UNDERWATER INSPECTION/TESTING/MONITORING OF OFFSHORE STRUCTURES

February 1978

Sponsored by: U.S. DEPARTMENT OF COMMERCE
U.S. DEPARTMENT OF ENERGY
U.S. DEPARTMENT OF THE INTERIOR

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Under Department of Commerce Contract No. 7-35336

Distributed By
NOAA/OFFICE OF OCEAN ENGINEERING
Rockville, MD 20852

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock No. 003-018-00089-0

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PREFACE

The extraction of offshore oil and gas deposits has resulted in installation of massive steel and concrete platforms in progressively deeper and more hostile waters. Concern for the safety of platform personnel, potential damage to the environment, and the assurance of profitable, unimpeded, extraction of these offshore resources is a concern of host-country governments and the offshore operators.

Requirements for underwater inspection of these structures and the techniques and tools to conduct such inspection vary widely from country-to-country. In some instances periodic inspection is required by law; in other instances there is no requirement whatever once the structure has been installed. The instruments to conduct underwater inspections also vary; their effectiveness is sometimes questionable, and the cost of underwater inspection to the operator (which will eventually be borne by the consumer) is high and will get higher as the water depth and complexity of the structure increases.

The purpose of this six month study was: 1) to identify and describe all actual or potential underwater inspection requirements (national and international) for fixed concrete and steel structures promulgated by the governments of offshore oil and gas producing countries and by the offshore operators themselves; 2) to identify and assess the state-of-the-art in underwater non-destructive testing/monitoring/inspection of offshore structures; 3) to evaluate the capability of servicing and hardware producers to meet the inspection requirements identified; and 4) to describe and establish priorities for specific tasks for technology development that should be undertaken to satisfy current and future requirements. While this study concentrates on fixed offshore oil and gas structures, the results also reflect the state-of-the-art in underwater inspection/testing for other offshore structures as well, e.g., floating power platforms; offshore terminals and deepwater ports.

The data for this study were collected in three stages. First, an intensive literature review was conducted to initially identify those organizations and governments active in projects related to the study goals (the results of this literature survey are presented in Appendix I). Second, telephone interviews were conducted to further identify "Requirements" sources and suppliers/manufacturers of inspection/testing capabilities in the U. S. and Europe. Third, personal interviews were conducted with individuals active in hardware production or inspection services. Personnel and organizations contacted (both by telephone and on a personal basis) are identified in Appendix II (Requirements) and III (Capabilities), respectively. Approximately four months were required to satisfy the data collection phase; the remaining two months were spent analyzing, reducing and synthesizing the data obtained.

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OVERVIEW

Between 1947 and 1975 over 3,000 structures for the production of oil and gas were erected in the Gulf of Mexico. According to the National Research Council, the offshore regions of the U.S. - of which only about 2 percent have been opened for production - provided 16.4 and 14 percent of the nation's oil and natural gas, respectively. American Petroleum Institute predictions indicate that this yield could double by 1985. Future sites for oil and gas exploration may include the Arctic, Atlantic and Gulf of Alaska, as well as the present Gulf of Mexico and Southern California.

Until 1953 the only requirements for inspection of such structures were those which the platform operator/owner elected to impose upon himself. In the U.S. this situation still prevails although the U.S. Geological Survey in 1953 and the Occupational Safety and Health Administration in 1970 obtained statuatory permission to conduct and/or require inspection of structures in U.S. waters. In the North Sea, the English and Norwegian governments established underwater inspection requirements and schedules in the mid-1970's to which the platform owners must comply. In England five classifying societies are authorized to set standards for underwater inspection: Lloyds Register of Shipping, Germanischer Lloyds, Bureau Veritas, Det Norske Veritas (DNV) and the American Bureau of Shipping. A sixth certifying organization, Halcrow Ewbank and Associates, has recently been recognized by the English government. Only DNV and Bureau Veritas have published requirements for inspection. DNV has the most explicit requirements at present, but all Societies approach the problem with a great deal of flexibility and look to the owner/operator to define the scope of certification.

The platform operators, the ultimate customers of all inspection services and the primary source of all inspection requirements, are not uniform in their approach to inspection. Some have outlined very definite programs, while others are developing programs. From the U.S. offshore operator's point of view, the most pressing need is for surface, rather than subsurface, techniques for inspection of structural members.

Traditionally the diver has been - and still is - the primary inspector. Visual inspection, photographic and TV documentation have been his primary tools. Inspection includes preliminary structure cleaning which can be a more arduous and time-consuming task than the inspection itself. What began as a relatively simple task in shallow and warm waters on relatively simple structures has now progressed to the most demanding work. Fixed oil and gas structures of the forties were 4- and 6-legged platforms, generally in 30 to 60m of water, where temperatures were moderate and weather - though occasionally tempestuous - generally allowed a wide working window. The picture has changed dramatically with the increased massiveness and complexity of present day platforms. For example, the recently-constructed Cognac platform will rest in

307m of water; it weighs over 30,000 tons and approximately 99km (61.5 miles) of welding was required to connect its tubular members (personal communication Mr. G. C. Lee, J. Ray McDermott & Co.).

An equally significant change has been in the geographic areas now being explored and from which oil and gas is produced. The North Sea in particular, has introduced environmental factors rarely, if ever, encountered in the Gulf of Mexico. Water temperatures, fouling rates and sea states are far more severe, and combine to test the limits of both men and machines. Operational failures, according to an unpublished report by the Construction Industry Research and Information Association (CIRIA) Underwater Engineering Group, have occurred on platforms in the North Sea only months after their installation. These failures were due to corrosion rates and marine organism fouling in excess of what was expected for the depth of water.

The more demanding conditions and more complex structures have produced a need for structure inspection which transcends simpler visual/photographic capabilities. Many companies offering undersea work capabilities have started investigating the problems involved in modifying surface non-destructive testing (NDT) instrumentation for undersea application. Other companies have progressed further and developed several underwater NDT techniques.

Traditionally five types of NDT techniques have been used in surface testing:

- Visual (surface crack detection)
- Magnetic Particle (surface and shallow subsurface crack detection)
- Ultrasonics (thickness and surface/subsurface flaw and crack detection)
- Radiography (internal flaw and crack detection, thickness)
- Liquid Penetrant (surface cracks, porosity, laps, cold shuts)

All of these methods, except liquid penetrants, are being used underwater. An additional method used on offshore structures is corrosion potential (CP) measurements.

The interest in developing such capabilities is growing rapidly, particularly in the North Sea-bordering countries where inspection is a legal requirement. While no diving company has a full range of all NDT capabilities, several companies are rapidly developing an expertise--either by purchasing an already existing NDT company, or by acquiring appropriate instrumentation, or both.

The field, at this point, can be described as emerging. Several groups are attempting to assess the needs and future requirements, and are conducting studies to this end. For example, the University of Strathclyde has an ongoing study to ascertain future developments in underwater maintenance, inspection and repair techniques in the U.K. offshore industry. Det Norske Veritas is conducting a state-of-the-art survey on NDT equipment, procedures, safety and operator's qualifications. The Ship Structures Committee (consisting of representatives from the

Maritime Administration, Coast Guard, Navy, ABS, and the Military Sea Command) is funding a study being conducted by the Naval Surface Weapons Center, White Oak, Maryland, to assess the state-of-the-art in underwater NDT. The CIRIA Underwater Engineering Group, London has two studies currently underway: first, "Underwater Inspection of Offshore Installations: Market Survey" will be completed in early 1978; second, "Underwater Inspection of Offshore Installations: Guidance for Designers" will also be completed in early 1978.

From the objectives of the above studies and the results of interviews with organizations potentially in a position to supply inspection/ certification services to this emerging market, it is evident that a market is foreseen. Precisely what this market will be and what will be its size is not certain.

Two alternatives to the diver are also being developed to serve a role in underwater NDT: the manned submersible and the remotely controlled vehicle. Both systems are capable of being used to produce high quality visual and photographic inspections, and both can bring some form of cleaning device (wire brush, chipping hammers) to the inspection site. Application of present NDT devices, however, is designed for the human hand, and utilization by present-day manipulators on both manned and remotely controlled vehicles is difficult, if not impossible. In view of this limitation, manned submersibles are being used primarily as transportation and support for divers locked-out at the inspection site. The major North Sea submersible operators are now in the process of acquiring NDT instrumentation which can be deployed by a locked-out diver or by the submersible itself. For example, Intersub will take delivery this spring on a diver-held ultrasonic flaw detection device which utilizes the principals of acoustic holography, Vickers Oceanics Ltd. and Intersub recently acquired a submersible-held c-p meter, P&O Subsea has acquired a diver-held Wells-Krautkramer UT thickness-measuring device and a company specializing in NDT, and COMEX has developed, among other devices, a closed circuit TV capable of providing bas relief on the monitor in which slight details appear as ridges or valleys. A variety of other NDT devices and capabilities, discussed in subsequent sections of this report, are being developed for application from lockout or one atmosphere submersibles.

The role of remotely controlled vehicles in underwater inspection/ testing is less well-defined than their manned counterparts. As inspection/photographic-documentation vehicles, they appear to be excellent. As platforms for deployment of NDT instrumentation, indications are that the capability is still emerging. In open waters they have been used quite successfully as pipeline inspection vehicles, but around and within steel structures they have - in addition to other problems - experienced difficulties with cable entanglement and location. Remote controlled vehicles, with adequate development, offer a wide range of potential capabilities for underwater NDT, and inspection.

A great deal of interest and research funding is being drawn into another area of structural monitoring: acoustic emission analysis and vibration analysis. These methods seek to determine - without requiring a diver or submersible - that a structural member has either broken or cracked, and where the member is located on the structure.

Acoustic emission monitoring detects minute, crack-induced pulses of acoustic energy by use of sensitive piezoelectric transducers attached to the structure being monitored. The signals are conditioned by electronic circuitry and then computer-processed to determine the location and the significance of the discontinuities of structural integrity. In this technique it is necessary to install the transducers underwater at strategic locations throughout the structure.

Vibration analysis or monitoring takes advantage of the fact that a fixed structure, which is continually excited by the motion of sea and wind, has a natural resonance frequency. These natural frequenices can be appreciably changed if a load-carrying member breaks or loosens significantly. Using vibration analysis techniques, the appropriate natural frequencies of a structure can be determined from a small number of measurements taken at selected stations above the water surface. The amount and distribution of the change in the natural frequencies caused when a member fails varies according to the position of the member within the structure and on the topology and degree of redundancy. Significantly, vibrational analysis techniques do not require that any component of the monitoring system be underwater.

Both techniques are presently being tested in long-term programs on several fixed platforms in the North Sea. U.S. offshore application of acoustic emission and vibration analysis techniques has been limited to government-owned structures.

A variety of other research and development programs in underwater NDT devices are being funded by industry and government in Europe. These programs are aimed at developing exportable technology for international clients as well as for current operations in the North Sea. Most NDT-oriented research and development programs in the U.S. are funded by industry. The USGS is investigating vibration monitoring and inspection via an untethered remotely controlled vehicle. The USGS together with the Office of Naval Research is investigating acoustic emission monitoring and underwater cleaning.

1.0 SUMMARY AND RECOMMENDATIONS

1.1 INSPECTION REQUIREMENTS

The only inspection requirements for fixed offshore structures in U.S. waters apply to pipelines. Both the Federal Government (Office of Pipeline Safety, Dept. of Transportation) and two state governments (Texas and California) require periodic overflights of the water surface above the pipeline to observe any indication of leakage. The Federal government also requires annual testing of each pipeline under cathodic protection to determine that it meets federal requirements.

Two Federal departments have statutory rights to require underwater inspection of fixed platforms: 1) Department of Interior (Geological Survey) under the Outer Continental Shelf Lands Act of 1953 and its Amendments (S.9) of 1977, and 2) the Department of Labor (Occupational Safety and Health Administration) under the Occupational Safety and Health Act of 1970 (Public Law 91-596). Neither Department has delineated their inspection requirements at this date.

The U.S. Coast Guard (Department of Transportation) provides inspection/testing requirements for its manned light stations, but the criteria established by the Coast Guard are for its own structures and are not meant to be applied to private structures.

Two North Sea bordering countries have prescribed underwater inspection requirements: the United Kingdom and Norway. U.K. requirements, contained in the Offshore Installation (Construction and Survey) Regulations of 1976, are legal requirements under which periodic inspections are required of the platform owners to maintain a valid Certificate of Fitness. While there is a legal basis for platform inspection in Norwegian waters, there has been no legal document produced which defines these requirements. Instead, provisional guidelines have been written by the Norwegian Petroleum Directorate, the certifying authority, delineating the scope, periodicity and nature of the underwater inspection program. Other North Sea countries (Denmark, West Germany, France, Belgium, the Netherlands and Sweden) are in various stages of development toward the writing and promulgation of inspection requirements.

Under the U.K. regulations five professional societies are authorized to issue a Certificate of Fitness: American Bureau of Shipping (U.S.); Bureau Veritas (France); Det Norske Veritas (Norway); Germanischer Lloyd (West Germany) and Lloyds Register of Shipping (U.K.). A sixth organization, Halcrow Ewbank and Associates Certification Group, has recently been added to the list of certifiers. Only Bureau Veritas and Det Norske Veritas have published guidelines regarding procedure and scope for underwater inspection of fixed structures, the remaining societies are in the process of writing their certification criteria.

Platform operators in U.S. waters can find guidance in designing their inspection programs from the American Petroleum Institute's "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms" (API RP 2A). North Sea platform owners have, or are establishing, inspection programs to comply with government requirements. Not all these programs are identical since the onus is laid on the owner to design and pursue an inspection program which he feels satisfies requirements. Consequently, inspection frequency, element selection procedure and inspection methods may vary from platform-to-platform.

All inspection programs (imposed and self-imposed) call for an annual platform survey. The government programs and those of the classifying societies call for a major survey once every four or five years. Special surveys are called for in several instances.

General Surveys consist primarily of visual inspection and testing for:

- Broken or bent members
- Cracking and pitting
- Corrosion
- Marine fouling
- Debris accumulation
- Corrosion system effectiveness
- Scouring at platform base

Major Surveys involve conducting all the inspections, noted above and a detailed examination on selected parts of the structure (10% is generally required). The Major Survey calls for cleaning of the structure and an examination by magnetic particle inspection or other techniques to determine the presence of cracks, pitting, or corrosion at preselected nodes. In practice, each General Survey is designed such, that by the time the fourth or fifth year (depending upon the Certifying Authority) is reached the previous inspections will cumulatively equal the requirements of the Major Survey.

Special Surveys are, essentially, damage assessment surveys which are called for if the structure has been subject to barge or ship impact, or severe loading by weather or by an object dropped over the side. Additionally, an inspection is required if changes in the condition or operation of the structure have been made which may affect its safety or a part of its scope of certification.

1.2 CAPABILITIES - INSPECTION/TESTING

Underwater NDT and inspection is a rapidly emerging technology; many limitations discovered during the tenure of this study will undoubtedly be resolved in the very near future. Particularly by the North Sea suppliers of inspection/testing services where the annual market for inspection, maintenance and repair is estimated at $500 million by 1985.

Five underwater inspection/testing techniques are being used in the U.S. and North Sea waters: 1) Visual inspection; 2) magnetic particle inspection; 3) ultrasonic inspection (thickness and flaw detection); 4) radiography, and 5) corrosion-potential (c-p) measurements. Variations on these techniques include a Magnetographic method of crack measurement and an acoustic holographic technique for internal flaw detection. Table I summarizes these methods and presents the advantages and disadvantages when used underwater.

Underwater inspection and testing introduces problems never encountered in surface work; these can severely limit - and sometimes prevent - the inspection or test from being conducted. All testing techniques listed in Table I require that the structures be cleaned of marine organisms. While brushing, chipping and scraping will sometimes suffice, it is frequently required that a high pressure water jet be applied, the jet is cumbersome and potentially dangerous to the operator. Cleaning is not only arduous, but it can constitute the major expenditure of underwater time.

Locating the site to be inspected and positioning oneself to conduct the inspection test can be quite difficult, particularly on complex nodes or in the interior of a steel structure. If there are no markings on the platform to identify the work site, location is made much more difficult. If underwater visibility is near zero, location is virtually impossible and testing cannot be done with present techniques.

A further complication to inspection/testing is in the splash zone where the periodical rise and fall of the sea surface can prevent the surveyor from maintaining his position at the work site. Above certain sea states, depending on the underwater inspecting techniques used, it is impossible to deploy any instruments to the work site at all.

Unlike surface NDT where a human being is used to conduct all testing, underwater NDT instruments are carried and deployed at the work site by one of four techniques: 1) divers; 2) manned submersibles; 3) remotely controlled vehicles and 4) one-atmosphere diving suits. The diver (either free-swimming, tethered, or deployed from a bell or lockout submersible) is most generally used for inspection and testing.

Each one of the above deployment capabilities has strengths and weaknesses in performing nondestructive testing. The greatest weakness at present is that nearly all underwater NDT devices are designed to be used by a diver. Consequently, the mechanical manipulators of the submersibles and remote controlled vehicles, and the grasping terminations of atmospheric diving suits are at a distinct disadvantage. Other limitations include positioning, stability, maneuverability and entanglement potential. No one vehicle or deployment capability is the ultimate substitute for the diver, each has its own peculiar advantages and disadvantages. One of the more promising capabilities for inspection and certain forms of testing is the remote controlled vehicle, but certain of its obvious deficiencies must be corrected before it can realize its full potential.

In view of the accelerated offshore drilling and production activities in ever-deepening waters, it is conceivable that the diver's capability to routinely conduct inspections and testing at the depths required will soon be surpassed. When this occurs, there is no deployment capability which can now be used as an alternative.

The relative performance of each deployment capability to perform the tests tabulated in Table I are presented in Table II. These evaluations take into account such factors as: locating the site; maneuverability at the work site, and manipulative dexterity.

All of the written government and society requirements to date are general in nature and do not specify measurement or position accuracies. Recommendations are made regarding types of tests to be applied, but the final testing technique is negotiable so long as it provides the data required.

Qualification of NDT personnel is not standard in U.S. or North Sea based companies. Most U.S. NDT instruments are deployed such that the qualified NDT technician, generally by American Society of Nondestructive Testing (ASNT) standards, is on the surface with the test data display unit while a diver carries the sensor (i.e., transducer) to the work site. It is not a common practice to use an NDT-qualified diver; instead, a pre-dive briefing of the diver's duties generally sufficies. North Sea servicing companies may or may not use divers qualified in accordance with CSWIP (Certification Scheme for Weldment and Inspection Personnel) or, in the case of Det Norske Veritas, an in-house NDT qualification program of its own. There are no known qualification standards for divers performing overall visual inspections.

Standards of accuracy and repeatability for NDT instruments are provided by the American Society for Mechanical Engineers and the American Society of Testing Materials. These standards apply to surface testing at one-atmosphere pressure. No standards could be found which apply to NDT instruments under high pressure and low temperatures in the marine environment; consequently, the data obtained from one manufacturer's instrument may not be comparable to the data obtained from a competitor's device.

1.3 CAPABILITIES - MONITORING

Two techniques have been developed which can be used to monitor a fixed structure's integrity: acoustic emission monitoring and vibration analysis. Both techniques are available in the U.S., but their primary use to date has been for demonstrational purposes. Several industrial firms in the U.K. are developing vibration analysis systems which are undergoing at-sea testing on North Sea platforms, these programs are supported in part, by government funds.

Acoustic emission analysis utilizes the minute acoustic emissions produced by discontinuity regions in materials under stress. By acquiring these emissions on strategically-located transducers attached

TABLE I

PRESENT UNDERWATER NDT TECHNIQUES: ADVANTAGES AND LIMITATIONS

Method	Material	Defects	Advantages	Limitations	Remarks
Visual	All materials	Surface cracks/pitting, Impact Damage, Surface Corrosion, Marine Fouling, Debris, Scouring, Concrete spalling/crumbling	Results easy to interpret. Can be conducted with a variety of techniques.	Limited to surface defects. Surface must be cleaned for detailed observation.	
Magnetic Particle	Magnetic materials only	Surface cracks, laps, seams, pits and some near-surface flaws.	Easy to interpret.	Thorough cleaning required. Weather dependent in splash zone. Limited to surface and near surface defects. Does not measure depth of defect. Interpretation done only in situ. Present equipment limited to diver use. Magnetic materials only. No permanent record. Cumbersome to perform underwater.	Surface Support required.
Magneto-graphic Method	Magnetic materials only	Surface cracks, laps, seams, pits and some near surface flaws.	Simple to perform. Permanent record. Signal enhancement possible. Defect depth can be obtained. Interpretation conducted on surface. No diver NDT qualifications required.	Thorough cleaning required. Limited to surface and near-surface defects. Geometry of structure can be prohibitive. Magnetic materials only. Equipment limited to diver use.	Potential for application by mechanical manipulators.

TABLE I (CONT.)

Method	Material	Defects	Advantages	Limitations	Remarks
Fe Depth Meter	Reinforced concrete	Depth of steel reinforcement in concrete.	Easy to perform. Results immediate. Can be preformed by mechanical manipulation.	Thorough cleaning required. Bar size must be known for greatest accuracy. No data recording feature.	
Ultrasonics	Metals, Concrete, Plastics, Creamics, Glass, Rubber Graphite	Cracks, Inclusions Porosity, Laminations, Bursts, Grain size, Lack of bond, Lack of weld penetration and fusion, Thickness variations.	High sensitivity. Fast Penetrates up to 10m of steel. Accurate flaw location. Access to only one side needed.	Thorough cleaning required. Operator skill is required. Usually no permanent record. Comparative standards only Surface roughness can affect test. Difficulty with complex shapes. Present equipment limited to diver use.	
Acoustic Holography	Same as above	Same as above.	Provides three-dimensional view of internal defects which can be precisely measured and located.	Thorough cleaning required. No field experience underwater. Present equipment limited to diver use.	
Radiography	All materials	Internal defects such as inclusions, porosity, shrinks, corrosion, lack of penetration and fusion in welds. Thickness measurements.	Provides permanent record Standards established. Accepted by codes and and industry. Portable.	Thorough cleaning required. Potential health hazard. Defect must be at least 2% of total section thickness. Difficulty with complex geometry. Water must be displaced between source and subject. Requires access to both sides. Present equipment limited to diver use.	

TABLE I (CONT.)

Method	Material	Defects	Advantages	Limitations	Remarks
Corrosion Potential	Metals	Tests cathodic protection system by measuring interface potential between structure and seawater.	Simple to perform. Rapid measurements. Easy to interpret. Can be performed by mechanical manipulation.	Thorough cleaning required. Measures external potential only.	

TABLE II

NDT DEPLOYMENT CAPABILITIES: PERFORMANCE AND POTENTIAL

Test/Examination	Diver	RCV	Sub	ADS[1]	ADS[2]
Cleaning	A	N	N	P	P
Visual	H	H (exterior only)	A (exterior only)	H (exterior only)	H
Magnetic Particle	H	N	N	P	P
Magnetographic	H	N	N	P	P
Fe-depth	H	P	P	P	P
Ultrasonic					
Thickness	H	P	P	P	P
Flaw	H	N	N	P	P
Acoustic Holography	H	P	P	P	P
Radiography	H	N	N	P	P
Corrosion Potential	H	H	H	P	P

H = High performance
A = Adequate performance
P = Potential performance
N = No foreseeable potential with present facilities
ADS[1] = JIM-Type
ADS[2] = WASP-Type

underwater to the structure, the detection, location and subsequent rate of crack growth can be derived. The data may be transmitted via radio communication to a shore station where it can be analyzed, or it can be analyzed onboard the platform.

Theoretical basis of vibration analysis is the fact that each offshore structure, regardless of type, has natural vibration modes that are continually excited by wind and wave forces. If the mass of the structure remains unchanged, the reduction in its stiffness, caused by damage to its load-carrying members, will result in shifting its vibration characteristics. By obtaining an initial "as built" signature with highly sensitive accelerometers and a recording device, subsequent measurements can be compared to the baseline signature to determine whether or not breakage of a load-carrying member has occurred.

Table III lists the advantages and disadvantages of both systems as they stand at present. As with any new form of technology, there are initial problems that only time and experience in the field can solve. With operational use and greater sophistication in the software area it is more than likely that many of the present problems can be solved and the techniques can be refined to the point where more definitive data can be obtained.

In terms of present inspection requirements the precise value of these systems is difficult to define since they do not satisfy any of the present stated requirements, nor is their application identified by any of the certification societies.

1.4 ON-GOING RESEARCH DEVELOPMENT PROGRAMS

A wide variety of research development programs are being pursued by North Sea-bordering companies and their respective governments which are directly and indirectly related to platform inspection/testing/monitoring. Where several programs are aimed directly at developing new NDT or monitoring technology, the majority are aimed at determining the fundamental characteristics of steels and concrete in the marine environment (e.g., corrosion, cracking and crack propagation, cyclic loading effects, effects of marine growth on wave and current loading, etc.). The results of these programs can find direct application to monitoring and testing techniques by providing information which can be used to evaluate the results of the inspection programs. Other related research toward increasing diver capabilities is in direct support of NDT deployment techniques.

U.K. industries are supported by funding from the Department of Energy's Offshore Supplies Office. The aim of this support is to produce needed and exportable technology. Approximately $1.8 million was spent by the Department of Energy in 1976 to support research and development in inspection, nondestructive testing, vibration monitoring in welding, and this figure increased to approximately $2.7 million in 1977. Some

TABLE III

MONITORING SYSTEMS SUMMARY PERFORMANCE

	Advantages	Disadvantages
Acoustic Emission	No diver required to conduct tests. Can detect a crack. Can ascertain relative rate of crack growth Can determine crack location.	Long-term reliability not yet verified. Components in water subject to environmental stresses. Cannot determine crack size. Cannot determine nature or significance of the crack. No standards of calibration from system-to-system. Expensive installation (i.e., diver) costs on existing platforms.
Vibration Analysis	No diver required to conduct tests. All components above water. Quick set-up time. Can detect broken load-carrying members.	Limited operational experience. Cannot assess significance of break. Cannot detect cracks unless they are significant in magnitude. Cannot locate cracks or break. Cannot monitor crack growth. No standards of calibration from system-to-system.

$13.3 million total was spent supporting related research on materials, design, foundations, wind, wave and current prediction, as well as inspection programs.

A partial listing of pertinent research programs and their sponsors is provided in Table IV. The comprehensiveness of this listing is unknown since there are undoubtedly industrial research and development programs for which details are not available.

1.5 RECOMMENDED RESEARCH AND DEVELOPMENT PROGRAMS

Since there are no U.S. underwater inspection requirements for fixed offshore platforms, the only basis upon which a technological research and development program can be recommended are the requirements of the North Sea countries and those of professional and classification societies. On this basis two types of research programs have been identified: immediate (those which enhance present techniques); and long-range (those which call for development or further refinement of new techniques). In some instances the recommendation is to obtain standards, rather than develop new technology. The results of present NDT techniques are so dependent upon human performance, that it is impossible to separate technological needs from operator qualifications.

The programs listed and briefly described in Table V are aimed at four objectives: 1) reduce time; 2) increase data reliability; 3) extend present capabilities and 4) decrease weather dependency. It is emphasized that these programs are based on European and society requirements, not U.S. government requirements. Until underwater inspection requirements are issued by the government, the priority (indeed, the need itself) for these programs cannot be established.

TABLE IV

PERTINENT RESEARCH AND DEVELOPMENT PROGRAMS

Country	Participants	Title	Objective
France	CNEXO	Ocean Structures Behavior	A variety of programs concerning safety, maintenance and performance of steel and concrete structures.
Norway	Univ. of Thondheim	Electrical Resistivity of Concrete in the Ocean	To investigate the electrical resistivity of concrete exposed to the ocean environment.
	SINTEF and DNV	Corrosion Fatigue Offshore	To determine fatigue properties of structural steel at different cathodic polarization levels.
	DNV	Concrete Structure Fatigue	To investigate parameters believed to affect the fatigue strength of concrete in the marine environment.
United Kingdon	The Welding Institute	Hyperbaric Welding	Evaluate hyperbaric arc welding procedures and measure properties of the results.
	DOE and Industry	Concrete in the Oceans	Obtain fundamental data on concrete in the marine environment.
	DOE, DNV, ABS, and Industry	Exxon Ocean Test Structure	To improve the understanding of wave forces on offshore structures.
	Building Research Station	Foundations of Offshore Structures	Improve the safety and economy of offshore structure foundations.
	DOE and a number of research organizations	Offshore Structures Fluid Loading Advisory Group (OSFLAG)	Ten separate programs directed towards understanding of wind, wave and current loading on fixed and floating offshore structures.

TABLE IV (CONT.)

Country	Participants	Title	Objective
United Kingdom (cont.)	DOE and Academic Institutions	Buckling Research	To test and improve the prediction methods used to check the buckling stability of single members of offshore structures.
	DOE, Ministry of Defense and Baxter, Woodhouse & Taylor	Diving Equipment	To develop an alternate to hot water heating and to reclaim helium in a push/pull breathing unit.
	DOE, Industrial Firms and the European Coal and Steel Community	United Kingdom Offshore Steels Research Program (UKOSRP)	A major program ($8.9 million) of fatigue and fracture studies which also includes participation of four European countries. Includes a series of related programs involving stress analysis, corrosion fatigue, brittle fracture studies and full-scale fatigue tests on welded joints.
	University of Glasgow	Dynamics of Offshore Structures	A study of vibration and damping in offshore structures to assist in design of vibration analysis monitoring systems.
	Wimpey Laboratories Ltd.	Strain Gage Application to Deep Water Structures	To study strain gage and installation procedures for instrumenting deep water structures.
	Taylor Woodrow Construction Ltd.	Steel Corrosion in Concrete-Detection	To develop permanently-embedded and surface-mounted half-cells to monitor the potential of steel embedded in concrete.
	Ward, Ashcroft and Parkman	Instrumentation of Submerged Concrete	To ascertain the behavior of mass concrete under static hydraulic loading in order to develop methods of remote sensing.
	Structural Monitoring Ltd.	Integrity Monitoring System	To develop an integrity monitoring system using the principles of vibration analysis.

TABLE IV (CONT.)

Country	Participants	Title	Objective
United Kingdom (cont.)	Strongwork Diving (International) Ltd.	Advanced Deep Water Inspection	To develop remote access devices capable of providing definitive information regarding physical damage, corrosion loss and fatigue cracking on deep water structures.
	Unit Inspection	Acoustic Emission Monitoring	To evaluate acoustic emission techniques for the detection and monitoring of fatigue in offshore structures.
United States	Shell Oil Co.	Vibration Analysis	To determine the fundamental periods and damping on four jacket-type platforms (program completed 1976).
	Keith, Feibusch, Associates, Engineers and 13 Oil companies	Vibration Analysis	To determine the effectiveness of vibration analysis techniques on three fixed platforms in the Gulf of Mexico.
	University of New Hampshire and USGS	Untethered Remote Controlled Vehicle	To develop an untethered remote controlled vehicle which would ultimately be capable of conducting inspections of pipelines and structures.
	USGS	Vibration Monitoring	To determine the feasibility and limitations of the vibration monitoring technique and to produce a bread-board equipment package.
	USGS and USN	Acoustic Emission Monitoring	Same as above but for acoustic emission monitoring.
	USGS	Dynamic Property Prediction	To predict and analyze the dynamic properties of offshore platforms for use during design.
	USGS and USN	Cavitating Jet	To develop a more efficient method of removing marine growth.
	USGS	Acoustic Emission	To determine if fatigue cracking can be differentiated from stress corrosion cracking.
	Petroleum Companies	Exxon Model Platform	To measure the response of a platform to various measured ambient conditions.

