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AIM (Assessment, Inspection, Maintenance) and Reliability of Offshore Platforms

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ABSTRACT

Concerns for requalification of existing fixed offshore platforms have served to focus a need for development of a practical engineering approach to the AIM (Assessment, Inspection, Maintenance) aspects of these structures. The principal concerns for requalification are focused on older platforms that are now in service, and that are providing a resource critical to U.S. energy requirements.

This paper defines one approach to the AIM process for fixed offshore platforms. Probabilistic methods are applied to several key parts of this approach. These include assessments of operating and environmental forces, the as-is and repaired capacities of the platform, and analyses of alternative remedial maintenance programs.

INTRODUCTION

Today, there are some 6,000 fixed offshore platforms sited on the world's Continental Shelves. Many of these structures have been in place for over 30 years.

Renewed drilling activity to further develop known reserves, and supplemental recovery operations indicate the need to requalify these structures for extended lives. In addition, there are extremely strong pressures to minimize costs, particularly in the light of depressed oil prices.

These developments have resulted in the vital concern with requalification of existing platforms. Fixed platforms have had an enviable safety record, and the objective is to maintain this record as platforms enter their twilight years.

AIM REQUALIFICATIONS

The AIM engineering approach to requalification of platforms involves three primary interrelated elements in what will be termed the platform AIM triangle (Fig. 1):

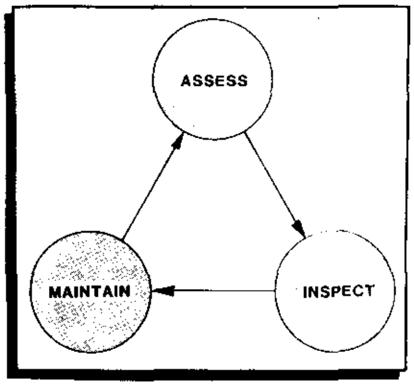


Fig. 1 Platform A I M Triangle

1. Assess - those engineering appraisals intended to evaluate present and future platform serviceability, determine the desirable characteristics of present and future serviceability, and examine alternative platform maintenance programs with the objective of identifying practical maintenance programs that will develop acceptable platform serviceability characteristics while preserving essential safety, economic, and environmental objectives.

2. Inspect - those engineering and operations programs directed toward detection and documentation of significant defects or damage in a platform that can lead to potentially significant reductions in platform capacities and serviceability characteristics.

3. Maintain - those engineering and operations programs developed and implemented to preserve or enable a platform to develop acceptable capacities and serviceability characteristics.

The AIM triangle indicates a continuing process of platform requalifications intended to keep platforms in service by using preventative and remedial engineering/operations techniques. The AIM process is intended to be one of progressive and continued reduction of risks to tolerable and acceptable levels.

The AIM approach is positive. Inspection, definition of defects and damage, and repairs or improvements are given high priority in platform operations, with an objective of establishing and maintaining the integrity of a given structure at the least possible cost. Practicality implicates an incremental investment in identifying and remedying platform defects in the order of the hazards they might represent. This is a prioritized, learn-your-way-through approach.

The focus of the AIM approach (Fig. 2) is on identification of high hazard potential structures that may possess significant defects or damage, and how to define cost effective, professionally acceptable, and practical solutions for these structures. The benefits of AIM engineering and operations activities must be justified by the benefits that are achieved and the resources that can be invested to keep a vital resource flowing to the market place.

The basis of the AIM approach is that the problem of a major platform with potentially significant defects is one that should be approached without rigid conformance to "conventional practice," maintaining a high level of technical and operational excellence, and defining creative and practical ways to lessen risks within the unavoidable constraints of currently available knowledge, manpower, money and time. This is a structure and problem-specific approach. It is not an engineering code or rigid guideline approach.

Unfortunately, at this time, there are no established engineering codes or guidelines for platform AIM. In this vacuum, many engineers would adopt current platform design guidelines and practices as a basis for evaluation of existing platforms.

