PRESERVATION OF AGEING MARINE STRUCTURES

Conference Notes
from the
California Sea Grant Symposium

August 13–14, 1990
Department of Naval Architecture and Offshore Engineering
and
Department of Civil Engineering
University of California, Berkeley

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INTRODUCTION

On August 13 and 14, 1990, a symposium was held at the University of California, Berkeley to discuss the approaches, problems, and future development needs associated with rehabilitating and re-qualifying ageing marine structures. The symposium addressed port structures, coastal structures, offshore structures, and ship structures.

This document summarizes key results developed from the presentations and discussions held during this symposium. These results were based on notes taken during the symposium and represent as accurately as possible what was heard by the note-takers. UCB research assistants Rob Pollard (Ship Structures), Mark Bufflkin (Coastal Structures), Don Kingery (Coastal Structures), and Rajiv Aggarwal (Platform Structures, Research and Development) helped develop these notes.

In addition, this document summarizes the results from a questionnaire distributed to participants regarding future workshops and short courses (Appendix B).

The symposium organizers would like to thank the speakers and participants for an extremely interesting and informative series of discussions. In particular, the organizers would like to thank the California Sea Grant Program for the support and encouragement provided to hold this symposium.

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PORT STRUCTURES

Session Chairman: Harvey Haynes, Haynes and Associates, Oakland, CA

Keynote Speaker: Charles Roberts, Port of Oakland, Oakland, CA

Panel Discussions: Charles Connors, Moffit & Nichols Engineers, Long Beach, CA. Mark Hollan, Naval Civil Engineering Laboratory, Port Hueneme, CA.

• Ageing Problems: time and damage effects, technical obsolescence, operational obsolescence, political obsolescence.

• Key Strategy: maintenance of structures and equipment is mandatory. Management commitment is necessary. Follow-through with the operations-maintenance staffs are critical. Planned retirement of outmoded facilities is important. During maintenance, upgrade the facilities to keep them up to present day requirements. In large commercial ports, the structures are rehabilitated at the rate of about 10-percent per year.

• Retrofits and damage repairs are a major challenge requiring innovation and extraordinary engineering. Retrofitted rock columns are being installed to provide stability to fills. Base-foundation isolation systems are being used to provide earthquake protection to critical facilities. Development work is needed to define more efficient and effective practical repair and retrofit procedures.

• Many problems are associated with poor initial design (e.g. use of rear row of batter piles in vertical pile groups in seismic areas, use of non-integral structures to support integral structures such as loading-unloading cranes in seismic areas, insufficient concrete cover over reinforcing steel).

• A major port problem is maintenance of channels and berths deep enough to handle the modern class of larger, greater draft ships. The problem is due to the concerns of pollutants and negative environmental imp acts associated with dredge material and finding a suitable discharge location.

• Availability is a key requirement for port facilities. Thus, maintenance is best accomplished on a daily basis.

• A key problem in port structures is the maintenance of the infrastructure of railways, roadways and bridges, electrical systems, piping systems, etc. that are required to keep a port in service. Generally, these systems are more of a problem that that associated with the port structures themselves.

• Key problem in California is seismic upgrading of facilities. To know when is enough, to know how to accomplish efficiently without substantial loss of availability of the facilities.

• Some ports and port facilities programs do not have the financial resources to mount continuous maintenance programs. Frequently, these ports must be reactive to maintenance requirements (something breaks, fix it if you can afford it; if not, patch it or take the system out of service).

• The U.S. Navy has 296 major shore bases around the world. These shore bases are critical to the supply logistics of the fleet. Many of these shore bases were built during the Second World War and are well beyond their design lives. Based on the current readiness rating system, many (50 % +) of the bases are marginal to unable to provide the necessary support logistics. Given a military need, many of these facilities face severe problems with resurrection.

• The Navy has developed a condition assessment procedure to evaluate the suitability for service of military port structures. The procedure includes a diagnostics process to take observations from operations inspections, nondestructive testing, load testing, combine these results with structural analyses and develop a conditions readiness evaluation.

• In the case of some port structures, the owner is unable to afford fixing the structure properly. Thus, intermediate repairs are made to keep the facilities in operation. Concerns were expressed with the adequacy of such repairs, particularly when consideration is given to long-term service without plans for inspections and continued maintenance.

• Experience has been excellent with concrete port structures when the steel cover has been 3 to 4 inches and the concrete quality has been high. Good repair schemes have been developed for damaged concrete piles and pile-girder connections.