TABLE V

RECOMMENDED TECHNOLOGICAL RESEARCH AND DEVELOPMENT PROGRAMS

Classification	Title	Objective
Immediate	Operator/Surveyor Qualifications	Determine the need for diver NDT qualifications. If a need exists, establish minimal qualifications standards.
	Instrumentation Standards/ Qualifications	Establish minimal acceptance and performance standards for NDT instrumentation. Evaluate present techniques with regards to accuracy of data in low temperatures/ high pressure environment.
	Cleaning	Assess present structure cleaning techniques to evolve more expeditious, safer techniques via remote controlled vehicles or by employing new cleaning concepts. Define cleaning standards for NDT.
	Positioning	Develop a navigation system which would rapidly and reliably guide and locate the diver, RCV, etc., to the test site on the extremities of a steel and concrete structure, and within the interior of a steel structure.
	Mechanical Manipulation	Design alternatives to hand-held NDT devices which could be deployed by mechanical manipulators.
	Remote Controlled Vehicles	Define the state-of-the-art in RCV application and problems in underwater inspection. Define development criteria required to optimize this technique as a visual inspection and NDT capability.
	Corrosion Potential Monitoring	Conduct design review, field test and operationally evaluate systems for remote corrosion potential monitoring.

TABLE V (CONT.)

Classification	Title	Objectives
Long Term	Structural Monitoring	Field test and evaluate present structural monitoring techniques to substantiate state-of-the-art and define potential limits of these systems in satisfying inspection requirements.
	Testing Unclean Structures	Develop NDT techniques that can detect corrosion, cracking and internal flaws without requiring prior cleaning of structure.

2.0 REQUIREMENTS - U.S.

2.1 INSPECTION

The requirements for inspection of fixed structures are derived from two sources: Federal/State Governmental bodies, and the platform operators. Classifying societies, such as the American Bureau of Shipping, Lloyds Register, Det Norske Veritas, etc., set up standards based upon inspection requirements derived from one or both of these sources (and insurers of platforms as well). While these Societies are grouped herein as having requirements, it is noted that they develop standards; not requirements. In the same category are professional societies such as the American Welding Society, the American Society of Mechanical Engineers and the American Society of Nondestructive Testing, who produce code standards of their respective societies; they are not requirements per se.

Requirements are grouped into three categories: Inspection; Personnel Training; and Instrumentation. For convenience, these three categories are discussed under the headings United States and North Sea.

UNITED STATES

Within this heading the results of interviews and literature surveys of Federal Government Agencies, State Governments, Professional and Classifying Societies and Offshore Operators are presented.

2.1.1 <u>Federal Government (Legislative)</u>

Two Federal inspection requirements exist for fixed offshore structures; one resides in the "Outer Continental Shelf Lands Act of 1953 and Its Amendments (S.9) of 1977". The Department of Interior (USGS) derives its inspection authority from Title 30 Chapter II of the Code of Federal Regulations and the OCS Lands Act. Paragraph 250.19 states:

> (a) The supervisor is authorized to approve the design, other features, and plan for installation of all platforms, fixed structures, and artificial islands as a condition of the granting of a right of use or easement under paragraphs (a) and (b) of P. 250.18 or authorized under any lease issued or maintained under the act. The Supervisor is authorized to require that lessees maintaining existing platforms, fixed structures and artificial islands equipped with helicopter landing sites and refueling facilities provide the use of such facilities for helicopters employed by the Department of the Interior in inspection operations on the Outer Continental Shelf.

At this time there is nothing written which specifies the nature of these surveys as pertains to the underwater aspect.

Under the "Occupational Safety and Health Act of 1970" (Public Law 91-596), OSHA is authorized to conduct inspections of fixed platforms on the Outer Continental Shelf lands. Section 8(a) of this Act states:

> "...the Secretary (of Labor), upon presenting appropriate credentials to the owner, operator, or agent in charge, is authorized -
>
> (1) to enter without delay and at any reasonable times any factory plant, establishment, construction site, or other workplace or environment where work is performed by an employee of an employer; and
>
> (2) to inspect and investigate during regular working hours and within reasonable limits and in a reasonable manner, any such place of employment and all pertinent conditions, structures, machines, apparatus, device, equipment and materials therein, and to question privately any such employer, owner, operator, agent or employee."

Under Section 8(c) of the same Act, it is stated (in regard to record keeping):

> "In order to carry out the provisions of this paragraph such regulations may include provisions requiring employers to conduct periodic inspections."

To determine whether any legislation was being written or pending regarding safety or inspection of offshore platforms and/or pipelines, telephone interviews were made to the offices of 46 U.S. Senators representing all coastal bordering states and 10 U.S. Representatives from coastal districts. The Senate and Congressional offices interviewed and the names of the staff members, when provided, are listed in Appendix II. In all of these interviews it was suggested that inquiries be made of pertinent activities in the state of representation; this too was performed and the activities queried are presented in Appendix II.

The results of the above efforts revealed that there is no other federal legislation written, proposed, or being written which is concerned with safety or underwater inspection of fixed offshore platforms. Copies of state legislation were received which bears directly and indirectly on underwater inspection; these are discussed under the subsequent section headed "State Governments".

2.1.2 Federal Government (Executive)

Queries were made of six federal government activities to identify any present or potential inspection requirements germane to this study. The only federal government activity which has its own inspection requirements for fixed structures is the U.S. Coast Guard. While the other activities - particularly the USGS - have an interest in this, only the Coast Guard has immediate on-going requirements. The following is a synopsis of each activities' interest in underwater inspection; the sources for this information are presented in Appendix II.

2.1.2.a Department of the Interior (Geological Survey)

Under the Outer Continental Shelf Lands Act, referred to earlier, the USGS is responsible for overseeing and regulating the structural integrity and operational safety of offshore drilling and production equipment. It requires (under OCS Order Number 8, Gulf of Mexico and Western Region Pacific area, third-party inspection by the Operator to certify that the structure will be constructed, operated and maintained as described in the application (1).

The USGS is presently focusing its efforts to the question of third party verification. In this area the Marine Board of the National Research Council was requested to undertake a review of the verification practices and the need for such practices concerning structural adequacy of fixed offshore oil and gas platforms. The results of the National Research Council's study are contained in reference (2); in short, the study recommends initiation of a third party verification system. An industrial critique of the Marine Board's recommendations is contained in references (3) and (4). Directly related to this study is a Marine Board recommendation that the USGS should establish procedures for the routine reporting of platform structural conditions and analysis. Within the verification system the Marine Board further recommends underwater inspection at four distinct stages:

a) immediately after installation to assure that the platform has been installed according to plan and that no critical damage has occurred. (If damage has occurred, then inspection should assure that the repair is adequate.)

b) inspection (reverification) when changes in configuration are made which affect structural integrity.

c) inspection (reverification when reports are necessary because of major platform damage due to ship collisions, corrosion and/or storms.

d) planned, periodic inspection.

The Geological Survey stated (5) that periodic reverification of platforms will be required to assure structural integrity throughout their operational life. Reverification will be required following major storms where damage is suspected or as a result of other events that could impact the structure. Reverification will be carried out in accordance with an approved plan submitted by the operator.

2.1.2.b Department of Transportation (Coast Guard)

The Coast Guard's requirements for inspection/testing of fixed offshore platforms are not applicable to the private sector; they are in-house requirements which the Coast Guard has imposed upon its manned light towers. The Requirements are not formally related to - nor are they meant to be - establishment of inspection standards by others. The Coast Guard has proposed requirements for inspection of Mobile Offshore Drilling Units (Federal Register, Vol. 42, No 84, 2 May 1977, pp. 22296-22329), but these are not yet law and will only apply to floating drilling platforms if they are made into law. Platforms which drill while bearing on the bottom are currently subject to the regulations in Subchapter N of Title 33 CFR, "Rules and Regulations for Artificial Islands and Fixed Structures on the Outer Continental Shelf", but these units are not issued Certificates of Inspection by the Coast Guard.

Light Tower inspections are divided into two distinct types: annual and "storm" inspection. The former is self explanatory; the latter are inspections which take place after a major storm has passed through the light tower area. The local District Commander is responsible for implementation and scope of these inspections; there are not written rules or regulations which apply to all Districts. The First Coast Guard District, Boston, Mass., provided the inspection scenario and requirements for the Buzzards Bay Light Tower which has been installed since 1977:

Annual Inspection
Requirement: Detect a hairline crack in welds
Scope of Inspection: Visually inspect platform members for integrity, no cleaning. 10% of all welds annually, splash zone to mid-line.
Cleaning Requirements: 10 cm each side of weld to bare metal
Operator Training Standards: ASNT, Ultrasonics Level No. 3

At this time 100% of the Buzzards Bay tower has been inspected by private contractors. The Coast Guard monitors the inspection on site. "Storm" inspections are primarily visual inspections by divers to check for structural integrity. A third type of inspection takes place when a barge or vessel might collide with the Light Tower. This too is primarily visual, but has included advanced vibrational testing with follow-up ultrasonic testing by a diver to assess the extent and nature of the damage (reference 6 & 7).

2.1.2.c <u>Department of Transportation (Office of Pipeline Safety)</u>

Since 1976 the Office of Pipeline Safety has had responsibility for providing inspection requirements (surface and underwater) for pipelines. Under the gas pipeline safety regulations Title 49 of the Code of Federal Regulation, Parts 192 and 195, the following regulations apply to offshore pipelines:

"192.465(a) Each pipeline that is under cathodic protection must be tested at least once each calendar year, but with intervals not exceeding 15 months, to determine whether the cathodic protection meets the requirements of 192.463..."

"192.613(a) Each operator shall have a procedure for continuing surveillance of its facilities to determine and take appropriate action concerning changes in class location, failures, leakage history, corrosion, substantial changes in cathodic protection requirements, and other unusual operating and maintenance conditions."

"195.412(a) Each carrier shall, at intervals not exceeding 2 weeks, inspect the surface conditions on or adjacent to each pipeline right-of-way."

According to Mr. C. Deleon, Office of Pipeline Safety, 192.613(a) is applicable to underwater pipelines and is interpreted to mean that if evidence existed to show that a pipeline required surveillance, then a surveillance or inspection program would be required on the operator's part. Section 195.412(a) can be satisfied by air or water craft route partrols.

2.1.2.d Department of Labor (Occupational Safety and Health Administration)

While PL 91-596, referred to earlier, does grant OSHA the authority to conduct and/or require underwater inspection, the Administration has not yet published any guidelines or policy statements regarding inspection requirements. The current primary ocean interest is in diving safety and above-water safety of employees working on offshore platforms.

2.1.2.e Department of Defense (U.S. Navy)

There are no in-house U.S. Navy standards or requirements for underwater inspection/testing of fixed platforms. While the U.S. Navy does conduct underwater inspection of ship hulls (visual and nondestructive testing), the inspection criteria is addressed to ships in drydock. When underwater welding is necessary (for repairs, strengthening, structural modifications, etc.) it is performed by private contractors. In such instances the welder runs a test bead on a plate in situ, the plate is brought to the surface where the weld bead is examined according to Navy standards. The assumption is drawn that the test bead reflects the quality of welding the diver will perform.

2.1.2.f Department of Commerce (National Bureau of Standards)

No requirements or standards for underwater testing/inspection have been developed by the Department of Commerce. The National Bureau of Standards has developed calibration blocks for testing new NDT personnel, but has had no requests to develop standards for underwater NDT.

2.1.2.g Environmental Protection Agency

EPA has no requirements for underwater inspection/testing of fixed structures. The Oil and Hazardous Materials Spill Branch, Edison, New Jersey is funding a current study which is essentially aimed at conceptual development of a pipeline leak detection system. While EPA's efforts are not directly applicable to the development of inspection/testing techniques or requirements, their study results could bear on the drawing up of inspection scheduling criteria for underwater pipelines. A copy of the contractor's (Science Applications, Inc., Santa Ana, California) Work Statement for this study is included in Appendix IV.

2.2 STATE GOVERNMENTS

No state has underwater inspection requirements for fixed offshore structures. Two states, Texas and California, have rules and procedures which are applicable to drilling, production and pollution control, but these are directed primarily to hardware/component material and test specifications. The closest procedure regarding periodic monitoring is the California Lands Commission's: Procedures for Drilling and Production Operation from Existing Facilities, Outside and Submerged Lands Currently Under State Oil and Gas Leases. (11 December 1973). Under Section F.7.h of these procedures it is stated:

> The ocean surface above all pipelines that service offshore structure, shall be inspected a minimum of once each week for indication of leakage, using aircraft or boats. Records of these inspections, including the date, methods, and results of each inspection, shall be maintained by the operator in its local district office.

None of the state activities interviewed were in the process of writing inspection requirements.

2.3 SOCIETIES/PROFESSIONAL ORGANIZATIONS

Two activities provide inspection guidelines for offshore structures: the American Bureau of Shipping and the American Petroleum Institute. Other activities, American Society of Mechanical Engineers; American Welding Society; American Society for Nondestructive Testing provide instrument and personnel qualification standards, but do not deal directly with underwater inspection/testing.

2.3.1 American Bureau of Shipping

ABS has no formalized underwater inspection program for fixed structures. The Bureau's 1975 Rules for Nondestructive Testing of Hull Welds is intended as a guide applicable to hull welds of ships and other marine structures. Underwater ultrasonic thickness measurements on steel has been conducted on a case-by-case basis, but no written requirements for underwater NDT exists.

At present underwater NDT/inspection is considered an emerging problem by ABS. To this end they are supporting (in conjunction with five other members of the quasi-governmental Ship Structures Committee*) a study being conducted by personnel of the Naval Surface Weapons Center, White Oak, Md., entitled "Underwater Nondestructive Inspection of Welds". The study began in September 1977 and is scheduled for completion by September 1978. The scope of work includes surveying existing methods of NDT (e.g., radiography, ultrasonics, magnetic particles) and to propose modifications to adapt such procedures to underwater use. Limited laboratory experiments are anticipated to verify feasibility of designs.

2.3.2 American Petroleum Institute

The American Petroleum Institute's publication API RP 2A addresses, in Section 8, surveys of fixed offshore structures (8). Recommended practices include:

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*Ship Structures Committee Members: USGS, USCG, ABS, NAVSEA, NAVSEC, DTNSRDC, MSC, MARAD.

Yearly Survey[1]

Splash zone only:

- -Visual inspection for corrosion and damage due to vessel collision.
- -Cathodic protection system check (first year only)

Additional Survey:

Entire structure (above and below water) once every five years; after exposure to severe loading:

- -Cracks and corrosion loss (visual, ultrasonic, radiographic)
- -Bottom conditions (evidence of scour, instability, etc.)
- -Boat and barge damage
- -Cathodic protection system effectiveness
- -Changes in the platform which may adversely affect structural integrity.

The API recommendation suggests two distinct inspections: One is annual and one is recommended every five years or at longer intervals if experience shows this to be warranted. An additional survey is recommended following severe loading exposure.

2.4 PLATFORM OPERATORS (U.S. AND FOREIGN)

Several attempts were made to obtain the inspection/testing requirements from individual operators (Shell, Chevron, Exxon). In every instance the interviewer was referred to the Offshore Operators Committee, an organization comprising 71 companies who operate essentially all of the oil and gas production in the Gulf of Mexico. Since the OOC does not maintain a permanent staff, they were not able to respond to the request for industry-wide data which was made. The only information obtained from the OOC was a letter response (from Mr. R. C. Vanbiber, Jr., Chairman OOC) in which is stated that the OOC considers "...the most important need in the area of platform inspections is surface techniques for inspection of structural members."

Inspection requirements from one individual operator (Shell Oil Company) were outlined in a 17 December 1976 letter from L. G. Otteman, Division Production Manager, to the Aerospace Corp. (under contract to USGS at the time); the following is a synopsis of Shell Oil Company's platform inspection program which has three components: routine inspections; major platform inspections; special inspection.

Routine Inspection: Conducted biannually to document the effectiveness of the cathodic protection system. Primarily an above water inspection. The only underwater inspection in this phase is to request divers working on the platform to report any damage or debris.

Major Platform Inspection: Conducted on a regular basis scheduled in light of the platform's history, age, design criteria, service life and past inspection results. Concentrates on detecting structural damage, corrosion and debris accumulation. Water-jet cleaning required; still photographic documentation with reference scales.

Special Inspections: Examination of platform immediately after a hurricane or unusual events (inspection details not provided).

As an example of a major platform inspection, Shell Oil provided a copy of the 1976 inspection specifications for their South Pass 62-C structure, the portion of the specifications dealing with inspection tasks are presented, verbatim, below, the maximum depth of this inspection was 40 m.

Inspection Techniques

Cleaning:

Water-blasting shall be the primary means of cleaning.
K-Joints: Water blast all welds joining designated members at the K-joints.
Vertical Diagonals: The diver shall water-blast a strip along the logitudinal butt weld. Whenever a circumferential butt weld is encountered, the diver shall blast a strip around the weld. As directed by the SHELL Inspector, the diver shall blast a 2' x 2' square area about half way up each diagonal.

Inspection and Reporting:

A contour gauge shall be used extensively.
K-joints: The diver shall report and video tape the:
WELD: Contour, corrosion depth, size and frequency of pits.
HAZ: Contour, corrosion depth and crevice corrosion.
BASE METAL: General condition, size and frequency of pits.
Circumferential Butt Welds (Girth Welds): The inspection diver shall make a detailed report and video tape at four locations around the weld (top, bottom and each side). Each report should cover an area about 6-inches long. The report format should be the same as for the "K-joint" welds.

The diver should then give a general description and video taping of the rest of the weld.

Longitudinal Butt Welds (Long Seams): The inspection diver shall make a general report on the condition of the long seams. It shall cover the weld metal, HAZ (Heat Affected Zone) and base metal. He should video tape unusual situations as directed by the SHELL Inspector.

2' x 2' Base Plate Area: The diver shall make a general report on the condition of the base plate including the size and frequency of any pitting.

Documentation:

The contractor shall have one individual whose duty will be to record (write) all divers's reports.

The divers' reports shall be tape recorded.

Still photographs will document the divers' reports. Every effort shall be made to include profile views of the welds.

A more comprehensive indication of the offshore operator's inspection programs is provided in reference (9), where personal contact with operating companies in the three main sectors of the North Sea - UK, Norway, Netherlands - provided the data. The report does not identify the companies, and all data was obtained through conversations, not by written documents. The choice for anonymity was made by the investigators, Atkins Planning, not at the request of the operators. While these data more properly fit under foreign requirements the fact that many of the companies are American, and the lack of National identification prompts their inclusion here for the sake of continuity.

FIELDS SOUTH OF 56° N LATITUDE

COMPANY A

Steel Jackets - annually

- -General visual examination of whole structure.
- -Typically 5 nodes in each structure needle gun cleaned and close visual/video taped.
- -Subsequent action dependent on findings and agreement with certification authority (Lloyds).
- -Inspect footings for scour/levels check.

Risers - annually

- -Platform end of external coating cut back to show any corrosion; if adequate, then recoated.
- -Remainder inspected for any detached coating; where this is evident, wall thickness measurements are made.

COMPANY B

Steel Jackets - annually

Full video records are maintained.

- -Full visual inspection for accumulation of flotsam and debris, and for mechanical damage.
- -Two or three critical welds by close visual (hot spots) and then by magnetic particle inspection (mpi) if considered necessary. Single most critical node looked at fully.
- -Check potentials on selection of critical points.
- -Inspect footings for scour and accumulation of metallic debris.

Risers - annually

-Visual inspection in splash zone only.

COMPANY C

Steel Jackets

Annually:

-General visual with main attention to splash zone area.
-Close visual and NDT only in selected areas.

Less frequently:

-Scour.

Pipelines

-Inspection - includes both side scan sonar and submarine viewing - but not every year.

COMPANY D

Steel Jackets

Three year cycle. Rotation of about one-third of platforms each year.

	1st year	2nd year	3rd year
Structural check	Full clean of total structure	On 8-10 welds/ platform. Detailed clean. TV viewing & video + mpi on half the welds.	Blank
General corrosion	cp survey at 10 ft. intervals on each leg and at selection of nodes. Ultrasonic thickness testing where necessary	cp survey as first year Thickness testing where necessary	Blank

	1st year	2nd year	3rd year
Riser check	Visual inspection of all risers and then thickness test on any corroded areas	As for first year	Blank
Footings	Scour Survey?	Scour Survey?	Blank

COMPANY E

Company inspection policy still being developed.

Steel Jackets

On a group of platforms, a 4-year rolling program is being devised such that over the 4 years every node has been looked at by mpi. In the coming first year 100 nodes are involved.

At certain nodes, ultrasonic wall thickness measurements are being taken and certain points will be selected as condition indicators.

Annually, prepare maps of debris, marine growth (type and thickness), scour (contour map by rodding), and any corrosion.

Check each anode by dimension, apparent hardness and potential measurement.

Risers

These are painted above water and epoxy coated below.

Annually:

- -General visual check for straightness, coating damage;
- -If coating is damaged, carry out wall thickness and corrosion protection tests;
- -Check scour under blocks and all clamps.

Estimated demand for services:

The above program is anticipated to require a team of 16 divers for 100 days. Of the divers, 6 will be qualified for NDT inspection.

Pipelines

Probably every two years a pinger and side scan survey for total route. In the alternate years, check only at critical points. Divers only used occasionally where some detailed attention is necessary.

COMPANY F

Steel Jackets

At least once per year, carry out a visual inspection for marine growth, mechanical damage, scour and anodes. Follow the whole of the structure during the visual examination. No NDT. Sometimes the inspection work is carried out during dives for other purposes.

Risers

Essentially as for jackets.

Pipelines

At least two surveys per year with side scan sonar using divers for bad spots. As opportunity allows, check anodes.

FIELDS NORTH OF LATITUDE 56°N - STEEL JACKETS

COMPANY G

Steel Jackets - annually

-Full visual inspection.
-Close visual inspection of approximately 5 nodes (hot spots). (This year devoted approximately 1,100 diver-hours - saturation - to a program of this kind. Anticipate this level will decrease.)

COMPANY H

Steel Jackets

-Anticipate that there will be no NDT testing.
-Anticipate that structural monitoring procedures will considerably reduce the need for close and detailed structural inspection.
-Anticipate that findings can be extrapolated to other platforms in the group.
-Presumably there will be a general visual inspection.

COMPANY J

Steel Structures

Details of program not finalized.

Annually:

-General visual inspection on all structures, cleaning as necessary (probably done to 40m).

- -Probably check about 1 percent of total weld length within the nodes. This would be a visual check with some NDT if necessary. (Weld distance on a medium sized platform might be about 1km.)
- -Check metal thickness on 10 percent of the length of the structure, taking one reading per metre of length. This applies to all members.
- -Check for scour.

Risers

Carry out a visual check on all risers at least once per year. Carry out thickness checks on 10 percent of total riser length at least once per year.

FIELDS NORTH OF 56^{o}N LATITUDE - CONCRETE JACKETS

COMPANY K

Concrete Structures

- -The structure is being monitored for vibrations, silt, ground pressure. If a disturbance is seen in any of these measurements, then visual checks will be made at the base of the columns and riser entry zones.
- -Otherwise, annually check for scour and any cracking in base zone, and also for fouling of sea water entries. Not planning for any inspection of splash zone.
- -Check the corrosion pitting on any exposed steel work.

COMPANY L

Concrete - annually

- -Initially, visual inspection of the whole surface (for first two years). Subsequently, 2-3 percent of the total area and mainly in the lower part of the platforms.
- -Inspect footings for scour.

COMPANY M

Concrete Jacket

Half-yearly:

- -Check sea water intakes for garbage and debris.
- -Check riser bridge over storage cells.
- -Check for scour.

Annually:

- -Visual inspection at level of change of section in columns.
- -Visual inspection of column root.
- -Visual inspection of perimeter at base of cells.

(<u>Note</u>: a) Plan to inspect splash zone by above surface means.
b) Platform equipped with monitored strain qauges on rebars at circumference and radii of base of each of cells. Also monitoring earth contact pressure. Accelerometer installed at root of one column).

<u>Risers</u>

No inspection program is planned, but problems are foreseen. Risers in 2 legs flooded with dead water and no corrosion protective coating. Monitoring temperature in columns with risers. Difficulty of access for divers.

Several operators have recently published technical papers regarding inspection work and programs they are performing on fixed structures. From these reports a further definition of the operator's requirements is provided.

BP Petroleum Development Ltd (10) conducts inspections programmed equally to cover a five year period. Three main areas are investigated: 1) integritity of the structure as a whole; 2) corrosion, and 3) marine growth. In the initial surveys the goal is to establish baseline data regarding major damage that could have occurred when the structure was installed; marine growth patterns; efficiency of cathodic protection system; sea bed state; faulty connections on supports and paint conditions. Four inspection capabilities are envisioned: saturation divers; one-atmosphere diving suits; manned submersibles and remotely controlled vehicles. NDT and inspection tools employed are visual inspection; TV and photographic cameras; mpi (weld inspection); ultrasonics (thickness measurements only on structures, used for crack detection on pipelines). Cleaning tools/ methods include waterjetting; grit blasting; and needle gunning.

Phillips Petroleum Co., Norway described their underwater inspection program and requirements in the Great Ekofisk area of the North Sea (11) which involves inspection of 33 steel jackets, one concrete tank, 650 miles of pipeline and 50 risers. The Phillips inspection program follows the Norwegian requirements set down by the Petroleum Directorate and are executed by Det Norske Veritas (described in the subsequent section under North Sea Requirements). Briefly, over a four year period (one survey every year) the program will nondestructively test 10 percent of the major structural nodes on steel jackets. The inspection work is divided into three categories by type of structure: 1) steel jackets; 2) risers and pipelines; and 3) concrete gravity structures.

Steel jackets are examined for mechanical damage due to dropped materials, collision with barges and boats, and anchor cables which might have become entangled in the platform. The principal methods of determining if and to what extent mechanical damage has occurred is visual inspection by divers or remotely controlled vehicles. Any damage is documented by still photography and video tapes, and measurements are taken of the damaged area. If the damage has caused deflection of a member, the weld area where the member attaches to the structural node is cleaned to bare metal and mpi is used to locate cracks. If a crack is detected it can: a)be ground down to determine its depth, or b) punch-marked at each end so that subsequent inspections can determine if the crack is propagating.

On a periodical (4 year) basis mpi is performed on selected structural nodes. Anodes are inspected for damage and deterioration; size, depth, density of pitting and condition of oxide coating is reported. Physical measurements of the anodes are taken to estimate weight loss. Electrical potential readings are routinely taken (by divers or remotely controlled vehicles) at numerous locations on the structure. If corrosion is noted a detailed description is obtained which identified the area involved and describes pitting size, depth and density. Still photography and electrical potential readings are normally required in the localized area.

A further purpose of the steel jacket inspection is to locate and remove debris in and around the structure. Scour and seabed material buildup, and quality and types of marine growth are also noted and recorded.

The pipeline riser system is visually inspected for mechanical damage and a coal tar (somastic)/concrete coating below the splash zone is inspected for cracks or missing portions. Electric potential readings and ultrasonic thickness measurements are required of the damaged area. If corrosion is present, sketches, still color photographs and video tapes are taken to show size and shape details.

The concrete gravity structure (a million barrel capacity tank) is visually inspected for mechanical damage and specific areas are cleaned to observe for small cracks. Divers and remotely controlled vehicles perform these tasks.

2.5 TRAINING

The training requirements for personnel conducting underwater NDT and inspection vary considerably. In conventional surface NDT the instrument operator is generally qualified to some level in accordance with the American Society of Nondestructive Testing, and conducts the entire test himself. Most underwater NDT, on the other hand, is conducted with two distinct divisions of labor: a diver transports and employs the sensor underwater, while a technician on the surface monitors and records the data the diver is obtaining and directs the diver in his task. In a few instances the diver performs both data collection and recording tasks. But most present underwater NDT instruments are modified surface devices where the display/recording/interpreting components remain on the surface, while the sensing device is taken below - this is particularly the case with ultrasonics, radiography and some forms of magnetic particle inspection.

The dilemma created by this division of labor is: who should be qualified, the diver or the surface technician or both? Since the diver does little, if anything, in the way of interpretation, several industrial firms believe it is not necessary for him to be NDT qualified; and a short (2-3 hours) orientation program is given the diver by the technician prior to the measurement. In radiographic NDT the orientation programs are more extensive and stress safety as well as performance. The surface technician is almost always qualified to some level by a recognized organization.

Only two U.S.-based diving firms were found who employed divers qualified in NDT. The general procedure, when underwater NDT is necessary, is to sub-contract this portion to a company specializing in surface NDT and assign the sub-contractor's qualified technicians the responsibility for directing the diver in his task.

The core of the qualification controversy ultimately resides in interpretation of the data. While the instruments used for NDT are quite sophisticated, interpreting their results is a human function which requires a highly-skilled and experienced technician. A detailed knowledge of the sensor's attitude, position on the structure, and the adequacy of sensor/material couplent is mandatory for accurate interpretation. Some organizations feel that monitoring the diver's activities via TV, and directing his activities by verbal communications is an adequate alternative to deploying an NDT-qualified diver. Other organizations feel that there is no substitute for a qualified NDT-diver, and point out that underwater visibility is not always adequate to monitor the diver's activities.

A tabulation of qualification requirements self-imposed by various organizations is given below.

Organization	Qualifications
API	Fabricators/Operators option
ABS	ASNT (or other recognized agencies)
USN	ASNT

Organization	Qualifications
Offshore Power Systems, Inc.	ASNT
Taylor Diving and Salvage Co., Inc.	Technician: ASNT Diver: Orientation Course
Mobil Testing Labs., Inc.	Technician: ASNT Diver: Orientation Course
Sylvester Undersea Inspection Inc.	Technician: ASNT Diver: ASNT
H. M. Tiedemann & Co., Inc.	Technician: ASNT Diver: ASNT
International Underwater Contractors, Inc.	Technician: ASNT (if requested) Diver: Orientation Course
Magnaflux, Inc. (Houston, Texas)	Technician: ASNT Diver: Orientation Course
Subsea International	Technician: ASNT Diver: Orientation Course
Charles T. Morgan Co.	Technician: ASNT Diver: Orientation Course

In the areas of Acoustic Emission monitoring and Vibration Analysis monitoring there are no present qualification standards other than those which the operator may wish to impose upon himself.

At present the most frequent underwater inspection is a visual one conducted by a diver and documented by him with TV or still photography. No qualification standards for personnel performing visual inspections could be located.

A further point should be discussed regarding operator qualifications. The American Society for Nondestructive Testing does not qualify or examine operators. Instead, the ASNT provides recommended practices - through SNT-TC-1A "Recommended Practice for Personnel Qualification and Certification", with supplements A-E - which establishes the general framework for a qualification and certification program. The supplements provide recommended education, experience and training requirements for the different testing methods, and also includes question-and-answer lists which may be used in composing a general examination for NDT personnel. The final structure of the test is the responsibility of the company offering NDT services. With regard to training, the employer can elect to write his own training program and conduct it at his facilities, or he may elect to send his employees to a training school. (There are over 82 schools in the U.S. and Canada offering NDT training ranging from high school to college level where a BS degree in NDT can be obtained.) In short, the responsibility lies with the employer for the training course content and for certifying that it meets the minimum recommended requirements (12). The term, therefore, "ASNT Qualified" is somewhat misleading since the Society merely provides recommendations and guidelines while the actual certifying and training requirements are solely in the hands of the employer, as is the decision regarding whether or not the technician is qualified and to what level.