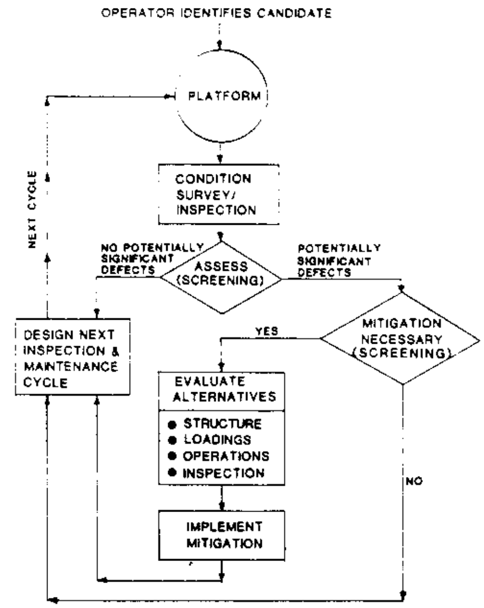


Fig. 2 A I M Approach

This can be a dramatic mistake for several reasons. Codes are general guides for practice. They cannot recognize many site, platform, and operation specific factors critical to platform requalifications. Codes are oriented to elements in a platform, and a general framework of common engineering practice. Codes are intended to result in a structure that is serviceable, safe, and economic.

Platform requalifications have a series of objectives that differ substantially from those of codes and guidelines intended for design of a structure. These objectives are those of realistically evaluating an existing platform which is frequently defective, and attempting to answer the question, "Will this structure, in its present condition, perform acceptably during its remaining life?" Alternatively, this question can be posed, "What can or should be done to allow this platform to perform acceptably during its next AIM cycle?" These objectives suggest a different set of engineering philosophies and approaches.

INITIATION

The AIM approach (Fig. 2) is initiated with the platform operator identifying a candidate platform. There are two principal considerations: 1) which platforms should be selected, and 2) how many platforms should be selected.

The first consideration is basically one of identifying the priorities of the AIM process. The second consideration is one of determining the allocation of resources for the AIM process.

There are a wide variety of quantitative and qualitative ranking procedures which can be used in the platform selection process. One practical approach consists of two qualitative priority evaluation attributes: 1) consequence potential, and 2) defect potential. The consequence potential is the likelihood, given an extreme loading event, that there could be extensive damage to property, lives, resources, and the environment. The defect potential is the likelihood of deficiencies in design, construction, and/or operation of the platform. The essence of the defects is as they might affect the capacity of the platform to resist extreme events (Fig. 3).

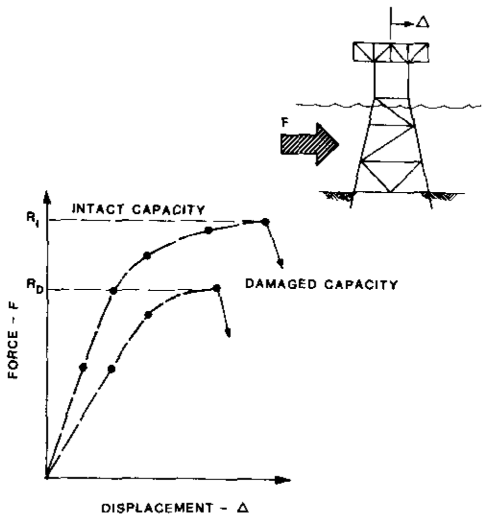


Fig. 3 Intact and Damaged Platform Capacities

Both of these potentials can be evaluated on a relative ranking scale, e.g., H = High, M = Moderate, L = Low. Knowledge of the structure, qualified judgment, and most importantly, the history of performance of the structure become the bases for the evaluation. The two evaluations are combined (Fig. 4) to result in nine different possible combinations of consequence and defect potentials. The first priorities for introducing a particular platform to the AIM process are given to those structures which possess both high consequence and defect potentials.

	DEFECT POTENTIAL		
CONSEQUENCE POTENTIAL	LOW	MODERATE	HIGH
LOW	L,L	M,L	L,H
MODERATE	L,M	M,M	H,M
HIGH	L,H	M,H	H,H

FIRST PRIORITY
SECOND PRIORITY
THIRD PRIORITY

Fig. 4 Platform Inspection Priorities

Now, given large number of platforms, the question becomes one of how many structures should be introduced to the AIM process? This is fundamentally a question of how much resource a particular operator feels is appropriate to invest in AIM programs, either for a specific platform or a fleet of platforms associated with some particular development.

At this time, there are no general or easy answers to this question. Quantitative cost-benefit analyses could be made based on the overall economics of a particular platform or development to assure that a reasonable investment of resources will be made to maintain the platform's abilities to perform acceptably during project operations [1-3].

