIGN OF MULTI-SPAN RIGID FRAMES,
Ph.D Dissertation, Lehigh University, 1956

Ketter, R. L.
PLASTIC ANALYSIS AND DESIGN AT THE UNDERGRADUATE LEVEL,
ASEE Civil Engineering Bulletin 22 (1) p. 7,
December 1956, Publication No. 114

Thurlimann, B.
PLASTIC DESIGN OF STRUCTURAL STEEL, The Engineering
Journal, Canada, February 1957, Publication No. 113

WRC-ASCE Joint Committee
COMMENTARY ON PLASTIC DESIGN IN STEEL, ASCE Manual No. 41,
1961, Publication No. 178

Ketter, R. L.
PLASTIC DESIGN OF PINNED-BASE GABLE FRAMES, Welding
Research Council Bulletin Series, No. 48, 1959,
Publication No. 134

Ketter, R. L. and Yen, B. T.
PLASTIC DESIGN OF PINNED-BASE "LEAN-TO FRAMES,
Welding Research Council Bulletin Series, No. 53, 1959
Publication No. 145

Beedle, L. S.
PLASTIC DESIGN OF STEEL STRUCTURES, AISI Regional Technical
Meeting, Philadelphia, November 1958, Publication No. 127

Project Staff
WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS - BIBLIOGRAPHY,
1959

Thurlimann, B.
NEW ASPECTS CONCERNING INELASTIC INSTABILITY OF STEEL
STRUCTURES, Trans. ASCE, Vol. 127, Part II, 1962,
Publication No. 154

Ketter, R. L.
DISCUSSION OF "SINGLE STORY FRAMES by J. Heyman", British

Ojalvo, M.
DISCUSSION OF "THE PLASTIC METHOD OF DESIGNING STEEL
STRUCTURES by J. F. Baker", Proc. ASCE, 85 (ST9), p. 89,
1959, Publication No. 151

Beedle, L. S.
ON THE APPLICATION OF PLASTIC DESIGN, Proc. Second Symposium
on Naval Structural Mechanics, 1960, Publication No. 168

* Published Report
205.71  Recchio, D. A.  
PLASTIC DESIGN OF PINNED-BASE SAW-TOOTH FRAMES,  
M. S. Thesis, Lehigh University, 1960

205.72  Beedle, L. S. and Hansell, W. C.  
PLASTIC DESIGN IN ACTION, AISC-USC Symposium "Structural  
Steel Progress and Performance", May 1961

205.73  Driscoll, G. C., Jr.; Galambos T. V.; Beedle, L. S.  
DISCUSSION OF "WEAKNESSES OF THE THEORY OF PLASTIC  
DESIGN" by A. Hrennikoff", May 1961

205.74  Driscoll, G. C., Jr.  
SELECTED BIBLIOGRAPHY ON PLASTIC DESIGN FOR STRUCTURAL  
ENGINEERS, ASCE Task Committee Report on "Structural  
Design Methods", October 1961

205.75  Galambos, T. V. and Beedle, L. S.  
RESEARCH ON PLASTIC DESIGN AT LEHIGH UNIVERSITY, 8th  
Summer Scientific Conference on C. E., Krynica, Poland, 1962

205.76  Driscoll, G. C., Jr., Galambos, T. V. and Beedle, L. S.  
DISCUSSION OF "PLASTIC DESIGN QUESTIONED" by A. Hrennikoff,  
October 1962

*205.77  Lu, L. W.  
LINEARIZED INTERACTION CURVES FOR PLASTIC BEAMS UNDER  
COMBINED BENDING AND TWISTING, Journal AIAA, Vol. 1,  
No. 3, p. 706, March 1963, Publication No. 223

*205.78  Lu, L. W.  
DISCUSSION ON "FINITE DEFORMATION OF A RIGID PERFECTLY  
PLASTIC ARCH" by E. T. Onat and L. S. Shu, Journal  
Applied Mechanics, Vol. 126, p. 473, September 1963,  
Publication No. 228

205.79  Beedle, L. S. and Christopher, R. J.  
TESTS OF STEEL MOMENT CONNECTIONS, October 1963

**Project 205A  **

**COLUMNS IN CONTINUOUS FRAMES**

205A.1  Ketter, R. L. and Beedle, L. S.  
SOME RESULTS OF COLUMN TESTS AND PROPOSED PROGRAM, 1950

205A.3  Ketter, R. L.  
COLUMN TEST MANUAL, 1951

205A.4  Ketter, R. L. and Beedle, L. S.  
INTERACTION CURVES FOR COLUMNS (COMBINED THRUST AND MOMENT),  
1951

* Published Report
*205A.6  Ketter, R. L.; Beedle, L. S. and Johnston, B. G.  
COLUMN STRENGTH UNDER COMBINED BENDING AND THRUST,  

205A.7  Ketter, R. L.  
INTERACTION CURVES FOR CIRCULAR COLUMN SECTIONS, 1951

205A.8  Beedle, L. S.  
METAL COLUMNS, 1948

205A.10  Ketter, R. L. and Beedle, L. S.  
THE MOMENT-CURVATURE RELATION FOR WF COLUMNS, 1952

205A.11  Ketter, R. L. and Beedle, L. S.  
MOMENT ROTATION CHARACTERISTICS OF BEAM-COLUMNS, 1952

*205A.12  Ketter, R. L.; Kaminsky, F. L. and Beedle, L. S.  
PLASTIC DEFORMATION OF WIDE-FLANGE BEAM-COLUMNS,  
ASCE Trans. Vol. 120, p. 1019, 1955, Publication No. 91

205A.13  Ketter, R. L.  
INELASTIC BUCKLING OF ECCENTRICALLY LOADED COLUMNS, 1953

*205A.14  Ketter, R. L.  
STABILITY OF BEAM-COLUMNS ABOVE THE ELASTIC LIMIT,  
Proc. ASCE, Separate 692, 81, 1954, Publication No. 103

*205A.15  Ketter, R. L. and Beedle, L. S.  
DISCUSSION OF "STRENGTH OF COLUMNS ELASTICALLY RESTRAINED  
AND ECCENTRICALLY LOADED, by Fisher, Bijllard and Winter",  
Proc. ASCE, Separate 532, 80, 1954, Publication No. 98

205A.16  Niimoto, S.  
BIAXIAL FLEXURE IN MODEL STEEL COLUMNS, Report for C. E.  
404, June 1955

205A.17  Huber, A. W.  
DISCUSSION OF 205A.12 "PLASTIC DEFORMATION OF WF BEAM  
COLUMNS" by R. L. Ketter, E. L. Kaminsky and L. S. Beedle,  
1955

205A.18  Shuga, M.  
ELASTIC AND INELASTIC BEHAVIOR IN MODEL STEEL COLUMNS, 1955

205A.19  Galambos, T. V. and Ketter, R. L.  
FURTHER STUDIES ON THE STRENGTH OF COLUMNS UNDER COMBINED  
BENDING AND THRUST, 1957

*205A.20  Galambos, T. V. and Jones, J.  
GERMAN BUCKLING SPECIFICATIONS, TRANSLATIONS OF GERMAN  
BUCKLING SPECIFICATIONS, CRC Bulletin, June 1957,  
Publication No. 166

* Published Report
Project 205H  LATERAL BRACING REQUIREMENTS

205H.1  White, M. W.
PROPOSAL FOR TESTS ON BRACING REQUIREMENTS, 1954

*205H.2  Lee, G. C.

* Published Report
205H.3A  Lee, G. C.
PRELIMINARY REPORT ON TESTS OF LATERAL BRACING REQUIREMENTS, 1960

204H.4  Lee, G. C. and Ueda, Y.
SURVEY ON LATERAL BUCKLING EXPERIMENTS, 1960

205H.5  Lee, G. C.
INELASTIC LATERAL INSTABILITY OF BEAMS AND THEIR BRACING REQUIREMENTS, Ph.D Dissertation, Lehigh University, 1960

LATERAL BRACING REQUIREMENTS FOR PLASTICALLY DESIGNED BEAMS, 1962

*205H.9  Ferrara, A. and Galambos, T. V.

*205H.10  Lay, M. and Galambos, T. V.

205H.12  Prasad, J. and Galambos, T. V.
THE INFLUENCE OF ADJACENT SPANS ON THE ROTATION CAPACITY OF BEAMS, August 1963

Project 223  PRESTRESSED CONCRETE BRIDGE MEMBERS

223.1  Mayo, R.; Lore, F.; Loewer, A. C., Jr. and Eney, W. J.
A COMPARISON BETWEEN ORDINARY REINFORCED AND PRESTRESSED REINFORCED CONCRETE BEAMS, February 1952

223.2  Mayo, R.; Loewer, A. C., Jr. and Eney, W. J.
TEST OF A PRETENSIONED PRESTRESSED CONCRETE BEAM CONTAINING 5/16-INCH DIAMETER BONDED STRAND, June 1952

223.3  Smislova, A.; Loewer, A. C., Jr. and Eney, W. J.
TEST OF PRETENSIONED PRESTRESSED CONCRETE BEAM, 1952

*223.4  Smislova, A.; Loewer, A. C., Jr. and Eney, W. J.
USING SR-4 GAGES TO MEASURE STRAINS IN WIRE STRAND, Product Engineering, April 1953, Publication No. 88

*223.5  Knudsen, K. E. and Eney, W. J.

* Published Report
223.6 Smislova, A.; Brown, D. H., Jr.; Roesli, A. and Eney, W. J.
ENDURANCE OF A FULL-SCALE POST-TENSIONED CONCRETE
MEMBER, May 1954

223.7 Brown, D. H.; Knudsen, K. E. and Eney, W. J.
BOND OF PRESTRESSED STRANDS, September 1953

*223.8 Roesli, A.; Loewer, A. C., Jr. and Eney, W. J.
MACHINE TO APPLY REPEATED LOADS TO LARGE FLEXURAL MEMBERS,
ASTM Bulletin 196, February 1954, Publication No. 94

*223.9 Roesli, A.; Smislova, A.; Ekberg, C. E., Jr. and Eney, W. J.
FIELD TESTS ON A PRESTRESSED CONCRETE MULTI-BEAM BRIDGE,
(Progress Report No. 9), Proc. Highway Research Board, 35,
(1956), Publication No. 117

*223.10 Roesli, A.
LATERAL LOAD DISTRIBUTION IN MULTI-BEAM BRIDGES, Published
as "THE ANALYSIS OF PRESTRESSED MULTI-BEAM BRIDGES AS
ORTHOTROPIC PLATES", co-author, Walther, R., Proc. World
Conference on Prestressed Concrete, San Francisco,
July 1957, Publication No. 130

223.11 Smislova, A.
STATIC TESTS ON PRESTRESSED CONCRETE BEAMS USING 7/16-INCH
STRANDS, June 1955

223.12 Debly, L. J.
STATIC TESTS ON PRESTRESSED CONCRETE BEAMS USING 7/16-INCH
STRANDS, September 1955

223.13 Debly, L. J.
STATIC TESTS ON PRESTRESSED CONCRETE BEAMS USING 7/16-INCH
STRANDS, June 1956

223.14 Walther, R. E.
INVESTIGATION OF MULTI-BEAM BRIDGES, Proc. ACI, 29 (6),
December 1957, Publication No. 128

223.14A Hulsbos, C. L.
LATERAL DISTRIBUTION OF LOAD IN MULTI-BEAM BRIDGES,
HRB Bulletin No. 339, 1962, Publication No. 229

223.15 Ekberg, C. E., Jr.; Walther, R. E. and Slutter, R. G.
FATIGUE RESISTANCE OF PRESTRESSED CONCRETE BEAMS IN
BENDING, (Progress Report No. 15), Proc. ASCE, 83 (ST4),
July 1957, Publication No. 142

223.16 Dinsmore, G. A. and Deutsch, P. L.
ANCHORAGE CHARACTERISTICS OF STRAND IN PRETENSIONED
PRESTRESSED CONCRETE, July 1957

* Published Report
**223.26B**
Ople, F. S., Jr., and Hulsbos, C. L.
PROBABLE FATIGUE LIFE OF PLAIN CONCRETE WITH STRESS GRADIENT, December 1963

**223.27A**
Hanson, J. M. and Hulsbos, C. L.
ULTIMATE SHEAR TESTS OF PRESTRESSED CONCRETE I-BEAMS UNDER CONCENTRATED LOADINGS, October 1963

**223**
Ekberg, C. E., Jr.
SUMMARY ON PRESTRESSED CONCRETE PROGRAM AT LEHIGH UNIVERSITY, Proc. World Conference on Prestressed Concrete, July 1957, p. A30-1, Publication No. 175

**223.84**
Ekberg, C. E., Jr., Walther, R. E. and Slutter, R. G.
FATIGUE RESISTANCE OF PRESTRESSED CONCRETE BEAMS IN BENDING, 1957

**223.86**
Slutter, R. G. and Ekberg, C. E., Jr.
STATIC AND FATIGUE TESTS ON PRESTRESSED CONCRETE RAILWAY SLABS, AREA Bulletin No. 544, June-July 1958, Publication No. 131

**223.87**
Walther, R. E.

**223.88**
Ekberg, C. E., Jr. and Warner, R. F.
PRESTRESSED CONCRETE RESEARCH AT LEHIGH UNIVERSITY 1952-58, (March 1959)

**223.89**
Nasser, K. W. and Ekberg, C. E., Jr.
STATIC AND FATIGUE TEST OF A 70 FOOT COMPOSITE PRESTRESSED CONCRETE BEAM, April 1959

**223.810**
HIGH SPEED FATIGUE TESTS ON SMALL SPECIMENS OF PLAIN CONCRETE, Prestressed Concrete Institute Journal, 4 (2), September 1959, Publication No. 173

**Project 248**
BUILT-UP MEMBERS IN PLASTIC THEORY

**248.1**
Kusuda, T. and Thurlimann, B.
STRENGTH OF WIDE-FLANGE BEAMS UNDER COMBINED INFLUENCE OF MOMENT, SHEAR AND AXIAL FORCE, 1958

**248.2**
Kusuda, T.
BUCKLING OF STIFFENED PANELS IN ELASTIC AND STRAIN-HARDENING RANGE, Ph.D Dissertation, Lehigh University, 1958. Published by Transportation Technical Research Institute (Japan), Report No. 39, Publication No. 150

* Published Report
248.3 Kusuda, T. and Thurlimann, B.
CORNER CONNECTIONS WITH CUT-OUT, (in preparation)

248.4 Ostapenko, A. and Lee, T. T.
TESTS ON LONGITUDINALLY STIFFENED PLATE PANELS
SUBJECTED TO LATERAL AND AXIAL LOADING, 1960

248.5 Rampetsreiter, R. H.; Lee, T. T. and Ostapenko, A.
TESTS ON LONGITUDINALLY STIFFENED PLATE PANELS (EFFECT OF
RESIDUAL STRESSES AND ROTATIONAL RESTRAINT BY STIFFENERS),
July 1962

248.6 Ostapenko, A.
APPARATUS FOR TESTING PLATE PANELS UNDER AXIAL AND LATERAL
LOADING, June 1961

248.7 Lee, T. T.
ELASTIC-PLASTIC ANALYSIS OF SIMPLY SUPPORTED RECTANGULAR
PLATES UNDER COMBINED AXIAL AND LATERAL LOADING, Ph.D.
Dissertation, Lehigh University, August 1961

248.8 Ostapenko, A.
SCANTLINGS OF LONGITUDINALLY STIFFENED SHIP BOTTOM PLATING,
April 1961

248.9 Lee, T. T. and Ostapenko, A.
INELASTIC STABILITY OF LONGITUDINALLY STIFFENED PLATE
PANELS (SHIP BOTTOM PLATING), Tests Conducted during 1960,
December 1960

248.10 Rampetsreiter, R. H.
COMpressive PROPERTIES OF THIN STEEL COUPONS, MS Thesis,
Lehigh University, May 1962

248.11 Ostapenko, A. and Kondo, J.
PROGRESS REPORT ON TESTS WITH FIXED LOADING EDGES AND
MEASUREMENT OF RESIDUAL STRESSES, November 1962

Project 249

RESIDUAL STRESSES AND WELDED COLUMNS

249.1 Fujita, Y.
PRELIMINARY REPORT ON WELDED AND RIVETED MEMBERS, May 1956

249.2 Fujita, Y.
BUILT-UP COLUMN STRENGTH, Dissertation, Lehigh University,
August 1956

249.3 Lee, G. C.
AN EXPERIMENTAL INVESTIGATION OF THE STRENGTH OF A RIVETED,
BUILT-UP COLUMN, December 1957

249.6 Fujita, Y.
ULTIMATE STRENGTH OF CENTRALLY LOADED COLUMNS, 1959
Tall, L. and Nagaraja Rao, N. R.

Tammaro, G.
THE COLUMN CURVE FOR LOW SLENDERNESS RATIOS, MS Thesis, Lehigh University, May 1961

Tall, L.
THE STRENGTH OF WELDED BUILT-UP COLUMNS, Ph.D. Dissertation, Lehigh University, May 1961

Tall, L.
RESIDUAL STRESSES IN WELDED PLATES - A THEORETICAL STUDY, Welding Journal, Vol. 43, p. 10-s, January 1964, Publication No. 235

Tall, L.
HEAT INPUT, THERMAL AND RESIDUAL STRESSES IN WELDED STRUCTURAL PLATES, August 1962

Tall, L. and Estuar, F. R.

Tall, L.

Tall, L. and Estuar, F.

Tall, L.
DISCUSSION OF "RESIDUAL STRESSES IN ROLLED I-SECTIONS" by Carmen Jez-Gala, submitted to the Institute of Civil Engineers, England, January 1963

Nagaraja Rao, N. R., Estuar, F. R. and Tall, L.
RESIDUAL STRESSES IN WELDED SHAPES

Nagaraja Rao, N. R. and Tall, L.
NEW CONCEPTS IN THE DESIGN OF STEEL COLUMNS AND ALLOWABLE STRESSES, April 1963

Nagaraja Rao, N. R.
MATERIAL PROPERTIES OF STRUCTURAL CARBON AND HIGH STRENGTH STEELS, April 1963

* Published Report
249.21 Tall, L.
RECENT DEVELOPMENTS IN THE STUDY OF COLUMN BEHAVIOR,
September 1963

249.22 Estuar, F. R. and Tall, L.
THE TESTING OF PINNED-END COLUMNS, January 1964

Project 273

MULTI-STORY FRAMES

273.1 Lu, L. W. and Levi, V.
LITERATURE SURVEY ON PLASTIC ANALYSIS AND DESIGN OF
MULTI-STORY FRAMES, (In preparation)

273.2 Baillie, D. S.
FAILURE DOMAINS FOR SINGLE BAY, FLAT ROOFED, ONE AND TWO
STORY PORTAL FRAMES, C. E. 406 Report, Lehigh University,
June 1960

273.3 Levi, V. and Driscoll, G. C., Jr.
PLASTIC DESIGN OF BRACED MULTI-STORY FRAMES, Lehigh
University, July 1961

273.7 Patel, N. V.
METHOD OF ANALYSIS AND LOAD-DEFLECTION SURVE FOR A

273.8 Levi, V.
PLASTIC DESIGN OF BRACED MULTI-STORY FRAMES, Ph. D.
Dissertation, 1962

RESPONSE OF COLUMNS TO IN-PLANE LOADING, April 1963

ANALYSIS OF BEAM AND COLUMN SUBASSEMBLAGES IN PLANE
MULTI-STORY FRAMES,(In preparation)

273.15 Driscoll, G. C., Jr.
LOAD DEFLECTION CURVE OF BRACED AND UNBRACED THREE-STORY
FRAME, September 1963

Project 276: FRAME STABILITY

*276.1 Galambos, T. V.
INFLUENCE OF PARTIAL BASE FIXITY ON FRAME STABILITY,
Proc. ASCE, 86 (ST5), 1960, Publication No. 156

*276.2 Lu, L. W.
LITERATURE SURVEY ON FRAME STABILITY, Welding Research
Bulletin No. 81, September 1962, Publication No. 206

* Published Report
276.3 Lu, L. W.  
STABILITY OF ELASTIC AND PARTIALLY PLASTIC FRAMES,  
Ph.D. Dissertation, Lehigh University, 1960

276.4 Lu, L. W. and Driscoll, G. C., Jr.  
BUCKLING TESTS ON MODEL STEEL FRAMES, 1962

*276.5 Lu, L. W.  
STABILITY OF FRAMES UNDER PRIMARY BENDING MOMENTS,  
Publication No. 227

*276.6 Ojalvo, M. and Lu, L. W.  
ANALYSIS OF FRAMES LOADED INTO THE PLASTIC RANGE, Proc.  
ASCE, 87 (EM4), August 1961, Publication No. 182

276.7 Lu, L. W.  
INELASTIC BUCKLING OF STEEL FRAMES, July 1963

*276.8 Lu, L. W.  
DISCUSSION ON "ELASTO-PLASTIC ANALYSIS BY NUMERICAL PROCEDURES" by A. L. Tong, Proc. ASCE, 87 (EM3), June 1961,  
Publication No. 184

*276.9 Yen, Y. C.; Lu, L. W. and Driscoll, G. C., Jr.  
TESTS ON THE STABILITY OF STEEL FRAMES, Welding Research Bulletin No. 81, September 1962, Publication No. 206

*276.10 Lu, L. W.  

276.11 Yen, Y. C., Lu, L. W. and Driscoll, G. C., Jr.  
PROPOSAL FOR THE INVESTIGATION OF INSTABILITY OF MULTI-STORY FRAMES, 1962

276.13 Yen, Y. C.  
INSTABILITY ANALYSIS AND TEST SET UP OF THREE-STORY FRAMES, September 1963

276.14 Yen, Y. C.  
ELASTIC AND PARTIALLY PLASTIC INSTABILITY OF MULTI-STORY FRAMES, January 1964

Project 278 RESTRAINED COLUMNS 278

278.1 Ojalvo, M.  
LITERATURE SURVEY ON RESTRAINED COLUMNS, Lehigh University, 1959

* Published Report
278.2 Ojalvo, M.

278.3 Ojalvo, M.
RESTRAINED COLUMNS, Ph.D. Dissertation, Lehigh University, 1960

*278.4 Ojalvo, M. and Levi, V.

*278.5 Ojalvo, M. and Fukumoto, Y.
NOMOGRAPHS FOR THE SOLUTION OF BEAM-COLUMN PROBLEMS, WRC Bulletin Series No. 78, 1962, Publication No. 197

278.7 Lay, M. G., Aglietti, R. A. and Galambos, T. V.
TESTING TECHNIQUES FOR RESTRAINED BEAM COLUMNS, October 1963

278.8 Lay, M. G., Aglietti, R. A. and Galambos, T. V.
PRELIMINARY REPORT ON RESULTS OF RESTRAINED COLUMN TESTS

278.9 Lay, M. G.
LETTER TO THE EDITOR, INTERNATIONAL JOURNAL MECHANICAL SCIENCES.

Project 284
FATIGUE OF USS "T-1" STEEL

284.1 Reemsnyder, H. S.
THE FATIGUE BEHAVIOR OF STRUCTURAL STEEL WELDMENTS - A LITERATURE SURVEY, November 1961

284.2 Heins, C. P.
THE EFFECTS OF STRESS GRADIENT ON THE FATIGUE LIFE OF "T-1" STEEL, MS Thesis, June 1962

284.3 Reemsnyder, H. S.
FATIGUE OF PLAIN AND FILLET-WELDED "T-1" STEEL, June 1962

284.5 Reemsnyder, H. S.
A STUDY OF THE FATIGUE RESISTANCE OF LONGITUDINAL FILLET WELDMENTS IN STEEL, Ph.D Dissertation, 1963

284.6 Reemsnyder, H. S. and Feenan, R. J.
THE FATIGUE RESISTANCE OF LONGITUDINAL FILLET WELDMENTS IN "T-1" STEEL, 1963

* Published Report
<table>
<thead>
<tr>
<th>Project 285</th>
<th>FATIGUE OF COMPOSITE BEAMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>285.3</td>
<td>King, C. D., Slutter, R. G. and Driscoll, G. C., Jr. FATIGUE TESTS OF COMPOSITE BEAMS, March 1962</td>
</tr>
<tr>
<td>285.5</td>
<td>Slutter, R. G., King, D. C. and Driscoll, G. C., Jr. PARTIAL TEST RESULTS; FATIGUE OF COMPOSITE BEAMS, April 1963</td>
</tr>
<tr>
<td>285.6</td>
<td>Driscoll, G. C., Jr., King, D. C. and Slutter, R. G. FATIGUE STRENGTH OF SHEAR CONNECTORS IN COMPOSITE BEAMS, January 1964</td>
</tr>
<tr>
<td>285.6A</td>
<td>King, D. C. THE FATIGUE OF STUD SHEAR CONNECTORS, M.S. Thesis, April 1963</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project 288</th>
<th>LARGE BOLTED CONNECTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>288.4</td>
<td>Fisher, J. W., Ramseier, P. O. and Beedle, L. S. STRENGTH OF A440 STEEL JOINTS CONNECTED WITH A325 BOLTS, April 1962</td>
</tr>
<tr>
<td>288.7</td>
<td>Fisher, J. W. and Beedle, L. S. CRITERIA FOR DESIGNING BOLTED JOINTS (Bearing Type)</td>
</tr>
<tr>
<td>288.8</td>
<td>Fisher, J. W. and Christopher, R. J. CALIBRATION OF A354 BOLTS (preliminary report)</td>
</tr>
<tr>
<td>288.9</td>
<td>Christopher, R. J. and Fisher, J. W. CALIBRATION OF A354 BOLTS (tension), March 1963</td>
</tr>
<tr>
<td>288.10</td>
<td>Fisher, J. W. THE ANALYSIS OF BOLTED PLATE SPLICES, February 1964</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project 290</th>
<th>WELDED AND ROLLED &quot;T-1&quot; COLUMNS</th>
</tr>
</thead>
<tbody>
<tr>
<td>290.1</td>
<td>Ueda, Y. ELASTIC, ELASTIC-PLASTIC AND PLASTIC BUCKLING OF PLATES WITH RESIDUAL STRESSES, Ph.D. Dissertation 1962</td>
</tr>
</tbody>
</table>

* Published Report
Project 291  COMPOSITION OF SHIP STEELS  291

Project 297  PLASTIC DESIGN IN HIGH STRENGTH STEEL  297

297.2  Lay, M. G.
       A BRIEF SURVEY OF U.S. STRUCTURAL STEEL TYPES,
       September 1962

297.3  Lay, M. G.
       THE EXPERIMENTAL BASIS OF PLASTIC DESIGN, A SURVEY OF
       THE LITERATURE, March 1963

297.4  Lay, M. G. and Gimsing, N.
       FURTHER STUDIES OF THE MOMENT-THRUST-CURVATURE RELATIONSHIP,
       January 1964

297.5  Lay, M. G. and Galambos, T. V.
       THE DUCTILITY OF STEEL STRUCTURES, March 1963

Project 301  DREDGE PUMPS AND DREDGING SYSTEMS  301

301.1  Murphy, H. D. and Herbich, J. B.
       SUCTION DREDGING LITERATURE SURVEY, June 1963

301.2  Isaacs, W. P., Mariani, V. R., Murphy, H. D. and Talian, S. F.
       PERFORMANCE STUDY OF A 1:6 MODEL DREDGE PUMP, September 1963

Project 303  FATIGUE STRENGTH OF WELDED PLATE GIRDERS  303

303.1  Yen, B. T.
       ON THE FATIGUE STRENGTH OF WELDED PLATE GIRDERS, November 1962

Project 304  LONGITUDINALLY STIFFENED PLATE GIRDERS  304

304.2  Cooper, P. B.
       LITERATURE SURVEY ON LONGITUDINALLY STIFFENED PLATES,
       September 1963
### PROJECTS LISTED BY DIVISIONS

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title of Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydraulics</strong></td>
<td></td>
</tr>
<tr>
<td>301</td>
<td>Dredge Pumps and Dredging Systems</td>
</tr>
<tr>
<td>310</td>
<td>Gas Removal Associated with Dredge Pumps</td>
</tr>
<tr>
<td><strong>Structural Concrete</strong></td>
<td></td>
</tr>
<tr>
<td>223</td>
<td>Prestressed Concrete Bridge Members</td>
</tr>
<tr>
<td>289</td>
<td>Bar-Mat Lap Failures in Pavements</td>
</tr>
<tr>
<td>306</td>
<td>Horizontal Shear Connection in Composite Beams</td>
</tr>
<tr>
<td><strong>Structural Metals</strong></td>
<td></td>
</tr>
<tr>
<td>205</td>
<td>Welded Continuous Frames and Their Components</td>
</tr>
<tr>
<td>205A</td>
<td>Columns in Continuous Frames</td>
</tr>
<tr>
<td>205H</td>
<td>Lateral Bracing Requirements</td>
</tr>
<tr>
<td>248</td>
<td>Built-Up Members in Plastic Design</td>
</tr>
<tr>
<td>249</td>
<td>Welded Built-Up Columns</td>
</tr>
<tr>
<td>273</td>
<td>Multi-Story Frames</td>
</tr>
<tr>
<td>276</td>
<td>Frame Stability</td>
</tr>
<tr>
<td>278</td>
<td>Restrained Columns</td>
</tr>
<tr>
<td>284</td>
<td>Fatigue of USS &quot;T-1&quot; Steel</td>
</tr>
<tr>
<td>285</td>
<td>Fatigue of Composite Beams</td>
</tr>
<tr>
<td>288</td>
<td>Large Bolted Connections</td>
</tr>
<tr>
<td>290</td>
<td>Welded and Rolled &quot;T-1&quot; Columns</td>
</tr>
<tr>
<td>291</td>
<td>Composition of Ship Steel</td>
</tr>
<tr>
<td>296</td>
<td>Hollow Structural Tubing</td>
</tr>
<tr>
<td>297</td>
<td>Plastic Design in High Strength Steels</td>
</tr>
<tr>
<td>302</td>
<td>Bibliography on Bolted and Riveted Structural Joints</td>
</tr>
<tr>
<td>303</td>
<td>Fatigue Strength of Welded Plate Girders</td>
</tr>
<tr>
<td>304</td>
<td>Longitudinally Stiffened Plate Girders</td>
</tr>
<tr>
<td>305</td>
<td>Hybrid Steel Columns</td>
</tr>
<tr>
<td>307</td>
<td>Impact Tests of Bridge Rail</td>
</tr>
<tr>
<td>308</td>
<td>Non-Circular Cylindrical Shells</td>
</tr>
<tr>
<td>311</td>
<td>Fracture Mode Transition of Mild Steel</td>
</tr>
<tr>
<td>312</td>
<td>Survey of Current Structural Research</td>
</tr>
<tr>
<td><strong>Structural Models</strong></td>
<td></td>
</tr>
<tr>
<td>313</td>
<td>Models for Three-Dimensional Structures</td>
</tr>
<tr>
<td>Author</td>
<td>Page(s)</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Aglietti, R. A.</td>
<td>278</td>
</tr>
<tr>
<td>Assimacopoulas, B.</td>
<td>223</td>
</tr>
<tr>
<td>Baillie, D. S.</td>
<td>273</td>
</tr>
<tr>
<td>Beedle, L. S.</td>
<td>205, 205A, 288</td>
</tr>
<tr>
<td>Brown, D. H.</td>
<td>223</td>
</tr>
<tr>
<td>Chen, C. H.</td>
<td>205</td>
</tr>
<tr>
<td>Christopher, R.</td>
<td>205, 288</td>
</tr>
<tr>
<td>Cooper, P. B.</td>
<td>304</td>
</tr>
<tr>
<td>Debly, L. J.</td>
<td>223</td>
</tr>
<tr>
<td>Deutsch, P. L.</td>
<td>223</td>
</tr>
<tr>
<td>Dinsmore, G. A.</td>
<td>223</td>
</tr>
<tr>
<td>Driscoll, G. C., Jr.</td>
<td>205, 273, 276, 285</td>
</tr>
<tr>
<td>Ekburg, C. E., Jr.</td>
<td>223</td>
</tr>
<tr>
<td>Eney, W. J.</td>
<td>223</td>
</tr>
<tr>
<td>Estuar, F.</td>
<td>249</td>
</tr>
<tr>
<td>Feenan, R. J.</td>
<td>284</td>
</tr>
<tr>
<td>Ferrara, A. T.</td>
<td>205H</td>
</tr>
<tr>
<td>Fisher, J. W.</td>
<td>288</td>
</tr>
<tr>
<td>Fujita, Y.</td>
<td>249</td>
</tr>
<tr>
<td>Fukumoto, Y.</td>
<td>205A, 278</td>
</tr>
<tr>
<td>Galambos, T. V.</td>
<td>205, 205A, 205H, 276</td>
</tr>
<tr>
<td>Gimsing, N.</td>
<td>297</td>
</tr>
<tr>
<td>Grigoriadis, M.</td>
<td>205A</td>
</tr>
<tr>
<td>Hansell, W. C.</td>
<td>205</td>
</tr>
<tr>
<td>Hanson, J. M.</td>
<td>223</td>
</tr>
<tr>
<td>Herbich, J. B.</td>
<td>301</td>
</tr>
<tr>
<td>Huber, A. W.</td>
<td>205A</td>
</tr>
<tr>
<td>Hulsbos, C. L.</td>
<td>223</td>
</tr>
<tr>
<td>Isaacs, W. P.</td>
<td>301</td>
</tr>
<tr>
<td>Johnston, B. G.</td>
<td>205, 205A</td>
</tr>
<tr>
<td>Jones, J.</td>
<td>205A</td>
</tr>
<tr>
<td>Kaminsky, F. L.</td>
<td>205A</td>
</tr>
<tr>
<td>Ketter, R. L.</td>
<td>205, 205A</td>
</tr>
<tr>
<td>King, D. C.</td>
<td>285</td>
</tr>
<tr>
<td>Knudsen, K. E.</td>
<td>205, 223</td>
</tr>
<tr>
<td>Kondo, J.</td>
<td>248</td>
</tr>
<tr>
<td>Kusuda, T.</td>
<td>248</td>
</tr>
<tr>
<td>Lane, R. E.</td>
<td>223</td>
</tr>
<tr>
<td>Lay, M. G.</td>
<td>205A, 205H, 278, 297</td>
</tr>
<tr>
<td>Lee, G. C.</td>
<td>205H, 249</td>
</tr>
<tr>
<td>Lee, T. T.</td>
<td>248</td>
</tr>
<tr>
<td>Levi, V.</td>
<td>273, 278</td>
</tr>
<tr>
<td>Loewer, A. C., Jr.</td>
<td>223</td>
</tr>
<tr>
<td>Lore, F.</td>
<td>223</td>
</tr>
<tr>
<td>Lu, L. W.</td>
<td>205, 273, 276</td>
</tr>
<tr>
<td>Luxion, W.</td>
<td>205</td>
</tr>
<tr>
<td>Mayo, R. W.</td>
<td>223</td>
</tr>
<tr>
<td>McClarnon, F.</td>
<td>223</td>
</tr>
<tr>
<td>Montemayor, J. L.</td>
<td>223</td>
</tr>
<tr>
<td>Murphy, H. D.</td>
<td>301</td>
</tr>
<tr>
<td>Nagaraja Rao, N. R.</td>
<td>249</td>
</tr>
<tr>
<td>Nasser, K. W.</td>
<td>223</td>
</tr>
<tr>
<td>Niimoto, S.</td>
<td>205A</td>
</tr>
<tr>
<td>Ojalvo, M.</td>
<td>205, 276, 278</td>
</tr>
<tr>
<td>Ople, F. S., Jr.</td>
<td>223</td>
</tr>
<tr>
<td>Ostapenko, A.</td>
<td>248</td>
</tr>
<tr>
<td>Patel, N. B.</td>
<td>273</td>
</tr>
<tr>
<td>Prasad, J.</td>
<td>205H</td>
</tr>
<tr>
<td>Rampetsreiter, R. H.</td>
<td>248</td>
</tr>
<tr>
<td>Ramseier, P. P.</td>
<td>288</td>
</tr>
<tr>
<td>Ready, J. A.</td>
<td>205</td>
</tr>
<tr>
<td>Recchio, D. A.</td>
<td>205</td>
</tr>
<tr>
<td>Reemsnyder, H. S.</td>
<td>284</td>
</tr>
<tr>
<td>Roesli, A.</td>
<td>223</td>
</tr>
<tr>
<td>Rumpf, J. L.</td>
<td>288</td>
</tr>
<tr>
<td>Ruzek, J. M.</td>
<td>205</td>
</tr>
<tr>
<td>Shuga, M.</td>
<td>205A</td>
</tr>
<tr>
<td>Slutter, R. C.</td>
<td>223, 285</td>
</tr>
<tr>
<td>Smislova, A.</td>
<td>223</td>
</tr>
<tr>
<td>Tall, L.</td>
<td>249</td>
</tr>
<tr>
<td>Tamaro, G.</td>
<td>249</td>
</tr>
<tr>
<td>Thurlimann, B.</td>
<td>205, 248</td>
</tr>
<tr>
<td>Topractsoglou, A. A.</td>
<td>205</td>
</tr>
<tr>
<td>Ueda, Y.</td>
<td>205H, 290</td>
</tr>
<tr>
<td>Van Kuren, R. L.</td>
<td>205A</td>
</tr>
<tr>
<td>Wakabayashi, M.</td>
<td>223</td>
</tr>
<tr>
<td>Waither, R. E.</td>
<td>223</td>
</tr>
<tr>
<td>Warner, R. F.</td>
<td>223</td>
</tr>
<tr>
<td>White, M. W.</td>
<td>205H</td>
</tr>
<tr>
<td>WRC-ASCE</td>
<td>205</td>
</tr>
<tr>
<td>Yang, C. H.</td>
<td>205</td>
</tr>
<tr>
<td>Yen, B. T.</td>
<td>205, 303</td>
</tr>
<tr>
<td>Yen, Y. C.</td>
<td>276</td>
</tr>
<tr>
<td>Yordy, E. L.</td>
<td>291</td>
</tr>
</tbody>
</table>
SUBJECT INDEX