2.6 INSTRUMENTATION STANDARDS

The only instrumentation requirements which could be located are those provided by the American Society of Mechanical Engineers and American Society for Testing and Materials. Several companies follow a practice which requires the diver to bring a calibration block with him to the work site and conduct calibration checks of the NDT instrument in situ, but this is not a standard procedure. Since underwater NDT is an emerging field and most instrumentation is modified from off-the-shelf inventories, performance standards are likely to be for an instrument used at one - atmosphere and in a dry environment; not underwater at high pressures and low temperatures.

3.0 REQUIREMENTS - NORTH SEA

3.1 INSPECTION

Inspection requirements were sought from the following countries: England, Norway, France, Ireland, Denmark, Sweden, Netherlands, Belgium, and West Germany. Queries (by telephone, letter and personal) were made of pertinent embassy staff members in the Washington, D.C. area and of pertinent government employees. Since England and Norway are the most active North Sea-bordering countries regarding development of inspection requirements, emphasis was placed on these two countries. Individuals contacted during this phase of the study are listed in Appendix II.

3.1.1 United Kingdom

In accordance with the terms of the Continental Shelf Convention, Parliament enacted the Mineral Workings (Offshore Installations) Act of 1971, to provide for the safety, health, and welfare of persons on installations concerned with the underwater exploitation and exploration of mineral resources in the waters in or surrounding the United Kingdom. The Petroleum and Submarine Pipelines Act of 1975 extended the scope of the earlier Act to cover any other installation, whether floating or not, which may be manned and which is used in connection with conveyance of things by means of a pipe constructed in or under the sea.

Under the powers granted in the Mineral Workings Act, the Secretary of State made the Offshore Installations (Construction and Survey) Regulations in 1976. These regulations require all offshore installations established or maintained in waters around the U.K. to be certified as fit for the purposes specified, and provide statutory force to ensuring that all aspects of the design and construction process are subject to an independent professional critique.

In regard to fixed platforms (conductor pipes, drilling risers and riser pipes carrying oil or gas are not considered a part of the installation): none may be established or maintained in relevant U.K. waters unless a valid Certificate of Fitness is in force for that platform. The Secretary of State may himself issue Certificates of Fitness, but, in practice, the following organizations have been authorized to do so and one or the other have carried out the Certification program:

- American Bureau of Shipping
- Bureau Veritas
- Det Norske Veritas
- Germanischer Lloyd
- Halcrow Ewbank and Associates Certification Group
- Lloyds Register of Shipping

An application for a Certificate of Fitness shall be made by the owner of the installation. The Certificate of Fitness is valid for such a period as the Certifying Authority may specify, not exceeding five years from the date of completion of the last major survey carried out pursuant to Regulations.

A "major survey" for newly constructed platforms is conducted on the surface and it is a continuous activity covering the whole of the construction period and the installation and testing of equipment. For fixed platforms it is the last above-water opportunity to inspect and test those elements that will be permanently submerged.

After an installation has been subjected to a major survey, a Certifying Authority may accept - instead of a subsequent major survey - a series of continuous surveys conducted in rotation in conjunction with annual surveys if satisfied that the results so obtained are equivalent to those which would have been obtained in the course of a major survey. The following deals with annual surveys:

(2) (a) "In respect of every installation in relation to which a certificate of Fitness is in force, there shall be carried out on behalf of the Certifying Authority which issued that certificate surveys (herein referred to as "annual surveys") of a selection of the members, joints and areas of the primary structure of the installation, the parts of the installation...and its equipment, the selection being sufficient in number, disposition or extent (as the case may be) to provide reasonable evidence as to whether the installation and its equipment continue to comply with the requirements of Schedule 2, or such of the same as may be applicable.

(b) The first annual survey shall be carried out within not less than 9 nor more than 18 months after the date of issue of the Certificate of Fitness and thereafter similar surveys shall be carried out within not less than 9 nor more than 15 months of each anniversary date of issue of the certificate during the period in which it is in force."

Offshore Installations (Construction and Survey) Regulations 1978

The annual surveys are not the only requirements for underwater inspection. At any time while an application for a Certificate of Fitness is being considered or is in force an additional survey may be required if:

a) the structure is damaged, or suspected of being damaged in a manner likely to impair safety, strength or stability, or

b) it demonstrates signs of deterioration to an extent likely to impair safety, strength or stability, or

c) its equipment is subject to any alteration, repair or replacement.

In the event that any of the three events outlined above take place, the owner should immediately notify the appropriate Certifying Authority of the occurrence of the event in such detail that the Authority can determine whether or not an additional survey should be carried out.

In 1974 the Department of Energy issued "Guidance on the Design and Construction of Offshore Installations" to explain the procedure whereby fixed and mobile offshore installations are certified as being fit for their purpose in accordance with the Offshore Installations (Construction and Survey) Regulations of 1974. On the basis of experience gained and suggestions made during the three year operation of the certification scheme, the Department of Energy has revised and rearranged this publication into a new format which will be published in early 1978 (13), it is not, however, a legal document.

Under the U.K. certification scheme the owner is responsible for arranging for surveys as they become due, and the Certifying Authority surveyor should agree with the particulars of destructive and non-destructive tests; the number and frequency or circumstances in which tests should be made and the competance of the personnel and organizations concerned. He should monitor all tests and request spot checks and confirmatory tests to be made as judged necessary.

The DOE document defines three types of surveys: Major Surveys (applies only to mobile installations that have not previously been certified); Major Surveys: re-certification; and Annual Surveys. The later two categories apply to fixed structures (and mobile as well) and define the scope of the underwater inspection. The following excerpts are taken from reference (13).

<u>Major Surveys: re-certification</u>

The object of this survey is to ensure that any deterioration is within acceptable limits and that the installation continues to comply with all relevant requirements of the Offshore Installations (Construction and Survey) Regulations.

In-service inspections of fixed installations should be planned by an experienced engineer who has examined the design characteristics, the records of severe environmental and other loads to which the structure may have been exposed and any available records of structural behaviour such as settlement, differential settlement, tilt, distortion or abnormal response. The initial inspection schedule should take account of the nature of the deterioration to which steel and concrete structures are liable in a marine environment and of the regions in which defects are most prone to occur (e.g., sudden changes in section, discontinuities, etc.) and of members or regions known to have been, or likely to have been, highly stressed or subjected to severe fatigue loading. Special attention should be given to areas of suspected damage or deterioration and to areas repaired following earlier surveys. Only after the nature and probable positions of defects have been established should the inspection schedules be prepared.

Fixed structures in deep water present special problems in that the examination of certain areas may present serious or unacceptable hazards. Subject to the need to ensure the continued safety of the installation the inspection schedule should require deep diving only where no other satisfactory means exist of carrying out essential work. Consideration should be given to using manned or remotely controlled submersibles.

In a jacket type structure the outer, more accessible, members may reasonably be taken as representative of the internal members unless the original design or service history suggest otherwise.

The lower elements of a gravity type structure are likely to suffer serious damage only if partly deprived of support by erosion, or by excessive or uneven settlement. Many units of this type incorporate instruments to record the state of the foundations.

Service history and/or design assessment will suggest areas requiring special attention and if no defects are detected, other deep water areas need receive only spot checks.

There are grounds for believing that corrosion of concrete reinforcement is less likely in permanently submerged areas than in the splash zone, quality and other circumstances remaining unaltered. If concrete in the splash zone is found to be in good condition only a limited number of spot checks need be made at lower levels, except in way of sudden changes of sections and other areas of high stress concentration.

Account may be taken of data recorded by instruments installed to monitor structural and foundation behaviour.

Annual Surveys

The purpose of the annual survey is to ensure that any deterioration of the structure is within acceptable limits; that secondary structures and fittings concerned with the safety of the installation and the safety of personnel are in sound condition; and that mechanical and electrical equipment and installations are being maintained to satisfactory standards.

The second annual survey after each major survey should include a general inspection of major parts of the installation below the splash zone to determine whether any change had occurred in the condition of the installation since the main survey was carried out.

Annual surveys should include a close visual inspection down to and including the splash zone, or to the water line as maximum freeboard as may be appropriate, to detect obvious damage and indicate areas likely to warrant further investigation. In the light of this inspection, previous service history, etc, the surveyor may then request that further inspections and/or tests be made, above or below water. The surveyor should cause a close examination to be made of any underwater repair work undertaken since the last survey and, if the manager of a fixed installation has had occasion to take emergency measures of any permanent scour prevention works.

Following the above inspections the surveyor may require that non-destructive tests be carried out to verify, or discount, suspected defects.

Behaviour records of structure and foundations should be examined, where available, and enquiry made into any apparent abnormality.

An assessment should be made of the thickness of marine growth on typical members or areas of the structure.

Additional Surveys

Additional surveys should be carried out in accordance with the principles laid down for major surveys insofar as the structure may be affected, either locally or as a whole, by alteration, deterioration or damage.

U.K. regulations are not fixed and unbending. In the event of a difference arising on the application of the regulations which cannot be resolved between the owner and Certifying Authority, the Certifying Authority should, at the formal request of the owner, refer the matter to the DOE with an agreed precis of the points of difference. Final judgement is made by DOE. As of June 1977 there were 103 fixed platforms in U.K. waters to which these regulations apply (9).

3.1.2 Norway

The Norwegian Petroleum Directorate is the Certifying Authority for structures in Norwegian waters. The legal basis for platform inspection is a Royal Decree of 9 July 1976 relating to safe practice for the production, etc., of submarine petroleum resources. In practice, the Petroleum Directorate employs the classification society Det Norske Veritas to carry out certification work and surveys on its behalf.

A draft of "Provisional Guidelines for the Inspection of Structural Parts on Production and Shipment of Installations and Pipeline Systems" was issued by the Petroleum Directorate on 2 April 1977 (14). In many respects the Norwegian regulations (though still not finalized) follow English regulations. A major difference is that Norwegian regulations consider the riser as a part of the structure; they have also included inspection criteria for submarine pipelines. The English have not yet issued pipeline inspection criteria.

Although the Petroleum Directorate's Guidelines are provisional, they are none-the-less an official opinion of the Norwegian Government and, since National regulations and rules take precedence over classification society rules, it is appropriate to review these regulations regardless of subsequent modifications. The following excerpts are taken from reference (14).

Inspection of Steel Structures (Underwater)

Initial Inspection

The extent will be evaluated for each individual installation taking into consideration:

- The condition record
- Function
- Type of corrosion protection system
- Environmental loads

Initial inspection shall normally comprise:

a) Visual inspection of the structure to locate mechanical damages, possible metallic waste in contact with or in the immediate vicinity of the structure.

b) Visual inspection of type, length and quantity of marine growth on areas pointed out beforehand in different depth levels (photo documentation).

c) Localization of corroded areas (photo documentation).

d) Visual inspection of the anode condition. The inspection shall comprise a sufficient representative number of the total number of anodes. The inspection shall also comprise potential reading of selected anodes.

e) Visual inspection of the sea bed for possible erosion or building up of scour (photo documentation).

f) MPI-inspection of selected nodes (selected in the design phase).

Annual inspection

Annual periodic inspection shall be based on the results from previous inspections and shall, in addition to the items mentioned above (a - f) also comprise:

Implementation of NDT-thickness-measurements on selected spots for reference measurement. In addition, the measurements shall comprise areas which, based on previous inspection and experience, have revealed these as relevant for thickness control purposes. In this connection due consideration shall be taken to areas having been revealed by potential readings to be corroded areas, special stress and/or fatique areas.

Photo documentation shall at least comprise the same areas as specified for the initial inspection.

4-year condition evaluation

4-year condition evaluation constitutes a summary of the results from previous inspections within the period. The condition evaluation does further comprise an evaluation of said results in order to establish whether the installation may be used with a reasonable degree of safety for the next period.

Inspection of Concrete Structures

Initial inspection

The extent will be evaluated for each individual installation taking into consideration:

- The condition record
- Function
- Type of corrosion protection system
- Environmental condition

Initial inspection shall normally comprise:

a) Visual inspection for the localization of surface cracks in highly stressed areas and for potential transportation and construction damages. The inspection areas shall be selected beforehand based on an evaluation of the stress level and shall be cleaned prior to the inspection.

b) Visual inspection for the localization of concrete erosion, primarily in the splash zone.

c) Visual inspection for the localization for corrosion on any steel members.

d) Control/measurements of possible corrosion protection systems.

e) Visual inspection of type, length and qualtity of marine growth on selected areas at different depth levels (photo documentation).

f) Visual inspection of spots having been repaired during the fabrication, transportation and installation phase. The spots shall be selected taking into due consideration each spot's importance to the safety of the installation.

g) Possible internal inspection when such inspection seems necessary.

h) Visual inspection of the seabed for possible erosion or building up of scour (photo documentation).

Annual inspection

Annual inspection shall be based on the results from the initial inspection. However, the annual inspection shall normally comprise:

a) Inspection as mentioned in the items above (a - h).

b) In addition to the visual inspection for localization of concrete erosion in the splash zone, specific areas shall be cleaned beforehand for visual inspection and photo documentation.

c) The specific requirements (a - h) outlined above shall be implemented, however, such that the photo documentation shall comprise the same area as inspected during the initial inspection.

4-year condition evaluation

4-year condition evaluation constitutes a summary of the results from previous inspections within the period.

The condition evaluation does further comprise an evaluation of said results in order to establish whether the installation may be used with a reasonable degree of safety for the next period.

Inspection of Risers (Splash Zone Included)

Initial inspection

This inspection is meant to be a control of the riser in those instances where the time interval from installation to start up exceeds 2-years. Inspection shall, in this case, be carried out after the first winter season following the installation. The extent and type will be evaluated for each individual installation taking into consideration:

a) Condition record

b) Environmental loads

Initial inspection shall normally comprise:

a) Visual inspection of the riser with accessories for localization of mechanical damage, possible metallic waste in contact with or in the immediate vicinity of the installation.

b) Visual inspection of the fastening device with testing tightness of the bolts for riser clamps. The torque shall be in accordance with the approved design specification.

c) Visual inspection of fastening device for anodes and potential readings of the corrosion protection system.

d) Control for verifying that the riser on the seabed is in accordance with the approved design specifications.

e) Control of the riser's horizontal/vertical position.

Start up inspection

Start up inspection is expected to render a complete status of the riser and its accessories enabling an evaluation as to whether the installation may be put into operation in a safe manner. It is assumed that a pressure test of the riser, including underwater pipelines, has taken place; the results having been found satisfactory.

The results from this inspection shall be submitted to the Norwegian Petroleum Directorate in connection with application for permit to start up.

The start up inspection shall, in addition, comprise control during and in the immediate period following the start up in order to, if possible, localize movements or behaviour which may be of importance for the safe operation of the installation.

Start up inspection shall normally comprise:

a) Inspection as mentioned in items a - e above.

b) Localization of corrosion. If corrosion is detected, a thickness measurement of the corroded areas shall be performed and photos taken in those areas having been most exposed for corrosion.

c) Visual inspection of the seabed for possible erosion or build-up of scour (photo documentation).

d) Visual inspection of type, length and quantity of marine growth or selected areas at different depth levels (photo documentation).

e) Pressure test of possible external protection device in the splash zone.

f) Verification of all weld tests and possible NDT-tests being satisfactorily completed.

Inspection during and in the immediate period following the start up shall normally comprise:

The control and measurements of the distance between the riserbend and the installation at fixed intervals the first 24 hours following the start up in order to localize movements between the riser and the installation. If necessary the measurements shall be continued until the movements are stabilized. Visual inspection of flanges and any mechanical couplings.

Semi-annual inspection

Semi-annual inspection shall be based on the results and experiences from previous inspections. In addition, due consideration shall be taken to operational conditions under which the installation has been operated, such as thermical exposures, internal pressure and environmental loads. The results of the inspections are expected to give a complete status of the riser's condition enabling an evaluation whether the installation may be operated with reasonable degree of safety for the following 6-month operational period.

Semi annual inspection shall in any event comprise:

a) All items as mentioned for the inspection prior to the start up.

b) Visual inspection of any fender device in the splash zone for detection of mechanical damages and possible corrosion.

Inspection of Underwater Pipeline Systems

Initial inspection

This inspection is meant as a control of the pipeline system after it is installed on the seabed. The type and extent will be evaluated in each individual case taking into consideration:

a) Expected time period between the initial inspection and the start up inspection.

b) Seabed condition, topography, etc., and hydro-dynamic conditions, water depth, etc.

c) Condition record.

Initial inspection shall normally comprise:

a) Visual inspection of the pipeline system with mechanical couplings for detection of any unsupported span, mechanical damages of importance to the safety of the pipeline system. Any unsupported spans, mechanical damages, etc., shall be documented by using videotape or other acceptable methods.

b) Control measurements of burial depth at specific intervals.

c) Detection of current conditions which may effect the pipeline system.

d) Internal inspection by use of calibrating pig or other acceptable methods for the detection of changes in the pipeline diameter.

Start up inspection

The start up inspection is meant to render a complete status of the pipeline system including mechanical couplings and bottom conditions enabling an evaluation whether the pipeline system may be put into operation in a safe manner. It is assumed that pressure testing of the pipe line has taken place, the results of which having been found satisfactory. The results from this inspection shall be submitted to the Norwegian Petroleum Directorate in connection with application for start up permit.

In addition, this application shall contain specific information on additives, quantities, etc., expected to be used as corrosion protection medium or other methods for the evaluation of the corrosion process (rate). The application shall also contain planned analyzing program.

Type or extent of the start up inspection will be evaluated taking into consideration:

a) Accomplished inspections.

b) Conditions as mentioned previously.

c) Activities in the area including trawler activities, shipping, etc.

d) Other pipeline systems, cables, etc.

The start up inspection shall normally comprise:

a) Inspection of the pipeline by using the best available method-- taking into consideration the location of the pipeline, etc. and which ensures satisfactory data for observing the burial, detection of possible unsupported spans. Unsupported spans shall be documented by use of videotape or other acceptable methods.

b) Measurement of the distance between mechanical couplings and concrete coating.

c) Potential readings of the pipeline where this is possible.

d) Internal inspection as described in item d (initial inspection).

Control by use of NDT log or other acceptable method shall be carried out not later than 30 days following the start up.

Annual inspection

Annual inspection shall be based on the results and experiences from previous inspections. In addition, due consideration shall be taken to the operational conditions the installation has been exposed to, such as thermical exposures, internal pressure and environmental loads.

The results from the inspection are expected to render a complete status of the condition of the pipeline system enabling an evaluation whether the installation may be operated with a reasonable degree of safety for the operational period of the coming year following the inspection.

Annual inspections shall normally comprise:

a) Visual inspection as mentioned under start up inspection (items a - d).

b) Control by use of NDT-log or other acceptable method.

Special control activities

When during an inspection, defects are detected in the concrete cover or the corrosion protection coating having access to open steel, the pipeline shall be thickness measured by using an NDT-method. In addition a potential reading shall be carried out.

3.1.3 France

There are no fixed oil or gas structures in French waters. Regulations are reportedly (15) being drafted by the Direction des Carbant of the Ministry of Industrial and Scientific Development, but no date is available regarding their publication.

3.1.4 Ireland

A valid Certificate of Fitness is required for offshore structures by the Department of Industry, Commerce and Energy. The certificate is issued by a Certifying Authority appointed by that Department. In the case of the Kinsale Gas Field, the initial certification of the platforms is being carried out by Lloyds Register of Shipping. Periodic certification will be the responsibility of the Institute for Industrial Research and Standards. Underwater inspection/testing procedures will form part of a Certification Procedures Manual which will be written by the IIRS in consultation with the Department of Industry, Commerce and Energy and the field operators: Marathon Petroleum Ireland Limited. (16)

3.1.5 Denmark

Reportedly (15) the Danish Government has produced legislation concerning certification of offshore installations, but no response was obtained to inquiries made in this direction. According to Hr. M. Forster (Dr. Forster Institute, Reutlingen, West Germany) the Forster Institute conducted magnetographic (mpi-like) tests on welds of four platforms in the Danish sector of the North Sea in the summer of 1977 for the Danish Welding Institute - an organization akin to Det Norske Veritas and Lloyds Register.

3.1.6 Sweden and Belgium

No requirements were obtained to inquiries made.

3.1.7 Netherlands

No requirements were obtained to inquiries made in the course of this study. According to reference (15), the Netherlands issued regulations (Mining Regulations Continental Shelf) in 1967 based on their Continental Shelf Mining Act of 1965. The regulations require a Certificate of Construction which is directed to the platform's pre-installation phase. Final approval is at the discretion of the Inspector General of Mines. Five classification societies have been approved as examiners for certification (ABS, Lloyds, DNV, Bureau Veritas, Germanischer Lloyd). Regulations covering regular inspection and renewal of certificates at specified intervals are being prepared.

3.1.8 West Germany

The only inspection requirements known to exist in the West German government are those from the Oberbergamt Clausthal-Zellerfeld, a group formed by the coalition of four coastal states to make one federal level agency which oversees all offshore work (licensing, exploration, drilling and production). Inspections are conducted on a case by case basis, and include initial (surface) inspection as well as underwater inspection. Following is an outline of the underwater inspection requirements.

Submerged Zone

For the checks of such items which are not accessible to the Surveyor himself, inspection methods should be used which enable the Surveyor to assess those parts (e.g., underwater TV - camera and surface monitor).

Structure

Annual: General check; should doubt arise, nondestructive tests are to be conducted.

Inspection of Seabed

Annual: General inspection of seabed in the vicinity of the platform supports for scour, mud buildup and debris.

Corrosion Protection

Annual: Visual inspection of anodes. Physical measurements of anodes in each horizontal construction plane. Potential measurements in each horizontal construction plane.

Marine Growth

Annual: Determination of the type and degree of growth.

Setting and Tilting of the Jacket

Check to verify that no alterations of the foundation of the jacket have occurred.

3.2 CLASSIFICATION SOCIETIES

3.2.1 Lloyds Register of Shipping

Lloyds Register has not published underwater inspection requirements at this time. A guidance for inspection is being prepared which is scheduled for publication in the first half of 1978. A paper which briefly describes Lloyds overall approach to structure certification and classification is referenced in this report (16), but its only reference to underwater inspection is to note that the Certificate of Fitness is valid for no more than five years from the date of the last major survey, and that annual surveys are required unless damage has been sustained which would necessitate an additional survey.

Lloyds presently requires two classes of underwater surveys: annual and major. Since guidelines are not firmed at this point, the following description of each survey should not be interpreted as official Lloyds policy.

Annual Survey

1) General visual survey of entire structure down to and including the splash zone (above water).

2) General visual inspection of structure for damage.

3) Investigate for local scour of seabed.

4) Ascertain corrosion system effectiveness by use of a potentiometer.

5) Determine extent and nature of marine fouling.

6) Conduct magnetic particle inspection of cracks located visually.

7) Drill or grind crack to measure depth.

8) Photographic/video documentation of cracks, faults, and observations.

Major Survey

1) Conduct all tasks outlined for the annual surveys.

2) Examine specific nodes in detail (10% of platform minimum).

In practice, by the time the fifth year is reached the major inspection will have been accomplished. Lloyds does not conduct the underwater portion of the survey; this is performed by contract divers whose work is monitored by the Lloyds Surveyor. All data is held by Lloyds.

Since there are no legal requirements for underwater pipeline inspection in the British sector of the North Sea, Lloyds has not been called upon to work in this area. However, the Irish government, which also uses Lloyds, does have pipeline inspection requirements which have been carried out under Lloyds surveillance. The Irish sector requires a sonar check of the backfall and an internal check of the pipeline subsequent to installation; the former is required annually, the latter after the first year of operation.

Lloyds is presently inspecting 65 steel structures and three concrete structures in the North Sea. One of the concrete structures has a total subsurface area of 15 acres of which 10 to 12 acres can be reached for inspection; this results in about 1.1 acres which must be inspected over a five year period.

3.2.2 Det Norske Veritas

Det Norske Veritas (DNV) has the most specific inspection requirements of any of the classifying societies approved for North Sea inspection. These are outlined in reference (18): "Rules For the Construction and Inspection of Offshore Structures". DNV is currently the Certifying Authority for between 40 to 50 steel and concrete North Sea structures. Unlike counterpart classifying societies, DNV personnel are qualified to conduct the actual underwater surveying portion, as well as to monitor the activities of contract divers who are engaged in this task. For this purpose DNV has its own cadre of personnel who are principally surveyors trained in diving. DNV certification scheme is in many respects similar to Lloyds, in that a Certificate of Approval is issued following the initial major survey which if it is to remain in force, must be followed by periodical and special surveys. The requirements and details of these surveys are as follows:

Periodical Surveys

General Requirements

The Owner is to submit to DNV sufficient drawings, schematics and supplementary notes to fully present and describe the structures that are included in the certificate. The schematics are to identify the structural elements and components that are included in the periodical surveys. The Owner is to submit to DNV for approval a general, long term program for the periodical surveys of the structure. Normally, the first long term survey program should appear in connection with commissioning of the structure. The program should describe the general arrangements the Owner intends to make and specify basic principles such as

- inspection frequency
- element selection procedure
- inspection methods

In due time ahead of each periodical survey, the Owner is to submit to DNV for approval a detailed description of the survey. The description shall define the structural elements to be included in the survey and given details on cleaning and other preparations, and on any nondestructive testing to be carried out. The Owner is to notify DNV in advance when periodical surveys will be carried out and make all necessary arrangements for a DNV Surveyor to be present during the survey. The methods, procedures and testing equipment used for inspection are subject to acceptance, and the work is to be carried out to the satisfaction of a DNV Surveyor.

Extent of periodical surveys

In principle the periodical survey is to comprise inspection of selected elements of the structure, e.g. selected joints, zones, members and components. The element selection should be on a rotational basis except for elements that are monitored regularly for trend analysis or other reasons. The extent of each periodical survey is to be based on accumulated evidence regarding the condition of the structure and its foundation as obtained by earlier surveys, monitoring systems or other relevant means. Operating conditions and the function of the structure are to be taken into account.

Normally each survey is to include:

a) General visual inspection of selected parts of the structure to determine the general condition of the structure and to locate areas that should be subjected to close inspection and testing.

b) Close visual inspection and non-destructive testing of selected local areas of the structure to detect possible material deterioration or incipient cracking.

c) Visual inspection and testing as needed to check the condition and function of corrosion protection systems.

d) Inspection as needed to check the condition of the foundation and of scour protection systems where installed.

e) Inspection as needed to determine the amount of marine growth on the structure and the presence of debris in contact with the structure.

In conjunction with surveys, cleaning of structures to be inspected is to be carried out as needed.

Frequency of periodical surveys

The long term survey program is to be scheduled so that the whole structure is covered in a period of 5 years, i.e., before renewal of the Certificate of Approval. The frequency of each periodical survey is to be evaluated in each case taking into account type and condition of structure, its foundations and degree of exposure to potential damage or deterioration. The frequency of all periodical surveys of structures below water and in the splash zone is to be evaluated in the light of the survey methods applied and the certainty attached to each survey.

Special surveys

General

In the event of accident, discovery of damages or deterioration, modifications or any other noted or possible change in the condition or operation of the structure that may affect its short term safety, a special survey may be required.

It is the obligation of the Owner to notify DNV of any events as mentioned above that may require a special survey. Special surveys are normally to be carried out by or in the presence of a DNV Surveyor. The DNV's Surveyor is to be provided with the facilities needed for first hand evaluation of the conditions necessitating the survey.

Extent and Methods

The extent of the survey and the methods, procedures and equipment etc. to be used are to be specified by the Owner and submitted to DNV for acceptance prior to execution.

Repairs

Repairs or rework of structural parts that are the subject of certification are to be approved and surveyed by DNV.

The Owner is to notify DNV in advance of any such action and to submit the necessary plans and specifications for approval. The exact documentation that is to be submitted for approval or information purposes is to be decided in each particular case.

Conversion

If changes are planned in the function of the structure so that assumptions and criteria used in the design and construction may be violated, the Owner is to notify DNV.

Such conversions will normally be subject to approval in accordance with the Rules for new constructions.

In practice DNV classes its surveys as Green, Blue or Red, each class incorporates the following activities:

Green: A general visual survey (using a diver or RCV or a manned submersible) the purpose of which is to detect obvious damage. Sometimes requires corrosion potential measurements.
Blue: A survey to detect hidden damages where cleaning is required.
Red: A "Blue" survey requiring nondestructive testing.

DNV has a variety of in-house equipment which it has acquired or built to conduct its surveys. These include: TV and photographic cameras, magnetic particle testing devices, ultrasonic thickness measurement devices and corrosion potential measurement devices. Ultrasonic flaw detection has been conducted, but thickness measurements and mpi are more frequently performed.

3.2.3 Bureau Veritas

Regulations for structure classification for the French society are set down in reference (19): "Rules and Regulations for the Construction and Classification of Offshore Platforms." Under Section 1-4 "Maintenance of Class" (reference 19) the following regulations for special surveys; Annual Surveys and Occassional Surveys are prescribed (these apply to mobile as well as fixed structures).

General

At all times Surveyors are to have free access to survey classed platforms in order to check their good condition. To avoid any possible inconvenience to the Owners resulting from loss of the class through absence of survey, it is up to them or to their Representatives to apply for the surveys to be carried out as prescribed in the present Rules and Regulations and to notify the Society of any damages sustained by the platform structure or by the various installations and units covered by classification. In the case of a platform already classed, no alteration may be made to the structure lay-out, installations, propelling engines and auxilliaries covered by classification unless the alteration has been notified, at the Owner's or the Builder's suit, for approval by the Society in view of maintenance of class. In the case of classed platforms, it is mandatory to use materials meeting the requirements of the present Rules and Regulations for repairs or alterations of the structure, installations or machines covered by classification.

Special Surveys

In order to have its class maintained, a platform is to be the subject of a special survey once every four years. A period of grace may be granted for performing the special survey. This period is granted after a brief survey of the platform; in no case is it to exceed 12 months. Where practicable, the special survey is to be performed at the same time as dry docking or an equivalent operation carried out in sheltered waters.

The special survey consists of a detailed examination of the essential parts of the structure, especially the columns, supports, bracings and articulations; non-destructive tests on these parts may be called for to check proper condition of the parts exposed to corrosion or subjected to alternation loads. The Surveyor further examines machines, installations, equipment, and the inner parts of the structure such as water ballast tanks.

In the case of fixed platforms, the systems and devices to be used for the survey (diving systems, detection installations) are to be defined in agreement with the Surveyor.

Annual surveys

Annual surveys are to take place every year within the three months following or preceding the anniversary of the date of the term, and may be carried out with the platform at its operating station. Less extensive than the special survey, the annual surveys mainly comprise:

a) a visual inspection of the outer parts of the structure, particularly those elements located close to the sea surface in the operating position, with a view to appreciating the damage caused by corrosion;

b) a visual inspection, after cleaning, of the welds subjected to variable stresses so far as these welds are accessible when the platform is in the operating position. The Surveyor may extend his examination to parts that normally are not accessible during operation of the platform if he has doubts as to their condition; He may call, for instance, for a diver to examine these parts or for the use of any appropriate method such as underwater photography or television, or even for a survey in a dry dock if such is possible.

   In addition, inspection of these parts may also be called for in the course of certain annual surveys if experience proves that the time between two systematic surveys, i.e. between two consecutive special surveys, is too long to guarantee the permanent good condition of the parts that are usually submerged;

c) an inspection of the machines, installations and equipment.

Occasional surveys

These surveys take place either during repairs or while modifications are being brought to the platform structure, or when the platform is shifted from one operation area to another.

3.2.4 Germanischer Lloyd

The German society is presently preparing regulations for certification of offshore structures. Nothing regarding this area was available for publication at this time.