• A major strategy for using damaged or defective port structures has been to de-rate them, placing load limits to avoid undesirable performance of the structures.

COASTAL STRUCTURES

Session Chairman: Professor Bob Wiegel, University of California, Berkeley.

Keynote Speaker: Joan Pope, U.S. Army Corps of Engineers, Vicksburg, MS.

Panel Discussions: Orville Magoon, American Shore and Beach Preservation Association, Middletown, CA. Fredrich Raichlen, California Institute of Technology, Pasadena, CA.

• Slow incipient failures (gradual degradation) pose the majority of problems associated with coastal structures. Degraded structures may be overloaded to cause problems.

• Coastal structures include breakwaters, sea walls, bulkheads, jetties, groins, and revetments. Some of these structures have been in service since the early 1800's.

• The U.S. Army Corps of Engineers as part of the REMR (Repair, Evaluation, Maintenance, and Rehabilitation Research Program) have issued reports documenting the history and problems associated with breakwaters. A list of REMR reports published to date is included as Appendix A.

• The primary problems associated with concrete breakwaters has been spalling and chemical attack; with timber has been deterioration in the water plane area; with foundations has been dynamic-cyclic loadings and scour. Many of the problems have been associated with bad (or in some cases, no) design.

• Rock degradation due to cracking has been a perplexing problem. Many proposed reasons and factors. A primary factor appears to be blasting stresses. Rock placed will crack up after placed. Protection decreased.

• Concrete armor on breakwaters has been a very difficult problem. Catastrophic failure problems associated with some units exposed to severe wave environments. Instrumentation program at Crescent City on Dolos units indicate static very high static stresses (due to settlement and interaction of units). Tide and wave pressures develop additional stresses. Information on loadings, optimal shapes, and design guidelines for reinforcement are needed.

• Important developments have been occurring in inspections and surveying. An acoustic 3-D imaging system is being developed by the Corps for underwater surveys. Much additional work is needed to improve underwater inspection methods for complex coastal structures.

• Ageing of coastal structures can result in loss of capacity, loss of serviceability (utility), and loss of durability (accelerated degradation).

• Model (laboratory) testing of existing coastal structures to replicate existing conditions and assist in the evaluation of future performance is an important tool for the Coastal Engineer. There are severe problems associated with condition surveys to detail the present conditions of coastal structures. There is a pressing need for more correlations of field and laboratory testing to provide guidelines to improve laboratory testing.

• Success of coastal structures is founded in the ability of these structures to perform their intended service. The requirements for service may change as a function of time. Problems are frequently founded in inadequacy of original designs with regard to durability. Systems frequently fail in a non-catastrophic manner. Many of these systems are readily repairable.

• During the last decade, there has been a noticeable attitude change toward maintenance of coastal structures. Little new-building is underway. Major emphasis is being placed on keeping in service what we now have.

• It is important to be alert to opportunities for upgrading the facilities during modifications and maintenance (e.g. berms added to breakwaters).

• Some designs invite failure through poorly known or understood interactions between the structural elements or between the structural elements and the marine environment.

• There is a need to form a National Coastal Research Facility to focus on the issues of maintenance of coastal structures and systems. The approach should be to chip away at small, high priority issues, rather than a massive attack on the entire problem of maintenance of coastal structures.

• Coastal pipelines are a key concern. These include sewage, intake and oil and gas transmission lines. Many are in unknown condition. There have been incidences of major damage. There is a need for instrumentation to locate and determine the condition of these pipelines.

• There is a need for a centralized data bank for coastal facilities that would permit documentation of design and construction information, maintenance information, and failure - loss of serviceability information.

• There is a need for coastal engineers to develop maintenance manuals for their structures. Operators frequently do not know what should be done to maintain the integrity and serviceability of the structures.

• Consistency between the various sectors (private, public, commercial, military) designing, constructing, operating, and maintaining coastal structures has not been developed. Thus, there is no unified approach to maintenance or evaluations of suitability for service.

OFFSHORE STRUCTURES

Session Chairman: Professor Rick Reimer, University of California, Berkeley.

Keynote Speaker: Felix Dyhrkopp, U.S. Department of Interior, Minerals Management Service, New Orleans, LA.

Panel Discussions: Michael Isenhower, Union Exploration Partners, Ltd. Houston, TX. William Krieger, Chevron Corporation, San Ramon, CA. Terence McGillivray, Santa Rosa, CA.