Beams
composite, 285
elastic-plastic design, 205
inelastic stability, 205A
lateral bracing, 205H
prestressed concrete, 223, 309
rotation capacity, 205H

Beam-column
bending and twisting, 205
elastic foundation, 276
inelastic stability, 205A
nomograph, 278
rotation capacity, 205A

Bolted Joints, 288

Bridge Rail, 307

Columns
bending and compression, 205, 205A
biaxial flexure, 205A
built-up, 249
eccentric loading, 205A
elastic-inelastic behavior, 205A
hollow tubing, 296
hybrid steel, 305
inelastic stability, 205A
in-plane loading, 273
moment-curvature, 205A
prestressed concrete, 223
restrained, 278
rotation capacity, 205A
"T-I" steel, 290

Composite Design, 285

Continuous Concrete Pavement, 289

Cylindrical shells, 308

Dredge Pump, 301, 310

Fatigue
composite beams, 285
plate girders, 303
prestressed concrete, 223
shear connectors, 285
"T-I" steel, 284

Frames
elastic-plastic design, 205
knee, 205
multi-story, 273
plastic design, 205
plastic, strength, 205, 276
rigid, 205
single story, 205
stability, 276
welded, 205

Lateral Bracing, 205H

Models
columns, 205A
plastic design, 205
three-dimensional, 313

Plastic
behavior members, frames, strength
steel frames, 205
theory, 205

Plastic Design
built-up members, 248
discussion, 205
gable frame, 205
graduate study, 205
high-strength steel, 297
"lean-to" frame, 205
models, 205
rules of practice, 205
saw tooth frame, 205
undergraduate study, 205

Plate Girders, 303, 304

Plates
brittle fracture, 291
buckling, 290
scantlings, 248
stiffened panels, 248
welded, 249

Prestressed Concrete, 223, 309

Reinforced Concrete, 306

Residual Stress, 249

Rotation Capacity
beams, 205H
columns, 205A

Stability
German specifications, 205A
inelastic, 205

Steel, fracture mode, 311

Structural Research Survey, 312
### SPONSOR INDEX

<table>
<thead>
<tr>
<th>SPONSOR</th>
<th>PROJECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Institute of Steel Construction</td>
<td>205, 205A, 205H, 273, 276, 278, 285, 288, 297, 303, 304</td>
</tr>
<tr>
<td>American Iron and Steel Institute</td>
<td>205, 205A, 205H, 273, 276, 278, 297, 303, 304</td>
</tr>
<tr>
<td>American Society of Civil Engineers</td>
<td>312</td>
</tr>
<tr>
<td>Column Research Council</td>
<td>205, 205A, 205H, 249, 273, 276, 278, 297, 305</td>
</tr>
<tr>
<td>Ellicott Machine Corporation</td>
<td>301</td>
</tr>
<tr>
<td>Fritz Engineering Laboratory</td>
<td>308, 312</td>
</tr>
<tr>
<td>Howe Engineering Company</td>
<td>307</td>
</tr>
<tr>
<td>Lehigh University Institute of Research</td>
<td>311, 313</td>
</tr>
<tr>
<td>Pennsylvania Department of Highways</td>
<td>223, 249, 288, 289, 303, 304, 305, 306, 309</td>
</tr>
<tr>
<td>Reinforced Concrete Research Council</td>
<td>223, 306</td>
</tr>
<tr>
<td>Research Council on Riveted and Bolted Structural Joints</td>
<td>288, 302</td>
</tr>
<tr>
<td>United States Army Engineers</td>
<td>310</td>
</tr>
<tr>
<td>United States Navy Department</td>
<td>205, 205A, 205H, 248, 273, 276, 278, 291, 297</td>
</tr>
<tr>
<td>United States Steel Corporation</td>
<td>284, 290, 296</td>
</tr>
<tr>
<td>Welding Research Council</td>
<td>205, 205A, 205H, 273, 276, 278, 297, 303, 304</td>
</tr>
</tbody>
</table>
223.17  Walther, R. E.
THE ULTIMATE STRENGTH OF PRESTRESSED AND CONVENTIONALLY
REINFORCED CONCRETE UNDER THE COMBINED ACTION OF MOMENT
AND SHEAR, May 1958

*223.17A   Walther, R. E.
SHEAR STRENGTH OF PRESTRESSED CONCRETE BEAMS,
World Conference on Prestressed Concrete, May 1958,
Publication No. 129

223.18  Walther, R. E. and Warner, R. F.
ULTIMATE STRENGTH TESTS OF PRESTRESSED AND CONVENTIONALLY
REINFORCED CONCRETE BEAMS IN COMBINED BENDING AND SHEAR,
September 1958

223.19  Dinsmore, G. A.; Deutsch, P. L. and Montemayor, J. L.
ANCHORAGE AND BOND IN PRETENSIONED PRESTRESSED CONCRETE
MEMBERS, December 1958

223.20  Warner, R. F.
The Calculation of Flexural Stresses in a Prestressed
Concrete Member, November 1958

223.21  Lane, R. E. and Ekberg, C. E., Jr.
Repeated Load Tests on 7 Wire Prestressing Strands,
January 1959

FURTHER INVESTIGATION INTO THE SHEAR STRENGTH OF PRESTRESSED
CONCRETE BEAMS WITHOUT WEB REINFORCEMENT, January 1962

223.23  Nasser, K. W.
STATIC AND FATIGUE TESTS OF A 30 FOOT COMPOSITE PRESTRESSED
CONCRETE BEAM, March 1961

223.24  Warner, R. F.
PROBABLY FATIGUE LIFE OF PRESTRESSED CONCRETE FLEXURAL
MEMBERS, Ph.D. Dissertation, Lehigh University, September 1961

*223.24A   Warner, R. F. and Hulsbos, C. L.
PROBABLY FATIGUE LIFE OF UNDER-REINFORCED PRESTRESSED
CONCRETE BEAMS, IABSE Publications, Vol. 22, 1962,
Publication No. 234

223.25  Hanson, J. M. and Hulsbos, C. L.
OVERLOAD BEHAVIOR OF PRESTRESSED CONCRETE BEAMS WITH WEB
REINFORCEMENT, November 1963

223.26A  Ople, F. S., Jr., and Hulsbos, C. L.
PROBABLY LIFE OR PRESTRESSED BEAMS AS LIMITED BY CONCRETE
FATIGUE, October, 1963

* Published Report
CURRENT RESEARCH PROJECTS

Description
and
Bibliography

Fritz Engineering Laboratory
Department of Civil Engineering
Lehigh University
Bethlehem, Pennsylvania

July 1965

237.17 (65)
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>205</td>
<td>WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS</td>
</tr>
<tr>
<td>223</td>
<td>PRESTRESSED CONCRETE BRIDGE MEMBERS</td>
</tr>
<tr>
<td>248</td>
<td>BUILT-UP MEMBERS IN PLASTIC DESIGN</td>
</tr>
<tr>
<td>249</td>
<td>WELDED BUILT-UP COLUMNS</td>
</tr>
<tr>
<td>273</td>
<td>MULTI-STORY FRAMES</td>
</tr>
<tr>
<td>276</td>
<td>FRAME STABILITY</td>
</tr>
<tr>
<td>280</td>
<td>SPUR DIKES FOR BRIDGE ABUTMENTS</td>
</tr>
<tr>
<td>290</td>
<td>WELDED AND ROLLED &quot;T-1&quot; COLUMNS</td>
</tr>
<tr>
<td>293</td>
<td>GRAVITY WAVES IN CONSTRUCTIONS</td>
</tr>
<tr>
<td>297</td>
<td>PLASTIC DESIGN IN HIGH STRENGTH STEELS</td>
</tr>
<tr>
<td>301</td>
<td>DREDGE PUMPS AND DREDGING SYSTEMS</td>
</tr>
<tr>
<td>302</td>
<td>BIBLIOGRAPHY OF BOLTED AND RIVETED STRUCTURAL JOINTS</td>
</tr>
<tr>
<td>303</td>
<td>FATIGUE STRENGTH OF WELDED PLATE GIRDERS</td>
</tr>
<tr>
<td>304</td>
<td>LONGITUinally STIFFENED PLATE GIRDERS</td>
</tr>
<tr>
<td>305</td>
<td>HYBRID STEEL COLUMNS</td>
</tr>
<tr>
<td>306</td>
<td>HORIZONTAL SHEAR CONNECTION IN COMPOSITE BEAMS</td>
</tr>
<tr>
<td>309</td>
<td>BOND BETWEEN CONCRETE AND PRESTRESSING STRAND</td>
</tr>
<tr>
<td>310</td>
<td>GAS REMOVAL ASSOCIATED WITH DREDGE PUMPS</td>
</tr>
<tr>
<td>312</td>
<td>SURVEY OF CURRENT STRUCTURAL RESEARCH</td>
</tr>
<tr>
<td>313</td>
<td>MODELS FOR THREE DIMENSIONAL STRUCTURES</td>
</tr>
<tr>
<td>314</td>
<td>CRACK PROPAGATION RATES OF ALUMINUM PLATES</td>
</tr>
<tr>
<td>315</td>
<td>LATERAL LOAD DISTRIBUTION ON CONCRETE BRIDGES</td>
</tr>
<tr>
<td>316</td>
<td>SHEAR CONNECTOR DESIGN FOR HIGHWAY BRIDGES</td>
</tr>
<tr>
<td>317</td>
<td>LARGE BOLTED CONNECTIONS OF HIGHER STRENGTH STEELS</td>
</tr>
<tr>
<td>318</td>
<td>SERVICE PERFORMANCE OF LARGE BOLTED JOINTS</td>
</tr>
</tbody>
</table>

BIBLIOGRAPHY

PROJECTS LISTED BY DIVISION

AUTHOR INDEX

SUBJECT INDEX

SPONSOR INDEX
Since its founding in 1909 Fritz Engineering Laboratory has advanced knowledge and techniques in the field of Civil Engineering through its research programs and industrial testing facilities. Modernization of the Laboratory in 1954-55 enabled the University to continue to provide the finest facilities for research in the fields of structures, materials, hydraulics, structural model analysis, soil mechanics and sanitation. Fritz Laboratory is a part of the Department of Civil Engineering.

The laboratory facilities are housed in two inter-connected units—a four-story unit and a seven-story unit. Ready access to the main testing areas is provided to facilitate the delivery of large and heavy equipment. With the available testing machines and special accessories, large structural members can be tested statically or dynamically. A research library is maintained where current reports from laboratories throughout the world are available for study.

Through its Institute of Research, Lehigh University contracts with research councils, industrial concerns, or associations to undertake cooperative research. The sponsor is expected to pay all costs plus a reasonable percentage for overhead. At least a one-year duration is expected on such projects, and publication of results in technical magazines is normally anticipated. About half of the research is sponsored by industry and half by government agencies.

Investigations have ranged from studies of material properties and characteristics up to tests of full-size structures for buildings and bridges. Structural steel research programs have improved design procedures by this approach. Specifications of the American Association of State Highway Officials, American Institute of Steel Construction, Association of Iron and Steel Engineers, and American Railway Engineering Association have been revised as a direct result of research projects.

In the following pages, the current research projects are described. A bibliography of reports on these projects is also included.

Head of Department of Civil Engineering and Fritz Engineering Laboratory
Director of Fritz Engineering Laboratory
Engineer of Tests
Hydraulics and Sanitary
Soil Mechanics
Structural Concrete
Structural Metals
Structural Models

W. J. Eney
L. S. Beedle
R. G. Slutter
J. B. Herbich
R. J. Leonard
D. A. VanHorn
G. C. Driscoll
L. W. Lu
Project 205: **WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS**

(PLASTIC DESIGN)

**Sponsors:**
American Institute of Steel Construction  
American Iron and Steel Institute  
Column Research Council (Advisory)  
United States Navy Department  
Welding Research Council

The general objectives of this research are to develop methods for predicting the ultimate load-carrying capacity of continuous steel structures and to develop practical design procedures for utilizing the reserve plastic strength. Such procedures must take into account such additional factors as fatigue, deflections, brittle fracture, local buckling, lateral buckling, etc., and this is being done on the project.

Results to date have shown that the plastic theory may be applied to the design of continuous beams and single-story industrial frames. Manuals and commentaries have been prepared to assist the designer of these structures. Research has also shown that the plastic theory shows promise for application to the design of other classes of structures, such as multi-story buildings and component parts of ships.

Test of full-size frame verifies plastic design theory
Project 223: PRESTRESSED CONCRETE BRIDGE MEMBERS

Sponsors: Pennsylvania Department of Highways
Bureau of Public Roads
Reinforced Concrete Research Council

This project was established to develop fundamental information for evaluating the behavior of prestressed concrete beams. Work has consisted primarily of studies in three areas:

1. Bond characteristics of steel strand.
2. Fatigue resistance of strand and concrete.
3. Ultimate strength under combined moment and shear.

Studies of the bond characteristics and the fatigue resistance have been completed. The study of bond characteristics between strand and concrete resulted in the establishment of design criteria for insuring adequate safety against a bond failure, and contributed to the acceptance of the larger sized 7/16 in. diameter strand in prestressing work. (At the present time a new project includes a bond study of 1/2 in. diameter strand). The study of fatigue resistance resulted in development of procedures for predicting the flexural fatigue life of prestressed beams.

A large number of tests have been carried out on prestressed beams with and without web reinforcement to determine and evaluate the significant factors causing inclined cracking, and to determine the variation in ultimate shear strength with amount of web reinforcement and length of shear span. Based on this research, a proposed specification for the design of web reinforcement in prestressed concrete bridge girders has been submitted to the AASHO Committee on Bridges for their consideration.

The project will terminate on September 30, 1965. The work has been completed except for final reports.
Built-up members are very often used in practice, especially in ship structures. Typical examples are deck girders with openings, Vierendeel girders, and the like. The application of plastic design to such members offers some new problems. One of these is the inelastic stability of stiffened plate panels.

The purpose of this program is to investigate the effect of some important parameters, such as the intensity of lateral pressure and the distribution of residual stresses, on the stability of stiffened plate panels under axial compression. Numerical analysis has been performed on panels with large and small plate width to thickness ratios. Design nomographs have been developed for panels with small (about 40) plate width to thickness ratios. Theoretical work is compared with experimental results. The post-buckling behavior of the plate between stiffeners will be studied theoretically and experimentally.
Columns used in tall multi-story buildings carry extremely high axial loads. These loads far exceed the carrying capacity of the largest available rolled shape so that a need for welded columns arises. The fabrication of column sections by welding sets up residual stresses different from the stresses found in rolled shapes. This results in a difference between the load carrying capacity of the welded shape and the rolled shape. The object of this research is to study the behavior of welded built-up columns as influenced by cross-sectional shape, thickness of component plates, weld size, use of hybrid shapes, and different methods of fabrication.

Early tests on small and medium-size welded shapes indicate that at medium range of slenderness ratios these shapes exhibit a column strength which is considerably less than that of a corresponding rolled shape. Current work includes studies on welded heavy shapes and welded shapes made up of flame-cut plates. The results of pilot tests indicate some improvement in strength over that of the small- and medium-size shapes made up of um plates.
In designing multi-story building frames, it is often advantageous to use bracing, such as X-bracing or K-bracing, to help resist the horizontal loads. The use of bracing reduces considerably the shear force in the columns and, consequently, the bending moment to be carried by the beams and columns is also reduced. The bracing can also effectively prevent the frame from swaying in the lateral direction and thus reduces the deflection of the frame.

In the current practice of building design, such frames are usually designed by the elastic or conventional method in which the design criterion is always the attainment of limiting stresses. An alternate and more logical approach would be to design the structures on the basis of their plastic strength. This approach is permitted only in the design of one or two story frames by the present AISC Specification, due to the lack of information concerning the plastic behavior of columns and frames. However, recent investigations conducted at Lehigh University have furnished the needed information not only for columns but also for beam-and-column subassemblies. The purpose of this study is to develop design procedures for such frames, utilizing the newly obtained information.
The plastic design of multi-story frames requires the knowledge of the behavior of subassemblies. A subassembly consists of a beam-column and the other structural members framing into its ends. Tests have been conducted on isolated subassemblies with ideal end conditions. However, a multi-story frame is composed of many subassemblies which are interdependent. In order to check the validity of the method for the plastic design of braced frames (developed in Proj. 273-1), it is necessary to compare the theory with actual frame behavior.

Four tests on braced multi-story frames are proposed to provide experimental data on the ultimate strength of multi-story frames to compare with plastic design methods. The frame itself (sections, geometry and bracing) is the same for all four tests; only the loading condition varies. The four loading conditions are: full dead and live load, full dead and partial live, and the previous two conditions with horizontal load.

The performance of bracing in multi-story frames will also be studied, with regard to its effectiveness in resisting horizontal forces and its interaction with the frame.
Project 273-III: TESTS ON BEAM-AND-COLUMN SUBASSEMBLAGES IN MULTI-STORY FRAMES

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
United States Navy Department
Welding Research Council

In the analysis and design of multi-story frames, it is often convenient to divide the entire frame into a number of smaller units, each consisting of a column and its neighboring beams. Such a unit is referred to as "beam-and-column subassemblage". In braced frames the deformations of the subassemblies generally do not involve sway, while in unbraced frames sidesway occurs when horizontal loads are applied to the structures. Two types of subassemblies should therefore be considered in multi-story frame design; namely, sway subassemblies and non-sway subassemblies. Analytical procedures for predicting the behavior and strength of both types of subassemblies are available (273.11) and are being used in developing methods for designing braced and unbraced frames. The objective of this study is to obtain experimental data on the behavior of these subassemblies.

Test of a Non-sway Subassemblage
Project 273-IV: **PLASTIC ANALYSIS OF UNBRACED MULTI-STORY FRAMES SUBJECT TO UNSYMMETRICAL GRAVITY LOADS OR COMBINED LOADS**

**Sponsors:** American Institute of Steel Construction  
American Iron and Steel Institute  
Column Research Council (Advisory)  
United States Navy Department  
Welding Research Council

The objective of this project is to construct a method for predicting the inelastic in-plane behavior of unbraced multi-story frames subjected to gravity or gravity plus wind loads. The effects of stiffness reduction due to yielding and of sway deflection on ultimate load capacity are of particular interest in this study. These effects are not considered in presently available frame analysis methods. The result is a gap in the ability to predict structural behavior which has hampered efforts to formulate and validate design procedures for unbraced multi-story frames. This study is intended to help fill this gap.
Project 273-V: DEVELOPMENT OF DESIGN METHODS FOR UNBRACED FRAMES SUBJECTED TO UNSYMMETRICAL GRAVITY LOADS OR COMBINED LOADS

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
United States Navy Department
Welding Research Council

The conventional method of designing unbraced frames subjected to loads which may produce sway accepts the attainment of limiting stresses as a design criterion. Recent investigations have demonstrated that the use of the inherent plastic strength of the frames as a design criterion is a more logical approach. However, due to the limitations on the available information regarding the behavior of swayed columns and frames, the AISC Specification (1963) permits the use of this approach for frames up to two stories high only.

The strength of columns with sway has recently been studied by an analytical method (273.11) and will be investigated experimentally in another project (Proj. 273-III). Also, the behavior of complete frames subjected to gravity loads and combined loads is being investigated theoretically and experimentally under two separate projects (Project 273-IV and Project 273-VI). The results obtained from these studies will provide the needed information for extending the plastic method to taller building frames. The purpose of this study is therefore to develop design procedures for unbraced multi-story frames subjected to loads causing sidesway.
Project 273-VI: TESTS OF PLASTICALLY DESIGNED UNBRACED FRAMES SUBJECTED TO UNSYMMETRICAL GRAVITY LOADS OR COMBINED LOADS

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
United States Navy Department
Welding Research Council

When an unbraced frame is subjected to unsymmetrical gravity load or gravity load in combination with horizontal load, the structure will generally be deformed into a swayed configuration. In such a frame, the resistance to horizontal load is provided by the beams and columns. These members are also called upon to resist the secondary moments caused by the sway deflections. The analysis and design of this type of frame are being investigated in two concurrent projects (Proj. 273-IV and Proj. 273-V). The purposes of this investigation are: 1) to develop testing techniques for multi-story frames with sidesway, 2) to obtain experimental data on the behavior and strength of unbraced frames, and 3) to verify experimentally the design procedures to be developed in Proj. 276-V.
Project 273-XII: EVALUATION, ANALYSIS, AND DESIGN

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
United States Navy Department
Welding Research Council.

Upon completion of the work on design methods for the plastic design of multi-story frames it will be necessary to update the present AISC Specification to include provisions for such design procedures as were developed. It will also be necessary to provide aids in the form of charts, tables, or computer programs to permit rapid plastic design of multi-story frames.

Outline of Work:

1. Prepare recommendations for specification revision as soon as a sufficient amount of the research is completed.

2. Prepare recommendations for the computation of desirable design aids.

3. Discuss, defend, and disseminate the information from research and the recommendations for specification revisions.
Project 273-XIII: 1965 SUMMER CONFERENCE
PLASTIC DESIGN OF MULTI-STORY FRAMES

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
United States Navy Department
Welding Research Council

The main objectives of the conference are as follows:

1. Inform civil engineering professors and professional engineers of recent progress in plastic analysis and design of multi-story steel building frames.

2. Introduce new design methods.

3. Illustrate design methods and behavior of frames by full-scale demonstration tests.

4. Provide opportunity for exchange of ideas between U. S. college professors and research workers and invited foreign authorities.
Project 276-I: BUCKLING ANALYSIS OF UNBRACED FRAMES UNDER SYMMETRICAL GRAVITY LOADS

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
United States Navy Department
Welding Research Council

When symmetrical gravity loads are placed on an unbraced multi-story frame, over-all buckling may take place at a load lever lower than that predicted by the plastic theory. This type of failure is often referred to as "Frame Instability" and should be guarded against in the design. For frames of practical dimensions, frame instability is likely to occur after the stress in some portion of the frame has exceeded the elastic limit. The problem is therefore the determination of the buckling strength of partially yielded frames.

The objective of this investigation is to study the inelastic buckling behavior of frames and to develop methods for computing the buckling loads.

Buckling Test on a Model Multi-Story Frame
In designing unbraced multi-story frames to carry gravity loads, one of the important factors to be considered is "Frame Instability". This phenomenon of failure is characterized by a sudden shift from a symmetrical deformed configuration to an anti-symmetrical configuration. Particular attention should therefore be given to this type of failure in the design. A design approach taking into account the reduction in strength due to over-all instability has been developed for one- or two-story frames (Fritz Lab. Report No. 276.7). The purpose of the study is to extend the same approach to taller frames.

It is also hoped that a design procedure based directly on the buckling strength may be developed so that better utilization of the strength of columns may be achieved by this procedure.
A sound highway bridge design also involves hydraulic considerations for the safety of the bridge foundation. Severe scouring around bridge abutments in times of flood result from the increased flow velocity in the constricted area between abutments and eddy currents and separation around the abutments and piers. In recent years the interest of engineers has been focused on the usefulness of spur dikes in minimizing scour at the abutments by streamlining the flow and establishing uniform velocity distribution through the opening. A spur dike has been defined as a projection extending upstream from the bridge abutment.

The objective of the study has been to obtain design parameters for optimum conditions. It was shown that spur dikes can protect bridge abutments during floods.
Project 290: WELDED AND ROLLED HEAT-TREATED "T-1" COLUMNS

Sponsor: United States Steel Corporation

The overall purpose of this research is to develop design criteria for welded box and H sections as well as for rolled heat-treated angle and wide flange sections, of "T-1" steel used in compression.

Phase I: BASIC STUDIES

Preceding the investigation of the compression strength of specific members it is necessary, and important, to obtain more basic knowledge on material properties. The most important of these are the stress-strain relationships, yield stress level and modulus of elasticity. The magnitude and distribution of residual stresses which exist in the members are also of importance.

Figure 1, below, shows typical residual stress patterns for welded plates, sections fabricated by welding, and rolled heat-treated sections.
Project 290: WELDED AND ROLLED HEAT-TREATED "T-1" COLUMNS

Phase II: LOCAL BUCKLING

Because of the high yield stress of "T-1" steel, local instability plays a more important role in the failure mechanism of compression members fabricated from the steel than it does in structural mild steel. This phase includes experimental and theoretical studies with emphasis placed on the effect of residual stresses on local buckling. Preliminary analysis shows that these residual stresses do have a significant effect on the buckling strength of the member, both in the elastic and inelastic range.

Design recommendations for the width-thickness ratio of the component plates used in the fabrication of the member will be the final result of this phase.
Experimental and theoretical studies of centrally loaded columns are carried out to determine the effect of residual stresses and small amounts of out-of-straightness on their behavior. Preliminary study has shown the effects of residual stress on the strength of the column was rather small compared with columns of constructional mild steel. This is especially true for rolled heat-treated sections.

The theoretical analysis includes a study of the possible torsional buckling modes in addition to the failure by flexure buckling. It is expected that torsional behavior will play an important role in the failure mode of angle or tee sections which are axially loaded.

The analysis will be extended to the strength of beam columns subjected to axial force and bending.
Project 293: WAVE REFLECTION AND TRANSMISSION FOR CYLINDRICAL PILE ARRAYS

Sponsor: Institute of Research

In Oceanographical Engineering the reflection of waves from solid sea walls of different types is an important occurrence. If the sea wall is permeable, the transmission of waves through the structure, as well as those reflected from it, combine to describe a part of the "wave characteristics" of the structure. A group of piles in a specific geometrical pattern might be generalized as a porous sea wall. Therefore, both wave reflection and transmission play an important part in the "wave characteristics" of pile groups.

The purpose of this investigation is to investigate the relationship between wave reflection and transmission, and several pile-group configurations. A total of 16 circular piles were used in different rectangular arrangements and one staggered pattern. In the rectangular arrangements both the spacings transverse to the oncoming wave and the spacings longitudinal to the oncoming wave were investigated. The experimental studies were performed in a two-dimensional wave channel.

Test set-up showing experimental pile group.
Note: Wave crest near center of photograph.
(Wave Height of 3.20 Inches)
Project 297: PLASTIC DESIGN IN HIGH STRENGTH STEELS

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Column Research Council (Advisory)
United States Navy Department
Welding Research Council

With the wide acceptance of high strength steels, it was found desirable to also investigate the inelastic behavior of members and frames made out of higher strength steels, notably steels in the 50 ksi yield strength range.

The purpose of this project is to investigate the applicability of available research information to high strength steels and to provide new results where these are necessary.

Current work consists of the determination of the material properties and an investigation of local and lateral buckling problems. The work is being performed by means of experiments and also through theoretical investigation.

Bending test of high strength steel beam laterally supported
Project 301: DREDGE PUMP RESEARCH

Sponsor: Ellicott Machine Corporation

A contract between the Lehigh University Institute of Research, the Fritz Engineering Laboratory Hydraulics Division, and the Ellicott Machine Corporation provided for study of a model dredge pump one sixth of actual size.

The objective of this investigation is to determine experimentally the operating characteristics of a one to six model dredge pump and the performance of a dredging system as it is influenced by the materials handled, suction head losses, size of impeller diameter, and impeller speeds. Particular emphasis has been on developing a dredge pump which will be free from cavitation.

The centrifugal pump and suction line assembly is a one to six scale model of the operating dredge "Alaska". The pump test stand assembly consists of a storage tank, suction pipeline, pump, and discharge line, all connected in a continuous flow loop. Exterior to this flow system is the motor which drives the model pump.

The study combines analytical, experimental, and visual investigation of the behavior of pumps handling solids visual observations are made through the plexiglas suction head with the aid of a high speed camera (5600 frames/second).
Since the Research Council on Riveted and Bolted Structural Joints was formed in 1947 much research has been conducted and reported. It is evident from the review of publications, and in light of the continuing program of research, that a comprehensive bibliography should be prepared on the subject of bolted and riveted structural joints.

The objective of this project is to provide informative abstracts of the work on bolted and riveted joints which was done between De Jorge's survey (up to 1944) and the initiation of the ASCE Information Retrieval Program in January 1963.

