STRUCTURAL STABILITY
RESEARCH COUNCIL

50th Anniversary Conference Workshops

Lehigh University

June 22, 1994

Workshop 1 - Specification Alternatives

Workshop 2 - Advanced Analysis Methods

Workshop 3 - Deteriorated Structures

Workshop 4 - Information Dissemination

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Lehigh University
Bethlehem, Pennsylvania

STRUCTURAL STABILITY RESEARCH COUNCIL
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FOREWORD

To recognize its 50th Anniversary, the SSRC organized a special conference on June 20-22, 1994, with the theme "SSRC - Link Between Research and Practice." The purpose of the conference was to review the complete scope of SSRC activities and to utilize the expertise of the entire SSRC membership to develop a vision of stability-related research and design in the future.

To help achieve this vision, four concurrent workshops were held during the conference. The topics of each of these, along with their Moderator and Recorder, were:

Workshop 1 - Specification Alternatives
Moderator: Nestor R. Iwankiw, AISC
Recorder: Jackson L. Durkee, Consultant

Workshop 2 - Advanced Analysis Methods
Moderator: Professor Gregory G. Deierlein, Cornell University
Recorder: Professor Ronald D. Ziemian, Bucknell University

Workshop 3 - Deteriorated Structures
Moderator: Professor Donald R. Sherman, University of Wisconsin-Milwaukee
Recorder: Dr. Robert J. Dexter, Lehigh University

Workshop 4 - Information Dissemination
Moderator: Professor Reidar Bjorhovde, University of Pittsburgh
Recorder: Dr. Took K. Sooi, Lehigh University

A summary from each workshop was developed by the Moderators and Recorders in order to summarize the content, presentations, and recommendations for future directions in structural stability. These, along with papers presented during the workshops, follow. The theme of each of the workshops complemented the twenty-seven papers presented during the conference that addressed the state-of-the-art and future of specific topics of concern to SSRC Task Groups and Task Reporters, and which appear in the 1994 Proceedings of the 50th Anniversary Conference.

J. M. Ricles
JAMES M. RICLES
Director

D.R. Sherman
DONALD R. SHERMAN
Chairman

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WORKSHOP 1

SPECIFICATION ALTERNATIVES

WORKSHOP 1 - SPECIFICATION ALTERNATIVES

WORKSHOP SUMMARY

Moderator: Nestor Iwankiw - AISC
Reporter: Jackson Durkee - Consultant

INTRODUCTION

There were 11 participants in the workshop from two different countries. Two were affiliated with universities and the remaining were from consulting firms or trade organizations. There were four brief prepared presentations with open discussion throughout the two hour session. Written statements from N. Iwankiw, G. F. Fox and C. D. Miller accompany this summary.

This summary is not a transcript of statements made in the Workshop nor does it repeat the accompanying written statements. Rather it summarizes the open discussions that took place in topic categories, regardless of when ideas were presented during the duration of the workshop.

PURPOSES OF SPECIFICATIONS & CODES

The ideal purpose for structural codes is to protect the public. However, codes realistically also have substantial economic purposes for their existence. Harmonization of codes provides level playing fields for economic competition. Codes dealing with a specific material require component suppliers to meet the same basic requirements. Uniformity in codes related to loadings and margins of safety permit fair competition among materials. International codes provide for global economic competition.

Specifications and codes reflect the needs and desires of owners, designers and buildings. These multi-purposes produce a complicated interaction and tend to add complexity to codes. Comprehensive versus simplicity in codes is an important consideration, but the latter seems to be a more practical approach.

EVOLUTION OF SPECIFICATIONS & CODES

There was some discussion on how new ideas are incorporated into codes and whether there is a reluctance to accept innovation. One viewpoint was that it is a slow process taking 5, 10 or more years. Prevailing project budget constraints and liability considerations do not tend to encourage creativity. However, in the case of composite construction, the process was much faster whether innovation came from practice rather than research. New concepts are sometimes used in construction well before they appear in codes. Construction practice leads to research, which in turn is used to form the basis for code provisions.

STATUS OF SPECIFICATIONS & CODES

There are numerous structural engineering related codes in the world. Ideally, for a given loading condition, the strength formulae should be the same whether the structure is a building, bridge, offshore structure of tower anywhere in the world. The degree to which harmonization or uniformity exist today varies considerably. The Eurocode has been a major effort to unify a number of national codes. In the U.S. there are a large number of building codes but only two bridge codes; highway bridges and railroad bridges. In the area of stability of shell structures, there are a number of voluminous codes with differing criteria and there is no outlook for consolidation in the foreseeable future. At the other extreme, the API recommended practices for fixed offshore platforms and tension leg towers have gained worldwide acceptance and are likely to form the basis for the first "world codes".

WRITING OF SPECIFICATIONS & CODES

The primary input in the writing of codes should come from practitioners as opposed to the academic community. Practitioners include designers, owners, government regulators and buildings. The structuring of code bodies in the U.S. Limits academic participants to a minority. In Europe, Professors have considerable influence in the preparation of codes, but they are also designers who have had considerable experience and significant responsibility in the design and construction of major structures. One way to use the expertise of academics who have been involved in research is to recognize that drafting panels for code provisions are different than the actual code bodies.

STRUCTURAL ENGINEERING PRACTICE AND EDUCATION

There was considerable discussion on the influence that the computer and information explosion have on engineering practice and consequently on code requirements. There is a trend, especially in large design firms, that much engineering design is being performed at a technician's level using sophisticated computer programs that perform detailed calculations and produce drawings. Engineers have primary responsibility for general layout of structures and developing design criteria that are used in the computer programs. Continuation of this trend will require engineers that have more specialized education with at least a Masters degree. However, the need for the number of people who are truly engineers will lessen. The engineer reverts to the historic role of the "master builder".

Computers have done much to shortcut the training period for graduate structural engineers. New engineers are no longer required to become familiar with structural systems through initial employment in drafting and taking off weights. This puts more pressure on the educational system and requires instructors to be in tune with design practice. It is also another factor in making post-BS education desirable.

Other important, but not necessarily desirable, trends can be noted in engineering practice. The role of the non-engineer manager is becoming greater in both construction practice and education, resulting in decisions that are made on the basis of economics rather than structural performance. The responsibility of the engineer is being reduced by cost and liability consideration, resulting in lack of inspection and on-site engineering. Recent debates over the responsibility for the design of connections is an example where liability and cost have influenced role that engineers play in design and/or review of structural performance. State registration as opposed to national registration also influences practice in a world where projects are no longer locally designed but have increasing national or global input.

The Workshop did not come to any conclusions as to whether these trends will continue or how codes can be structured to insure safety and adequate performance.

FUTURE DIRECTIONS

Inevitably at some time in the future there will be world codes. These will be motivated by economic conditions both to enhance international competition and to avoid expensive duplication of effort in code development. Offshore industry codes will probably lead the way but others are already being written or considered on regional bases.

Electronic codes are probably nearer to reality. These are not just programs for looking up code provisions, but programs where code provisions continue to be integrated into increasingly comprehensive design programs. Programs are also likely to include expert systems to provide designers access to a wide range of past experience in addition to code criteria.

It is difficult to foresee the structure of future codes, but they will probably be less restrictive and may be based on a hierarchy principle. Main provisions could be written in the form of performance standards. These could be followed by acceptable alternative methods for achieving the required performance. The alternatives could range from simple conservative methods that can be applied in routine situations to more sophisticated criteria that produce the most efficient use of material in complex applications.

The development of the next generation of codes will probably be accompanied by changes in engineering education and practice that will define a greater separation between structural engineers and technicians who operate programs that generate designs and drawings. Engineers will be heavily involved with criteria and program development in addition to regulation to insure that performance standards will be met.

SSRC Workshop 1 - Specification Alternatives

Nestor Iwankiw
AISC, Director of Research & Codes

Introduction

Attempting to predict the future, even for a shorter period of time, is often a frustrating exercise, as evidenced by the disappointing success rate of many weather or economic forecasters. When this uncertainty is compounded over a longer-term, the expectations of given outcomes naturally must be devalued even further, because various changes in the underlying forecast assumptions or new factors can have a significant effect.

The theme of Workshop 1 is Specification Alternatives. All the panelists have been advised to interpret this to mean the possible future direction and development of structural design specifications (standards), both short and long-term. This introductory disclaimer precedes our workshop comments and discussion, because the latter represents only the panelists' personal evaluations of future trends, needs and resources. We are obviously not in any position to make any infallible pronouncements but only to raise certain issues, express reasoned judgments or desires, make observations, and/or propose feasible options.

Fortunately or unfortunately, design and construction, as a whole, have historically been reluctant to immediately embrace new methods or procedures. This conservative mindset results in the incremental evolution of traditional practice rather than any sudden upheavals. In contrast to the consistently much more volatile weather and financial conditions, not much change or fluctuation in structural design methods is generally expected over the next few years. Therefore, it is not until the next decade, which also marks the start of a new century, or even a more remote time, that a more dramatic, in my opinion, departure from current design will become apparent. This distant future may experience some of the exciting, challenging, and perhaps, unsettling, features about which we will soon speculate.

Workshop 1 will explore this theme from the perspective of several common structural systems and both domestic and international outlooks. Our distinguished panelists and their topics in this context are:

Prof. Patrick Dowling, Imperial College - international
Mr. Gerard Fox, Consultant - bridges
Mr. Clarence Miller, CBI - pressure vessels and offshore

I will address the theme from a building viewpoint. Mr. Jackson Durkee, Consultant, has graciously agreed to serve as the session recorder.

BUILDINGS

Codes, Standards & Design

In order to provide a necessary background, the overall traditional objective of building codes and standards is briefly described. Standards or specifications, are the authoritative technical documents for design and construction, while the codes represent the official legal requirements, which usually include or reference the various standards. To paraphrase a very concise and meaningful description, these exist for the dual purpose "to guide the naive and to protect society from scoundrels." Thus, both codes and standards are intended to serve as a measuring stick to ensure that a minimum level of structural strength, and, in some cases, other performance indexes are attained for the safety and welfare of the general public.

Due to pervasive competitive pressures, time and budgets constraints, etc., most building projects, except for selected critical or major facilities, are actually designed to this minimum acceptance level. The reason for this is that a large majority (on the order of 90%) of buildings are rather simple structures, containing a modest 4-5 stories in height or less, which do not demand much engineering sophistication nor do they lend themselves to becoming research or prototype efforts. Convenient conservative assumptions often expedite this more routine work without violating the applicable code. A lag time often exists from the original development of new concepts to their eventual implementation as common practice in the standards and codes. However, only a small minority of engineering firms with leading edge technology, staff expertise, and appropriate projects can justify implementing more advanced structural designs that exceed the basic prescriptive scope of the existing codes and standards.

My simple point is that prescriptive codes and standards are not just an abstract minimum, they, in fact, are the actual design criteria that most practioners use. Consequently, there will continue to be a definite public need for them in the future.

Prescriptive Versus Performance Criteria

Specification (standard) and code provisions can be classified as prescriptive or performance based. A prescriptive requirement is intended to completely and explicitly control what shall or shall not be done, whereas performance criteria merely state the desired end objective(s) without prescribing the means to accomplish these goal(s). Our modern structural standards and codes are usually a blend of these two approaches but with a dominant prescriptive flavor, particularly in matters dealing with structural strength and safety. All the various design formulas and numerical limits are prescriptive in nature, giving the user a convenient "cookbook" type recipe for compliance. However, a clear example of performance criteria can be seen in this country in the treatment of building serviceability: short general descriptions and some approximate limits for functionality relative to deflections, drift, vibrations, etc. that are void of substantive measures or procedures. Many standards also have alternative "catch-all" performance clauses that permit demonstration of satisfactory results through special testing and/or analysis. Performance statements rely more on the integrity and technical competence of the engineer of record and regulatory official to properly interpret and implement an adequate design solution. Some engineers favor performance options as better opportunities to express their creativity and professional judgment.

The initial early versions of the AISC Specification, and probably others, were much more performance oriented than currently, even relative to design for strength. With time, new knowledge and project experience, many prescriptive details have been added to clarify the meaning and application of the broader objective(s); this development has contributed to the so-called "information explosion" that is now overwhelming many and is a separate subject later in this presentation. However, as codes and standards approach becoming all-encompassing encyclopedias of knowledge, there is a danger that they might become irrelevant to the majority of engineering practioners, construction contractors, and building officials that are focused more on typical structures and conditions.

This proliferation of the number and size of the various prescriptive structural standards is expected to eventually reverse course, in my opinion, and start partially reverting to briefer selected performance requirements substantiated by appropriate references to the available technical literature. Supplementary special purpose publications, such as the relatively new AISC Design Guide series, can offer needed guidance for attaining suitable performance without overloading the main standard itself or unduly restricting the users' discretionary judgment. Some of the emerging structural subtopics are so complex that they can only be effectively described in this manner. For example, effects of semi-rigid connections, inelastic second-order analysis, including seismic time-history response, composite steel-concrete frame construction, and other special design situations appear to be difficult to prescriptively cover within the traditional format. Therefore, the optimum balance between prescriptive and performance requirements to provide for adequate safety and functionality but without impairing design advancements will remain an important consideration.

Format

Some may convincingly argue that the steel Load and Resistance Factor Design (LRFD) vs. Allowable Stress Design (ASD) issue in the USA is much more than a format question. However, in order to bypass the continuing debate about the theoretical or practical merits of each, I will regard it as such for the purposes of this discussion. Both LRFD and ASD essentially cover elastic load analysis and individual member design with due corrections for second-order effects in beam-columns. From the average user or public point of view, LRFD, or limit states design, can be easily perceived as only a different, but parallel, procedure for proportioning structural members. Other building materials, like timber and masonry, are now developing their limit states design methods as alternates to working stress procedures, in addition to the ACI-318 reinforced concrete provisions, which have been expressed in ultimate strength terms for over twenty years.

A second major format concern for standards is the system of units. In accordance with a recent US federal government declaration, the metric system has been stipulated as the preferred measurement system for trade and commerce. Within the next year or two, this act is scheduled to be enforced for all federal construction projects, and those dependent on federal financing. Whether the private sector also moves in this direction, and how quickly, is realistically still an open question.

After some transition period, my expectations are that eventually both the LRFD and metric formats will become more widely accepted for steel construction, but how many more years this evolution will require in this country is uncertain. Nondimensionalizing standards (specifications) is an effective way to provide for metrication while retaining the possibility for use of the traditional units, as needed, within a single document. Dual units would only be needed where specific distances and sizes are given, such as for connection fastener spacing. An LRFD-based ASD alternative could be salvaged in the form of a short Appendix, or supplementary Part II, for those that wish to continue designing for service load combinations. In this manner, two design methods can be effectively integrated into one, similar to the new US cold-formed steel specification being developed by AISI that is being consolidated into a LRFD/ASD document.

Nondimensionalization and an abbreviated ASD within a LRFD framework provides the great benefit of reducing the four distinct format options (metric or traditional, LRFD or ASD) to only a single neutral unified standard. Therefore, within our laissez-faire environment in the USA, it would remove any format dependence on these particular professional and public preferences.

Information Explosion

Modern society has been experiencing for some time now a major information explosion. Various past knowledge has accumulated through a variety of sources and publications, both national and world-wide. Man's continued research quest for even greater understanding of nature continues to fuel this boom. One example of this definite trend can be found in the AISC Specification for Structural Steel Buildings, whose first edition issued in 1923 was a mere total of nine pages long. Currently, the AISC Allowable Stress and LRFD Specification versions each contain more than 100 pages, not counting the Commentary material: more than a ten-fold increase in technical content! If the separate supplementary AISC Seismic Provisions, Specification for Single Angles, Specification for A325 and A490 High-Strength Bolts, and Code of Standard Practice are also considered, these represent a vast reservoir of design knowledge just for one building material, without even counting the numerous related reference journals, conference proceedings, or university reports. A second example can be found in the Structural Stability Research Council (SSRC) 50th anniversary itself. Originally founded as the Column Research Council with essentially a single mission, the SSRC and its thirty technical Task Groups now cover a much wider variety of topics as the organizational name change implies.

Main member and connection design are continually being refined and fine-tuned, such as multiple column curves and other discretionary alternatives. Such growth of technical information is expected to continue. The dilemma this poses for the engineering profession is how to properly assimilate all the information, manage it, separate the germane from the peripheral, and apply it to their everyday design work. Much of this translation and conversion of new research results and other advances into state-of-the-art design criteria is performed through the various committee activities of the codes and standards organizations. However, this is resulting in a plethora of standards, which, in addition to the various building materials and their special products, includes in the USA the documents produced by ASTM, ASCE, ANSI, etc. In response, basic education and job training are continually adding new dimensions, and career long continuing education is becoming an even greater necessity. The enormous amount of material that a conscientious engineer must keep pace with is staggering, and the information growth curve is showing no signs of slowing.

How many pages and volumes of technical requirements can the average engineering office absorb and the regulatory official enforce before reaching a threshold of oversaturation?

Computerization

The emergence of computers as a readily available engineering tool is definitely a landmark development. Their general presence also offers one excellent answer to the previous information overload problem. They can serve as the needed data storage, transfer, search, and retrieval mechanisms. Similar to the futuristic consumer information and entertainment "superhighway" being seriously contemplated by the communications industry, its technical counterpart can provide an effective solution to the oversaturation faced by structural engineers and code officials. Electronic mail, bulletin boards and electronic versions of existing technical documents, such as AISC-ELRFD, are probably just the proverbial "tip of the iceberg" for this new era where most design communications and data exchange will be processed directly and exclusively through computers.

The speed, power, and relative affordability of personal computers has also opened new analysis and design horizons for most engineers. Lengthy and repetitive calculations can be programmed, or appropriate commercial software purchased, that offers almost immediate solutions to what previously would have been long and laborious undertakings. Pre and post processors offer amazing user conveniences for data input and output evaluation. Different framing options, geometrics, member sizes, loadings, special conditions and higher order effects can be quickly and accurately examined. One of the other SSRC Workshops is concentrated solely on advanced analysis.

These design productivity and capability increases due to computers also has some recognized downsides. The knack for practical manual solutions, drawing, and space perception are becoming lost, through obsolescence, thereby handicapping the experienced human intuition, or preliminary approximations, that have been previously found to be so invaluable in assessing the adequacy and compatibility of structural members and their connections. The Williot-Mohr diagram, slide rules, moment distribution, portal method, logarithm tables, nomograms and other design aids are becoming mere relics of a past era. In their place are stiffness based matrix methods, other numerical algorithms, and now even the newest breed of biologically-based neural networks and genetic programming, that are amendable to automated processing but that may, as some suspect, hinder the basic user application of equilibrium, solid mechanics, stability, and engineering judgment. The vagaries of modeling assumptions, data input, numerical processing sensitivity, and other inherent limitations of software may not be fully recognized or understood by all users. In addition to such accidental shortcomings, it will also be more difficult to safeguard these advanced tools from intentional misuse. Much more could be said about the advantages and abuses of computers; it suffices to conclude that we should all strive toward prudent use of this powerful hardware and software only as computational devices and not as substitutes for good engineering.

Diversity or Uniformity

Momentum for centralized standardization is gaining not only in the US, but also internationally. The latter aspect will be addressed by another panelist. The general primary stimulus for greater uniformity of standards is ease of commercial trade already precipitated by progress in transportation, communications, and political understandings. Broader acceptance of the same types and sizes of products for applications removes many marketing and manufacturing obstacles that would otherwise be presented by state, provincial, or national borders. In the US, this trend is becoming evident through greater reliance on the three national model building codes and on their movement toward a common format. Canada, Mexico, and the USA have recently started exploring protocols for North American harmonization based on NAFTA (North American Free Trade Agreement) similar to the ongoing efforts of the European community. Other blocks of neighboring countries are also expected to pursue parallel agreements.

However, even in the US, important regional differences exist that have for many years been reflected in the multitude of local (city, county, state) and the model building codes. Many of these differences are generally attributed to the more local tradition and practice, pride of authorship, population density and demographics, available resources, life style, climate, and the related perceived threat from the natural phenomena of earthquakes, wind, snow, and flooding. Despite commercial pressures for more uniformity, it is difficult to expect that all these can effectively be fully normalized on a national basis, and even more so globally. A similar code format and organization is a relatively easy first step. However, one area's legitimate preferences and risk tolerances may be totally unacceptable to another for example, bolting or welding, tubular or wide-flange members, material grades, low or high-rise construction practices. Various risk tolerances, together with the more subjective controls on property damage, are particularly manifest in the loads and load combinations, which serves to explain why there isn't more uniformity on this basic issue. For example, the ACI reinforced concrete code contains load factors and combinations which are substantially different from the ASCE-7 standard on which steel LRFD is based. More uniformity, or consistency, is clearly the direction on which standards developments are heading, but the degree of progress based on actual public acceptance remains an unknown.

Conclusions

Rather than summarize my previous thoughts on specification format, information management, computerization, and consistency which future reality may prove erroneous, I will conclude on a simple optimistic note relative to the strength, character, and creativity of the *human spirit*. It is in this positive frame of mind that the expected technology advancements and related changes should be received.