3.3 TRAINING

North Sea underwater NDT personnel qualification requirements are still in the formative stage. Most UK-based service companies anticipate that their diver/NDT technicians will be qualified under CSWIP (Certification Scheme for Weldment and Inspection Personnel), a qualification program established by the Welding Institute. The classification societies do not state minimal NDT qualifications. DNV has an in-house program for training its diver/NDT technicians, the program requires that they successfully meet all the standards for surface testing (e.g., mpi, ultrasonics, radiography) and subsequently test various calibration blocks underwater to demonstrate accuracy and repeatibility.

The Canadian Government, under the Canadian Government Standards Bureau (CGSB), has a qualification program for NDT technicians; Can Dive Services, Ltd. anticipates that its diver/NDT personnel will meet some level (Junior; Senior) of these qualifications.

The need for qualification of North Sea divers/technicians is comparatively more pressing than for their U.S. counterparts; this is based on the techniques now being employed. At present the underwater NDT techniques in the North Sea are performed and the data interpreted/recorded by the diver with no assistance from the surface. Magnetic particle inspection, for example, is performed in its entirety underwater. The results are measured, photographed and recorded by the diver. The only means available to check his progress are by television, verbal communication, or actually diving to observe him at work in situ. The same situation prevails with certain forms of ultrasonic thickness measurements, the Wells-Krautkramer Digital Wall Thickness Meter, for example, is completely self-contained and all measurements and data readouts are conducted in situ. In such instances the diver does not necessarily obtain directions from the surface; hence, the need for him to have more than a 30 minute briefing is more pressing.

The North Sea NDT requirements also include a dimension not yet introduced in the U.S.: concrete structures. From the literature surveyed and the interviews conducted in this study, no NDT qualifications or, for that matter, even guidelines were discovered regarding concrete structures. Browne et al (20) have reviewed this area and substantiate the lack of inspection criteria. Significantly, while both DNV and Bureau Veritas include inspection/testing criteria for concrete structures as they are being constructed ashore, neither society mentions post-installation inspection/testing.

3.4 INSTRUMENTATION STANDARDS

Similar to U.S. standards, North Sea instrumentation and procedural standards are written primarily for surface application. The most detailed, published standards are those of Det Norske Veritas (18) dealing with underwater welding. These qualifications do not specify minimum or maximum acceptance standards. Instead, they place the responsibility for a sound inspection procedure on the Owner. Section 6.4.43.14 of reference (18) states:

> "Non-destructive testing: The permanent welds are to be visually inspected and non-destructive tested. Methods and extent of testing will be evaluated in each case. The finished welds are to comply with the soundness specified for the structural part.
>
> All non-destructive testing is to be carried out by competent operators following qualified or accepted procedures."

3.5 REQUIREMENTS - SUMMARY

Inspection

A summary of the frequency of voluntary and imposed inspection requirements is presented in Table VI, it is emphasized that only the English requirements are official government policy and that API, DNV and Bureau Veritas are the only published requirements reflecting an official view of the respective societies. Particular caution is advised in interpreting

TABLE VI

REQUIREMENTS SUMMARY
U.S. AND NORTH SEA INSPECTION FREQUENCY

		SURVEYS	
	Annual	Major	Special
Coast Guard	X	1/10 years	X
API	X	1/5 years	X
Shell		X	X
Operator A	X		
Operator B	X		
Operator C	X		
Operator D	X	1/3 years	
Operator E	X	1/4 years	
Operator F	X		
Operator G	X		
Operator H	No data		
Operator J	X		
Operator K	X		
Operator L	X		
Operator M	X		
BP	X	1/5 years	
Phillips	X	1/4 years	
U.K.	X	1/5 years	X
NPD	X	1/5 years	
West Germany	X		
Lloyds	X	1/5 years	X
DNV	X	1/5 years	X
Bureau Veritas	X	1/4 years	X

the operators requirements. These are not official company policy and most are still in the formative stages. Where an operator (i.e., Owner) in the North Sea sector does not adhere strictly to the guidelines of one of the classifying societies it cannot be assumed that he is deficient. The scope and frequency of each inspection program is outlined by the operator on the basis of design, platform history, etc.. This program is then presented to the classifying society where the actual inspection program is, in effect, negotiated. None of the classifying societies maintain rigid, inflexible rules, they present guidelines. It is conceivable that the operator can formulate a program that is considered a proper one by the particular society, and yet be quite different from the one the society recommends.

The major thrust of all government and society inspection programs is to specify three types of surveys: Annual, Major and Special. The annual surveys are designed such that when they are finished they will cummulatively constitute a major survey which has inspected some percentage (10% is generally mentioned) of the structure. The special survey is one that is conducted after some event has taken place that could affect the platform's integrity (e.g., collision with a barge, the passing through of a major storm, an earthquake, etc).

The indicated nature of these inspections can be obtained from Table VII. Visual inspection is a universal requirement. Magnetic particle inspection, ultrasonic thickness, corrosion potential measurements and marine growth assessment are seen to constitute the majority of programs. Documentation by photographs and/or video tape is also recommended. One Operator (H) anticipates that no inspection or NDT will be required. In this instance structural monitoring procedures are planned which, hopefully, will negate the use of in-water techniques. Monitoring inspection procedures of this type are discussed in Chapter 4 of this report.

TABLE VII

REQUIREMENTS SUMMARY
U.S. AND NORTH SEA INSPECTION/TESTING RECOMMENDATIONS

	VI*	PHOTO*	VIDEO*	MPI*	UT*	RAD*	CP*	MG*
Coast Guard	X				X			
API	X				X	X	X	
Shell Oil	X	X	X					
Operator A	X		X		X			
Operator B	X			X			X	
Operator C	X			X	X			
Operator D	X		X	X	X		X	
Operator E	X			X	X		X	X
Operator F	X							X
Operator G	X							
Operator H	No data							
Operator J	X			X(?)	X			
Operator K	X							X
Operator L	X							
Operator M	X							
BP Petroleum	X	X	X	X	X			X
Phillips Petroleum	X	X	X	X			X	X
NPD**	X	X		X	X			X
West Germany	X			X(?)	X(?)		X	
Lloyds Register	X			X			X	X
DNV	X	X	X	X	X		X	X
Bureau Veritas	X	X	X	X(?)	X(?)			

*VI = Visual Inspection
PHOTO = Photographic Documentation
VIDEO = TV Documentation
MPI = Magnetic Particle Inspection
UT = Ultrasonic Thickness Measurements
RAD = Radiographic Flaw Detection
CP = Corrosion Potential Measurements
MG = Marine Growth Assessment
**NPD = Norwegian Petroleum Directorate
(?) = implied, but not stated

4.0 CAPABILITIES-INSPECTION/TESTING

To ascertain the state-of-the-art in underwater nondestructive testing and inspection over 70 activities were contacted in the U.S. and Europe. These include manufacturers of NDT equipment, suppliers of undersea service capabilities, fabricators of structures and academic institutions traditionally involved with work in this area. (A listing of these organizations is provided in Appendix III). The state-of-the-art is minimal in the U.S. and somewhat better in the North Sea.

Since the statutory requirements for underwater test/inspection of fixed offshore structures have not been outlined or published for U.S. waters, the companies which would manufacture appropriate instrumentation are not doing so: no apparent market. The U.S. diving companies and the manned submersible and remotely controlled vehicle operators who would buy and employ this equipment are also proceeding slowly; they sense a market, but apparently have not seen substantial interest on the part of their customers to warrent investment of funds into instruments and devices for underwater NDT.

Suppliers of inspection/testing instruments and diving services to the North Sea are far more active; some, particularly English firms, are financed to varying degrees by their government to develop exportable technology. The capabilities in North Sea-bordering countries are, though still emerging, more advanced than their U.S. counterparts.

"Capabilities" in surface-oriented NDT generally implies instruments and personnel, in underwater NDT it also implies a means to deploy the instrumentation and/or personnel in situ. The means of deployment can be a diver, a manned submersible or a remotely controlled vehicle. A state-of-the-art assessment of underwater NDT capabilities must include the means of deployment as well as the means for testing.

Virtually all NDT instruments used underwater are surface-oriented devices which have been encapsulated or modified for underwater application. Consequently, various aspects of particular instruments are unknown. For example, ultrasonic transducers are known to experience a change in the beam path characteristics when subjected to high pressure, but no user of ultrasonics underwater knew what these changing beam characteristics under high pressure were. Calibration plates used concurrently and in situ to measure thickness relieves much of this problem, but for flaw detection and subsequent interpretation the problem remains.

The underwater services field is highly competitive. Consequently, many current research development projects which might be aimed at NDT products or techniques may be considered proprietory, and would not be revealed to outside inquiries. Consequently, the results of this survey may not be all inclusive. In other instances (e.g., acoustic holography), the general goals of the instrument or project are divulged, but the details are not owing to proprietory information.

The foregoing preamble is necessary to qualify the following discussions on capabilities, and to emphasize the emerging nature and complexity of this field. A subsequent section, "Research and Development", describes programs aimed at increasing underwater NDT and structural monitoring capabilities. As a result of such programs the capabilities described in this section can be expected to change rapidly in the near-future.

In the Overview four types of NDT techniques were listed which are being used underwater: Visual, Magnetic Particle, Ultrasonics and Radiography, to these are added Magnetic Detection and Corrosion Potential measurements. Eddy current measurements, a typical NDT technique, are excluded from this discussion because no underwater application of this technique could be found. Only those techniques found to be in use are discussed.

Sixteen U.S. and Canadian firms were located which actually performed or participated in underwater NDT; these are listed in Table VIII.

There are numerous small diving companies which can provide inspection services, but only the larger firms are listed herein. Companies in Table III which do not have an undersea capability are those which have supplied (i.e., sub-contracted) NDT qualified technicians and instrumentation to one or the other of the diving companies listed. No U.S. or Canadian company was located which provided mpi or cp measurements; this is particularly interesting since these two capabilities are required in virtually every North Sea inspection/certification requirement. For comparative purposes attention is redrawn to Table VII where the emphasis of North Sea operators can be seen in mpi and cp measurements as well as ultrasonics.

4.1 DEPLOYMENT CAPABILITIES

There are four capabilities which can be used to inspect a structure and/or deploy an NDT instrument at the worksite: divers, manned submersibles, one-atmosphere diving suits (ADS) and remotely controlled vehicles. Technically the ADS is a manned submersible, but their capabilities for manipulation and maneuvering are so different from typical submersibles that they are treated separately herein. To list the numbers and types of capabilities available would verge on the encyclopedic; hence a brief review of each field in general will serve to describe these capabilities.

4.1.1 Ambient Pressure Diving

Describing the diver's capabilities is to describe the human being with which the reader is familiar and needs no further introduction. There is a wide variety of individual capabilities and diving techniques between commercial companies, but in general three modes of diving and diving operations are followed:

- SCUBA (self Contained Underwater Breathing Apparatus)
- Surface Supplied/Tended Air or Mixed-Gas Diving
- Observation, non-saturation and saturation diving employing a diving bell

TABLE VIII

U.S./CANADIAN COMPANY'S
NDT CAPABILITIES

Services	DIVER	SUB	RCV	VI*	MPI*	UT*	RAD*	CP*
BC Research	X			X		⊠		
Can-Dive Services	X	X		X		X	X	
Gamma Industries							X	
General Oceanographics		X		X				
Hydrotech International	X			X				
International Underwater Contractors	X	X		X		X		
Martech International	X		X	X				
Mobile Testing				X		X	X	
C.T. Morgan Co.						⊠		
New England Ocean Services		X		X				
Ocean Systems	X	X	X	X		X		
Oceaneering International	X		X	X				
Peabody Testing						⊠	X	
Subsea International	X		X	X		⊠		
Sylvester Inspection	X			X		⊠		
Undersea Graphics		X		X				

*VI = Visual Inspection - includes photographic & TV documentation
MPI = Magnetic Particle Inspection
UT = Ultrasonics: X = thickness only; 0 = flaw detection; ⊠ = both
RAD = Radiography
CP = Corrosion Potential

Owing to the wide diversity of techniques and capabilities between companies, it would be a major undertaking to list each and every approach to diving. Instead, the following description is presented as being representative of the field at large, and is reflective of Ocean System Incorporated's (Houston, TX) approach to offshore diving.

4.1.2 SCUBA

SCUBA diving provides the diver with his own portable air supply and increased freedom of movement due to the fact he is completely free from the surface and an umbilical cable. The disadvantages in SCUBA diving are its depth limitations, limited air supply and difficulties of communicating with the surface. OSI limits SCUBA diving to 30m.

4.1.3 Surface Supplied/Tended Air or Mixed-Gas Diving

Surface supplied/tended diving involves those forms of diving in which the breathing media (air or mixed gas) is supplied to the diver from the surface by a flexible hose. In addition to the diver's air/gas hose, there is a communication cable, lifeline, and a pneumofathometer attached to the diver. The diver's dress may be either the heavyweight (Hard Hat) equipment using a dry suit or the lightweight (face sealing mask) equipment using a wet suit or hot water suit. OSI normally limits surface supplied/tended diving to 50m breathing air and 91m breathing mixed-gas. When diving in excess of 67m, an open type (pick up) bell is used.

4.1.4 Diving Bell

All diving within OSI in excess of 67m requires a bell system. The mode of diving may be as observation, non-saturation or a saturation dive. (Note: In the Norwegian and UK sector of the North Sea, a closed type bell system is required for diving in excess of 50 meters.)

With the above equipment OSI follows three modes of diving: Observation, Non-Saturation, and Saturation.

Observation Dives

In observation dives the bell (Submersible Decompression Chamber) is held at atmospheric pressure and lowered to depth for the purpose of observing or viewing the work or task to be accomplished. The SDC is equipped with viewports. The advantage of using the SDC in this manner permits a thorough study of the job to be done with no decompression penalty for a long period of observation, plus the relative comfort of the SDC. This mode also permits non-diving personnel, engineers or customer to view the work site.

Non-Saturation Diving Mode

Deep short-term (usually less than 1 hour) dives for inspection, repair, construction, or recovery requiring extensive decompression time can be conducted using this mode. This mode of diving limits the diver's wet exposure to that of actual excursion time from the SDC and provides the safety and comfort of the Submersible Decompression Chamber (SDC), Deck Decompression Chamber (DDC) or Living Chamber (LC) for subsequent lengthy decompression. Without the SDC, many dives routinely conducted would be beyond the limits of human endurance if they were attempted with in-water decompression. In addition, short dives conducted under particularly adverse environmental conditions can be conducted using this mode. The short length of the diver's umbilical results in minimum drag when in heavy current which would be impossible for surface supplied/tended diving. The equipment the diver wears in this mode of diving is the lightweight full face mask and either a wet suit or a hot water suit. This type of diving is normally limited to about 180m.

Saturation Diving

Underwater jobs at deep depth which demand extensive bottom work time are best conducted with the diving bell in the saturation mode. Multiple diving crews can be cycled between the living chambers, DDC and an Entrance Lock (EL) via the SDC to the work site permitting continuous diving operations. In the saturation mode divers are pressurized in the LC/DDC or EL to a saturation depth equal to the deepest work site. Divers then enter the SDC which also has been pressurized to depth. The SDC is then unmated from the DDC/LC/EL and lowered to saturation depth where the divers egress from the SDC and proceed to the work site by excursion. The divers wear hot water suits with gas heaters and lightweight diving masks in this mode of diving. Upon completion of the job and/or their work time, the divers return to the SDC which is raised to the surface and remated with the DDC/LC/EL wherein the divers can rest, sleep, eat, etc., in preparation for their next dive or decompression. The primary advantage of saturation diving is that once the body tissues are saturated with gas the diver can remain at depth indefinitely without increasing his decompression time. In saturation diving, the occasion often exists when a diver must make an excursion dive to depth greater than his saturation depth. Using OSI's saturation excursion tables, the diver may dive for short periods of time to deeper depth and return to his saturation depth without difficulty.

These tables are designed to limit the quantity of gas (Helium) absorbed during the excursion to an amount which can be safely released in his body by the return to the lesser saturation pressure depth. This is the same situation as in diving from the surface except, instead of saturation with nitrogen at a fixed surface pressure of 1.03kg/cm^2 (14.7 psi) the saturation pressure can be varied. It is not possible at this time for the diver to ascend to depths shallower than his saturation depth except in the process of final decompression from his saturation exposure.

A sampling of international saturation diving system capabilities is as follows:

Company	Depth Capability
Can Dive Services Ltd.	183m
Sub Sea International	305m

Sub Sea Oil S.P.A.	305m
Santa Fe Engineering	305m
International Underwater Contractors	366m
Oceaneering International	366m
Taylor Diving and Salvage	366m
Lockheed Petroleum Ltd.	366m
Ocean Systems Inc.	460m
COMEX	460m

The deepest open ocean dive by a commercial operator was made by Comex in October 1977. This dive was to 501m for 10 minutes. A 460m depth dive for 10 hours duration was also accomplished.

While most diving companies do not routinely dive much beyond 90 to 120m, the capability to dive and inspect/test the deepest fixed structure today (307m) is available. Research being conducted by the Royal Naval Physiological Laboratory, Alverstoke, is seeking to push the present depth limit to 605m depth.

The most unique capability the diver brings to the work site is his manipulative dexterity and tactile senses. The diver can, when necessary, perform many mechanical tasks by feel alone; there is no present manipulator system than can work on an object without seeing it. The diver's dexterity and sense of feel is a critical capability in present NDT techniques.

4.1.5 One-Atmosphere Diving Suit (ADS)

The ADS (typified by the JIM-type suit) is essentially a pressure-resistant suit that permits the wearer to conduct work at great depths (910m maximum) without incurring decompression penalties. The greatest advantage the ADS brings to underwater testing and inspection is the manipulation system which is - in essence - akin to the human arm, but with much reduced tactile senses. There are approximately 23 ADS's in various stages of operation and construction. Some are propelled by motors and others by movement of the wearer's legs (i.e., walking). All are self-contained in terms of life support and power.

The ADS is designed and built to work primarily on the bottom, but it can operate from a stage in mid-water depths. More recent models are equipped with propulsion motors that provide a hovering capability and greater maneuverability. The light weight of the ADS (about 500kg with occupant) allows for any deployment from a fixed structure.

4.1.6 Manned Submersibles

There are over 67 commercial manned submersibles in operation or under construction which have a depth capability of over 180m. It is very difficult to generalize when discussing design and capabilities of manned submersibles. Only a handful are identical and even within these there are variations. The following characteristics describe the industrial field at large:

- The average maximum operating depth capability is 572m, the deepest is 3,000m (the French submersible CYANA); the average length, beam and height is 6.2m, 2.3m and 2.7m respectively.

- All use lead acid batteries.

- Crew complement is from two to six.

- Dive working duration is from six to eight hours.

- The average cruise speed and endurance is 1 knot for 7.9 hours.

- The average payload is 480kg.

- Dry weight is from 2 to 26 tons.

- About half of the newly-constructed vehicles have diver lockout capability.

- Approximately 80 percent carry at least one manipulator; 40 percent of these carry two.

- Launch/retrieval can be generally conducted in Sea State 4 and, in some instances, Sea State 7.

The major exception to the above is the AUGUSTE PICCARD. Being 29m long, 168 tons, and having a life support duration of 90 mandays, it is in a class by itself.

Work tools, e.g., drills, wrenches, grinders, brushes, etc., are available to varying degrees on all vehicles. The most dominant work capability is direct viewing coupled with TV video documentation.

Submersibles confront several obstacles as inspection/testing vehicles: the manipulators - even the most sophisticated - are capable of only very basic motions and have no tactile sense; hovering in mid-water is impossible unless the vehicle holds to the structure; the vehicle bulk prohibits it from getting into confined areas and electrical power is limited. To gain dynamic stability and reduce the likelihood of collision, all submersibles are launched and retrieved from a ship underway. Launch/retrieval from a fixed platform - while not impossible - is not a general practice and would require a measure of research and development to evolve a competant system.

The diver lockout submersible has gained much favor with industrial users in the last decade. In this approach the submersible provides both transportation and support to the diver and his work tools. In essence the lockout submersible is a maneuverable diving bell which requires no umbilical or lift cable. A second pressure-resistant compartment attached to the lockout chamber provides a shirtsleeve environment for the pilot and one or two observers. In many applications it is possible for the submersible to position itself within viewing range of the locked out diver where supervisory personnel in the vehicle can observe and direct him in his task. This is an ideal arrangement for NDT work where the diver is not NDT qualified, for it allows close supervision and monitoring of his activities by a qualified technician inside the support vehicle. A disadvantage with lockout submersibles is the limited electrical power which must be shared for propulsion, hotel load and diver heating, as well as for NDT instrumentation. Most submersibles are designed to sit on the bottom when the diver is locked out, but mid-water stationing on a structure can be obtained by grasping (mechanically or magnetically) the structure itself. The greatest commercial lockout depth to date has been 154m, at this depth the diver can be supported with breathing gasses and heat for about five hours. A recent innovation to the lockout submersible has been the addition of a power umbilical which can be attached when needed to supply as much power as needed from the surface.

4.1.7 Remotely Controlled Vehicles

There are several types of vehicles which fall under this category: 1) tethered, free-swimming vehicles; 2) tethered, bottom-crawling vehicles; 3) towed vehicles and 4) untethered, free-swimming vehicles. This discussion is limited to the tethered, free-swimming vehicles.

Undoubtedly, the most dynamic growth in a particular underwater platform has been exhibited by the Remotely Controlled Vehicles (herein they will be called RCVs; RCV is a registered trademark of Hydro Products, San Diego, CA). In 1974 there were approximately eight RCVs; today there are over 70. RCVs are as varied in design as are manned vehicles, and generalities regarding their characteristics are attended by numerous exceptions.

The basic tethered, self-propelled vehicle system consists of the vehicle itself (and sometimes an underwater clump or launcher), a cable and a shipboard control/display console. Supporting equipment includes a launch/retrieval device, a cable winch, an enclosed area for the vehicle operators and shipboard components and, if shipboard power is not available or suitable, a power supply unit.

Vehicles owned by industrial users range in depth capability from 200m to 2,000m; the average is 1,300m. Depth, per se, presents no problem to the RCVs. Control of the vehicles at great depths is a problem which is discussed later.

Most vehicles are constructed of an open, metal framework that supports and encloses (for protection) its various components. Buoyancy is generally positive by a few kilograms when the vehicle is submerged; this provides a fail-safe assurance that the vehicle will surface in the event of a power failure. Generally, but not always, syntactic foam blocks mounted atop the framework provides the required buoyancy.

The underwater components(s) or "vehicle" of these systems weigh from 68kg to as much as 2,268kg. The Sea State limitations on launch/retrieval are controlled by the nature and sophistication of the shipboard handling equipment. Some indications of Sea State limits can be gained from the following operator statements: CONSUB 1 can be launched/retrieved through Sea State 4; DEEP DRONE is designed to be handled up through Sea State 5 if "normal" handling equipment is available which is generally employed to handle manned submersibles. These two are not the heaviest vehicles operating, but they do fall around the average vehicle weight of 961kg.

The speed of RCVs is similar to that achieved by manned vehicles, and ranges, at the surface, from one to five knots (1.8 to 9.3 km/hr). There is a decrease in speed with depth and/or with increase in currents which may range from 20 percent to 84 percent of the surface speed. The reduction is caused mainly by cable drag, but can be alleviated by different modes of vehicle deployment. The SCAREB vehicles are designed to cruise along the bottom while (in conjunction with the surface ship), they tow the entire length of cable. The RCV-225 is deployed from a launching cage, and works around the launcher on 120m of tether cable; hence, cable drag is substantially reduced. For this reason, many of the RCVs employ a launcher or clump.

All but a few vehicles are capable of two translation motions and one rotational motion; these are thrust (forward/reverse) and heave (up/down); and yaw (left/right) heading changes, respectively. These motions are provided by the arrangement of two horizontal or forward thrusters and one vertical thruster. By adding a fourth lateral or side thruster, a third translational motion is obtained: sway or sidle. If the lateral thruster is mounted forward, it is used to augment yawing, rather than providing a sideward translational motion.

For routine operatons the support crew complement ranges from one to seven; three to four is average.

The instruments listed in Table IX are those which are standard onboard equipment. All RCVs carry underwater lights. The majority of RCV manipulators are simple devices which can do no more than extend and open/rotate the claw. The limited orientor and locator motions are not a liability because the vehicles themselves can provide several more degrees-of-freedom to the manipulator by virtue of their excellent maneuvering capability.

Payload, or the ability to carry additional submerged weight (i.e., work tools) is very small and, without modifications, generally limited to no more than one or two percent of the vehicle's weight.

The RCV is a most promising inspection vehicle, indeed it would seem to be the ideal alternative to divers or manned submersibles. There are, unfortunately, some problems. The umbilical cable has a tendency to foul when working around structures (several RCV's have been lost in this manner, and several others required rescuing by divers or manned vehicles). Locating the precise position of the vehicle is extremely difficult around structures (active acoustic systems are not reliable due to sound path interference by the structure itself). The television camera provides a one-dimensional view, this hinders interpretation of

TABLE IX

WORK INSTRUMENTS

		----VIEWING/PHOTOGRAPHY----					----SONAR----	
	DEPTH (Meters)	TV	STILL	STEREO	CINE	MANIPU-LATOR	SEARCH	HOMING
CONSUB 1	610	X		X				
CONSUB 2	610	X		X				
EV-1	363	X				X		
RCV-225	2,012	X						
RCV-150	1,829	X				X		
RECON II	457	X				X		
SAAB SUB	700	X(2 ea)	X	X		X(3 ea)	X	X
SCARAB I & II	1,829	X	X			X(2 ea)		
SCORPIO	908	X	X			X(2 ea)	X	X
SEA SURVEYOR	200	X						
TOM 300	300	X(2 ea)	X		X	X	X	X
TROV	366	X				X(2 ea)		

observations. There is no force-feed back from the manipulator; consequently, the operator has no sense of feel. Recent developments in manipulator technology (e.g., the General Electric "Diver Equivalent Manipulator") has provided a system capable of some tactile sense, but as an equivalent human hand it is lacking.

The foregoing is not aimed at denigrating the role RCV's can play in underwater inspection/testing. Because there is a general lack of information regarding their activities, a more extensive discussion is necessary to gain some perspective on their capabilities and limitations.

Of all four capabilities (diver; ADS, manned submersibles and RCV) the diver is presently best suited to conduct NDT operations. The reason is no more complex than the fact that virtually all underwater NDT equipment is designed to be used by human hands; not mechanical manipulators.

Further limitations are revealed when testing is required in the splash or surge zone in any but the calmest seas. The periodic, sea or swell-induced rise and fall of the surface can thwart all efforts to gain the stability required to remain at a specific site. Submersibles, RCV's and ADS's are not designed to work in the splash zone or, for that matter, at any depth where sea or swell affects are appreciable. Even the diver must accede when seas exceed not much more than 1m or more in height. A possible solution may be found in attaching guide-rails or tracks to which an RCV or ADS might hold on or be driven to its splash zone work site; but no such technique is known to be employed.

Depth is not a problem to any of the four capabilities, but this situation may not always prevail. Table X tabulates 1976 and future deep water drilling projects, when the depths of these projects are compared against the present working diver depth record, 457m, it is apparent that the diver will be incapable of reaching the entire structure if these projects result in a producing field. Further, unless some alternative is found to replace visual or remote viewing for inspection purposes, then the technological and operational problems discussed above must be overcome at great depths. The problem is even more pressing if inspections are to be a regular routine. While 457m depth has been reached, it is not a "routine" dive. Indeed, any ambient pressure diving beyond 300m is a special case requiring long-range planning, extensive support, complex logistics, and generous funding. If inspections are to be routine, then at great depths an alternative to the diver must be developed.

4.2 LOCATION/POSITIONING

Locating oneself on an underwater structure is accomplished using a depth indicator and visual references. The general procedure is to orient the diver (or the submersible pilot or the RCV operator) on the surface by virtue of a drawing concerning where the work site is. The diver can, if necessary, carry a waterproof sketch with him for orientation underwater. The diving bell (if used) can be lowered to

TABLE X. PRESENT AND FUTURE DEEP WATER DRILLING PROJECTS

OPERATOR	COUNTRY	RIG NAME	WATER DEPTH (Meters)
Future			
Seagap Group (Getty, Hispanoil, Phillips, AGIP)	West Coast of Africa	Discoverer Seven Seas	1,372
HIPCO of New Zealand	S. Island, New Zealand	Penrod 74	701
HIPCO of New Zealand	S. Island, New Zealand	Penrod 74	701
HIPCO of New Zealand	S. Island, New Zealand	Penrod 74	640
HIPCO of New Zealand	S. Island, New Zealand	Penrod 74	640
Arco	California	---	373
British Petroleum	Worldwide - 9 or more wells	Sedco 471	183+
Arco	West Greenland	Sedco 445	183+
Arco	North Sea	---	183+
1976			
Esso Explorations	Thailand	Discoverer 534	914-1006
Esso Explorations	Thailand	Discoverer 534	914-1006
Esso Explorations	Thailand	Discoverer 534	823-914
Esso Explorations	Thailand	Discoverer 534	802
Placid	Louisiana	Penrod 72	547
Placid	Louisiana	Penrod 72	537
Union of Cal. et al	Thailand	Sedco 445	512
HIPCO of New Zealand	New Zealand	Penrod 74	480
Esso Explorations	Red Sea	Discoverer 11	460
Amco Espana	Spanish Mediterranean	Discoverer 511	427
American Petrofina	Louisiana	Blue Water No. 4	387
Exxon USA	Louisiana	---	354
American Petrofina	Louisiana	Blue Water No. 4	350
American Petrofina	Louisiana	Blue Water No. 4	342
Exxon USA	Louisiana	Zapata Lexington	324
Exxon USA	Louisiana	---	323
Exxon USA	Louisiana	---	320
Shell Expro	North Sea	Sedco 700	299
Mobil	Texas	Zapata Concord	292
Exxon USA	Santa Barbara Channel	Glomar Coral Sea	282
Mobil	Texas	Zapata Concord	268
Chevron Overseas	Spanish Mediterranean	Bideford Dolphin	234
Esso Exploration	North Shetlands	Dixilyn Venture 1	229
Exxon USA	Texas	---	227
Gulf Oil	Okinawa	Wodeco VIII	215
Arco	Louisiana	Glomar Java Sea	212
Arco	Louisiana	Glomar Java Sea	212
Exxon USA	Santa Barbara Channel	---	204
Challenger Oil & Gas	Southern Portugal	Glomar Sirte	189
Oceanic Explor. Co. of Greece	Greece	Wodeco V	183+
Arco	Louisiana	Glomar Java Sea	183+
Arco	Louisiana	Glomar Java Sea	183+
Arco	Louisiana	Glomar Java Sea	183+

(from Offshore, June 1976)

the exact depth required and, if the bell launch/retrieval device is properly located, in the same vertical plane and adjacent to the member in question. When a barge or other vessel is used as the support platform, it can be located immediately above the area of interest.

Submersibles and RCV's confront a different set of circumstances. Since submersibles are almost always launched from a ship underway, the vehicle will be at some distance from the structure when it is ready to dive. Generally the pilot will maneuver the vehicle as closely as prudent to a point adjacent to the platform and over the work site. He will then power or drive down to the predetermined depth level, while attempting to keep the reference leg in visual sight. If the vehicle drifts out of sight of the platform a gyrocompass or directional gyro can be employed to direct him to the work site. A magnetic compass can be used near a steel structure, but there is some question concerning its reliability. Physical markings (tags, prints, welds, letterings, numbers, etc.) on the structure are presently the only reliable means of informing the pilot that he is at the correct node or location (this holds true for the diver also).