Below is a typical abstract of a paper written about connections:

KEY WORDS: bolts; connections; steel; structural engineering; testing

ABSTRACT: Direct tension and torqued tension tests of 170 A325 bolts were carried out to determine the behavior and performance of individual A325 bolts. The major variables studied in the program included the effect of thread length between the thread run-out and the face of the nut, the effect of grip, continuous and incremental torquing, and reserve strength in tension after torquing. The behavior and performance of the bolts is examined, and typical data are presented. The results are related to the current "Specification for Structural Joints Using ASTM A325 Bolts" and have influenced the amount of nut rotation required when the turn-of-nut method of tightening is used. For usual grips, the grip length was found to have no appreciable effect on the load-elongation characteristics when the length of thread under the nut was approximately the same. Nut rotations greater than one-half turn from snug yielded little additional clamping force. Decreasing the amount of exposed thread under the nut results in a decrease in the deformation capacity of the bolt.

Project 303: **FATIGUE STRENGTH OF WELDED PLATE GIRDERS**

**Sponsors:** American Iron and Steel Institute  
U. S. Bureau of Public Roads  
Pennsylvania Department of Highways  
Welding Research Council

The objective of this project is to investigate the fatigue strength of plate girders. Previous studies indicate that tension field action and redistribution of stresses in webs contribute to girder static strength which can be utilized in the design of building girders. The significance of the static strength for bridge girders is being examined both experimentally and analytically.

Several large-sized plate girders have been tested, some under bending and others under high shear. Preliminary results indicate a close relationship between lateral web deflection and failure modes. Further experiments are in progress, including the investigation of fatigue properties of web boundary joints. The results of all these tests will be used in the analytical study.

The ultimate aim is the formulation of design recommendations for safe and economical bridge girders.
Project 304: **LONGITUDINALLY STIFFENED PLATE GIRDERS**

**Sponsors:** Pennsylvania Department of Highways  
Bureau of Public Roads  
Welding Research Council  
American Iron and Steel Institute  
American Institute of Steel Construction

The objective of this project is to investigate the possible contribution of longitudinal stiffeners to the static load-carrying capacity of plate girders and to make recommendations that would be useful in translating the results into design rules.

Six bending tests and eight shear tests have been conducted on full size longitudinally stiffened girders. Based on the observed behavior of these girders, analytical methods are being developed to predict the bending and shear strength of longitudinally stiffened plate girders and to position and proportion the stiffeners.

![Test Specimen](image-url)
Project 305: HYBRID STEEL COLUMNS

Sponsor: Pennsylvania Department of Highways
Column Research Council

Hybrid steel shapes are those built up by welding together different types of steels. The availability of a number of constructional steels has enabled the engineer to design a variety of hybrid members. A hybrid shape has the advantage that the stronger material can be utilized in regions of high stress and the material of lower yield can be used in the lower stressed regions.

This project is a pilot study which will explore the feasibility of using hybrid shapes as columns. Column shapes are built up of "T-1", A441 and A36 steels. Residual stress measurements are made; stub column tests and pinned ended column tests are conducted to evaluate the strength of hybrid columns. A theoretical analysis is also made and verified by the results of the tests.

Fabrication of a Hybrid H-shape with "T-1" steel flanges and A441 web
A study of the requirements for the connection between a precast concrete web and a cast-in-place slab under static loading has been completed at the University of Wisconsin. A series of tests were conducted at Fritz Lab to evaluate the behavior of the horizontal shear connection under repeated loads.

The variables included:

a) Roughness of the contact surface of the beam.

b) Ratio of shear span to effective depth.

c) Percentage of shear connection reinforcement.

In any test in which a failure under repeated load did not occur with at least 2,000,000 cycles, the beam was loaded to failure with a static load.

On the basis of the limited number of tests included in this project, it has been possible to develop very conservative equations for the allowable stress in the joint of a composite concrete beam as a function of the joint reinforcement and of the geometry of the beam. A large number of additional tests would be required to obtain equations which would more accurately predict the fatigue strength of the joint.

The project will terminate on September 30, 1965. The work has been completed except for the final report.

Fatigue test of composite beams
The main objective of this investigation is the study of flexural bond in members pre-tensioned with 1/2 inch high-strength (270 ksi) strand. In the first phase, a series of 12 specimens was subjected to static loading to establish (1) the development of flexural bond stresses, and (2) the effect of this development on overall flexural behavior. In the second phase another series of 12 specimens was used to determine the effects of repeated loads on flexural bond characteristics. All of the specimens have been tested, and reports are now in progress.

A supplemental phase of the investigation was a pilot study of the effect of low temperature on the fatigue life of the 1/2 inch high strength strand. The results of these tests provided the basis for a more extensive investigation of the fatigue life of the 1/2 inch high strength strand. This experimental work is now in progress.
In dredging operations, the pump may encounter mixtures consisting of widely varying amounts of solids, liquids and gases. When material containing a considerable amount of entrained gas is encountered, some of this gas is liberated in the suction pipe of the dredge and may accumulate in such quantities that the volume of solids discharged by the pump is reduced or completely stopped.

A model study will be conducted to determine the best and most efficient way of removing gas before it reaches the pump. Such parameters as gas content, pump speed and suction pipe geometry will be studied. The relative merits of such evacuators as vacuum pumps and water ejectors will be evaluated.

Transparent pumping system which makes it possible to trace the movement of water and material through the pump with the use of high-speed photography.
A survey of current research in structures is being conducted in conjunction with the Structural Division Research Committee and various Technical Committees of the American Society of Civil Engineers.

The principal purpose of the survey is to provide information which will assist these committees in carrying out their work; another purpose is to inform the Structural Division membership of research that is in progress, and to assist the Society in planning further research.

A typical abstract appears below:

FRAME STABILITY
Lehigh University (G. C. Driscoll); Welding Research Council

For simple frames, the load to cause formation of a mechanism is easily predicted by simple plastic theory. However, it is possible that "frame instability" may occur before attainment of the predicted ultimate load. Frame instability is that phenomenon by which a frame, unrestrained against sidesway at the column tops, buckles as a unit. The columns which buckle in this form of failure are subjected to restraints at their connections and bases which have not been evaluated heretofore for the plastic range. This problem is of particular interest in the lower stories of multi-story buildings where the columns are most heavily loaded. The purpose of this project is to determine, both theoretically and experimentally, the extent to which the simple plastic theory requires modification. The project will also develop methods for proportioning columns to assure the needed stability.
Architects and structural engineers when designing complex structures such as sports arenas, exhibition halls, and large auditoriums, often strive to support the roof with a minimum number of columns impeding on main floor areas. This has given rise to new structural frames with unusual appearance (mostly shell type structures). Such frames are often complex in nature and become very difficult or impossible to analyze for the internal stresses resulting from dead and live loads. A useful tool which can be effectively used in analyzing these structures is structural models.

The work involved in this project consists of the following phases:
1) a study of the properties of various available materials which can be used to make the models, 2) development of practical methods of fabricating shell models of constant and variable thickness, 3) investigation of the reliability of various methods of loading structural models, and 4) development of methods for interpreting results obtained from models and extrapolating them to prototype structures.
Project 314: CRACK PROPAGATION RATES OF ALUMINUM PLATES

Sponsor: National Aeronautics and Space Administration

This inter-departmental project between the Mechanics and the Civil Engineering Departments is a phase of an overall project on crack propagation. This phase is conducted in the Structural Metals Division.

Description of Work:

Recent studies of crack growth rates in aircraft structural members have been toward the formulation of theoretical and empirical relationships between stresses and crack growth rates. One speculation has been that some cracks are "non-propagating" under certain conditions. The purpose of the present phase is to determine whether cracks may be truly non-propagating or merely growing discontinuously with long delay intervals. These delays would cause extremely small values for average growth rates.

Another facet of the present investigation is to examine the values of stress concentration factors under the testing conditions for later correlation with information on faster ratios.

Test Set-up
Project 315: LATERAL DISTRIBUTION OF LOAD FOR BRIDGES CONSTRUCTED WITH PRESTRESSED CONCRETE BOX BEAMS

Sponsors: Pennsylvania Department of Highways
Bureau of Public Roads

One of the important considerations in the design of beam-slab highway bridge is the determination of the distribution of load to the longitudinal stringers. In the period 1954-1956, a research project was conducted at Lehigh University on the lateral distribution of load in multi-beam bridges. The work included a field test, an analytical solution, and a laboratory model study of the type of bridge built at that time -- adjacent box beams joined together with longitudinal shear keys, prestressed laterally, and covered with an asphalt roadway surface. At present, the beams are being designed compositely with a concrete slab, and no lateral prestressing is used. In addition, many of the current bridges are designed with space between adjacent beams. Therefore, no direct interaction between beams is obtained, and the results of the earlier work do not apply directly to the more current construction practice.

In 1964, Project 315 was outlined and approved, for the development of information needed to evaluate the load distribution in bridges of current design. During the first year, a pilot field study was conducted of analytical studies and to provide experience for further field tests. During the second year, the testing program is a more extensive field study involving load tests of three structures similar to the bridge used in the pilot study. The dynamic bridge testing equipment owned and operated by the Bureau of Public Roads is being used in the field investigation. Along with the field studies, a theoretical analysis is in progress.
Currently shear connectors in composite steel and concrete composite bridges are designed using formulas derived from static tests. The allowable connector loads are derived by limiting the slip between slab and beam to a small value. This small magnitude at slip was chosen so that complete interaction between slab and beam would be maintained. Recent investigations have revealed that it is not necessary to maintain complete interaction in such members.

If incomplete interaction is allowed, the design of shear connectors should be based on their fatigue strength. The purpose of this project was to obtain data on the fatigue strength of shear connectors of various types, and to use this data in formulating a new design procedure. The spacing and the number of shear connectors required by this new design procedure will be quite different from that required by the present specifications.
The latest advance in the application of high strength steel bolts has been the adoption in March 1964 of "Specifications for Structural Joints Using ASTM A325 or A490 Bolts", by the Research Council on Riveted and Bolted Structural Joints. In particular, this specification reflects the adoption for use of the A490 high strength alloy steel bolt. The need for this fastener grew out of the availability of higher strength steels. To attain full advantage of the greater load bearing capabilities of these steels, a stronger bolt than the A325 had to be developed. This led to the introduction of the A490 bolt and resulted, in part, from studies made at Lehigh University.

The increasing use and importance of the higher strength steels is evidenced by the fact that one of the more important of these, a proprietary steel USS "T-1", is now covered by a new ASTM specification, A514. If full advantage is to be attained, the behavior of A514 and other higher strength steels when fastened with high strength bolts must be established. Since these new steels are not generally used throughout a structure but rather only in the more highly stressed regions, the behavior of joints in which two or more different grades of steel will be fastened will also be investigated.

Test Setup
A considerable number of analytical studies and tests have been performed over the past ten years on the properties of bolts and bolted joints. This has led to rather good understanding of the relationship between deformation and load throughout the elastic and inelastic regions for the component parts of the joints when these are of ASTM grades A7 through A440 steel. A number of important aspects of joint behavior have not yet been investigated, however. Typical of these is the question of whether or not large plates in bolted connections can be pulled up properly. Resistance to slip in these connections is determined by the amount of bolt tension and the nature of the contact surfaces. It is not known whether current methods of installation will ensure the development of the desired clamping force in large connections which may be out of flat. It is also of interest to know what effect warping has on the slip coefficient (nominal coefficient of friction).

The work will be done in these phases:

Phase I Analysis and tests of large joints which are out-of-flat.

Phase II Analysis and tests of smaller joints to determine the effect of controlled variation of the faying surface on the slip resistance of the joints.

Phase III Analysis and tests to determine the effect of slotted and oversize holes upon joint behavior.
BIBLIOGRAPHY OF REPORTS ON CURRENT PROJECTS
Published Report

Project 205

WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS

*203.3
Luxion, W. and Johnston, B. G.
PLASTIC BEHAVIOR OF WIDE FLANGE BEAMS,
Welding Journal, 27 (11), p. 538-s, 1948,
Publication No. 63

205.B
Yang, C. H.
PLASTIC BEHAVIOR OF CONTINUOUS BEAMS, 1949

205.C
Chen, C. H.
STRENGTH OF COLUMNS UNDER COMBINED BENDING AND
COMPRESSION, 1949

205.D
Ruzek, J. M. and Topractsoglou, A. A.
TEST OF A RIGID FRAME KNEE, 1949

205.H
Beedle, L. S. and Yang, C. H.
DISCUSSION OF "FLEXURE OF I-SECTION ABOVE
PLASTIC RANGE", 1950

*205.2
Beedle, L. S.; Ready, J. A. and Johnston B. G.
TESTS OF COLUMNS UNDER COMBINED THRUST AND MOMENT,
Proc. SESA, 8 (1), p. 109, 1950, Publication No. 72

*205.14
Johnston, B. G.; Yang, C. H. and Beedle, L. S.
AN EVALUATION OF PLASTIC ANALYSIS AS APPLIED TO
STRUCTURAL DESIGN,
Welding Journal, 32 (5), p. 224-s, 1953,
Publication No. 87

205.15
Knudsen, K. E.
ABSTRACT TRANSLATION OF MAIER-LEIBNITZ'S "CONTRI­
BUTION TO THE PROBLEM OF ULTIMATE CARRYING CAPACITY
OF SIMPLE AND CONTINUOUS BEAMS OF STRUCTURAL STEEL
AND TIMBER", 1950

*205.18
Beedle, L. S.
RESEARCH ON RIGID FRAMES,
Proc. AISC National Engineering Conference,
p. 21, 1952, Publication No. 79

205.20
Beedle, L. S. and Johnston, B. G.
RULES OF PRACTICE IN PLASTIC DESIGN, 1954

*205.23
Beedle, L. S.
RECENT TESTS OF RIGID FRAMES,
Proc. AISC National Engineering Conference,
p. 13, 1954, Publication No. 97

*205.26
Beedle, L. S.
PLASTIC STRENGTH OF STEEL FRAMES,
Trans. ASCE, 122, p. 1139, 1957 Publication No. 102

*205.28
Ketter, R. L. and Thurlimann, B.
CAN DESIGN BE BASED ON ULTIMATE STRENGTH?
Civil Engineering, 25 (1), p. 59, January 1955,
Publication No. 100

* Published Report
205.29  Thurlimann, B.
ANALYSIS OF FRAMES FOR ULTIMATE STRENGTH, 1955

*205.31  Ketter, R. L.
THE USE OF MODELS IN PLASTIC DESIGN,
Proc. AISC National Engineering Conference, p. 35,
1955, Publication No. 116

*205.32  Beedle, L. S.; Thurlimann, B. and Ketter, R. L.
PLASTIC DESIGN IN STRUCTURAL STEEL,
Summer Course Lecture Notes, Lehigh University,
AISC publication, 1955, Publication No. 106

*205.34  Beedle, L. S.
PRACTICAL APPLICATIONS OF PLASTIC DESIGN IN STRUCTURAL STEEL,
Proc. SEAOC, October 1955

*205.36  Driscoll, G. C., Jr. and Beedle, L. S.
THE PLASTIC BEHAVIOR OF STRUCTURAL MEMBERS AND FRAMES,
Welding Journal, 36 (6), p. 275-s, 1957, Publication No. 115

*205.41  Ketter, R. L. and Beedle, L. S.
DISCUSSION OF "ELASTIC-PLASTIC DESIGN OF SINGLE-SPAN BEAMS AND FRAMES",
by H. A. Sawyer, Proc. ASCE, 82 (ST4), p. 1024-11,
1956, Publication No. 109

*205.42  American Institute of Steel Construction
Proc. AISC National Engineering Conference, 1956,
Publication No. 110

Thurlimann, B.
SIMPLE PLASTIC THEORY, p. 13.

Ketter, R. L.
ANALYSIS AND DESIGN EXAMPLES, p. 19

Beedle, L. S.
EXPERIMENTAL VERIFICATION OF PLASTIC THEORY, p. 36

Thurlimann, B.
MODIFICATIONS TO "SIMPLE PLASTIC THEORY", p. 50

Driscoll, G. C., Jr.
TEST OF TWO-SPAN PORTAL FRAME, p. 74

205.45  Beedle, L. S.
EXPERIMENTAL VERIFICATION AND MODIFICATIONS TO THE SIMPLE PLASTIC THEORY, 1956

*205.47  Beedle, L. S.
GRADUATE STUDIES IN PLASTIC ANALYSIS AND DESIGN, ASEE
Civil Engineering Bulletin 22 (1), p. 8, December, 1956,
Publication No. 114

* Published Report
Ketter, R. L.
PLASTIC DESIGN OF MULTI-SPAN RIGID FRAMES,
Ph.D. Dissertation, Lehigh University, 1956

Ketter, R. L.
PLASTIC ANALYSIS AND DESIGN AT THE UNDERGRADUATE LEVEL,
ASEE Civil Engineering Bulletin 22 (1) p. 7, December 1956, Publication No. 114

Thurlimann, B.
PLASTIC DESIGN OF STRUCTURAL STEEL,
The Engineering Journal, Canada, February 1957, Publication No. 113

WRC-ASCE Joint Committee
COMMENTARY ON PLASTIC DESIGN IN STEEL, ASCE MANUAL No. 41, 1961, Publication No. 178

Ketter, R. L.
PLASTIC DESIGN OF PINNED-BASE GABLE FRAMES
Welding Research Council Bulletin Series, No. 48, 1959, Publication No. 134

Ketter, R. L. and Yen, B. T.
PLASTIC DESIGN OF PINNED-BASE LEAN-TO FRAMES,

Beedle, L. S.
PLASTIC DESIGN OF STEEL STRUCTURES,
AISI Regional Technical Meeting, Philadelphia, November 1958, Publication No. 127

Project Staff
WELDED CONTINUOUS FRAMES AND THEIR COMPONENTS - BIBLIOGRAPHY, 1959

Thurlimann, B.
NEW ASPECTS CONCERNING INELASTIC INSTABILITY OF STEEL STRUCTURES,

Ketter, R. L.
DISCUSSION OF "SINGLE STORY FRAMES by J. Heyman",

Ojalvo, M.
DISCUSSION OF "THE PLASTIC METHOD OF DESIGNING: STEEL STRUCTURES by J. F. Baker",

Beedle, L. S.

* Published Report
<table>
<thead>
<tr>
<th>Project 223</th>
<th>PRESTRESSED CONCRETE BRIDGE MEMBERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>*223</td>
<td>Ekberg, C. E. Jr.</td>
</tr>
<tr>
<td></td>
<td>SUMMARY ON PRESTRESSED CONCRETE PROGRAM AT LEHIGH UNIVERSITY, Proc. World Conference on Prestressed Concrete, July 1957, p. A30-1, Publication No. 175</td>
</tr>
</tbody>
</table>

* Published Report
Ekberg, C. E. Jr., Walther, R. E. and Slutter, R. G.  
FATIGUE RESISTANCE OF PRESTRESSED CONCRETE BEAMS IN  
BENDING, 1957

Slutter, R. G. and Ekberg, C. E., Jr.  
STATIC AND FATIGUE TESTS ON PRESTRESSED CONCRETE  
RAILWAY SLABS, AREA Bulletin No. 544, June-July 1958,  
Publication No. 131

Walther, R. E.  
THE SHEAR STRENGTH OF PRESTRESSED CONCRETE BEAMS,  
Proc. 3rd Congress, F. I. P., 1958

Ekberg, C. E., Jr. and Warner, R. F.  
PRESTRESSED CONCRETE RESEARCH AT LEHIGH UNIVERSITY  
1952-58, (March 1959)

Nasser, K. W. and Ekberg, C. E., Jr.  
STATIC AND FATIGUE TEST OF A 70 FOOT COMPOSITE  
PRESTRESSED CONCRETE BEAM, April 1959

Assimocoupoulos, B.; Werner, R. F. and Ekberg, C. E., Jr.  
HIGH SPEED FATIGUE TESTS ON SMALL SPECIMENS OF  
PLAIN CONCRETE, Prestressed Concrete Institute  
Journal, 4 (2), September 1959, Publication No. 173

Mayo, R; Lore, F.; Loewer, A. C., Jr. and Eney, W. J.  
A COMPARISON BETWEEN ORDINARY REINFORCED AND PRE­  
STRESSED REINFORCED CONCRETE BEAMS, February 1962

Mayo, R.; Loewer, A. C., Jr. and Eney, W. J.  
TEST OF A PRETENSIONED PRESTRESSED CONCRETE BEAM  
CONTAINING 5/16-INCH DIAMETER BONDED STRAND,  
June 1952

Smislova, A.; Loewer, A. C., Jr. and Eney, W. J.  
TEST OF PRETENSIONED PRESTRESSED CONCRETE BEAM, 1952

Smislova, A.; Loewer, A. C., Jr. and Eney, W. J.  
USING SR-4 GAGES TO MEASURE STRAINS IN WIRE STRAND,  
Project Engineering, April 1953, Publication No. 88

Knudsen, K. E. and Eney, W. J.  
ENDURANCE OF A FULL-SCALE PRETENSIONED CONCRETE MEMBER,  
Proc. Highway Research Board, 36, 1957,  
Publication No. 105

Smislova, A.; Brown, D. H., Jr.; Roesli, A. and Eney, W. J  
ENDURANCE OF A FULL-SCALE POST-TENSIONED CONCRETE  
MEMBER, May 1954

Brown, D. H.; Knudsen, K. E. and Eney, W. J.  
BOND OF PRESTRESSED STRANDS, September, 1953

Roesli, A.; Loewer, A. C., Jr. and Eney, W. J.  
MACHINE TO APPLY REPEATED LOADS TO LARGE FLEXURAL  
MEMBERS, ASTM Bulletin 196, February 1954, Publi. 94

* Published Report
*Roesli, A.; Smislova, A.; Ekberg, C. E., Jr. and Eney, W. J.*

*Roesli, A.*
LATERAL LOAD DISTRIBUTION IN MULTI-BEAM BRIDGES, Published as "THE ANALYSIS OF PRESTRESSED MULTI-BEAM BRIDGES AS ORTHOTROPIC PLATES", co-author, Walther, R., Proc. World Conference on Prestressed Concrete, San Francisco, July 1957, Publication No. 130

*Smislova, A.*
STATIC TESTS ON PRESTRESSED CONCRETE BEAMS USING 7/16-INCH STRANDS, June 1955

*Debly, L. J.*
STATIC TESTS ON PRESTRESSED CONCRETE BEAMS USING 7/16-INCH STRANDS, September 1955

*Debly, L. J.*
STATIC TESTS ON PRESTRESSED CONCRETE BEAMS USING 7/16-INCH STRANDS, June 1956

*Walther, R. E.*
INVESTIGATION OF MULTI-BEAM BRIDGES
Proc. ACI, 29 (6), December 1957, Publication No. 128

*Hulsbos, C. L.*

*Ekberg, C. E., Jr.; Walther, R. E. and Slutter, R. G.*
FATIGUE RESISTANCE OF PRESTRESSED CONCRETE BEAMS IN BENDING, (Progress Report No. 15), Proc. ASCE, 83 (ST4), July 1957, Publication No. 142

*Dinsmore, G. A. and Deutsch, P. L.*
ANCHORAGE CHARACTERISTICS OF STRAND IN PRETENSIONED PRESTRESSED CONCRETE, July 1957

*Walther, R. E.*
THE ULTIMATE STRENGTH OF PRESTRESSED AND CONVENTIONALLY REINFORCED CONCRETE UNDER THE COMBINED ACTION OF MOMENT AND SHEAR, May 1958

*Walther, R. E.*
SHEAR STRENGTH OF PRESTRESSED CONCRETE BEAMS, World Conference on Prestressed Concrete, May 1958, Publication No. 129

*Walther, R. E. and Warner, R. F.*
ULTIMATE STRENGTH OF PRESTRESSED CONCRETE BEAMS, World Conference on Prestressed Concrete, May 1958, Publication No. 129

*Published Report*
223.19 Dinsmore, G. A.; Deutsch, P. L. and Montemayor, J. L.
ANCHORAGE AND BOND IN PRETENSIONED PRESTRESSED CONCRETE MEMBERS, December 1958

223.20 Warner, R. F.
THE CALCULATION OF FLEXURAL STRESSES IN A PRESTRESSED CONCRETE MEMBER, November 1958

223.21 Lane, R. E. and Ekberg, C. E., Jr.
REPEATED LOAD TESTS ON 7 WIRE PRESTRESSING STRANDS, January 1959

FURTHER INVESTIGATION INTO THE SHEAR STRENGTH OF PRESTRESSED CONCRETE BEAMS WITHOUT WEB REINFORCEMENT, January 1962

223.23 Nasser, K. W.
STATIC AND FATIGUE TESTS OF A 30 FOOT COMPOSITE PRESTRESSED CONCRETE BEAM, March 1961

223.24 Warner, R. F.
PROBABLY FATIGUE LIFE OF PRESTRESSED CONCRETE FLEXURAL MEMBERS, Ph.D. Dissertation, Lehigh University, September 1961

*223.24A Warner, R. F. and Hulsbos, C. L.
PROBABLY FATIGUE LIFE OF UNDER-REINFORCED PRESTRESSED CONCRETE BEAMS, IABSE Publications Vol. 22, 1962, Publication No. 234

223.24C2 Warner, R. F. and Hulsbos, C. L.
FATIGUE PROPERTIES OF PRESTRESSING STRAND, May 1965

223.25 Hanson, J. M. and Hulsbos, C. L.
OVERLOAD BEHAVIOR OF PRESTRESSED CONCRETE BEAMS WITH WEB REINFORCEMENT, November 1963

223.25B Hanson, J. M. and Hulsbos, C. L.
FATIGUE TESTS OF TWO PRESTRESSED CONCRETE I-BEAMS WITH INCLINED CRACKS, January 1965

223.26 Ople, F. S.
PROBABLE FATIGUE LIFE OF CONCRETE WITH STRESS GRADIENT, Ph.D. Dissertation, Lehigh University, September 1963

223.26A Ople, F. S., Jr. and Hulsbos, C. L.
PROBABLY LIFE OR PRESTRESSED BEAMS AS LIMITED BY CONCRETE FATIGUE, October, 1963

223.26B Ople, F. S., Jr., and Hulsbos, C. L.
PROBABLE FATIGUE LIFE OF PLAIN CONCRETE WITH STRESS GRADIENT, December 1963

223.27 Hanson, J. M. and Hulsbos, C. L.
ULTIMATE SHEAR STRENGTH OF PRESTRESSED CONCRETE BEAMS WITH WEB REINFORCEMENT, April 1965

* Published Report
*223.27A  Hanson, J. M. and Hulsbos, C. L.

223.28 Brecht, H., Hanson, J. M. and Hulsbos, C. L.
ULTIMATE SHEAR STRENGTH TESTS OF FULL-SIZED PRESTRESSED CONCRETE BOX AND I-BEAMS, May 1965

223.28A Brecht, H. E.
ULTIMATE SHEAR TESTS OF FULL-SIZED PRESTRESSED CONCRETE BEAMS, M. S. Thesis, May 1965

223.29 Hanson, J. M. and Hulsbos, C. L.
FATIGUE TESTS ON PRESTRESSED CONCRETE BEAMS WITH A SMALL AMOUNT OF WEB REINFORCEMENT, June 1965

**Project 237**

**Laboratory Facilities**

237.1 Staff
RESEARCH AT FRITZ LABORATORY
(Talk to Chi Epsilon Fraternity)

237.4 Staff
FRITZ LABORATORY BROCHURE (Post-dedication)

237.6A Staff
RESEARCH MANUAL, September 1963

237.7 Thurlimann, B., and Eney, W. J.
AMSLER INSTALLATION REPORT, 1956
Proceedings SESA, 1959, Publication No. 147

237.10 Staff
TORSION TEST MANUAL - Using the 2,000 Pound-Inch Torsion Testing Machine

237.16 (M-23) Herbich, J. B.
FACILITIES FOR INSTRUCTION AND RESEARCH IN FLUID MECHANICS AND HYDRAULICS, March 1961

237.18 Dwyer, T. J.
BIBLIOGRAPHY OF REPORTS ON CURRENT RESEARCH PROJECTS 1962

237.20 Lyse, I.
CURRENT WORK AT LEHIGH UNIVERSITY, ENR, February 15, 1934

237.21 Lyse, I.
CURRENT STUDIES AT LEHIGH UNIVERSITY, ENR, April 25, 1935

237.22 Lyse, I.
CURRENT STUDIES AT LEHIGH UNIVERSITY, ENR, March 12, 1936

* Published Report
237.23 Lyse, I.
THE FUNCTION OF FRITZ ENGINEERING LABORATORY
April Meeting of Alumni Conference, 1937

237.24 Staff
BIBLIOGRAPHY OF REPORTS ON COMPLETED PROJECTS

237.25 Staff
HISTORY OF FRITZ LABORATORY

237.26 Beedle, L. S.
Notes on "The History of Research in Steel Structures"

237.27 Staff
EVALUATION OF FATIGUE TESTING CAPACITY OF FRITZ ENGINEERING LABORATORY

*237.28 Staff
RESEARCH AND INDUSTRIAL TESTING AT FRITZ ENGINEERING LABORATORY, Brochure, 1964, Publication No. 238

237.29 Estuar, F. R.
LIST OF PUBLICATIONS, 1964

237.30 Staff
CURRENT RESEARCH PROJECT BROCHURE for Alumni All Class Reunion, June 1965

Project 248

BUILT UP MEMBERS IN PLASTIC THEORY

248.1 Kusuda, T. and Thurlimann, B.
STRENGTH OF WIDE-FLANGE BEAMS UNDER COMBINED INFLUENCE OF MOMENT, SHEAR AND AXIAL FORCE, 1958

*248.2 Kusuda, T.
BUCKLING OF STIFFENED PANELS IN ELASTIC AND STRAIN-HARDENING RANGE, Ph.D. Dissertation, Lehigh University, 1958. Published by Transportation Technical Research Institute (Japan), Report No. 39, Publication No. 150

248.3 Kusuda, T. and Thurlimann, B.
CORNER CONNECTIONS WITH CUT-OUT, (in preparation)

248.4 Ostapenko, A. and Lee, T. T.
TESTS ON LONGITUDINALLY STIFFENED PLATE PANELS SUBJECTED TO LATERAL AND AXIAL LOADING, 1960

248.5 Rampetsreiter, R. H.; Lee, T. T. and Ostapenko, A.
TESTS ON LONGITUDINALLY STIFFENED PLATE PANELS (EFFECT OF RESIDUAL STRESSES AND ROTATIONAL RESTRAINT BY STIFFENERS), July 1962

248.6 Ostapenko, A.
APPARATUS FOR TESTING PLATE PANELS UNDER AXIAL AND LATERAL LOADING, June 1961

* Published Report
Lee, T. T.
ELASTIC PLASTIC ANALYSIS OF SIMPLY SUPPORTED RECTANGULAR PLATES UNDER COMBINED AXIAL AND LATERAL LOADING, Ph.D. Dissertation, Lehigh University, August 1961

Ostapenko, A.
SCANTLINGS OF LONGITUDINALLY STIFFENED SHIP BOTTOM PLATING, April 1961

Lee, T. T. and Ostapenko, A.
INELASTIC STABILITY OF LONGITUDINALLY STIFFENED PLATE PANELS (SHIP BOTTOM PLATING), Tests Conducted during 1960, December 1960

Rampetsreiter, R. H.
COMPRESSIVE PROPERTIES OF THIN STEEL COUPONS, M. S. Thesis Lehigh University, May 1962

Ostapenko, A. and Kondo, J.
PROGRESS REPORT ON TESTS WITH FIXED LOADING EDGES AND MEASUREMENT OF RESIDUAL STRESSES, November 1962

Kondo, J. and Ostapenko, A.
TESTS ON LONGITUDINALLY STIFFENED PLATE PANELS WITH FIXED ENDS, July 1964

Kondo, J.
ULTIMATE STRENGTH OF STIFFENED PLATE PANELS SUBJECTED TO COMBINED AXIAL AND LATERAL LOADING, Ph.D. Dissertation, June 1965

Tsuiji, T.
STRENGTH OF LONGITUDINALLY STIFFENED PLATE PANELS WITH LARGE b/t, M.S. Thesis, June 1965

Davidson, H. L.
POST BUCKLING BEHAVIOR OF LONG RECTANGULAR PLATES, M. S. Thesis, June 1964

Project 249
RESIDUAL STRESSES AND WELDED COLUMNS

Fujita, Y.
PRELIMINARY REPORT ON WELDED AND RIVETED MEMBERS, May, 1956

Fujita, Y.
BUILT-UP COLUMN STRENGTH, Dissertation, Lehigh University, August 1956

Lee, G. C.
AN EXPERIMENTAL INVESTIGATION OF THE STRENGTH OF A RIVETED, BUILT-UP COLUMN, December 1957

Fujita, Y.
ULTIMATE STRENGTH OF CENTRALLY LOADED COLUMNS, 1959
| *249.7 | Tall, L. and NagarajaRao, N. R.  
| 249.9 | Tamaro, G.  
THE COLUMN CURVE FOR LOW SLENDERNESS RATIOS,  
M.S. Thesis, Lehigh University, May 1961 |
| 249.10 | Tall, L.  
THE STRENGTH OF WELDED BUILT-UP COLUMNS,  
Ph.D. Dissertation, Lehigh University, May 1961 |
| *249.11 | Tall, L.  
RESIDUAL STRESSES IN WELDED PLATES - A THEORETICAL STUDY, Welding Journal, Vol. 43, 10-s, January 1964, Publication No. 235 |
| 249.12 | Tall, L.  
HEAT INPUT, THERMAL AND RESIDUAL STRESSES IN WELDED STRUCTURAL PLATES, August 1962 |
| *249.13 | Tall, L. and Estuar, F. R.  
| *249.14 | Tall, L.  
| *249.15 | Tall, L. and Estuar, F.  
| 249.17 | Tall, L.  
DISCUSSION OF "RESIDUAL STRESSES IN ROLLED I-SECTIONS" by Carmen Jez-Gala, submitted to the Institute of Civil Engineers, England, January 1963 |
| *249.18 | NagarajaRao, N., Estuar, F. and Tall, L.  
| *249.19 | NagarajaRao, N. and Tall, L.  
NEW CONCEPTS IN DESIGN OF STEEL COLUMNS AND ALLOWABLE STRESSES, Journal of the Inst. of Engineers (India) November 1964, Publication No. 265 |
| 249.20 | NagarajaRao, N. R.  
MATERIAL PROPERTIES OF STRUCTURAL CARBON AND HIGH STRENGTH STEELS, April 1963 |