• A key problem is associated with developing an inspection and condition survey data base on the some 4,400 major offshore platforms in the Gulf of Mexico (GOM). Some of these platforms have been in place since the 1940's. In 1988, operators began to submit reports to the Minerals Management Service (MMS) on inspections and condition assessments. Inspection guidelines have been developed by the American Petroleum Institute (API), and these guidelines provide the basis for the inspections required by the MMS. Due to limited MMS resources, there have not been any systematic evaluations of the accumulated inspection data. Initial evaluations indicate that the majority of structures are in good to excellent condition and are suitable for their proposed service.

• Inspections of GOM platforms have disclosed a wide variety of defects and damage including fatigue cracks, environmental overload damage, accidental damage (boats, dropped objects), and corrosion. Fatigue damage has been relatively localized. Most pervasive problem is corrosion, accidental damage, and trash (cables, equipment) on the sea floor (preventing cathodic protection of the platforms, damaging structural members).

• Environmental overload is potentially a big problem. It has not been a big problem to date. GOM hurricanes have long warning lead times. This allows shut-in of the wells and evacuation of personnel.

• This is not the case for Pacific Coast platforms. These platforms can be affected without warning by earthquakes. The numbers, extent, and speeds of movement of Pacific Coast severe winter storms can be such as to effectively prevent shut-in and evacuation. Combined with the extreme environmental sensitivities of this region, this makes the Pacific Coast platforms a major concern.

• Platform overload failures experienced during hurricane Juan in the GOM indicated joint pull-outs from thin-wall legs, failure of bolted connections used to repair damaged braces. The platforms were expected to be able to take a 10-year return period wave, and took a 100-year return period wave at the time of collapse.

• Corrosion is the most common problem with GOM platforms. When corrosion protection is not maintained, corrosion develops localized pitting, holes, thinning, and cracks.

• Platform operators have high variable maintenance philosophies. There are no state requirements regarding maintenance of platforms. Recent industry developments are attempting to develop guidelines for minimum maintenance.

• There is a wide range of acceptability criteria for platforms ranging from bringing the platform up to its original (although obsolete) criteria to strengthening the platform to present day criteria. De-rating the platform, unloading it, and other consequence mitigation measures are frequently used as a measure of last resort to re-qualify the platform for service. Decisions must be economics driven from the industry standpoint. Decisions must be safety and pollution prevention driven from the government standpoint.

• Failure risks or consequences evaluations should address pollution potential, oil spill response time, distance from shore, the ability of the wells to flow under natural reservoir pressure, and the quartering of personnel on the platforms. There are severe problems associated with the evaluations of consequences associated with deaths and pollution.

• There are significant problems with underwater inspections. It is dangerous (for the divers), the results are very dependent on the planning and personnel involved in the inspections, the inspections and expensive. Work is needed on automated (e.g. Remote Operated Vehicles) inspection and monitoring (in-service instrumentation) equipment and methods.

• Structural analytical methods are very costly and time consuming. There are limited qualified personnel to perform the analyses. Analytical modeling is imprecise. There is an important need for simplified methods to evaluate the strength or capacity characteristics of structures.

• There is a critical need for an industry-government consensus manual of engineering practice for the re-qualification and rehabilitation of platforms. The manual should give engineering guidance on how to perform inspections and analyses and on re-qualification or performance acceptability.

• Experience with repairs in many cases has not been good. Underwater welded braces and joints, bolted - clamped connections have in many cases failed. Good engineering design is required if repairs are to be effective. Both the capacity and fatigue strength - durability of the repaired elements should be considered. Work is needed on developing engineering guidelines for repairs to joints and members.

• Extensive work has been done on the effects of holes and dents on the capacities of tubular braces. Engineering guidelines and and analytical procedures are now available to describe the load-deformation characteristics of defective braces.

• There is a need for screening procedures to evaluate the capacity characteristics of offshore platforms. The primary concern is with the older damaged and high consequence platforms. Solutions are not obvious. Elastic computer modeling can be used for the vast majority of assessments. Need nonlinear models if concerned with ultimate strength characteristics; these analyses are costly and difficult to perform.

• The principal problems of condition assessments are associated with not knowing with a high degree of precision the present condition of the structures, and with not knowing with any precision the future loadings. This makes the results imprecise (uncertainties in the future demands and capacities). This makes the decision process very difficult. Guidelines and procedures are needed for recognition of the uncertainties in the decision processes. The acceptability criteria should reflect these uncertainties.