CONDITION SURVEY

In this AIM step, a data bank is initiated or continued on a particular structure, including all available pertinent information on the design, construction, and operational history of this structure. Of major importance are identifying and recording exceptional events or developments. The greater the knowledge about a particular structure, then the more realistic is the evaluation, and the more effective the AIM program results. It is impossible to realistically evaluate a platform's performance or safety without definite information on the structure. The primary components that should be incorporated into a platform data bank are summarized in Table I.

An AIM program can only be effective if there is an adequate store of information on the platform or fleet of platforms. This store of information, or data bank, should contain information on the design, construction, operation, maintenance, and as-is condition of the platform. This data bank becomes vital in directing the course of inspection surveys -- determining which elements to inspect, what to look for, the methods to inspect, and the timing or frequency of inspections [4-12].

SCREENING

The next two AIM steps are concerned with assessing or screening the candidate platform's need for defect mitigation. Examples of platform defects are given in Table II. If there appears to be no potentially significant defects in the structure, the procedure is concerned with the engineering of the next inspection and maintenance cycle. If there appear to be significant defects, the next step is to determine if mitigation of these defects is necessary.

Mitigation of defects refers to a prioritization of remedying those defects, and identification of practical alternative remedial actions. The evaluation necessarily depends on the hazard potential of a given platform; given that the platform would not perform adequately during the next AIM cycle, and on the potential for such performance. If no mitigation appears to be warranted, the procedure again branches to the design of the next inspection and maintenance cycle for the platform.

EVALUATION OF MITIGATION ALTERNATIVES

If mitigation appears to be warranted, the AIM process branches to the detailed evaluation of the alternatives for mitigation (Table III). The alternatives include:

a. The structure itself - repairs to damaged, in-place, load-carrying members.

b. Loadings - removal of deck equipment, removal of marine fouling, removal of unused or unneeded elements (e.g. boat landings, risers, etc.).

c. Operations - improvement of corrosion protection, installation of additional well and production safety equipment, installation of additional personnel safety equipment, demanning in advance of storms.

d. Information - on-site inspections and measurements to improve detail of data on present condition of the structure, development of detailed information on past loading events.

IMPLEMENTATION AND DESIGN OF NEXT AIM CYCLE

Once the mitigation alternative has been defined, the next step is to engineer that alternative and implement it in the platform operations.

1. Design - Site data, criteria, guidelines, procedures, drawings, etc. pertaining to the initial engineering phase of the structure.

2. Fabrication - Specifications, materials, equipment, quality assurance procedures and reports, etc. pertaining to the onshore construction phase of the structure.

3. Transportation - Specifications, equipment, quality assurance procedures and reports, etc., pertaining to the load-out and transport of the structure to the offshore installation site.

4. Installation - Specifications, equipment, materials, quality assurance procedures and reports, etc., pertaining to the preparation for placement and replacement of the structure at the location.

5. Operations - Information pertaining to plaform loading and capacity characteristics and modifications that are developed during the drilling phase and during the production phase of operations of the structure.

6. Maintenance - Specifications, equipment, materials, procedures used to preserve or modify the capacity of or loadings on the platform.

Table I Platform Data Bank Components

1. Design

   a. Storm wave and current forces underestimated

   b. Earthquake forces underestimated

   c. Tubular joint design results in low capacity and short fatigue lives

   d. Conductor and riser wear on supports

   e. Insufficient corrosion protection

   f. Unanticipated scour

   g. Gravity load underestimated

2. Construction

   a. Misalignments of legs, braces, and joints

   b. Undercut welds

   c. Insufficient penetration welds

   d. Tank welds

   e. Lamellar tearing

   f. Insufficient pile penetration (lowering axial capacity, lowering lateral capacity)

   g. Load-out, transportation, and launch damage to primary structural elements

3. Operation

   a. Corrosion protection not maintained (above and below water)

   b. Boat bumpers and landings not maintained (resulting in damage to primary structural elements)

   c. Trash dumping (cables, pipe) resulting in damage to legs and braces

   d. Field modifications to structure (cutting holes in members, adding risers and riser supports, adding deck sections and deck cantilevers)

   e. Addition of well conductors and production risers above design

   f. Addition of deck equipment and loadings abode design

   g. Poorly engineered and implemented repairs to primary structural elements

4. Accidental

   a. Boat and barge collisions, resulting in damage to primary structural elements.

   b. Dropped objects resulting in damage to primary structural elements.

   c. Workover operations fires and explosions resulting in damage to primary structural elements.

   d. Production equipment fires and explosions resulting in damage to primary structural elements.

   e. Drilling fires and explosions resulting in damage to primary structural elements.