* Published Report
<table>
<thead>
<tr>
<th>Project 273</th>
<th>MULTI-STORY FRAMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>273.1</td>
<td>Lu, L. W. and Levi, V.</td>
</tr>
<tr>
<td></td>
<td>LITERATURE SURVEY ON PLASTIC ANALYSIS AND DESIGN OF MULTI-STORY FRAMES, (In preparation)</td>
</tr>
<tr>
<td>273.2</td>
<td>Baillie, D. S.</td>
</tr>
<tr>
<td></td>
<td>FAILURE DOMAINS FOR SINGLE BAY, FLAT ROOFED, ONE AND TWO STORY PORTAL FRAMES, C. E. 406 Report, Lehigh University, June 1960</td>
</tr>
<tr>
<td>273.3</td>
<td>Levi, V. and Driscoll, G. C., Jr.</td>
</tr>
<tr>
<td></td>
<td>PLASTIC DESIGN OF BRACED MULTI-STORY FRAMES, Lehigh University, July 1961</td>
</tr>
<tr>
<td>273.7</td>
<td>Patel, N. V.</td>
</tr>
<tr>
<td>273.8</td>
<td>Levi, V.</td>
</tr>
<tr>
<td></td>
<td>RESPONSE OF COLUMNS TO IN-PLANE LOADING, April, 1963</td>
</tr>
</tbody>
</table>

* Published Report
<table>
<thead>
<tr>
<th>Project</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>273.11</td>
<td>Analysis of structural subassemblies prevented from sway</td>
<td>Levi, V., Driscoll, G. C., Jr. and Lu, L. W.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>ANALYSIS OF STRUCTURAL SUBASSEMBLAGES PREVENTED FROM SWAY</strong>, December 1964</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>REVISED PROPOSAL FOR BRACED MULTI-STORY FRAME TESTS</strong>, February 1964</td>
</tr>
<tr>
<td>273.15</td>
<td>Load deflection curve of braced and unbraced three-story frame</td>
<td>Driscoll, G. C., Jr.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>LOAD DEFLECTION CURVE OF BRACED AND UNBRACED THREE-STORY FRAME</strong>, September 1963</td>
</tr>
<tr>
<td>*273.17</td>
<td>Research in plastic design of multi-story frames</td>
<td>Driscoll, G. C., Jr. and Beedle, L. S.</td>
</tr>
<tr>
<td>273.18</td>
<td>The ultimate strength of single-story frames</td>
<td>Yura, J. A. and Galambos, T. V.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>THE ULTIMATE STRENGTH OF SINGLE-STORY FRAMES</strong>, July 1964</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>PLASTIC DESIGN OF MULTI-STORY FRAMES</strong>, May 1965</td>
</tr>
<tr>
<td>273.21</td>
<td>Load-deflection relationships for simple frames</td>
<td>Adams, P. F.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>LOAD-DEFORMATION RELATIONSHIPS FOR SIMPLE FRAMES</strong>, December 1964</td>
</tr>
<tr>
<td>273.22</td>
<td>Project staff summary of project descriptions and plans</td>
<td>Project Staff</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>1964 SUMMARY OF PROJECT DESCRIPTIONS AND PLANS</strong>, November 1964</td>
</tr>
<tr>
<td>*273.23</td>
<td>Discussion of &quot;elastic and inelastic buckling of portal frames&quot;</td>
<td>Adams, P. F. and Yura, J. A.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>PROPOSAL FOR UNBRACED MULTI-STORY FRAME TESTS</strong>, March 1965</td>
</tr>
<tr>
<td>*273.27</td>
<td>Research spurs plastic design of multi-story frames</td>
<td>Staff</td>
</tr>
</tbody>
</table>

**Project 276**

**Frame Stability**

*276.1 Galambos, T. V.  
Influence of partial base fixity on frame stability,  
Proc. ASCE, 86, (ST5), 1960, Publication No. 156

*276.2 Lu, L. W.  
Literature survey on frame stability, Welding  
Research Bulletin No. 81, September 1962,  
Publication No. 206

* Published Report
276.3 Lu, L. W.  
STABILITY OF ELASTIC AND PARTIALLY PLASTIC FRAMES,  
Ph.D. Dissertation, Lehigh University, 1960

276.4 Lu, L. W. and Driscoll, G. C., Jr.  
BUCKLING TESTS ON MODEL STEEL FRAMES, 1962

*276.5 Lu, L. W.  
STABILITY OF ELASTIC AND PARTIALLY PLASTIC FRAMES,  
Ph.D. Dissertation, Lehigh University, 1960

276.4 Lu, L. W. and Driscoll, G. C., Jr.  
BUCKLING TESTS ON MODEL STEEL FRAMES, 1962

*276.5 Lu, L. W.  
STABILITY OF FRAMES UNDER PRIMARY BENDING MOMENTS,  
Publication No. 227

*276.5A Lu, L. W.  
DIGEST OF "STABILITY OF FRAMES UNDER PRIMARY  

*276.6 Ojalvo, M. and Lu, L. W.  
ANALYSIS OF FRAMES LOADED INTO THE PLASTIC RANGE,  
Proc. ASCE, 87 (EM4), August 1961, Publication No. 182

276.7 Lu, L. W.  
INELASTIC BUCKLING OF STEEL FRAMES, July 1963

*276.8 Lu, L. W.  
DISCUSSION ON "ELASTO-PLASTIC ANALYSIS BY NUMERICAL  
PROCEDURES" by A. L. Tong, Proc. ASEC, 87 (EM3),  
June 1961, Publication No. 184

*276.9 Yen, Y. C.; Lu, L. W. and Driscoll, G. C., Jr.  
TESTS ON THE STABILITY OF STEEL FRAMES, Welding  
Research Bulletin No. 81, September 1962,  
Publication No. 206

*276.10 Lu, L. W.  
DISCUSSION ON "CONTINUOUS BEAM-COLUMNS ON ELASTIC  
FOUNDATIONS" by S. L. Lee, T. M. Wang, and  
J. S. Kao, Proc. ASCE, 87, (EM4), p. 149,  
August 1961, Publication No. 183

276.11 Yen, Y. C., Lu, L. W. and Driscoll, G. C., Jr.  
PROPOSAL FOR THE INVESTIGATION OF INSTABILITY OF  
MULTI-STORY FRAMES, 1962

276.13 Yen, Y. C.  
INSTABILITY ANALYSIS AND TEST SET UP OF THREE-STORY  
FRAMES, September 1963

* Published Report
276.14 Yen, Y. C.
ELASTIC AND PARTIALLY PLASTIC INSTABILITY OF MULTI-STORY FRAMES, Ph.D. Dissertation, September 1964

*276.16 Lu, L. W.
EFFECTIVE LENGTH OF COLUMNS IN GABLE FRAMES,
Journal AISC, Vol. 1, No. 1, January 1965, p. 6
Publication No. 270

*276.17 Galambos, T. V.
LATERAL SUPPORT FOR TIER BUILDING FRAMES,
Journal AISC, Vol. 1, No. 1, January 1964,
Publication No. 253

Project 290 WELDED AND ROLLED "T-1" COLUMNS 290

290.1 Ueda, Y.
ELASTIC, ELASTIC-PLASTIC AND PLASTIC BUCKLING OF PLATES WITH RESIDUAL STRESSES, Ph.D. Dissertation 1962

290.2 Ueda, Y. and Tall, L.
BUCKLING OF PLATES WITH RESIDUAL STRESSES,
December 1964

290.4 Odar, E., Nishino, F. and Tall, L.
RESIDUAL STRESSES IN T-1 CONSTRUCTIONAL ALLOY STEEL PLATES, January 1965

290.10 Nishino, F.
BUCKLING STRENGTH OF COLUMNS AND THEIR COMPONENT PLATES, Ph.D. Dissertation, 1964

Project 293 GRAVITY WAVES IN CONSTRICTIONS 293

293.2 Murphy, H. D.
SCOUR OF FLAT SAND BEACHES DUE TO WAVE ACTION,
M.S. Thesis, June 1964

293.3 Van Weele, B.
BEACH SCOUR DUE TO WAVE ACTION ON SEA WALLS,
April, 1965

293.4 Van Weele, B.
WAVE REFLECTION AND TRANSMISSION FOR CYLINDRICAL PILE ARRAYS, M.S. Thesis, May 1965

Project 297 PLASTIC DESIGN IN HIGH STRENGTH STEEL 297

297.2 Lay, M. G.
A BRIEF SURVEY OF U.S. STRUCTURAL STEEL TYPES,
September, 1962

*297.3 Lay, M. G.
THE EXPERIMENTAL BASES OF PLASTIC DESIGN
WRC Bulletin No. 99, September 1964,
Publication No. 257

* Published Report
297.4 Lay, M. G. and Gimsing, N.  

297.5 Lay, M. G. and Galambos, T. V.  
THE DUCTILITY OF STEEL STRUCTURES, March 1963

297.6 Lay, M. G.  
THE STATIC LOAD-DEFORMATION BEHAVIOR OF PLANAR STEEL STRUCTURES, Ph.D. Dissertation, Lehigh University, April 1964

297.7 Adams, P. F.  
DETERMINATION OF THE STATIC YIELD LEVEL AND THE STRAIN-HARDENING MODULUS, March 1964

297.8 Lay, M. G., Adams, P. F. and Galambos, T. V.  
EXPERIMENTS ON HIGH STRENGTH STEEL MEMBERS, July 1964

297.9 Lay, M. G. and Galambos T. V.  
THE INELASTIC BEHAVIOR OF CLOSELY BRACED STEEL BEAMS UNDER UNIFORM MOMENT, July 1964

297.10 Lay, M. G.  
SOME STUDIES OF FLANGE LOCAL BUCKLING IN WIDE-FLANGE SHAPES, July 1964

297.11 Lay, M. G. and Galambos, T. V.  
BRACING REQUIREMENTS FOR INELASTIC STEEL BEAMS, July 1964

297.12 Lay, M. G. and Galambos, T. V.  
THE INELASTIC BEHAVIOR OF BEAMS UNDER MOMENT GRADIENT, July 1964

297.14 Kerfoot, R. P.  
ROTATION CAPACITY OF BEAMS, June 1965

Project 301  
DREDGE PUMPS AND DREDGING SYSTEMS

301.1 Murphy, H. D. and Herbich, J. B.  
SUCTION DREDGING LITERATURE SURVEY, June 1963

301.2 Isaacs, W. P., Mariani, V. R., Murphy, H. D. and Talian, S.F.  
PERFORMANCE STUDY OF A 1:6 MODEL DREDGE PUMP, September 1963

301.3 Isaacs, W. P. and Herbich, J. B.  
HIGH SPEED AND CAVITATION CHARACTERISTICS OF DREDGE PUMPS

Project 302  
BIBLIOGRAPHY ON BOLTED AND RIVETED STRUCTURAL JOINTS

302.1 Fisher, J.W. and Beedle, L. S.  
BIBLIOGRAPHY ON BOLTED AND RIVETED STRUCTURAL JOINTS

* Published Report
### Project 303

**FATIGUE STRENGTH OF WELDED PLATE GIRDERS**

303.1 
Yen, B. T.  
ON THE FATIGUE STRENGTH OF WELDED PLATE GIRDERS,  
Ph.D. Dissertation, November 1963

303.3 
D’Huy, G. J.  
FATIGUE TESTS OF FILLET-WELDED TEES IN BENDING,  
M. S. Thesis, June 1964

*303.5 
Fisher, J. W. and Yen, B. T.  
DISCUSSION OF "FLEXURAL FATIGUE TESTS OF PRESTRESSED STEEL I-BEAMS" by W. D. Reneker and C. C. Ekberg,  
Publication No. 275

303.6 
Yen, B. T. and Mueller, J. M.  
FATIGUE TESTS OF WELDED PLATE GIRDERS IN SHEAR,  
November, 1965

303.7 
Mueller, J. M., Dudley, K. E. and Yen, B. T.  
PROPOSAL FOR AN INVESTIGATION ON WEB-BOUNDARY JOINTS OF WELDED PLATE GIRDERS, January 1965

303.8 
Mueller, J. M. and Yen, B. T.  
PROPOSAL FOR FATIGUE TESTING OF WELDED PLATE GIRDERS UNDER THE INTERACTION OF BENDING AND SHEAR, January 1965

303.9 
Corrado, J. A., Mueller, J. A. and Yen, B. T.  
FATIGUE TESTS OF WELDED PLATE GIRDERS IN BENDING AND SHEAR, January 1965

### Project 304

**LONGITUDINALLY STIFFENED PLATE GIRDERS**

304.1 
Cooper, P. B.  
PRELIMINARY REPORT AND PROPOSAL, July 1963

304.2 
Cooper, P. B.  
LITERATURE SURVEY ON LONGITUDINALLY STIFFENED PLATES  
September, 1963

304.3 
Cooper, P. B.  
PROPOSAL FOR BENDING TESTS ON LONGITUDINALLY STIFFENED PLATE GIRDERS, February 1964

304.4 
Cooper, P. B.  
PROPOSAL FOR SHEAR TESTS ON LONGITUDINALLY STIFFENED PLATE GIRDERS, October 1964

304.5 
D'Apice, M. A. and Cooper, P. B.  
STATIC BENDING TESTS ON LONGITUDINALLY STIFFENED PLATE GIRDERS, April 1965

### Project 305

**HYBRID STEEL COLUMNS**

305.1 
Nagaraja Rao, N. R.  
THE STRENGTH OF HYBRID STEEL COLUMNS,  
Ph.D. Dissertation, June 1965

* Published Report
Project 309

BOND BETWEEN CONCRETE AND PRESTRESSING STRAND

309.1
Badaliance, R.
ULTIMATE FLEXURAL BOND BETWEEN CONCRETE AND PRESTRESSING STRAND, M. S. Thesis, May 1965

Project 310

GAS REMOVAL ASSOCIATED WITH DREDGE PUMPS

310.1
Herbich, J. B.
GAS REMOVAL SYSTEMS ASSOCIATED WITH DREDGE PUMPS

310.2
Vesilind, A. and Herbich, J. B.
GAS REMOVAL SYSTEMS ASSOCIATED WITH DREDGE PUMPS, Status Report No. 2

310.3
Isaacs, W. P. and Herbich, J. B.
GAS REMOVAL SYSTEMS PART I: LITERATURE SURVEY AND FORMULATION OF TEST PROGRAM, July 1964

310.4
Herbich, J. B.
GAS REMOVAL SYSTEMS ASSOCIATED WITH DREDGE PUMPS: PHASE B, October 1964

310.5
Shindala, A., Herbich, J. B., Amatangelo, A., and Bagge, G.
GAS REMOVAL SYSTEMS, PHASE B: PART I FORMATION OF TEST PROGRAM, December 1964

310.6
Shindala, A., Herbich, J. B., Amatangelo, A. and Bagge, G.
GAS REMOVAL SYSTEMS, PHASE B: PART I FORMATION OF TEST PROGRAM, January 1965

310.7
Shindala, A., Herbich, J. B.,
GAS REMOVAL SYSTEMS: PART II FORMULATION OF TEST PROGRAM DEVELOPMENT OF FACILITY LAYOUT, Feb. 1965

Project 312

SURVEY OF CURRENT STRUCTURAL RESEARCH

*312.7
Research Committee of the Structural Division, ASCE

Project 313

MODELS FOR THREE-DIMENSIONAL STRUCTURES

313.1
Gaedeke, K. P.
MODEL INVESTIGATION OF A NORTHLIGHT BARREL SHELL STRUCTURE, March 1965

Project 314

CRACK PROPAGATION

314.1
Linder, B., Yen, B. T. and Paris, P.
EXTREMELY SLOW CRACK GROWTH RATES IN ALUMINUM ALLOY 7075-T6, June 1965

*Published Report
SHEAR CONNECTOR DESIGN FOR HIGHWAY BRIDGES

Slutter, R. G. and Fisher, J. W.
TENTATIVE DESIGN PROCEDURE FOR SHEAR CONNECTORS
IN COMPOSITE BEAMS, March 1965
### PROJECTS LISTED BY DIVISIONS

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title of Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hydraulics</strong></td>
<td></td>
</tr>
<tr>
<td>280</td>
<td>Spur Dikes for Bridge Abutments</td>
</tr>
<tr>
<td>293</td>
<td>Gravity Waves in Constrictions</td>
</tr>
<tr>
<td>301</td>
<td>Dredge Pumps and Dredging Systems</td>
</tr>
<tr>
<td>310</td>
<td>Gas Removal Associated with Dredge Pumps</td>
</tr>
<tr>
<td><strong>Structural Concrete</strong></td>
<td></td>
</tr>
<tr>
<td>223</td>
<td>Prestressed Concrete Bridge Members</td>
</tr>
<tr>
<td>306</td>
<td>Horizontal Shear Connection in Composite Beams</td>
</tr>
<tr>
<td>309</td>
<td>Bond Between Concrete and Prestressing Strand</td>
</tr>
<tr>
<td>315</td>
<td>Lateral Load Distribution on Concrete Bridges</td>
</tr>
<tr>
<td><strong>Structural Metals</strong></td>
<td></td>
</tr>
<tr>
<td>205</td>
<td>Welded Continuous Frames and Their Components</td>
</tr>
<tr>
<td>248</td>
<td>Built-up Members in Plastic Design</td>
</tr>
<tr>
<td>273</td>
<td>Multi-story Frames</td>
</tr>
<tr>
<td>276</td>
<td>Frame Stability</td>
</tr>
<tr>
<td>290</td>
<td>Welded and Rolled &quot;T-1&quot; Columns</td>
</tr>
<tr>
<td>297</td>
<td>Plastic Design in High Strength Steels</td>
</tr>
<tr>
<td>302</td>
<td>Bibliography on Bolted and Riveted Structural Joints</td>
</tr>
<tr>
<td>303</td>
<td>Fatigue Strength of Welded Plate Girders</td>
</tr>
<tr>
<td>304</td>
<td>Longitudinally Stiffened Plate Girders</td>
</tr>
<tr>
<td>305</td>
<td>Hybrid Steel Columns</td>
</tr>
<tr>
<td>312</td>
<td>Survey of Current Structural Research</td>
</tr>
<tr>
<td>314</td>
<td>Crack Propagation Rates of Aluminum Plates</td>
</tr>
<tr>
<td>316</td>
<td>Shear Connector Design for Highway Bridges</td>
</tr>
<tr>
<td>317</td>
<td>Large Bolted Connections of Higher Strength Steels</td>
</tr>
<tr>
<td>318</td>
<td>Service Performance of Large Bolted Joints</td>
</tr>
<tr>
<td><strong>Structural Models</strong></td>
<td></td>
</tr>
<tr>
<td>313</td>
<td>Models for Three-Dimensional Structures</td>
</tr>
</tbody>
</table>
AUTHOR INDEX

Adams, P. F., 273, 297
Amatangelo, A., 310
Assimacopoulos, B., 223
Badaliance, R., 309
Bagge, G., 310
Baillie, D. S., 273
Beedle, L. S., 205, 237, 273, 302
Brecht, H., 223
Brown, D. H., 223
Chen, C. H., 205
Christopher, R., 205
Cooper, P. B., 304
Corrado, J., 303
D'Apice, M. A., 304
Davidson, H. L., 248
Debly, L. J., 223
Deutsch, P., L., 223
D'Huy, G. J., 303
Dinsmore, G. A., 223
Driscoll, G. C., Jr., 205, 273, 276
Dudley, K. E., 303
Dwyer, T. J., 237
Ekburg, C. E., Jr., 223
Eney, W. J., 223, 237
Estuar, F., 237, 249
Feder, D., 249
Fisher, J. W., 273, 302, 303, 316
Gaedeke, K. P., 313
Galambos, T. V., 205, 273, 276, 297
Gimsing, N., 297
Grigoriadis, M., 205A
Hansell, W. C., 205
Hanson, J. M., 223
Herbich, J. B., 237, 301, 310
Hulsbos, C. L., 223
Issacs, W. P., 301, 310
Johnston, B. G., 205
Kerfoot, R. P., 297
Ketter, R. L., 205
Knudsen, K. E., 205, 223
Kondo, J., 248
Kusuda, T., 248
Lane, R. E., 223
Lay, M. G., 297
Lee, G. C., 249
Lee, T. T., 248
Levi, V., 273
Linder, B., 314
Loewer, A. C., Jr., 223
Lohrmann, M., 249
Lore, F., 223
Lu, L. W., 205, 273, 276
Luxion, W., 205
Lyse, L., 237
Mariani, V. R., 301
Mayo, R. W., 223
McClarnon, F., 223
Montemayor, J. L., 223
Mueller, J. A., 303
Murphy, H. D., 293, 301
Nagaraja Rao, N. R., 249, 305
Nasser, K. W., 223
Nishino, F., 290
Odar, E., 290
Ojhalvo, M., 205, 276
Ople, F. S., Jr., 223
Ostapenko, A., 248, 273
Parikh, B. P., 273
Paris, P., 314
Patel, N. B., 273
Rampetsreiter, R. H., 248
Ready, J. A., 205
Recchio, D. A., 205
Roesli, A., 223
Ruzek, J. M., 205
Seaman, W. B., 249
Shindala, A., 310
Slutter, R. G., 223, 316
Smislova, A., 223
Talian, S. F., 301
Tall, L., 249, 290
Tammaro, G., 249
Thurlimann, B., 205, 237, 248
Topreactsoglou, A. A., 205
Tsuiji, T., 248
Ueda, Y., 290
Van Weele, B., 293
Wakabayashi, M., 223
Walther, R. D., 223
Warner, R. F., 223
WRC-ASCE, 205
Yang, C. H., 205
Yarimei, E., 273
Yen, B. T., 205, 303, 314
Yen, Y. C., 276
Yordy, E. L., 291
Yura, J. A., 273
<table>
<thead>
<tr>
<th>Sponsor</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Institute of Steel Construction</td>
<td>205, 273, 276, 297, 304, 317</td>
</tr>
<tr>
<td>American Iron and Steel Institute</td>
<td>205, 273, 276, 297, 303, 304</td>
</tr>
<tr>
<td>American Society of Civil Engineers</td>
<td>312</td>
</tr>
<tr>
<td>Column Research Council</td>
<td>205, 249, 273, 276, 297, 305</td>
</tr>
<tr>
<td>Ellicott Machine Corporation</td>
<td>301</td>
</tr>
<tr>
<td>Fritz Engineering Laboratory</td>
<td>312</td>
</tr>
<tr>
<td>Lehigh University Institute of Research</td>
<td>293, 313</td>
</tr>
<tr>
<td>Modjeski &amp; Masters, Consulting Engineers</td>
<td>280</td>
</tr>
<tr>
<td>National Aeronautics and Space Administration</td>
<td>314</td>
</tr>
<tr>
<td>Reinforced Concrete Research Council</td>
<td>223, 306</td>
</tr>
<tr>
<td>Research Council on Riveted and Bolted Structural Joints</td>
<td>302, 318</td>
</tr>
<tr>
<td>United States Army Engineers</td>
<td>310</td>
</tr>
<tr>
<td>United States Navy Department</td>
<td>205, 248, 273, 276, 297</td>
</tr>
<tr>
<td>United States Steel Corporation</td>
<td>290</td>
</tr>
<tr>
<td>Welding Research Council</td>
<td>205, 273, 276, 297, 303, 304</td>
</tr>
</tbody>
</table>
CURRENT RESEARCH PROJECTS

Fritz Engineering Laboratory
Lehigh University
Bethlehem, Pennsylvania

1969

237.17 (69)
RESEARCH
AT
FRITZ ENGINEERING LABORATORY

Founded in 1909, the Fritz Engineering Laboratory serves for the advancement of knowledge and techniques in the fields of structures, structural mechanics, structural model analysis, soil mechanics, materials, hydraulics and fluid mechanics, and sanitation.

The Fritz Engineering Laboratory is one of the research organizations of the University under the cognizance of the Vice President for Research. The Laboratory is associated primarily with the department of Civil Engineering. In addition, there are cooperative research efforts with other departments of the University and with other institutes and universities. Research projects are sponsored through the Office of Research by national research councils, industrial corporations and associations, private companies, and by state and federal government agencies.

In 1955 the Laboratory was expanded and modernized to provide excellent facilities for research and instruction. Since then the additional necessary equipment has been acquired to fill the needs of new research investigations.

Through the Laboratory organization, technical seminars and lectures are presented on current research findings and on new design applications in the various fields of Civil Engineering and related disciplines.

The staff of the Laboratory consists of Lehigh University faculty members, research associates, research assistants, and supporting technical personnel.

As a result of the research studies conducted by the staff of the Laboratory, it has been possible to make basic changes to design procedures and specifications in numerous specialty fields. The Laboratory participates in a worldwide exchange of research information, maintains a special library of technical papers appropriate to its fields, and stimulates the publication of papers in technical journals both in this country and abroad.

In the following pages, the current research projects are described. A list of these projects and of the staff members directing them is included at the beginning. A bibliography of reports on particular projects is available upon request.

L. S. Beedle, Director
<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title</th>
<th>Project Directors</th>
</tr>
</thead>
<tbody>
<tr>
<td>248</td>
<td>BUILT-UP MEMBERS IN PLASTIC DESIGN</td>
<td>A. Ostapenko</td>
</tr>
<tr>
<td>273</td>
<td>TESTS OF NON-SWAY SUBASSEMBLAGES IN MULTI-STORY FRAMES</td>
<td>L. W. Lu</td>
</tr>
<tr>
<td>276</td>
<td>FRAME STABILITY</td>
<td>G. C. Driscoll, Jr.</td>
</tr>
<tr>
<td>290</td>
<td>WELDED BUILT-UP AND ROLLED HEAT-TREATED &quot;T-1&quot; STEEL COLUMNS</td>
<td>L. Tall</td>
</tr>
<tr>
<td>297</td>
<td>PLASTIC DESIGN IN HIGH STRENGTH STEEL</td>
<td>L. W. Lu</td>
</tr>
<tr>
<td>302</td>
<td>BIBLIOGRAPHY ON BOLTED AND RIVETED STRUCTURAL JOINTS</td>
<td>J. W. Fisher</td>
</tr>
<tr>
<td>309</td>
<td>BOND BETWEEN CONCRETE AND PRESTRESSING STRAND</td>
<td>D. A. VanHorn</td>
</tr>
<tr>
<td>310</td>
<td>GAS REMOVAL ASSOCIATED WITH DREDGE PUMPS</td>
<td>J. R. Adams</td>
</tr>
<tr>
<td>312</td>
<td>SURVEY OF CURRENT STRUCTURAL RESEARCH</td>
<td>L. S. Beedle</td>
</tr>
<tr>
<td>315</td>
<td>LATERAL DISTRIBUTION OF LOAD FOR BRIDGES CONSTRUCTED WITH PRESTRESSED CONCRETE BOX GIRDERS</td>
<td>D. A. VanHorn</td>
</tr>
<tr>
<td>317</td>
<td>LARGE BOLTED CONNECTIONS OF HIGHER STRENGTH STEELS</td>
<td>J. W. Fisher</td>
</tr>
<tr>
<td>318</td>
<td>SERVICE PERFORMANCE OF BOLTED JOINTS</td>
<td>J. W. Fisher</td>
</tr>
<tr>
<td>321</td>
<td>WELDED COLUMNS AND FLAME-CUT PLATES</td>
<td>L. Tall</td>
</tr>
<tr>
<td>322</td>
<td>A STRUCTURAL MODEL STUDY OF LOAD DISTRIBUTION IN HIGHWAY BRIDGES</td>
<td>D. A. VanHorn</td>
</tr>
<tr>
<td>323</td>
<td>GRILLAGES UNDER NORMAL AND AXIAL LOADS</td>
<td>A. Ostapenko</td>
</tr>
<tr>
<td>327</td>
<td>WELDED PLATE GIRDERS - DESIGN RECOMMENDATIONS</td>
<td>B. T. Yen</td>
</tr>
<tr>
<td>328</td>
<td>UNSYMMETRICAL PLATE GIRDERS</td>
<td>A. Ostapenko</td>
</tr>
<tr>
<td>329</td>
<td>DESIGN OF LATERALLY UNSUPPORTED COLUMNS</td>
<td>L. W. Lu</td>
</tr>
<tr>
<td>331</td>
<td>SPACE FRAMES WITH BIAXIAL LOADING IN COLUMNS</td>
<td>L. W. Lu</td>
</tr>
<tr>
<td>332</td>
<td>BEHAVIOR OF STEEL FRAMES UNDER REPEATED LOADING</td>
<td>L. W. Lu</td>
</tr>
<tr>
<td>333</td>
<td>BEAM-TO-COLUMN CONNECTIONS</td>
<td>G. C. Driscoll, Jr.</td>
</tr>
<tr>
<td>334</td>
<td>EFFECT OF WELDMENTS ON FATIGUE STRENGTH OF STEEL BEAMS</td>
<td>J. W. Fisher</td>
</tr>
<tr>
<td>335</td>
<td>FRACTURE BEHAVIOR OF HIGH STRENGTH LOW ALLOY STRUCTURAL STEEL FOR BRIDGES</td>
<td>G. R. Irwin</td>
</tr>
<tr>
<td>336</td>
<td>TWO-LICK CREEK DAM MODEL STUDY</td>
<td>A. W. Brune</td>
</tr>
<tr>
<td>Project No.</td>
<td>Title</td>
<td>Project Directors</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>337</td>
<td>RESIDUAL STRESSES IN THICK WELDED PLATES</td>
<td>L. Tall</td>
</tr>
<tr>
<td>339</td>
<td>LOSS IN PRESTRESSED CONCRETE</td>
<td>T. Huang</td>
</tr>
<tr>
<td>340</td>
<td>STRENGTH OF LARGE SHINGLE JOINTS</td>
<td>J. W. Fisher</td>
</tr>
<tr>
<td>341</td>
<td>GROUNDWATER &amp; SEEPAGE</td>
<td>H. Y. Fang</td>
</tr>
<tr>
<td>342</td>
<td>EARTH PRESSURES AND RETAINING STRUCTURES</td>
<td>H. Y. Fang</td>
</tr>
<tr>
<td>343</td>
<td>PLASTIC DESIGN IN A572 (GRADE 65) STEEL</td>
<td>L. S. Beedle</td>
</tr>
<tr>
<td>345</td>
<td>DESIGN RECOMMENDATIONS FOR MULTI-STORY FRAMES</td>
<td>G. C. Driscoll, Jr.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L. W. Lu</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L. S. Beedle</td>
</tr>
<tr>
<td>346</td>
<td>STRENGTH OF SWAY SUBASSEMBLAGES IN UNBRACED FRAMES</td>
<td>L. W. Lu</td>
</tr>
<tr>
<td>348</td>
<td>SOIL PROPERTIES AND THEIR MEASUREMENT</td>
<td>H. Y. Fang</td>
</tr>
<tr>
<td>349</td>
<td>LATERAL LOAD DISTRIBUTION FOR CONCRETE I BEAM BRIDGES</td>
<td>D. A. VanHorn</td>
</tr>
<tr>
<td>350</td>
<td>PERFORMANCE OF SOIL-PAVEMENT SYSTEMS</td>
<td>H. Y. Fang</td>
</tr>
<tr>
<td>351</td>
<td>STABILITY OF STEEL COLUMNS</td>
<td>L. Tall</td>
</tr>
<tr>
<td>352</td>
<td>DRAG COEFFICIENTS FOR STILLING BASIN BAFFLES</td>
<td>J. R. Adams</td>
</tr>
<tr>
<td>353</td>
<td>TRANSPORT OF SOLID SUSPENSIONS IN CONDUITS</td>
<td>W. H. Graf</td>
</tr>
<tr>
<td>355</td>
<td>SOIL MECHANICS AND THEORIES OF PLASTICITY</td>
<td>W. F. Chen</td>
</tr>
<tr>
<td>356</td>
<td>THE APPLICATION OF LIMIT ANALYSIS TO TWO AND THREE DIMENSIONAL PROBLEMS IN METALS, SOILS, AND CONCRETE</td>
<td>W. F. Chen</td>
</tr>
<tr>
<td>357</td>
<td>GUIDE TO DESIGN CRITERIA FOR MECHANICALLY FASTENED JOINTS</td>
<td>J. W. Fisher</td>
</tr>
<tr>
<td>358</td>
<td>LOW-CYCLE FATIGUE (&quot;THEMIS&quot;)</td>
<td>L. Tall</td>
</tr>
<tr>
<td>359</td>
<td>DEVELOPMENT OF DESIGN CRITERIA FOR CONTINUOUS COMPOSITE STEEL-CONCRETE BRIDGES</td>
<td>J. W. Fisher</td>
</tr>
<tr>
<td>360</td>
<td>DEVELOPMENT OF DESIGN PROCEDURES FOR COMPOSITE BEAMS WITH LIGHTWEIGHT CONSTRUCTION</td>
<td>J. W. Fisher</td>
</tr>
<tr>
<td>361</td>
<td>BENDING OF WIDE FLANGE SHAPES ABOUT THE WEAK AXIS</td>
<td>L. W. Lu</td>
</tr>
</tbody>
</table>
The purpose of this project is to develop a design procedure based on the ultimate strength of longitudinally stiffened plate panels such as those used for ship bottom plating and thus subjected to axial compression and distributed transverse loading. Results of theoretical work are being presented in the form of design nomographs which allow rapid determination of panel scantlings for a given set of loads. Experimental work substantiate the validity of the proposed theoretical method.
Project 273-III: TESTS OF NON-SWAY SUBASSEMBLAGES IN MULTI-STORY FRAMES

Sponsors: American Institute of Steel Construction
American Iron and Steel Institute
Naval Ship Engineering Center
Naval Facilities Engineering Command
Welding Research Council

In analysis and design of multi-story frames, it is convenient to divide the entire frame into a number of beam-and-column subassemblages. It is well known that a subassemblage will fail at loads that are greater than the ultimate strength of any one of its individual members, because of the rotational restraint offered by each member to the joint. This increased strength has also been noted in a multi-story frame and is, in fact, the reason why a frame may be designed by assuming that it is composed of a series of subassemblages.