An RCV can be launched from the fixed structure itself, or from a barge, etc., moored alongside. Like the submersible, it will generally be driven to an appropriate point on the structure before diving. If it is of the type that uses a launcher or clump, the launcher will be lowered, similar to the diving bell, to the appropriate depth where the vehicle will "swim" out to perform its work. Since most RCV's do not carry a gyrocompass, a directional gyro or a magnetic compass are the only means of directing the vehicle when it is out of visual range or contact with the structure. All directional gyros experience some degree of drift; consequently, the greater the period of time the vehicle is out of visual contact, the more difficult becomes the problem of locating the structure. Meanwhile, the operator must maintain constant vigilance that the umbilical cable does not foul with the structure. A further complication is introduced when the structure's external vertical support legs are not, in fact, vertical. The Cognac platform, for example, is approximately 36m wider at the base than it is at the surface. Since the RCV launcher is designed to hang vertically downward, it must be launched at some distance from the surface of the platform if it is to intersect with the base of the structure. While this is not an insurmountable problem, it does introduce further complexity in initially positioning the vehicle to begin its chore.

Location on concrete platforms is a far more formidable task owing to the lack of reference points. Since the structure is monolithic and the surface is virtually identical throughout, the inspector can only rely upon depth and on relative bearing from the center of the structure to determine that he is at the correct location. To alleviate this problem, one operator, Shell Expro, will specify identification markers on new concrete platforms - 0.5m^3 markers on a 5m grid (21).

There are a variety of acoustic navigation systems that are used to determine an underwater vehicle's position; some advertise relative position accuracies of ± 1m. But the steel structure itself would interfere with the sonic signals to such a degree that the data would, at best, be unreliable and, at worst, useless. The problem is further complicated by background voices generated by the platform operations. Working within, rather than on the extremities of the structure further intensifies the interference problem. There is research now underway at several commercial organizations (e.g., Martech International) to solve the problems encountered with acoustic structure positioning. Recent tests of an inertial navigation system aboard a submersible in the North Sea indicate that positioning accuracies of ± 15cm are attainable (22). The submersible operator, Intersub, believes this technique can be used effectively for positioning on fixed structures.

The salient features of all present location/positioning techniques for the diver or vehicle working on a structure is the total reliability on underwater vision for final closure. If the water is too murky for viewing, all inspection and/or testing must be done by feel.

4.3 CLEANING

Every NDT device now in use requires that the surface of the structure be cleaned to bare metal in order to obtain accurate measurements. Depending on the environment, preparatory cleaning can be - and often is - a more time consuming chore than the actual testing.

The cleaning chore involves removal of sessile organisms (barnacles, mussels, tube worms, algae anemones, etc.). The quantity of these organisms on a specific structure varies according to the environment, reproduction rates and other factors. Consequently, it is not possible to predict how many of a particular specie will be present. The depth of fouling organism growth also varies according to the specie. Generally, but not always, below 50-60m the population density decreases and the cleaning problem is considerably less. Several programs to identify population types and rate of fouling organisms are being pursued by the UK Department of Energy and Aberdeen University in the North Sea.

Several techniques are used to remove marine growth. These include hydraulic grinders, brushes, scrapers, needle guns and high pressure water jets. The technique employed varies from company-to-company, but water jetting is most often used on both concrete and steel structures.

Cleaning with a needle gun is a questionable technique. Lloyds Register would prefer that the needle gun technique be used only on the parent material, not on structure areas that have been heat-treated or on welds. The needle gun is, essentially, a mechanical chipping hammer and it has a tendency to peen the weld or heat-treated area. Consequently, it may introduce a problem rather than reveal one. It should be emphasized that Lloyds does not prohibit the use of a needle gun, it simply prefers that an alternate technique be used on the HAZ and weld.

There are several manufacturers of high pressure water jets and each one differs somewhat from its competitor, but basically the system consists of a surface pump; a high pressure hose, and the gun. High pressure water is pumped at pressures dependent on the material being cleaned, up to 1,019kg/cm^2 (14,500 psi) has been used on steel and 253kg/cm^2 (253 psi) on concrete (23). Up to 100 l/minute (379 gal) can be pumped at the high pressure range. The gun nozzles range in orifice size and type, a lance nozzle might be used to cut concrete or remove fouling organisms on steel, while a fan jet nozzle might be used to do the same job on concrete. The gun control is a pistol grip, for underwater work the gun flow is divided into a primary flow for cutting and a secondary flow which provides a counterbalancing jet to prevent the diver from being pushed off the site.

The standoff distance from nozzle to work site varies, but 10cm and closer is an average value. The water jet gun is simple to use, but is potentially dangerous. The supply hose, under high pressures, is virtually solid within the few meters behind the gun; consequently, it is awkward to control and is a task requiring both hands. If the diver is at mid-water depths he must have a stage or support on which to stand. The water jet control is a dead man control; even so, the diver must be ever-cautious to keep the working end of the jet pointed away from himself, the jet can remove bone and muscle easier than it can concrete coatings or fouling organisms.

Hydronautics Inc. has developed a technique utilizing high-pressure, cavitating water which harnesses the destructive power of cavitation. Originally developed for tunneling, this technique, called CAVIJET, is being applied to cleaning ship's hulls in dry dock. According to the manufacturer, CAVIJET should work even more effecitvely underwater, and its advantages are that it is more effective than conventional water jetting and operates at much lower pressure. There are no immediate plans to produce an underwater version of CAVIJET.

Removal rates of marine organisms depend on the type of organism and the degree of finish or clearing required. One operator (24) claims a rate of removal of 0.3m^2/minute (3 ft.^{2}), another report (15) states 0.2m^2 (2.2 ft.^{2}) minute can be cleaned by a practiced operator.

For NDT purposes the structure must be cleaned to at least bare metal, any protusions left on the surface can introduce an error into the results; conversely, any abrasion causing removal of parent material or weldment produces the same effect. "Clean", therefore, is an arbitrary condition. What is clean to an individual not aware of the subtleties of NDT techniques, may not be clean to an experienced NDT surveyor. On a bare, dull surface imprints from organisms can remain although the structure is "clean", on a bright shiny surface there is no question that all fouling or corrosion products have been removed. However, to attain a bright surface an abrasive might be introduced into the water flow; this abrasive might also remove some of the unaffected material and introduce a defect or weakness in the process. None of the requirements of Chapter 2 defines "clean"; consequently, the manufacturers of water jets and the service companies are not altogether certain of the market requirements.

Concrete structures present a special cleaning problem where "clean" is, in fact, governed by how much fouling/corrosion material can be removed and not harm the parent material.

Cleaning of offshore structures whether by water jets, needle guns, or brushes - is presently the diver's domain. Submersibles are generally too large to gain access to many of the joints or nodal areas. Neither the RCV nor the submersible can conceivably manipulate a water jet or needle gun to clean effectively. These tools are made for the human hand to operate. There are remotely controlled vehicles which have been designed for - and are used to brush-clean ship hulls underwater (e.g., Winn Technology's SCAMP), but no incident of their use on fixed structures could be located. The ADS might be capable of using a water jet if it were working on the bottom or from a stage or platform in mid-water, the gun trigger would probably require modification to fit the ADS hand configuration. In any event, unless a bright metal finish is specified, the diver's final check to assure that the surface is clean is to feel it, no manipulator has been built that can equal this final, quality assurance check.

4.4 VISUAL INSPECTION/DOCUMENTATION

The means of transporting the human being, both directly and remotely, to the inspection site were discussed. In this section the ability of the human to visually detect structural weaknesses and failures, and the capabilities for documenting his observations are discussed.

4.4.1 Human Limitations

The most obvious limitation to visual inspection is water clarity. For purposes of this discussion it will be assumed that water clarity is sufficient to allow viewing of at least 1m. The diver is capable of carrying out a survey by feel alone in zero visibility, but it is difficult, if not impossible, to qualitatively assess the accuracy of this technique, particularly when the diver is wearing gloves and is uncertain of his location on the structure.

Visual inspections are carried out by divers, submersibles, RCV's and ADS's. The ability of the human eye to detect cracks, bends, or complete failures in structural members varies considerably depending upon which of these capabilities is used and the extent of marine fouling and corrosion which has taken place.

If a structure has not been cleaned visual observations can reveal the following:

- Scope, depth and general nature of marine fouling
- Collision or impact damage

- Degradation (scouring) or aggradation (silting) at the sediment/water interface
- Presence and nature of debris
- Evidence of cracking (at times there is a color change in organisms immediately over a crack)

On a clean structure visual observations can reveal, in addition to the above:

Hairline cracks (steel and concrete)
Corrosion of reinforcements or prestressing tendons in concrete (by surface staining and spalling)
Sulphate attack in concrete (by crumbling)
Pitting (by surface relief)
Local corrosion (by color and relief)

In all of these instances the observations are surficial and dimensional values are approximations. (The diver can - and frequently does - provide quick dimensional approximations by comparisons with his height, arm span, hand span, fingers, etc.). All of these observations require light (ambient or artificial), and many defects (e.g., cracks, pitting, crumbling) are better seen by the shadows they cast in artificial light. How small a pit or crack a human can see is so subjective that it precludes discussion herein. A portable artificial light source is also required to visually detect the presence of corrosion, since the most apparent visual evidence of corrosion is the color difference created by the by-products relative to the parent material. Whereas steel corrosion by-products are red-orange, the light source must: a) produce "white" light of the incandescent tungsten filament variety, and b) be in sufficient proximity to the corrosion products such that the water column does not absorb the red and orange bands before they reach the object (2.5m is generally the limit for 1,000 watt quartz-iodide lights).

A major consideration in defining the accuracies and effectiveness obtained through visual observations is the physiological and psychological state of the surveyor. While the diver is most vulnerable to physiological factors, the surveyor inside a submersible or an ADS is also well aware that he is not in his natural environment. There are, as far as is published, no comparisons, regarding the psychological state of the one-atmosphere surveyor vs. the diver at depth, probably the best one can say is that both are not as observant as they would be on the surface, and that the diver is more aware - or concerned about - external environmental factors than is the submersible or ADS surveyor.

Since both the submersible and ADS surveyor are exempt from the effects of high pressure and low temperature, physiological effects as regards their ability to observe, are not limiting. If it is assumed that the diver is heated and otherwise comfortable in his surroundings, there are still factors that influence his judgement. The diver using air as the breathing medium can expect some loss of judgement at 30m and a severe loss at depths over 45m owing to inert gas narcosis. Reportedly (25), the diver cannot always recognize the exact relationship of objects with the vertical and horizontal, and an error in judgement of up to 30 degrees may be expected. This limitation is said to be related to the diver's weightless state in water.

Another factor regarding in situ direct observation is the nature of the medium through which the surveyor is viewing. A diver's face plate will both magnify an object and make it appear closer (30% is a general approximation); consequently, his judgement of size and distance will be distorted. Both the submersible and ADS surveyor are subject to similar distortions. The plastic bow dome which most contemporary submersibles provide for observation presents a further complication, in that the peripheral view is distorted and - though the observer can become accustomed to this distortion - it introduces an error in judging verticality, (26).

A further limitation regarding visual observations is the mobility and bulk of the viewing system. The diver can position himself to visually assess almost any external component of a structure. The first generation ADS's (JIM) are cumbersome, the later models - particularly their progeny WASP - are more maneuverable owing to propulsive devices. It is likely that the later models can position themselves to view any component available to the diver. The conventional submersible is limited by virtue of its greater size and the fact that an overhanging brow or underhanging equipment rack can restrict it from gaining access to nodes where the members are sharply angled to each other (in some instances 30 degrees between upright and member is found). As a consequence, it can prove physically impossible to bring the surveyor's eyes close enough to the structure to detect a hairline crack or pitting. In other instances it may be impossible to bring the light source close enough to the object, with the result that the full color spectrum does not reach the object. Not all submersibles are so limited by size, some are quite small and can gain access to tight areas, but the large, lockout submersible must weigh its size against the task.

The RCV has not been mentioned in the foregoing discussion because it is not a direct visual inspection technique. Since the surveyor is on the surface he does not confront the psychological limitations of those who are underwater. Physiologically he is only limited by the amount of time he can effectively operate the vehicle and his skill in its operation. While the endurance of the vehicle is not power limited, the operator's endurance to maintain the degree of concentration required for 100 percent performance is, and his performance can be expected to degrade as time passes. There are no figures available regarding time limitations on RCV operators, (the degree of concentration required on the part of some RCV operators has been likened to that of an air traffic controller) but - being human - they are subject to fatigue as is the diver and submersible operator.

From the point of view of maneuverability the smaller RCV's are capable of attaining virtually any external position or location required to aim its cameras. They are equally as maneuverable as the diver. Present developments with the RCV-150 have produced a propulsion control system which - because the propulsion system is controlled by its onboard computer - continuously delivers thrust commands to stabilize vehicle motions so that the operator may concentrate solely on the job at hand (27).

4.4.2 Data Recording

Visual observations can be recorded by one of three means: handwritten notes; verbal reports, and photography/television. Reliance on memory is not a sound inspection procedure and is not discussed.

Handwritten Notes

Handwritten notes are an inconvenient, awkward and crude method of data recording. This is particularly true for the diver who is generally encumbered with other essential equipment to the point where a plastic tablet and grease pencil are just one more aggravation. If this method is used at all it is generally only to make crude sketches and measurement notes, relying on these and memory to write a report on the surface. In the comfort of a submersible hand-written notes can be more easily made, but generally the observer will favor a hand-held tape recorder rather than pad and pencil. The ADS surveyor is physically restricted from taking notes of any kind owning to the lack of adequate manipulation.

Verbal Reports

Hardline communications from diver-to-surface or diver-to-sub are the most routine method the diver uses to describe his observations; these can be recorded for playback subsequent to the dive. Interpretation is sometimes difficult--and particularly within a helium atmosphere. The ADS diver uses hardline communications exclusively, within his one-atmosphere environment communication quality is generally adequate. Submersibles rarely communicate job details to the surface; instead, the observations are recorded inside the vehicle.

Photography/Television

It is now general practice to document all significant observations by photography or television, in offshore platform inspection it is almost imperative.

The capabilities and varieties of underwater photographic cameras are numerous and 35mm or 70mm formats are offered by most manufacturers. High quality black and white and/or color film is available for either format. Still photography cameras are available for divers which are hand-held, or for submersibles and RCV's which can be mounted external to the pressure hull of the vehicle. Light sources (strobe or flood) for any exposure are also available for virtually any underwater photographic task. The major deficiency is in the operator's ability to properly use the equipment at the correct distance, angle and exposure to obtain a usable photograph. Photography from submersibles can be through the viewport/bow dome or from an externally-mounted camera. The first case allows for reloading of film and a greater variety of camera positions. The externally-mounted camera (and its lights) may be mounted on a pan/tilt mechanism for positioning, but unless a TV camera with internal (in-hull) monitoring is adjacent to the camera lens there is no certainty that the object is question is being photographed.

A recent innovation in diver-held still cameras is the Hydroscan, an automatic, 35mm underwater camera manufactured by Marine Unit Technology Ltd. The Hydroscan is designed to enable divers with no photographic experience to carry out close-up photography of welds, corrosion, or local damage. The camera is supplied with a preset function to cover a specific area, for example, at a coverage of 12cm x 8cm (4.7 in. x 3.1 in.) an object of 0.04cm (0.004 in.) can be detected. The diver's function is simply to place a zoning frame (preset) over the required area and pull the trigger. The light source is a short-duration electronic flash which encircles the lens, the color temperature remains constant to ensure consistency. Recycling time is two seconds and 250 exposures can be taken on one full charge. Singling out the MUT camera is not meant to endorse it as being superior to its competitors, it is meant to exemplify photographic equipment which has been designed primarily for detailed inspection documentation. Although the Hydroscan is equipped with a pistol grip for diver utilization, it would not require a great deal of modification to use it from a submersible or RCV manipulator. In spite of the apparent advantages offered by stereophotography, no application of this technique to platform inspection was revealed.

Documentation of observations on video tape has become a fairly standard practice. Like photographic cameras, the types and capabilities of commercially available underwater TV cameras are numerous, and virtually any ocean depth is attainable. The cameras are designed to be hand-held or rack-mounted. Television offers no particular advantage over still or cine photography as a documentation tool. Television lacks the resolution and color rendition qualities of photography; hence, for detailed work it is inferior. It is a common practice to back-up TV with still photographs. For other than close up observations TV is quite adequate and offers the advantage of real-time display to the surface (if a telemetry cable is provided) and real-time quality control of the video image.

Comparatively innovative video techniques were employed by Comex in a recent diver inspection of Total Oil Marine Limited's concrete structure MCP-01 in the North Sea (23). A video typewriter superimposed relevant inspection data onto the video image. A video timer provided constant real-time and date displays on the video image and a video pointer indicated specific areas of interest. A contour synthesizer converted differences in density within the video image into differences in contour. In the resulting monitor display the image became a bas relief in which details were discernible as ridges or valleys; thus, in effect, simulating the introduction of a third dimensional image. A 19mm (3/4 in.) video cassette replaced the more conventional 12mm (1/2 in.) video tape recorder to improve picture definition and increase length.

Television is the eyes of an RCV; without it it cannot navigate or work. There is no choice but to employ it, and to back it up with still or cine photography if details are required. Because no RCV uses TV to obtain a 3-dimensional picture, depth perception is absent. Still, for a general inspection survey the image is satisfactory and, obviously, this technique does not jeopardize human life nor does it require the extensive support facilities or personnel which the manned submersible and diver require.

The underwater television field is advancing rapidly, it seems likely that improved resolution and color rendition will be seen in the near future.

4.5 MAGNETIC PARTICLE INSPECTION

This technique is the most widely used method of NDT found in the North Sea. The method is capable of detecting discontinuities at or near the surface in ferro-magnetic materials. Thorough cleaning to at least bare metal is required. To perform conventional mpi the test object is intensely magnetized, and then finely divided magnetic particles are applied to its surface. When properly oriented to the induced magnetic field, a discontinuity creates a leakage field which attracts and holds the particles to form a visible indication of the discontinuity. Magnetic field direction and character are dependent upon how the magnetizing force is applied and upon the type of current used. For best sensitivity, the magnetizing current must flow in a direction parallel to the principal direction of the expected defect. Alternating, direct, or half-wave direct current may be used for the location of surface defects. Half-wave direct current is most effective for locating subsurface defects. Magnetic particles may be applied dry or as a wet suspension in a liquid. Colored dry powders are advantageous when testing for subsurface defects and when testing objects which have rough surfaces, such as castings, forgings, and weldments. Wet particles are preferred for detection of very fine cracks, such as fatigue or grinding cracks. Fluorescent wet particles are used to inspect complex objects with the aid of ultraviolet light. Application of particles while the magnetizing current is on (continuous method) produces stronger indications than is obtained if the particles are applied after the current is shut off (residual method). Interpretation of subsurface-defect indications requires considerable experience (28).

There is no underwater mpi system which the surveyor can obtain "off the shelf". All systems in use were either designed and built from the ground up, or are combinations of conventional components (some for surface work, others for underwater application) modified and packaged for use underwater. All known mpi systems are designed for diver application. It is possible that the ADS operator might be capable of performing mpi with the present techniques; it is inconceivable that a manned submersible or RCV operator could use any of these techniques without major modifications.

While the principles of all mpi techniques are similar, the actual approach differs from surveyor-to-surveyor. Consequently there is no single technique that is truely representative of the overall field. The following description outlines the approach Det Norske Veritas employs to mpi, It should be noted that others vary in their approach to the same measurement.

The DNV method involves thorough cleaning and subsequent magnetizing of the area to be examined. This is followed by applying a liquid suspension (water; liquid detergent; iron filings) of ferro-magnetic particles to the magnetized area. If there is a crack in the surface the magnetic particles will deposit themselves along the crack due to the leakage in the magnetic flux at the discontinuity in the material (29). To improve the indication given by the magnetic particles the liquid is mixed with a fluorescent agent. An ultraviolet light (black light) source is used to produce better contrast between the particles gathering along the discontinuity and the dark surroundings. If a discontinuity is discovered it is recorded photographically or on TV. In practice the current is impressed and the liquid suspension released during the same operation; sufficient residual magnetism remains to employ the black light after the current is shut off. It is common practice to punch-mark the discontinuity in order to establish a reference to observe subsequent growth. It may also be necessary to determine the depth of the discontinuity; if so, a grinding wheel is used to grind out the crack for measurement. To lessen the potential for corrosion in the crack it may also be necessary to completely grind out the entire crack. The mpi system is presently operable to 100m depth.

The DNV system is quite large and complex. The entire underwater portion is housed in a metallic cage and weighs 1.5 tons (dry). An articulated crane is required to launch/retrieve the unit and to hold it at the working depth. The cage encloses: a transformer; a magnetic ink container; and a compressed air bottle. Leading from the cage are: a working light; a black light and the magnetic prod. An electric motor inside the magnetic ink container has baffles which prevent settlement of the magnetic particles during operation. The compressed air is used as the propellant force for the magnetic ink. Two smaller units have also been designed and constructed by DNV in which permanent magnets are used to produce the magnetic field. These are mainly for use on flat surfaces and where it is impractical to use the large unit.

An mpi method employed by B.I.X. differs in that the magnetic particle reservoir, compressed air tank and power source remain on the surface and are supplied by hose and cable to the diver. Defect indications through mpi are confirmed or rejected by the removal of 0.8mm (0.03 in.) of surface material and re-testing.

Two other instruments utilizing magnetic properties for NDT were revealed: a Magnetographic Method, and a method using an Fe Depth Meter. The following describes these techniques.

4.5.1 The Magnetographic Method

The Magnetographic method is built and patented by Magnetische Prufanlagen GmbH, Reutlingen, West Germany. The physical principle of the method is similar to mpi, in that, the technique utilizes flux leakage emanating from a discontinuity when the area has been magnetized. Whereas the discontinuity is detected by the accumulation of magnetized particles in the mpi technique, in the Magnetographic technique it is detected and stored permanently on magnetic tape (30, 31, and personal communication with Hr. M. Forster). The tape is then taken to the surface where it is processed, the signals or signature can be displayed on an oscilloscope or reproduced on a strip chart where the results can be interpreted by a qualified technician. The record obtained permits measurements of length and depth of defect. The test area must be thoroughly cleaned prior to testing. There is no depth limit on this technique.

The Magnetographic method has been used for over ten years in the steel industry for billet testing and continuous weld testing on tubes. A preselectable defect size indicator can be used to eliminate all indications considered unimportant. Since the evaluation is electronically performed, signal enhancement procedures can be employed to investigate details more closely.

The test procedure is relatively simple. After cleaning, the diver lays a pre-identified tape over the area to be tested. A magnetization unit -- consisting of: a) a flexible belt, or b) a hand-held, roller-type head -- is laid or pushed over the tape. In the former instance the magnetization belt is activated for 1 to 2 seconds; in the latter instance the roller head activates as it is rolled over the tape. Application of the belt or roller head is governed by the accessibility of the weld under inspection. The Magnetographic method was used to investigate four platforms in the Danish sector of the North Sea in the Summer of 1977.

This technique, like the mpi techniques, is designed to be used by a diver. There is possibility, according to reference (31), that the Magnetographic method can be applied by submersible manipulators.

4.5.2 Fe Depth Meter

The Fe Depth Meter is used to locate and measure the depth of steel reinforcement - or any magnetic material - in concrete structures. The unit is manufactured by C.N.S. Instruments Ltd., London and is presently limited to 91m depth. The underwater version is designed for diver application, but it has been modified and used from an RCV.

A magnetic field is generated between two poles at either end of a hand-held probe shaped akin to a telephone receiver. A field is created. The meter measures any disturbance caused by magnetic material passing within the magnetic field generated by the probe. The magnitude of the disturbance is indicated on the instrument meter which may be calibrated to read directly in bar size and distance of the reinforcing bar from the probe.

The following specifications are for the surface unit. In salt water the unit has slight positive buoyancy.

Dimensions	340mm x 295mm x 125mm (13 3/8 in. x 11 5/8 in. x 4 7/8 in.)
Weight	5.6kg (12.5 lbs)
Power Source	Rechargeable Storage Battery with built in charger.
Battery Life	8 hours continuous operation after full discharge/charge cycle recharge time 3 1/2 hours.

Operating Temperature Range	-1°C - +43°C
Storage Temperature Range	-18°C - +60°C
Detection Range, 16mm dia. bar	Max. 200mm, Min. 6mm with spacer
Bar Size	5 Calibrated ranges, 10mm to 40mm dia. (3/8 in. - 2 in.)
Bar Size Measurement Accuracy	±3mm or ±1/8 in.

A clean surface is required for highest accuracy from the Fe Depth Meter. Data is presented in an analog format; hence it is necessary for the operator to either communicate his readings to the surface or record them by hand at the time. The technique can be used as a measure of concrete erosion, or as a measure of reinforcement corrosion. It is advisable to know the diameter of the reinforcing bar prior to the measurement, although this diameter can be estimated through techniques supplied by the manufacturer. The Fe Depth Meter could be made for application from an ADS submersible or RCV with minor modifications. In such applications the problem of gaining adequate stability to conduct the measurement has been addressed by employing magnetic clamping devices which would hold the vehicle to the structure. The potential obstacle to this approach is that the magnetization induced by the clamps might adversely affect the magnetization induced by the prod.

4.6 ULTRASONIC TESTING

Ultrasonic NDT methods are employed underwater to detect and locate discontinuities or flaws and to measure thickness in steel, concrete and wooden structures (or any material which will transmit vibrational energy). Whereas mpi is primarily a technique for detecting surficial defects, ultrasonics is capable of detecting internal material defects. Like mpi, ultrasonics also requires a clean, bare surface for highest accuracy results.

In the ultrasonic method an electric pulse is generated in the test instrument and transmitted to a transducer which converts the electric pulse into mechanical vibrations. The vibrations are transmitted into the object being tested where they are scattered, attenuated, reflected or resonated. A portion of this energy returns to the transducer where it is reconverted to electrical energy and transmitted to the test instrument where it is amplified and displayed, either digitally or on a cathode ray tube. Interpretation of the data for defect presence, sizing, and significance must be conducted by highly skilled ultrasonic NDT technicians. All materials have a characteristic sound velocity which must be known for interpretation purposes, calibration blocks containing variously-sized holes may be employed _in situ_ to calibrate the test instrument. The sound frequency emitted by the transducer for metals testing is high, generally in the range of 3.5 to 5 MHz. For concrete and wood testing it is lower and ranges from 20 kHz to 250 kHz.

Two different test techniques are used in ultrasonic NDT: Resonance techniques and pulse techniques. Resonance techniques are employed for measurement of test object thickness by measuring from one side only.

Pulse techniques are used for flaw detection and may be classified as pulse echo wherein a single (transmit/receive) transducer is used, or through transmission wherein two transducers (one transmitter; one receiver) are employed. For underwater testing the pulse echo or single transducer technique is used exclusively. Additionally, two testing methods are used: immersion and contact. In immersion testing the transducer is separated from the object. In contact testing the transducer is placed directly against the test object, contact testing is used in offshore inspections.

There are numerous manufacturers of ultrasonic NDT equipment in the U.S., and all, except one, are primarily designed for surface application. The exception is the SUIS III, produced by Sylvester Underseas Inspection, which will be discussed later. Specification brochures for ultrasonic and other NDT instruments are contained in Appendix VI.

While there are differences in details, most U.S. and Canadian ultrasonic instruments provide the test unit which includes a CRT display and an immersible transducer. The transducer is carried to the job site by a diver where he applies it to the area in question. Generally the diver's helmet is equipped with a closed circuit TV which monitors the area in which he is applying the probe. By monitoring his actions on the surface he can be directed, by underwater telephone, in his work. Such monitoring also provides the surface technician with information regarding placement and orientation of the probe. The diver does not see the results of his work, all data is displayed on the surface CRT where it can be photographed if a record is necessary.

Thickness measurements are conducted in the same fashion, but in one instance, Can-Dive Oceaneering, the measurement result is recorded on the surface. Also, Can-Dive has equipped the transducer with a light that only flashes when a positive contact has been made.

4.6.1 SUIS III

Sylvester Underseas Inspection's SUIS III is equipped with two transducers: one is a conventional transducer (5 MHz) for thickness measurements; the second is a transducer that is shaped to transmit its pulse at 70 degrees to the vertical and is used for detection of flaws or pitting. A digital display is obtained for thickness measurements, while an A-scan (CRT) presentation is used for flaw detection. The diver's helmet has also been modified to work with the SUIS III; it supports a TV camera, a light and a small TV monitor. The helmet-mounted TV monitor is directly atop the diver's head and a mirror, angled downward, permits the diver to view the TV monitor which is displaying the same picture that the surface test unit is seeing. The surface test unit (a split screen) displays both the results of the diver's transducer measurements and the area being televised by the diver. Consequently, the surface can concurrently see what data the diver is getting and what is the orientation/location of the transducer. This graphic display is relayed back to the diver to allow him to see his results also. As a consequence, communication problems are reduced to a minimum. The surface data can also be stored on video tape for subsequent replay. An additional feature of this system is that directions (via sketches or graphs) can be televised to the diver and read by him through his helmet-mounted, monitor/mirror system.

Thickness measurements on a flat steel plate to accuracies of 1.5mm (0.06 in.) at 5 KHz and 5mm (0.2 in.) at 1 MHz are representative of accuracies obtainable from ultrasonic NDT units available in the U.S. Flaw detection accuracies vary but no dissatisfaction was found with the measurement, the most critical area is in interpreting the significance and origin of the flaw.

4.6.2 Wells-Krautkramer DM 1 and USM 2

Two ultrasonic NDT units were identified in the North Sea community which are specifically designed for underwater application; both are manufactured by Wells-Krautkramer Ltd, Hertfordshire, England. One unit, the DM 1 is for thickness measurements; the other unit, USM 2, is for flaw detection. Both units are designed to be diver-held, both are self-powered and operate completely free of the surface. The specifications for both units, as designed for surface operations, are contained in Appendix VI.

The DM 1 is capable of operating to 242m (800 ft) depth and permits thickness measurements from 1.2mm (0.05 in.) to 600mm (2.4 in.) in steel with an accuracy of 0.1mm. Thickness measurements are digitally displayed; consequently, the diver either records the values by hand or relays them verbally to the surface. The pressure-resistant, aluminum housing which encapsulates the test unit is fitted with a 2m (6.6 ft) lead to which is attached the probe (i.e., transducer). Underwater exchange of probes is not possible.

The ultrasonic flaw detector (USM 2) is also encapsulated within an aluminum, pressure-resistant housing which permits operations to 70m (230 ft). The USM 2 is designed such that different types of probes can be exchanged while the device is underwater, and can be used in a pulse-echo mode or through transmission mode. Data display is on a CRT, there are no provisions for recording the display.

4.6.3 PUNDIT

Ultrasonic NDT techniques have been employed experimentally for concrete testing. One particular unit, PUNDIT (Portable Ultrasonic Non-destructive Digital Indicating Tester) is manufactured by C.N.S. Electronics Ltd, London and reportedly has been reconfigured for application from an RCV. The PUNDIT system uses the through transmission technique, and consists of the testing unit and one transmitting and one receiving transducer. A variety of transducers are available for frequencies ranging from 24 kHz to 1 MHz, but 50 kHz is considered most appropriate for concrete testing. The data obtained is a digital display of pulse velocity between transmitter and receiver (the exact distance between the two transducers must be known). The indirect transducer arrangement (both transducers on the same plane) is most applicable to testing underwater concrete structures than is the direct arrangement (transmitter and receiver on opposite sides of the test specimen) since access to both the internal and external side of the structure is not feasible. Since the ultrasonic pulse is scattered by discontinuities or large air voids in the concrete, the PUNDIT will indicate the time taken by the pulse which circumvents the void by the quickest route.