Chances are that the means and methods for steel building design may be totally revolutionized in the next fifty years for the 100th anniversary of SSRC. While some sentimental nostalgia about the past is healthy, it cannot obstruct legitimate advancements. I trust that the entire structural engineering profession and academia will successfully guide the technical developments in the next century with due prudence and objectivity.

WORKSHOP 1 - SPECIFICATION ALTERNATIVES

HIGHWAY BRIDGES

Presentation by Gerard F. Fox

Highway bridges in the United States are, for the most part, designed according to the specifications of the American Association of State Highway Officials (AASHTO). The bridge committee members are mainly the chief bridge engineers of the individual states. They identify needed research which is then carried out under the auspices of the National Cooperative Highway Research Program (NCHRP). In addition some research is carried out by the Federal Highway Administration (FHWA) and individual states. The specifications permit allowable stress design or load factor design and in a few months a Load and Resistance Factor Design (LFFD) version will be available.

Railroad bridges in the United States are designed according to the specification developed by several bridge committees of the American Railway Engineering Association (AREA). Membership of the bridge committees consist of the bridge engineers of the various railroads, private consulting engineers and some supplier representatives. While the Association supports some research that is directly related to railroad operations, it relies on and utilizes pertinent AASHTO research results. The specifications, at the present time, is limited to only an allowable stress design version.

The AASHTO and AREA are mature bridge specifications having been established many years ago. Both are kept up-to-date and are revised yearly by hard-working committee members. Each will shortly release metric versions of their specifications.

The question asked in the conference program and for this particular workshop is "How can more uniformity in design standards be achieved"? I believe that uniformity in bridge design standards have been achieved in the United States since there are only two design specifications to contend with, one for highways and one for bridges. This is in contrast with building specifications where there are many city building codes, a separate steel and concrete design specification, an ASCE/ANSI load specification and several National Building Codes.

Whether or not the United States will join with other countries to develop an International Bridge Standard is a political decision which does not seem to be forthcoming in the immediate future.

The second question, addressed to this workshop, concerned the future development of bridge structural design specifications. There is an old catch-22 saying; that when one is asked to focus on future directions, he must be wary since it is dangerous to make predictions, especially about the future.

It is apparent that there is an ever expanding amount of research results being added to the knowledge base. As this material is incorporated in design specifications, either as an addition or revision, the specifications become more voluminous and complicated. These last two factors lead to more computerization. Use of computers lead naturally to an integration of analysis, design, drawings and specifications. A lot of bridge design that is being done today is integrated in this manner. Using the rules of logic, the constraints dictated in the specifications are easily checked and the design automatically changed as necessary.

Design specifications are an approximation of more complex models. These complex models, such as column curves, equations etc. will be programmed using object-oriented ideas, into modules that would replace the corresponding design specification items.

Specifications will come to rely increasingly on probabilistic concepts, especially concerning loads. The siting of major bridges including their orientation will be used to determine earthquake and wind loads. What return periods to use during construction and for the life of the bridge are a question of risk which must be addressed. What risk is acceptable to the public?

As bridge integrated design packages become more sophisticated they will be used not only by engineers but also by technicians, especially for the run-of-the-mill bridges. This of course results in some legal implications for regulatory officials. Should technicians be allowed to have the responsibility for design of certain types of bridges? Are four year graduates going to be technicians? Will these ideas and technologies change how colleges train engineers?

WORKSHIP 1 - SPECIFICATION ALTERNATIVES

PRESSURE VESSELS AND OFFSHORE STRUCTURES

Clarence D. Miller
Chicago Bridge & Iron Technical Services Company
Plainfield, Illinois
USA

There are several sets of rules related to stability which are currently used in the United States for design of shell type structures. The principle rules are provided by ASME (American Society of Mechanical Engineers, Boiler and Pressure Vessel Codes), API (American Petroleum Institute) and AWWA (American Waterworks Association). The following is a list of rules in use by these three organizations.

CODES, SPECIFICATIONS AND STANDARDS

API RP 2A-WSD 93
Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design, Twentieth Edition, American Petroleum Institute.

API RP 2A-LRFD 93
Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Load and Resistance Factor Design, First Edition, American Petroleum Institute.

API BUL 2U 87
Bulletin on Stability Design of Cylindrical Shells, First Edition, American Petroleum Institute.

AWWA D/100-84
Standard for Welded Steel Tanks for Water Storage, American Water Works Association.

API STD 620 90
Design and Construction of Large, Welded Low-Pressure Storage Tanks, Eighth Edition, American Petroleum Institute.

API STD 650 93
Welded Steel Tanks for Oil Storage, Ninth Edition, American Petroleum Institute.

ASME VIII 92
Pressure Vessels, Divisions 1 and 2, 1992 ASME Boiler and Pressure Code, American Society of Mechanical Engineers.

ASME III 92
Rules for Construction of Nuclear Power Plant Components, Division 1, Subsection NE: Class MC Components, 1992 ASME boiler and Pressure Vessel Code, American Society of Mechanical Engineers.

ASME N-284
Code Case N-284, Code Cases: Nuclear Components, 1992 ASME Boiler and Pressure Vessel Code, American Society of Mechanical Engineers.

API RP 2A-WSD 93 provides working stress design rules for unstiffened and ring stiffened cylindrical members and conical transitions with diameter/thickness (D/t) ratios less than 300 for offshore structures. Loads considered are axial compression or tension, bending and external pressure. Design equations are provided for any two load combinations. API RP 2A-LRFD 93 provides load and resistance factor design rules similar to those given by the working stress design rules.

A study was performed by Miller and Saliklis (1993) for API to compare design rules with the available test data base (350 tests). The data base is limited to test specimens that are formed from steel sheet plate and joined together by welding. This study also includes an analysis of the effect of external pressure on beam-columns. The best fit equations based upon a statistical analysis were determined for each load case. Several of these best fit equations were then modified to obtain better correlation with the test data. The API work group has made recommendations for revisions to API RP 2A-WSD 93 and API RP 2A-LRFD 93 to include equations for combined axial compression, bending and external pressure. API BUL 2U 87 provides working stress design rules for unstiffened, ring stiffened and ring and stringer stiffened cylinders subjected to any combinations of axial compression, bending and external pressure. The rules apply to cylinders with D/t ratios up to 2000.

A similar study to that described above is being made by Miller and Saliklis to compare design rules with the currently available test data base (370 tests) for cylinders with D/t ratios greater than 300. The data base is limited to test specimens that are formed by steel sheet or plate and joined together by welding. The two sets of design rules selected in this study were API BUL 2U 87 and ECCS 88. ECCS provides design rules for stringer stiffened cylinders subjected to axial compression but ignores the presence of stringers for cylinders subjected to external pressure. The API rules provide much better correlation with the test data than the ECCS rules.

API STD 620 90 and API STD 650 93 provide rules for steel cylinders under axial compression but the design equations are independent of the yield stress. The same allowable stress equations apply to yield stresses of 30 ksi or greater. The stability equations have remained the same for many years.

ASME VIII 92 and ASME III 92 provide similar design rules for unstiffened and ring stiffened cylinders under axial compression or external pressure, for unstiffened spheres under external pressure and unstiffened formed heads under internal or external pressure. The rules can be applied to shells fabricated from a wide range of metal materials. No interaction equations are given for combined loads. These rules have remained unchanged for many years.

A recent study was made by Miller, Mokhtarian and Latif (1994) for the Pressure Vessel Research Council to develop alternative rules for determining allowable compressive stresses for cylinders, cones, spheres and formed heads. These rules may become an appendix to ASME VIII 92. The rules include equations for unstiffened and ring stiffened cylinders and cones subjected to any combination of axial compression, bending, shear and external pressure. The study by Miller and Saliklis (1993) was utilized in the PVRC project.

An AWWA committee has developed a revised standard for AWWA D/100 which includes two design equations for cylinders and cones subjected to axial compression. The two equations apply to steels with yield stresses of 30 to 33 ksi and to steels with yield stresses greater than 33 ksi. These equations provide buckling stresses quite close to those given by API BUL 2U if yield stresses of 30 and 36 ksi are selected.

API has a committee working on the development of an ISO (International Organization for Standardization) standard for offshore structures. The proposed standard includes API RP 2A-LRFD 93.

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Miller, C.D. and Saliklis, E.P. (1993). "Analysis of Cylindrical Shell Database and Validation of Design Formulations," API PRAC Project 90-56, CBI Contract No. N90406, Final Report, Chicago Bridge & Iron Technical Services Company, October 1993.

Miller, C.D., Mokhtarian, K. and Latif, O. (1994). "Alternative Rules for Determining Allowable Compressive Stresses for Cylinders, Cones, Spheres and Formed Heads, ASME Code, Section VIII, Div. 1, PVRC Grant 93-06, Final Report, Chicago Bridge & Iron Technical Services Company, May 1994.

USA CODES, SPECIFICATIONS AND STANDARDS FOR SHELL STABILITY

API RP 2A-WSD 93
Fixed Offshore Platforms - Working Stress Design

API RP 2A-LRFD 93
Fixed Offshore Platforms - Load and Resistance Factor Design

API BUL 2U 87
Bulletin on Stability Design of Cylindrical Shells

API STD 620 90
Large, Welded Low-Pressure Storage Tanks

API STD 650 93
Welded Steel Tanks for Oil Storage

USA CODES, SPECIFICATIONS AND STANDARDS FOR SHELL STABILITY - CONTINUED

ASME VIII 92
Pressure Vessels, ASME Boiler and Pressure Code

ASME III 92
Nuclear Power Plant Components, ASME Boiler and Pressure Vessel Code

ASME N-284
Code Case N-284, Nuclear Components, ASME Boiler and Pressure Vessel Code

AWWA D/100-84
Standard for Welded Steel Tanks for Water Storage, American Water Works Association

API RP 2A-WSD 93 AND API RP 2A-LRFD 93
Fixed Offshore Platforms

SHELL TYPES

- UNSTIFFENED AND RING STIFFENED CYLINDERS AND CONICAL TRANSITIONS

LOADS AND LOAD COMBINATIONS

- AXIAL COMPRESSION
- BENDING
- EXTERNAL PRESSURE
- ANY TWO LOADS COMBINED

FUTURE DIRECTION

- AN API SPONSORED STUDY WAS COMPLETED IN 1993 WHICH COMPARED RULES WITH TEST DATA FOR CYLINDERS WITH D/T < 300. IMPROVED EQUATIONS WERE RECOMMENDED

- EQUATIONS WILL BE INCLUDED FOR COMBINED AXIAL COMPRESSION, BENDING AND EXTERNAL PRESSURE IN NEXT REVISIONS OF API RP 2A

- API COMMITTEE IS WORKING ON ISO STANDARD FOR FIXED PLATFORMS USING API RP 2A-LRFD

API BUL 2U 87
Bulletin on Stability Design of Cylindrical Shells

SHELL TYPES

- UNSTIFFENED, RING STIFFENED AND RING AND STRINGER STIFFENED CYLINDERS

LOADS AND LOAD COMBINATIONS

- AXIAL COMPRESSION
- BENDING
- EXTERNAL PRESSURE
- ANY COMBINATION OF LOADS

FUTURE DIRECTION

- A STUDY IS IN PROGRESS TO COMPARE THE DESIGN RULES WITH EXISTING DATABASE FOR D/T > 300
- STUDY INCLUDES EVALUATION OF ECCS 1988 RULES
- IMPROVEMENT IS DESIRED FOR STRINGER STIFFENED CYLINDERS

ASME VIII 92	**Pressure Vessels**
ASME III 92	**Nuclear Components**

SHELL TYPES

- **UNSTIFFENED, AND RING STIFFENED CYLINDERS AND CONES SPHERES AND FORMED HEADS**

MATERIALS

- **MOST METALS**

LOADS AND LOAD COMBINATIONS

- **AXIAL COMPRESSION**
- **EXTERNAL PRESSURE**
- **NO LOAD COMBINATIONS**

FUTURE DIRECTION

- **IN A STUDY FOR PVRC ALTERNATIVE RULES WERE DEVELOPED BASED UPON STUDIES BY MILLER AND SALIKLIS. THESE RULES GIVE EQUATIONS FOR ANY COMBINATIUON OF AXIAL COMPRESSION, BENDING, EXTERNAL PRESSURE AND SHEAR.**

- **THE NEW RULES ARE PROPOSED AS AN APPENDIX TO ASME VIII 92**

ASME CODE CASE N-284 Nuclear Components

SHELL TYPES

- UNSTIFFENED, RING STIFFENED AND RING AND STRINGER STIFFENED CYLINDERS,
- UNSTIFFENED AND STIFFENED SPHERES
- UNSTIFFENED AND STIFFENED FORMED HEADS

LOADS AND LOAD COMBINATIONS

- AXIAL COMPRESSION
- SHEAR
- EXTERNAL PRESSURE
- ANY COMBINATION OF THESE LOADS

FUTURE DIRECTION

- A REVISION TO THE RULES WAS PROPOSED BY MILLER IN 1991. THE PROPOSED REVISION IS GOING THROUGH THE APPROVAL PROCESS

- ENTIRE CODE CASE SHOULD BE UPDATED BASED UPON RECENT STUDIES

AWWA D/100-84

Standard for Welded Steel Tanks for Water Storage

SHELL TYPES

- **UNSTIFFENED CYLINDERS AND CONES**

LOADS AND LOAD COMBINATIONS

- **AXIAL COMPRESSION**
- **BENDING**
- **COMBINATION OF THESE LOADS**

FUTURE DIRECTION

- **A REVISION TO THE RULES WAS PROPOSED BY AN AWWA COMMITTE AND IS GOING THROUGH THE APPROVAL PROCESS.**

- **NEW RULES PROVIDE TWO EQUATIONS FOR AXIAL COMPRESSION --ONE FOR YIELD STRESS < 33 KSI (228MPa) AND ONE FOR YIELD STRESS > 33 KSI**

API STD 620 90 Large, Welded Low-Pressure Storage Tanks
API STD 650 93 Welded Steel Tanks for Oil Storage

SHELL TYPES

- **UNSTIFFENED CYLINDERS**

LOADS AND LOAD COMBINATIONS

- **AXIAL COMPRESSION**

FUTURE DIRECTION

- **NO CHANGES HAVE BEEN MADE FOR SEVERAL YEARS**
- **NO CHANGES ANTICIPATED**

WORKSHOP 2

ADVANCED ANALYSIS METHODS

WORKSHOP 2 - ADVANCED ANALYSIS METHODS

WORKSHOP SUMMARY

Moderator: Gregory G. Deierlein, Cornell University
Recorder: Ronald D. Ziemian, Bucknell University

PREFACE: The basic charge for this session was to discuss the question: **"How can advanced analysis methods be incorporated into design specifications?"** In this context, *advanced analysis* refers to frame-type methods of analysis which include geometric and material nonlinearities that account for frame stability effects directly in the analysis. As such, many questions arise as to how and whether the results of such analyses can be used in lieu of specification provisions to evaluate the strength limit state of structures.

The workshop was attended by about thirty practicing engineers and academic researchers with varying backgrounds and experience with advanced analysis. What follows below is a written transcript of the discussion and questions that were raised during the workshop. In addition, the workshop included three short presentations by Professors Trahair, Nethercot and Morino who summarized how advanced analysis methods are used and handled by design specifications in Australia, the UK, Europe and Japan. Summaries of their presentations are included below, and copies of their transparencies are attached as appendicies to the workshop report.

WORKSHOP REPORT

Introduction by G. Deierlein: Deierlein began by outlining the focus of the workshop as an opportunity to discuss the incorporation of advanced analysis methods into general design specifications. Deierlein indicated that in some ways, this workshop is intended to provide ideas to SSRC TG29: 2nd-Order Inelastic Analysis as they begin to develop guidelines for this topic. To provide a basis for discussion, three speakers representing different parts of the world were introduced including, N. Trahair (Australia), D. Nethercot (United Kingdom), and S. Morino (Japan). Before they gave their presentations, Deierlein provided a review of the guidelines for using inelastic analysis that exist in the current AISC LRFD Specification. It was pointed out that the guidelines in the current AISC LRFD Specification are more or less intended for classical methods of plastic analysis and not necessarily advanced analysis. It was also indicated that, in general, current U.S. practice rarely applies advanced methods of analysis in design. The limited number of applications seemed to be in seismic design. Prof. Deierlein completed his presentation with a review of the potential uses for advanced analysis methods. Beyond the design of new structures, it was felt that these methods of analysis may have their greatest merits when used to evaluate existing structures for either retrofit work or seismic response behavior. Another example that was provided included evaluating existing offshore oil platforms for up-to-date storm loading criteria.

REVIEW OF AUSTRALIAN STEEL SPECIFICATION AS 4100 GUIDELINES

Prof. N. Trahair, The University of Sydney, Australia

Trahair began his presentation with a review of the current AS4100 Specification (Australian steel specification) guidelines for incorporating advanced analysis methods into design. Subject to several requirements, including incorporating initial imperfections and second-order effects, such analysis methods can be used to confirm the limit states strength of structures constructed of members with compact sections and full lateral restraint. Where system capacity is confirmed by the analysis, only section and connection capacity checks using design equations need to be made. Trahair indicated that the use of advanced analysis in Australia is primarily intended for structures of unusual geometry, investigations into structural failures, and to check systems where strength capacity is at doubt. The details of an advanced analysis computer program NIFA developed by M. Clarke, also at the University of Sydney, were then provided. Using this program as a basis, requirements for commercialization of such programs were then outlined. Trahair indicated that commercialization of advanced analysis programs will probably not come from newly developed software, but rather, will come into design practice through modifications and enhancements of existing analysis software. The presentation was completed with a review of future developments that are needed for advanced analysis. These included incorporating local buckling effects and providing three-dimensional advanced analysis capabilities that capture inelastic bi-axial bending and torsion as well as lateral-torsional buckling. *(Appendix A includes a copy of overhead transparencies from Trahair's presentation)*

Discussion after Presentation #1

W.F. Chen: Questioned why the Australian research was targeting plastic zone analysis capabilities instead of refining plastic hinge analysis routines. Considering that the Australian Specification provided for different levels of inelastic analysis, why shouldn't the programs provide the same different levels of analysis?

N. Trahair: Responded that the development of the plastic zone program, NIFA, was based on several of The University of Sydney's research needs. In developing this software it was felt that the refined analysis capabilities were needed and just as importantly, the power of the computer is advancing at such a rapid rate that the computational time needed to complete a plastic zone analysis will soon be acceptable to the design engineer.

W.F. Chen: Questioned if the specification requirements for advanced analysis were calibrated against the existing code requirements. He wondered how a design using advanced analysis would compare against a design developed using a more conventional method of elastic analysis in conjunction with the existing Australian Specification.

N. Trahair: Responded that for a single member, the results would closely match. Some differences would result wherever approximations are employed, e.g. employing amplification factors in place of performing a comprehensive second-order analysis. In this regard, it was observed that the benefits of advanced analysis are not necessarily in reducing the amount of steel rather that advanced analysis provides for an easier design approach.

W.F. Chen: Emphasized Trahair's latter point. That is, the key selling point for software development companies should be the fact that advanced analysis simplifies the design process.

S. Kitipornchai: Questioned if the Australian Specification was only using advanced analysis to check for equilibrium under design load conditions. He was concerned that such application would provide only a small amount of information about the limit state behavior of the structure.

N. Trahair: Responded that the intent of the Australian Specification was for the advanced analysis to simply confirm that the structural system could resist design load conditions.

S. Kitipornchai: Felt that in some ways advanced analysis could be dangerous because it was attempting to provide the "true" collapse load. In this regard, specification requirements for employing advanced analysis should be calibrated with existing design rules and/or against full scale experimental tests. It was also felt that response plots such as load-deflection traces are just as important if not more important than a single ultimate load value.

G. Deierlein: Questioned if specification guidelines for advanced analysis should include requiring the engineer to produce load-deflection curves at key-points on the structure.

W.F. Chen: Cautioned against calibrating against the current codes. It was felt that the code will give a very good indication "on average" of a structure's limit state behavior but will it will not necessarily define the "actual" limit state behavior.

S. Ladkany: Inquired about what types of connections the advanced analysis methods were intended for. He indicated that connection behavior is an essential element to predicting strength limit state behavior. He also wanted to confirm that advanced analysis will indeed make the design process easier for the engineer.

A. Sherbourne: Indicated a concern for the designer. Sherbourne reminded the group that the designer is not a simple-minded person who needs the design process significantly simplified. That person is most likely a well-educated engineer who can handle complicated analysis.

N. Trahair: Disagreed with what Sherbourne was implying. Trahair was not attempting to indicate that the designer needed simple design procedures because he or she could not handle more complicated ones.

BRITISH STANDARDS

Prof. D. Nethercot, University of Nottingham, U.K.