Table II Examples of Platform Defects

REDUCING PLATFORM DEMANDS - MINIMIZE LOADS AND LOAD EFFECTS

- Reduce deck loads - dead loads from equipment and facilities, live loads from storage
- Reduce wave and current forces - removal and prevention of marine fouling; removal of non-essential components and appurtenances
- Reduce wave and current forces - re-evaluation of wave and current conditions based on site (bathymetric), platform and operations (exposure period) specific conditions and BAST*

INCREASING PLATFORM CAPACITIES - MAXIMIZE STRENGTH OF ELEMENTS

- Increase strength of joints by grouting, welding, profiling, replacement
- Increase strength of primary and secondary members by doubler wraps, replacement, grout fill, secondary bracing, soil strengthening (foundation members)
- Add members - braces, piles, beams
- Re-evaluate Serviceability and Ultimate Limit States resistances and capacities based on platform, site, and operations specific conditions and BAST

REDUCING OPERATIONS EXPOSURES

- Reduce operations carried out onboard or adjacent to the platform
- Reduce deck equipment
- Reduce storage
- Reduce wells and risers
- Increase pollution control, clean-up equipment and measures
- Increase well and production protection equipment and measures
- Reduce manning requirements
- De-manning in advance of anticipated/forecast hazardous events
- Reduce boat/barge transfer operations with equipment tied to platforms or in hazardous conditions
- Reduce frequency of well work-over operations
- Additional effective life-saving equipment and injury treatment facilities and procedures
- Additional training of operations personnel in conduct of safe operations and maintenance of facilities
- Reduce unengineered field alterations to the structure

INCREASING MAINTENANCE EFFECTIVENESS

- Increase corrosion protection - above and below water
- Increase scour protection
- Increase frequency and extent of inspections and conditions surveys
- Increase effectiveness of operations to maintenance engineering reporting systems

*Best Available and Safest Technology

Table III Examples of Platform Hazard Mitigation Alternatives

The results of this implementation are incorporated into the platform condition survey/inspection data bank.

The final step concluding an AIM cycle for a platform is that of designing and implementing the next inspection and maintenance cycle. The length of the cycle will depend upon the projected performance characteristics of the platform, and the need for and benefits of improving knowledge and data on the platform condition and performance.

RISK ANALYSIS

The risk analysis that will be discussed is basic, appropriate for a practical engineering state-of-practice to develop AIM programs. The reader is referred to references [3-21] for background on more comprehensive risk analyses.

The approach (Fig. 5) has been cast in a demand versus capacity format. "Demand" refers to future loadings that may be imposed on the structure. "Capacity" refers to future resistances (or ability to carry loadings) of the structure. The capacities that will be of primary concern are those that connote primary consequences of the loss of serviceability of the platform. The probabilities of the demands exceeding the capacities of the structure will be termed the probabilities of failure.

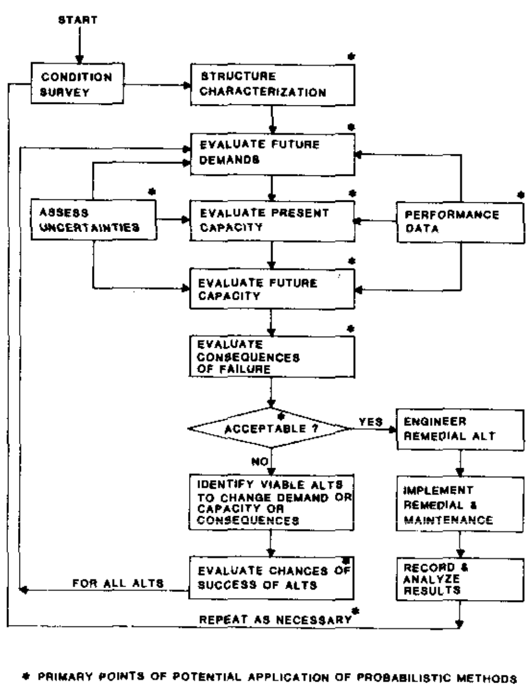


Fig. 5 Risk Analysis Approach

Uncertainties and probabilistics are important ways of describing the structure. They are based on the knowledge provided by the condition survey(s), the future demands (e.g. knowledge of environmental forces), and the future capacities (e.g. knowledge of the load-carrying capacity of the platform). The basics of the approach are deterministics; assessments of uncertainties are added to make the picture more complete. Experience and performance data on either the demands or the capacities play a vital role in assuring reasonable characterizations of these items.