Two types of subassemblages—sway and non-sway types—are often considered in multi-story frame design. In this study, tests of non-sway subassemblages will be conducted to show that the theory developed to predict the behavior of the individual components can be used to predict the behavior and strength of the entire system.
Project 276: FRAME STABILITY

Sponsors: American Iron and Steel Institute
Naval Ship Engineering Center
Welding Research Council

This project investigates the general behavior and strength of unbraced planar multi-story frames subjected to gravity loading. A problem of major concern is the influence of inelastic frame buckling on the load-carrying capacity of such frames.

An analytical method has been developed for determining the critical load corresponding to the sway mode of buckling, after partial yielding has occurred in portions of the structure. The method has been applied to examine the effect of certain structural parameter changes on the inelastic buckling strength. The parameters included are: slenderness ratio of columns, yield stress level of beams, the position of beam loads and the fixity of the foundations. A design procedure which will safeguard against premature buckling failure is being developed.

In the experimental phase of this investigation, buckling tests have been conducted on single and multi-story frames made from structural size shapes. These frames were loaded vertically by specially designed loading mechanisms, called "Gravity Load Simulator" (M-shaped apparatus), which could move freely with the frame as the sway displacements developed. Good correlation between the observed and the predicted loads have been established.
Project 290: **WELDED BUILT UP AND ROLLED HEAT TREATED "T-1" STEEL COLUMNS**

Sponsor: United States Steel Corporation

The project objectives, in general, are to present information from which design criteria can be prepared for T-1 steel columns. Specifically, the following details are included: determination of the residual stresses and the mechanical properties of T-1 steel plates and shapes; investigation of the buckling strength of centrally loaded columns, especially those made of T-1 steel; the local buckling strength of columns including the solution for component plates as well as for plate assemblies; and the ultimate strength and load-deformation characteristics of T-1 steel beam-columns.

The experimental program consists of residual stress measurements on various plates and shapes, mechanical property tests, local buckling tests of four square box-shapes, sixteen full-scale pinned-end column tests of both welded and rolled H-shapes and two full-scale beam-column tests.

Both theoretical and experimental studies for this research have been completed. The findings of the research project have been presented in various publications and reports, and a final summary report is under preparation.
The 1963 AISC Specification permitted the application of plastic design procedures to structures made of low carbon steels, with a yield stress level ranging from 36 ksi.

The purpose of this project is to investigate the possibility of extending the same procedures to high strength steel structures. Theoretical and experimental work has been done regarding the inelastic behavior of members and frames made of A441 steel with a yield stress level up to 50 ksi. It is now possible to consider the inclusion of the use of higher strength steels in design specifications.

Current work consists of a closer study of the existing provisions in the specification with a view to liberalizing them wherever possible, based on both experimental and theoretical research. The possibility of the use of non-compact shapes in plastic design is also under consideration.
Project 302: BIBLIOGRAPHY ON BOLTED AND RIVETED STRUCTURAL JOINTS

Sponsor: Research Council on Riveted and Bolted Structural Joints

Since the Research Council on Riveted and Bolted Structural Joints was formed in 1947 much research has been conducted and reported. It is evident from the review of publications, and comprehensive bibliography should be prepared on the subject of bolted and riveted structural joints.

The objective of this project is to provide information abstracts of the work on bolted and riveted joints which was done between De Jorge's survey (up to 1944) and the initiation of the ASCE Information Retrieval Program in January 1963.

Below is a typical abstract of a paper written about connections:

4845 A440 STEEL JOINTS CONNECTED BY A490 BOLTS

KEY WORDS: bolted joints; bolts; coefficients; joints; structural engineering; testing

ABSTRACT: The results of tests conducted to determine the behavior of joints fabricated of A440 steel plate and fastened with 7/8-in. diameter ASTM A490 bolts are covered in this report. The experimental results of four compact joints, conducted to determine the bolt shear strength and the effect of variation in $A_p/A_b$ ratio, and four long joints are presented. The variables covered in this investigation include pitch, joint length, and changes in the $A_p/A_b$ ratio. Theoretical studies were carried out and the conclusions reached concerning the experimental variables are included. The present (1966) specification for all A490 bearing-type bolted short joints, and the slip coefficient used for the design of friction-type joints are examined in relation to the test results.

Project 309: BOND BETWEEN CONCRETE AND PRESTRESSING STRAND

Sponsors: Pennsylvania Department of Highways
Reinforced Concrete Research Council
U. S. Bureau of Public Roads

The main purpose of this project is to develop information on the embedment length requirements for 1/2 inch 270K seven-wire prestressing strand.

The project was divided into three phases:

Phase one included three series of tests. The first series included static load tests. The second series was designed to establish the possible effects of repeated loads on the embedment length requirements. The third series involved a pilot study to ascertain whether strands above the bottom row may be more critical than those in the bottom row.

Phase two involved the testing of some of the structural properties of the 1/2 inch 270K strand. Samples from five manufacturers were tested. Load-strain relationships were developed as well as S-N relationships from three of the manufacturers. A pilot study was also conducted to test the possible influence of low temperature on the fatigue life of all samples.

Phase three involved the collection of detailed information on the fabrication of the 270K strand. Visits to the plants of the five manufacturers were carried out and the required information has been compiled, but a report is still outstanding.
Project 310: GAS REMOVAL SYSTEMS FOR DREDGE PUMPS

Sponsor: Philadelphia District, U. S. Army Corps of Engineers

This project encompasses four phases:

Phase A: 1. Literature search
          2. Formulation of test program

Phase B: 1. Formulation of specific test setups
          2. Development of facility layout

Phase C: 1. Establishment of test setup
          2. Performance of test with water only

Phase D: 1. Performance of tests with solids in water mixture

Phases A and B have been completed. Testing in Phase C continues on a 1 to 8 model of a dredge pump and drag arm in the hopper dredge Essayons. Air is used to simulate the gas which is encountered in dredging estuaries and harbors.

Test Series No. 1 determined the effect of continuous gas flow on dredging performance. Test Series No. 2, which is still in progress, showed that the vacuum pump gas removal systems in use are not effective on steady gas flows. Unsteady gas injection was investigated, and the gas removal system is more effective for pulsed or slug air flow.

Factors remaining in Test Series No. 2, Phase C, are (1) ejector driven removal systems, and (2) a redesigned accumulator. Phase D is to be a verification of the gas-liquid tests when dredged solids are included in the mixture being pumped.
Project 312: **SURVEY OF CURRENT STRUCTURAL RESEARCH**

Sponsors: Fritz Engineering Laboratory
National Science Foundation

The object of this project is to compile information about all structural research in progress or recently completed both in the United States and abroad.

The information is gathered by sending questionnaires to many universities, industries, and to the professional societies. The requested information is the title of the project, the name of the research organization, the names of the investigators and sponsors, and a brief description of the project.

Several reports have been published since the work was started in 1963. The purpose of these reports is:

a. To give information about research currently in progress.
b. To provide interested individuals and industries an opportunity to make contact with one another.
c. To help avoid overlapping and repeating of research.
d. To assist in planning further research.
One important consideration in the design of a beam-slab highway bridge is the determination of the distribution of load to the longitudinal stringers. In 1964, Project 315 was outlined and approved to conduct research to develop the information needed to evaluate the load distribution in bridges of current design--equally spaced prestressed box girders designed compositely with a concrete slab, without lateral prestressing.

The first phase of the testing program was a pilot study to obtain information for the evaluation of analytical studies and to obtain experience for future field tests. The second phase, completed in 1965, was a more extensive field study involving load tests of three structures similar to the bridge used in the pilot study. In all structures the spans were approximately 65 ft. and the beam spacing approximately 9 ft. However, the skew angle and beam widths were different for the three structures and comparison of the test results should enable determination of their effects. The third phase was a study of the effects of mid-span diaphragms on load distribution completed in 1966. The structure selected was a bridge constructed with a cold joint between the mid-span diaphragms and the deck to facilitate removal of the diaphragms. Two series of tests were conducted, one with the diaphragms in place and the other with the diaphragms removed. Computer programs have been developed for analysis of the data.
The September 1966 "Specifications for Structural Joints Using ASTM A325 or A490 Bolts" of the Research Council on Riveted and Bolted Structural Joints reflects the use of the A490 high strength alloy steel bolt. The need for this fastener grew out of the availability of higher strength steels. To attain full advantage of the greater load bearing capabilities of these steels, a stronger bolt than the A325 had to be developed. This led to the introduction of the A490 bolt and resulted, in part, from studies made at Lehigh University.

The increasing use and importance of the higher strength steels is evidenced from the fact that one of the more important of these is now covered by an ASTM specification (A514). The behavior of A514 and other higher strength steels when fastened with high strength bolts was established. Since these new steels are not generally used throughout a structure but rather only in the more highly stressed regions, the behavior of joints in which two or more different grades of steel will be fastened was also investigated.
Analytical studies and tests cover a number of important aspects of joint behavior which have not yet been investigated sufficiently. It is of interest to know if current methods of installation will insure the development of the desired clamping forces in large connections which may be out-of-flat. Surface variations, such as clean mill scale or blast cleaning with or without a surface treatment, influence the slip resistance of bolted joints. A closely related topic is the effect of washers or filler plates as well as the effect of slotted or oversize holes upon joint behavior. The work is done in three phases:

1. Analysis and tests of large joints which are out-of-flat. An instrument has been developed to measure the forces required to flatten plates.

2. Effects of the variation of the contact area on the slip behavior of bolted joints is considered. Specimens with clean mill scale and blast cleaned surface were tested. The effect of either circular washers or rectangular filler plates inserted between the faying surfaces was studied as was the effect of surface treatments.

3. The slip behavior and ultimate strength of joints with slots parallel and transverse to the load were studied. Also evaluated was the influence of oversize holes.
Earlier investigations in the area of welded column strength have
been concerned primarily with shapes manufactured from universal-mill
plates. Welded H-shaped columns manufactured from universal-mill plates
are characterized by fairly high compressive residual stresses at the
flange tips. However, a large percentage of welded columns manufactured
today are built-up from flame-cut plates. Such column shapes have a
more favorable residual stress distribution which would result in higher
column strength.

This research project is to obtain information on the strength of
flame-cut welded columns of practical sizes in ASTM A36 and A572 steels,
so as to develop specific design recommendations that will make use of
the advantages inherent in the use of flame-cut plates.

The work involves the study of residual stresses in flame-cut plates
and shapes, pinned-end column tests, stub column tests, and tension
specimen tests.

Preliminary study shows that tensile residual stresses at the flange
tips are a direct result of the flame-cutting of the plates. These tensile
residual stresses cause comparatively high weak-axis column strengths in
the important lower slenderness ratios. Because of allowable values of
initial out-of-straightness, and hence, of the slight reduction of ultimate
strength, the tangent modulus theory appears to give a good approximation
of the ultimate strength of flame-cut welded columns.
Project 322: A STRUCTURAL MODEL STUDY OF LOAD DISTRIBUTION IN HIGHWAY BRIDGES

Sponsor: National Science Foundation

This project is a plexiglass structural model study designed in such a way that all the elements of the bridge may be varied: slab thickness, size and spacing of beams, curbs, and parapets. Plexiglass was selected as model material because of its elastic properties, workability and low cost.

The load is applied to the model with a mechanical jack simulating the load applied to the prototype by travelling loads. The displacements can be measured with a properly distributed net of extensometers and strain gages.

The data is processed by a computer program which gives the resultant strain, stresses, and other analysis parameters of the model.
Project 323: GRILLAGES UNDER NORMAL AND AXIAL LOADS

Sponsor: Naval Ship Engineering Center

The ultimate objective of this project is the development of a design procedure for grillages incorporating consideration of both working load behavior and overload capacity. A grillage is a plate stiffened by orthogonal beam gridworks, subjected to combined normal and axial loads.

The current phase of the investigation is devoted to the formulation and development of an analytical method by means of which the response of grillages to combined loads can be predicted.

The work to be done is as follows:

1. Development of plate and beam-column theories incorporating consideration of second order effects and inelastic behavior.
2. Formulation of a numerical method by means of which the plate and beam-column theories can be applied in the working stress and ultimate strength analyses of grillages under combined loads.
3. Writing and testing of a computer program by means of which the analysis can be accomplished.

Particular emphasis is to be placed on the heavy grillages employed in ship structures. This phase of the investigation is to be terminated with the preparation of reports describing the theory, the numerical method, and the computer program.
The slender web now permitted in the design of plate girders for buildings has led to the investigation of phenomena associated with the repeated out-of-plane deflection which results when the girder is subjected to bridge-type loading. Because of the possible large magnitudes of deflection encountered, fatigue cracks may initiate in the web at web toes of the panel fillet welds.

The purpose of this project is to investigate these cracks and the stresses causing them and to develop design recommendations based on fatigue considerations.

A preliminary result has been the verification of the fact that the out-of-plane bending stresses, and not the in-plane membrane stresses are the primary cause of fatigue cracks in welded plate girder webs. A method has been developed for determining the plate bending stresses for a web panel boundary from measured web deflections.

Preliminary design recommendations are being formulated and present work includes proof-testing of two girders designed accordingly.

SUMMARY OF FATIGUE CRACK LOCATIONS IN GIRDER WEBS
Project 328: **UNSYMMETRICAL PLATE GIRDERs**

Sponsors: Pennsylvania Department of Highways  
American Iron and Steel Institute  
Welding Research Council (1966-67)

The objective of this project is to develop design rules for unsymmetrical plate girders. Neither the current design code specifications nor the research that has been conducted take into consideration the behavior or strength of a plate girder when its cross section is unsymmetrical with respect to the horizontal centroidal axis.

The following phases of experimental and theoretical research are being conducted:

1. Investigation of the static ultimate strength under pure bending, predominant shear, and combined bending and shear.

2. Determination of the behavior of the girder, in particular, the behavior of the web plate.

3. Study of the effect of one longitudinal stiffener on the strength and behavior of an unsymmetrical plate girder.

4. Correlation of the behavior of unsymmetrical girders with fatigue studies on symmetrical girders.

5. Formulation of design recommendations based on the ultimate strength and on the fatigue strength.
Project 329: **DESIGN OF LATERALLY UNSUPPORTED COLUMNS**

Sponsor: American Iron and Steel Institute

In the plastic method of design of planar multi-story frames, columns are designed on the assumption that out-of-plane deformation can be prevented by lateral bracing. In many practical situations, however, the interior columns in multi-story frames are often left isolated. Such columns must be designed as unbraced columns. The available methods of column design should, therefore, be modified to include this possibility.

The objective of this investigation is to formulate a practical design procedure for laterally unsupported columns in planar multi-story frames.

Current work consists of pilot tests on non-sway beam-and-column subassemblages (as shown in the figures below) with laterally unsupported columns and theoretical studies of the initiation of lateral-torsional buckling and the post buckling strength of restrained beam-columns.
Frames in a multi-story building are usually designed as planar structures—structures with all their members lying in a single plane and with all the loads applied in the same plane. The columns in a planar frame are, therefore, designed to resist bending moments acting only in the plane of the frame. While this idealization has resulted in satisfactory designs in the past, it does not necessarily represent the true loading condition existing in a building frame. In an actual building, because of the space action of the entire framing system, the columns are frequently subjected to bending moments acting in two perpendicular directions (commonly called "biaxial loading").

Recent research conducted at a number of institutions in this country has produced ultimate strength solutions for pinned-end columns subjected to biaxial bending. These solutions, with suitable simplifications, can now be incorporated in developing a practical design procedure. However, additional studies on restrained columns with biaxial bending and on sway and non-sway subassemblages are needed in this development.

The objective of this project is to study the strength of WF columns subjected to two bending moments and a twisting moment and develop the solutions for biaxially loaded columns having end restraints in two perpendicular directions. These solutions will then be applied to the analysis of space subassemblages with and without sway. Also included in this investigation is the development of analysis techniques (and computer programs) for space frames subjected to combined gravity and lateral loading.
Project 332: BEHAVIOR OF STEEL FRAMES UNDER REPEATED LOADING

Sponsor: American Iron and Steel Institute

An understanding of the inelastic behavior of frames under the action of constant gravity loads and cyclic displacements is necessary to correlate recent research in earthquake engineering. The earthquake problem is essentially one of constant gravity loads and variable displacements of the base of the frame. Currently available methods of frame analysis are adequate to predict the static behavior of frames under the combined effect of gravity and monotonically increasing horizontal loads. However, these methods are not adequate to describe the behavior of frames under reversed and repeated horizontal loading.

The purpose of this project is to find an accurate accounting of the static load-deformation behavior of unbraced structural steel frames having constant vertical loads and cycled horizontal displacements for earthquake simulation. From the results a method of analysis suitable to account for the behavior of steel frames under cycled static horizontal displacements will be formulated. Following a study of the variables involved in a dynamic loading, and based on the static analysis, a prediction for frame behavior under dynamic conditions will be made.
In the currently used methods for the design of exterior beam-to-column connections, the effect of high axial load combined with the shear induced by the beam moments is not taken into consideration.

Recent tests on multi-story frames have indicated that the high axial loads in the columns of the lower stories affect considerably the behavior of the connections.

Previous studies on interior connections considered axial loads in the columns and only symmetrical moments induced by the beams, so that the connections were not subjected to large shear forces. These, however, can be introduced by wind and earthquakes.

The general objective of this project is to develop by both theoretical and experimental study, design methods for beam-to-column connections subjected to moment, shear, and axial load. First, the different types of connections for a given size of the members will be considered. In a later phase of the project, the field of study will be expanded to the influence of member sizes on the behavior of the connections, especially web buckling and crippling.
Project 334: THE EFFECT OF WELDMENTS ON THE FATIGUE STRENGTH OF BEAMS

Sponsor: Highway Research Board

The objective of the project is to determine the fatigue life of typical welded details used on beams in bridge structures. The details being investigated are: welded coverplates with square ends (with and without transverse and welds), flange splices and web to flange welds. The effect of coverplate thickness, width and number of coverplates is also being investigated. A36, A441 and A514 steel are included in the testing program.

The testing program contains a complete factorial of the four controlled variables: maximum stress, stress range, type of steel and weld detail. Each variable will be analyzed statistically.

The data generated will be used as a basis for the design of bridge structures.
Project 335: FRACTURE BEHAVIOR OF HIGH STRENGTH LOW ALLOY STRUCTURAL STEEL FOR BRIDGES

Sponsor: Bethlehem Steel Corporation

The objective of the project is to relate the brittle fracture characteristics of A-441 steel, a typical high strength low alloy bridge steel, as determined in the standard drop weight tear test with the behavior of the material in a bridge structure.

Small plate specimens of the material are tested in a drop weight apparatus which is instrumented to determine the stress rate and crack velocities encountered during the test. The information obtained from these tests is analyzed using fracture mechanics to determine the brittle behavior of the material at the lower rates of loading found in bridge structures.

The theoretical results will be checked on full size simulated bridge sections subjected to typical bridge loadings.
Project 336: TWO LICK CREEK DAM MODEL STUDY

Sponsor: Gilbert Associates Inc.

The dam prototype is being constructed for the Pennsylvania Electric Co. and the New York State Electric and Gas Co. to provide cooling water for the Homer City power station.

The objective of the project is threefold:

1. Model study—to study the flow to the spillway under the unusual approach conditions.

2. The calibration of gated and free discharge.

3. Erosion study of the downstream apron.

Laboratory work:

A 40:1 model of the dam prototype was constructed to study the approach flow and, more significantly, the erosion problem. A very weak bonded sand-cement mixture was used to model the sandstone which prevailed at the prototype site.

Results:

The model study indicated the need for modifications to improve approach conditions.

The erosion study resulted in a recommendation to modify the right training wall as an additional safety measure.
Project 337: RESIDUAL STRESSES IN THICK WELDED PLATES

Sponsor: National Science Foundation

The project is a study of the magnitude and distribution of residual stresses in heavy shapes formed by welding thick plates; and to relate this to the stability under load of structural members, such as columns and beam-columns. The program is both experimental and theoretical.

The experimental investigations include measurements of residual stresses, temperature during fabrication, and mechanical properties, as well as stub column and column tests. Comparisons will be made on the effect of different materials and fabrication procedures, such as between flame-cut and universal mill plates and between rolled and welded sections. The theoretical study includes prediction of residual stresses in welded plates and column strength.

This is a basic study of importance to many areas, and will provide information hitherto unknown on the properties of heavy plates and shapes. The present direction of the project is the development of design criteria for heavy shapes.
Prediction of losses of prestress in structural concrete members has always been a rather difficult engineering problem. Presently the total loss is estimated by two methods: a flat percentage or by an empirical expression, considering the individual factors contributing to the loss. It is felt that both of these methods are inadequate.

The basic purpose of this project is to establish a rational basis for the prediction of prestress losses in pre-tensioned bridge beams.

The first phase of the project entails a study of the creep and shrinkage characteristics of specimens representing all the prestressed concrete companies producing bridge beams for Pennsylvania.

In the second phase, representative specimens are produced with various magnitude and eccentricity of prestress. Separately, strand specimens are tested for their relaxation characteristics.
Project 340: **STRENGTH OF LARGE SHINGLE JOINTS**

Sponsors: State of Louisiana, Department of Highways

Significant preliminary work was undertaken on simulated bridge joints. This work showed conclusively that the current design of the connections for large truss structures are unduly conservative and most likely wasteful. It is believed that the work to be done on this project will lead to analytical techniques and design criteria that will alter current practice and provide the basis for specification provisions leading to more economical and safe design.

The purpose of this study is twofold:

1. To develop design criteria for shingle splices.
2. To determine the behavior and resulting design recommendations for joints that have out-of-flat surfaces.

The current program will evaluate the ultimate strength characteristics of shingle joints, so that the full range of behavior is known.
Attempts to apply mathematics to the complicated phenomenon of groundwater movement have met with limited success. Therefore, it is necessary to use models and analogs, such as the sand model, the electric analog, the heat analog, the membrane analog, and the viscous flow analog, for the study of groundwater movement.

In the study of well flow phenomena, the viscous flow model (Santing 1957, Varrin and Fang 1966) appears to be highly promising. The first model of this kind was developed by H. S. Hele-Shaw in 1897-1899, but since then has had many modifications (Todd 1959, Bear 1960, Sternbert and Scott 1964, Columbus 1966, and DeWiest 1966). It has proved to be very useful for the analysis of most two dimensional groundwater flow patterns. Bear and Van Overstraaten Kryses (1956) and Santing (1957) improved the model to include three dimensional flow. By use of conformal mapping techniques to take fully into consideration the infinite extent of domain, further improvement has been made on the model (DeWiest 1966, Varrin and Fang 1967). This is the model presently being tested.

The major objectives of this project are: to demonstrate the fundamental behavior of groundwater movement during a pumping test; to verify the validity of the classical equilibrium and non-equilibrium well flow equations; and to determine the boundary effects of nonsteady well flow.
Project 342: EARTH PRESSURES AND RETAINING STRUCTURES

Sponsor: American Iron and Steel Institute

Using standard methods for calculation of soil pressures and friction between the sheet piling wall and the soil, the project involves the full scale testing of an anchored steel sheet piling wall to ascertain, by measuring the state of stress in the wall, the ability of the pile interlocks to transmit shear forces.

A major aspect of this project involved establishing reliable techniques for determining the stresses developed in the sheet piling under field conditions.

Other information to be obtained from this study includes:

1. Verification of the location of the inflection point on the sheet piling, under increasing load conditions.
2. Determination of the critical driving depth for stability of the sheet piling.
3. Comparison of measured field maximum moments with those calculated using lateral earth pressure theories.
4. Determination of the maximum height of a cantilever wall that can be permitted before an anchorage system is required.
Project 343: PLASTIC DESIGN IN A572 (GRADE 65) STEEL

Sponsor: American Institute of Steel Construction
Naval Facilities Engineering Command
Naval Ship Engineering Center

With the development of high strength steel and their adoption under elastic design procedures, increasing interest has been taken in determining their suitability for plastic design. For the extension of plastic design procedure to include steels of up to 50 ksi (A441) yield stress, a series of theoretical and experimental investigations has been performed at Lehigh University and tentative recommendations based on this research have been presented. However, there is no available information on the plastic behavior of steels beyond 50 ksi yield stress level. In order to evaluate the plastic design procedures as applied to 65 ksi yield stress steel, further studies are required.

The objective of this investigation is to determine mechanical properties of A572 (Grade 65) steel and to check whether the present provisions regarding local buckling and lateral bracing spacing as developed for A36 and A441 steel can be extended to include A572 steel after accounting for the increase in the yield stress and the observed value of strain hardening modulus. The mechanical properties will include strain hardening modulus \( E_{st} \), strain at strain hardening \( \varepsilon_{st} \) as well as yield stress \( \sigma_y \), elastic modulus \( E \), ultimate stress \( \sigma_u \), and percent elongation. Stub columns and beams will be tested to check the provisions.
Project 345: DESIGN RECOMMENDATIONS FOR MULTI-STORY FRAMES

Sponsors: American Iron and Steel Institute
Welding Research Council

This project covers work on summarizing and interpreting for design recommendations the results of recent experimental work on steel structures. Attention is now being directed to the following topics:

(1) Design of Unbraced Multi-Story Frames

Papers suited to design office reference are being prepared on design of unbraced frames, preliminary design using a computer, and changing of the subassemblage method of analysis from a manual process to a computer program.

(2) ASTM A572 Grade 65 Steel

Theoretical and experimental studies of behavior of A572 Grade 65 Steels are being conducted to provide information for application of these steels in plastic design.

(3) Revisions to "Commentary on Plastic Design in Steel"
ASCE Manual No. 41

This manual was first published in 1961 as a reference for engineering educators, practicing engineers, and students. It documents the applicability of the plastic design techniques to beams and low building frames made of structural carbon steel.

Further research has since been conducted on many areas of plastic design. Results are now available. This project will summarize the new information and prepare a revised edition of the commentary.

A major addition will be recent results on the behavior of high-strength steel (A441 and A572) members and frames. Substantial revisions will be made to the sections on local and lateral buckling of beams, lateral-torsional buckling of beam-columns, and frame stability. Changes will also be made on the effect of shear force, methods of analysis, variable repeated loading, connections and calculation of deflections. A chapter on braced multi-story frames will be added.

(4) Revisions to AISC Specification

Detailed studies are being made for a number of changes in the forthcoming revised AISC Specification.
Recent analytical studies at Fritz Laboratory indicate that the middle and lower stories of unbraced multi-story frames which are subjected to combined loads can be designed using a three-step procedure. First, tentative beam and column sizes are selected in a preliminary design based on the plastic moment balancing method. The preliminary design can include and approximate $P\Delta$ effect resulting from an estimated sway deflection. A load-deflection analysis of each story of the frame is then performed using the sway subassemblage method. Finally, one or more members selected in the preliminary design may be revised based on the results of the analysis or on the basis of other factors such as economy.

The objective of this investigation is to provide an experimental evaluation of the sway subassemblage method of analysis. Initially tests will be conducted on exterior and interior sway subassemblages in order to study the behavior of such frames under combined gravity and lateral loads. Later phases of the project will study the load-deflection behavior of one-story assemblages under combined loads.
With the increasing availability of analytical techniques for the solution of complex boundary value problems involving materials which exhibit a wide range of engineering properties, it has become increasingly important to correctly define and identify the engineering properties of soils.

Current studies involve investigations of the strength, deformation, permeability and compressibility characteristics of soils and their response to changes in environment, as well as identification and measurement of engineering properties both in the laboratory and in the field.

Attention has been specifically directed towards study and improvement of current laboratory and field techniques for measuring soil parameters. Also under investigation is the influence of compositional and environmental factors on the stress-strain-time behavior of laboratory prepared soil.
Project 349: LATERAL LOAD DISTRIBUTION FOR CONCRETE I-BEAM BRIDGES

Sponsor: Pennsylvania Department of Highways

This project is similar to the project which is now underway on the lateral load distribution for concrete spread box-beam bridges. The object of the project is to evaluate the lateral distribution of live load to the longitudinal I-beams.

At the present time a literature survey is underway involving a review of past field study work, and a compilation of analytical methods and techniques developed to date.

Because of the lack of field study information, two I-beam bridges will be instrumented and tested during the summer of 1968. In addition, the possibility of modifying a currently in-process analytical development for box-beam bridges to cover I-beam bridges will be investigated.

TYPICAL I BEAM BRIDGE
Project 350: PERFORMANCE OF SOIL-PAVEMENT SYSTEMS

Sponsor: Pennsylvania Department of Highways
          U. S. Bureau of Public Roads

In 1962 a new pavement design method, based on the AASHO Road Test Findings, was developed by the AASHO Committee on Design. The method, however, is limited in precise application to certain areas where the conditions are similar to those of the AASHO Road Test. Due to the wide variation of soil types and different environmental conditions, it is necessary to develop certain modifications of the AASHO Interior Guide for pavement design.

The primary objectives of the current investigation are: To validate or modify the AASHO coefficients of pavement components for Pennsylvania conditions, and to develop laboratory or field tests for predicting the soil support values of the AASHO Guide.
Project 351: **STABILITY OF STEEL COLUMNS**

Sponsors: European Convention of Constructional Steelwork Associations
National Science Foundation
Welding Research Council

The purpose of this project is to conduct a theoretical and experimental study into the strength of heavy steel columns and to relate the results of the study to design practice in the United States and to current efforts in Europe to prepare a column curve for design use. A further objective is to examine testing techniques, comparing the "centering-under-load" method with geometrical centering of as-delivered members.

Theoretical study includes preparation of column strength curves for centrally loaded members according to the tangent modulus buckling concept; and use ultimate load prediction taking into account variations both in straightness of the column and the symmetry of residual stress distribution, and the effect of variations of residual stresses throughout the thickness of the flange and web.

The experimental program includes coupon tests for mechanical properties, residual stress measurements, stub column tests, and full-size column tests. There are a total of 30 full-size column tests with three different slenderness ratios. A statistically oriented column curve based on taking the statistical mean of a number of similar column test results will be determined.
Project 352: **DRAG COEFFICIENTS FOR STILLING BASIN BAFFLES**

Sponsor: U. S. Army Corps of Engineers, Waterways Experiment Station

The Corps of Engineers and the Bureau of Reclamation have had baffle block hydrodynamics on their lists of desired research for many years. This project is being conducted at the Waterways Experiment Station to develop a general correlation between approach flow conditions, baffle block geometry, and stilling basin performance which will allow rational design of stilling basins and baffles. Measured drag coefficients will be used as the basic parameter describing baffle effectiveness. This will be compared with various criteria of stilling basin performance including: sweep out depth, velocity distribution, waves, scour, and cavitation.
Project 353: TRANSPORT OF SOLID SUSPENSIONS IN CONDUITS

Sponsor: Department of the Interior - Federal Water Pollution Control Agency

This investigation concerns moving solid-liquid mixtures in pipelines. Measuring devices for water-solid mixtures are developed. An effort is made to explain the experimental results theoretically.

The research is divided into two parts:

a) The friction factor for pipes carrying suspension is investigated. When the friction factor is determined the head loss $h_L$ can be found with a recently developed equation.

b) The Venturi meter is widely used as a flow rate measuring device. It is a combination of nozzle and diffuser section. A modification of the Venturi meter was recently suggested, so that information on concentration may also be obtained. (A modified Venturi meter measures not only the pressure drop in the meter, but also the head loss across the meter. The pressure drop provides information on the flow rate, while the head loss is expected to give information on the mixture's concentration.) A limited number of experiments conducted in previous investigations seems to prove this suggestion, but more experimentation is needed.