Nethercot began his presentation with a brief overview of the current British Standard used in steel design. The focus then shifted to Eurocode 3, the design specification that all of Europe including the U.K. will soon be adopting. An overview of the various analysis methods recognized in Eurocode 3 and their corresponding specification requirements were then presented. After a discussion on employing advanced analysis under Eurocode 3, related guidelines for incorporating member and frame imperfections, including residual stresses and initial geometrical imperfection, were presented. *(Appendix B includes a copy of overhead transparencies from Nethercot's presentation)*

<u>Discussion after Presentation #2</u>

G. Deierlein: Indicated that based on his experience, it appeared that Eurocode 3 seemed to be fairly complicated and involved.
D. Nethercot: Agreed, but felt that it was the best that could be done considering that many different countries speaking several different languages all desiring different levels of details and mathematics contributed to the production of Eurocode 3.
A. Sherbourne: Questioned the different design assumptions that corresponded to the different analysis methods available under Eurocode 3. He wondered if a more efficient design would necessarily result from using a more advanced analysis method.
D. Nethercot: Responded that very few studies have been done in Europe to answer this question. Based on those limited studies it would be difficult to extrapolate from their results and make any general conclusions.
P. Green: Questioned if Eurocode 3 or any other specifications incorporate the residual forces that are generated during the erection process of the steel frames. For example, how are the effects on a system in which the columns are determined to be out-of-tolerance and later jacked back into place being incorporated into the design process? He furthered referenced the work on this subject by Chowdhury at Lehigh University.
D. Nethercot: Responded that Canada and Germany do attempt to include provisions regarding these effects of erection in-tolerances. Nethercot felt that this issue is critical in the design of suspension bridges and other types of similar structures. He was not aware that Eurocode 3 or any other codes besides those mentioned were attempting to account for these forces in the design of steel buildings.
D. White: Indicated that Green's point was valid, but felt that construction sequence requirements should be kept separate from specification requirements regarding the use of advanced analysis. That is, if construction sequence needs to be included then it should be for all levels of analysis.
N. Morris: Questioned the notional load concept offered by both the European and Australian

Specifications and incorporated in a draft AISC document that was presented by J. Hajjar at the TG4: Frame Stability and Columns as Frame Members committee meeting. He indicated that these loads were only a function of the gravity load. It would seem that the geometric nonlinear effect they are trying to capture should be represented in some form by the system's bifurcation load.

D. White: Indicated that the notional load concept seemed to work well in the studies he had seen, but also indicated that its use was limited. For example, the notional load concept does not work well in seismic design.

S. Stoman: Tried to develop a consensus on the use of advanced analysis. He could clearly see the potential benefit of simplifying the design process, but wondered at what cost. For example, the designer must be made aware of how to incorporate all of the necessary details when employing advanced analysis, i.e. initial imperfections. He furthered questioned how the designer could make the best use of advanced analysis, if made commercially available, without treating it like a "black-box".

D. Nethercot: Responded that further education of the designer and more evaluation of the specification requirements will be necessary.

N. Morris: Indicated a concern on the number of specification requirements that are necessary for employing advanced analysis. He stated that problems with these guidelines would begin to resemble those of the nuclear industry some 20 years ago.

J. Hajjar: Indicated that we do not want a "black-box". Specific requirements for advanced analysis are needed. This could possibly come in the form of a separate document on guidelines for using advanced analysis.

N. Morris: Agreed, but felt that time was of the essence.

A. Sherbourne: Felt it was more a question of education. He drew an analogy to the acceptance of limit states design specifications. A limit states design code was released in Canada and 5 years later the ASD Specification was withdrawn. In this regard, the designers had to learn the new Specification. He felt that sophisticated analysis methods can be further developed under a limit states specification, but only after removal of the currently available allowable stress design specifications.

D. Nethercot: Agreed and further drew an analogy to use the use of the metric system.

STRUCTURAL DESIGN FOR SEISMIC LOAD IN JAPAN

Prof. S. Morino, Mie University, Japan

Morino's presentation focused on the role of inelastic analysis in the seismic design of steel buildings. In Japan, seismic design consists of a three tier approach that includes static and dynamic elastic design, an inelastic static analysis, and an inelastic dynamic analysis. The inelastic analyses are used to confirm that the basic assumptions made in the elastic design phase are appropriate. The inelastic analyses are also used to assess the ductility demands via the calculation of a structural characterization factor. It was also pointed out that the degree of the analysis employed in design can be a function of who is checking the overall design, i.e. the Ministry of Construction or some other agency, depending on the height of the building.(Appendix C includes a copy of overhead transparencies from Morino's presentation)

Discussion after Presentation #3

S. Stoman: Questioned what methods the Ministry of Construction use to evaluate the designs presented for construction.
S. Morino: Responded that various checks, that are mostly made on good engineering judgment, are used. In this regard, the level of analysis performed by the designer can be a critical factor in confirming the adequacy of the design.
D. White: Asked who is responsible for code evaluations of structural systems taller than 45 meters.
S. Morino: Indicated that the bureaucracy was more complicated but it essentially came down to several committee checks.
D. White: Indicated that tall buildings are probably not the market for employing advanced analysis. Low-rise buildings can include enough stability problems that the benefits of advanced analysis can certainly be realized.
M. Xue: Questioned the Japanese limitation on the ratio of load factor a first plastic hinge to load factor at collapse.
S. Morino: Responded that it was probably due to the fact that second-order effects were not included the design procedures.
G. Deierlein: Indicated that it probably also had to do with accessing rotation capacity demands. He suggested that there is most likely a relationship between frame ductility and the implied member ductility.
S. El-Tawil: Questioned if there are guidelines in the specification for more advanced methods of analysis.
S. Morino: Replied that engineers are free to use whatever level of analysis they see fit but their specification does not provide guidelines or suggestions as to which methods of analysis should be used.
M. Nakashima: Indicated that in Japan most of the analyses that are now being performed are

three-dimensional. It had been realized that this was the only way to capture the behavior of a structural system especially when designing for seismic effects.

M. Xue: Questioned what type of inelastic analyses are being performed.

S. Morino: Indicated that the methods were not very sophisticated and were primarily based on plastic hinge models.

M. Xue: Further asked if these plastic hinge models incorporated both bending and axial force effects as well as changes in frame geometry after the first plastic hinge.

S. Morino: Replied that axial force is incorporated into the yield criteria but changes in frame geometry due to deformation were typically not incorporated.

M. Nakashima: Questioned whether advanced analysis programs would need to be authorized by some committee.

S. Morino: Indicated that some pier reviews are done on designs that are based on inelastic analyses. So in some ways pier reviews are being completed on the different programs being employed.

S. Kitipornchai: Indicated that it seems that future engineers should be given the option as to which level of analysis they would like to use. He further felt that education was a key factor in the successful applications of advanced methods of analysis. There is no doubt that advanced analysis capabilities are coming quickly with advances in computer technology providing an impetus. In fact, he concluded that a solution to the many questions regarding the development of a world building code may be answered through the use of advanced analysis.

D. Nethercot: Indicated that there is probably no unique definition of advanced analysis. He further questioned who these methods of analysis are intended for, newer engineers or today's current engineers.

S. Kitipornchai: Thought Nethercot's latter point was a good one. His response was that through education, the next generation of young engineers is who advanced analysis is probably intended for. He felt, however, that calibration of advanced analysis methods with current specification requirements is critical.

G. Deierlein: Agreed that calibration is important, but felt that today's engineer's could make just as good use of advanced analysis as the next generation of engineers. He offered the petroleum industry as an example of a group of engineers who currently need this technology to evaluate the strength of off-shore oil-platforms damaged by storms.

R. Ziemian: Noted that as part of his Ph.D. studies, he was the "designer" who got to compare and contrast designs made by using conventional analysis methods and those based on more advanced analysis methods. He felt that benefits of potential weight savings and simplicity in design procedure were important, but are secondary to what he felt was the most important benefit toward using advanced analysis in design, and that was the engineer was being provided through load-displacement curves, plastic hinge sequences, and ultimate load ratios, the unique opportunity to predict and comprehend the limit state behavior of the system being designed. He felt that this opportunity for understanding structural behavior will undoubtedly lead to more rational designs.

G. Deierlein: Agreed and added that once a system is designed for strength using advanced analysis, additional steel needed for serviceability requirements could be placed where deemed most effective with respect to both strength and serviceability needs.

J. Hajjar: Indicated that we should stay away from selling advanced analysis as simply a means for reducing the weight and hence cost of steel structures. He cited a similar pitch by AISC to encourage engineers to go with LRFD. Hajjar felt that this has not been very effective.

G. Deierlein: Agreed to some extent, but felt the key was to show that some existing structures do have more reserve strength than we had originally thought. He felt that this is an important use of advanced analysis.

D. White: Commented that we will always need some code checks like compact section requirements. In fact, he indicated, that many of the specifications' current rules will still need to apply to design procedures that employ advanced analysis.

M. Nakashima: Questioned where there are potentially so many different methods of advanced analysis, how are these programs going to be qualified with respect to accuracy?

G. Deierlein: Indicated that although there will probably be no governing board on these qualification procedures, he pointed to what is being done at research universities in this area. These efforts included i) comparing results with experimental tests done at Lehigh Universities and other research laboratories, ii) checking against the studies used by AISC to develop interaction equations, and iii) comparing with results generated by more refined methods of analysis such as the plastic zone method.

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ADVANCED ANALYSIS OF AUSTRALIAN STEEL STRUCTURES

R.Q.Bridge, M.J.Clarke, and N.S.Trahair

Lehigh, 1994

AS4100 STEEL STRUCTURES

Advanced analysis is

- Permitted by Clause 4.1.1
- Defined by Appendix D
- Discussed by Commentary CD

APPENDIX D ADVANCED ANALYSIS

Compact sections
Full lateral restraint
Inelastic material properties
Second order effects
Residual stresses
Initial crookedness
Erection procedures
Interaction with foundation

DESIGN USING ADVANCED ANALYSIS

Strength limit state
Use design (factored) loads
Satisfy requirements of
- section capacity
- connection capacity

Overconservative section capacity requirements are not modelled in advanced analysis

IMPLIED ALTERNATIVES

Use ϕf_y and ϕE

Structure is adequate if analysis under design loads shows it can reach an equilibrium position

But ϕE overestimates second order effects

Use System ϕ instead (?)

APPLICATION OF ADVANCED ANALYSIS

Special or exceptional structures
Structures whose capacity is in doubt
Investigations of failures
Unusual for normal design

ADVANCED ANALYSIS REQUIREMENTS

Special expertise in modelling
Specialised computer programs
- research programs
- not widely available

IMPERFECTIONS

Residual stresses
Initial crookedness
Magnitudes to match design code compression member strengths, or fabrication and erection tolerances

Notional loads instead of crookedness

Patterns - initial crookedness
- notional loads

ADAPTATION OF COMMERCIAL PROGRAMS

Replacement of analysis routines

Adaptation
- data input
- results output

Selection of company and program

PROGRAM NIFA
Nonlinear Inelastic Frame Analysis

Plastic zone basis

Wider application than plastic hinge
Higher computational expense

Cross-sectional shape
Residual stresses
Geometric imperfections
Stress-strain curve

COMMERCIALISATION OF RESEARCH PROGRAMS

User friendliness - data
- results
- graphics, help
- checking

Marketing and distribution
Maintenance
- program development
- user help

Effectiveness - market penetration

FUTURE DEVELOPMENTS

Multiple load cases
Member sizing for initial structure
Semi - rigid connections
Local buckling
Lateral buckling
Biaxial bending and torsion
Three - dimensional structures

AUSTRALIAN REFERENCES ON ADVANCED ANALYSIS

1. Standards Australia (1990, 92, 93), *AS4100-1990 Steel Structures, Including Amendments 1 and 2*, Standards Australia, Sydney.

2. Clarke, MJ, and Hancock, GJ (1990), A Study of Incremental-Iterative Strategies for Non-Linear Analyses, *Int. J. Numerical Methods Eng.*, Vol. 29, pp. 1365-1391.

3. Clarke, MJ, and Hancock, GJ (1991), Finite-element Nonlinear Analysis of Stressed-Arch Frames, *Journal of Structural Engineering*, ASCE, Vol. 117, No. 10, pp 2819-2837.

4. Clarke, MJ, Bridge, RQ, Hancock, GJ, and Trahair, NS (1991), Design Using Advanced Analysis, *Proceedings*, Structural Stability Research Council Annual Technical Session, "Inelastic Behaviour and Design of Frames", Chicago, Illinois, pp 27-40.

5. Clarke, MJ, Bridge, RQ, Hancock, GJ, and Trahair, NS (1992), Advanced Analysis of Steel Building Frames, *Journal of Constructional Steel Research* Vol. 23, pp. 1-29.

6. Clarke, MJ, Bridge, RQ, Hancock, GJ, and Trahair, NS (1993), Australian Trends in the Plastic Analysis and Design of Steel Building Frames, in *Plastic Hinge Based Methods for Advanced Analysis and Design of Steel Frames: An Assessment of the State-of-the-Art*, White, DW and Chen, WF, Eds, Structural Stability Research Council, Lehigh University, Bethlehem, PA, pp 65-93.

7. Clarke, MJ, Bridge, RQ, Hancock, GJ, and Trahair, NS (1993), Benchmarking and Verification of Second-Order Elastic and Inelastic Frame Analysis Programs, in *Plastic Hinge Based Methods for Advanced Analysis and Design of Steel Frames: An Assessment of the State-of-the-Art*, White, DW, and Chen, WF, Eds, Structural Stability Research Council, Lehigh University, Bethlehem, PA, pp 245-274.

8. Clarke, MJ (1994), Plastic Zone Analysis of Frames in *Advanced Analysis of Steel Frames: Theory, Software and Applications*, Chen, WF and Toma, S, Eds, CRC Press, Boca Raton, Florida, pp. 259-319.

9. Clarke, MJ and Bridge, RQ (1994), Draft Chapter 3 - Notional Load Approach for the Assessment of Column Strength, *Effective Length and Equivalent Imperfection Approaches for Assessment of Frame Stability: Implications for Steel Design*, ASCE Committee on Load and Resistance Factor Design.

EXTRACTS FROM AUSTRALIAN STANDARD AS4100-1990 STEEL STRUCTURES

SECTION 4 METHODS OF STRUCTURAL ANALYSIS

4.1 METHODS OF DETERMINING ACTION EFFECTS

4.1.1 General For the purpose of complying with the requirements for the limit states of stability, strength and serviceability specified in Section 3, the design action effects in a structure and its members and connections caused by the design loads shall be determined by structural analysis using the assumptions of Clauses 4.2 and 4.3 and one of the methods of—

(a) elastic analysis, in accordance with Clause 4.4; or

(b) plastic analysis, in accordance with Clause 4.5; or

(c) advanced analysis, in accordance with Appendix D.

APPENDIX D

ADVANCED STRUCTURAL ANALYSIS

(Normative)

D1 GENERAL For a frame comprising members of compact section (see Clause 5.2.3) with full lateral restraint (see Clauses 5.3 and 5.4), an advanced structural analysis may be carried out, provided the analysis can be shown to accurately model the actual behaviour of that class of frame. The analysis shall take into account the relevant material properties, residual stresses, geometrical imperfections, second-order effects, erection procedures and interaction with the foundations.

D2 DESIGN For the strength limit state, it shall be sufficient to satisfy the section capacity requirements of Clause 8.3 for the members and the requirements of Section 9 for the connections.

EXTRACT FROM AS4100 STEEL STRUCTURES COMMENTARY

APPENDIX CD

ADVANCED STRUCTURAL ANALYSIS

This Appendix is included so as to allow a more precise method of structural analysis to be used to predict the load-deformation behaviour of the structure. This method will not be used in normal design, but might be used for a special or exceptional structure, or for an existing structure whose capacity is in doubt, or in the investigation of a structural failure.

CD1 GENERAL The use of this method may require special expertise in the modelling of the structure so as to include the effects of yielding, instability, and residual stresses and initial crookedness, and the use of specialized computer programs. While such programs have been developed for research purposes (Reference 1), they are not yet widely available.

CD2 DESIGN Because the effects of the material and geometrical imperfections and non-linearities are included in the analysis, it is not necessary to carry out any member capacity checks. In this case, design simplifies to the satisfying of the section capacity requirements of Section 8 and the connection requirements of Section 9.

REFERENCE TO APPENDIX CD

1 McGuire, W., *Research and Practice in Computer-Aided Structural Engineering*, Department of Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder, 1988.

U.K.

BS 5950 : Part 1 : 1990 (1985)

Section 5 : Continuous construction

5.2 Elastic design

5.3 Plastic design

5.5 Portal frames

5.6 Multi-storey rigid frames : elastic design

5.7 Multi-storey rigid frames : plastic design

Plastic design – full elastic-plastic sway analysis or simplified method

- all combinations of loading using $L_E = 1.0L$
- vertical loads + notional horizontal loads (0.5% of factored DL + vertical IL applied horizontally)
- columns checked under pattern loading using L_E from Appendix E

Frame Stability

- **mechanism – sway mode, hinges in all beams and at base of each column**

- **lower lengths of columns remain elastic**

- **elastic under all combinations of unfactored loads**

- **for clad frames (no account taken of stiffening)**

$$\lambda_{cr} \geq 4.6$$

when $4.6 \leq \lambda_{cr} < 10 : \lambda_p \geq \frac{0.9\,\lambda_{cr}}{(\lambda_{cr} - 1)}$

when $\lambda_{cr} \geq 10 : \lambda_p \geq 1$

in which λ_{cr} = elastic critical load factor (App. F)

λ_p = rigid-plastic load factor

Appendix F : Frame instability

λ_{cr} - deflection method (F2)

or

any other recognized method

Use in – amplified sway moments (elastic)

frame stability (plastic)

Deflection method

Linear elastic analysis to determine horizontal deflections due to 0.5% factored vertical load at that level applied to each floor level

$$\lambda_{cr} = \frac{1}{200\phi_{s\,max}}$$

in which $\phi_{s,max}$ = largest value of sway index ϕ_s for any floor

and $$\phi_s = \frac{\delta_u - \delta_L}{h}$$

May allow for partial sway bracing as a diagonal strut

Elastic design

First check under patterned vertical loading as a non-sway frame

Either : L_E values allowing for sidesway

or

Amplify moments due to horizontal loading by :

$$\left[\frac{\lambda_{cr}}{\lambda_{cr} - 1}\right]$$

and take $L_E = 1.0L$

Eurocode 3: Design of Steel Structures

Part 1.1 General rules and rules for buildings

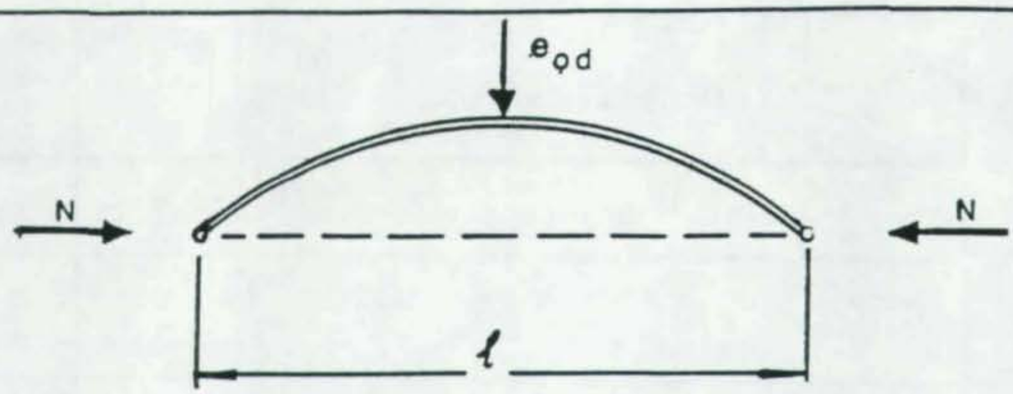
(ENV published in U.K. 15 November 1992)

5 Ultimate limit states

pp. 53 – 71

Table 5.2.1 Design assumptions

Type of framing	Method of global analysis	Types of connections
Simple	Pin joints	Nominally pinned (6.4.2.1) Nominally pinned (6.4.3.1)
Continuous	Elastic	Rigid (6.4.2.2) Nominally pinned (6.4.3.1)
	Rigid-Plastic	Full-strength (6.4.3.2) Nominally pinned (6.4.3.1)
	Elastic-Plastic	Full-strength - Rigid (6.4.3.2 and 6.4.2.2) Nominally pinned (6.4.3.1 and 6.4.2.1)
Semi-continuous	Elastic	Semi-rigid (6.4.2.3) Rigid (6.4.2.2) Nominally pinned (6.4.2.1)
	Rigid-Plastic	Partial-strength (6.4.3.3) Full-strength (6.4.3.2) Nominally pinned (6.4.3.1)
	Elastic-Plastic	Partial-strength - Semi-rigid (6.4.3.3 and 6.4.2.3) Partial-strength - Rigid (6.4.3.3 and 6.4.2.2) Full-strength - Semi-rigid (6.4.3.2 and 6.4.2.3) Full-strength - Rigid (6.4.3.2 and 6.4.2.2) Nominally pinned (6.4.3.1 and 6.4.2.1)



Cross-section		Method of global analysis	
Method used to verify resistance	Section type and axis	Elastic or Rigid - Plastic or Elastic - Perfectly plastic	Elasto-plastic (plastic zone method)
Elastic [5.4.8.2]	Any	$\alpha(\bar{\lambda} - 0,2)\, k_\gamma W_{el}/A$	-
Linear plastic [5.4.8.1(12)]	Any	$\alpha(\bar{\lambda} - 0,2)\, k_\gamma W_{pl}/A$	-
Non-linear plastic [5.4.8.1(1) to (11)]	I-section yy-axis	$1,33\alpha(\bar{\lambda} - 0,2)\, k_\gamma W_{pl}/A$	$\alpha(\bar{\lambda} - 0,2)\, k_\gamma W_{pl}/A$
	I-section zz-axis	$2,0\, k_\gamma e_{eff}/\epsilon$	$k_\gamma e_{eff}/\epsilon$
	Rectangular hollow section	$1,33\alpha(\bar{\lambda} - 0,2)\, k_\gamma W_{pl}/A$	$\alpha(\bar{\lambda} - 0,2)\, k_\gamma W_{pl}/A$
	Circular hollow section	$1,5\, k_\gamma e_{eff}/\epsilon$	$k_\gamma e_{eff}/\epsilon$

$k_\gamma = (1 - k_\delta) + 2\, k_\delta \bar{\lambda}$ but $k_\gamma \geq 1,0$

Buckling curve	α	e_{eff}	k_δ			
			$\gamma_{M1} = 1,05$	$\gamma_{M1} = 1,10$	$\gamma_{M1} = 1,15$	$\gamma_{M1} = 1,20$
a	0,21	$\ell/600$	0,12	0,23	0,33	0,42
b	0,34	$\ell/380$	0,08	0,15	0,22	0,28
c	0,49	$\ell/270$	0,06	0,11	0,16	0,20
d	0,76	$\ell/180$	0,04	0,08	0,11	0,14

Non-uniform members:

Use value of W_{el}/A or W_{pl}/A at centre of buckling length ℓ

Figure 5.5.1 Design values of equivalent initial bow imperfection $e_{o,d}$

Global Analysis

- elastic
- plastic
- first order
- second order

Allowance for imperfections

Include in – Global analysis

Analysis of bracing systems

Member design

Neglect member imperfections for global analysis, except in sway frames for members subject to axial compression for which

$$\bar{\lambda} > 0.5 \, [\, Af_y/N_{sd}]^{0.5}$$

in which N_{sd} = design value of compressive force

$\bar{\lambda}$ = in-plane slenderness using system length

Bracing imperfections

Analysis of bracing systems – equivalent geometric imperfection

$$e_o = k_r L/500$$

in which L = span of the bracing system

K_r = $[0.2 + 1/n_r]^{0.5}$ but $K_r \leq 1.0$

and n_r = no. of members to be restrained

May use equivalent stablizing force (Fig. 5.2.5)

Member imperfections

- Normally in design (buckling) formulae

- Alternatively, for a compression member, use values from Fig. 5.5.1 in second order global analysis.