Risk (P_f) will be defined as the probability (P) that the platform's lateral capacity (R_c) is equal to or less than the maximum lateral loading (S_m) imposed on the platform during the exposure period (L):

$$P_{f_L} = P\,(R_c \leq S_m) \qquad (1)$$

The platform's capacity will be taken as the Ultimate Limit State (ULS) resistance or the maximum lateral force that can be imposed on the platform before collapse (unable to support vertical loadings).

Note that the platform's capacity will be dependent upon the as-is condition of the platform's members and upon any changes that might take place in this condition. Such changes might take place as the result of strengthening or rehabilitation measures, or as the result of fatigue, corrosion, or operations damage. Further, note that the platform's lateral capacity will be conditional upon its vertical loadings (as-is, altered in future).

The platform's demands will be expressed as the maximum lateral loadings or forces that could be developed by storms (combination of wind, wave, and current forces) or other similar events that could occur during the platform's exposure period.

The platform's exposure period risk (P_{f_L}) will be related to its annual risk (P_{f_a}) as follows [22]:

$$P_{f_L} = 1 - (1 - P_{f_a})^L \qquad (2)$$

or approximately,

$$P_{f_L} = (P_{f_a}) \cdot L \qquad (3)$$

The environmental lateral loadings will be taken as the dominant source of variability and uncertainty. The uncertainties and variabilities associated with the platform's lateral capacity can be evaluated by determining the changes in risk that develop as a result of changes in the evaluated capacity.

The annual platform risk (annual probability that demand will exceed capacity) is determined as a function of the return period (RP_C) of the storm that develops lateral loads equal to the platform's capacity or ULS resistance:

$$P_{f_a} = 1/RP_C \tag{4}$$

DEMANDS

Characterization of the demands that can be imposed on a platform starts with evaluation of the likelihood of experiencing various intensities of events. These events could be environmental (e.g. developed by hurricanes or earthquakes), or they could be operational (e.g. due to drilling and production activities).

For example, measurements and analyses of hurricanes affecting the northwest Gulf of Mexico [23,24] could develop information on the Average Return Periods (ARP), $\overline{T}$, associated with different possible maximum wave heights occurring at a given platform location (Fig. 6). The ARP's express the average time between occurrences of wave heights that equal or exceed a given maximum wave height (H_m).

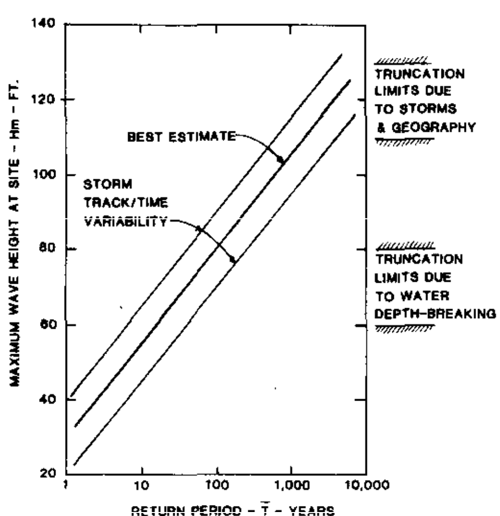


Fig. 6 Wave Heights Vs. Return Period

A similar illustration could be developed for any source of demands. For example, for earthquakes, meaningful measures of the intensity of ground motions (acceleration, velocity, displacement) would replace the wave heights [25].

The key element is to choose parameters that adequately describe the force effects developed by the source of the demand.

Generally, there are two primary sources of variability with regard to environmental demands: intensity and proximity. For example, the heavy line in Fig. 6 represents a typical site in a geographical region. The wave heights are primarily a function of variable storm intensities. The scatter band indicated around the heavy line indicates the uncertainties contributed by proximity, or storm tracks in the case of hurricanes. Both sources of uncertainty should be considered to determine the resultant uncertainty of the occurrence of maximum wave heights at a given platform location.