This research provides new knowledge about the design of conduits to carry suspensions of solid materials (e.g. sludges or slurries, sand, and other solids in storm drains etc.) under turbulent conditions.
Idealizations in soil mechanics are usually necessary in order to obtain solutions in a readily applicable form. Limit equilibrium has been a method of solving various soil stability problems.

One weakness of the limit equilibrium method has been the neglect of the stress-strain relationship of the soil. According to the mechanics of solids, this condition must be satisfied for a complete solution. Limit analysis, through the concept of a yield criterion and its associated flow rule, considers the stress-strain relationship.

It is the objective of this project, through a review of the standard and widely known techniques used in the solutions of soil stability problems, to accomplish two purposes. The first is to investigate the meaning and nature of existing, "classical", soil mechanics solutions from the limit analysis point of view. The second purpose is to demonstrate the usefulness and power of the plastic limit theorems in developing a limit analysis technique.

Three types of typical stability problems will be examined:

1. The critical height of a vertically unsupported cut.
2. Active and passive lateral earth pressure.
3. The bearing capacity of soils.

ROTATIONAL MECHANISM CONTAINING A SIMPLE TENSION CRACK AND A HOMOGENEOUS SHEARING ZONE FOR SOIL UNABLE TO TAKE TENSION
Project 356: THE APPLICATION OF LIMIT ANALYSIS TO TWO- AND THREE-
DIMENSIONAL PROBLEMS IN METALS, SOILS, AND CONCRETE

Sponsor: National Science Foundation

The design and analysis of Civil Engineering structures is being
swiftly and drastically altered by the increasing role that limit analysis
is playing in the calculations of load-carrying capacity. Limit analysis
for a steel structure idealized to behave in a perfectly plastic manner
is highly developed, and its limitations are well understood.

In spite of this dramatic progress and acceptance in the use of limit
analysis, its application to two- and three-dimensional continua has not
been studied thoroughly. In particular, the work on non-metallic materials
(soils, rock, and concrete) is just beginning, a few solutions having
been obtained. More two- and three-dimensional problems of theoretical
significance and practical importance must be investigated for non-metallic
as well as for metallic materials.

It is the purpose of this project to investigate the following three
particular problems:

1. The rigid punch on a plane surface of a perfectly plastic
material with finite dimensions.

2. The general strip foundation problem, including soil weight.

3. The bearing capacity of concrete blocks eccentrically loaded
by a flat rigid punch.

The results should provide a better understanding of the implications
of plasticity for these materials and an insight into more complicated
cases.
The purpose of this program is to develop a guide for the design of mechanically fastened joints. The guide will cover the basic types and behavior of mechanical fasteners. It will discuss in detail and provide design recommendations on the basis of existing information shear splices, gusset plates, beam and girder splices, beam-to-column connections, beam seats, standard butt splices and other miscellaneous joints.
Project 358: LOW-CYCLE FATIGUE BEHAVIOR OF JOINED STRUCTURES

Sponsors: Department of Defense (Project Themis)
U. S. Navy, Office of Naval Research

It is proposed to study low-cycle fatigue, with particular emphasis on welded joints in high-strength steels.

The initial research is studying the mechanism of fatigue initiation and propagation in welded joints in high-strength steels. This includes the state of stress and metallurgical structures, and the consideration of fracture mechanics, plasticity, and microstructural analysis. Statistical analysis will be applied to all phases of the experimental investigation.

The end product of the study is to develop an understanding essential for design procedures for structural components and complete structures.
Project 359: DEVELOPMENT OF DESIGN CRITERIA FOR CONTINUOUS COMPOSITE STEEL CONCRETE BRIDGES

Sponsors: Pennsylvania Department of Highways
U. S. Department of Transportation - Bureau of Public Roads

The objective of this research program is to develop a comprehensive design procedure for continuous composite beams. Reported pilot studies have indicated the feasibility of applying to continuous composite beams the design criteria proposed for shear connectors in composite beams. However, numerous variables of importance in the negative moment region have been identified and noted to require evaluation. Among these are:

1. The number and spacing of connectors
2. The required amount and arrangement of the longitudinal reinforcement
3. Evaluation of the width limitations for placement of reinforcement
4. The effect of coverplates
5. Prestressing of the longitudinal reinforcement

Both the performance under working load and the flexural strength need to be evaluated by analytical and experimental studies so that design recommendations can be rationally formulated.
The objective of this research program is to provide recommendations for the design of composite beams with light-weight concrete slabs. Both performance under working load and the flexural strength will be evaluated by study of existing theoretical and experimental studies. Additional analytical and experimental studies will be undertaken as required, so that design recommendations can be rationally formulated.
Project 361: BENDING OF WIDE-FLANGE SHAPES ABOUT THE WEAK AXIS

Sponsor: American Institute of Steel Construction

When wide-flange sections are used as columns to carry combined bending moment and heavy axial force, it is sometimes convenient and practical to orient the section so that the bending moment will be applied about its weak axis. Only very limited information is available on the behavior and strength of beam-columns bent about the weak axis, although the general behavior is expected to be similar to that of columns under strong axis bending. Two problems that will be studied both experimentally and theoretically in this project are:

1. Local buckling and inelastic deformation of the flange elements under combined bending and axial stresses. Short columns subjected to eccentrically applied load will be tested in this study.

2. The influence cooling residual stresses in the load carrying capacity of beam-columns. Previous studies have shown that the effect of residual stresses is much more pronounced in weak axis bending than in strong axis bending.

Also to be studied in conjunction with Project 332 is the behavior of the columns with partial yielding.
CURRENT FRITZ LAB PROJECTS

Description
and
Bibliography

Fritz Engineering Laboratory
Lehigh University
Bethlehem, Pennsylvania
July 1975

LEHIGH/FL/237-17(75)
This report contains the current research projects being conducted at Fritz Engineering Laboratory, Lehigh University. Projects are described citing facts and objectives.

A selected list of reports generated from the projects is presented in the bibliography.
RESEARCH
AT
THE FRITZ ENGINEERING LABORATORY
LEHIGH UNIVERSITY

Since its founding in 1909 Fritz Engineering Laboratory has been advancing knowledge in Civil Engineering through its basic and applied research programs and industrial testing and related fields. Modernization of the Laboratory in 1954-55 enabled the University to continue to provide the finest facilities for research in the fields of structures, materials, hydraulics, soil mechanics and sanitation.

The laboratory facilities are housed in two inter-connected units—a four-story unit and a seven-story unit. Ready access to the main testing areas is provided to facilitate the delivery of large and heavy equipment. With the available testing machines and special accessories, large structural members can be tested statically or dynamically. A research library is maintained where current reports from laboratories throughout the world are available for study.

Through its Office of Research, Lehigh University contracts with research councils, industrial concerns, or associations to undertake cooperative research. The sponsor is expected to pay all costs plus a reasonable percentage for overhead. At least a one-year duration is expected on such projects, and publication of results in technical magazines is normally anticipated.

Investigations have ranged from studies of material properties and characteristics up to tests of full-size structures for buildings and bridges. Structural steel research programs have improved design procedures by this approach. Specifications of the American Association of State Highway Officials, American Institute of Steel Construction, Association of Iron and Steel Engineers, American Railway Engineering Association and American Concrete Institute have been revised as a direct result of research projects.

In the following pages, the current Fritz Lab projects are described.
STAFF

L. S. Beedle  Director
G. C. Driscoll, Jr.  Associate Director
J. W. Fisher  Associate Director
B. A. Laub  Administrative Associate

PROJECT DIRECTORS AND ASSOCIATES

L. S. Beedle  T. J. Hirst  J. A. Manson  P. J. Usinowicz
A. W. Brune  T. Huang  W. A. Murray  J. W. Vanderhoff
W. F. Chen  G. R. Irwin  A. Ostapenko  D. A. VanHorn
J. H. Daniels  R. L. Johnson  A. W. Pense  B. T. Yen
G. C. Driscoll, Jr.  C. N. Kostem  R. Roberts
H. Y. Fang  B. A. Laub  R. G. Slutter
J. W. Fisher  L. W. Lu  L. Tall
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUILDING SYSTEMS DIVISION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>361</td>
<td>Bending of Wide Flange Shapes</td>
<td>1</td>
</tr>
<tr>
<td>367</td>
<td>Plastic Design of Unbraced Frames</td>
<td>1</td>
</tr>
<tr>
<td>369</td>
<td>Planning &amp; Design of Tall Buildings</td>
<td>1</td>
</tr>
<tr>
<td>369-4</td>
<td>International Conferences on Tall Buildings</td>
<td>1</td>
</tr>
<tr>
<td>369-8</td>
<td>Tall Buildings: Reg. Conference</td>
<td>2</td>
</tr>
<tr>
<td>369-10</td>
<td>Tall Buildings: Bibliography</td>
<td>2</td>
</tr>
<tr>
<td>369-12</td>
<td>Tall Buildings: Monograph</td>
<td>2</td>
</tr>
<tr>
<td>369-14</td>
<td>Tall Buildings: Surveys</td>
<td>2</td>
</tr>
<tr>
<td>369-15</td>
<td>Tall Buildings: Systems</td>
<td>3</td>
</tr>
<tr>
<td>371</td>
<td>Load Factor Design of Buildings</td>
<td>3</td>
</tr>
<tr>
<td>396</td>
<td>Frame Stability</td>
<td>3</td>
</tr>
<tr>
<td>403</td>
<td>Composite Assemblages Experiments</td>
<td>3</td>
</tr>
<tr>
<td>408</td>
<td>Design of Biaxially Loaded Columns</td>
<td>4</td>
</tr>
<tr>
<td>FATIGUE &amp; FRACTURE DIVISION</td>
<td></td>
<td></td>
</tr>
<tr>
<td>386</td>
<td>High Cycle Fatigue</td>
<td>5</td>
</tr>
<tr>
<td>397</td>
<td>Rio-Niterio Box Girder Bridge</td>
<td>5</td>
</tr>
<tr>
<td>398</td>
<td>Fatigue of Curved Steel Bridge Elements</td>
<td>5</td>
</tr>
<tr>
<td>399</td>
<td>Flaws in Full Size Bridges</td>
<td>5</td>
</tr>
</tbody>
</table>
### TABLE OF CONTENTS (cont.)

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GEOTECHNICAL ENGINEERING DIVISION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>355</td>
<td>Limit Analysis and Soil Plasticity</td>
<td>6</td>
</tr>
<tr>
<td>409</td>
<td>Analysis and Design of Foundations for Tall Buildings</td>
<td>6</td>
</tr>
<tr>
<td><strong>HYDRAULIC &amp; SANITARY ENGINEERING DIVISION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>388</td>
<td>Biological Regeneration</td>
<td>7</td>
</tr>
<tr>
<td>401</td>
<td>Highway Drainage Inlets</td>
<td>7</td>
</tr>
<tr>
<td>404</td>
<td>Math Model, Lehigh River</td>
<td>7</td>
</tr>
<tr>
<td>410</td>
<td>Sedimentation in Reservoirs</td>
<td>7</td>
</tr>
<tr>
<td>411</td>
<td>Sediment Transport Characteristics of Cohesive Soil</td>
<td>8</td>
</tr>
<tr>
<td><strong>STRUCTURAL CONCRETE DIVISION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>339</td>
<td>Prestress Losses</td>
<td>9</td>
</tr>
<tr>
<td>378</td>
<td>Overloading of Highway Bridges</td>
<td>9</td>
</tr>
<tr>
<td>382</td>
<td>Prestress Loss of In-Service Bridges</td>
<td>9</td>
</tr>
<tr>
<td>387</td>
<td>Load Distribution</td>
<td>9</td>
</tr>
<tr>
<td>390</td>
<td>Polymers in Highway Concrete</td>
<td>10</td>
</tr>
<tr>
<td>402</td>
<td>Prestress Loss in Post-Tensioned Members</td>
<td>10</td>
</tr>
<tr>
<td>412</td>
<td>Behavior of Reinforced Concrete Column-Grid Structures under Earthquake Loading</td>
<td>10</td>
</tr>
<tr>
<td>414</td>
<td>Reinforced Concrete Constitutive Relations</td>
<td>11</td>
</tr>
</tbody>
</table>
## TABLE OF CONTENTS (cont.)

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STRUCTURAL CONNECTIONS DIVISION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>333</td>
<td>Beam-to-Column Connections</td>
<td>12</td>
</tr>
<tr>
<td>381</td>
<td>Composite Beams with Formed Metal Decks</td>
<td>12</td>
</tr>
<tr>
<td>405</td>
<td>Beam-to-Column Web Connections</td>
<td>12</td>
</tr>
<tr>
<td>413</td>
<td>Aquisition of a Random Loading Fatigue Testing System</td>
<td>12</td>
</tr>
<tr>
<td><strong>STRUCTURAL STABILITY DIVISION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>217</td>
<td>Column Research Council</td>
<td>13</td>
</tr>
<tr>
<td>217</td>
<td>3rd Edition of CRC Guide</td>
<td>13</td>
</tr>
<tr>
<td>380</td>
<td>Box Girders</td>
<td>13</td>
</tr>
<tr>
<td>389</td>
<td>Columns Under Biaxial Bending</td>
<td>13</td>
</tr>
<tr>
<td>393</td>
<td>Tubular Columns</td>
<td>13</td>
</tr>
<tr>
<td>406</td>
<td>Local Buckling of High Strength Tubes</td>
<td>14</td>
</tr>
<tr>
<td><strong>OPERATIONS DIVISION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>Industrial Testing</td>
<td>15</td>
</tr>
<tr>
<td><strong>MISCELLANEOUS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>237</td>
<td>Laboratory Facilities &amp; Research</td>
<td>16</td>
</tr>
</tbody>
</table>

**SELECTED BIBLIOGRAPHY OF REPORTS ON CURRENT PROJECTS**

**LIST OF CURRENT PROJECT SPONSORS**

29
TABLE OF CONTENTS (cont.)

PROJECT NUMBER INDEX 31

PROJECT TITLE INDEX 34
Bending of Wide Flange Shapes
About the Weak Axis
(Proj. No.) 361
(AISC) (Sponsor) Lu
(Proj. Dir.)

Plastic Design of Unbraced Frames Manual
367 NSF, AISI, AISC
Driscol

A practical design-office manual for the plastic design of unbraced multistory frames is being prepared. A description of the methods used in designing beams, columns, connections, supported bents and wind resistant bents is given. The complete design of a typical unbraced multistory frame is illustrated. This manual is intended to be a follow up to the 1968 AISI and AISC manual "Plastic Design of Braced Multistory Steel Frames."

Planning & Design of Tall Buildings
369 NSF-AISI
Beedle

The objective is to study and report on the planning and design of tall buildings -- to hold local, regional, national, international conferences, reporting the results in proceedings -- to prepare a monograph on tall buildings for use by those responsible for design practice. The project is concerned with stimulating research in the field and with the utilization of most recent findings from research laboratories and from design practice.

International Conferences on Tall Buildings
369-4 NSF-UNESCO
Beedle

This phase of the Tall Building project is concerned with the organization and the preparation for the International Conference on Tall Buildings to be held in 1977. The emphasis is on providing an impetus to the utilization of the results achieved up to that time by the Joint Committee on Planning and Design of Tall Buildings.
Tall Buildings: Regional Conferences 369.8 NSF Beedle

As part of the larger project on Planning and Design of Tall Buildings, this phase concentrates on one key medium for coordination and advancement of the state of knowledge. The function of this project is to assist local organizers in the planning of Regional Conferences. Through these meetings, research results are communicated to concerned individuals, new problems are identified, and further work is stimulated.

Tall Buildings: Reports and Publications 369-10 AISI, NSF Beedle

As the need for documented information on tall buildings increases, the distribution of reports & publications on the subject becomes of paramount importance. In coordination with library and editorial activity, a controlled and extensive distribution of such material will serve not only as an educational aid to the general public. It will also serve as an important catalyst for increased exposure, and consequently, increased interest in the contents of the MONOGRAPH.

Tall Buildings: MONOGRAPH 369-12 NSF Beedle

The MONOGRAPH is projected as a 5-volume publication which will provide technical information to engineers, architects, planners and other professionals who are responsible for planning and design practice for high-rise buildings.

A. The subject areas of the MONOGRAPH cover environmental criteria planning, systems methodology, social and political aspects, structural and service systems, the various loading functions, and structural design methods -- copy both concrete and steel buildings.

Tall Buildings: Surveys 369-14 NSF, ASCE, IABSE, Driscoll

Under the direction of an international advisory committee, an ongoing survey of tall building characteristics is being conducted. The information from this survey is tabulated and presented in computerized tabulated format for reference purposes. These tables have been published in Volume C of the PROCEEDINGS, and is updated from time to time. A new published version is anticipated.
The purpose of this project is to implement the "Systems Approach" into the management and direction of project 369 (See Above). The objectives include (1) formally linking all phases of the project together, (2) formulating purposes and goals of each phase, (3) giving the director and supervisors of the project a scientific management base for their operations, and (4) an eventual MIS (Management Information System) for the project, i.e. computerized information from a data base source.

One of the potentials for further advances in the design of steel buildings is in the use of the so-called "probabilistic" approach. In view of the advances made abroad, one of the purposes of the project is to analyze and summarize developments in Europe. In coordination with a project at Washington University at St. Louis (T. V. Galambos), a second objective is to make available selected summaries of the large mass of test data available at Fritz Lab.

For certain regular unbraced multistory steel frames, it has been found that a simple procedure can be used for design which is less involved than the conventional allowable stress method. Frames proportioned by this simplified technique are being investigated analytically when they are subjected to gravity loads alone.

The plastic strength of unbraced frames has been investigated and new AISC specifications for use in steel frame design have been adopted. Much of this work involved the understanding of subassemblies behavior and the one-story assemblages. An analytical extension of this work to include the contribution of the composite steel-concrete floor system to frame strength and drift has concluded. This project will investigate the adequacy of the analytical results as well as proposed design and specification provisions by means of large scale tests of two one-story concrete composite assemblages.
The behavior of steel H-columns subject to compression combined with biaxial bending has been the subject of research at Fritz Engineering Laboratory for many years (Proj. 331 and Proj. 389). Simple, direct and accurate approximate formulas were proposed as a method for practical design. Despite this, the problem is still not fully explored and the proposed method is, for the most part, limited to compact square H-shape columns under combined axial load and symmetric biaxial bending. The present research attempts to extend the proposed method of design to include I shapes and square and rectangular hollow steel shapes (HSS) under symmetric as well as unsymmetric biaxial loading.
Laboratory fatigue tests and field measurements on fatigue damaged bridges are being undertaken to evaluate the mechanism of cumulative damage and correlate their behavior in the extreme life region (up to 100,000,000 cycles). Experimental laboratory work includes basic crack growth studies, coverplated beam tests and other bridge details experiencing fatigue damage.

Stress history studies of a portion of the orthotropic steel deck will be made to determine the fatigue strength of the various welded details under projected bridge truck traffic.

The primary intent of this research investigation is to evaluate the effects of weldments on the fatigue strength of curved steel plate and box girder bridge elements with various details such as groove welds, web-flange fillet welds and transverse stiffeners and attachments. The approach taken was first to define the several types of details of most interest based partly on the results of previous research at Fritz Engineering Laboratory on straight beams and girders and then to design the required number of curved plate and box girder test assemblies to provide an adequate evaluation of the details tested. Recommendations for revisions to the fatigue portion of the AASHTO bridge code are to be made, if required.

Many fatigue and fracture tests to date have revealed that fatigue failure is precipitated by the presence of small initial flaws or defects. A welded detail in a bridge structure can be viewed as a region of material containing initial flaws and subject to high tensile residual stresses. Through testing full size bridge weldments the major objective of this project is to provide the designer with information to determine tolerable sizes of fatigue cracks and thus, the ability to recognize any potential fracture problem.
Limit Analysis and Soil Plasticity 355 L.U. Chen

Between 1950 and 1965, the method of limit analysis forms the central and most extensively developed part of the theory of metal plasticity. However, the corresponding extension to problems in soil mechanics is more recent. In view of the advances made in metal plasticity, one of the purposes of the project is to develop techniques of limit analysis as applied to soil mechanics. The project also concerns the development of a consistent theory of plasticity for soil, rock, and rock-like material such as concrete.

Analysis and Design of Tall Building Foundations 409 L.U. Fang

Presenting a comprehensive, systematic and up-to-date series of lectures in the field of analysis and design of foundations for tall buildings.
Biological Regeneration of Activated Carbon 388 OWRR Johnson

A major drawback to activated carbon use in advanced wastewater treatment is the high cost of thermal regeneration-activation of the granular carbon. Enhancement of biological activity in the granular media contacting process is being evaluated as a replacement and/or adjunct operation of the thermal regeneration currently in use. Both batch and quasi-continuous biological regeneration of the spent carbon are being studied.

Optimal Dimensions for Inlet Gratings 401 PennDOT Brune

Previous tests about the capacity of each inlet currently being installed by the sponsor along highways indicated that the downstream part of an inlet received little of the approaching flow. The present investigation is to determine the best length of a much wider grating in order that more of the approaching water will enter into the drainage inlet.

Math Model, Lehigh River 404 NSF Johnson

Sedimentation in Reservoirs 410 NSF Murray

Reservoirs are efficient sediment traps and may often collect nearly all of a river's sediment load. An understanding of reservoir sedimentation is of great importance economically. It has been reported that damage due to sedimentation is about 50 million dollars annually in the U.S.

The objective of the research program is to gain a better understanding of how to predict the quantities and spatial distribution of the sediment deposited in reservoirs.
A joint research program between Lehigh University and the Universidad Industrial de Santander is to develop an improved description of the hydraulic transport characteristics of natural cohesive soils, in particular those of the Bucaramanga Mesa in the Republic of Columbia. The project should result in substantially more effective erosion control projects both in the Bucaramanga area and other similar erosion-prone areas.
Overloading of Beam-Slab Highway Bridges

Currently used methods of analysis, which are based on elastic or ultimate behavior, can not be used to accurately determine the inelastic behavior from elastic range throughout the design and loading stages to the ultimate strength of simple-span beam-slab bridge superstructures. The behavior of such structures in the inelastic range is needed to judge the effects of overloading, and to compute the various load carrying capacities of the structure as a whole. The investigation will determine the effects of overloading development of a computer based analytical model.

Field Evaluation & Prestress Losses

In an earlier project (FL 339), a procedure was developed for the direct determination of prestress losses in pretensioned concrete members. This project involves field observations on an experimental bridge for the purpose of detecting any effect of the varying environmental condition on the behavior of the members. Also included are studies regarding the properties of 1/2" diameter prestressing strands and stabilized strands.

Development and Refinement of Load Distribution Provisions for Prestressed Concrete I-Beam Bridges

The primary objective of the project is to develop new specification provisions covering live load distribution in prestressed concrete I-beam highway bridges. In addition, provisions covering the effects of skew will be included, as well as a pilot study of the effects of diaphragms, parapet sections, and continuity. This project is a follow-up to a similar effort which resulted in the current AASHTO specifications covering load distribution in prestressed concrete spread box-beam bridges.
Use of Polymers in Highway Applications
Chen, Manson Vanderhoff

Every highway department is confronted with the problem of deterioration of concrete bridge slabs. In large part, this deterioration is the result of extensive use of deicing salts during winter time. The objective of this project is to develop field techniques to seal the void spaces of the concrete layer above the reinforcing steel with an impermeable solid substance that would prevent penetration of salt solution, for example, by incorporating a low-melting wax or by polymer impregnation.

Prestress Losses of Post-Tensioned Members
PennDOT Huang

A 30-month study will be conducted to extend the usefulness of the procedures developed in a previous research project (339) whose purpose was to estimate prestress losses in pre-tensioned concrete members. New parameters to be included in the project are post-tensioned members, pre-post-tensioned members, the effect of ambient relative humidity and the gaining of concrete strength with time. General and practical procedures will be developed and incorporated into computer programs for possible use in design offices.

Behavior of Reinforced Concrete Column-Grid Structures Under Earthquake Loading
NSF Huang

This is an international cooperative research project jointly undertaken by Lehigh University and the Escuela Colombiana de Ingenieria in Bogota, Colombia.

The column-supported open-grid structural system has recently been used extensively in high-rise concrete buildings in Colombia. The floor system consists of two intersecting series of narrow joists containing preformed non-structural filler blocks. This system offers a number of architectural and structural advantages, but improved design criteria are needed to assure safety of this new structural system, particularly against seismic loading. This research is aimed at satisfying this need.
The project attempts to develop constitutive relations for reinforced concrete under general three-dimensional stress condition. Further, a corresponding computer code in the form of a subroutine will be developed to reflect material response. This code will be adaptable for use in an existing or postulated larger finite element analysis program.
STRUCTURAL CONNECTIONS DIVISION

Beam-to-Column Connections 333 AISI Beedle, Driscoll, Chen
See Project 405

Composite Beams with Formed Metal Deck 381 AISI Fisher

Full scale composite beams with formed metal deck were tested and existing literature studied. Design relationships for shear connectors and the composite beam are being developed for implementation by AISC. All available experimental work is being used.

Beam-to-Column Connections 405,333 AISI & AISC Chen & Beedle

Beam-to-column connections play an important role in the load partition of structural frames. The behavior of beam-to-column connections is of major interest to engineers and a significant amount of research has been done on welded or riveted specimens. The studies of this project are aimed at developing and improving design rules for bolted connections and combination bolted and welded connections because of decreased fabrication and erection costs.

Acquisition of a Random Loading Fatigue Testing System 413 NSF Slutter, Fisher

The fatigue and fracture testing capabilities of Fritz Engineering Laboratory will be extended through the acquisition of new hydraulic fatigue testing equipment to be used with the existing dynamic test bed and test frames. The new capabilities will include increasing the load capacity by a factor of two, variable frequency operation and programming capability for random loading.
The headquarters of the Column Research Council are at Lehigh University, including the Office of Director, Secretary and the Council files. The major activity is coordination of world-wide research on stability problems, the maintenance of a "Guide to Design", and organization of an annual technical session.

The objective of the project is to examine the stresses in composite box girder with concrete deck. Analytical predictions are compared with experimental results in order to formulate recommendations for working-load design procedure. Also under investigation are the behavior of box girders (open shapes) under construction and the behavior of composite box girders beyond the working load range.

The two-dimensional in-plane behavior of columns has been the subject of research for many years. Despite this the extension into three-dimension space situation is still not fully understood and design methods are, for the most part, based on empirical formulae. This project attempts to achieve the following two objectives: (1) obtaining accurate information regarding the behavior of such columns throughout the entire range of loading up to ultimate load; (2) developing simple procedures to enable designers to assess this behavior.

Of particular concern to designers of off-shore oil-drilling platforms is the lack of data, both from experimental tests and theoretical analyses, from which rational design of large diameter tubular columns can be evolved. One of two research projects currently in progress at Lehigh, this project is concerned with the measurement and prediction of the overall buckling behavior of such columns, with a view to reviewing the adequacy of present design codes.
Design of large-diameter tubular members for offshore oil drilling platforms is handicapped by the uncertainty of the present criteria for local buckling. The purpose of this project is to provide an experimental basis for developing more rational and accurate local buckling criteria for large-diameter high-strength tubular columns, specifically, for the stress range between the proportional and yield levels.
In addition to sponsored research, a program of industrial tests is carried out in Fritz Laboratory. Appropriate test projects (usually with report) are those for which the Laboratory facilities are particularly unique. Routine tests are usually not included.
<table>
<thead>
<tr>
<th>MISCELLANEOUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory Facilities &amp; Research</td>
</tr>
</tbody>
</table>
SELECTED BIBLIOGRAPHY OF REPORTS ON CURRENT PROJECTS
### Project 333: Beam-to-Column Connections

<table>
<thead>
<tr>
<th>Section</th>
<th>Author(s)</th>
<th>Title</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>333.7</td>
<td>Huang, J. S.; Fielding, D. J. and Staff</td>
<td>Future Connection Research Problems, July 1972.</td>
<td></td>
</tr>
<tr>
<td>333.9</td>
<td>Fielding, David J. and Huang, Joseph S.</td>
<td>Shear in Beam-to-Column Connections, September 1970. (71-21)</td>
<td></td>
</tr>
<tr>
<td>333.10</td>
<td>Chen, W. F. and Oppenheim, I. J.</td>
<td>Web Buckling Strength of Beam-to-Column Connections, September 1970. (74-1)</td>
<td></td>
</tr>
<tr>
<td>333.14</td>
<td>Chen, W. F. and Newlin, David E.</td>
<td>Column Web Strength in Steel Beam-to-Column Connections, ASCE Meeting Preprint 1524 (FL 73-45)</td>
<td></td>
</tr>
</tbody>
</table>
333.31 Standig, K. F.; Rentshler, G. P. and Chen, W. F.
TESTS OF BOLTED BEAM-TO-COLUMN MOMENT CONNECTIONS,
May 1975.

Project 339 PRESTRESS LOSSES IN PRETENSIONED CONCRETE
STRUCTURAL MEMBERS

339.1 Rokhsar, A. and Huang, T.
COMPARATIVE STUDY OF SEVERAL CONCRETES REGARDING THEIR
POTENTIAL FOR CONTRIBUTING TO PRESTRESS LOSSES,
May 1968.

339.3 Frederickson, D. C. and Huang, T.
PRELIMINARY REPORT ON CONCRETE STRAINS IN PRETENSIONED
STRUCTURAL MEMBERS, May 1969.

339.5 Batal, Rabih J.
RELAXATION LOSSES IN SPECIAL GRADE PRESTRESSING STRAND,
June 1970.

339.6 Schultchen, E. G.; Ying, H. T. and Huang, T.
RELAXATION BEHAVIOR OF PRESTRESSING STRANDS, June 1972.

339.7 Ying, H. T.; Schultchen, E. G. and Huang, T.
ESTIMATION OF CONCRETE STRAINS AND PRESTRESS LOSSES
IN PRETENSIONED MEMBERS (Preliminary Draft), May 1972.

339.9 Huang, T.
PRESTRESS LOSSES IN PRETENSIONED CONCRETE STRUCTURAL

Project 355 SOIL PLASTICITY

355.1 Chen, W. F.
ON THE RATE OF DISSIPATION OF ENERGY IN SOILS,
January 1968. (68–24)

355.3 Chen, W. F. and Scawthorn, C.
LIMIT ANALYSIS AND LIMIT EQUILIBRIUM SOLUTIONS IN
SOIL MECHANICS, June 1968. (70–19)

355.4 Chen, W. F., Giger, M. W., Fang, H. Y.
ON THE LIMIT ANALYSIS OF STABILITY OF SLOPE

355.6 Chen, W. F. and Giger, M. W.
LIMIT ANALYSIS OF STABILITY OF EMBANKMENTS, 1970.
355.13 Chen, W. F.; Snitbhan, N. and Fang, H. Y.
STABILITY OF SLOPES IN ANISOTROPIC NONHOMOGENEOUS SOILS,

355.14 Rosenfarb, Jack L. and Wai F. Chen
LIMIT ANALYSIS SOLUTIONS OF EARTH PRESSURE PROBLEMS,
May 1972. (73-64)

355.15 Chen, W. F. and Davidson, H. L.
BEARING CAPACITY DETERMINATION BY LIMIT ANALYSIS,
January 1972. (73-35)

355.15 Chen, W. F.; Dismuke, T. D. and Fang, H. Y.
TENSILE STRENGTH OF ROCK BY THE DOUBLE-PUNCH METHOD,
to be published in Jr. of the International Soc. for
Rock Mechanics, 1972. (72-34)

355.15 Davidson, Hugh L. and Chen, W. F.
ELASTIC-PLASTIC, LARGE DEFORMATION RESPONSE OF SOIL TO
FOOTING LOAD, ASCE Annual Meeting, October/November
1973, Meeting Preprint 2070.

Project 361
WIDE-FLANGE BEAM-COLUMNS BENT
ABOUT WEAK AXIS

361.1 Lybas, John M.
STRENGTH OF WIDE-FLANGE SECTIONS UNDER COMBINED AXIAL
FORCE AND WEAK-AXIS BENDING, October 1970.

367.6 Driscoll, George C. Jr. and Reed, Paul W.
Report to Members of Task Group on AISI Project 165
MANUAL FOR UNBRACED FRAMES, March 9, 1971.

367.7 Driscoll, G. C. and Reed, Paul W.
QUESTIONNAIRE TO MEMBERS OF TASK FORCE ON AISI
PROJECT 165, MANUAL FOR UNBRACED MULTISTORY STEEL
FRAMES, March 1971.

367.9 Reed, Paul W.
SIMPLIFIED ANALYSIS OF UNBRACED FRAMES, M.S. Thesis,
June 1972.

367.14 Gsellmeier, Reinhard L.
PLASTIC DESIGN OF UNBRACED MULTISTORY SPACE FRAMES,
April 1975.
369.12 Beedle, Lynn S.
TALL BUILDINGS: WHY?, July 15, 1971. (71-41)

369.17 Lu, L. W. and Beedle, L. S. (Eds.) Research
CURRENT QUESTIONS, PROBLEMS AND NEEDS, Committee
Report No. 5, August 1972.