- Where the $\bar{\lambda} > 0.5\,[Afy/Nsd]^{0.5}$ rule applies second order global analysis using values from Fig. 5.5.1 must be used.

Frame imperfections

initial sway imperfection ϕ

$$\phi = k_c k_s \phi_o$$

in which $\phi_o = 1/200$

$k_c = [0.5 + 1/n_c]^{0.5}$ but $k_c \leq 1.0$

$k_s = [0.2 + 1/n_s]^{0.5}$ but $k_s \leq 1.0$

and n = no. of columns per plane

n_s = no. of storeys

Columns which carry N_{sd} < 50% mean value of vertical load per column need not be included in n_c

Alternatively use a closed system of equivalent horizontal forces (Fig. 5.2.3 and 5.2.4)

Classification as sway or non-sway

- Non-sway if response to in-plane horizontal forces sufficiently stiff for it to be acceptably accurate to neglect any additional internal forces or moments arising from horizontal displacements of its nodes.

- Non-sway for a given load case if

$V_{sd}/V_{cr} \leq 0.1$

in which V_{sd} = design value of total vertical load

V_{cr} = elastic critical load (sway mode)

- For beam and column type frames, using first order theory, horizontal displacements in each storey due to horizontal and vertical loads plus initial sway imperfection applied in the form of equivalent horizontal forces.

$$\left[\frac{\delta}{h}\right] \left[\frac{V}{H}\right] \leq 0.1$$

Frame stability – elastic analysis

Include for second order effects by either :

- second order analysis
- first order analysis, with amplified sway moments
- first order analysis, with sway-mode buckling lengths

If second-order elastic global analysis is used, member design uses non-sway in-plane L_E values.

Amplified sway moments from :

sway moments from first order elastic analysis factored by $\frac{1}{1 - V_{sd}/V_{cr}}$

Do not use if $V_{sd}/V_{cr} > 0.25$

For beam and column frames

$$\frac{V_{sd}}{V_{cr}} = \left[\frac{\delta}{h}\right] \left[\frac{V}{H}\right]$$

Frame stability – plastic analysis

Plastic global analysis should allow for second order effects → second order elastic plastic analysis

May use rigid plastic approach for:

- Frames of 1 or 2 storeys for which:

  no plastic hinges in columns or columns satisfy $\bar{\lambda} \leq 0.32 (Af_y/N_{sd})^{0.5}$ (ensures rotation capacity)

- Frames with fixed bases with sway failure mode having only column base hinges (Fig. 5.2.8)

For both the above $V_{sd}/V_{cr} \leq 0.20$

Structural Design for Seismic Load in Japan

Design Flow for Building Frame ≥ 45 m

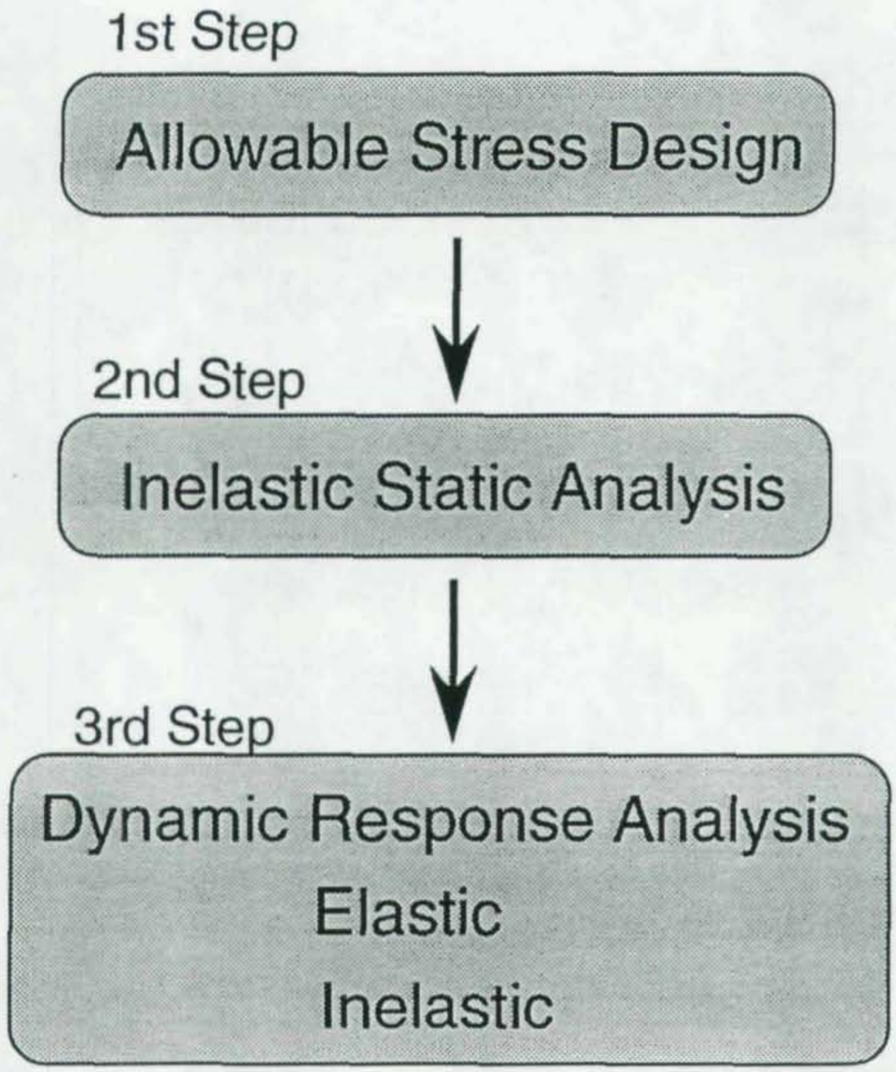
Design Seismic Load

Design Criteria

Inelastic Analysis

Dynamic Analysis

Design Flow for Building Frame ≥ 45 m



Design Seismic Load

Story Shear $Q_i = C_i \cdot W_i$

C_i = Shear Coefficient
W_i = Accumulated Vertical Load

$C_i = Z \cdot R_t \cdot A_i \cdot C_0$

Z = Zone Factor
R_t = Design Spectral Coefficient
A_i = Distribution Coefficient of Story Shear
C_0 = Standard Base Shear Coefficient

Allowable Stress Design

Safety Check against
Moderate Earthquake
$C_0 = 0.2 \sim 0.3$

↓

Check:
- Elastic Behavior
- Story Drift Angle ≤ 1/200
- Distribution of Lateral Stiffness
- Torsion; Distance between Centers of Rigidity and Gravity

Inelastic Static Analysis of Designed Frame

Safety Check against
Severe Earthquake

↓

Method: Incremental Analysis
by Plastic Hinge Method

Check:

Lateral Load Resisting Capacity Q_{ui}
$\geq$ Required Strength Q_{ni}

Q_{ui} = Strength
at Collapse Mechanism State
at Max. Story Drift Angle
equal to 1/100
at Brace Buckling
etc.

$Q_{ni} = D_S \cdot C_i \cdot W_i \quad ; \quad C_0 = 1.0$

Structural Characteristic Factor D_S

Steel Frame:

$D_S =$ *0.25* (Ductile Story)

$\sim$ *0.5* (Brittle Story)

Depends on:

- Width-Thickness Ratio
- Slenderness Ratio for Lateral Buckling
- Joint Condition
- Slenderness Ratio of Braces
- Ratio of Lateral Load Carried by Braces

Dynamic Response Analysis

Ground Motion:
- El Centro *NS 1940*
- Taft *EW 1952*
- Tokyo 101 *NS 1956*
- Hachinohe *NS 1968*
- Local Record

Velocity Level:
25, 50 cm/sec

Damping Constant:
$h_1 = 0.02$

Elastic Dynamic Analysis

Frame Model
(Full-Matrix Model)

↓

Check Design Conditions:
- Fundamental Period
- Story Shear
  - Distribution Pattern
  - Intensity
- Stress Level
- Story Drift Angle
  - $\leq$ 1/200
  - Sway Concentration
- Torsional Vibration

Inelastic Dynamic Analysis

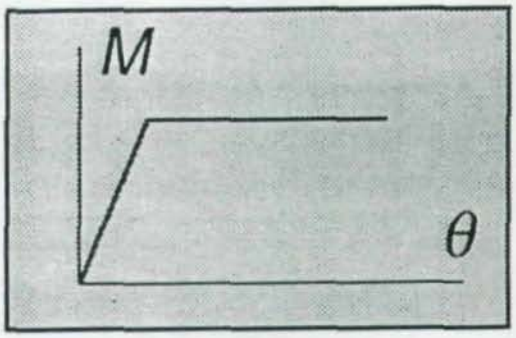
Lumped Mass Model
Tri-linear Elasto-Plastic
Restoring Force

↓

Check for:
- Plastic Hinge Pattern
- Plastic Deformation Ratio
  ≤ 2
- Story Drift Angle
  $\leq 1/100$
  Sway Concentration
- Torsional Vibration

Restoring Force Characteristics

Member:
Bi-linear Model



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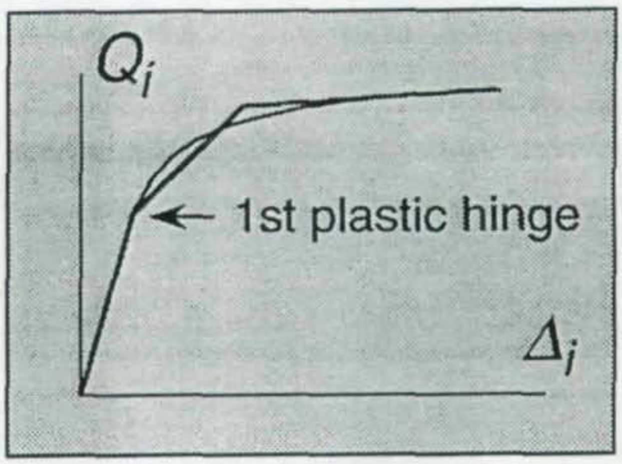
Static Analysis:
Story Shear-Sway Relation



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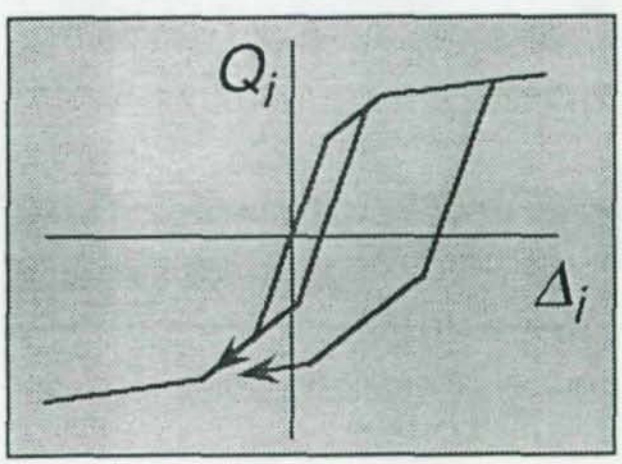
Story:
Normal Tri-linear Model



WORKSHOP 3

DETERIORATED STRUCTURES

SSRC 50th ANNIVERSARY CONFERENCE

WORKSHOP 3 ON DETERIORATED STRUCTURES
22 June 1994

SUMMARY

Moderator: Donald Sherman - University of Wisconsin-Milwaukee
Reporter: Robert Dexter - Lehigh University

INTRODUCTION

There were 19 participants in the workshop from six different countries. Fourteen were affiliated with universities and the remaining five were from industry or government agencies. There were five brief prepared presentations with open discussion throughout the two hour session. Written statements from S.C. Goel, S.X. Gunzelman and J. M. Ricles accompany this summary.

TYPES AND CAUSES OF DETERIORATION

In the discussion concerning the types of deterioration that can occur in structures, it was concluded that more than just physical damage should be considered. The topic should be broadened in scope to include the consideration of any stability problems that can occur in existing structures as opposed to new designs. With this extended definition, the following types of deterioration were identified.

DAMAGE - Local denting or out-of-straightness that produces a condition that members or the structure are no longer within original construction tolerances.

ENVIRONMENTAL - Conditions that lead to loss of cross section in members or alterations of joint characteristics that change the boundary conditions of members.

LEGAL - Changes in applicable codes or in the function of the structure that produce different loads or criteria.

ERRORS - Either design or construction errors that are not detected until after the structure is built.

Several causes of damage or environmental types of deterioration were identified. These were divided into categories of every day usage and catastrophic events.

EVERYDAY USAGE

REPETITIVE LOADS - This includes cyclic loads from equipment, random load variations or other repetitive loads that can produce fatigue conditions.

CORROSION - Environmental conditions can lead to loss of section or deterioration of joints.

LACK OF MAINTENANCE - This could lead to corrosion, build up of material in joints or structural misalignments due to use of equipment (e.g. cranes)

CATASTROPHIC

IMPACT - Impact damage occurs from moving vehicles or falling objects.

SINGLE OVERLOAD - Hurricanes, tornados or unusual vehicle or equipment loads.

SEISMIC EVENT - Severe horizontal cyclic loads on the structure

FIRE - Twisting or bending of members beyond construction tolerances but not to the degree where replacement is obviously required.

BLAST - Explosions that occur either from industrial accidents or intentional bombing.

Any type of steel structure could require evaluation due to errors or changes in loadings and applicable codes. Deterioration in various forms could occur in many types of steel structures. However, the frequency of types or causes of damage is more prevalent in different structure categories.

BUILDINGS - Exposed columns in industrial buildings and parking structures are frequently subject to vehicle impact and are potentially subject to environmental deterioration. Industrial buildings are also subject to maintenance, overload or cyclic load problems. Any type of building can experience fire, blast or seismic damage. Seismic damage is the most prevalent and most commonly affects braces and joints in steel buildings.

BRIDGES - Vehicle impact frequently occurs in members of bridges. Corrosion and maintenance problems are also frequently encountered. Other source of damage often affect bridge supports and foundations, but these are not within the scope of stability of metal structures.

OFFSHORE STRUCTURES - Work platforms are subject to any of the types or causes of damage that have been identified.

LIFELINE STRUCTURES - Seismic events can damage pipelines and towers. Pipelines are also subject to corrosion or accidental impact from moving equipment. As exposed structures, towers are subject to environmental damage.

Starting 50 years ago, offshore structures were originally designed for a 30 year life and to withstand a 25 year wave. Now there is an interest in extending the life of older platforms and the design criteria is a 100 year wave. However, hurricane Andrew took out many of the older structures in the Gulf. Bridges were also commonly designed for 30 to 50 year lives. Bridge loadings have increased considerably over this period and many existing bridges are over 50 years old. As in the case of buildings, many of these older structures have survived and continue to function with loadings well beyond their original design loads because of very conservative design practices. With modern analysis methods and refined criteria, older structures can frequently be shown to still be adequate.

ASSESSMENT

Once it has been determined that a member or structure is in a deteriorated condition, a decision must be made on selecting one of three options:

1. Leave it as is since it can perform its function in a satisfactory manner.

2. Rehabilitate to improve its condition so it will perform satisfactorily.

3. Replace the member, subassemblage or entire structure.

Although analysis for re-rating bridges has been common practice for many years, general methodologies for assessment are still in formative stages. A draft of a section of API RP2A (Offshore Platforms) has been prepared that presents a general strategy. Similar studies for cracks in bridge structures are also underway. Essentially the strategy consists of sequence of classifications of the severity of deterioration and its consequences. Each stage increases in complexity. If the results are satisfactory in any stage, the deterioration is dismissed. If not, proceed to the next stage. The stages are:

1. Gather data to document the severity of deterioration.

2. Screen the information and make an experience judgement as to whether the deterioration might be severe enough to limit the function of the structure.

3. Consider the effects at working stress levels.

4. Perform an ultimate strength analysis. Simple and conservative analyses are used first and increasingly complex analyses are used if necessary to demonstrate a margin against failure; e.g.

    a) Elastic analysis without safety factors and using mean yield strengths.

    b) Detailed local analysis if few members are involved.

    c) Global analysis (eg. pushover in the case of offshore platforms)

5. Design the required rehabilitation or replacement.

At any stage the economics of proceeding must be considered. It may be less expensive to rehabilitate or replace than to proceed with the assessment.

Parameters to be considered in the evaluation and assessment are the location of the deterioration in a member and in the structure, severity, structural type (e.g. degree of redundancy), consequences of failure. Included in the latter are considerations of whether the structure is manned, possible evacuation of personnel with adequate storm warnings, potential environmental pollution and economic importance of the structure.

Although knowledge of the reserve strength of an individual member is important, primary consideration must be given to its effect on the total structure. Therefore, information on its altered stiffness must be known for an elastic analysis and nonlinear characteristics are required for an ultimate strength analysis. If there are many sources of out-of-tolerance in the structure, it can add up to potentially dangerous situation. In an ultimate strength analysis, there is the possibility of a complex analysis to determine a beta or reliability factor for the structure. Although this is an option for engineering decisions, reference to reliability or probability of survival should be avoided when dealing with the public; the public wants a clear statement that the unrepaired or rehabilitated structure is reliable.

Inspection is an important part of the assessment process especially when deterioration is caused by everyday events. In any assessment, it is important to determine the root cause of deterioration so that simple repair does not lead to recurring problem. As an example not directly related to stability, a crack caused by overload during installation can be rewelded, but fatigue cracks should not be simply rewelded.

REHABILITATION

Tubular members have been rehabilitated with internal grouting and external sleeves or clamps to encase the damaged section with grout. Fiber-reinforced concrete and shotcrete have been used to encase buckled web members in open-web joists to obtain stable hysteresis loops. The object of grouting is to stabilize local buckles or dents so they do not grow under subsequent static or cyclic loads. However, research has shown that there is a limiting dent depth and out-of-straightness beyond which the original strength of the member cannot be regained. Grout has also been used to reinforce connections.

In bridges, rehabilitation frequently involves increasing capacities and widths in addition to repair of physical deterioration. Several strategies from both bridge and offshore experiences were mentioned.