• The **AIM (Assess, Inspect, Maintain)** joint industry-government sponsored project was started in 1984 and completed its fourth phase in 1989. More than 20 organizations have sponsored this effort. This project has produced general guidelines and procedures that can be used by industry and government to re-qualify platforms in the Gulf of Mexico. Similar guidelines are needed for West Coast California and Cook Inlet platforms.

• The next steps in improving the processes of re-qualification of offshore platforms were summarized as follows: 1) Improve inspection methods and equipment; 2) Improve the analytical procedures to describe the failure mechanisms associated with damaged and repaired platform elements; 3) Improve the methods used to make risk evaluations (need to calibrate methods); 4) Improve the methods used to define suitability for service; 5) Develop an engineering code and manual of practice for the re-qualification of platforms.

SHIP STRUCTURES

Session Chairman: Professor Alaa Mansour, University of California, Berkeley.

Keynote Speaker: Bob Ternus, Chevron Shipping Company, San Francisco, CA.

Panel Discussions: Michael Parmelee, U.S. Coast Guard, Washington, D.C. Walter Czerny, American Bureau of Shipping, Paramus, NJ. John Gosling, Matson Shipping Company, San Francisco, CA.

• At this time there is no significant ship building in the U.S., it is cheaper to build abroad. Because of this there has been more technological development in foreign yards. There are still ships however, and U.S. shipping companies are still competitive and strong. Because of this there has been a shift of emphasis to maintenance and the design for maintenance.

• Aging begins from the first day the ship is in service. This is not always the case with all operators however, and some don't examine life extension until after some years of service. By way of example a 9 year old ship obtained in a company merger was in such bad shape externally that the company was not interested in keeping and repairing the ship. Another comparable ship of similar age has been well maintained and is worth keeping, even though it is aging because proper maintenance has been performed.

• **There are four key elements of ship maintenance:**
  - **Design for Maintainability**
  - **Inspection**
  - **Data handling and Evaluation**
  - **Repair strategies and Procedures**

• Role of Class Societies
  - Development of Rules
  - Approval of Design
  - Inspection at construction
  - In service survey
  - Approval of repairs
  - Certificates

• Class Societies are primarily concerned with safety, not maintenance or life extension. However, the technology requirements are developed by a committee of owners and operators, so there will be compromises.

• Design for Maintainability

High tensile steels are attractive to ship yards because they weigh less, and so are less costly, but use requires care in detail alignment, and reduces fatigue life in standard details, requiring more rigorous design and inspection.

Coating systems. Standard coating for coal tar epoxy is 1 coat. High durability (life 12 to 15 years) coatings require 2 coats and 3 coats in double bottom spaces.

Double bottom height. In a conventional single hull tanker it easy to access the structures. In a double bottom space however it is more difficult to get to structure. A small double bottom space means more difficulty in getting men and tools in for repair. Double bottom separations are generally specified to be not less than 2 meters. However, such separation distances provide great difficulties in inspections and repairs. Separation distances of the order of 3 meters are necessary to facilitate inspections, repairs, and maintenance.

• Design for Durability. Examples were discussed where "standard details" had been proposed for use for brackets in critical structural elements of the ship. Study of these details indicated that they had very short fatigue lives (e.g. 19 years). The details had to be re-designed (decreasing stress concentrations and decreasing nominal stresses) to obtain satisfactory fatigue lives (e.g. 44 years). Experience with many standard details indicates that they can lead to severe durability problems, particularly if higher strength steels are used to develop lighter scantlings.

• Inspectability is a key to maintainability. What can't be inspected can't be maintained. Class Societies requires periodic inspections, the special surveys (generally 5-year periods). Many operators concerned with ship structures maintenance have expanded inspection scope, even at the beginning (when special survey not that detailed). These early detailed inspections are intended to disclose the presence of construction flaws and design flaws. Many operators also have interim inspections between the special surveys (e.g. yearly inspections of cargo and ballast tanks).

• Timing of inspections is critical to efficient maintenance. Often the corrosion gagings are done in the yard, in which case the technicians are often hurried by the yard to complete the survey so work can begin. Unanticipated repairs can lead to very high ship yard costs. Many operators often send inspectors out 6 months in advance of the scheduled dry docking to begin survey while ship still at sea, so a plan for yard work can begin before the ship arrives.

• Wastage limits. Class Societies have their own limits for corrosion which take into account the wastage which might take place before the next survey. These corrosion limits are generally based on experience and the survey techniques used by the Class Societies and their surveyors. For high tensile steel construction, there is a serious question regarding the adequacy of these wastage limits. Localized (weld area) and pitting corrosion provide difficulties regarding interpretation of wastage limits.