The PUNDIT method may be applied to plain, reinforced and prestressed concrete whether it is precast or cast _in situ_. The measurement of pulse velocity may be used to determine: concrete homogeneity; the presence of voids, cracks or other imperfections; changes due to time (i.e., hydration) or chemical attack, and concrete quality relative to standards which can be related to strength. The correlation between strength and pulse velocity depends on concrete composition. It is advisable to establish a correlation for each mix used. This can be done by making bars with different water-cement ratios and correlating the pulse velocity along the bar axis with both the modulus of rupture and the equivalent cube strength at ages from a few days to one month. Interpretation of PUNDIT data is a chore calling for a great deal of knowledge and experience. While the technique has been used for some time in surface measurements, its application underwater is still experimental.

Development of self-contained, portable, underwater, ultrasonic NDT units with data display available only to the operator, such as described above, virtually demands that the operator be NDT-qualified; particularly since only he can see the results of the tests. It is, of course, possible to monitor the diver with closed circuit TV and to record his observations on the surface or in a lockout submersible. If such monitoring/directing techniques are employed, then there would seem to be no need for the test unit to be portable and self-contained or for the data to be displayed only to the diver. It would seem more improbable that an unqualified diver would be deployed to conduct ultrasonic flaw detection tests unless there is a means of recording the data and monitoring his procedures.

4.6.4 Acoustic Holography

The French-based firm Intersub (International Submarine Services) of Marseilles has awarded a contract to Holosonics, Inc., Richland, Washington for development of an ultrasonic flaw detection technique utilizing the principles of acoustic holography. A prototype, diver-held model for deployment from a lockout submersible is scheduled for field testing in the Spring of 1978.

As the name implies, holography records all of the information (amplitude, time and phase) from the sensing signal, and, through the holography process, provides a full three-dimensional image of an object. The process may be applied to sound or acoustical signals in order to visualize the interior structure of an opaque object (i.e., a weldment) by the process of acoustical holography.

Holosonics, Inc. has spent the last seven years performing acoustic holographic inspection of welds and parent materials in nuclear reactors, nuclear submarines, aircraft wing structures, and other areas.

It is Holosonics' objective to apply this technology to underwater weldment inspection so that the results will not only meet the objectives of the inspection procedures, but will provide additional information which is not otherwise available from other means.

The Holosonics system will be designed for application by submersible manipulation systems or manually by divers from a lockout vehicle. The flaws can be viewed in real-time by an inspector and permanent records kept on videotape or magnetic tape or hard copy prints. Flaws can be located, magnified for close examination and then viewed in three-dimension by utilizing a memory system. The diver's task is to locate and clean the area to be inspected.

The equipment includes:

- a gun probe, hand-held by the diver;
- a chest-pack, in the vicinity of the diver, containing the electronic scanner for an array of transducer elements;
- an operator display, a digital cassette recorder and a video recorder (in the submersible);
- and an operator display and computer for offline reprocessing and interpretation of results (aboard the support vessel).

The principle is to record the Ultrasonic image obtained by focusing the Ultrasonic beam on several planes (probably 32) and scanning in a two-dimension mode. Thus, an area of 150mm x 150mm x 300mm (6 in. x 6 in. x 12 in.) is explored and recorded in memory. The operating frequency is 2 MHz.

The system will include:

- real-time imaging
- electronic scanning
- variable focal length
- automatic sweep focus
- manual focus
- magnification zoom
- three-dimensional display
- interchangeable scanning heads
- matrix array of multiple elements
- light emitting diode array for diver monitor

The equipment will have general performance specifications as follows:

a. Diver-held inspection gun

Scanning array with variable focus and electronics housed in pistol grip design gun. Number of sensor elements will be 160.

Inspection gun will also house a miniature TV camera and light, and an LED display to indicate to the diver the location of a defect within the inspected volume.

Physical specifications of the gun:

. Weight: 0.7kg in water, 2.5kg in air
. Flexibility of the array will adapt the gun to pipe diameters higher than 61cm (24 in.)
. Operational pressure rating to 212m (700 ft) of water
. TV camera focuses from 76mm (2 in.) to infinity
. Diver display: 25mm x 25mm (1 in. x 1 in.) array of light emitting diodes
. Power consumption: 15 watts

b. Chest pack

The chest pack contains mainly the power amplifiers driving the elementary transducers of the gun array and the circuitry processing the received signals.

Specifications:

. Operational depth: 212m (700 ft)
. Weight: 10kg (22 lbs) in air - buoyant in water
. Size: 25cm x 30cm x 12 cm (10 in. x 12 in. x 5 in.)
. Power consumption: 75 watts

c. Electronic circuitry fitted aboard the submersible and support vessel

The electronic circuitry itself is contained in two separate boxes and the TV monitor is mounted in a separate frame.

d. Operating principles

The surveyor operating the system inside the submersible has to achieve two main tasks:

- To control and assist the diver to position the gun on the various parts of the weld under inspection;
- To operate the system, control the quality of the acoustic data stored in the memory and record the more significant exposures on tape (digital and video).

The operator must have a good overview of the scene and will sit in the viewport. The general procedure to perform the inspection of a given weld segment is as follows:

- The gun is properly positioned by the diver in front of marks previously installed around the weld area. The operator controls the gun position through the TV camera information displayed on the right hand side of the TV screen.

- The operator initiates the acoustic scanning of the weld. Then the acoustic beam encounters a defect, the corresponding time of flight and the acoustic intensity are stored in a main memory, at the address corresponding to the point of focus in the inspected volume. These data are simultaneously processed to build B and C scan images of the weld. The results are stored in an auxiliary memory which is continuously interrogated to build the video image on the left hand side of the TV screen.

- If some defect appears on the TV screen, the operator can switch the 3D viewing on. Then the data contained in the main memory are used to build the projection of the volume on a plane of the operator's choice. The display of this projection on the TV screen is obtained via the auxiliary memory. The operator can then make a decision on the quality of the acoustic data contained in the main memory, and store them on a magnetic tape.

The operator may also ask the diver to improve the gun position and take another set of acoustic data.

The light emitting diode array (LED display) will help the diver in positioning his gun with respect to the defects (C scan representation on LED display).

When back at the surface, the contents of the magnetic tape can be restored in the main memory and 3D viewing of the different weld segment reconstituted to perform a more careful examination of the weld. Hard copies of the most significant defects can be provided, together with an image of the external appearance of the weld obtained through the TV camera, including the position of reference marks.

e. Design specifications

Acquisition time for one 3D image will be less than 1 second.

Power supply and equipment design will be for acceptance of either 24 VDC or 120 VDC from the submersible. A 15% voltage variation may be present.

Electronic components tropicalised and splash proof.
Power: 50/60 cycles 115 volts.
Power consumption: 500 watts.

4.7 CORROSION POTENTIAL MEASUREMENTS

Virtually all inspection requirements identify the need for annual cathodic potential (cp) measurements. The measurement is taken to monitor the effectiveness (need for anode replacement) of the cathodic protection system. The instrument employed is some form of half cell which measures the potential between the structure and the ambient sea water.

Three instruments were discovered which are used underwater: the Anode Analyzer produced by Sabines Industries, Inc., Long Beach, California; the Bathycorrometer produced by Corrosion and Welding Engineering Ltd., Sidcup, Kent, England; and a submersible-mounted device modified for underwater use by Intersub Development, Paris. The first two instruments are designed to be diver-held, but can be readily modified for application from a submersible or an RCV. The diver-held instruments provide an analogue readout; consequently, the operator must either record his observations in situ or transmit them to the surface. The procedure simply involves making contact to the structure with the probe and reading the display. Minimal cleaning of the structure is required for application. The reference half cell is Silver/Silver chloride in both instruments. The Sabins instrument also includes a saturated calomel and Copper/Copper sulphate half-cell. Modifications to the next generation Bathycorrometer will include a data storage feature.

Intersub Developpement an affiliate of Intersub, Marseille, has developed a range of equipment for cathodic protection system measurements which can be adapted to operations on pipelines and/or platform bracings and provide potential and current measurements. The equipment is designed for application by a submersible or a diver.

The equipment for cp measurements includes: 1) a point-probe, either single or double, to achieve a good quality ground contact to the metal under test; 2) a Ponselle Silver/Silver Chloride reference electrode; and 3) an electronic panel. For steel platform inspection a two point probe is used in order to validate the cp reading by a resistance measurement.

The operating procedure is as follows.

- The submersible will locate the measurement location.
- The measurement location will be cleaned if there is excessive growth (not usually required).
- The probe is placed at the desired location on the structure using the manipulator (or it can be attached directly to the submersible's bow-guard).
- The submersible is put in forward motion so as to press the probe against the measurement point.
- Once a good electrical contact has been obtained the data is automatically obtained and recorded, as well as the time of acquisition.
- The location of the measurement point is recorded according to what positioning system is being used.

One measurement takes approximately one minute, not including the possible cleaning operation. This method, and all probe methods, can only be used on uncoated platforms. If a heavy coating has been applied to the platform and a two point probe cannot be used it is necessary to obtain a ground connection of some sort to the platform in order to take the readings.

The cp readings are obtained by using a Silver/Silver Chloride reference electrode contained in a protective housing. The waterproof connection provides for up to 100 meters depth of operation in an operating temperature of 0 to 60 degrees C. A measurement accuracy of better than 1 millivolt is advertised.

An electronic panel within the submersible performs two functions: 1) to evaluate the quality of the electrical contact between the probe and the steel structure by electrical resistance measurement between the two probes (in the case of the two probe device); and 2) if the resistance between the two probes is small enough (or if there is only one probe), the cp measurement is validated and the DC voltage is measured, using a digital high impedance voltmeter. The measurements can be recorded on a digital recorder (a digital/analog conversion is also possible) in order to obtain a complete log.

4.7.1 CP Current Readings

The equipment for cp current measurement consists of a current probe that must be clamped around the electrical connection in which the current to be measured is flowing. The clamping operation can be made automatically with the manipulating arm of the submersible. The closure of the magnetic circuit is hydraulically actuated from inside the submersible.

The DC current flowing through the probe creates a magnetic field in the magnetic circuit of the system. A measurement current is then applied to a winding around the circuit and cancels out the magnetic field created by the DC current under evaluation. The value of the measurement current then is digitally displayed. Performance specifications are as follows:

Current range:	0 to 40 Amps.	
Accuracy:	-1 Amps.	
Noise level:	-03 Amps.	
Demagnetization:	5 Oersted.	
Calibration current:	10 Amps.	
Response time:	1 Sec.	
Environment:	Temperature:	0 - 50°C
	Humidity:	0 - 85%
	Depth:	0 - 300 meters.

A novel approach to underwater measurements has been developed by Anautics, Inc., Santa Ana, California which seeks to conduct cp measurements of underwater structures from the surface. The system, called the Remote Potential Reader (RPR) consists of an underwater module and a surface module.

The underwater module consists of a non-polarizing reference cell which is welded or strapped to the structure and measures the impressed voltage potential. A data encoder receives millivolt readings from the reference cell and translates them into a signal suitable for acoustic transmission. An acoustic data pinger receives input from the data encoder and transmits, on command from the surface, potential readings to the surface. An acoustic receiver/decoder "listens" for an interrogation signal from the surface. When it is interrogated it turns on the data pinger allowing it to receive information from the encoder for transmission to the surface. Other components consist of a battery pack and fuel cell charger which powers the encoder only when it has been interrogated; a battery pack to power the receiver and encoder; and a timer which momentarily switches on the receiver/decoder periodically to listen for a surface interrogation signal. A battery pack life span of seven or eight years is anticipated before it would require replacement by divers or submersibles.

The surface module consists of an omni-directional towed hydrophone which interrogates and receives signals from the subsurface data pinger. The signal is passed to a decoder which translates it into suitable display terminology. The potential reading is digitally displayed where it can be permanently recorded with appropriate date/time/location data.

In practice the surface equipment would be installed on a suitable vessel and then traverse the pipeline or structure. The interrogator would periodically send out an activating signal, the subsurface component would acquire the surface signal and respond with a signal that identifies the location and provides the potential reading. A signal range of at least 1km is minimal.

At this time the Remote Potential Reader has been field tested; it is not in commercial use. The Anautics Corporation is actively seeking a commercial outlet for the RPR.

4.8 RADIOGRAPHY

As applied to metals and metal fabrication processes, such as weldments and castings, radiography-on-film is used as a flaw detection technique and is often used as a basis of comparison for most other flaw detection methods. Through penetration of x-rays or gamma rays shadows are cast on the other side of "solid" objects. Voids in the material being tested permit more rays to penetrate and the shadows are recorded on photographic film. The primary underwater use of radiography is for weldment inspection. The advantages of radiographic techniques are that they permit a visual analysis of varied defects (cavities, cracks, porosity, non-metallic inclusions) and a reasonably sharp and clear image is recorded on film as permanent documentation. The technique is also applied for thickness measurements. The disadvantages are: expense; complex shapes are difficult to analyze; there is an economic limit to depth penetration; it is not sensitive to defects less than 2 percent thickness of the total metal; and it is a potentially hazardous operation requiring special enclosures and stringent safety precautions (32; 33).

While radiographic techniques are standard and common surface NDT procedures, they are not a common underwater procedure. Several service companies do perform this test (e.g., Taylor Diving and Salvage, Ocean Systems Inc., Can-Dive Services Ltd, B.I.X.), details of techniques and instruments employed are generally considered proprietary.

In most instances radiographic techniques are employed in dry habitats; in this application the techniques are quite similar to surface techniques. The diver's function in radiography is to conduct the test; interpretation is done on the surface by a qualified NDT technician. In the case of Taylor Diving and Salvage Co., their divers are trained in the principles of radiography and in the use of equipment specially developed by Gamma Industries. During the operation the surface technician monitors and guides the diver. As much time is spent in instructing for safety as it is gaining quality data. The level of diver training, according to Dr. R. Parker, Gamma Industries, would be equivalent to Assistant Radiographers by comparison with standards set up by the Nuclear Regulatory Commission.

Can-Dive Services Ltd., Vancouver, B.C. has emplyed radiographic techniques on underwater portions of metallic structures such as docks, grain elevators and pulp mills. The technique they have developed is for flat plates, not tubular structures. The radioactive source employed is Radium 192. The film cassette is carried in a heat-sealed plastic bag which is held to the structure by magnets. The radioactive source is positioned approximately 30cm (12 in.) from the structure on the side opposite the film. Since sea water will quickly absorb the radiation (15cm or 6 in. of water is considered equal to about 2.54cm of steel), a plastic box is set between source and structure. The box is designed such that it can be totally evacuated of sea water by the diver's air. When the box has been evacuated the test is conducted. The film is developed and read on the surface. The system is capable of being used only by a diver, but it is possible that it could be conducted by an ADS operator.

B.I.X. employs radiographic techniques in conjunction with and to supplement other methods of inspection. For example, if a defect located using ultrasonics or mpi is found to extend in the parent metal, a radiograph may be obtained for surface evaluation where a permanent record of weld integrity is essential.

If this technique is required it is carried out as follows:

A gamma source contained inside a B.I.X. Pot is lowered to the diver after he has placed the underwater cassettes containing either Industrex 'D' 'C' or 'M' industrial x-ray film, penotrameters and appropriate indents into position. The gamma source is held in position by means of a magnetic castle. A lead shield is placed around the cassette to reduce back scatter to a minimum.

High quality radiographs have reportedly been produced by B.I.X. using this technique in depths of up to 61m (200 ft) using gamma isotopes Cobalt 60 for thicker sections or Iridium 192 on the normal thickness range of mild steels. If required on single-wall, single-image shots, the water can be displaced between the source and film to reduce the exposure time to equal that of surface conditions. Results are processed on location.

4.9 INSPECTION/TESTING SUMMARY

There is no shortage of capabilities to deploy an NDT instrument or conduct a visual inspection at the present installation depth of any fixed structure. Of the four primary deployment capabilities (diver, submersible, RCV, ADS), the diver is most frequently used.

The deepest known fixed structure to date is 307m (the Cognac platform in the Gulf of Mexico). This depth - and greater - can be reached by divers, 501m has been demonstrated. Present and future drilling projects are at greater depths than the diver can now reach. Consequently, the time is not too distant until NDT and inspection will have to be conducted by manned submersibles, RCV's or ADS's.

Location of a specific work site on a structure is done by visual identification. Without some degree of underwater visibility locating the precise work site would be virtually impossible. Acoustic tracking techniques are not fully reliable owing to the sound path interference by the structure itself. Positioning in a concrete structure is more difficult than on a steel structure since the concrete is monolithic in appearance and visual reference points are not always available.

Structure cleaning to bare metal prior to inspection/testing is required for all NDT techniques. Cleaning instruments to remove marine fouling organisms consists of a wide variety of brushes, grinders, chipping hammers, etc., the high pressure water jet is generally applied as the ultimate solution. While most of these instruments have been modified for application by mechanical manipulators, the water jet has not. In its present form the water jet can only be employed by a diver. "Clean" is a relative term that does not define whether the object to be tested must be bare metal or bright metal. To obtain the latter condition it may be necessary to use abrasives which might remove some of the material under investigation. The cleaning chore is frequently more time-consuming and laborious than is the NDT procedure itself.

Five techniques for underwater inspection/testing of steel and concrete structures are presently being employed: visual inspection (with photographic/TV documentation); magnetic particle inspection (and techniques using principles of magnetics); ultrasonics; corrosion-potential measurements and radiography. All but a few of the testing techniques are designed to be hand-held, all depend upon some degree of underwater visibility for application, and all are essentially surface designed techniques repackaged for underwater use.

Visual inspection techniques (direct or remote) can be pursued with divers, submersibles, RCV's and ADS's to detect debris accumulation, scour and gross structural damage and material changes. Pitting and corrosion can also be detected, but the size resolution of pits and/or cracks which can be seen by each capability is not uniform and will generally require cleaning prior to the inspection. Documentation of observations is made by verbal communications, handwritten notes and sketches, and with still photography and closed circuit TV, depending upon the inspection technique employed. Still photography provides the best resolution and color rendition, but advances in the TV industry may soon change this situation.

Magnetic particle inspection is confined to the North Sea-bordering countries. Present techniques involve cumbersome support equipment and are most difficult to apply in the splash zone. A new technique, called the Magnetographic method, has been manufactured and employed in the field. The method obtains the magnetic signature of a surface crack or defect on a magnetic tape which can be activated by a magnetization yoke laid over the tape or by a hand-held magnetization roller. The resulting tape is processed on the surface to produce a permanent record of defect length, width and depth.

An Fe Depth meter has been encapsulated for underwater use on concrete structures. The device is hand-held and generates a magnetic field that can measure the distance (field intensity) from the outside of a concrete structure to the reinforcing bars; thereby providing an indication of concrete erosion or corrosion of the reinforcing bar. The technique has been used for some years on surface structures; recent modifications have encapsulated the meter for application by a diver or a mechanical manipulator.

Ultrasonic NDT techniques for thickness measurement and flaw detection are available from a variety of manufacturers. Most off-the-shelf devices are designed for surface application and modified for subsurface application by divers. Thorough cleaning of the test object is required. Measurement accuracies underwater compare favorably with surface accuracies. Data is either displayed on the surface or read by the diver in situ. Recent manufacture in the U.S. of the SUIS III permits ultrasonic thickness measurements and flaw detection which displays data obtained to both the diver and the surface in real-time; a video and digital record is obtainable. The French-based firm of Intersub is funding development of a diver-held acoustic holography technique that will obtain a three-dimensional representation of a buried flaw. The first unit is scheduled for field testing in the Spring of 1978.

Radiographic techniques for underwater NDT are not in common use. These techniques are employed in a dry habitat or in the ambient environment. The future application of this technique toward routine underwater inspection is unclear. Problems of cost, complexity and safety considerations seem to indicate that alternate techniques may be more desirable for routine platform inspection.

5.0 CAPABILITIES - MONITORING

The previous chapter dealt with techniques for direct inspection and testing of fixed structures. In this chapter techniques are discussed which are designed to monitor the platform's structural integrity without requiring the inspector to enter the water or dispatch an underwater vehicle on his behalf.

Ten candidate monitoring techniques are identified in reference (34) as potential and feasible candidates for structural integrity monitoring:

1. Attitude Measurement
2. Systems of Witness Device
3. Strain Gage Systems
4. Leak Testing of Tubular Members
5. Ultrasonic Lamb Wave Systems in Steep Structures
6. Television Scanning
7. Low Frequency Ultrasonic Testing (concrete structures)
8. Acoustic Emission to Size and Locate Growing Cracks
9. Calculation of Dynamic Response Function to Wave Motion
10. Coherence and Cross Correlation Techniques

Of these ten techniques only two were identified in this study which appeared to be viable candidates: 8) Acoustic Emission Monitoring and 9) Vibration Analysis Monitoring. This is not to imply that no other monitoring techniques are in use or are worthwhile, it is simply an expression of the evidence gained during the course of this study. It is possible that other techniques are employed, but only these two were identified. Chapter 2 identified one platform owner who has fixed strain gages to his structure which are monitored for changes. Nothing regarding results or objectives of this technique is publically available.

5.1 ACOUSTIC EMISSION MONITORING

Acoustic emission is defined as a class of phenomena whereby transient elastic waves are generated by rapid release of energy from a localized source or sources within a material (35). Acoustic emission analysis technology utilizes the minute acoustic emissions produced by discontinuity regions in materials under stress to analyze a structure for physical integrity. The acoustic emissions are given off from discontinuities under stress conditions; to use this technology it is necessary that stress be applied to the structure. In monitoring an offshore platform for structural defects the cyclic stress imposed on the structure by wave motion provides adequate stress for analysis (36).

The earliest application of acoustic emission techniques appears to be in early 1966 and was concerned with post-weld cracking (35). Today the technique is used to monitor pressure vessels, wire ropes, rock movements, aircraft structures, and as a survey tool to test the integrity of buried gas pipelines (37). The first offshore application of this technique began in about 1975. While the technology is hardly more than a decade old, the technique has been used by man for years, for example: the roll of thunder, a cracking tree limb, the screeching of tires, etc.

Two industrial firms in the U.S. produce acoustic emission systems for use on offshore structures: Dunegan/Endevco, San Juan Capistrano, California, and Exxon Nuclear Co., Inc., Richland, Washington. No industrial firms in the North Sea-bordering countries are known to be manufacturers of acoustic emission monitoring systems. Unit Inspection Co., Swansea, Wales has a test program utilizing the Dunegan/Endevco system, but its future plans in this area are not known. Significantly, at this writing there is no U.S. platform which uses acoustic emission monitoring techniques on a routine basis. All applications to date have been for experimental and demonstration purposes.

The sensing equipment consists of sensitive piezoelectric transducers attached to the structure underwater. Cables transfer the received signals to the platform deck where they are amplified and conditioned electronically and subsequently processed by special computers to identify the location and significance of the discontinuities.

Positioning or locating the crack is accomplished by measuring the time of arrival of the acoustic emission wave (a point source) to each transducer, and the difference in arrival time to each transducer can be used to calculate the source location. Since there are a wide variety of acoustic point sources on and around a producing platform (production operations, ship traffic, divers, marine organisms, rain, etc.) special techniques have been devised to discriminate valid from extraneous noise signals. Dunegan (35) described three such techniques: Spatial Filtering (the capability of accepting signals coming only from specific areas of interest); Parametric Filtering (to accept only signals that correlate in time with the peak load on the specimen), and Distribution Analysis (crack growth rate measurement as a function of signal amplitude distribution).

Both the Exxon system (trademarked as ACOUST) and the Dunegan/Endevco system can be instrumented to conduct the signal analysis aboard a platform or to transmit the data ashore for analysis. Monitoring need not be continuous; it can be preformed periodically at specified intervals. Whatever the monitoring/analysis format selected, the transducers must either remain attached to the structure or re-attached for a subsequent monitoring. The most convenient and practical arrangement is to permanently install the transducers and cabling in housings and conduits, respectively, prior to installation of the structure.

The Exxon system was tested in the North Sea in 1975 and in the Gulf of Mexico in 1976, a report of both tests is given in references (36) and (38). A description of the Dunegan/Endevco system is contained in reference (35), results of the North Sea tests in conjunction with Unit Inspection Ltd. are not available at this time.

Since these systems have been available for only a short period of time, and since they have only been used in tests and demonstrations, it is impossible at this time to ascertain their effectiveness. The only obvious shortcoming of either system is the fact that the transducers and cabling must be retrofitted onto existing platforms, a procedure requiring the expense of divers. The number of transducers can be minimized if only the nodes of a structure are monitored. Exxon Nuclear estimates that on an 8 legged production platform (depth not given) a minimum of 60 transducers would be required to conduct the spatial and parametric filtering and distribution analysis described above. It is significant that for a final inspection of the Exxon Nuclear, Gulf of Mexico tests divers were used to determine the nature and source of the acoustic emission. This is not a shortcoming exclusive of their system, The Dunegan/Endevco system would be required to resort to the same means for final identification of the nature and cause of a recordable discontinuity.

J. F. Borst (39), Dunegan/Endevco, related some of the unanswered questions in acoustic emission monitoring when applied to nuclear reactors; the same can be applied to offshore structures. According to Borst, acoustic emission reports: a) that a defect exists, and b) whether it is growing. Unlike other NDT techniques, it can tell nothing concerning the defect's size. Consequently, it is virtually impossible at present to develop a standard of performance. A further shortcoming, except under controlled laboratory conditions, is that acoustic emission techniques cannot tell what is happening or how serious it might be. Furthermore, there is not sufficient experience to demonstrate conclusively that the equipment can be installed and operated for many years. Comparisons of tests from installation to installation are problematical due to lack of an absolute calibration procedure. Borst reports that this problem has been recognized by the ASME and similar activities trying to codify acoustic emission testing, and work is now underway at the U.S. National Bureau of Standards to develop such calibration procedures.

5.2 VIBRATION ANALYSIS MONITORING

Vibration analysis monitoring, similar to acoustic emission monitoring, does not depend upon a diver or underwater vehicle. Unlike acoustic emission monitoring, this method does not require installation of equipment underwater, nor does it require permanent installation of its monitoring/recording instrumentation.

According to Stiansen (7; 40), the theoretical basis of the vibration analysis method is the fact that each offshore structure, regardless of type, has natural vibration modes that are continually excited by the wind and wave forces of the environment. These modes are dependent on the characteristics of each structure and not on the excitation and they are peculiar to each structure. If the mass of a structure remains unchanged, the reduction in its stiffness, caused by possible damage inflicted to its load-carrying members, will result in shifting of its vibration characteristics. Specifically, the fundamental frequencies will be lower while the frequencies of the higher overtones may change to higher or lower values.

Eleven parameters have been identified which, if they vary, result in measurable frequency changes: the presence of concrete in the main legs, marine growth, corrosion, fabrication tolerances, additional deck masses and restraint of some deck rotational degrees of freedom result in small frequency changes. Entrained water and fluids in platform tanks result in more significant frequency changes. Breakage of members, measurement of the sediment foundation and varying sediment characteristics results in the greatest frequency changes (7).

The measurements are taken by an instrumentation package consisting of the sensors (highly sensitive accelerometers) and a recording device. Initially, a vibration "signature" is obtained; this signature is then compared with subsequent vibration responses. The method can be applied to confirm structural damage below (and above) the waterline and may also be used to detect microcracks in reinforced concrete.

The only practical implementation of this technique in the U.S. has been supported and conducted by the American Bureau of Shipping in conjunction with H. M. Tiedeman and Co., Greenwich, Connecticut. Early in the program J. K. Vandiver of the Massachusetts Institute of Technology formed a part of the development group. Detection of structural factors by vibration analysis is not without precedence; the technique has been employed in measuring earthquake damage in large buildings and rotating machinery. The first application of this technique offshore is reported by Vandiver (6). In May, 1974 the Coast Guard's Buzzards Bay Lighthouse Tower was struck by a 900 ton vessel. The signature of this tower had been previously obtained. Vibration analysis measurements immediately afterwards determined that no significant damage had occurred. Ultrasonic NDT by divers confirmed this conclusion. Subsequent development, by ABS, included a more extensive computer analysis combined with measurements on the Coast Guard's Ambrose Light Station. At this point in time ABS feels confident of this monitoring technique for fixed structures and is now investigating its potential for application on semi-submerged structures. ABS has no present plans to implement this technique as a part of its certification scheme, the development program was pursued to produce a technique which would be available for industrial use. Although this system has been used only on four-legged structures, ABS believes the same technique could do equally as well on an 8 or 10 legged structure.

A parallel vibrational analysis development program is being carried out in the U.K. by Structural Monitoring Limited in conjunction with the University of Glasgow (41; 42). In this program three fixed platforms in the southern North Sea belonging to BP Ltd. were monitored during a six to nine month period. The goal of the program was to extend earlier laboratory and computational studies to full scale platforms. The ultimate end-product is a reliable and unambigious inspection method which can be used for primary inspection of fixed offshore structures. The details of this program are related by Loland and Dodds in reference (41); these investigators conclude that a vibration monitoring system has been demonstrated that can be employed as a primary monitoring scheme.

In the Fall of 1977 a much larger scale, two year program of vibrational monitoring techniques began which is funded by the U.K. Department of Energy. In this program three industrial groups are involved: Structural Monitoring Ltd.; SEATEK (a consortium of English Companies) and Structural Dynamics Ltd. Each firm will instrument a different platform of varying complexity: 4, 8 and 10 legged, respectively. The same basic technique will be employed by each firm, but different methods of analysis will be used. Each firm will carry out a full dynamic analysis of each structure and then place sensors on the structure at deck level and as deep as 30m below the surface. Mini computers will be installed which may eventually be linked to parent computers ashore. The total cost of the project is estimated at $1.86 million. (43; 44; personal communication with J. Hughes, Offshore Supplies Office).

Vibrational monitoring is subject to many of the shortcomings of acoustic emission monitoring: no standards of performance; limited experience; no standards in sensing instruments. Additionally, vibrational analysis cannot determine that a crack has occurred until the crack becomes large enough to affect the structure's natural vibration frequency. Detection of a bent member depends upon whether it is a primary or secondary member, what function it plays on the structure, and the magnitude of the bend. Unlike acoustic emission, present vibrational analysis techniques cannot precisely locate the broken member, it can only provide an indication regarding where the failure might be. Also, the results of vibration analysis do not tell what is happening or to what degree. All significant measurements are only significant when compared to the previous measurement.

5.3 MONITORING SUMMARY

Monitoring techniques offer the only present potential alternative to the diver and the underwater vehicle. Although both acoustic emission and vibrational analysis techniques have been applied ashore successfully, they're appearance in the offshore industry is recent. Consequently, their acceptance as alternatives to traditional NDT techniques is yet uncertain. As far as is known, none of the certifying or classification societies have accepted these techniques as a part of any operator/owner's inspection scenario. The nature of European (particularly English) involvement in monitoring systems indicates that this is an emerging technique offering considerable potential. Certain of the advantages of these techniques are:

- A rapid, gross inspection of the entire structure can be obtained without requiring deployment of divers or underwater vehicles.
- Weather conditions do not influence ability to monitor underwater; visibility or illumination is not a limiting factor.

The acoustic emission technique might offer a means of directing a submersible or vehicle to a defect by tracking a pinger on the vehicle and directing the operator verbally. Essentially, it might be capable of working as a passive tracking system.