Replace members with higher strength steel
Add additional braces to compression members
Cantilever structural additions to increase widths
Post-tensioning schemes
Internal or external grout
Insert piles in tubular members with grouted annular space
Intentionally flood tubular members to reduce external pressure
Reduce loads by removing unnecessary appendages that catch drag forces
Control marine growth that add to diameters by starfish colonies

CURRENT RESEARCH

Offshore industries have directed research efforts toward the evaluation of deteriorated tubular members. Circular tubes are manufactured to close tolerances due to stability related imperfection sensitivity. Damage, particularly in the form of local dents, can cause considerable loss of strength under axial loads or bending moments. Several detailed reports that include experimental data are available. Some information is available on axial load-shortening curves for virgin, dented and repaired tubular members. An example was cited where a member was corroded with a hole completely through the wall, but the buckle in a laboratory test occurred at another section with reduced thickness.

Due to the large number of parameters and the expense of testing, considerable effort has been made to develop analytical methods for determining behavior and reserve strength. These are finite element analyses that include highly nonlinear behavior and large geometric distortions. The results are correlated with experimental data and the programs can then be used for parametric studies. Moment-curvature-axial load calibrations have been made with dent depths up to 20% of the diameter. To date most of the analytical research work has been on how to analytically model members with out-of-straightness and local cross section changes.

Steel bracing in building is another area where research has been conducted. The Mexico City earthquake revealed the serious consequences of local buckling and the recent Northridge earthquake has been a real wakeup call. Tests have indicated that once a local buckle forms, the strength of a member under subsequent cyclic loads is severely affected. Hysteresis loops become unstable and the member may fracture after very few cycles. As a result, compact section requirements for braces in buildings subject to seismic conditions have been made more restrictive in recent years. Assessment of brace connections must consider out-of-plane eccentricities resulting from post-buckling deformations. Out-of-straightness is not as great a factor as local buckling, so that tension braces are acceptable if local buckling is prevented. Due to the sensitivity of bracing to local damage, there is some thought of eliminating the use of concentrically braced frame in seismic regions. However in real structures as opposed to lab tests, columns take over and loads can continue to increase. Although there is some concern in having the columns take over, it may be acceptable for emergency reserve capacity, similar to the strong column/weak beam concepts in plastic design.

NEEDED RESEARCH

The whole area of dealing with deteriorated structures is still in the early stages of development, and considerable research is needed for economical and efficient assessment and rehabilitation.

EXPERIMENTAL - Tests are required to determine the behavior and reserve capacity of various types of deterioration to different types of members. These tests are needed to provide a baseline for analytical predictors. Tests are also required to provide information on innovative methods for repairing deterioration.

ANALYTICAL - Further research is needed to develop reliable, efficient and economical analytical methods to determine reserve capacities and behavior of damaged members of various cross sections. The complete nonlinear behavior of members, including the descending branch, must be known in order to conduct collapse analyses of the entire structure.

PRACTICE - Information is needed to classify which dents (severity and location) or other types of deterioration can be accepted. General methodologies must be developed for assessing older structures. A good exchange of information is required so that successful methods of assessment and rehabilitation are widely known.

SSRC WORKSHOP ON DETERIORATED STRUCTURES - (June 22,1994)

SEISMIC DAMAGE POTENTIAL AND UPGRADING OF STEEL STRUCTURES

By
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Northridge earthquake of January 17, 1994, is the first major earthquake to occur in the middle of a heavy populated area, thus, causing serious damage to almost all types of construction, both new as well as old. Unprecedented widespread damage to steel building structures has received special attention, including moment frame connection failures as well as bracing member failures in some concentric braced frame structures.

Unlike lateral forces due to wind, design earthquake forces are somewhat fictitious. Due to reasons of economy, code specified lateral seismic forces are generally a fraction (in the order 1/10) of lateral inertia forces that would be induced in a structure if it were to remain elastic during a major earthquake. Therefore, in the event of such an earthquake, code designed structures are expected to undergo large cyclic deformations far beyond their elastic limits, causing severe cyclic yielding and buckling at local, member and connection levels. Compactness requirements of member cross sections and lateral bracing requirements become very important. If a steel structure experiences a major ground shaking during its service life, such yielding and buckling in critical elements is expected to occur.

Because of evolving nature of design codes based on available knowledge at a given time, there is need for evaluation and upgrading of existing structures for survival during future earthquakes. Filling of hollow box sections of critical members with concrete or encasement of slender elements with fiber reinforced concrete are among possible techniques available at present for mitigating the detrimental effects of buckling at local or member levels. For new structures, preferred design philosophy leans toward minimizing structural damage in addition to the primary goal of providing life safety during a major "design level" earthquake. Strong column-ductile girder framing systems, systems with controlled "yield" mechanisms by using limit analysis and design methods, and use of active and passive vibration control techniques are some of the possible techniques that are currently available.

DETERIORATED STRUCTURES

AN OFFSHORE INDUSTRY PERSPECTIVE

by
Stephen X. Gunzelman (Brown & Root, Inc.)

An overview of deteriorated structures in the offshore oil industry environment was presented. The causes of deterioration of typical offshore oil platforms were listed. These include ship impact, dropped objects (e.g. pile sections during installation), design environmental events (e.g. hurricane, seismic and arctic ice events), blast and fire, corrosion, and cyclic loadings (e.g. waves and reciprocating equipment in the decks). One rather unusual cause was also noted -- that of fishing with explosives immediately adjacent to platforms in the offshore region of West Africa. The resulting types of deterioration range from the local denting and associated out-of-straightness of tubular members to the reduction of cross-sectional material via corrosion to general deformation due to loading across the entire member, arising from sources such as extreme storm waves or thermal forces from a fire.

The offshore oil industry has adopted the philosophy that the criteria for assessing deteriorated structures should be consequence-dependent. Is the platform manned or unmanned? Would the environmental impact of a failure be significant? What is the relevance or importance of the deteriorated component to the overall structural behavior of the platform? The assessment methodology is a step-by-step process. First, data is gathered as to the dent geometry or other appropriate characterisistics of the deterioration. Then, the affected members are screened as to whether the deterioration is a potential local and/or global issue. Finally, the effects of the deterioration are assessed at the working stress level, and, if the check fails at the working stress level, then an ultimate strength analysis is performed.

The ultimate strength analysis would be carried out in stages as well, and, if the structure passes any stage, the assessment can be considered complete at that point. First, an elastic model with all safety factors removed and which uses the median or measured yield stresses can be analyzed. If this model still indicates a problem, then a global overload analysis can be performed where the environmental loadings are incremented using a nonlinear analysis tool such as Abaqus.

If the ultimate strength analyses still show that the structure is not capable of handling the deteriorated components, then there are various mitigation methods that can be undertaken. These include the following:

1.) Reduce the vertical loads by, for example, not installing future equipment or drilling from a cantilever jack-up rig that is separate from the main platform.

2.) Reduce the lateral loads by, for example, removing boatlandings and unused risers, conductors and launch members to reduce wave loading or by periodically removing marine growth by using water jetting or other methods.

3.) Strengthen the deteriorated member by grouting either internally or externally between the damaged member and a clamped sleeve.

4.) Replace the member. Replacement underwater is expensive in any case, but, below about a 300 ft. water depth, this may require a diverless operation which adds even more expense.

5.) Miscellaneous other methods might be worthwhile depending on the nature of the overstress such as using insert piles or soldier piles, intentionally flooding members where hoop-type buckling is an issue, and installing guylines on free-standing caissons.

The American Petroleum Institute (API) has completed a draft version of Section 17 of its recommended practice document RP2A-WSD. This new Section 17 is entitled "Assessment of Existing Platforms", and it describes many of the concepts outlined in this presentation. API anticipates that Section 17 will loose its draft status and become official by the end of 1995.

WORKSHOP 3 - DETERIORATED STRUCTURES

BEHAVIOR, ANALYSIS AND REPAIR OF DENTED MARINE PLATFORM BRACINGS

James M. Ricles[1], Took Kowng Soo[2] and William M. Bruin[3]

ABSTRACT

The results of an ongoing research study related to the residual strength of dent-damaged steel tubular bracing in offshore platforms are presented. Large scale experimental and analytical studies indicate that a significant reduction in strength occurs due to dent damage. Two repair methods using grout are demonstrated to restore the capacity of dented members.

INTRODUCTION

In the United States alone, there presently are over 3500 major offshore platforms. Surveys have shown [Dunn, 1983] that a majority of them have some form of damage, including brace member denting due to collisions with either dropped objects or vessels. Knowledge of the residual strength and repairability of these members are highly relevant to the reassessment and requalification of the platforms.

Experimental and analytical research on the residual strength of steel tubulars with dents has been conducted since the late 1970's. An up-to-date summary of the previous work is provided by Ricles et al [1992]. Most of the experimental work has been done on small scale specimens, where the diameter D is less than 76 mm and the dent depth d_e is less than 0.2D. Fewer tests have been conducted to study the behavior of repaired bracing members. This paper presents the results of an analytical and experimental study on the residual strength and repair of dented tubular marine platform bracings. Large scale tests were conducted on specimens with dent depths of 0.1D that were unrepaired and grout repaired, respectively. Analysis were conducted to predict and assess unrepaired specimen behavior, as well as to evaluate the effects of deeper dent depths and global out-of-straightness combined with dent damage on member residual strength.

EXPERIMENTAL TEST PROGRAM

The experimental test program consisted of the 13 test specimens listed in Table 1.

---

[1] Associate Professor of Civil Engineering, [3]Research Assistant, Lehigh University, 117 ATLSS Drive, H Building, Bethlehem, PA 18015-4729. Member, ASCE.

[2]Research Engineer, ATLSS Engineering Research Center, Lehigh University, 117 ATLSS Drive, H Building, Bethlehem, PA 18015-4729. Member, ASCE.

Non-damaged, dent damaged, and grout repaired dent damaged specimens having diameter-to-thickness ratios of D/t=34.5, 46 and 64 were tested. The repaired specimens were either grouted internally (Specimens A3, B3 and C3) or grouted externally between the member and a steel sleeve (Specimen C4). All specimens had a nominal diameter of D=219 mm, and a slenderness ratio of kL/r=60. The testing of the specimens in the test matrix enabled a direct comparison to be made between the strengths of: non-damaged and unrepaired dented members; non-damaged and grout repaired members; and grout repaired and unrepaired dented members.

The dented specimens were damaged under controlled conditions; a blunt headed steel wedge was slowly displaced into the side of the tube at mid-span to obtain the dent depth of d_d=0.1D. During the denting process, the member was continuously supported along 609 mm to each side of midspan in order to minimize development of global out-of-straightness damage. The out-of-straightness δ_p following denting was less than 0.0012L, where L is the specimen's length (4542 to 4572 mm). The material properties for each specimen, consisting of steel tensile strength σ_y and grout compression strength f_g' were also measured and are reported in Table 1. All specimens were tested in the self-reacting 2224 kN test frame shown in Figure 1. Frictionless spherical bearings were used to obtain pin-ended specimen boundary conditions. Repaired specimens and similar undamaged and unrepaired, dented specimens were tested under applied axial load with an end eccentricity of e=0.2D.

The normalized axial load-axial shortening response of specimens having D/t=64 and eccentrically applied axial load is shown in Figure 2. In general, it was found that a dent depth of 0.1D significantly affected the member's capacity, where the residual strength of the unrepaired dented specimens ranged from 50% (Specimen B2) to 71% (Specimen C2) of the strength P_o of their corresponding non-damaged specimens (Specimens B5 and C5), respectively. Unrepaired Specimen A2 had a residual strength of 59% of the undamaged strength of Specimen A5. As shown in Figure 2, both the internally grout repair (Specimen C3) and grouted sleeve repair (Specimen C4) reinstated the strength of damaged members of D/t=64. A comparison of the repaired strength P_r with the unrepaired residual strength P_{exp} and the undamaged strength P_o for corresponding specimens of the test matrix is given in Table 2. The comparison indicates that the internal grout and grouted sleeve repairs resulted in a substantial increase in strength above the non-repaired strength, reinstating the member to its full non-damaged capacity.

Internal grout and grouted sleeve repairs were successful because they inhibited the dent from growing inwards, as shown in Figure 3 for specimens with D/t=64. Non-repaired specimens had significant inwards dent growth, leading to local instability and overall failure. Repaired specimens had the steel tube develop yielding and fail by subsequent outward local buckling. Although not tested, it is expected that specimens with smaller D/t ratios than 64 with dent depth of 0.1D could also be successfully repaired by a grouted steel sleeve.

ANALYSIS OF NON-REPAIRED MEMBERS

Analysis of the non-repaired specimens was conducted in order to evaluate and calibrate selected analytical methods. These methods were then used to conduct a parametric study to assess the effect of deeper dent depth and combined dent with out-of-straightness damage, respectively, on residual strength under concentric axial loading. The analytical methods include an integration method [Chen et al. 1987] using a displacement control algorithm [Mathew et al. 1993] in conjunction with empirical moment-curvature-thrust (M-P-Φ) relationships of Duan et al. (1993) for dented and undented segments, respectively, of the member. The dented member was discretized into 50 segments, with 2 segments used to model the dent. The M-P-Φ relationship for the dented segments is shown in Figure 4. This method provides, in addition to member ultimate capacity, information on load-deformation response. A second approach, the non-linear finite element method (FEM), was also used to produce ultimate capacity and load-deformation response. For this purpose, the commercially available finite element program ABAQUS (1989) was used. The finite element analysis was based on the updated Lagrangian formulation, with Green's strain and second Piola-Kirchoff stress to account for large displacements. The von Mises yield criterion with isotropic strain hardening was used to model the inelastic material behavior. Taking advantage of symmetry in boundary conditions, the finite element model consisted of a mesh with 1319 nodes and 405 eight-noded shell elements. The finite element analysis involved four stages, similar to the experiments, namely: 1) loading of a knife edge indentor to create the dent, supporting the member to prevent imposing out-of-straightness damage; 2) unloading of the indentor; 3) removal of the indentor and associated support from the model, as well as specifying the pin-ended boundary conditions; and 4) imposing the axial load, utilizing the modified RIKS solution scheme to solve for the non-linear force-deformation response of the member. The finite element model of a specimen is shown in Figure 5.

A comparison between the experimental and the predicted behavior of Specimen B1 by the two analytical methods is shown in the axial load-shortening plot of Figure 6. The predicted responses by the FEM and integration method agree closely with the experimental results. The analyses were stopped at an axial shortening of Δ=0.001L, where L is the member's length.

The FEM analysis overpredicted by 8% and the integration analysis underpredicted by 4% the experimental residual strength P_{exp} of Specimen B1. A summary comparing the analysis results with the experimental capacities is given in Table 3. The FEM and integration analyses had a maximum discrepancy of 10% and 12%, respectively, with the experimental results (Specimen B2). Overall, the agreement between the predicted and experimental results is good, particularly in the other specimens which exclude Specimen B2.

The effect of dent depth d_d on the brace capacity, P, predicted by both the FEM and numerical integration method is shown in Figure 7 for members having D/t=34.5, 45 and 64. In Figure 7, P_y represents the members' yield capacity. Both methods show a significant decrease in capacity as the dent depth d_d is increased. Furthermore, for a given dent depth, members with higher D/t ratios are shown to have a lower capacity. A discrepancy exists between the analytical methods. The FEM predicts a lower and higher residual strength P for the braces with D/t=34.5 and 64, respectively, compared to the numerical integration method. This discrepancy is associated with the empirical nature of the M-P-Φ relationships used in the integration method. It is believed that the FEM results are more accurate.

The effects of global out-of-straightness δ_p due to denting on the capacity of dented braces having d_d/D=0%, 10% and 20% is shown in Figure 8. These results were produced using the numerical integration method, and show a significant decrease in brace capacity as the out-of-straightness δ_p is increased. The effect is more pronounced for braces having smaller dent depths.

CONCLUSIONS

The experimental results show a significant decrease in brace member capacity associated with a dent depth of 0.1D. Internal grout repair and grouted sleeve repair were both able to prevent dent growth under axial loading, leading to a reinstatement of the member's strength. The non-linear finite element method and numerical integration method were both able to reasonably predict the behavior of the unrepaired specimens with dents. Analysis indicates that deeper dent depths, and combined dent and out-of-straightness damage, has an even more significant effect on a member's capacity. Current research at the

ATLSS Research Center at Lehigh University is experimentally investigating these phenomena. In addition, analytical studies are being conducted on grout repaired dented members. The loss of strength, repair and analyses of dented members is an important issue, particularly in reassessing and requalifying existing offshore platforms.

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Table 1. Experimental Test Matrix

Specimen	D/t	e	d_d/D	σ_y [MPa]	f_g' [MPa]	Comments
A1	34.5	0	0.1	240	-	Non-repaired
B1	46	0	0.1	230	-	Non-repaired
C1	64	0	0.1	272	-	Non-repaired
A2	34.5	0.2D	0.1	240	-	Non-repaired
B2	46	0.2D	0.1	230	-	Non-repaired
C2	64	0.2D	0.1	272	-	Non-repaired
A3	34.5	0.2D	0.1	240	30.2	Internally Grout Repair
B3	46	0.2D	0.1	230	26.8	Internally Grout Repair
C3	64	0.2D	0.1	272	47.5	Internally Grout Repair
C4	64	0.2D	0.1	272	42.1	Grouted Sleeve Repair
A5	34.5	0.2D	0	240	-	Non-damaged
B5	46	0.2D	0	230	-	Non-damaged
C5	64	0.2D	0	272	-	Non-damaged

Table 2. Comparison of Repaired and Unrepaired Specimen Capacities.

Specimen	P_r [kN]	P_r/P_{exp}	P_r/P_o
A3	850	2.10	1.23
B3	520	2.25	1.13
C3	543	2.65	1.88
C4	329	1.61	1.14

Table 3. Comparison Between Experimental and Predicted Ultimate Load.

Specimen	D/t	P_{exp} [kN]	P_{exp}/P_{pred}	
			FEM	Numerical Integration
A1	34.5	627	1.01	0.98
A2	34.5	405	1.02	0.97
B1	46	440	0.92	1.04
B2	46	231	0.90	0.88
C2	64	205	0.92	1.00