369.20 Beedle, L. S. and Lu, L. W.
WHAT'S A TALL BUILDINGS? ASCE Meeting Preprint 1553,
October 1971.

369.49 ASCE-IABSE Joint Committee, L. S. Beedle, Chairman
CURRENT RESEARCH ON TALL BUILDINGS, June 1972,
Report No. 10. (72-6)

369.56 ASCE-IABSE Joint Committee, L. S. Beedle, Chairman
PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON

369.58 Tuffy, Barbara
WHERE TO PUT THE PEOPLE, NSF, MOSAIC, Vol. 3, No. 4,
Fall 1972.

369.63 Joint Committee on Planning & Design of Tall Buildings
THE TREND TO TALL BUILDINGS, World Construction,
November 1972.

369.69 American Institute of Architects

369.170 Beedle, L. S.
Project 371 LOAD FACTOR DESIGN IN STEEL BUILDINGS

371.1 Marek, Pavel
PRELIMINARY REVIEW OF CZECHOSLOVAK SPECIFICATIONS,
February 24, 1970.

371.2 Marek, P. J. and Beedle, L. S.
REVIEW OF CZECHOSLOVAK AND FRENCH SPECIFICATIONS,
October 1970.

371.3 Marek, P. J. and Covarrubias, S.
DATA COLLECTION ON THE MECHANICAL PROPERTIES OF
STRUCTURAL STEELS, October 1970.

371.2A Marek, P. J.
REVIEW OF CZECHOSLOVAK AND FRENCH SPECIFICATIONS,
Revised March 1973 by N. Zettlemoyer.

Project 378 OVERLOADING BEHAVIOR OF BEAM-SLAB
HIGHWAY BRIDGES

378A Wegmüller, A. W. and Kostem, C. N.
effect of imperfections on the static response of
beam-slab type highway bridges, Proc., speciality
conf. on the finite element method in civil eng'g,
Montreal, Canada, June 1972. (72-12)

Wegmüller, Anton W. and Kostem, Celal N.

Wegmüller, Anton W. and Kostem, Celal N.

Kulicki, John M. and Kostem, Celal N.
INELASTIC ANALYSIS OF REINFORCED AND PRESTRESSED CONCRETE BEAMS, November 1972.

Kulicki, John M. and Kostem, Celal N.

Peterson, W. S.; Kostem, C. N. and Kulicki, J. M.

Peterson, W. S.; Kulicki, J. M. and Kostem, C. N.
INELASTIC ANALYSIS OF BEAM-SLAB HIGHWAY BRIDGES, June 1974.

Peterson, W. S. and Kostem, C. N.
INELASTIC ANALYSIS OF BEAM-SLAB HIGHWAY BRIDGE SUPER-STRUCTURES, March 1975.

Peterson, W. S. and Kostem, C. N.
USER'S MANUAL FOR PROGRAM BOVA, March 1975.

Yen, B. T.; Corrado, J. A. and Yen, Y. S.
MODAL COMPOSITE BOX GIRDERS FOR TESTING, October 1971.

Corrado, J. A. and Yen, B. T.
FAILURE TESTS OF RECTANGULAR MODAL BOX GIRDERS, April 1972. (73-38 & 74-13)
Chern, C.; Parsanejad, S. & Ostapenko, A.
COMPUTER PROGRAMS FOR ULTIMATE STRENGTH ANALYSIS OF TRANSVERSELY AND LONGITUDINALLY STIFFENED PLATE GIRDER, September 1972.

McDonald, Robert E.

Yilmaz, C. and Yen, B. T.
STRESS AND DEFLECTIONS OF COMPOSITE BOX GIRDER BY FINITE ELEMENT METHOD, April 1975.

Grant, John A.
HIGH STRENGTH STEEL COMPOSITE BEAMS WITH FORMED METAL DECK AND LOW PARTIAL SHEAR CONNECTIONS, October 1973, M.S. thesis.

Grant, John A. Jr.; Fisher, John W. and Slutter, Roger G.
TESTS OF COMPOSITE BEAMS WITH FORMED METAL DECK, Presented at the 2d Specialty Conf. on Cold-Forced Steel Structures, October 22-24, 1973.

Tansu, J. and Huang, Ti
SOME OBSERVATIONS ON THE PRESTRESS LOSS BEHAVIOR OF BEAMS IN A EXPERIMENTAL BRIDGE, June 1975.

Fisher, J. W., Yen, B. T. and Marchica, N. V.
386.2  Klingerman, D. J. and Fisher, J. W.
      THRESHOLD CRACK GROWTH IN A36 STEEL.

386.3  Yen, B. T. and Fisher, J. W.
      STRESS HISTORY STUDIES ON THE ALLEGHENY RIVER BRIDGE
      (Turnpike), September 1975.

386.4  Daniels, J. H. and Fisher, J. W.
      FIELD EVALUATION OF TIE PLATE GEOMETRY, December 1974.

386.5  Coates, A., Yen, B. T. and Fisher J. W.
      STRESS IN SEVERAL TYPES OF BRIDGES, October 1975.

386.6  Talhelm, J. T. and Yen, B. T.
      STRESS DISTRIBUTION IN A CURVED PLATE GIRDER BRIDGE,
      October 1975.

386.7  Fisher, J. W., Daniels, J. H., Yen, B. T. and Pense, A. W.
      STRESSES IN EYE-BARS OF LIBERTY BRIDGE, February 1975.

Project 387  LOAD DISTRIBUTION

387.1  Zellin, M.; Kostem, C. N. and VanHorn, D. A.
       BIBLIOGRAPHY ON LOAD DISTRIBUTION AND ANALYSIS OF BEAM-

387.2  Zellin, Martin
       INVESTIGATING METHODS OF MODELING PRESTRESS CONCRETE

Project 389  COLUMNS UNDER BIAXIAL BENDING

389.1  Chen, W. F. and Shoraka, M. T.
       TANGENT STIFFNESS METHOD FOR BIAXIAL BENDING OF REIN-
       FORCED CONCRETE COLUMNS, October 1972. (74-17)

389.2  Tebedge, Negussie and Chen, Wai-Fah
       DESIGN CRITERIA FOR STEEL H-COLUMNS UNDER BIAXIAL
       LOADING, January 1973. (74-2)
Rentschler, Glenn P. and Chen, Wai-Fah

Chen, W. F. and Shoraka, M. T.
DESIGN CRITERIA FOR BIAXIALLY LOADED CONCRETE COLUMNS, ASCE National Structural Eng'g Meeting Preprint 2226, April 1974.

Project 390  POLYMERS IN HIGHWAY CONCRETE

Dahl-Jorgensen, Einar and Chen, Wai-Fah
STRESS-STRAIN PROPERTIES OF POLYMER MODIFIED CONCRETE, February 1973. (73-52)

Dahl-Jorgensen, E., Chen, W. F., Manson, J. A., Vanderhoff, J. W., Liu, Y. N.
POLYMER-IMPREGNATED CONCRETE: LABORATORY STUDIES, May 15, 1974. (75-2)

POLYMER-IMPREGNATED CONCRETE: FIELD STUDIES, (75-3)

Manson, J. A.; Chen, W. F.; Vanderhoff, J. W.; Liu, Y. N.
Dahl-Jorgenson, E. & Mehta, H.

Mehta, H. C., Chen, W. F., Manson, J. A. and Vanderhoff, J. W.
INNOVATIONS IN IMPREGNATION TECHNIQUES FOR HIGHWAY CONCRETE, prepared for presentation at Transportation Research Board, annual meeting, January 1975.

Chen, W. F.; Manson, J. A.; Mehta, H. C. and Vanderhoff, J. W.
USE OF POLYMERS IN HIGHWAY CONCRETE, presented at ASCE National Structural Eng'g Con., April 1975, meeting pre­print 2472.

Mehta, H. C. and Chen, W. F.
STRUCTURAL USE OF SULFUR FOR IMPREGNATION OF BUILDING MATERIALS, October 1974.
Project 393  TUBULAR COLUMNS

393.3 Ross, D. A. and Chen, W. F.
DESIGN CRITERIA FOR STEEL I-COLUMNS UNDER AXIAL LOAD AND BIAXIAL BENDING, April 1975.

393.2A Ross, D. A. and Chen, W. F.
IMPROVED THEORETICAL ANALYSIS OF A SHORT BIAXIALY LOADED TUBULAR COLUMN, June 1975.

393.4 Ross, D. A. and Chen, W. F.
RESIDUAL STRESS MEASUREMENT & FABRICATED TUBULAR STEEL COLUMNS, July 1975.

Project 397  RIO-NITEROI BOX GIRDERS BRIDGE

397.A DePaoli, David
STRESS HISTORY OF THE RIO-NITEROI BRIDGE, CE 385

397.B O'Brien, John
STATIC STUDY OF RIO-NITEROI BRIDGE, CE 385

397.2 Ostapenko, A. and Fisher, J. W.

397.3 Ostapenko, A.
RIO DE JANEIRO TO NITEROI,
Lehigh Research Review, Vol. 5, No. 2, Lehigh University, Bethlehem, PA.

397.4 O'Brien, John E.
BENDING STRESSES IN THE TRANSVERSE FRAMES DUE TO POISSON'S RATIO EFFECT IN A BOX GIRDERS BRIDGE (RIO-NITEROI), M.S. thesis, May 1975.

397.4 Ostapenko, A.; Yen, B. T.; Daniels, J. H. and Fisher, J. W.

397.5 Ostapenko, A.; Daniels, J. H. and Fisher, J. W.
Project 398  
**FATIGUE OF CURVED STEEL BRIDGE ELEMENTS**

398.1 Daniels, J. H.; Fisher, J. W.; Yen, B. T.; Abraham, D. and Zettlemoyer, N.
*FATIGUE OF CURVED STEEL BRIDGE ELEMENTS, Interim Report #1, Design of Test Assemblies, August 1975.*

Project 401  
**HIGHWAY DRAINAGE INLETS**

401.2 Spear, Andrew D. and Brune, Arthur W.
*OPTIMAL DIMENSIONS OF MEDIAN HIGHWAY DRAINAGE INLETS IN GRASSED CHANNELS, May 1975.*

Project 405  
**BEAM-TO-COLUMN WEB CONNECTIONS**

405.1 Rentschler, G. P. and Chen, W. F.
*PRELIMINARY PROPOSAL FOR TESTS OF STEEL BEAM-TO-COLUMN WEB CONNECTIONS, June, 1973.*

405.2 Rentschler, G. P. and Chen, W. F.
*PROPOSAL FOR TESTS OF MOMENT-RESISTANT STEEL BEAM-TO-COLUMN WEB CONNECTIONS, April, 1974.*

405.3 Rentschler, G. P. and Chen, W. F.
*PROGRAM OF PILOT TESTS ASSOCIATED WITH BEAM-TO-COLUMN WEB CONNECTION STUDIES, August 1974.*

405.4 Rentschler, G. P. and Chen, W. F.
*TEST PROGRAM OF MOMENT-RESISTANT STEEL BEAM-TO-COLUMN WEB CONNECTIONS, May 1975.*

Project 406  
**LOCAL BUCKLING OF HIGH STRENGTH TUBES**

406.3 Ostapenko, A.
*PROPOSAL FOR RESEARCH ON HIGH STRENGTH TUBULAR COLUMNS, continuation with AISI, 1975.*
LIST OF CURRENT PROJECT SPONSORS
# LIST OF CURRENT PROJECT SPONSORS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISC</td>
<td>American Institute of Steel Construction</td>
</tr>
<tr>
<td>AISI</td>
<td>American Iron and Steel Institute</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>CRC</td>
<td>Column Research Council</td>
</tr>
<tr>
<td>CSICC</td>
<td>Canadian Steel Industries Construction Council</td>
</tr>
<tr>
<td>ECEX</td>
<td>Express De Construcaco E Exploracao Da Ponte Presivente Cofta E Filva</td>
</tr>
<tr>
<td>ERDA</td>
<td>Energy Related Development Administration</td>
</tr>
<tr>
<td>IABSE</td>
<td>International Association for Bridge &amp; Structural Engineers</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>L.U.</td>
<td>Lehigh University</td>
</tr>
<tr>
<td>NCHRP</td>
<td>National Cooperative Highway Research Program</td>
</tr>
<tr>
<td>NSF</td>
<td>National Science Foundation</td>
</tr>
<tr>
<td>ONR</td>
<td>Office of Naval Research</td>
</tr>
<tr>
<td>OWRR</td>
<td>Water Resources Research &amp; U.S. Dept. of Interior</td>
</tr>
<tr>
<td>Penn Dot</td>
<td>Pennsylvania Department of Transportation</td>
</tr>
<tr>
<td>RCRC</td>
<td>Reinforced Concrete Research Council</td>
</tr>
<tr>
<td>USDOT</td>
<td>United States Department of Transportation</td>
</tr>
<tr>
<td>WRC</td>
<td>Welding Research Council</td>
</tr>
</tbody>
</table>
PROJECT NUMBER INDEX
### PROJECT NUMBER INDEX

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>Industrial Testing (Various Industrial Governmental Concerns)</td>
<td>15</td>
</tr>
<tr>
<td>217</td>
<td>Column Research Council</td>
<td>13</td>
</tr>
<tr>
<td>237</td>
<td>Laboratory Facilities &amp; Research</td>
<td>16</td>
</tr>
<tr>
<td>333</td>
<td>Beam-to-Column Connections</td>
<td>12</td>
</tr>
<tr>
<td>339</td>
<td>Prestress Losses</td>
<td>9</td>
</tr>
<tr>
<td>355</td>
<td>Limit Analysis and Soil Plasticity</td>
<td>6</td>
</tr>
<tr>
<td>361</td>
<td>Bending of Wide Flange Shapes</td>
<td>1</td>
</tr>
<tr>
<td>367</td>
<td>Plastic Design of Unbraced Frames</td>
<td>1</td>
</tr>
<tr>
<td>369</td>
<td>Planning and Design of Tall Building</td>
<td>1</td>
</tr>
<tr>
<td>369-0</td>
<td>Tall Buildings: Interaction</td>
<td>1</td>
</tr>
<tr>
<td>369-1</td>
<td>Tall Buildings: Steel Design</td>
<td>1</td>
</tr>
<tr>
<td>369-4</td>
<td>International Conference on Tall Buildings</td>
<td>1</td>
</tr>
<tr>
<td>369-8</td>
<td>Tall Buildings: Reg. Conference</td>
<td>2</td>
</tr>
<tr>
<td>369-10</td>
<td>Tall Buildings: Reports and Publications</td>
<td>2</td>
</tr>
<tr>
<td>369-12</td>
<td>Tall Buildings: MONOGRAPH</td>
<td>2</td>
</tr>
<tr>
<td>369-14</td>
<td>Tall Buildings: Surveys</td>
<td>2</td>
</tr>
<tr>
<td>369-15</td>
<td>Tall Buildings: Systems</td>
<td>3</td>
</tr>
<tr>
<td>371</td>
<td>Load and Resistance-Factor Design</td>
<td>3</td>
</tr>
<tr>
<td>378</td>
<td>Overloading of Beam Slab Highway Bridges</td>
<td>9</td>
</tr>
<tr>
<td>380</td>
<td>Strength of Rectangular Composite Box Girders</td>
<td>13</td>
</tr>
<tr>
<td>381</td>
<td>Composite Beams with Formed Metad Deck</td>
<td>12</td>
</tr>
<tr>
<td>382</td>
<td>Field Evaluation &amp; Prestress Losses</td>
<td>9</td>
</tr>
<tr>
<td>386</td>
<td>High Cycle Fatigue of Welded Bridge Details</td>
<td>5</td>
</tr>
<tr>
<td>387</td>
<td>Development and Refinement of Load Distribution Provisions for Prestressed Concrete I-Beam Bridges</td>
<td>9</td>
</tr>
<tr>
<td>388</td>
<td>Biological Regeneration of Activated Carbon</td>
<td>7</td>
</tr>
<tr>
<td>389</td>
<td>Analysis and Design of Biaxially Loaded Columns</td>
<td>13</td>
</tr>
<tr>
<td>390</td>
<td>Use of Polymers in Highway Applications</td>
<td>10</td>
</tr>
<tr>
<td>393</td>
<td>Axially Loaded Tubular Steel Columns</td>
<td>13</td>
</tr>
<tr>
<td>396</td>
<td>Stability of Steel Frames</td>
<td>3</td>
</tr>
</tbody>
</table>
# PROJECT NUMBER INDEX

<table>
<thead>
<tr>
<th>PROJECT</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>397</td>
<td>Rio-Niteroi Box Girder Bridge</td>
<td>5</td>
</tr>
<tr>
<td>398</td>
<td>Fatigue of Curved Steel Elements</td>
<td>5</td>
</tr>
<tr>
<td>399</td>
<td>Determinations of Tolerable Flaw Sizes in Full Size Weldments</td>
<td>5</td>
</tr>
<tr>
<td>401</td>
<td>Optimal Dimensions for Inlet Gratings</td>
<td>7</td>
</tr>
<tr>
<td>402</td>
<td>Prestress Losses of Post Tensioned Members</td>
<td>10</td>
</tr>
<tr>
<td>403</td>
<td>Composite Assemblage Experiments</td>
<td>3</td>
</tr>
<tr>
<td>404</td>
<td>Math Model, Lehigh River</td>
<td>7</td>
</tr>
<tr>
<td>405</td>
<td>Beam-to-Column Connections</td>
<td>12</td>
</tr>
<tr>
<td>406</td>
<td>Local Buckling of High-Strength Tubes</td>
<td>14</td>
</tr>
<tr>
<td>408</td>
<td>Design of Biaxially Loaded Columns</td>
<td>4</td>
</tr>
<tr>
<td>409</td>
<td>Analysis and Design of Tall Building Foundations</td>
<td>6</td>
</tr>
<tr>
<td>410</td>
<td>Sedimentation in Reservoirs</td>
<td>7</td>
</tr>
<tr>
<td>411</td>
<td>Sediment Transport Characteristics of Cohesive Soils</td>
<td>8</td>
</tr>
<tr>
<td>412</td>
<td>Behavior of Reinforced Concrete Column-Grid Structures Under Earthquake Loading</td>
<td>10</td>
</tr>
<tr>
<td>413</td>
<td>Acquisition of a Random Loading Fatigue Testing System</td>
<td>12</td>
</tr>
<tr>
<td>414</td>
<td>Reinforced Concrete Constitutive Relations</td>
<td>11</td>
</tr>
<tr>
<td>TITLE</td>
<td>PROJECT</td>
<td>PAGE</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>---------</td>
<td>------</td>
</tr>
<tr>
<td>Acquisition of a Random Loading Fatigue Testing System</td>
<td>413</td>
<td>12</td>
</tr>
<tr>
<td>Analysis and Design of Biaxially Loaded Columns</td>
<td>389</td>
<td>13</td>
</tr>
<tr>
<td>Analysis and Design of Tall Building Foundations</td>
<td>409</td>
<td>6</td>
</tr>
<tr>
<td>Axially Loaded Tubular Steel Structures</td>
<td>393</td>
<td>13</td>
</tr>
<tr>
<td>Beam-to-Column Connections</td>
<td>333</td>
<td>12</td>
</tr>
<tr>
<td>Beam-to-Column Connections</td>
<td>405</td>
<td>12</td>
</tr>
<tr>
<td>Behavior of Reinforced Concrete Column-Grid Structure Under Earthquake Loading</td>
<td>412</td>
<td>10</td>
</tr>
<tr>
<td>Bending of Wide Flange Shapes</td>
<td>361</td>
<td>1</td>
</tr>
<tr>
<td>Biological Regeneration of Activated Carbon</td>
<td>388</td>
<td>7</td>
</tr>
<tr>
<td>Column Research Council</td>
<td>217</td>
<td>13</td>
</tr>
<tr>
<td>Composite Assemblage Experiments</td>
<td>403</td>
<td>3</td>
</tr>
<tr>
<td>Composite Beams with Formed Metal Deck</td>
<td>381</td>
<td>12</td>
</tr>
<tr>
<td>Design of Biaxially Loaded Columns</td>
<td>408</td>
<td>4</td>
</tr>
<tr>
<td>Determination of Tolerable Flaw Sizes in Full Size Weldments</td>
<td>399</td>
<td>5</td>
</tr>
<tr>
<td>Development and Refinement of Load Distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Provision for Prestressed Concrete I-Beam Bridges</td>
<td>387</td>
<td>9</td>
</tr>
<tr>
<td>Fatigue of Curved Elements</td>
<td>398</td>
<td>5</td>
</tr>
<tr>
<td>Field Evaluation of Prestressed Losses</td>
<td>382</td>
<td>9</td>
</tr>
<tr>
<td>High Cycle Fatigue of Welded Bridge Details</td>
<td>386</td>
<td>5</td>
</tr>
<tr>
<td>Industrial Testing</td>
<td>200</td>
<td>15</td>
</tr>
<tr>
<td>International Conferences on Tall Buildings</td>
<td>369-4</td>
<td>1</td>
</tr>
<tr>
<td>Laboratory Facilities &amp; Research</td>
<td>237</td>
<td>16</td>
</tr>
<tr>
<td>Limit Analysis and Soil Plasticity</td>
<td>355</td>
<td>6</td>
</tr>
<tr>
<td>Load and Resistance-Factor Design</td>
<td>371</td>
<td>3</td>
</tr>
<tr>
<td>Local Buckling of High Strength Tubes</td>
<td>406</td>
<td>14</td>
</tr>
<tr>
<td>Math Model, Lehigh River</td>
<td>404</td>
<td>7</td>
</tr>
<tr>
<td>Optimal Dimensions for Inlet Gratings</td>
<td>401</td>
<td>7</td>
</tr>
<tr>
<td>TITLE</td>
<td>PROJECT</td>
<td>PAGE</td>
</tr>
<tr>
<td>-----------------------------------------------------------</td>
<td>---------</td>
<td>------</td>
</tr>
<tr>
<td>Overloading of Beam-Slab Highway Bridges</td>
<td>378</td>
<td>9</td>
</tr>
<tr>
<td>Planning and Design of Tall Buildings</td>
<td>369</td>
<td>1</td>
</tr>
<tr>
<td>Plastic Design of Unbraced Frames</td>
<td>367</td>
<td>1</td>
</tr>
<tr>
<td>Prestress Losses</td>
<td>339</td>
<td>9</td>
</tr>
<tr>
<td>Prestress Losses of Post Tensioned Members</td>
<td>402</td>
<td>10</td>
</tr>
<tr>
<td>Reinforced Concrete Constitutive Relations</td>
<td>414</td>
<td>11</td>
</tr>
<tr>
<td>Rio-Niteroi Box Girder Bridge</td>
<td>397</td>
<td>5</td>
</tr>
<tr>
<td>Sediment Transport Characteristics of Cohesive Soils</td>
<td>411</td>
<td>8</td>
</tr>
<tr>
<td>Sedimentation in Reservoirs</td>
<td>410</td>
<td>7</td>
</tr>
<tr>
<td>Stability of Steel Frames</td>
<td>396</td>
<td>3</td>
</tr>
<tr>
<td>Strength of Rectangular Composite Box Girders</td>
<td>380</td>
<td>13</td>
</tr>
<tr>
<td>Tall Buildings: Interactions</td>
<td>369-0</td>
<td>1</td>
</tr>
<tr>
<td>Tall Buildings: MONOGRAPH</td>
<td>369-12</td>
<td>2</td>
</tr>
<tr>
<td>Tall Buildings: Reg. Conference</td>
<td>369-8</td>
<td>2</td>
</tr>
<tr>
<td>Tall Buildings: Reports &amp; Publications</td>
<td>369-10</td>
<td>2</td>
</tr>
<tr>
<td>Tall Buildings: Steel Design</td>
<td>369-1</td>
<td>1</td>
</tr>
<tr>
<td>Tall Buildings: Surveys</td>
<td>369-14</td>
<td>2</td>
</tr>
<tr>
<td>Tall Buildings: Systems</td>
<td>369-15</td>
<td>3</td>
</tr>
<tr>
<td>Use of Polymers in Highway Applications</td>
<td>390</td>
<td>10</td>
</tr>
<tr>
<td>Project Title</td>
<td>Page</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Partners in Education</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Industrial Testing</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Structural Stability Research Council</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Laboratory Facilities and Research</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Planning and Design of Tall Buildings</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Strength of Rectangular Composite Box Girders</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Local Buckling of High-Strength Tubes</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Finite Element Analysis of Bridge Structures</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Prediction of the Earthquake Response of Building Systems and Components</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Overloading Behavior of Steel Highway Bridges</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Stability of Multi-Story Steel Frames</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Impact of Tall Buildings: Implementation</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Bibliographic Data Base on Tall Buildings and Urban Habitat</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>High-Rise Building Data Base</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Corrosion Fatigue of Bridge Steel</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Ultimate Strength Testing of Horizontally Curved Steel Bridge Girders</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Development of Substitute Construction Materials</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Steel Bridge Members Under Variable Amplitude Long Life Loading</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Field Studies of Sudan Railroad Bridges</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>U.S.-Japan Research Program Using Large Testing Facilities</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Fracture of Moment Connections</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Implementation of Prestress Loss Estimation Procedures</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Stability of Steel Columns</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Seismic Resistance of Precast Buildings</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3-D Wave-Induced Forces on Buried Pipelines</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Earthquake Resistance of High-Rise Building Systems</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Hydraulics of Hereford Inlet</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Strength of Composite Plate Girders</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Ship Structures</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Hull Strength Analysis</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Diaphragm Behavior of Floor Systems and its Effect on Seismic Building Response</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>U.S.-Japan Cooperative Earthquake Research Program</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Fatigue Strength of Weathered and Deteriorated Riveted Members</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
## Table of Contents

### BUILDING SYSTEMS

- **107** Partners in Education

### Earthquake Engineering

- **433** Prediction of the Earthquake Response of Building Systems and Components
- **467** U.S.-Japan Research Program Using Large Testing Facilities
- **472** Seismic Resistance of Precast Buildings
- **474** See "Tall Buildings"
- **481** Diaphragm Behavior of Floor Systems and its Effect on Seismic Building Response
- **482** U.S.-Japan Cooperative Earthquake Research Program

### FATIGUE AND FRACTURE

- **447** Corrosion Fatigue of Bridge Steel
- **463** Steel Bridge Members Under Variable Amplitude Long Life Loading
- **466** Field Studies of Sudan Railroad Bridges
- **483** Fatigue Strength of Weathered & Deteriorated Riveted Members

### GEOTECHNICAL ENGINEERING

- **458** Development of Substitute Construction Materials
- **462** Soil as a Heat Collector & Thermal Storage in Solar Energy Systems

### HYDRAULICS

- **473** 3-D Wave-Induced Forces on Buried Pipelines
- **477** Hydraulics of Hereford Inlet

### STRUCTURAL CONCRETE

- **470** Implementation of Prestress Loss Estimation Procedures

### STRUCTURAL CONNECTION

- **432** Finite Element Analysis of Bridge Structures
- **435** Overloading Behavior of Steel Highway Bridges
- **469** Fracture of Moment Connections

### STRUCTURAL STABILITY

- **217** Structural Stability Research Council
- **380** Strength of Rectangular Composite Box Girders
- **406** Local Buckling of High-Strength Tubes
- **437** Stability of Multi-Story Steel Frames
- **454** Ultimate Strength Testing of Horizontally Curved Steel Bridge Girders
- **471** Stability of Steel Columns
- **478** Strength of Composite Plate Girders
- **479** Ship Structures
- **480** Hull Strength Analysis

### Tall Buildings & Urban Habitat

- **369** Planning and Design of Tall Buildings
- **440** Impact of Tall Buildings: Implementation
- **441** Bibliographic Data Base on Tall Buildings and Urban Habitat
- **442** High-Rise Building Data Base
- **474** Earthquake Resistance of High-Rise Building Systems

### OPERATIONS

- **200** Industrial Testing
- **237** Laboratory Facilities and Research
The Partners-in-Education program, sponsored by AISC, is research of another kind. It explores ways in which the effectiveness of teaching steel design can be improved and seeks to identify ways in which the steel industry can assist faculty. A series of 21 Regional Workshops held in 1982 (educators, consulting firms, fabricators) is to be followed by presentation at the 1983 AISC National Engineering Conference. An implementation program will follow.
Earthquake Engineering

Prediction of the Earthquake Response of Building Systems and Components

Lehigh Kostem

The pilot research program has been investigating two specific areas: seismic response of steel and reinforced concrete frames stiffened by reinforced concrete shear walls, and seismic response of shallow circular cylindrical tanks. The latter program has indicated that the current design approaches for the tanks, especially the scheme recommended by the American Petroleum Institute, need major revisions. Additional research for the implementation of the findings will be carried out.

The research program on the shear walls has directed the focus to the development of simple formulae to predict the fundamental frequency of vibration (to be employed in the seismic analysis) of frame-shear wall systems. The data base for this activity was provided through previous activities carried out within this research.

U.S.-Japan Research Program Using Large Testing Facilities

A joint U.S.-Japan research program studying the seismic response of building structures was initiated in 1980 with the major goal of testing full-scale reinforced concrete and steel buildings in the special structural testing laboratory of the Japanese Building Research Institute in Tsukuba, Japan. Lehigh's work at the present time is to perform a structural design for the seven-story steel office building and to test certain beam-to-column connections of that building. Another support test on the U.S. side is also being planned.

Seismic Resistance of Precast Buildings

Lehigh Mueller

There is an obvious lack of guidelines and code provisions for the design of earthquake resistant precast bearing wall structures. The studies conducted under this program are aimed at developing alternative design concepts and identifying the most urgent research needs. These studies resulted so far in two extensive invited papers on the seismic behavior of precast walls, in the research proposal to NSF "Hysteretic Behavior of Precast Walls" and in three research proposals to CERL. The proposed program "Hysteretic Behavior of Precast Walls" addresses the identified urgent need for experimental data on the effect of horizontal connections on the strength and inelastic rotation capacity of precast walls subjected to seismic excitation. This is expected to be funded by NSF by the end of 1982.
This project is a follow-up of an earlier project (F.L. Project 422), which dealt with the in-plane behavior of common floor slab systems. Both experimental and analytical work are included on the in-plane performance of several floor slab systems, under both monotonic and cyclic loads. The ultimate goal is to develop practical design guidelines for improved performance of buildings using these floor systems. The present project is primarily concerned with the behavior of the waffle slab floor system, but also includes the consolidation of information from the previous project.

This project is a result of another joint U.S.-Japan research program studying the seismic response of building structures (F.L. Project 467) and is to be the U.S. support test of the testing done in Japan.
The failure of the U.S. 35 Highway Bridge at Point Pleasant, West Virginia raised serious questions as to the ability of bridge steels to resist fatigue and fracture. Subsequent to this event, laboratory tests and field experience indicate that the possibility of bridge steels possessing inadequate fracture toughness is not as serious a concern as originally suspected. The test data and field experiences point to fatigue as the primary concern to be dealt with in the design of bridges. It is the purpose of the research undertaken in this project to highlight the fatigue characteristics of bridge steels and their weldments. Particular emphasis will be placed on contrasting the behavior of bridge steels in benign and aggressive environments.

Fatigue problems have developed in the cover-plated beams at the Yellow Mill Pond bridges when only infrequently subjected to stress ranges that exceeded the fatigue limit of comparable constant cycle laboratory tests. Small cracks have been detected in several bridge beams where only 0.1% of the measured stress range cycles exceeded the constant cycle fatigue limit.

This study is intended to provide additional test data on details where different amounts of cyclic stresses above the constant cycle fatigue limit are examined. All tests will be carried out on Category E details. Ten test beams with three web gusset plates in the constant moment region and with cover-plated flanges in the shear span will be tested under random variable fatigue loading. A wide band Rayleigh-type stress range spectrum will be used to control two basic parameters in the random variable stress spectrum. The frequency of occurrence of stress cycles above the constant cycle fatigue limit and the magnitude of the peak stress range in the stress spectrum will be controlled. The maximum stress range will be varied between 6 and 7.5 ksi.

The Sudan Railroad was constructed in 1900 and has been subjected to a substantial amount of traffic since that time. To assist with assessing the possible cumulative damage of the bridge structures on the system, Frits Laboratory was requested to instrument and test four of the bridge structures and to evaluate their susceptibility to fatigue damage. Sudan Railway personnel are also to be trained in the use of strain record equipment and the evaluation of test data.
Fatigue and Fracture (continued)

Fatigue Strength of Weathered and Deteriorated Riveted Members

One of the major concerns of bridge engineers is the safety and potential fatigue damage that has accumulated in older riveted structures. This problem is significant as ever increasing traffic, deteriorated components and the accumulation of large numbers of stress cycles are a reality for highway, railroad and mass transit bridges. The criteria adopted for control of fatigue and fracture in new bridge structures is based upon studies of modern welded construction and ongoing laboratory studies on welded members. Most older bridges are constructed of riveted built-up members. Research is needed to establish better estimates of the fatigue resistance of riveted built-up sections, as most laboratory work has been carried out on simple butt splices. The purpose of this study is to carry out a pilot study on the fatigue behavior and resistance of full scale riveted built-up members in their weathered and deteriorated state. Stringers from actual bridges will be utilized in the study.
Development of Substitute Construction Materials

Due to the world-wide energy and serious material shortages in some countries, it becomes worthwhile to explore new or low-cost substitute construction materials. Among these possibilities is the utilization of indigenous replenishable biological matter. The first phase of the project is the full-scale field applications of various substitute materials such as bamboo and rice husks. These tests are being conducted in the People's Republic of China with the cooperation of the Chinese National Academy of Science, Tongji University and Chekiang University.