6.0 CAPABILITIES VS REQUIREMENTS

There are no inspection/testing requirements - written or proposed - for steel structures which cannot be satisfied with present capabilities. The only conditions under which this statement does not hold true is: 1) if there is a total lack of visibility, and 2) if a diver cannot be deployed to the work site. A third condition which might also prohibit application of present NDT techniques is the Arctic ice cap. There the problem is one of access to the structure and application of techniques within the ice zone (i.e., splash zone).

The fact that present requirements can be met with present capabilities does not imply that the latter are totally satisfactory. They are all time comsuming and expensive, and weather plays a dominant role regarding when, where and over how long a period inspection will take place. Currents, cold temperatures, water clarity and fouling organisms can dictate how accurate the measurement will be and how long it will take to conduct.

The purpose of this chapter is to identify areas where inspection/testing requirements cannot be met by existing techniques. In light of the fact that there is no area that cannot be satisfied to some degree. By today's technology, the goal of this chapter can be best attained by identifying deficiencies and/or limitations in techniques, since all known test requirements can be met. The subsequent evaluations are based, in part, on published reports of platform owners/operators; interviews with service companies, and the undersea work experience of Busby Associates. It is again emphasized that this field is dynamic; therefore, deficiencies identified herein may have been corrected during the tenure of this study.

In some instances operators have identified problem areas that have already been solved, but, due to lack of communication between supplier - servicing company - operator, the solution is unknown. For example, Capt. L.G. Buckenham, BP Petroleum Development Ltd., states (10) that absolute reliability in the inspector/diver is essential in ultrasonic flaw or thickness measurements, as no permanent record is produced except the report submitted by the diver. Yet the SUIS III ultrasonic flaw detector/thickness device manufactured by Sylvester Undersea Inspection Co., provides a recording feature on video tape or digitally. Most present NDT systems are depth limited, but this is not considered a serious deficiency, in that, there is no technological breakthrough required to upgrade these instruments for use in greater depths.

6.1 CONCRETE STRUCTURES

The requirements cited in Chapter 2 for the British and Norwegian governments apply to concrete as well as steel structures. Yet virtually all test instrument developmental efforts are aimed at steel structures. According to Browne et al (20) the total amount of steel in a concrete platform is similar to that in an equivalent steel jacket structure, but it is buried within the concrete as reinforcement or prestressing.

The problem has been recognized by the U.K. Government who commissioned two state-of-the-art reports on performance and inspection of offshore concrete structures. The first report, "Concrete in the Oceans" (45), recommends a variety of programs of which several are now underway. The second report, "Inspection, Maintenance and Repair of Concrete Offshore, Structures" (46), identified the lack of any techniques sufficiently developed for offshore inspection, and also recommended various research and development work.

The only detailed inspection requirements for concrete structures are issued by the Norwegian Petroleum Directorate. Inspection requirements are primarily all visual with photographic documentation, and include measurements of possible corrosion protection systems. One item addresses the possibility of internal inspection when it seems necessary, but it is not clear if this is an inspection of the buried steel or the internal face of the structure.

Since the only inspection requirements for concrete structures are minimal, and can be met by today's technology, capabilities in this area are equal to requirements. Browne et al (op. cit.) cite a number of potential problems with concrete structures (e.g., corrosion of steel; cracking and spalling of concrete) and note that, while concrete structures have proven extremely durable under marine conditions over their 70 year history, almost all problems occur exclusively in the splash zone. In Chapter 3 the difficulties of working in the splash zone were discussed. It is evident that weather will determine when and in what detail present inspection requirements can be conducted in the splash zone. From a U.S. point of view the concrete inspection problem is academic since there are no major concrete gravity offshore structures in deep U.S. waters and no present plans to construct any. The most likely area where major concrete structures may find application is in the form of artificial islands.

6.2 PERSONNEL

The question of whether or not the inspector/diver should be NDT-qualified to conduct the particular test he is performing is significant. In view of the fact that instruments are becoming available which are self-contained and portable, and permit the operator to work unencumbered by cables to the surface, one must question the wisdom of sending an unqualified NDT technician to perform these tests without supervision. Bullington and Loper (11) identify the qualification question as one of standardization of terms, in that, one diver's assessment of "general corrosion" can be quite different from another. Such observations, they believe, should have a precise meaning and boundaries in order to attain a uniform description of the corrosion conditions.

Most perplexing is the need, if any, of qualifications for the diver performing visual inspection. In this instance there are no known qualification standards. In many land-based visual inspections of bridges a registered professional engineer is desired. But there is a shortage of professional engineers who are trained and qualified to safely and effectively use today's saturation diving equipment. On the other hand, qualifications to this degree may be considered unnecessary when the task of visual inspection is simply to observe and record what is present. TV can be carried by the unqualified diver to allow surface monitoring by a qualified surveyor, but the judgement concerning what is significant to televize is in the hands of the diver.

6.3 SPLASH ZONE

The splash zone is possibly the only area on a structure where inspection requirements cannot always be met. Because of the periodic surge, merely staying at the work site can be a major undertaking. The obvious solution is to perform inspections in the splash zone during calm weather, but this approach creates difficult scheduling problems. Furthermore, since inspections are conducted during platform operations they must fit into the working schedule, and access to a particular part of the platform may be pre-empted by other, more critical supporting activities which also seek to fully utilize hospitable seas.

Certain functions which must be performed during the inspection are not only difficult, they can be dangerous. Water jet cleaning, for example, not only requires a relatively stable platform for the diver to work from, but if the cutting edge of the jet is periodically wrenched out of control it could prove debilitating to the diver. Detailed photography is also difficult when the photographer may be alternately thrown against the object to be photographed or carried several feet away. This same problem is true for application of any NDT instrument discussed in Chapter 4.

The sea state limitations to working in the splash zone vary, but one operator estimated that a 1 to 2m surge would be the likely limit of splash zone operations.

6.4 LOCATION/POSITIONING

If there is adequate visibility and illumination, and if the structure is clearly marked with reference points, locating a structural member or a node can be accomplished to meet inspection requirements. Gaining access to the interior of a complex steel structure and knowing precisely where one is is problematical.

The diver offers the best - and possibly the only - capability for internal structure inspection due to his small size and maneuverability. A recent report by Beyerstein (47) related that the 38m long diver umbilicals used by his company (Sub Sea International) allows access to the center of virtually all large steel structures. Another company (CxJB, London) has used 45m long umbilicals from a diving bell. In such instances there is no point on the structure the diver cannot reach, although Beyerstein allowed that great care must be taken in such endeavors.

The recently-constructed ADS OSEL - a one-manned, untethered, highly maneuverable submersible - should offer an equal, if not greater, capability for gaining access to the interior of a structure. Since these vehicles have their own propulsion, are small, and are not restricted by an umbilical, there would seem to be nothing that would hinder the operator from guiding them virtually anywhere to a point on the platform. At present there is no operational feedback available to assess the capability of this device in structure inspection. The prototype ADS JIM would be able to work on the exterior of a structure, but lack of adequate maneuverability provides an obstacle in gaining access to a structure's interior areas.

More conventional manned submersibles can employ electronic and acoustic aids to navigation which can assist the operator toward locating the general inspection site. But they, like the diver and ADS, rely on visibility and reference marks to assure that the precise location has been attained. The manned submersible cannot easily "feel" its way into a structure as does the diver. If the pilot loses visual contact with the member he is following - say, by encountering unexpectedly fast currents - locating the reference member can be exceedingly difficult. One instance occurred in the mid-sixties where a submersible was literally lost within a steel structure in the Gulf of Mexico. The operator must visually locate a known reference point on the structure which he can use to regain his original position; this can take a great deal of time, and the massive bulk of the submersible, relative to the diver, makes for cumbersome and difficult maneuvering in fairly close quarters. This is not to infer that a manned submersible cannot locate a specific point on a structure if reference marks are available, it is simply a more difficult task when compared to other manned inspection capabilities.

Remote controlled vehicles have positioning problems similar to manned submersibles, with the added disadvantage that the umbilical cable is a potential fouling source. Both Buckenham (10) and L. van den Berg (48), BP Petroleum Development Ltd. and Shell U.K. Exploration and Production, respectively, state that positioning capabilities of RCV's is in need of improvement. According to van den Berg, RCV's are required which are capable of precisely entering a structure and identifying accurately where they have been. A further complication in using an RCV for inspecting is that operators are reluctant to enter the structure owing to alleged impossibility of obtaining insurance coverage on their vehicle when used in this mode (10).

6.5 CLEANING

Virtually all commercially-available cleaning devices are for diver application. By employing one or several of the various devices available (brushes, chippers, scrappers, needle guns, water jets) the diver can meet requirements for inspection. Some of these impact-type cleaners (e.g., needle guns) may be undesirable since they may disturb the very material they are cleaning to inspect. High pressure water jets are cumbersome and potentially dangerous. Additionally, there is no submersible or RCV from which a high pressure water jet can be efficiently deployed.

6.6 VISUAL INSPECTION

Requirements for visual inspection can be met by divers, ADS's, submersibles or RCV's. Documentation of the observations is adequately fulfilled by present underwater still and cine camera systems. Television video tape documentation is adequate, but improvements are needed in resolution and color rendition to obtain details which only the photographic camera now provides.

6.7 MAGNETIC PARTICLE INSPECTION

The obvious disadvantage of conventional magnetic particle inspection is that it does not measure crack depth and it does not measure flaws or discontinuities below the metal surface. Also, there is no permanent record unless a photograph of the magnetized area is taken. Buckenham and Allis (10) identified other disadvantages: many separate tools are required, often more than one inspector/diver can handle at one time, and it cannot be applied to non-magnetic materials (e.g., monel cladding).

In addition to the normal difficiulities encountered in the splash zone, the surge can also reach proportions that will wash out the magnetic particle slurry. One potential solution to this problem was to package the slurry in a thin, transparent plastic bag that would be placed over the test area. Reportedly, the particles aged before they were used and were not fully effective. The DNV system would seem to offer a potential hazard to the operator in moderate and higher sea states, in that, the heave of the surface platform will be transmitted to the large, heavy underwater component and thereby constitute a physical threat to the diver. Positioning the support barge directly over the work site is a further complication of the DNV system. Since the underwater component is large and not designed for positioning by the diver, precise surface positioning is required.

A potential deficiency of the mpi technique is that there are no standards for the level of magnetic current induced; consequently, it is virtually impossible to compare results of one surveyor's efforts against another from a different organization.

The Magnetographic Method of mpi seems to offer solutions in most areas where conventional mpi offers problems. Two criticisms of this technique are: 1) the limits of a crack (invisible to the naked eye) cannot be marked (i.e., punch-marked) to follow potential crack propagation on a subsequent test; 2) the system cannot be employed in nodes where the angle between members is less than 30 degrees. The first criticism does not seem justified, in that, the operator can easily punch-mark the location of the start of a tape and use this as a subsequent reference point. The second criticism may be valid, but the manufacturers of this system believe that the flexible yoke procedure, in lieu of a roller, has satisfied this requirement.

The Fe Depth Meter presents much the same problems as does the Magnetographic Method: the system's employment underwater is too recent and too limited to evaluate it as an underwater tool. The lack of a data recording feature provides an additional encumbrance to the diver in the way of a slate and grease pencil, and also slows down the number of measurements which can be made. Communicating the readings to the surface introduces the chance for misinterpretation of readings.

6.8 ULTRASONIC TESTING

The major use of ultrasonic NDT techniques at present is in thickness measurements. For this application there are no reported or apparent discrepancies in the techniques being used other than the problem of recording the data. (Can-Dive Services made in excess of 338 thickness measurements in the course of one dive).

Ultrasonic techniques for flaw detection are not in general use. DNV has used this technique only once, and Lloyds Register does not generally use it underwater because interpretation of the data and deployment procedures, in their opinion, are not yet fully established. On the other hand, ultrasonic flaw detection has been employed on U.S. Coast Guard structures with reportedly good results. Since "good" results in ultrasonic flaw detection is a function of both the instrument and its human interpreter, it is difficult to determine whether the deficiencies are instrumentational or human or both.

Acoustic holography is too recent a development to assess. The technique has been used successfully in the medical profession, the Holosonic's work is the only known underwater application. The manufacturer's acknowledge that until field experience is gained with the prototype instrument, its full potential will be speculative. A similar case can be offered for the PUNDIT method used in concrete flaw detection. Although PUNDIT is used successfully in surface concrete structures, its underwater application is incipient and, therefore, too recent for assessment.

6.9 CORROSION POTENTIAL MEASUREMENTS

The diver-held, autonomous c-p measuring devices seem to satisfy all current requirements. A self-recording feature would expedite measurement operations. The only potential obstacle to obtaining accurate measurements is if the user does not follow calibration procedures prior to each application. This is one of the few NDT measurements which can, and has been conducted by RCV's, but only the external areas of a structure are accessible owing to the potential for fouling (49). CP measurements as described in Chapter 4 do not provide an indication of internal corrosion on a steel jacket, they only measure the external corrosion potential.

6.10 RADIOGRAPHY

Radiography is not a common underwater NDT technique. As now performed it is a too complex and potentially dangerous technique for routine structural surveys. Also, the geometry of most steel structures is not amenable to radiography.

6.11 ACOUSTIC EMISSION AND VIBRATION ANALYSIS MONITORING

Both of these techniques are too complex and sophisticated to assess without the benefit of extensive field testing and analysis. At this point in time the only reports regarding performance of either system is from the designers and/or manufacturers.

From a requirements point of view, there is no regulation which addresses these monitoring techniques. All offshore platform inspection requirements are written to reflect inspection/testing as it is essentially performed on land with conventional techniques. In order to identify the deficiencies of these techniques in terms of satisfying inspection requirements it is necessary to precisely identify what technique or procedure they are intended to replace. Visual inspection (either directly or remotely) is meant to identify and position:

(1) Degree and scope of marine fouling
(2) Collision or impact damage
(3) Scouring
(4) Debris
(5) Cracking
(6) Corrosion
(7) Concrete crumbling
(8) Pitting

Of the above factors acoustic emission monitoring can identify items (2) if a crack has resulted; (5) and possibly (6) if the corrosion is within a crack that is "talking". Vibration analysis can identify (2) if the impact has resulted in a broken or severely bent member, and (3) if the scouring has been sufficiently extensive to cause a shift in the platform's attitude.

Neither technique can provide crack dimensions, consequently, they cannot replace mpi, or ultrasonic or radiographic internal flaw detection. Since neither technique provides information regarding material thickness they cannot replace ultrasonic thickness measurements. Nor can they obtain corrosion potential measurements.

Based on the above considerations, it is difficult to ascertain the precise role of monitoring systems at this present stage of development. Assessment of damage caused by impact, as described by Vandiver (6) on the Buzzards Bay Lighthouse Tower, would appear to offer an excellent "quick-look" capability to identify immediate and significant damage, an alternate technique is still required to identify cracking. On the other hand, while acoustic emission monitoring might inform the operator that a crack is present and where it is located, it cannot presently provide information regarding the size and nature of the crack, this information is obtained by <u>in situ</u> observations and testing. In short, both techniques appear to offer a means of economizing, not replacing, diver time. More at-sea application is necessary in order to provide an accurate assessment.

7.0 TECHNOLOGICAL RESEARCH/DEVELOPMENT REQUIREMENTS

The objective of this chapter is to identify specific tasks for research technology development that should be undertaken to satisfy current and future inspection/testing requirements. Since there are no present U.S. inspection requirements which pertain to public offshore fixed structures, except for pipelines, the only requirements to use as a yardstick are those of the North Sea countries. It is not the intent of this study to recommend or suggest inspection criteria; consequently, no assumed set of U.S. inspection standards will be used. Further, even those requirements from North Sea countries which are available lack much of the specificity needed to derive research technology development tasks. To illustrate this point, if one re-examines the inspection requirements of Chapter 3, it is seen that none of the inspections or tests required state accuracies of measurements; lacking such boundary conditions it is impossible to establish a goal for technological improvement.

In the previous chapter it was concluded that all present requirements can be met with present technology if visibility and weather permits, (i.e., there is an instrument and deployment capability available to conduct stated investigations). This conclusion does not imply that there is no need for improvements. The most obvious and pressing problem in conducting underwater NDT and inspection is the time involved, which equates to expense and scheduling problems. Present inspection techniques, using divers, call for complex support facilities; they are weather sensitive and the work is laborious. If inspection/testing requirements are called for at depths of 300m and more, it is possible that the diver will not be able to respond and since virtually all present NDT instruments are designed for diver (i.e., hand-held) application, technology must adapt to mechanical manipulation. These are some of the major problem areas; others will be detailed later in this chapter from which specific technological research tasks will be derived.

7.1 PERTINENT ON-GOING RESEARCH/DEVELOPMENT PROJECTS

There are a variety of research programs now underway in the U.S. and Europe which are aimed at developing techniques for offshore structure inspection. Some of these are directly supportive, in that, their goal is to produce a new or improved device or system for structure inspection, testing or monitoring. Others are indirectly supportive and are aimed towards obtaining data that would help to interpret the implication of NDT measurements and to identify the nature, location and frequency of future inspections or tests.

In a few instances several countries have combined their research efforts to reach a common goal, so there is sometimes an apparent duplication of efforts. A similar apparent duplication exists with some British developmental efforts involving the Offshore Supplies Office and private industrial firms. OSO's charter, in part, is to jointly fund various projects with British industry to develop exportable technology; hence, several U.K. developmental efforts may be found in both industrial and government agendas. The comprehensiveness of the following tabulation is unknown since much industrial research in this field is proprietary and not generally available until the new product or service is commercially marketed. A number of research programs were identified in Chapters 4 and 5, these are not listed in the following tabulations.

France

Title: Ocean Structures behavior (ref. 50)
Organization: CNEXO
Task/Objective: A variety of programs concerning steel and concrete structures are being conducted to look at all aspects in connection with safety, maintenance and performance. The program is divided, at present, into five areas: 1) environmental forces; 2) concrete (creep, corrosion, spalling, etc.); 3) steel (fatigue, fractures, etc.); 4) soil mechanics and 5) Nondestructive testing. In testing/monitoring areas the programs are aimed at determining precisely what the results mean in terms of platform safety. Acoustic emission and vibration analysis techniques are also being investigated. The program on concrete began in September 1975 and several projects have now been completed.

Title: Steel structure design review
Organization: Centre National pour l'Exploitation des Oceans (CNEXO); Centre Technique Industriel de la Construction Metalique (CTICM)
Task/Objective: A joint publication, over 800 pages, was produced which reviews the methods used in the design, construction and deployment of steel offshore structures. Three main categories are addressed: 1) forces and their effects; 2) effects of materials and welding on the behavior of marine structures in fatigue and 3) damage due to fatigue: fracture mechanics.

Norway

Title: Electrical resistivity of concrete in the oceans (ref. 51)
Organization: University of Trondheim
Task/Objective: Experiments were undertaken in order to provide data and information on the electrical resistivity of concrete in general and for concrete exposed to ocean environments in particular.

Title: Corrosion fatigue - offshore (ref. 52)
Organization: The Foundation of Scientific and Industrial Research at the Norwegian Institute of Technology (SINTEF) and Det Norske Veritas
Task/Objective: To determine fatigue properties of structural steel at different cathodic polarization levels. The measurements are carried out in sea water at low frequency, and the investigation will include both initiation and growth of fatique cracks. Other research includes investigation of fatigue strength of welded joints at different cathodic polarization levels.

Title: Fatigue of concrete structures (ref. 53)
Organization: Det Norske Veritas

Task/Objective: A pilot program to investigate some of the parameters believed to affect the fatigue strength of concrete in the marine environment. The main parameter investigated is the effect of water pumped in and out of cracks when the repeated flexural stress is such that the cracks will open and close - possibly leading to a buildup of hydraulic pressure within the crack.

United Kingdom

Title: Hyperbaric welding (ref. 54)
Organization: The Welding Institute
Task/Organization: To evaluate the performance of arc welding processes under high atmospheric pressure and to measure the properties of the resulting joint welds. The program is supported by the Dept. of Energy and will include the use of a hyperbaric chamber with a working pressure of 32 bars (about 300m of sea water).

Title: Concrete in the oceans (ref. 55)
Organization: Various participants. The Department of Energy is jointly funding this program with 22 industrial contributors. DOE is providing approximately 2/3rd of the funds (approximately $585,000 total). Overall management and supervision is supplied by representatives from DOE, CIRIA and the Cement and Concrete Association.
Task Objective: The program began in March 1976 and it is aimed at gathering fundamental data on concrete in the marine environment. The following projects constitute the program as of June 1977:

- Fundamental mechanism of corrosion of steel reinforcement in concrete immersed in sea water.
- Evaluation of methods for designing against excessive cracking and examination of the relationship between corrosion design and crack width.
- Influence of environment, stress and materials on corrosion of reinforcement in concrete
- Experimental investigation of the effects of temperature gradients on walls of oil storage structures
- Survey of existing reinforced concrete marine structures
- Strength of large prestressed concrete members in shear
- Corrosion fatigue of reinforced concrete in seawater - a review of existing information
- Appraisal of possible causes of local and total failure (e.g., fire, impact, foundation failure, etc.) of offshore concrete platforms and their effects on the structure

Title: Exxon ocean test structure (ref. 55)
Organization: Department of Energy, Det Norske Veritas, American Bureau of Shipping and several oil companies.
Task Objective: The program is designed to improve the understanding of wave forces on offshore structures and is centered around a highly instrumented structure in 20m of water in the Gulf of Mexico. Instruments measuring wind, wave and current forces will be monitored. Lloyds Register of Shipping has been contracted to analyze the data. Data will remain confidential to the sponsors for one year after the project is completed.

Title: Foundations of offshore structures (ref. 55)
Organization: Building Research Station (researcher and research coordinator)
Task/Objective: This program is financed by the Dept. of Energy. Its aim is to improve the safety and economy of offshore structure foundations. Subjects under examination include site investigation, effects of cyclic loading, instrumentation and full-scale monitoring, gravity platform foundation design and piling development. The program was originally estimated to cost over $975,000.

Title: Offshore Structures Fluid Loading Advisory Group (OSFLAG) (ref. 56)
Organization: National Maritime Institute (Program Manager)
Task/Objective: Ten research organizations are involved in this work, which includes analytical studies, laboratory investigations and large scale experiments to study the wind, wave and current loading on fixed and floating offshore structures. The sponsor for this $3.9 million study, which began in 1973 and is still underway, is the Offshore Energy Technology Board of the Department of Energy. Ten projects are identified of which nearly all are now complete.

1. Wave forces on vertical columns
2. Wave slamming loads on horizontal members
3. Wave forces on pile groups
4. Effects of marine growth on wave and current loading
5. Prediction of long-term wave loading
6. Wind forces
7. Dynamic positioning forces on floating structures
8. Capsizing forces and criteria for floating structures
9. Field trials - Christchurch Bay Project
10. State-of-the-art appraisals

Title: Buckling research (ref. 56)
Organization: Glasgow University, University College and Imperial College, London University and the Naval Construction Research Establishment
Task/Objective: A total of 34 test cylinders will be fabricated and loaded at the research centers listed above, to test and improve the prediction methods used to check the buckling stability of single members of offshore structures. The program has a tenure of two years and is supported by the Department of Energy.

Title: Diving equipment (ref. 57)
Organization: Baxter, Woodhouse & Taylor
Task/Objective: Two pieces of diving equipment are being developed which is funded jointly by the Ministry of Defense and the Dept. of Energy: an alternate method to hot water heating (electrically heated undergarment and outer dry suit) and a push/pull breathing unit which reclaims the used helium.

Title: United Kingdom Offshore Steels Research Project (UKOSRP) (ref. 57)
Organization: Atkins Research & Development
Lloyds Register of Shipping
National Engineering Laboratory
The Welding Institute
U.K. Atomic Energy Authority
University of Nottingham

Task/Objective: UKOSRP is one of the major research and development programs supported by the Offshore Energy Technology Board, Dept. of Energy. It also includes participation by the European Coal and Steel Community. An overall program of fatigue and fracture studies is being pursued by the organizations listed above which includes a series of related projects involving stress analysis, basic tests of corrosion fatigue, brittle fracture studies and full-scale fatigue tests on welded joints. The program goals are related to inspection by identifying areas of greatest platform vulnerability and by providing detailed information on the way in which fatigue cracks might propagate on various tubular joint configurations. The total program is estimated at approximately $8.9 million, UKOSRP takes up about half of this total. The parts of the joint program other than UKOSRP are as follows:

British Steel Corporation (U.K.) - The BSC work concerns the initiation and growth of corrosion fatigue cracks on test pieces of node quality between 25 and 76mm thick. The environment is seawater, the loading frequency 0.125 Hz and the stress ratio ranges from 0.05 to 0.7. BSC is also seeking a correlation between acoustic emissions, crack propagation and metallographic structure.

Harwell (U.K.) - Harwell is studying corrosion fatigue crack propagation on node quality steels in both seawater and in 3.5% sodium chloride solution, but loading frequencies vary down to 10^{-3} Hz and stress ratios are usually high. The effects of electrochemical potential, shape of the cyclic wave form and seawater pollution are also being investigated along with other variables.

Institut de Recherche Siderurgie (France) - In laboratory specimen tests, IRSID is determining the shape of crack propagation curves using three levels of biaxial loading and three steel thicknesses. Stress ratio, load amplitude, electrochemical potential and the oxygen content of the saltwater are being varied and both parent metal and the heat affected zone of welds are to be tested. IRSID is also testing large welded assemblies under uniaxial and biaxial loads over a range of stress ratios. A special effort is being made to separate the initiation and propagation phases of crack development.

Verein Deutscher Eisenhuttenleute (Germany) - The main variable in the VDEh contribution is the steel type - five steels with yield strengths up to 690N/mm^2. Other variables are steel thickness, the type, shape, method and heat treatment of the weld, and the electrochemical potential of the artificial seawater. Test pieces will also be tested ultrasonically.

Foundation for Materials Research in the Sea (The Netherlands) - The SMOZ program is centered on a series of large scale tests on tubular joints which are similar to the UKOSRP tests. The differences include a stress ratio of -1, a study of scatter, comparison between large scale air and seawater tests, cathodic protection, X-joints, out of plane braces and prestressed chords. Crack propagation and endurance tests will be made in the laboratory on a wide range of welded specimens.

Italsider (Italy) - The practical part of the Italian program investigates, on a large scale, the static and fatigue strength of Y-shaped joints, some of which are ring stiffened and some unstiffened. The same joints are also being subjected to a finite element stress analysis.

Title: Diving physiology (ref. 57)
Organization: Aberdeen University
Task/Objective: A study of diving incidents in the North Sea where the diver actually lost consciousness or showed other signs of distress. Its purpose is to determine the extent of the problem and to isolate common factors. The program is funded by the Dept. of Energy.

Title: Dynamics of offshore structures (ref. 58)
Organization: University of Glasgow
Task/Objective: A study of vibration and damping in offshore structures is involved which includes laboratory measurements made on a model platform (in and out of the water) and on full scale platform in the North Sea. The results will be used by the sponsor (Structural Monitoring Ltd.) to assist in designing vibration analysis monitoring systems.

Title: Application of strain gage to deep water structures (ref. 58)
Organization: Wimpey Laboratories Ltd.
Task/Objective: To study strain gage and installation procedures for instrumenting deep water structures where a strain monitoring system may be required to function for a prolonged period in an aggressive environment. Materials and installation procedures required to ensure long-term durability, corrosion resistance and electrical stability are being investigated.

Title: Detection of corrosion of structural steel in concrete offshore structures (ref. 58)
Organization: Taylor Woodrow Construction Ltd.
Task/Objective: To develop both permanently embedded and surface-mounted half cells to monitor the potential of steel embedded in concrete with reference to a standard electrode. The goal is to detect the onset of corrosion in the reinforcement in the submerged tidal and splash zones of an offshore structure particularly in highly stressed regions of the structure where concrete cracking is most likely to develop.

Title: Instrumentation of submerged water retaining concrete (ref. 58)
Organization: Ward, Ashcroft and Parkman
Task/Objective: To asertain the behavior of mass concrete under static hydraulic loading in order to develop methods of remote sensing.

Title: Development of integrity monitoring system for offshore platforms (ref. 58)
Organization: Structural monitoring Ltd.
Task/Objective: Develop an integrity monitoring system for offshore platforms using sea-induced vibrations to provide information on structural integrity. The program began on several North Sea platforms starting in the summer of 1975 and extended over a 12 month period. Sponsors include B.P. Ltd. and Comex Diving (U.K.) Ltd.

Title: Advanced Deep Water Inspection (ref. 58)
Organization: Strongwork Diving (International) Ltd.
Task/Objective: To produce remote access devices capable of providing definitive information concerning physical damage, corrosion loss and fatigue cracking on deep water structures.

Title: Acoustic emission monitoring (ref. 58)
Organization: The Unit Inspection Co.
Task/Objective: To evaluate acoustic emission techniques for the detection and monitoring of fatigue in offshore structures. Weld joints in a 10 cm (4 in.) diameter tube in a "T" and "K" configuration will be tested to failure under fatigue loading in a test rig fixed to the seabed. The test rig is designed to produce loading of the specimen from sea waves and welds will be monitored using stress wave emission instrumentation.

United States

Title: Vibration anlaysis (ref. 59)
Organization: Shell Oil Co.
Task/Objective: This program took place in 1975-1976. Fundamental periods of damping were determined on four jacket-type platforms in the Gulf of Mexico by two techniques: damped, free vibration tests (induced by boat pulls and impacts); and random response data (measurement of platform response to ambient sea conditions). Three objectives were sought: 1) measure platform natural periods and compare them to theoretical predictions; 2) measure platform damping; and 3) for small sea states, measure platform motions and wave heights simultaneously and compare the measured behavior with theoretical predictions.

Title: Proof test of vibration analysis technique
Organization: Keith, Feibusch, Associates, Engineers, San Francisco, Ca.
Task/Objectives: Three fixed platforms in the Gulf of Mexico will be visited at three separate intervals over a six-month period and monitored to establish baseline stability through vibration analysis techniques. The objective is to obtain a stable dynamic signature on each platform; on the last visit a member will be intentionally failed on one platform in an attempt to pick up the change in vibration frequency which should result. The platforms are in water depths between 64m and 99m. Vibration analysis systems developed by the Atkins Group and EMI Electronics (a member of the Seatech Consortium) of the U.K. will be used. The project is funded by 13 U.S. offshore oil and gas operators.

Title: Remotely controlled vehicles
Organization: University of New Hampshire
Task/Objective: To develop an untethered, remotely controlled vehicle which can follow an underwater pipeline in an automatic mode and/or by an acoustic data/command link. The program has been underway since 1976 and will continue into the Summer of 1978, it is funded by the U.S. Geological Survey. At this point the first generation vehicle has been constructed, two series of operational tests are scheduled for the summer of 1978. A total evaluation of the prototype will be performed to determine its limitations, follow-on work will attempt to minimize these limitations.

Other U.K. research programs in which the Offshore Supplies Office is a participant includes: 1) development of a flexible belt of transducers by which a weldment can be electronically scanned for thickness or defects; 2) development of an ultrasonic crack detector that, at a certain stand-off distance, will be able to detect a crack located beneath marine growth without removing the growth. Further details on these programs were not available.