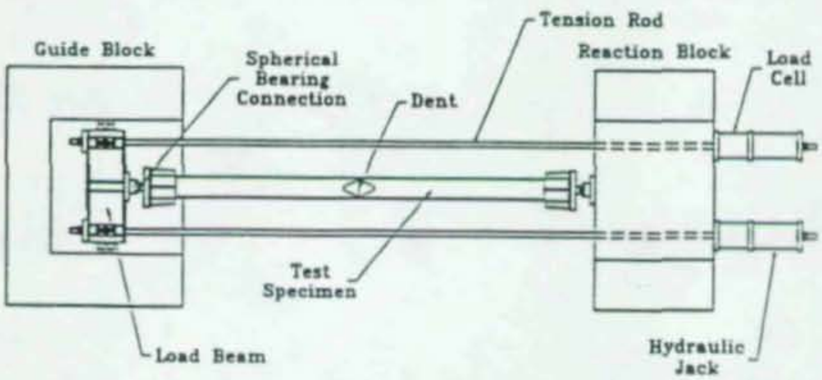

FIGURE 1 PLAN VIEW OF EXPERIMENTAL TEST SETUP

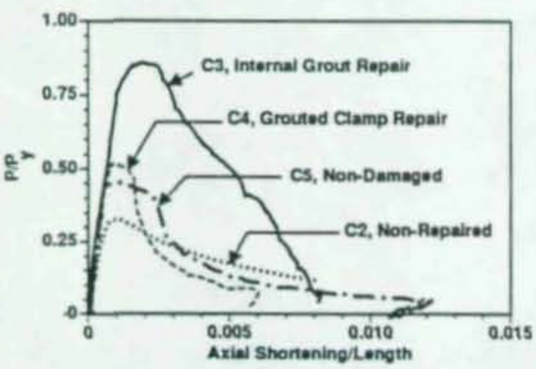

FIGURE 2 AXIAL LOAD-SHORTENING RESPONSE, SPECIMENS WITH D/t = 64

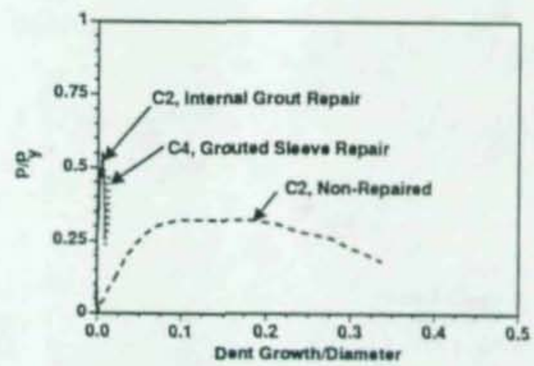

FIGURE 3 DENT GROWTH-AXIAL LOAD RESPONSE, SPECIMENS WITH D/t = 64

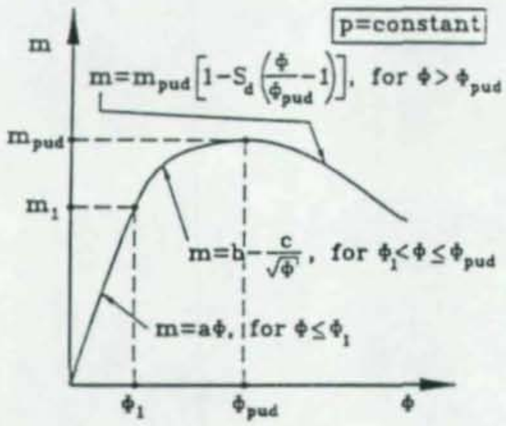

FIGURE 4 M-P-Φ RELATIONSHIP FOR DENTED TUBULAR SECTIONS

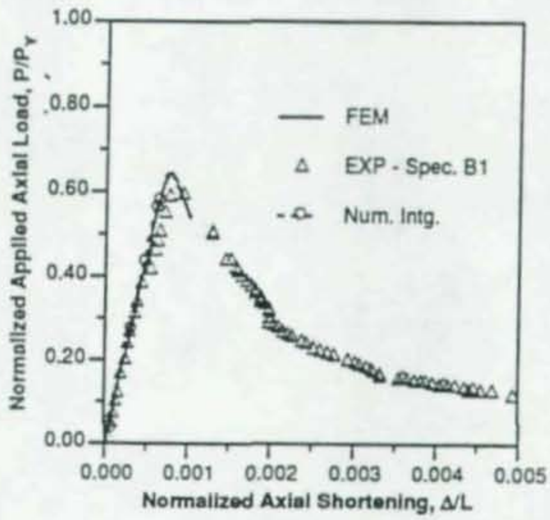

FIGURE 6 COMPARISON OF AXIAL LOAD-SHORTENING RESPONSE, SPECIMEN B1

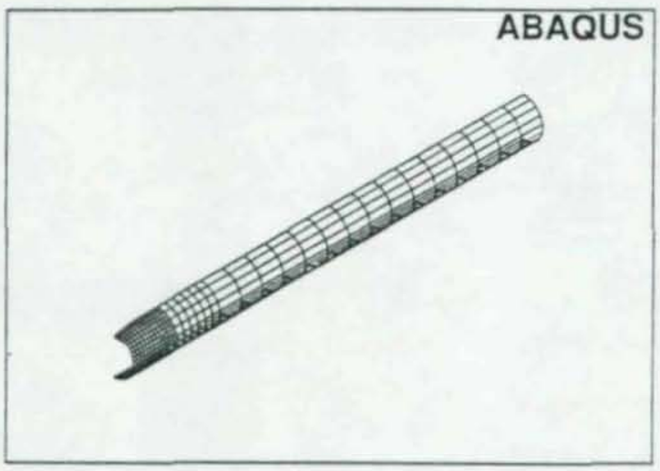

FIGURE 5 FINITE ELEMENT MODEL FOLLOWING DENTING STAGE

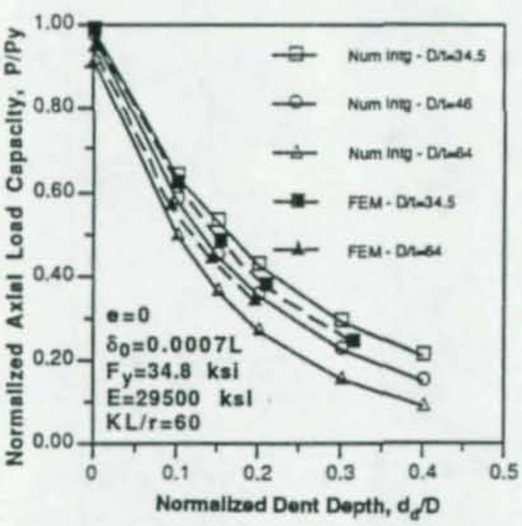

FIGURE 7 EFFECT OF DENT DEPTH ON RESIDUAL STRENGTH

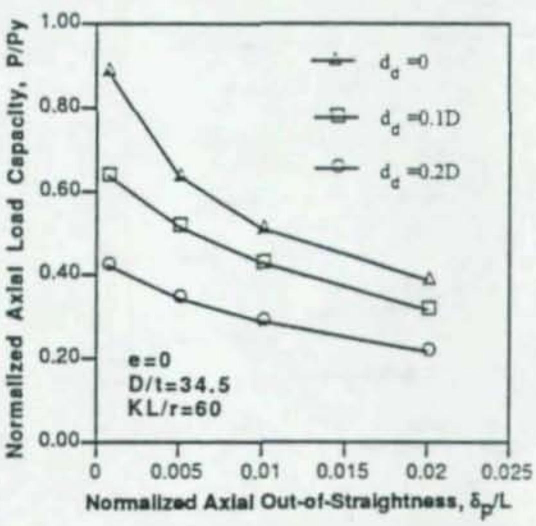

FIGURE 8 EFFECT OF GLOBAL IMPERFECTIONS ON RESIDUAL STRENGTH

WORKSHOP 4

INFORMATION DISSEMINATION

TECHNOLOGY TRANSFER

AND

INFORMATION DISSEMINATION

by

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1. INTRODUCTION

Successful engineering research is characterized by implementation into practice, whereby the end users have the opportunity to make actual use of the developments and new data that have been provided by the researchers. Only when this goal has been achieved can the work be regarded as completed. In other words, research for its own sake is a contradiction in terms for all engineering disciplines.

On this background, information dissemination (ID) and technology transfer (TT) are essentially one and the same. Traditionally, however, ID has come to be understood as the publication, in whatever form, of details of the research work, including background studies, theoretical and experimental analyses, verification of models, and implications and utilization of the findings. Sometimes application recommendations are made for end users; in other cases it is left to the recipients to make whatever use of the results that is deemed suitable. The literature contains a very large number of publications of this kind.

TT, on the other hand, is most often thought of in conjunction with the development of new materials, procedures, or devices. The products may or may not be patentable, but in all cases it is the aim of the developer to bring the development to market in an economically viable and competitive form. Examples abound in the marketplace of today, and new products see the light almost on a daily basis.

Efficient ID and TT encounter a number of potential problems, as follows:

Expedience of Delivery: Getting the information out in expedient fashion depends somewhat on the type of research and who the presumed end user(s) are.

Information Outlets: The multitude of information outlets and outlet types presents a challenge to the researcher, because the eventual acceptance hinges on getting the information out in forums that are used by the potential clients. It matters little if a new solution approach is published in a journal, for example, that is read exclusively by other researchers. Further, the information dissemination environment has been changing very rapidly over the past decade, especially because of electronic media and similar forms of communication. The *electronic information highway* is likely to have very significant impact on all forms of ID and TT.

Acceptance of Information: A key area of concern, acceptance of the results or products by any number of interested individuals or groups ("peers") is critical to the eventual implementation. Further, for many engineering research results final acceptance depends on their incorporation into design codes or standards, providing a form of official *imprimatur*.

Use of Information or Products: Regardless of peer or code acceptance, getting the results or devices actually to be used in practice is a major hurdle. For a new method of design, for example, engineers must be convinced that it will lead to improved safety or economy, or that it will place them in a favorable competitive position. For a new product, it is essential to demonstrate market and income-producing potential, for investors as well as end users.

2. THE KNOWLEDGE RETURN PERIOD

All of the above point to critical elements in the information dissemination process. In addition, coining the term *knowledge return period*, long-term experience has demonstrated that information may be accepted and even well known for some time, during which specific problems are solved and suitable design methods are devised. However, several years later needs for similar information may arise, but the availability of proven techniques or products has somehow disappeared or been forgotten.

The demands of everyday work and the sheer volume of information make this situation understandable, but it is nevertheless a significant problem. There is no need "to reinvent the wheel", but at the same time it is critical to recognize that even the best knowledge has a finite life of usage. Examples of problems abound, where known solutions were in fact available in the public domain, yet did not reach or otherwise come to the attention of the individual(s) responsible for the design or the product development. The Quebec Bridge disaster is a prominent example; Engesser's compression member design procedure had been published approximately 20 years earlier.

Experience has shown that the *knowledge return period* is approximately five to seven years, after which it is quite likely that the information is shelved or otherwise forgotten. A reoccurrence of problems may bring it to the fore again, but often only after considerable duplicate work and expense. This needs to be a key issue for researchers and end users alike; it can only be solved by vigilant attention to continuing education and thorough and efficient dissemination of information. The expansion of electronic communication holds significant promise, through the use of bulletin boards and similar means.

3. AIMS OF INFORMATION DISSEMINATION

3.1 Ongoing Research

While information regarding completed research work is clearly more important, communication about ongoing studies needs to be an integral part of the dissemination process. This may take the form of informal review groups and project advisory committees, with membership from academia as well as interested industrial organizations and government. For larger projects it is also useful to issue newsletters about staffing, progress, and important new developments.

Such modes of communication aim for feedback and other input from peers, including rational critiques of methods and means, providing additional ideas, interpretation of results, and suggestions for applications. In addition, the benefit of allowing colleagues to be aware of current studies ensures that overlap and costly duplication of work can be avoided.

It is clear that an active program of information dissemination as the work progresses will be of significant help. The process will be improved through constant attention to distribution networks, via professional and industrial societies, personal interaction with colleagues, and other means of maintaining data bases for interest groups. Electronic bulletin boards can serve very useful purposes in these efforts.

3.2 Completed Research

Through research reports and various journal and other papers, traditional communication on completed projects aims at getting the information to fellow researchers and practicing professionals. Such publications detail key elements of the studies, rationales, findings of theory and experimentation, practical implications, recommendations for practical usage, and suggested design and code criteria.

The common methods of information dissemination include all forms of written and oral contributions. While this is satisfactory in and of itself, distribution networks have a tendency to be very limited, with the result that there may be large potential user groups that are not aware of the new developments. "Word of mouth" communication is inefficient and impractical, especially in view of the tools of multi-media presentations that are now commonly used for any number of business programs.

Finally, presentations of research results are traditionally made in manners that are not conducive to catch the attention of many user groups. That is, whereas the findings may be scientifically correct and pleasing to the researcher, the form of delivery often prevents access by users who may not be as technically proficient as the originator. This is clearly one of the reasons for the gap that appears to exist between academia and practice, and may ultimately prevent acceptance and adoption. Obviously both sides of the gap end up losing in the process.

4. TECHNOLOGY TRANSFER

As noted in the introduction, technology transfer and information dissemination are basically one and the same, although traditional, current understanding of the two focus on different products. Specifically, TT reflects *technology* developments, such as found in new devices, processes or other industrially oriented developments. Further, TT involves prototype evolution and its eventual translation into a marketable, saleable commodity.

Under the TT banner, new applications or devices often reflect novel uses of existing knowledge, although numerous examples also can be found of rapid translation of original, basic knowledge into industrial products. For example, the entire electronic media market evolved rapidly from the invention of the transistor and related products; the discipline of genetic engineering evolved from an array of basic research projects dealing with the biology of genes.

However, by any measure, the transmission of new information, whether through printed and other media or through the availability of new products and processes, focuses on getting from the originator to the user. In that respect ID and TT are identical.

5. MEANS AND METHODS OF INFORMATION DISSEMINATION

Due to the rapid evolution and expansion of communication through all forms of electronic media and similar outlets, information dissemination is likely to see significant changes over the next several years. Some observations on means and methods are offered in the following.

5.1 Technical Papers and Reports

There will continue to be a large number of individuals who prefer to study materials in the familiar fashion. The traditional forms of dissemination through journal papers, conference proceedings and technical reports are therefore likely to be maintained, if for no other reason than the convenience of having "hard" copies of the documents. Some changes may occur in the way libraries store such publications; storage space demands and financial needs may force documents to be available primarily via microfilm or similar facilities.

Over the years a number of specialized journals have been developed; these address specific, but limited audiences, and broad distribution is further hampered by high subscription costs. Annual rates of more than $1,000 are not uncommon; such figures strain library budgets severely, and often result in cancellations.

Depending on the nature of the research that has been conducted, distribution of reports, in particular, may also be restricted because of sponsors' requirements (government or industrial secrecy demands, for example). In addition, research reports usually reach only small groups, although they may have been cited in journal papers, for example. From a distribution and wide dissemination standpoint, reports are therefore the least effective form of communication.

The most thorny, and probably unsolvable, problem remains the need to get other researchers and especially practicing professionals to *read* the documents that have been made available. This is clearly one of the key reasons for the short knowledge return period.

Although desirable for a number of reasons, traditional paper and report publication is therefore the least efficient means of information dissemination.

5.2 Textbooks, Monographs and Manuals

Historically the most common outlet for information in any form, books also are rarely completely up-to-date, due to the time needed for writing and production. However, they offer the advantage of having sizeable amounts of information on subjects within well-defined areas, and as such have a tendency to become better known and more authoritative as time passes. This serves the information dissemination needs well for basic sciences and theory of elasticity, for example, since concepts and methods have long been established and accepted.

A monograph fills some of the same needs, although the volume of the contents that is up-to-date diminishes rapidly with time. Nevertheless, such a book has the advantage of being a collection of established information, offering users much material in a condensed space.

Manuals and similar handbooks are rarely state-of-the-art, since information that is presented in such books usually will have had to meet the combined test of time and practice. For an engineering design manual, for example, the methods and criteria that are presented must meet the requirements of standards as well as professional practice. Both tend to lag significantly behind current research findings. In fact, the time needed to go from research to standard to accepted practice can be as long as 15 to 20 years.

5.3 Newsletters and Technical Bulletins

Potentially very useful devices of information dissemination, newsletters and technical bulletins tend to be used in far too limited fashion. The significant advantage of such current, more short-term notice publications is that they are frequently able to present almost day-to-day developments. Larger research institutions or even research projects have made effective use of such tools of communication, allowing them to be particularly well positioned for technology transfer regarding devices and the like.

These types of publications should also be considered excellent outlets for new developments on applications of theory, specific design methods, analysis procedures, fastening devices, and so on. With appropriate distribution lists and mechanisms, information dissemination of this kind is possibly the most expedient, especially as far as many engineering applications are concerned. Their disadvantage is that the information that is presented is often simply too new; however, this is readily recognized by end users who are looking for short as well as long term uses of recent findings.

5.4 Electronic Media

For current and future modes of information dissemination, nothing equals the potential of the electronic media. Current uses include electronic bulletin boards, user groups and other applications of e-mail, disk distribution networks for new software, and CD-ROM usage. Additional applications are almost limitless.

Book and journal publishers and other organizations are also positioning themselves for the changes that are taking place. For example, many journals now encourage authors to submit manuscripts electronically, as do book publishers, research funding groups, and others.

There is no question that the almost instantaneous transmission of new developments will aid significantly in getting processes and products evaluated and tested at an early stage. The communication facilitates and encourages feedback between originators and potential users, allowing constant updating and upgrading of the work that is being done.

For the practicing professional the advantage of being able to communicate directly with researchers and other developers of new information cannot be overemphasized. That is, what often used to require months or years to attract the attention of large user groups may now be accomplished in weeks. Most importantly, the information is getting to the end users, allowing them to assess practicality and economic potential, and to have the opportunity to discuss utilization with colleagues in many regions of the world.

Finally, electronic communication is inherently international in scope. Coupled with the largely English-based information transfer, it facilitates world-wide distribution of new information and improved uses of known data.

5.5 Video and Other Visual Media

At this stage of development video presentations and related tools appear to have limited uses in information dissemination efforts, especially as far as many types of research results are concerned. Beyond assisting speakers in delivering efficient oral presentations, and promoting technology transfer through product demonstrations away from the laboratory or company, cost and audience development have limited the effectiveness of these forms of communication. It is highly likely that it will play an increasingly important role, particularly as computer modeling and computer video presentations become economical tools. Currently the price is high; it has been falling over the last several years.

Video presentations are essential for technology transfer, as sales and marketing tools. Production costs are high.

6. LIMITATIONS AND RESTRICTIONS

Aside from potential limits for the distribution of certain types of information, there really are neither limitations nor restrictions on the many manners of getting information into the public domain. Papers and other works must be sufficiently well developed and thought out; this is facilitated and ensured by the common *peer review* process. Electronic communication will enhance reviews and discussions among diverse groups and individuals.

Restrictions are much more severe when it comes to practical acceptance and implementation, especially when code provisions and needs are to be addressed. It is difficult to avoid such hurdles, for the very reason that code approval implies safe and satisfactory performance, whatever the product or process may be. On the other hand, it is also clear that the code approval mechanism can be made more efficient, such that it will not be necessary to wait 15 or 20 years before new products or methods can be used.

Eventually, processes and products will prove themselves in the appropriate marketplace. Once that has been achieved, information dissemination becomes synonymous with effective marketing and public relations.

7. SUMMARY

This paper has presented an overview and evaluation of means and methods of information dissemination and technology transfer. Evaluating current and potential future distribution approaches, it is clear that electronic communication holds the key to fast and efficient interchange between developers and end users. However, all forms of dissemination have certain advantages; most are likely to continue to be used for the foreseeable future.

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TESTING COMPLETE MULTISTOREY BUILDINGS

D B MOORE*

INTRODUCTION

A large proportion of research into the behaviour of structures has been concerned with the structural performance of isolated members, subassemblages and the development of analytical techniques. Local failures in structures is generally studied by large-scale component testing, while the overall behaviour of the structural system is investigated using scaled-down experimental models. Such tests are designed to provide basic data for model development and verification. Simplified test structures cannot, however, truly represent the behaviour of a complicated building fabricated and erected under normal commercial conditions.

So many differences from the behaviour of isolated component parts arise when they are connected together that questions concerning the force redistribution capability of highly redundant structural systems cannot be answered by component testing. Furthermore, the global and local failure behaviour of the building and the effectiveness of both structural and non-structural repairs can be proven only with tests on a number of different types of completed building.

THE FACILITY

In response to this need the UK Government's Building Research Establishment developed at its Cardington Laboratory a facility for the full-scale testing of buildings up to 10 storeys in height under static, dynamic, accidental and fire loads. Figure 1 shows the inside of the Cardington Laboratory with the first eight storey building.

Structural testing in this new facility will include the following:

- Full-scale multistorey buildings loaded horizontal with four vibration generators to simulate wind loading.
- Realistic fires in individual or multiple cells to determine the performance of the whole structure when subject to local thermally induced distortions

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- Response to accidental damage caused by explosion and impact

- Local failures of floors will be simulated by applying hydraulic loads

EXPERIMENTAL BUILDINGS

The first test building is a steel framed structure representing an office block. It is eight storeys in height and has a rectangular area of approximately $945m^2$ ($10,172ft^2$), fire bays long and three bays wide. The building is designed as a no-sway structure with a central liftshaft and two staircases providing the necessary resistance to lateral wind loads. The main steel frame is designed for gravity loads, and the connections are designed to transmit vertical shear only. The floor construction is a steel deck and in-situ concrete composite floor.

All structural components of the building have been designed to the most up-to-date European Standards. Testing on this building will encompass:

- Vertical and horizontal loading
- Serviceability tests
- Ambient and forced vibration tests
- Blast testing
- Fire tests

The steel framed building outlined above is the first building in a 10 year programme to test a series of buildings constructed from different materials. Other buildings in the programme include reinforced concrete, timber and masonry. Discussions with the concrete industry are well under way and, while all aspects of the concrete building will be the subject of detailed definition during the planning stage, it is possible to identify provisionally its main features. The building will probably be about eight storeys high (approximately 32m (105ft)) five bays long and three bays wide covering a plan area of approximately $844m^2$ ($9,082ft^2$). All structural components will be designed to the most economical interpretation of the Eurocodes.

The range of tests to be carried out on this building will be similar to those planned for the steel framed buildings and will include:

- fire tests on part of the complete building so that the safety and economy of new designs may be adequately assessed and computer models calibrated

- static and fire tests on structural elements to provide data to calibrate both design methods and more economic small-scale and isolated tests

- the effect of explosions on the complete building so that practical design methods for protection may be developed

- the development and evaluation of robotic aids to building construction, management and demolition in a controlled environment

Construction of the concrete building is due to start in April 1995 and the research programme will start in October 1995 and continue for approximately 2 years.

The timber framed building is currently the subject of a joint feasibility study between BRE and TRADA. This study is concerned with establishing the research requirements for full-scale tests and developing the specification for an experimental multistorey timber framed building to be constructed at Cardington.

MANAGEMENT/INFORMATION DISSEMINATION

Each experimental building will be operated as a resource for research and demonstration projects. The partners in each experimental programme will be allocated time in the building according to their individual contributions. They will be able to use their own staff and equipment or to commission work.

Information about and the main findings from each research programme will be disseminated to users through the following mediums:-

- a quarterly newsletter. This is distributed to a wide audience of consultants, manufacturers and academics and includes reports on progress and new developments

- yearly conferences will be held at Cardington. These conferences will give those conducting research and demonstration projects on the building the opportunity to present their findings

- many of the tests will be recorded on film and video tape to make the experimental demonstrations available to a wider audience

CONCLUSION

This new resource facilitates the construction of complete buildings up to 10 storeys. A full range of performance, development and demonstration tests can be conducted on the structure, the cladding and the service systems.

The opportunities offered by this world-class facility will contribute to the efficiency and competitiveness of the construction industry. Research and innovation must be the key to success, and full-scale testing can be an essential element in the achievement of growth in the future.