Soil as a Heat Collector & Thermal Storage in Solar Energy Systems

Using soil and foundation structures as heat collectors and thermal storage units in solar energy systems is being studied. Various types of soil, densities, and moisture contents were used for the evaluation of thermal conductivity and specific heat resistivity. Special types of thermal needles are being developed for both laboratory and in-situ uses.
Previously developed computer programs have been adapted to this current problem. Several test runs have been completed to verify the program. Preliminary 3-D geometry results show that the three-dimensional effects due to the end of the pipe (edge effects) will be felt for only one or two pipeline diameters down the pipe. The results are very encouraging for future laboratory measurements which can be made in the rehabilitated wave channel of the hydraulics laboratory project.

This project deals with the application of an implicit two-dimensional finite difference model for predicting tidal records. From the initial coarse model, this finer grid model work has shown good reproduction of historical tidal records. Field measurements should be undertaken to provide data for calibration of this model.
Experimental and analytical studies over the past fifteen years have resulted in the development of a general procedure for the estimation of losses in prestressed concrete structural members. This project is aimed at implementing this procedure both for PennDOT design offices and for adoption by the AASHTO Bridge Committee.
Field observations of a number of highway bridges have indicated that due to unexpected loadings, improper design, and construction practices, the response of bridge superstructures is sometimes substantially different from that assumed by the designers. The primary and secondary members tend to interact as if the members are all envisioned as primary load carrying members, leading to stress build-up at connection details.

Furthermore, bridge designers have been designing continuous bridges through the extrapolation of knowledge gained in simple span bridges. Many bridges, simple or continuous construction, have also been designed essentially for static loading, ignoring the vibration susceptibility of the superstructures.

Analytical and experimental studies have indicated that certain bridge configurations require closer inspection to identify the critical design parameters and details that govern the service life and reliability of the superstructures.

The research program is nearing completion, even though in the conduct of the research critical problems have been uncovered which require further studies. Depending upon the future funding of the project, these areas could be studied or deferred to other funded research projects to come.

Two versions of the computer program BOVAS (Bridge Overload Analysis—Steel) have been developed, and the draft copies of the user's manuals have been completed. The Simplified Version is designed to be used in "overload permit operations," and the Detailed Version is designed as a research tool, as well as for the in-depth analysis of bridges. The developed computer programs are being installed in the sponsoring agency's computers by the sponsoring agency.

A parametric study has also been designed, to give an insight to the post-elastic response of steel highway bridges. The execution of this study has been delayed due to extensive delays in the installation of BOVAS at PDT.
Improved design methods are required for beam-to-column moment connections which are framed to bend the column about its weak axis. Prior experiments on full-scale beam-to-column connections resulted in some fractures of tension flange connection plates. These occurred at load levels near the expected maximum, but at deformations less than desired for good ductile behavior. A subsequent brief investigation of material quality showed both to be of normal quality for structural use. Finite element investigations showed that high stress concentrations caused by restraining effects of heavy column flanges were a more probable cause of fracture initiation.

A theoretical and experimental investigation is attempting to find configurations of connection details which will reduce the tendency to fracture while maintaining adequate strength and stiffness.
STRUCTURAL STABILITY

The headquarters of the Structural Stability Research Council (formerly the Column Research Council) are at Lehigh University, including the office of Director, the Technical Secretary and the Administrative Secretary. The major activity is coordination of world-wide research on stability problems, the maintaining of the currency of the "Guide to Design Criteria," and organization of an annual technical session.

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Author 1</th>
<th>Author 2</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength of Rectangular Composite Box Girders</td>
<td>380</td>
<td>PennDOT</td>
<td>Yen</td>
</tr>
<tr>
<td>Local Buckling of High-Strength Tubes</td>
<td>406</td>
<td>AISI</td>
<td>Ostapenko</td>
</tr>
<tr>
<td>Stability of Multi-Story Steel Frames</td>
<td>437</td>
<td>AISI</td>
<td>Lu</td>
</tr>
</tbody>
</table>

The objective of the project is to examine the stresses in composite box girders with concrete deck. Analytical predictions are compared with experimental results in order to formulate recommendations for working-load design procedure. Also under investigation are the behavior of box girders (open shapes) under construction and the behavior of composite box girders beyond the working load range.

Design of large-diameter tubular members for offshore oil drilling platforms is handicapped by the uncertainty of the present criteria for local buckling. The purpose of this project is to provide an experimental basis for developing more rational and accurate local buckling criteria for large-diameter high-strength tubular columns, specifically, for the stress range between the proportional and yield levels.

The strength of a multi-story steel frame subjected to combined gravity and lateral loads may be significantly reduced by the effect of overall instability, also known as the P-delta effect. The complete load-deflection response of the structure, in the presence of such effects, can be calculated analytically by computer programs developed in a previous project. The purpose of this research is to identify the major parameters affecting the strength and stiffness characteristics of bridge frames and to develop design provisions taking into account the strength reductions due to instability. Much of the work has already been completed.
Ultimate Strength Testing of Horizontally Curved Steel Bridge Girders

At the present time, there is no simple, analytical procedure to predict the load carrying capacity or ultimate strength of curved steel plate girders or curved steel box girders. Existing methods of analysis are intended primarily for the elastic range of girder behavior. Current and proposed tentative bridge design rules specify proportioning of girder components without sufficient knowledge of the actual load carrying capacity of the curved girders. An adequate amount of test data is needed to substantiate the proposed allowable stress and load factor design criteria. A simple analytical model also needs to be developed to accurately predict the load carrying capacity of horizontally curved steel girders.

Stability of Steel Columns

A comprehensive study of the in-plane strength of initially crooked and end restrained steel columns has been completed. Good progress has been made on the development of a general finite element method for analyzing beam-columns with out-of-plane loads and deformations. This method has been successfully applied to biaxially loaded H columns and single-angle columns. The theoretical calculated ultimate strength has shown good agreement with the available test results.

Strength of Composite Plate Girders

This project examines the available analytical procedures and existing test information on composite plate girders, with the aim of developing simple design provisions for these girders.

It is planned to follow the strength prediction approach for composite box girders under flexural loads and to apply it to composite plate girders. Practical geometry and dimensions of girders will be considered in establishing simple strength prediction formulas. Needs for further research will also be explored.

Ship Structures

Research has been continued on the nonlinear behavior and ultimate strength of ship hull girders subjected to moment, shear and torque. The analytical method was modified to generate a continuous relationship between curvature and the load parameter. The degree of warping can be preset or optimized for minimum energy. The effect of shear on the buckling of plate subpanels in the compression flange was included as a corrective measure.

Hull Strength Analysis

Simplified analytical models have been developed for the axial ultimate and post-ultimate behavior of the principal components, plate and stiffened plate, of ship hull structures. These models are suitable for incorporating into hull strength programs of moderate size computers.
The objective is to coordinate the study and reporting on the planning and design of tall buildings. The activity is carried out primarily through the secretariat for Council on Tall Buildings and Urban Habitat, that is headquartered in Fritz Lab. Principal activity is in the preparation and updating of a monograph on tall buildings for use by those responsible for design practice. The project is concerned with stimulating research in the field and with the utilization of most recent findings from research laboratories and from design practice.

The objective is to translate the results of new research that is contained in the MONOGRAPH. A special committee organized by the American Institute of Steel Construction to study the monograph and to identify materials for possible incorporation into its design specification is making its final recommendations. Work still remains in the concrete building area.

Development of a systematized data base is necessary in order to utilize effectively the large and expanding mass of available tall building data and literature. Dynamic and other types of load effects due to natural and man-caused hazards are especially important parameters in the design of tall buildings. Some examples of such hazard effects are earthquake loads, high wind (hurricane, tornado) loads, and fire and blast. The development of such a data base will facilitate the search for particular documents and will lead to better design methods accounting for the hazards mentioned. A continuously available information source is also a necessary adjunct to a viable implementation activity.

Information on existing high-rise buildings and projects as they exist throughout the world is an essential part of a comprehensive data base. The major characteristics of over 3000 high-rise buildings were presented in Volume SC of the Tall Building Monograph. Continuing work extends the coverage of the physical characteristics of high-rise buildings. Special attention is being given to classification and identification of structural systems. Other aspects to be covered include site location information, economic and financial information, construction information, and companies or firms involved. The information gathered should be helpful not only to engineers, planners, and architects, but also to investors, owners, managers, public officials, suppliers, and manufacturers.
The objective is to identify which of the systems used in tall buildings are effective in resisting earthquakes and which are less suitable. Structural systems are receiving first attention, to be followed by mechanical and architectural systems. The project consists of study of damage reports and a survey of unpublished information and data supplied by design professionals. A classification system is necessary if the results are to be computerized (see Project 442).
In addition to sponsored research, a program of industrial tests is carried out in Fritz Laboratory. Appropriate test projects (usually with report) are those for which the Laboratory facilities are particularly unique. Routine tests are usually not conducted.

This "project number" exists primarily to facilitate information retrieval of reports and publications that relate to the Fritz Laboratory research activity in a general way and to the facilities and equipment.
CURRENT RESEARCH

PROJECT DESCRIPTIONS

Civil Engineering Staff

March 1985

Fritz Engineering Laboratory Report No. 237.17(85)
RESEARCH
AT
FRITZ ENGINEERING LABORATORY
LEHIGH UNIVERSITY

Since its founding in 1909 Fritz Engineering Laboratory has been advancing knowledge in Civil Engineering through its basic and applied research programs and industrial testing and related fields. Modernization of the Laboratory in 1954-55 enabled the University to continue to provide the finest facilities for research in the fields of structures, materials, hydraulics, geotechnical engineering and sanitation.

The laboratory facilities are housed in two inter-connected units composed of a four-story unit and a seven-story unit. Ready access to the main testing areas is provided to facilitate the delivery of large and heavy equipment. With the available testing machines and special accessories, large structural members can be tested statically or dynamically. A research library is maintained where current reports from laboratories throughout the world are available for study.

Through its Office of Research, Lehigh University contracts with research councils, industrial concerns, or associations to undertake cooperative research. The sponsor is expected to pay all costs plus a reasonable percentage for overhead. At least a one-year duration is expected on such projects, and publication of results in technical magazines is normally anticipated.

Investigations have ranged from studies of material properties and characteristics up to tests of full-size structures for buildings and bridges. Structural steel research programs have improved design procedures by this approach. Specifications of the American Association of State Highway and Transportation Officials, American Institute of Steel Construction, Association of Iron and Steel Engineers, American Railway Engineering Association and the American Concrete Institute have been revised as a direct result of research projects.

In the following pages, the current Fritz Lab projects are described.
PROJECT INDEX

107 Partners in Education
200 Industrial Testing - General
217 Structural Stability Research Council
237 Laboratory Facilities and Research
432 Finite Element Analysis of Bridge Structures
433 Prediction of the Earthquake Response of Building Systems and Components
435 Overloading Behavior of Steel Highway Bridges
447 Corrosion Fatigue of Bridge Steel
466 Field Studies of Sudan Railroad
469 Fracture of Moment Connections
471 Stability of Steel Columns
482 U.S.-Japan Cooperative Earthquake Research Program
485 Hysteretic Behavior of Precast Panel Walls
486 Residual Stress and Strength of Jumbo Columns
487 Bolt Guide Revision
488 Fatigue Behavior of Variable Loaded Bridge Details Near the Fatigue Limit
489 Composite Flanges for Continuous Steel Box Girders
490 Structural Evaluation of In-Service Bridges Using W-I-M Technology
491 Bridge Diaphragm Cracking
492 Torsional Strength of Longitudinals in Marine Structures
493 Bridge Studies on Route I-80
494 I-79 Tied Arch Cracking Neville Island Bridge
495 Bridge Inspection Training Program
496 Programmable Wave Generating System
497 Sea Level Rise Study
498 Structural and Beachfill Studies in Atlantic City
499 Fatigue and Fracture Evaluation for Rating Riveted Steel Bridges
500 Causes and Deformation Induced Cracking in Steel Bridges and Methods to Retrofit the Damage
501 Web Cracking of Curved Girders
502 Wanaque Reservoir Overflow Channel Study
503 Redundancy of Welded Steel I-Girder Bridges
720 Permeation of Hazardous Wastes Through Landfill Liners Formulated of Clay
725 Application of Relational Data Bases in Construction Management
Project 107: **PARTNERS IN EDUCATION**

Sponsor: American Institute of Steel Construction

The Partners-in-Education program, sponsored by AISC, is research of another kind. It explores ways in which the effectiveness of teaching steel design can be improved and seeks to identify ways in which the steel industry can assist faculty. A series of 21 Regional Workshops held in 1982 (educators, consulting firms, fabricators) was followed by a presentation at the 1983 AISC National Engineering Conference. An implementation program follows as part of each of these annual conferences.

Project Directors: Beedle and Lu
Project 200: **INDUSTRIAL TESTING - GENERAL**

Sponsors: Various Industrial and Governmental Testing and Research

In addition to sponsored research, a program of industrial tests is carried out in Fritz Laboratory. Appropriate test projects (usually with report) are those for which the Laboratory facilities are particularly unique. Routine tests are usually not conducted.

Project Director: Slutter
Project 217: **STRUCTURAL STABILITY RESEARCH COUNCIL**

**Sponsor:** SSRC, National Science Foundation, and various agencies

The headquarters of the Structural Stability Research Council are at Lehigh University, including the office of the Director, the Technical Secretary and the Administrative Secretary. The major activity is coordination of world-wide research on stability problems, the maintaining of the currency of the "Guide to Design Criteria," and organization of an annual technical session.

**Project Director:** Beedle  
**Technical Secretary:** (vacancy)  
**Administrative Secretary:** Federinic
Project 237: LABORATORY FACILITIES AND RESEARCH

Sponsor: Lehigh University

This "project number" exists primarily to facilitate information retrieval of reports and publications that relate to the Fritz Laboratory research activity in a general way and to the facilities and equipment.

Project Director: Driscoll
Field observations of a number of highway bridges have indicated that due to unexpected loadings, improper design, and construction practices, the response of bridge superstructures is sometimes substantially different from that assumed by the designers. The primary and secondary members tend to interact as if the members are all envisioned as primary load carrying members, leading to stress build-up at connection details.

Furthermore, bridge designers have been designing continuous bridges through the extrapolation of knowledge gained in simple span bridges. Many bridges, simple or continuous construction, have also been designed essentially for static loading, ignoring the vibration susceptibility of the superstructures.

Analytical and experimental studies have indicated that certain bridge configurations require closer inspection to identify the critical design parameters and details that govern the service life and reliability of the superstructures.

Project Director: Kostem
The pilot research program has been investigating two specific areas: seismic response of steel and reinforced concrete frames stiffened by reinforce concrete shear walls, and seismic response of shallow circular cylindrical tanks. The later program has indicated that the current design approaches for the tanks, especially the scheme recommended by the American Petroleum Institute, needs major revision. Additional research for the implementation of the findings will be carried out.

The research program on the shear walls has directed the focus to the development of simple formulae to predict the fundamental frequency of vibration (to be employed in the seismic analysis) of frame-shear wall systems. The data base for this activity was provided through previous activities carried out within this research.

Project Director: Kostem
Project 435: OVERLOADING BEHAVIOR OF STEEL HIGHWAY BRIDGES

Sponsor: Pennsylvania Department of Transportation

The research program is nearing completion, even though in the conduct of the research critical problems have been uncovered which require further study. Depending upon the future funding of the project, these areas could be studied or deferred to other funded research projects to come.

The computer program BOVAS (Bridge Overload Analysis-Steel) and the draft copy of the user's manual are completed. The program is designed to be used in "overload permit operations," as well as for the in-depth analysis of bridges.

A parametric study has also been designed to give an insight to the post-elastic response of steel highway bridges. The execution of this study has been delayed due to extensive delays in the installation of BOVAS at PDT.

Project Director: Kostem
Project 447: CORROSION FATIGUE OF BRIDGE STEEL

Sponsor: U. S. Department of Transportation

The failure of the U.S. 35 Highway Bridge at Point Pleasant, West Virginia raised serious questions as to the ability of bridge steels to resist fatigue and fracture. Subsequent to this event, laboratory tests and field experience indicate that the possibility of bridge steels possessing inadequate fracture toughness is not as serious a concern as originally suspected. The test data and field experiences point to fatigue as the primary concern to be dealt with in the design of bridges. It is the purpose of the research undertaken in this project to highlight the fatigue characteristics of bridge steels and their weldments. Particular emphasis will be placed on contrasting the behavior of bridge steels in benign and aggressive environments.

Project Director: Roberts and Fisher
The Sudan Railroad was constructed in 1900 and has been subjected to a substantial amount of traffic since that time. To assist with assessing the possible cumulative damage of the bridge structures on the system, Fritz Laboratory was requested to instrument and test four of the bridge structures and to evaluate their susceptibility to fatigue damage. Sudan Railway personnel are also to be trained in the use of strain record equipment and the evaluation of test data.

Project Directors: Fisher and Yen
Improved design methods are required for beam-to-column moment connections which are framed to bend the column about its weak axis. Prior experiments on full-scale beam-to-column connections resulted in some fractures of tension flange connection plates. These occurred at load levels near the expected maximum, but at deformations less than desired for good ductile behavior. A subsequent brief investigation of material quality showed both to be of normal quality for structural use. Finite element investigations showed that high stress concentrations caused by restraining effects of heavy column flanges were a more probable cause of fracture initiation.

Theoretical and experimental studies of simulated beam tension flange to column web connections resulted in recommendations for revision of design procedures. A pending proposal includes cyclic tests of full-scale connections to gather information on the probable performance of the new designs under earthquake conditions. (National Science Foundation provided the bulk of the funding for this research.)

Project Faculty: Driscoll, Beedle, Lu
Project 471: STABILITY OF STEEL COLUMNS

Sponsor: Lehigh University

A comprehensive study of the in-plane strength of initially crooked and end restrained steel columns has been completed. Good progress has been made on the development of a general finite element method for analyzing beam-columns with out-of-plane loads and deformations. This method has been successfully applied to biaxially loaded H columns and single-angle columns. Current work includes stepped columns used in industrial buildings and tubular columns.

Project Director: Lu
Project 482: U.S.-JAPAN COOPERATIVE EARTHQUAKE RESEARCH PROGRAM

Sponsor: National Science Foundation

This project is another joint U.S.-Japan research program studying the seismic response of building structures. A 3-D steel building frame, which is a scale model of the prototype structure tested at the Japanese Building Research Institute, will be constructed and tested.

Project Director: Lu
Project 485: HYSTERETIC BEHAVIOR OF PRECAST PANEL WALLS

Sponsor: National Science Foundation

This project comprises a combined experimental and analytical investigation on the behavior of structural walls built up from large precast concrete panels under earthquake loading. The ultimate objective is the development of design guidelines for seismic areas.

Using moment-curvature-thrust diagrams for connection and panel regions, curvature distribution, plastic rotation capacity, and ductility ratio of various precast walls have been determined. The results indicate that inelastic behavior may be strongly concentrated in the connections and that the ductility factor may be significantly lower than for cast-in-place walls. A moment - axial load - shear interaction relationship for the ultimate strength of horizontal connections has been developed. Using truss models and diagonal compression field theory, the interrelationship between the shear transfer mechanisms of horizontal connections and precast panels has been investigated.

A test set-up for the testing of eight one-third scale precast walls under earthquake and axial load has been designed and constructed. A computerized actuator control and data acquisition system has been developed. To date one specimen has been constructed which is currently being tested.

Project Director: Mueller
Project 486: RESIDUAL STRESS AND STRENGTH OF JUMBO COLUMNS

Sponsor: Bethlehem Steel Corporation

The magnitude and distribution of cooling residual (or locked-in) stresses in a jumbo shape will be investigated experimentally using both the "Method of Sectioning" and the "Hole-Drilling Method." The results will then be incorporated into an existing computer program to determine the axial strength of columns fabricated from this shape. The results may show that the strength characteristics of jumbo columns may be more favorable than presently recognized.

BSC is a major producer of jumbo shapes in the U.S. The new information on column strength may permit designers to made better (and probably more extensive) use of jumbo columns in their structures.

Project Director: Lu
Project 487: **BOLT GUIDE REVISION**

Sponsor: Research Council on Structural Connections (RCSC)

Updating the bibliography on riveted and bolted structural joints which was published in 1973 through the collection and revision of the database to include recent studies with preparation of new plots and other summary material is the main purpose of this project. The project will update the various chapters in the bolt Guide.

Project Director: Fisher
In order to provide a larger, more comprehensive data base, additional full-scale random variable amplitude beam tests similar to those tested in a previous NCHRP project (F.L. project 463) are proposed for this research.

The primary parameters under investigation are the root mean cube effective stress of the Rayleigh-type variable amplitude load distribution and the percentage of the loadings in the spectrum which exceed the constant amplitude fatigue limit. More data is necessary to properly evaluate the effect of exceedance of the constant amplitude fatigue limit on the fatigue life of such beams.

Project Director: Fisher
Steel box girders have been frequently used as the main load-carrying members of bridges in recent years. Both the existing and the proposed design provisions for steel box girder bridges recognize the stress distribution pattern and the limitations of the compression flange in the negative moment region. The basic condition is that the compression flanges should provide sufficient margin of safety against local buckling between stiffeners and against overall buckling of the stiffened compression plate as a bridge component.

Many possible types of arrangement for improving the strength and stiffness of the compression flange have been used in actual bridge construction, but no study has focussed on the method of using steel-concrete composite compression flanges.

This project evaluates the technical and economic feasibility of using a composite cast-in-place layer of concrete on the top of the bottom flange of continuous steel box girder bridges to provide the necessary compression and stiffness capacity.

Work includes state-of-the-art level analytical studies to evaluate the use of the subject concept as an alternative form of construction for three existing continuous steel box girder bridges; structural laboratory testing of large scale sections or models of compression flanges incorporating this concept; and development of recommended structural design criteria for applying the concept to bridge designs.

Project Faculty: Daniels, Huang and Yen
Highway bridges sustain vehicular loading which varies in weight, overall length, number of axles and their spacing, speed, and dynamic characteristics. The volume and conditions of traffic and its correlation with bridge type, geometry and configuration, as well as other factors, such as adequate maintenance, determine the integrity and life expectancy of a bridge and its components. For any bridge, its static and dynamic response to a vehicle can be accurately monitored and evaluated if the geometrical and loading characteristics of the vehicle are available. Unfortunately, in actual highway conditions, none of the vehicular characteristics are exactly known for any specific bridge. Consequently, damages by vehicular traffic on a bridge cannot be estimated with accuracy.

Inspection of bridges have revealed that damages do exist. Such damages are generally caused by excessive load magnitudes, high impact, large volume of traffic, poor maintenance, or the combination of these conditions.

Specific traffic monitoring systems have been developed, with one prototype portable system now available for use. To examine this weigh-in-motion (W-I-M) system and to explore the use of bridge W-I-M technology for monitoring bridge component stresses and behavior are among parts of this research.

Project Director: Daniels
Project 491:  BRIDGE DIAPHRAGM CRACKING

Sponsor:  Modjeski and Masters

This study was carried out to assess the significance of the cracked wires discovered at the cable hanger connection to the tie girders of the I470 bridge at Wheeling, West Virginia on the residual fatigue and static strength of damaged and undamaged cables.

In order to assess the significance of the cracked wires found in the hanger cables, extensive tests were carried out on cables removed from the structure which included cables with cracked wires and some with no detectable damage. The studies included fatigue tests of the 2¼ in. cables, dissection of several cable sockets to evaluate the interior wires, and tensile tests on the cables.

During the course of the studies cracks were detected in the tie girders at diaphragms where floor beams framed into the tie girders. Several segments of these cracked elements were removed from the diaphragms so that fractographic studies could be carried out on the crack surfaces. In order to establish the causes of the cracking in the diaphragm-web welded connections, strain measurements were initially acquired with controlled loads. The results of the controlled load studies were evaluated and a report was written.

Project Directors: Fisher and Slutter
Axial response of longitudinal plate stiffeners endangered by lateral-torsional (tripping) mode of failure is the least investigated aspect of post-disaster behavior of marine structures. The usual approach is to proportion the members so as to preclude this mode of failure, but only with respect to the elastic buckling capacity. The resultant conservative, and often contradictory, rules need careful re-evaluation, especially for asymmetrical shapes. The project is concerned with the evaluation and extension of the present methods of analyzing the pre- and post-ultimate torsional behavior of symmetrical and asymmetrical longitudinal plate stiffeners and the formulation of practical design rules.

Project Director: Ostapenko
Project 493: BRIDGE STUDIES ON ROUTE I-80 (Clarion & Deer Creek)

Sponsors: Modjeski and Masters

The objective of this project is the measurement of live load stresses in two deck truss bridges (one over the Clarion River and another one over the Deer Creek on Interstate Highway Route 80). The intent is to monitor strains under routine truck traffic for comparison with computed live load strains and for the evaluation of fatigue strength.

Project Directors: Yen and Slutter
Project 494: I-79 TIED ARCH CRACKING NEVILLES ISLAND BRIDGE

Sponsor: Pennsylvania Department of Transportation

This project evaluates the strain measurements taken by FHWA on two diaphragms within the I79 tie girders, the cracking that has been observed between the tie girder web and diaphragms at the floor beam panel points, and review and recommend retrofit procedures based on these studies and other valuable information.

Project Director: Fisher
Project 495: BRIDGE INSPECTION TRAINING PROGRAM

Sponsor: New Jersey Department of Transportation

The objective of this program is to establish a pool of qualified bridge inspectors for the State of New Jersey. The beginning course deals with the fundamentals of bridge inspection. The advanced course concentrates on a few selected topics such as fatigue and fracture, retrofitting and rehabilitation, and load rating.

Project Faculty: Fisher, Daniels, Huang, Yen, and Slutter
Project 496: **PROGRAMMABLE WAVE GENERATING SYSTEM**

Sponsor: National Science Foundation

As part of a program of renovation and expansion of the Hydraulics Laboratory at Lehigh University, a 107 ft long, 3 ft wide and 3 ft deep concrete flume is currently under construction. Funds are available to construct this flume.

The completed flume with a programmable generator capable of producing any desired spectrum of waves or special periodic waves (e.g. cnoidal waves) will be the keystone to a rejuvenated and expanded laboratory and field research program in coastal engineering. The NSF Equipment Grant provided funding for the purchase of a Seasion Wave Generator which is being installed in the flume.

Project Director: Sorensen
Project 497: **SEA LEVEL RISE STUDY**

**Sponsor:** Environmental Protection Agency/Corps of Engineers

This project involves an investigation of the impact of predicted future sea level rise scenarios on the coastal works at Sea Bright, NJ. Of particular concern are the existing stone sea wall and planned beach nourishment.

**Project Director:** Sorensen
The Atlantic City beaches have not been nourished since 1970-71 and are in need of replenishment. As Atlantic City continues its revitalization, there is a need to attract not only casino patrons but also the more traditional beach user back to Atlantic City. Wide beaches will serve them and also provide storm protection for the newly created and remaining buildings an infrastructure. Because of the plethora of existing structures along the beachfront, there may be some complications to the longshore currents when beachfill is emplaced. The data from this project will determine any difficulties before the emplacement and will help design the fill placement specifications to gain the maximum use from this precious resource. This project ranks 3rd on the DEP's Shore Protection Master Plan priority list.

Project Director: Sorensen
Project 499:  **FATIGUE & FRACTURE EVALUATION FOR RATING RIVETED STEEL BRIDGES**

Sponsor:  National Cooperative Highway Research Program

Thousands of riveted highway bridge structures exist in nearly every state
in the United States. Since existing rating procedures do not clearly
define the role that cumulative fatigue damage and the fracture toughness
of the material provide when establishing the safe load capacity of the
bridge, major differences have occurred as no guidance was available. Direct
use of the AASHTO provisions for fatigue and fracture toughness is likely
too conservative in many applications. This can lead to premature elimina-
tion of the structure and ineffective use of the facility.

The results of this study should permit uniform provisions for riveted
structures to be developed that will permit some relaxation of the fracture
toughness and fatigue criteria in current use for the design of modern
welded structures. The results of this study should also be beneficial to
railroad and mass transit elevated structures that were put into service
in the early part of this century.

Project Directors: Fisher and Yen
Project 500: CAUSES & DEFORMATION INDUCED CRACKING IN STEEL BRIDGES & METHODS TO RETROFIT THE DAMAGE

Sponsor: Pennsylvania Department of Transportation

A large variety of bridge details may exhibit vulnerability to out-of-plane deformation-induced fatigue cracking. The proposed research program is intended to focus on those considered most critical. In this study, those details that are known to have experienced cracking and are likely to have the lowest fatigue strength will be investigated, and corrective measures for these details will be developed. Primary focus is on floor beam and diaphragm connection plates, which are commonly used in Pennsylvania. The experience gained during the conduct of this research should substantially assist in future investigations on the fatigue strength of other types of bridge details not directly addressed in this study.

Project Faculty: Fisher, Kostem, and Yen
This research deals with the studies of West Virginia DOT bridges 2680 and 2682 on I-79 north of Charleston, W. VA. that have exhibited cracking in the web of curved plate girders along the web to flange connections. Since crack growth has developed in the cut-short stiffener web gaps and extended along the web-flange welds, assessment of the stress gradient regions and the forces that are continuing to drive the developed cracks will be made. Also assessment of the diaphragm connection plate gaps and the laterals will be made. Determination of the ways and reasons for the cracking will be attempted.
Project 502: HYDRAULIC MODEL STUDY OF WANAQUE RESERVOIR OVERFLOW CHANNEL

Sponsor: O'Brien and Gere

In the spring of 1984, a flood flow, estimated to have peaked at 10,000 cfs (cubic feet per second) just over-topped the wall of the overflow channel downstream of the Wanaque Reservoir spillway. The high flow rate caused damage to the embankment behind the wall. Because larger flood flows could cause serious damage, the North Jersey District Water Supply Commission, owner of Wanaque Reservoir, retained O'Brien and Gere Engineers, Inc. to design modifications to the overflow channel to contain flood flows. O'Brien and Gere retained the Herbert R. Imbt Hydraulics Laboratory, Lehigh University to perform a physical model study of the modified overflow channel.

The major objective of the study was to determine the step and sill configuration to best contain one-half of the Probable Maximum Flood (PMF) (20,000 cfs) within the channel walls. Another objective was to protect the downstream entrance of the tunnel that projects through the north channel wall. These objectives were to be satisfied in a manner that would provide a volume of rock excavation from the channel to satisfy the demand for rock fill to be used for construction activities in the vicinity of Wanaque Reservoir.

The recommended test case was chosen based upon the hydraulic performance of the model channel at large design flows. The model channel contained a flow equivalent to 1/2 PMF. The flow was increased up to 3/4 PMF before constant overtopping of the wall was observed. In light of this study, the final design of the overflow channel specifies an enlarged cross-sectional area of the channel. The excavation will cut into the inside wall starting at the top of the steps and result in a channel width 8' larger than the channel model. This larger cross-section will probably contain flows beyond 3/4 PMF.

Project Directors: Weisman and Lennon
This research project's objective is to develop and implement a framework to facilitate decisions regarding the realistic adequacy of welded steel I-girder bridges to resist catastrophic failure in the event of the fracture of a critical member. Recognizing the complexity of the 3-dimensional interaction of members requires a synthesis of bridge-related expertise, structural behavior and computer modeling to develop meaningful quantitative comparisons of potential collapse mechanisms. These are fundamental to the provision of design criteria for the determination of redundancy. The results of this research will serve as a practical, supportive tool for the engineering analysis of the redundancy of welded steel I-girder bridges.

Project Directors: Daniels and Wilson
The purpose of this study is to develop a technique for determining the rate of permeation of leachate from waste residual landfills through clayey materials in contact with the leachate. The ideal will be to elucidate a function of chemical characteristics of the leachate and liner material and specific geotechnical properties of the liner material. The program will elucidate and demonstrate techniques to making accurate and rapid measurements of permeation rate and other significant geotechnic properties of liner materials when the liner is in contact with leachates.

The most cost effective technique for management of waste residuals is containment in a secure landfill. Clayey liners have been used in the construction of such landfills because of their low permeability to water, long term stability and low cost. Such liners are also frequently used as cutoff walls as part of a remedial action system for containment/clean-up of existing improperly installed landfills. It has been shown recently, however, that organic and inorganic constituents in leachate can significantly alter the permeability of such liners as the leachate replaces the original pore water. The significance of this study will be in the elucidation of the quantitative effect of specific components of leachate over a range of concentrations on the permeability of a number of clayey liner formulations. The results can be used to design liners for long term stability when such liners are used for waste residual containments.

Project Director: Fang
This two phase project involves the development of an interactive computer-assisted scheduling and costing system for engineers and construction managers. The project will permit timely answers to questions regarding time and material estimates, budgets, schedules, alternative construction methods and alternate financing strategies. The first phase will make use of the results from the model for concrete wall construction as developed through present cooperative efforts between Lehigh and the Alvin H. Butz Company. The second phase will build on the model's logic in forming a corporate database that will encompass most of the facets of the Alvin H. Butz activities in construction management.

Project Director: Wilson