• Contractors. Use of the same inspection companies, and even the same personnel insure that the technicians are familiar with the ships, and are aware of where potential problems might lie, insuring a good inspection.

• Data handling & Evaluation. Decisions are based on gagings and the survey reports. During the past several years, Chevron Shipping has been developing a personal computer based program to aid in the maintenance of ship structures (CATSIR, Computer Aided Tanker Structure Inspection and Repair). This program is intended to automate the data handling and evaluation processes. CATSIR uses a CAD package and a database to aid in the evaluation of damage to ship structure. CATSIR can produce various reports to track the aging of the ship.

• Repair strategies. Basic philosophy; repair now or defer to next maintenance cycle. A basic philosophy used by many ship owners and operators is to insure that the safety of the crew and the environment is not in danger. All other decisions to repair or defer are made on an economic basis

• Shipyard partnering. IMR (Inspection, Maintenance, Repair) quality is a key item. In the past, many ship operators have used bids to determine which yard to use to do repairs. Now several operators pre-qualify yards around the world to do their repair work and negotiate the repairs on a unit price basis a year in advance. The owners-operators tell the yards one year in advance to expect the ship, and give an estimate of the scope of the work to be done. The yards have CATSIR. The owner-operator and the repair yards also use program SPECGEN to evaluate non-structural (mechanical equipment, piping, electrical systems) work to be done.

• All possible planning for overhaul work is done previous to the arrival of the ship. The owner-operators frequently have offices in the repair yards so that the owner-operator can work directly and efficiently with the repair yard. In addition, many of the repair yards will dedicate repair personnel to a particular owner-operator to ensure continuity of experience with a given fleet of ships and application of the owner-operator's philosophy regarding IMR.

• Present experience is indicating that design of a ship for high reliability and maintainability can cost approximately five percent of the cost of the ship. Experience is indicating that this is an excellent investment.

• If all ship owners and operators used used a pro-active approach to maintenance, the job of the Class Societies would be much easier. Class Societies act in behalf of regulatory agencies to assure that basic requirements are met to assure safety of the vessel. The constructors should be responsible for fabrication of the vessel to meet minimum and owner-operator specified serviceability - durability and safety characteristics. The owner-operator must be responsible for the economic and safe operation of the ship.

• The development of Class rules are based on experience. The rules are changed by technical committees. Some new rules evolve, others appear overnight. After the Amoco Cadiz incident, new rules appeared on the redundancy of steering gear. With the tremendous growth that has occurred in ship size, the evolution of the rules has not been able to keep pace. However with the advent of computers, an analytical method of determining rules has developed.

• Corrosion. It is well known that salt water, hot cargo and fatigue (high material strains) lead to corrosion. What is not well known, is how to minimize the damage from corrosion. Corrosion can be exacerbated by abrasion , flexure, failure of coatings and cathodic protection, temperature, and the trade route (many cycles of high levels of strains). Inert gas in cargo tanks have had the effect of reducing corrosion.

• Coatings and cathodic protection has reduced the corrosion in the cargo tanks. Still ballast tanks have 3 times the corrosion rate that cargo tanks do. There is question concerning the effectiveness of cathodic protection in salt water ballast tanks due to inhibition by sediment in the bottoms of these tanks covering the anodes and the inability of anodes to protect the tops of the tanks not covered by water.

• Some owners have higher standards than class societies. Ships can last indefinitely if maintenance is performed properly. Class society rules try to prolong ship life only five years, to the next special survey, often ship owners want more than five years. This is particularly true today given the cost of new building and the value of existing ships.

• Segregated ballast and high tensile steels have led to an increase in the importance of tracking wastage.

• Second hand ships values have skyrocketed. Thus, the economic life has been much increased. But since some of these ships were near the end of the economic life already, insufficient maintenance may have been performed, only enough to keep the ship running. Now with asset increased in values, owners don't want to risk a major refit (which means down time where the ship may loose value), but do maintenance day to day sometimes to keep the ship running. Sometimes the ship is kept as an asset play; an owner keeps the ship long enough to realize a substantial profit, performing only the maintenance required to keep the ship running, and then the ship is sold to another owner who may repeat the process. Poorly maintained ships are the result. This gives much concern for the safety of such ships. There is a need to determine how to better manage the asset owner firms.