Fig. 1. Eight Storey Steel Framed Building

Implementation of New ATLSS Technologies

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Overview

Innovation, technology transfer, and competitiveness issues are receiving more attention recently, and with good reason. Clearly to be competitive on a global basis, the United States must innovate and move technologies to practice more effectively, as well as rebuild the national infrastructure. This paper will explore opportunities from the perspective of a university research center created to enhance the competitive position of the large structures and construction industries through the development and implementation of advanced technology. Large structures include bridges, buildings, offshore structures, and other major infrastructure facilities.

In addition, the author will discuss the newly-formed subsidiary of Lehigh University, Competitive Technologies, Inc. (CTI), which has a mission of Collaborative R&D and Technology Transfer.

Industry Collaboration and Technology Transfer

The ATLSS Center was established by the National Science Foundation in 1986 with a mission in four areas: research, education, industry collaboration and technology transfer, and large scale experimentation. ATLSS is one of eighteen Engineering Research Centers currently funded by the National Science Foundation. The emphasis on the industry partnership is an important requirement and was clearly seen as a mechanism to enhance innovation and technology transfer.

Industry and Government Participation in the Research Program

Industry and Government participation is critical for a research program which meets the needs of industry and which will be accepted and implemented in practice.

Several mechanisms are used to enhance industry participation, including an Industry Advisory Council, Project Advisory Panels, workshops, one-on-one contacts, and industry-funded graduate study. Participation levels include annual partnership support, specific project funding, and technical advisory roles.

The Industry Advisory Council, composed of representatives from General Partners and invited advisors, meets twice per year. These meetings have several purposes:

- To update industry partners and advisors on research progress.
- To solicit input on the direction of the research program.
- To address specific issues to enhance interaction with industry or the research program.
- To enhance technology transfer by early involvement of the users of the ATLSS research and to develop technology transfer teams.

These Council meetings are designed to be an interactive forum to encourage effective dialogue between our researchers and industry. In addition to plenary sessions and presentations on ATLSS research projects, project panel meetings are held, typically on the day preceding the main meeting. These project panel meetings bring together the ATLSS researchers, students, industry partners, and invited industry experts.

Technology Transfer

A unique opportunity for an Engineering Research Center to implement its results lies in the early and continuous involvement of industry in the research program. Such industry involvement allows early assessment of results, provides continuous guidance so that industry issues are being addressed, and establishes an early "buy-in" of the technology user to facilitate acceptance and implementation. The key to transferring technology is the "adoption and diffusion" process which clearly depends upon the active role of the user. The successful transfer requires a "demand-pull" from the user of technology, rather than a "technology-push" in which the developer of technology seeks out users of the technology after its development. The involvement of industry is also critical to identify barriers to implementation, including codes and specifications, requirements, government regulations, or contractual and legal issues.

Project Activities

Industry and government collaboration are critical at the project level. Several examples are discussed here.

ATLSS Integrated Building Systems (AIBS) - Work is continuing on the commercialization strategy. Detailed cost estimates for fabrication and erection were developed by five industry partners, and these are being incorporated into the Economic Assessment. Additional market data is being developed with the help of industry. In addition, several papers were presented at major conferences over the past six months, including the International Symposium on Automation and Robotics in Construction (ISARC), and the EPRI 3rd International Conference on Fossil Plant Construction. Also, an article was published in AISC's Modern Steel Construction magazine (December, 1993 issue), and several inquires were received regarding field demonstration sites. These contacts will be pursued to broaden the field testing of the connections.

An Economic Assessment was also completed for the Stewart Platform Crane, part of the AIBS system concept. The Cooperative Research and Development Agreement (CRADA) with NIST's Robot Systems Division is under negotiation, including licensing agreements among CTI, ATLSS, and NIST. To facilitate the commercialization of AIBS, a new company has been formed by Competitive Technologies, Inc. **Sage Building Systems, Inc.** will serve as the vehicle to attract capital investment to launch the commercialization effort.

ATLSS Bridge Inspection Technologies - This group of technologies includes four ATLSS innovations:

a. Hypermedia Bridge Fatigue Investigator (HBFI) - This system is being readied for transfer to practice, and on December 2, 1993 a major project meeting was held at ATLSS. A strategy for implementation will be developed, based on industry and agency interests defined at the project meeting and beta site evaluations. Five organizations agreed to serve as beta test sites to evaluate the system. A new ATLSS report has recently been published.

b. Smart Paint - A patent application assessment is currently underway to determine the feasibility of patenting this technology. An Economic Assessment was completed this past spring and laboratory tests were completed to evaluate performance. The next step is to evaluate the paint in a field environment.

c. Corrosion Monitor - An Economic Assessment was completed for this patented technology and identified market potential and competing products. Industry opinion was incorporated via surveys, mailing and phone interviews. Two recent application projects have been completed, one in Maine and one in Hawaii, and results are being incorporated into the data base for the monitor.

d. Fatigue Data System - A patent application has been filed for this technology, and an Economic Assessment was developed over the summer. Recently, the system has been installed on the ATLSS lab floor and is currently being evaluated on full-scale beam tests. The next step is to move the system to the field for more rigorous evaluation. One of the ATLSS partner companies, Wiss Janney Elstner, provided valuable field information to the Economic Assessment and offered to serve as a beta site host.

Based on the completion of the Economic Assessments for these technologies and the HBFI project meeting, a comprehensive Commercialization Plan will be developed. A draft Business Concept paper has been written which "packages" these four technologies into a single development company and is being reviewed with the ATLSS researchers and several potential investors. This led to formation of a new company **Bridge Technologies, Inc.** to facilitate the integration and commercialization of these bridge-related technologies.

Competitive Technologies, Incorporated

Recognizing the need to coordinate and expand technology transfer activities within the Lehigh University research programs, a new subsidiary has been established, called Competitive Technologies, Inc. (CTI). The mission of CTI includes **Collaborative Research & Development** and **Technology Transfer**. In the 1990's, more emphasis will be placed on collaborative efforts and partnerships for research implementation.

CTI assists the researchers in identifying potential innovations at an early stage and providing tools and mechanisms to effectively demonstrate and implement these innovations. The industry and government participants are playing a key role in these transfer activities as users and facilitators to enhance the implementation. Recently, CTI has entered into a partnership with University Patents, Inc. (UPI) a publicly-traded corporation, to further enhance commercialization and technology transfer efforts. UPI has developed a portfolio of over 400 patents over a twenty-year history. As part of this new arrangement, CTI was re-incorporated as a for-profit company.

Opportunities for the 1990's

The Engineering Research Center concept is one example of an effective partnership among government, universities, and industry, providing continuous dialogue and participation of industry. The emphasis on technology transfer assists in the implementation of new technologies as part of the ongoing research program - not as an afterthought. The National Science Foundation played a critical role in creating the original structure, which has now progressed to an effective partnership including leveraging of funds through the private sector and other Federal Agencies. These Centers could be considered as models to create partnerships and to encourage innovation and more efficient implementation of new technologies.

In addition, Universities will likely seek more partnerships with private industry, such as Lehigh's formation of Competitive Technologies, Inc., to enhance their technology transfer missions. CTI is an example of the next phase of University-Industry partnerships with an emphasis on developing collaborative R&D programs, as well as providing critical private sector expertise and resources for technology transfer.

TECHNOLOGY TRANSFER

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The objective of research work is to generate new knowledge and/or improve the state of an existing one. In both cases the generated new or improved knowledge need to be transferred to the intended users. The traditional method of transfer has been through publication in technical journals and conference proceedings; which are becoming numerous and are seldom read by the intended users of the research results. Most of the research work is conducted by faculty at universities, and most of this research is conducted not because the results are needed. Graduate students have to do research in partial fulfillment of their graduate degrees requirements and faculty are required to do it in order to write and publish papers for their advancement. Unfortunately in most cases it is the number of publications rather than the content of these publications which count most. It is fair to say that, the research is being done because the researcher needs to do it, rather than it needs to be done. As a result most of our technical publications are not read by engineers who are suppose to apply the knowledge generated, with extremely few exceptions. This was not the case several decades ago, when many papers in the ASCE Transactions of the Forties, Fifties, and the Sixties were read by engineers because the knowledge was applicable and of use. Information from these papers were incorporated in design guides and aides. In summary, we are producing too much and it is very difficult to search and select what is useful and usable.

Let us concentrate now on how to disseminate useful and usable research results. In each field we should have a publication which publish only applicable results of research, such as the AISC Engineering Journal. This journal is widely used by consulting engineers; the articles in this journal address issues of practical application and supplement the AISC Specification. Furthermore it is available, without subscription fees, to researchers in the field. We need more publications similar to the AISC Engineering Journal for technology transfer. These publications in the form of journals, news letters, or bulletins can be either in hard copies or can be made available through the electronic media, which is readily available and is easily used particularly by our young engineers; unfortunately some of the older ones are still intimidated. In the past, steel companies, in particular Bethlehem and US Steel, produced publications which included research results in a usable form; these publications were made available free of charge to consulting engineers and engineering students as a way of promoting the use of steel. Most of these publications are not available nowadays. Disseminating information cost money; research budgets should include funds for disseminating the results.

In order to conduct applicable research our industries have to develop the interest and sponsor or co-sponsor the research work. The research funds for a research project should come from federal agencies and the industry interested in the application. These funds should include the cost of the information dissemination. The research work should be conducted because there is a need and there is a user waiting for the results and the information generated by the researcher. We should not do research and then try to find a user for our findings. It is sad to say that the big industries in the United States have abandoned engineering altogether. It is becoming common to see foreign industries providing funds to researchers in the United States to help them disseminate the findings of their research which was conducted using US federal research funds. Worthwhile research results will have no difficulty being disseminated to competitive industries. In summary our research work should address issues and problems coming from our industry, and our industry should be a partner in the research effort. Research funds should come from federal agencies as well as the industry and should include the cost of research findings dissemination.

SSRC - THE VIEW AHEAD

James M. Ricles

SSRC Director

Slide Presentation

SSRC - THE VIEW AHEAD

James M. Ricles

SSRC Director

SSRC - THE VIEW AHEAD

SSRC - The First 50 Years

- **Provided Annual International Forum**
- **Reviewed and Evaluated Structural Stability World Literature**
- **Initiated and Guided Several Research Projects**
- **Produced Several Special Publications**
- **Cooperated with Specification Writing Organizations**

SSRC - FUTURE DIRECTIONS

1. **Dissemination of Information Related to Stability of Metallic Structures:**

   - **Modification of ATS&M Format to Include Theme Conference**
   - **Short Courses**
   - **Collaboration with Other Organizations**
   - **Information Explosion**

Forthcoming Short Courses:

- **"Stability of Metal Structures - A World View"**
- **"Design and Analysis of Structural Bracing"**

Near-Future Collaborative Efforts:

- **SSRC ATS&M - 5th International Colloquium/ASCE Structures Congress, 1996 Chicago**

SSRC - FUTURE DIRECTIONS

Information Explosion:

- Need for Developing Strategies for Evaluating and Disseminating Results of Stability Related Research Information
- Utilization and Exploitation of Electronic Media and Knowledge Base Systems

2. Refinements of Existing Knowledge and New Stability Topics

- Advanced Computational Analysis Methods
- Evaluation of Damaged and Deteriorated Structures
- High Performance Steels
- Composite Construction Utilizing High Performance Steels

SSRC - FUTURE DIRECTIONS

Analysis Methods:

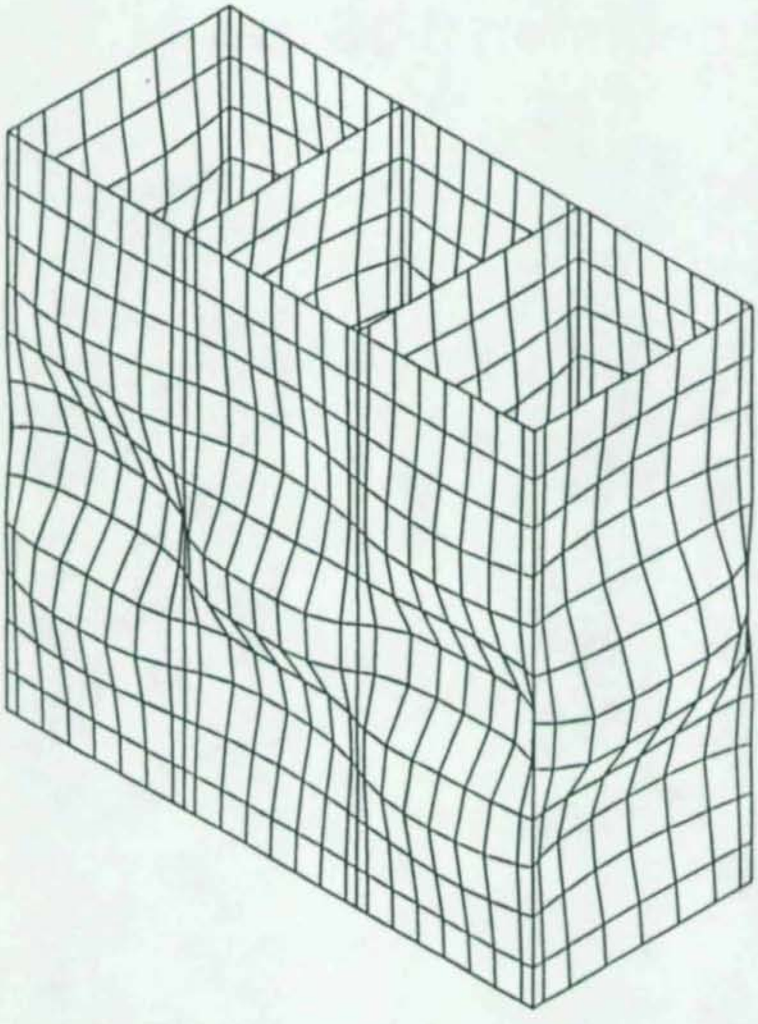
- **Have Become More Sophisticated and Efficient**
- **Standards are Needed for Benchmarking and Reporting Results**

Evaluation of Damaged and Deteriorated Structures:

- **Lack of Information and Methods for Structural Performance Assessment**
- **Applications to Infrastructure**

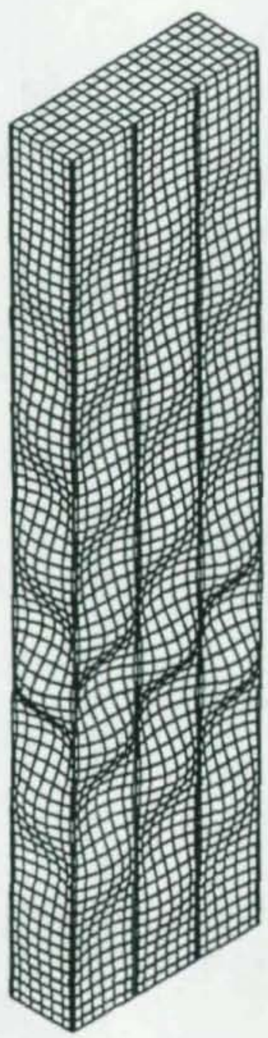
High Performance Steels:

- **Need to Examine the Effects of Basic Material Properties and Shapes on Member Stability**
- **Need for Further Evaluation and New Developments**

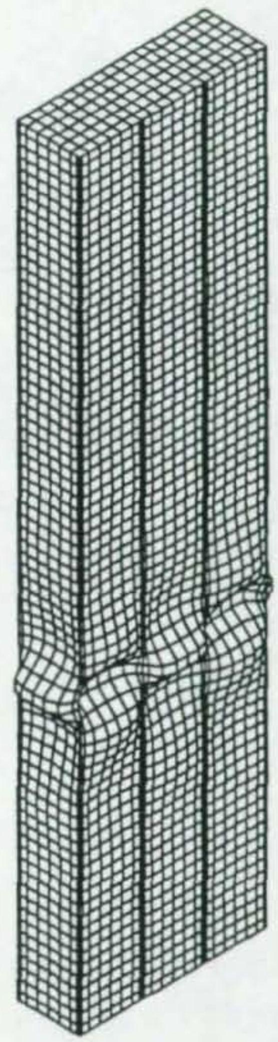


Finite Element Analysis Deformed Geometry at P/Py = 0.447, Specimen 3-2430-6

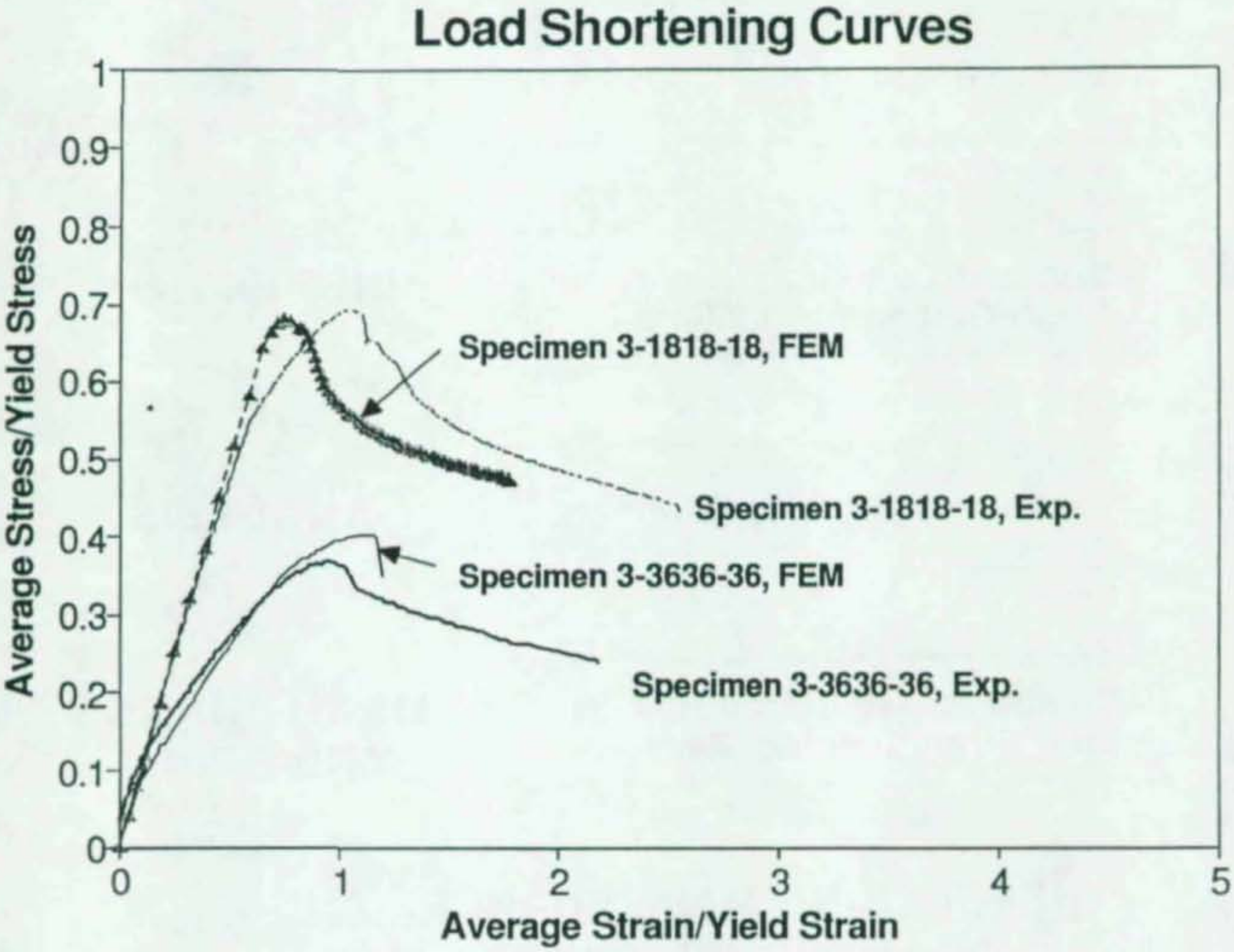
Local Buckling Patterns - Specimen 3-1818-18