Analyzing the foregoing projects, particularly those of the North Sea countries, reveals that the majority of research is aimed toward gaining information on the fundamental characteristics of steel and concrete exposed to the marine environment. While several of these projects are hardware-oriented, the majority seek basic knowledge of structures. The application of these basic programs to underwater inspection/testing/monitoring is quite direct: the results will reveal what factors are important to measure; what the measurements mean in terms of platform safety and integrity, and what inspection requirements - as they now stand - should be strengthened or minimized, or what new ones should be introduced. Particularly advantageous is the U.K.'s Offshore Supplies Office support of industrial development. This arrangement allows the designer of a monitoring or testing system to obtain operational feedback to improve or sophisticate his approach. An example is EMI Limited's participation in the vibrational monitoring program mentioned in Chapter 4, the system they have developed can be field-tested and then brought back to the factory to correct weaknesses in their technique. U.S. producers of monitoring systems do not enjoy this advantage.

7.2 SPECIFIC TASKS FOR RESEARCH TECHNOLOGY DEVELOPMENT

The introduction to this Chapter pointed out the difficulty of defining a technological development program designed to satisfy non-existant (i.e., U.S.) underwater inspection requirements. While North Sea requirements can be used as a guide, the data sought in that area may not reflect U.S. thinking. For example, fixed offshore oil and gas structures in U.S. waters number over 3,000 and in their entire operational history there are no reported failures due to lack of structural integrity. These structures have all been in relatively calm waters, but with the recent interest in east coast and Arctic drilling the environmental conditions encountered can equal the North Sea in hostility. Consequently, where North Sea requirements deal with a high-latitude environment, U.S. requirements must address a far wider spectrum of ocean conditions.

A further consideration which weighs heavily upon the design of a technological development program is the goal of the requirements. Structural integrity and safety determinations are frequently mentioned inspection goals, but these determinations are difficult to reach. A hairline crack in a secondary support member or in a concrete structure does not necessarily mean the structure is unsafe. If the goal of inspection is to assure safety, then hairline cracks may well be acceptable, and it may be decided that the crack can propagate to a far greater dimension until it becomes significant. In the same vein, the location of the crack on the structure (e.g., splash zone, mid-depth, near bottom) might be the determining factor rather than its dimensions. Such distinctions are extremely important, because they can determine what present instrumentation is adequate, in need of improvement or entirely lacking. As a case in point: present underwater television does not provide sufficient resolution to detect a hairline crack; consequently, one might suggest a program to improve its resolution. On the other hand, if a hairline crack is acceptable in terms of safety and integrity, then present TV may indeed provide the resolution required to locate the crack at a later stage in its development. In effect, until boundary dimensional values are placed on such goals as safety and integrity, the goals of inspection, testing or monitoring of offshore structures are unclear.

In spite of a lack of inspection requirements and specificity in measurements, it is possible to identify areas where technological improvements will be required regardless of the degree of detail called for in future inspections. The problem areas can be grouped into immediate and long-term programs. The primary assumption made in identifying the following programs is that the need for a human eye (either directly or remotely) in the water will be required in the foreseeable future. In Chapter 5 the deficiencies in vibration analysis and acoustic emission monitoring were listed in terms of present inspection requirements; it is impossible to foresee where these techniques - no matter how sophisticated they become - will remove the human being from the inspection/testing scenario. It is likely that human intervention will be required for the next five to ten years and possibly longer.

7.2.1 Immediate Programs

By "immediate", the objective is to enhance inspection/testing techniques as they are now performed; three goals are sought: 1) reduce time; 2) increase data reliability and 3) extend present capabilities. Because NDT techniques and interpretation are so human dependent, the human factor is included into the following discussion, although this topic does not corrently fall into technology development. Many of the programs are not development projects as such, but are projects aimed at improving present techniques instead of developing an entirely new technology. Implementation of these projects is not dealt with in this report; however, in order to obtain an objective (i.e., system, device or technique) that is both practical and usable, the participation of servicing companies, offshore operators and platform designers should be actively sought.

Operator/Surveyor Qualifications

The question of qualifications has been addressed throughout this report; it must be resolved. The fundamental question is: should the person conducting the inspection test, or measurement be qualified to some standard. If no qualifications are required, then: are there minimal in situ communication, documentation or monitoring procedures between the testor and the qualified technician that should be maintained while the test is proceeding? Four qualification areas should be addressed:

Visual Inspection
Material Thickness Measurements
Surface Crack Detection
Internal Flaw Detection

This question can probably best be answered through a cooperative effort of organizations such as: the American Society for Nondestructive Testing; the American Welding Society; the American Society for Mechanical Engineers and the American Bureau of Shipping.

Instrumentation Standards/Qualifications

Minimal acceptance standards for present and future NDT devices should be established. At the very least, the capabilities of current instruments to provide stated measurement accuracies equivalent to surface application should be verified under pressures and temperatures at which they will be working. Ultrasonic transducers, for example, which are designed to be used in not much higher than a one-atmosphere environment, may undergo some deformation at depth which could change their acoustic beam pattern. The surveying or certifying authorities and the platform operators should be assured that, if two different ultrasonic devices were employed from one annual survey to another, the results of both are truly comparable.

The National Bureau of Standards or some other recognized activity might be prepared to recommend standards in conjunction with a private laboratory to conduct evaluation tests on existing and future instrumentation. The goal of this project should not necessarily be to establish an on-going test and evaluation program, instead, it should initially strive to ascertain whether or not the devices are accurate in the marine environment and to what extent the results of one manufacturer's device are comparable to another's.

Cleaning

The entire subject of platform cleaning should be investigated with the primary objective of reducing the time now required to clean a structure for testing or inspection. A secondary objective should aim at defining standards for cleaning.

Techniques for safer and more expeditious deployment of the water jet should be developed. Alternatives to the high pressure water jet should be identified and investigated. Many servicing companies involved in hull cleaning operations use an RCV called SCAMP. The device employs a rotating brush; friction drive wheels and a vertical thruster to hold it against the hull. It is unknown whether or not the present SCAMP can brush away barnacles or other encrustations; but the concept of dispatching a remotely controlled vehicle to conduct the cleaning chore is compelling. Other techniques, such as ultrasonic cleaning and explosive cleaning should also be investigated. The cleaning tasks for steel and concrete structures are guite different and should be approached independently.

The extent and degree of cleaning required for visual inspection and NDT should be defined. Methods which are unacceptable and acceptable should be identified.

Positioning

An alternative to visual location should be developed which would permit the surveyor to rapidly and confidently locate the work site. Particularly critical is a means of positioning within the framework of a steel structure and on the exterior of a concrete structure. Whereas acoustic techniques may be applicable to concrete structures, alternate techniques should be investigated for the interior of steel structures. Accuracy of positioning should be within $\pm$ 1m. The positioning system should be designed for utilization by divers, submersibles, RCV's and one-atmosphere diving suits.

Mechanical Manipulation

Alternative to human hand-held deployment of NDT instrumentation and cleaning devices should be developed which would permit their application by mecahnical manipulators of submersibles and RCVs, and by one-atmosphere diving suits. This development must consider vehicle requirements for stability and maneuverability while deploying the device. Consideration for deployment by various manipulator termination should include commonly used claw types (e.g., Dorrance, scissors, parallel jaws).

Remote Controlled Vehicles

The RCV appears to offer the most immediate potential for reducing time and logistics for underwater inspection and testing. The various problems encountered by RCV's when operating around and in steel structures were outlined in Chapter 2. Since there are a variety of designs, some are more vulnerable to specific problems than are others. This field, however, is one of the fastest-growing and dynamic areas of underwater technology and many present problems will undoubtedly see near-future solution. The growth has been so rapid that it is impossible to obtain an accurate state-of-the-art summary, particularly from the servicing companies who operate these vehicles. Entanglement, cable drag and lack of positioning are the more obvious problems, others may be present that are not so obvious. The reported inability to obtain insurance coverage for an RCV that seeks to work inside a steel structure acts as a barrier to progress in terms of applying RCV's toward inspection and testing. At this point in its development, there is insufficient operational feedback to recommend a development program in this area. What is needed is a forum through which the manufacturers, operators and insurance companies can air their success, failures and reservations. The results of such a forum (i.e., workshop) could realistically identify the shortcomings and areas for technological development.

The concept of an untethered RCV is appealing, and certainly a worthwhile long-range goal. But the technological obstacles that must be overcome to match even today's tethered RCV's are formidable. A near-future, more attainable goal, should be one that seeks to capitalize on present capabilities to satisfy present and near-future requirements.

Corrosion Potential Monitoring

The remote c-p monitoring system proposed and tested by Anautics Inc. offers a great potential saving in time and reduces weather dependency. As far as can be determined it is the only one of its type in the U.S. Several questions regarding its practical application should be answered: what is the impact of installing this system on an already-functioning platform; what are the interference problems in obtaining an acoustic signal from the platforms interior; how accurate is the data over a long-term period; can the data be obtained from the platform itself rather than from a vessel. These, and other considerations can only be obtained by conducting a vigorous design review and field testing. It is recommended that such a program be pursued, not only for its application to platforms, but to pipelines (buried and unburied) as well.

7.2.2 Long Term Programs

Programs within this catagory are ones which would require heavy investment of funds and a more extensive research effort than those delineated in the foregoing. The worthiness of these programs is directly related to the detail eventually called for by Federal inspection/testing requirements and by the offshore operators themselves. The ultimate objective is to inspect and/or test under any undersea conditions and to reduce the dependency on weather.

Structural Monitoring

Both acoustic emission and vibration analysis monitoring offer the best foreseeable alternative to in situ inspection. The short-comings of these systems are listed in Chapter 5. The ultimate goal of these techniques should be to reduce and eventually abolish the need for manned underwater intervention - we are a long way from this goal. As is evident from the European programs, particularly those of the U.K., at-sea testing on full-scale structures and concurrent studies on fundamental structural material properties in the marine environment are required in order to understand what these techniques are measuring and what is the impact of the measurement. As such information unfolds, the monitoring system can, perhaps, be made to yield more specific data regarding cracking, corrosion, tilting and deformation. Judgements concerning a structure's condition as "unsafe" would seem a not overly-ambitious initial goal - providing agreement can be reached concerning what is "unsafe". Through further development the system or the analysis of its data might undergo additional sophistication to the point where it can replace or substantially reduce the effort and time now involved in annual inspections, such as conducted on North Sea platforms.

A type of program paralleling the one supported by the U.K.'s Offshore Supplies Office efforts on three North Sea platforms would appear in order. Coincident with this, a survey of the various materials testing programs underway in the U.S. and their relevancy to monitoring techniques should be conducted. The program calls for the combined efforts of the platform designer,fabricator and operator, and the monitoring system operator. It is imperative that such programs are aimed at satisfying the requirements for inspection; and this must wait until the requirements are written.

Inspection/Testing of Unclean Structures

Since cleaning is the major time-consuming chore on many inspections, devices which can perform without cleaning the structure could substantially reduce time and, ultimately, costs. Detecting a crack that is covered by a four to six centimeter-thick coating of organisms is a challaging task; detecting an internal flaw under these conditions is seemingly impossible. A capability of this type, nonetheless, is very desireable, not only to detect the crack, but to quantify it as well. None of the present crack detection techniques, except acoustic emission, seem suitable for this task. A feasibility program to assess the possible means of addressing this problem should be undertaken. Active corrosion zones on the structure should be sought, as well as cracks or failures.

APPENDIX I

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(58) SIRA Institute Ltd. 1976 Directory of Current U.K. Research and Development Relevent to Underwater and Offshore Instrumentation and Measurement. CIRIA Underwater Engineering Group, London, Tech. Note 8, 57 p.

(59) Ruhl, J.A. 1976 Offshore platforms: observed behavior and comparisons with theory. Proc. Offshore Tech. Conf., V. II, p. 334-352.

APPENDIX II

CONGRESSIONAL, STATE AND FEDERAL AGENCY PERSONNEL CONTACTED

STATE	SENATOR	CONTACT	STATE ACTIVITY
Maine	Hathaway	Mr. Bentson	Dept. of Marine Resources Mr. E. Bradley
	Muskie	Staff Member	
New Hampshire	McIntyre	Mr. Aylwood	Office of the Attorney General
	Durkin	Mr. Burke	State Coastal Zone Management Dept.
Massachusetts	Brooke	Mr. Wosowicz	State Dept. of Environmental Protection
	Kennedy	Staff	State Coastal Zone Management Dept.
Rhode Island	Pell	Mr. Young	Energy Dept., Governor's Office
	Chafee	Ms. Barrow	Coastal Zone Management Council, Mr. Lyons
Connecticut	Weicker	Mr. Wicklund	Governor's Office
	Ribicoff	Staff	Dept. of Environmental Protection, Mr. Taylor
New York	Javits	Staff	Governor's Office
	Moynihan	Staff	Governor's Office
New Jersey	Williams	Staff	Mrs. Thompson
	Case	Mr. Vandenberg	State Offices
Delaware	Biden	Mr. Laudicina	Coastal Zone Management, Mr. Hugg
	Roth	Mr. Moore	Dept. of Natural Resources
Maryland	Mathias	Mr. biGenova	Coastal Zone Management Dr. Zeni
	Sarbanes	Mr. Gilmore	Coastal Zone Management Dr. Zeni
Virginia	Byrd	Mr. Brooks	Governor's Committee
	Scott	Staff	Governor's Committee
North Carolina	Morgan	Staff	Governor's Office
	Helms	Mr. Anderson	Governor's Office
South Caroline	Hollings	Staff	Governor's Office
	Thurmond	Mr. Lyon	Governor's Office
Georgia	Nunn	Staff	Energy Office, Ms. Omie Walden
	Talmadge	Staff	Dept. of Environmental Protection, Mr. Ledbetter
Florida	Stone	Staff	Mr. Rowens
	Chiles	Ms. Goodgame	Outer Continental Shelf Manager, Mr. Currie
Louisiana	Johnston	Mr. Szabo	Coastal Zone Management in state
	Long	Mr. Stahl	Committee of Conservation, Mr. Sutton, Baton Rouge
Alabama	Sparkman	Mr. Sokol	Mr. Gentry
	Allen	Staff	Mr. Gentry

APPENDIX II (CONT.)

STATE	SENATOR	CONTACT	STATE ACTIVITY
Mississippi	Eastland	Mr. Barber	Coastal Zone Management in state
	Stennis	Staff	Oil and Gas Board
Texas	Bentsen	Mr. Knight	Governor's Committee
	Tower	Mr. Smith	Governor's Committee
California	Cranston	Mr. Forcier	California State Coastal Zone Management
	Hayakawa	Ms. Haberstroh	California Coastal Zone Management or Dept. of Environmental Protection
Oregon	Hatfield	Staff	Dept. of the Environment, Head, Dr. Miller
	Packwood	Ms. McLennon	Coastal Zone Management, Mr. Zedwick
Washington	Jackson	Staff	Coastal Zone Management in state
	Magnuson	Staff	Senator Jackson
Alaska	Gravel	Mr. Cowles	Dept. of Natural Resources, Juneau, Mr. LeResche
	Stevens	Mr. Logan	Mr. Perles
Hawaii	Inouye	Mr. Rovenholt	Own contact
	Matsunga	Mr. Case	Energy Office, Mr. Harris

UNITED STATES HOUSE OF REPRESENTATIVES

STATE	REPRESENTATIVE	CONTACT	STATE ACTIVITY
Alabama	Edwards	Ms. Casper	Dept. of Environmental Protection, Mr. Black
Alaska	Young	Mr. Moore	Committee of Natural Resources, Mr. LaRoche
Louisiana	Breaux	Mr. Marmillion	Coastal Zone Management in state
Massachusetts	O'Neill	Mr. Peterson	Coastal Zone Management in state and Outer Continental Shelf
Mississippi	Lott	Staff	
New York	Pike	Staff	Governor's Office
Rhode Island	Beard	Staff	State Senator Castro
Texas	Brooks	Staff	Mr. Sheffield
Virginia	Daniel	Mr. Foster	Marine Resources Committee
Office of Technology Assessment		Mr. R. Niblock	Ocean Programs

APPENDIX II (CONT.)

FEDERAL DEPARTMENT	CONTACT	ACTIVITY
Interior (Geological Survey)	Mr. R. Krahl Mr. J. Gregory Mr. R. Giangerelli	Marine Oil and Gas Operations
Transportation (Coast Guard)	Mr. Iglesias	Merchant Marine Safety Branch, Merchant Vessel Inspection Division
	CDR K. Bishop, Jr.	Merchant Marine Safety Inspection Standards Branch
	CDR S. Masse	Deep Water Ports Division
	Mr. R. Voetch	Construction and Engineering Branch
	Mr. M. Medic	First Coast Guard District, Boston
Office of Pipeline Safety	Mr. C. Deleon	Office of Pipeline Safety, Operations
Labor (OSHA)	Mr. J. Proctor Mr. E. March	Safety Standards
	Mr. J. Donnely	Administrative Dept.
Defense (Navy)	Mr. T. Dawson Mr. G. Silva	Materials Command
	Mr. J. Bladh	Supervisor of Salvage
	Mr. R. Provencher	Ships Engineering Center
	Mr. E. L. Crisculo, Jr. Mr. C. Dyer	Naval Surface Weapons Center
Commerce	J. Lisnyk	Maritime Standards Division
	H. Berger	National Bureau of Standards
Environmental Protection Agency	Mr. J. Dorrler	Oil and Hazardous Materials Spill Branch, Edison, New Jersey

NORTH SEA REQUIREMENTS

COUNTRY	CONTACT	ACTIVITY
United Kingdom	Mr. C. T. Brant, Energy Counsellor	British Embassy, Washington, D.C.
	Mr. R. Street, Asst Dir, (Research and Development)	Petroleum Engineering Division Dept. of Energy, London
	Mr. M.S. Iggleslen	Offshore Technology Unit Dept. of Energy, London
	Mr. J. Hughes Mr. V.S. Davey	Offshore Supplies Office Dept. of Energy, Glasgow
	Mr. J.B. Cowan, Principal Surveyor	Lloyds Register of Shipping London
	Mr. N.R. Williams	Atomic Energy Research Establishment, Harwell, Oxfordshire

APPENDIX II (CONT.)

COUNTRY	CONTACT	ACTIVITY
Norway	Mr. L. Tangeraas, First Secretary	Norwegian Embassy, Washington, D.C.
	Mr. R. Sletten, Principal Surveyor	Det Norske Veritas, Oslo
France	Mr. Mourlon	French Scientific Mission, Washington, D.C.
	Mr. F. Dreyer, Director	CNEXO, Brest
	Mr. P. Ozanne	
	Mr. B. Barnouin	
	Mr. J. Jarre	
	Mr. D. Girard, Director	CNEXO, Paris, Direcion des Carburants, Paris
Ireland	Mr. R. Townsend, First Secretary	Embassy of Ireland, Washington, D.C.
	Mr. D. McCluskey, Third Secretary	
Denmark	Mr. N. Egelund, Secretary of Embassy	Royal Danish Embassy, Washington, D.C.
	Mr. O. Konig	
Sweden	Mr. L. Helander, Asst Scientific Attache	Office of the Scientific Counselor, Swedish Embassy, Washington, D.C.
Netherlands	Mr. H. VanVierssen	Royal Netherlands Embassy, Washington, D.C.
Belgium	Mr. H. Paemen, Economic Minister	Belgian Embassy, Washington, D.C.
West Germany	Dr. Witt, Energy Advisor	West German Embassy Washington, D.C.
	Mr. Ambos	Oberbergamt in Clavethal-Zellerfeld

APPENDIX III

CAPABILITIES-INSPECTION/TESTING
UNITED STATES/CANADA

American Society for Nondestructive Testing
Columbus, OH

Automation Industries
Danbury, CT

B & K Instruments, Inc.
Cleveland, OH

Bastelle Columbus Laboratories
Columbus, OH

Battelle-Northwest
Richland, WA

B. C. Research
Vancouver, B.C. CANADA

Benthos, Inc.
N. Falmouth, ME

Can-Dive Services, Ltd.
No. Vancouver, B.C. CANADA

Channel Industries, Inc.
Santa Barbara, CA

Charles T. Morgan Co., Inc.
Danvers, MA

Chevron Oil Co.
New Orleans, LA

Chicago Bridge & Iron Co.
Prarieville, LA

Consolidated X-Ray Service Corp
Dallas, TX

Daedalean Associates
Woodbine, MD

Detek, Inc.
Camp Springs, MD.

Dunegan/Endevco
San Juan Capistrano, CA

Econospect Corp.
Napa, CA

Exxon Nuclear Services Co., Inc.
Richland, WA

Gamma Industries
Baton Rouge, LA

Global Divers, Inc.
Lafayette, LA

Harisonic Laboratories' Inc.
Stamford, CT

Harold Liddle Divers
Barstow, MD

Holosonics, Inc.
Richland, WA

Hydronautics, Inc.
Laurel, MD

Hydrotech International
Houston, TX

International Underwater Contractors, Inc.
City Island, NY

Jones & Laughlin Steel Corp.
Aliquippa, PA

Krautkramer-Branson, Ind.
Stratford, CT

J. Ray McDermott & Co., Inc.
New Orleand, LA

Martech International
Houston, TX

Massachusetts Institute of Technology
Cambridge, MA

Metals Testing Co., Inc.
South Windsor, CT

APPENDIX III (CONT.)

Mobile Testing Labs
Harvey, LA

National Pipe & Tube Co.
Houston, TX

New England Ocean Services
Boston, MA

Nondestructive Test Engineering Co.
Deep River, CT

Ocean Systems, Inc.
Houston, TX

Oceaneering International, Inc.
Houston, TX

Offshore Power Systems, Inc.
Jacksonville, FL

Offshore Services Co., Inc.
Port Monmouth, NJ

Peabody Testing/Magnaflux
Chicago, IL

Reading & Bates
Houston, TX

Science Applications, Inc.
Santa Ana, CA

Shell Oil Co.
Houston, TX

Southwest Research Institute
San Antonio, TX

Subsea International
New Orleans, LA

Sylvester Underseas Inspection
Rockland, MA

Taylor Diving & Salvage, Inc.
Belle Chasse, LA

H. M. Tiedemann & Co., Inc.
Greenwich, CT

Torr X-Ray
Van Nuys, CA

Undersea Systems Inc.
Bay Shore, NY

University of New Hampshire
Durham, NH

URESCO
Cerritos, CA

Vetco Offshore Industries, Inc.
Ventura, CA

XMAS, Inc.
Norfold, VA

X-Ray Industrial Distributors
Clifton, NJ

X-Ray Products Corp.
Pico Rivera, CA

NORTH SEA

B. I. X.
Great Yarmouth, Norfolk
ENGLAND

Bruker-Physik A. G.
Karlsruhe
WEST GERMANY

CNEXO
Brest
FRANCE

CNS Electronics
London
ENGLAND

COMEX Diving Ltd
Aberdeen
SCOTLAND

Corrosion & Welding Engineering, Ltd.
Sidcup, Kent
ENGLAND

APPENDIX III (CONT.)

Heriot-Watt University
Edinburgh
SCOTLAND

F. A. Hughes
Epson, Surrey
ENGLAND

Intersub Developpment
Paris
FRANCE

Magnetische Prufanlagen GmbH
Reutlingen
WEST GERMANY

Marine Unit Technology
Plymouth
ENGLAND

P & O Subsea, Ltd.
Montrose
SCOTLAND

Vickers Oceanics, Ltd.
Edinburgh
SCOTLAND

Wells-Krautkramer, Ltd.
Hertfordshire
ENGLAND

ADDENDUM

1. At the request of the USGS and the DOE, a Committee on Offshore Energy Technology has been established under the auspices of the Marine Board, Assembly of Engineering, National Research Council. The committee will assist the federal government in the identification, initiation, evaluation and securing of technological developments leading to improvements in:

a) efficient economic exploration and development of OCS energy resources; and

b) standards and procedures used by the government in fulfilling its statutory responsibilities for safety, conservation of resources and protection of the environment.

Specific areas of study have been assigned to working groups that include members of the committee and representatives of the USGS, DOE, and NOAA. The committee expects to issue three final reports, one of which will focus on in-situ inspection of offshore oil and gas structures and pipelines based on the working group studying this issue. Other reports will deal with the methodology for developing environmental criteria needed for the design of offshore oil and gas structures and the identification of determination of priorities for technical areas for R&D support by the government and government-industry jointly.

2. The USGS also has responsibility to DOT for inspection of offshore gathering pipelines but their responsibility begins upstream of OCS Order No. 9, Pt. 1E. USGS responsibility is for conservation of resources and prevention of waste.

Under a Memorandum of Understanding between the Department of Interior and the Department of Transportation, dated 6 May 1976, the USGS has responsibility for inspection of offshore gathering lines upstream of the outlet flange where hydrocarbons are produced or processed. Authority for this responsibility is outlined in OCS Order No. 9, Pt. 1E.

3. Subsequent to finalization of this study the USGS conducted a survey of U.S. Gulf of Mexico platform operator's inspection programs. The results of this study are as follows below.

OCS Platform Underwater Inspections - Gulf of Mexico

Small Operators

Company A has no specific program frequency, but it has conducted some inspections after hurricanes. Also, it has had reason to inspect welds when questions arose over welding practices during the fabrication stage. If installing a pipeline riser, it will have divers check the general condition of platform structural members and, if platform redesign or modification is being considered, will perform an inspection. A thorough visual inspection is performed by divers, with still photographs, the emphasis being placed on structural members just below the water surface and close to the bottom. No remote vehicles have been used, and no water depth limitations are involved. It has not encountered structural problems as a result of past inspections, but the bottom is always checked for junk and debris and removed if found. The cathodic protection system is checked every 6 months on every platform by means of a silver chloride probe lowered into water and the potential measured.

Company B does not inspect periodically but will inspect if a diver is there for some other reason. Also, it will inspect if the platform is in the direct path of a hurricane or if involved in a ship collision. It uses divers only and has no depth limitation on inspections since no platforms are located in more than 250 feet water depth. Inspections consist of a spot check of structural members, visual only, unless damage is found, and then photographs are used. The cathodic protection system is checked annually for every platform. It relies on a check of cathodic protection system. If the potential falls below .85 volts, anodes are replaced, and a spot check of the structural members is conducted.

Company C does not inspect regularly, only if the platform is damaged by a ship collision or by a hurricane. Also, it may inspect before moving a drilling rig on to the platform. It runs a corrosion potential check annually by lowering a probe into the water on each side of the platform to various depths to measure the voltage. Divers only are used for inspections, and there is no water depth limitation. When an inspection is performed, the diver will visually check every structural member and hand-chip marine growth from all joints from the mudline to the water surface. If any damage is found, the joints are water blasted, photographs taken, and videotapes used. It has not used Nondestructive Testing (NDT) inspection methods.

Medium Operators

Company D does not inspect on a regular basis, but only if it has a particular reason such as the platform being in the direct path of a hurricane, there being surface indication of damage, or a diver being there for another purpose. It checks the cathodic protection system annually with silver chloride or copper probes lowered into the water on cables at various locations and depths to measure voltage. Records are maintained on each platform and, if the voltage is .85 or greater, the system is considered all right. Last summer it replaced the anodes on five platforms, and divers made visual checks of the overall condition of the platforms. It uses divers only and makes visual inspections. If problems are found, it takes photographs and uses videotape. An engineering analysis of the data is made to determine if further inspections are needed. They are not limited by water depth and have not used NDT methods.

Company E has started a regular program in the last 2 years and has inspected all of their platforms by now. Also, it inspects after an extensive drilling program, when the rig is moved or if hurricane damage is indicated. Inspection is basically visual by a diver to spot check, clean and videotape a few joints, and check for debris or junk on bottom. Check of the cathodic protection system is made annually but not necessarily with divers. They have no water depth limitation. A cost of $30,000-$50,000/platform was mentioned.

Company F has not regularly scheduled program and inspects only when there is reason to expect damage or structural weakness such as after a hurricane or ship collision. Generally it uses divers to visually check structural members and welds near the mudline and waterline, as experience indicates damage is more likely to occur in these areas. A diver will chip or water-blast welded joints and, if needed, use photographs or videotape. It has used a remote control vehicle ($2,500/day) with a television camera to install a jacket over a template. Water depth is not a limiting factor, and it has not used ultrasonic inspection in the water due to questionable results and lack of efficiency of the tool. It checks the cathodic protection system (sacrificial anodes only) annually with a silver chloride probe from the surface. If the voltage measures at least .85, the system is considered to be all right.

The diving services contractor reported the following as typical for the operators serviced in the Gulf of Mexico:

1. The riser is inspected in detail to mudline.

2. All joints at the first elevation below the waterline are water blasted and visually inspected.

3. If first level inspection does not indicate problems, 25 percent of second level joints are inspected.

4. If second level inspection does not indicate problems, only critically stressed joints determined from a computer analysis and possible "x-brace" joints are inspected to the bottom level.

5. The bottom level is wire-brushed and visually inspected at one diagonal and one horizontal member per leg.

6. A check is made for debris at base.

7. Potential readings are taken at some anodes.

8. If problems are detected in the above procedures, an inspection may be extended to 100 percent of all joints being blasted and visually inspected.

9. This kind of inspection is done at approximately 4- to 5-year intervals per platform.

10. After a hurricane, all joints at the first and second level below the water level and all critical stress joints are blasted and visually inspected.

11. There are not water depth limitations.

12. If problems are detected, the operator may inspect annually until confident that the problem is solved.

13. NDT methods have not been used in the past, but, recently, ultrasonic inspection has been used on flowlines and risers by some operators.

14. Remote control vehicles are not used to any extent for structural inspections.

Company G inspects all major platforms annually as well as smaller platforms located in more than a 50-foot water depth. Also, it inspects after a hurricane occurs in an area. It does three levels of inspection as follows:

1. A diver makes a cursory check of the general conditions annually, cleans a few joints, and makes a random check for corrosion and the condition of the anodes.

2. If damage is found a more thorough inspection is made with still photographs and videotape.

3. If additional damage is found, every joint is cleaned and checked for an overall evaluation of the platform condition with photographs and videotape. It has tried ultrasonic inspection in the past but has not been satisfied with the results as the equipment is too operator-sensitive. Divers only are used, and there is no water depth restriction. The condition of the sacrificial anodes and voltage potential is checked by divers annually. Some problems have been found, and it has had to remove a structure due to corrosion damage.

Large Operators

Company H inspects some of their platforms annually depending on the conditions at previous inspection. If trouble is indicated, the platform is inspected every year (three or four are in this category). Deepwater platforms are inspected every 1 to 3 years. Eleven platforms were inspected in 1976 and 60 platforms in 1977. The company operates a total of 190 structures of various sizes in the Gulf of Mexico. Previously, it inspected each platform every 2 years but found it was not necessary due to a lack of problems. It conducts an annual above-water inspection of structures during winter months and schedules underwater inspections in summer months. After a hurricane, if there is a surface indication of damage, a detailed underwater inspection is performed. Generally, it uses divers but has used a remote-control vehicle for special purposes. Divers will spot check overall conditions, take photographs, and use videotape on large multi-pile platforms. Also, it checks the condition and takes photographs of the anodes. Further inspection of the cathodic protection system is performed by a corrosion engineer. It has used ultrasonic inspection methods on special occasions if conditions found by a divers inspection requires further checks. There is no water depth limitation.

Company I generally inspects every platform over a 5-year period (some scheduled each year) but also conducts an inspection if the platform is in the path of a hurricane. It has found no problems except corrosion of structural members of a platform using an impressed current cathodic protection system that failed. It uses divers only and has no water depth restriction. Inspection will involve a thorough visual check of a typical platform leg, waterblasting every joint, taking still photographs, and checking for scour and debris at the mudline. Also, the cathodic protection system is checked on a certain number of platforms annually with all being checked on a 4- to 5-year basis. It has not used the ultrasonic inspection method.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1978 O—266-730