• There is no secret how to make a ship last. The secret is doing it! There are four key things to realizing the long life of a ship:

- **Start with a policy of long life (design for IMR, design for durability),**
- **Keep control of the ship (don't trust others to see that IMR is done),**
- **Don't change the policy of high quality IMR,**
- **Obtain and have resources to conduct that policy (this takes management commitment).**

When the initial costs of ships is high, there are strong incentives to maintain the serviceability and value of these ships for a long period of time.

The ship owner-operator management must be committed to the purchase of a high quality ship and to enduring high quality maintenance if long ship life is to be realized. Generally, such a commitment will be associated with successful companies that have a long-term commitment to being successful.

There is the perception that an old ship is necessarily a bad ship (a rust bucket), that if involved in an accident, the the age can be linked to the cause of the accident. **The dominant cause of ship accidents is human operator error.** An older and well maintained ship can be safer and more durable than a newer and poorly maintained ship. **Age is not the sole determinant of safety and serviceability; maintenance can be. High quality maintenance can cost of the order of 4 percent of the ship value per year. Given the high costs associated with loss of availability of the ship and with pollution incidents, high quality maintenance will pay dividends.**

• The U.S. Coast Guard is helping lead a long-term joint government agency sponsored research program to improve the maintainability of ship structures. The Ships Structure Committee (SSC) is made up of the U.S. Coast Guard, American Bureau of Shipping, Maritime Administration, U.S. Navy, and Military Sealift Command. SSC looks at fundamental research in areas such as ship loadings, materials, weld technology, corrosion fatigue, etc..

• SSC is sponsoring two research projects focusing on ship maintenance at the University of California at Berkeley. The first project is known as **MSIP (Marine Structural Integrity Programs).** The objective of this project is to develop a procedure for definition of MSIP for commercial ships that will include more efficient inspection, more economical and safer operation, and more effective maintenance. The MSIP will suggest a sequence of events to be performed by the various parties involved in the life cycle of ships in order to better ensure the integrity of the structures during their useful lifetimes. The MSIP procedure is based on developments from the U.S. Air Force and Federal Aviation agency Airframe Structural Integrity Programs.

The second project is the **Structural Maintenance of New and Existing Ships.** This two-year project involves eighteen sponsoring organizations including government agencies, Classification Societies, new build and repair yards, and ship owners and operators. The objective of the project is to develop more effective structural maintenance procedures for ships. There are five primary efforts in this project: **fatigue cracking evaluations, corrosion evaluations and corrosion mitigation, guidelines for repairs of fatigue cracking and corrosion, local details interactions with adjacent structure, and software development.**

RESEARCH AND DEVELOPMENT

Session Chairman: Professor Bob Bea, University of California, Berkeley.

Keynote Speaker: Professor Bob Bea, University of California, Berkeley.

Panel Discussions: Charles Roberts, Port of Oakland, Oakland, CA. Joan Pope, U.S. Army Corps of Engineers, Vicksburg, MS. Felix Dhyrkopp, U.S. Department of the Interior, Minerals Management Service, New Orleans, LA.

• Efforts are needed to focus priority attention to the importance of high quality maintenance; to publicize the results of good maintenance so management understands the incentives for good maintenance and the public understands the results.

• Broad based peer review of the engineering design of new facilities and of the repair and rehabilitation of existing facilities is needed to help assure that creative and effective results are developed. Thinking well beyond the tried and true, or the conventional base of practice is required if one is to realize effective solutions to difficult marine structural maintenance management problems.

• There is a major need to build data bases on our existing facilities; to be able to understand and communicate the successful and the unsuccessful experiences.

• The primary ageing issues associated with coastal facilities are scour (due to waves, currents, and structure interactions), dynamic loadings (waves), realistic characterizations of the joint probability of occurrences of different marine loadings (winds, waves, currents), and understanding of **unraveling scenarios** (structural element-system interactions).

• Research on coastal-harbor structural elements is needed including information on in-place stress build-up or relaxation due to interactions of different elements comprising the structure system, the use of reinforcement in concrete construction to better assure durability, the ideal shapes of breakwater armor units, how to better assure the quality of quarried stone used in breakwaters, and the understanding of what causes the in-place breakup of armor materials.

• Research is needed on improving above and below water inspection and condition surveying methods. We need guidelines to better understand the effects of service degradation on function of the facilities and rating methods and criteria to help prioritize maintenance. Improved methods are needed to help predict operation and maintenance needs and costs (e.g. beach fills and maintenance, and structure maintenance).