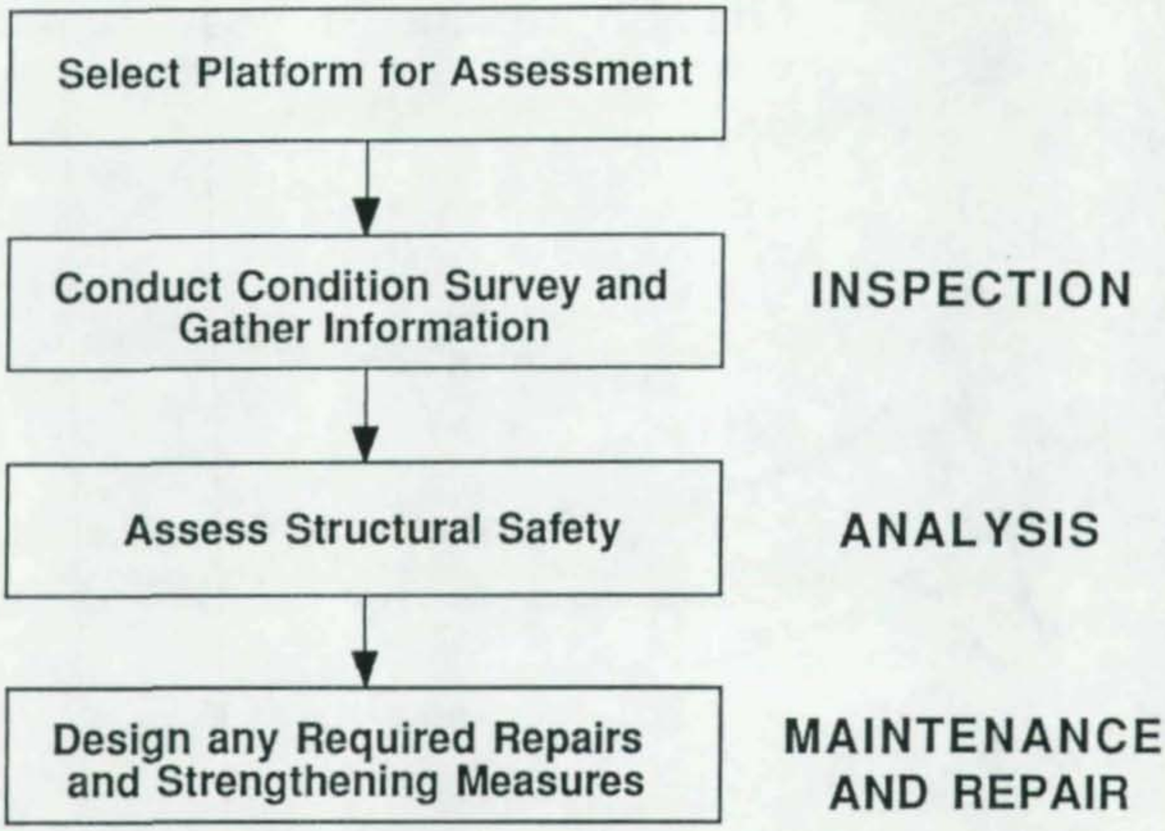


$\varepsilon/\varepsilon_y = 0.817$



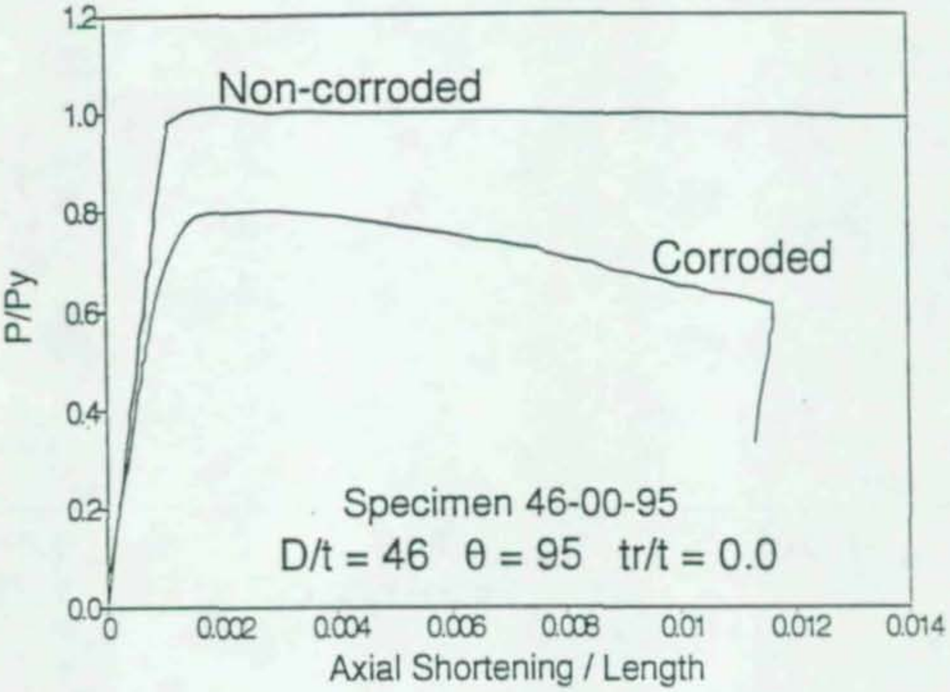
$\varepsilon/\varepsilon_y = 1.782$


Load Shortening Curves
Average Stress/Yield Stress
Average Strain/Yield Strain
Specimen 3-1818-18, FEM
Specimen 3-1818-18, Exp.
Specimen 3-3636-36, FEM
Specimen 3-3636-36, Exp.
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
1
2
3
4
5



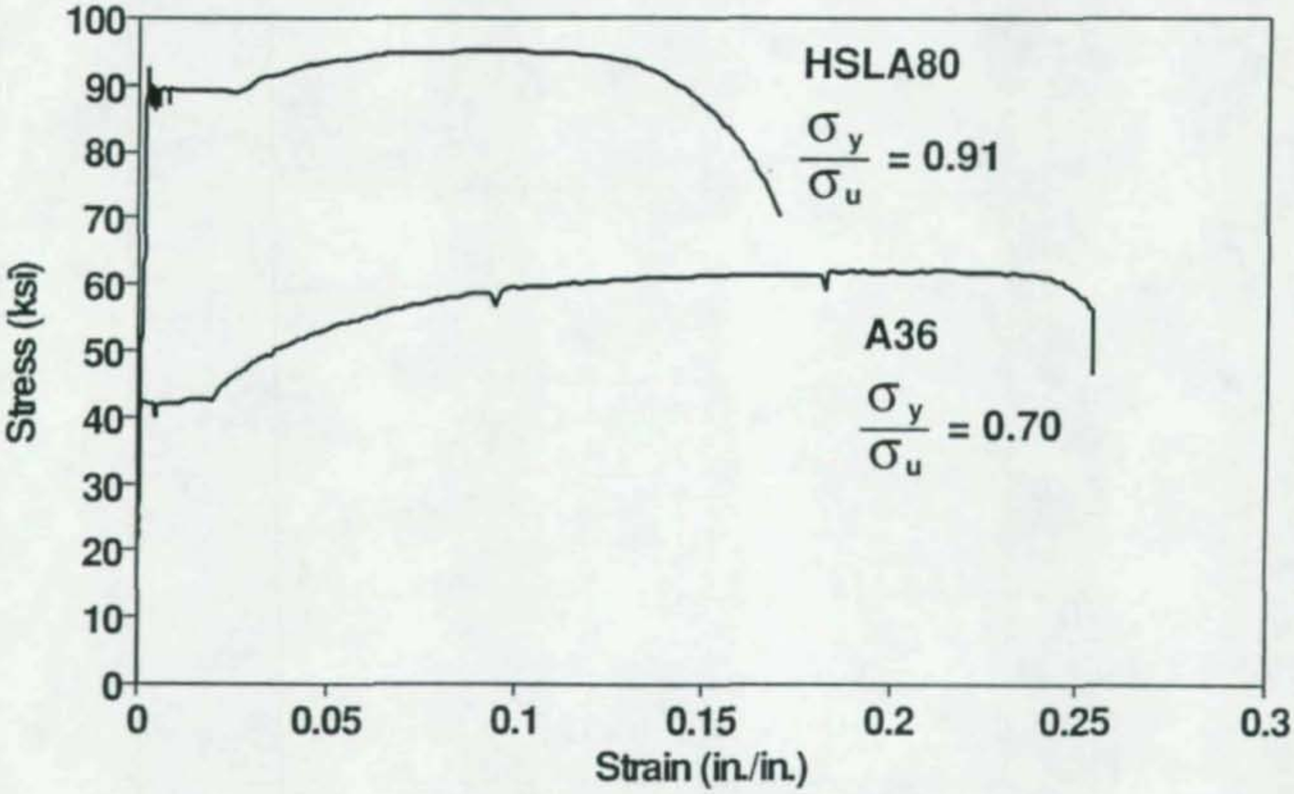
INSPECTION, MAINTENANCE, AND REPAIR (IMR) PROCEDURE

Typical Normalized Load-Deformation Plot for a Corrosion Damaged Tubular

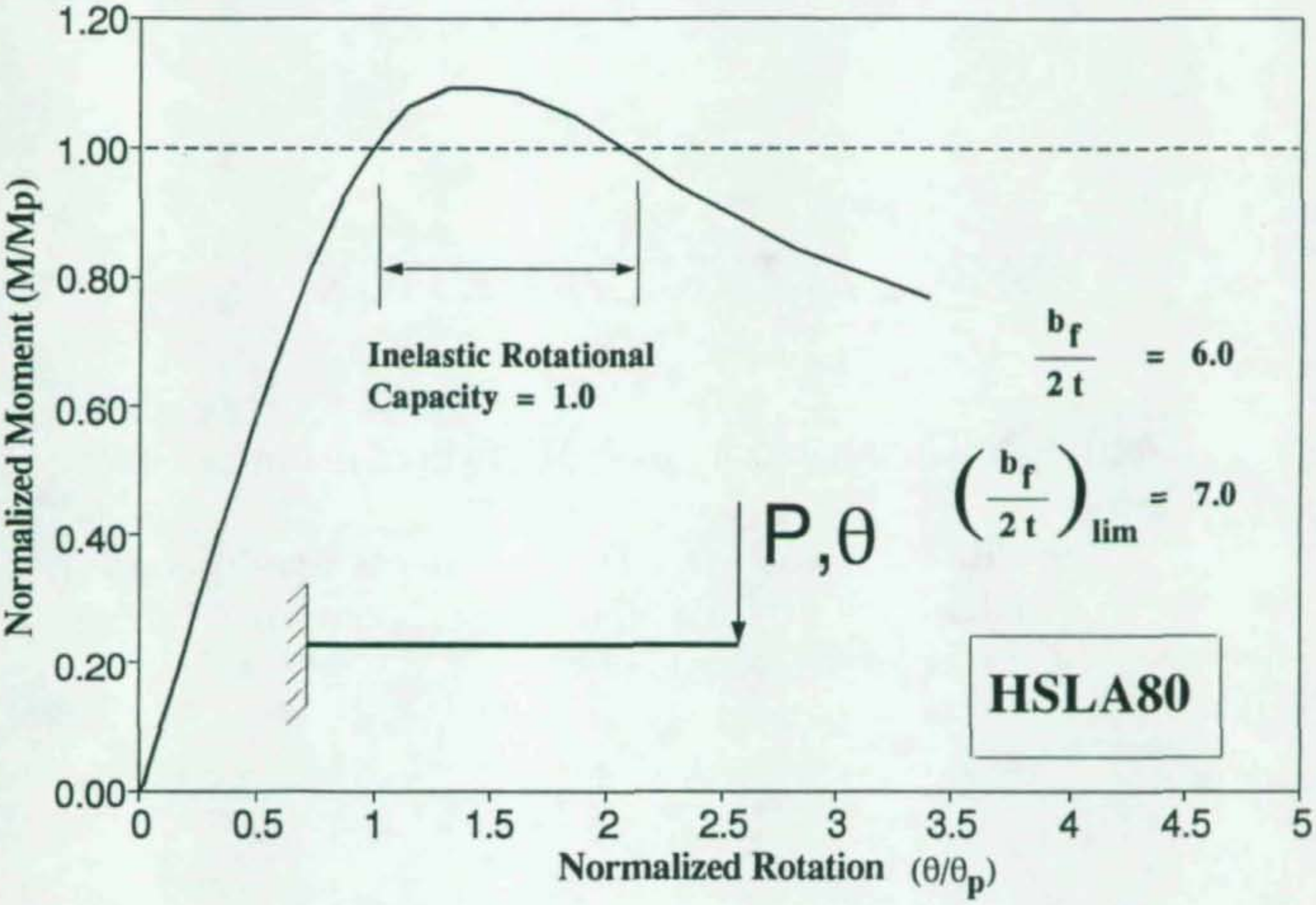


Stress-Strain Relationships

Comparison of A36 to HSLA80 Steel



Moment-Rotation Relationship
Specimen 2

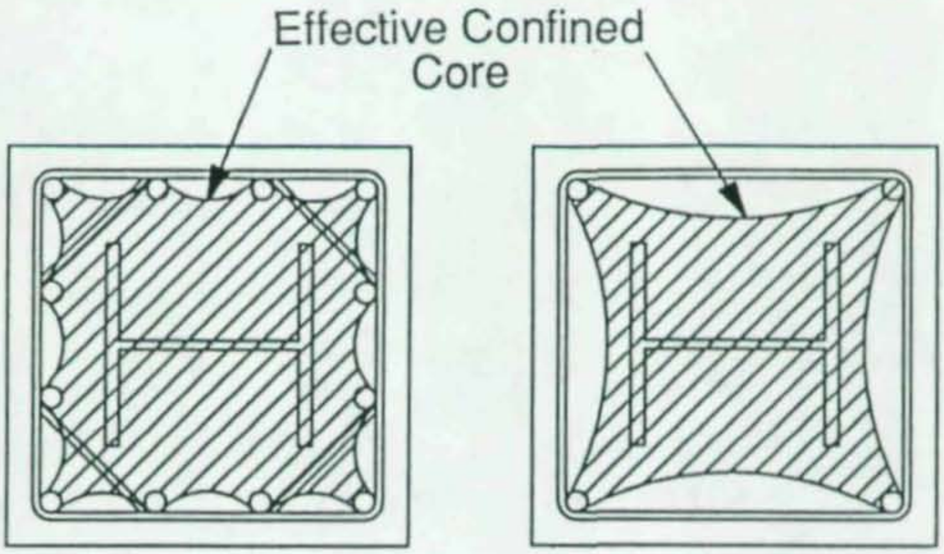


SSRC - FUTURE DIRECTIONS

Composite Construction with High Performance Steels:

- **Evaluation and New Developments are Needed in Order to Fully Exploit High Strength Material Characteristics**

Composite Construction - Encasement of Structural Shapes



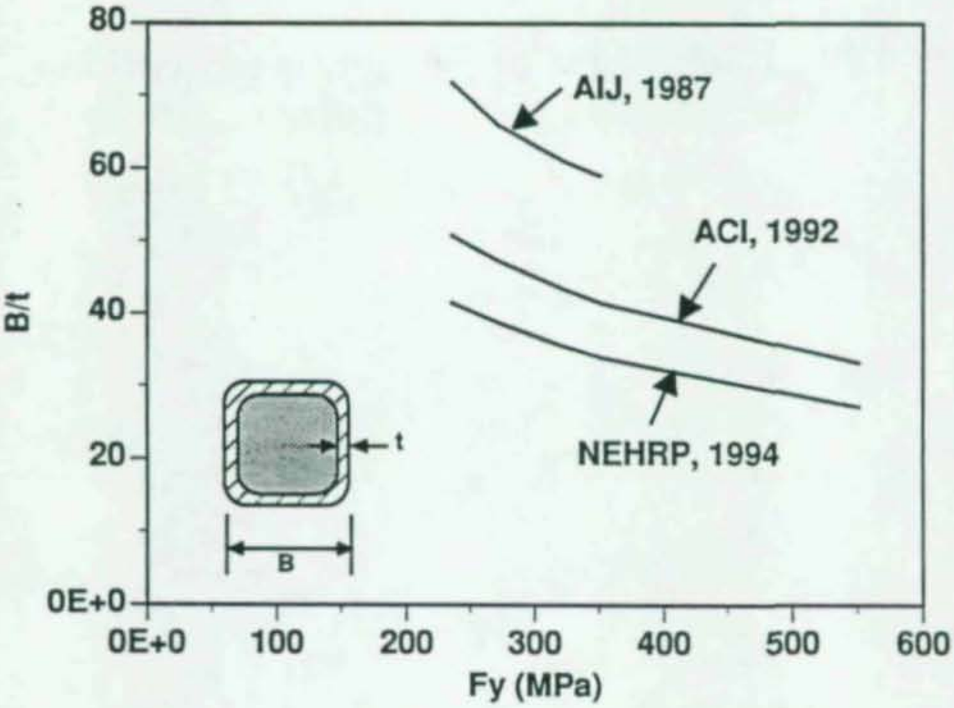


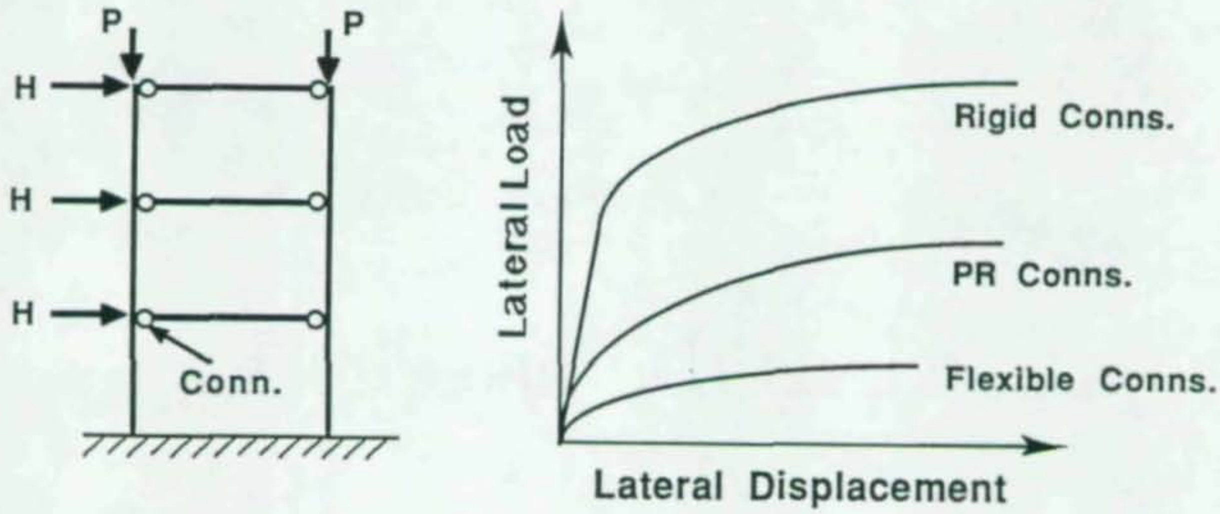
Figure 2 Comparison of Limiting Member Width-to-Thickness Ratios For Square CFT Columns.

<u>SSRC - FUTURE DIRECTIONS</u>

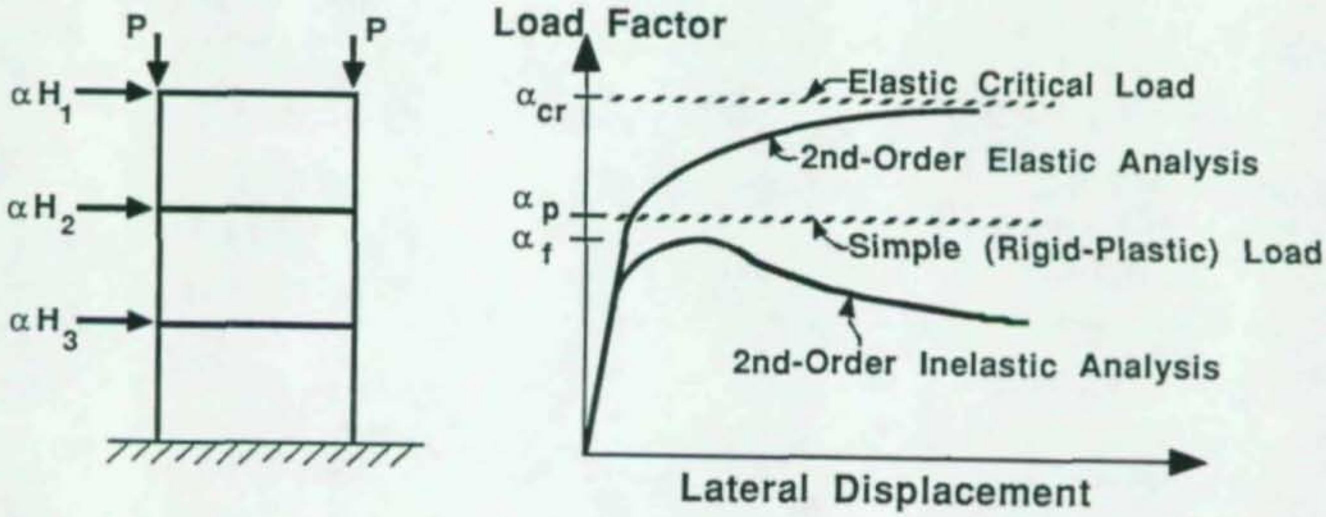
3. Advanced Analysis Methods:

- Need for Integration in Design Specifications

Semi-Rigid Connections



2nd Order Analysis



SSRC - FUTURE DIRECTIONS

4. Design Specifications:

- **Need for Achievement of More Uniformity in Design Standards**

- **International Cooperation**

SUMMARY AND CONCLUSIONS

SSRC's international membership of researchers and practitioners, experience, resourcefulness, and ability to interact with other organizations and disseminate information make it the ideal organization to address future developments.

The next 50 years will be as challenging and interesting as the first.