• Research is needed on the effects of combinations of dissimilar units or elements placed as the result of repair or rehabilitation efforts. Improved criteria are needed to define when repairs or rehabilitation are necessary. Improved methods are needed for repairs; one needs more options and knowledge of the effectiveness and costs of these options.

• Development is needed to better train engineers for maintenance of marine structures. Engineers need to be trained to design for long-life maintenance considerations. Engineers need to be trained for repairs and rehabilitation of structures. Engineers need to be trained in methods needed to justify and obtain resources for life-cycle maintenance of marine structures.

• **A critical need is for engineering, management, and regulatory guidelines for addressing the unique problems associated with existing and old marine structures. Guidelines are badly needed for marine pipelines and mobile drilling units (MODU's). Guidelines are badly needed for marine structures in seismic areas.**

• Research is needed on **analytical methods** to evaluate the effectiveness of new designs and repairs. More standardized finite-element procedures are needed. More standardized loading procedures are needed. More efficient methods are needed to evaluate the characteristics of damaged and repaired structural elements.

• Research is needed on how to better **protect structures from the effects of corrosion; including long-life internal coatings, abrasion resistant external coatings, and more effective cathodic protection systems.**

• Research is needed to improve the inspections and inspectability of marine structures, including the cargo and ballast tanks of ships, critical structural elements of platforms and pipelines, and critical structural elements of coastal and harbor structures. A particular need is to improve inspection techniques for small-diameter, multiple bend piping systems.

• Research is needed to better understand the effects of tertiary cyclic flexure on the corrosion and durability of critical structural elements.

• The MMS is developing an industry-wide platform inspection data base. This data base needs to be analyzed to determine where and how defects and damage are developing in platforms. This information can be useful in helping improve future inspections. Information also should be developed on repairs, successful and unsuccessful.

CONCLUSION

• The results of this symposium indicate that we have begun the formalization of the engineering art and science of "marine structures geriatrics." We are using similar approaches, are experiencing similar successes and problems, and have similar R&D needs.

• Our R&D priorities need to result in improvements in:

- Condition surveys,
- Repair techniques,
- Definition of maintenance and rehabilitation goals,
- Engineering guidelines for maintenance and rehabilitation,
- Definition of effective alternative repair and mitigation measures,
- Definition of environmental and operational loadings and effects,
- Design for maintenance and damage tolerance.

• At the close of the symposium, a questionnaire was distributed to the participants that asked if this type of workshop or symposium should be continued, how it might be improved, and how it should be focused.

• The majority of participants indicate that this type of process should be continued. Future offerings should have greater focus and more time allotted for discussions. Workshops (case history - experienced oriented) and short courses (instructional) should be the format for future offerings.

• Key topics for future offerings suggested by participants are:

- Inspections of marine structures (above and under water),
- Repairs and rehabilitation techniques for marine structures,
- Seismic re-qualification and rehabilitation of marine structures,
- Re-qualification procedures, guidelines, and performance goals for Mobile Offshore Drilling Units (MODUs) and submarine pipelines (including risers),
- Development and maintenance of computer data bases on condition surveys, inspections, repairs, and maintenance of marine structures,
- Beach management, channel management, and sand-by passing,
- Development of structural maintenance and integrity programs for innovative structures such as tension leg platforms and floating production systems,
- Characterization and quantification of potential negative impacts associated with loss of serviceability or failure of marine structures (cost, life, pollution, loss of productivity) and characterization of goals for the re-qualification of marine structures.

• Appendix B summarizes the responses from the participants.

• Appendix C contains a roster of the symposium participants.

APPENDIX A

LISTING OF REMR REPORTS PUBLISHED TO MAY 1989

REMR Reports Published to Date

Number	*Date*	*Title*	*AD Number*
Unnumbered	Feb 83	REMR Research Program Development Report, by John M. Scanlon, Jr., James E. McDonald, Clifford L. McAnear, E. Dale Hart, Robert W. Whalin, Gilbert R. Williamson, and Jerome L. Mahloch	AD A125 998
Unnumbered	Sep 85	The REMR Notebook with two Supplements	
Unnumbered		REMR Subject Index thru Jul 88	
REMR-CS-1	Sep 84	Engineering Condition Survey of Concrete in Service, by Richard L. Stowe and Henry T. Thornton, Jr.	AD A148 893
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APPENDIX B

SUMMARY OF RESPONSES TO QUESTIONNAIRE

Continuing Education in Engineering, U.C. Berkeley Extension
2223 Fulton Street, Berkeley, CA 94720

California Sea Grant Symposium
Preservation of Ageing Marine Structures
August 13-14, 1990

Based on 27 responses out of 55 registered
and 85 attending

PROGRAM EVALUATION

Please take a moment at the end of this meeting to complete and return this form to Professor Bea or to the Nanette Pike, Extension representative.

1. I found the length of the presentations

   Too short 5 About right 22 Too long ____

2. I found the level of presentations

   Too basic 6 About right 21 Too complex ____

3. How did you hear about this program?

   Brochure in mail 20 Associate 3 News/meeting announcements 4

   Information provided at work ____ Other (specify) 4

4. Would you recommend this workshop in its current format to an associate?

   Yes 21 No 6

5. What changes in format to this meeting would you like to see offered?

   Instructional course 13 Case histories 14

   Other (specify) see attached

6. Suggestions for topics you would like to see added or expanded upon:

   see attached

7. Comments on workshop and/or speakers:

   see attached

Thank you for taking the time to comment.

The 6 respondees who answered "NO" to question 4 answered questions 5 through 7 in the following manner:

5. What changes in format to this meeting would you like to see offered?

Case histories - 3
Instructional course - 1

* much more technical content
* need to modify schedule to leave more time for discussion
* length of presentation OK but need more time on each topic
* too basic and general -- need more detailed repair and inspection schemes

6. Suggestions for topics you would like to see added or expanded upon:

* minimize sections on breakwater sea walls
* for ships - get people who have technical knowledge and can explain it
* 3 day workshop
    day 1 - problems; experiences of operators
    day 2 - existing solutions and approaches
    day 3 - on-going research and future needs
* I believe that more concentration should be given to repair case histories or analyses of procedures being used particularly in the ports area.
* actual repair techniques, unique underwater inspection techniques, training and educating managers to appreciate need for prevention maintenance
* more on offshore structures, less on ships, ports, docks

7. Comments on workshop and/or speakers:

* The subject area was too broad: those involved in port structures, for example, had little interest in ships. As a result, there were times that parts of the audience seemed disinterested.
* Much too simplistic!
* Too short a program. Wasting 3/4 of the 2nd day is unreasonable since out of station people cannot get any further work done that day.
* Although interesting, the diversity of topics limits attraction of specific disciplines. Limit topics. Bea's summary presentation was excellent and applicable to all disciplines.
* Would like to see more speakers from oil industry (oil companies & contractors). Bob was excellent.

The 11 respondees who answered "YES" to question 4 responded to questions 5 through 7 in the following manner:

5. What changes in format to this meeting would you like to see offered?

Case histories - 5
Instructional course - 2

* more question and answer time
* expanded, more in-depth

6. Suggestions for topics you would like to see added or expanded upon:

* approximation/calibration of non-linear response
* seismic
* event selection procedure
* seated attenuation/modulation
* pltfm response
* sand transport problems & sand
* bypass systems
* engineering implications of environmental concerns (ie spills)
* beach management
* Beaufort Sea and Cook Inlet Structures
* make the program a full two-and-a-half days to include case histories
* floating drilling units, floating production systems, tension leg platforms
* The subject matter covered was very good (from a structural engineering perspective, inclusion of trips was very good) - expand on all aspects under the main topics, which are good!
* MODU's, individual workshop on Databses spcifically
* inspection techniques and concerns
* this is how you document the ageing process
* additional info on ships, MODU & offshore oil and gas applications
* need to expand participation of oil/gas industry and ship operations
* mobile drilling units

7. Comments on workshop and/or speakers:

* excellent speakers/choice of topics
* very enjoyable
* Well done. Good speakers. Enjoyed lunch and dinner at Faculty Club. Meeting room was perfect for this program. Only negative -- the Durant Hotel was noisy, had poor ventilation so I did not sleep. Would have preferred to stay at Faculty Club if I had been aware of it.
* Good!
* Excellent. Need to have them more often.
* Need more joint industry projects.
* At times, too much focus on general design considerations rather than the ageing process and preservation concerns.
* Excellent workshop. Impressively qualified speakers.
* Should not mix port/offshore/coastal structures. Too broad!! It would be better to concentrate on like issues, ie port/coastal or ships/MODU/offshore.

APPENDIX C

ROSTER OF PARTICIPANTS

California Sea Grant Symposium
Presented by the
Departments of Civil Engineering and Naval Architecture and
Offshore Engineering, and University Extension,
University of California at Berkeley

PRESERVATION OF AGEING MARINE STRUCTURES

August 13-14, 1990

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