It is important to recognize site-specific effects, and see that these are properly reflected in the evaluation of uncertainties. For example, shoaling effects at a given location could indicate wave heights that are substantially different from a typical or "average" site condition [26]. Also note that the site can exert important limiting or truncating effects on what could otherwise be a continuous or unlimited distribution of potential wave heights (Fig. 6). Water depth and breaking wave processes place a physical limit on the maxium wave heights that can be developed in shallow water locations. Similar types of site-specific and source-specific factors can place important limitations on the maximum magnitudes of many types of environmental demands.

The next step of the platform demand characterization concerns the prediction of loadings or forces, given the measure of the demand intensities. In the case of hurricanes, given the maximum wave heights, this step determines the loadings on the platform of concern (Fig. 7). This involves computing hydrodynamic forces for the range of wave heights of interest. Other forces of potential concern are those generated by the water currents and winds that occur at the time of the maximum waves. Note the conditionality of the combination of winds, waves, and currents. It is not the maximum wind, wave and current. It is the combination that produces the maximum forces or force effects on the platform. The conditionality not only applies to the magnitudes of the other sources of loading, but also on their directions.

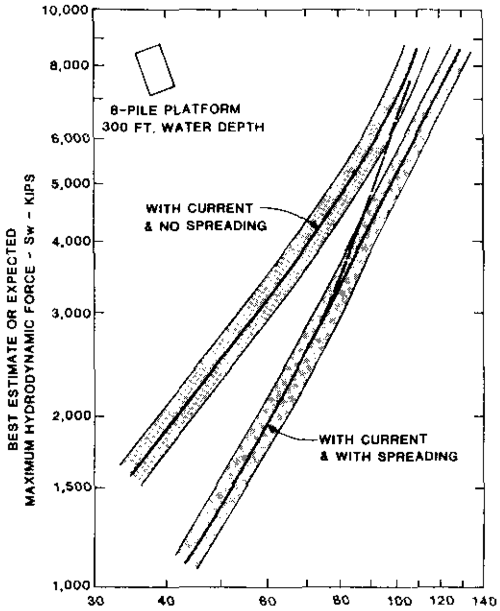
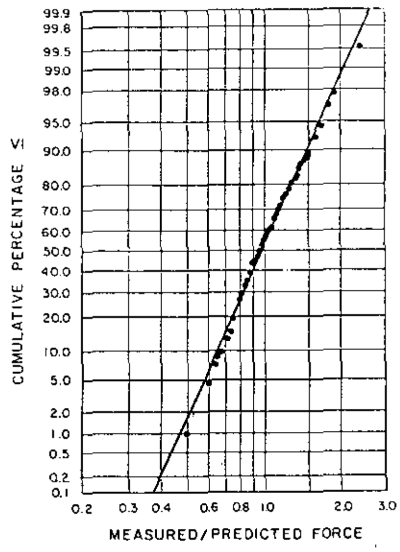


Fig. 7 Influence of Current and Wave Spreading on Hydrodynamic Forces



(PREDICTED FORCE = API GUIDELINE WAVE FORCE, C_D= 0.6, C_m=1.5, NO CURRENT)

Fig. 8 Correlations Between Measured and Predicted Wave Forces

The problem of force prediction is complex, and thus it may be necessary to characterize the forces in a parametric manner, investigating the potential influences of various elements involved in the prediction of forces. For example, one might wait to investigate the effects of including and excluding the hydrodynamic forces associated with directional wave spreading (understanding that the greatest amounts of directional spreading are associated with the maximum wave heights near the storm center).

In this regard, results from recent wave force measurement programs can provide important sources of information to calibrate or verify conventional hydrodynamic force models (Fig. 8). Results from a full-scale instrumented platform in a water depth of 175 feet subjected to maximum wave heights up to 40 feet, and associated surface currents in the range of 1.9 to 3.8 feet per second, indicate that a conventional hydrodynamic force model tends to substantially overpredict the true forces [27,28]. The overprediction exceeds 100 percent when plausible combinations of currents and marine fouling effects are included: the mean ratio of measured to computed force ranges between 0.44 and 0.8. The coefficient of variation (measure of scatter) on the predicted versus measured forces falls in the range of 20 to in excess of 45 percent.

Since the hydrodynamic force computations involve major modeling assumptions concerning computations of wave kinematics, wave propagation through the structure, forces and force coefficients shielding, roughness, etc., the questions regarding the true or best estimate forces must be carefully weighed in contrast to conventional (and intentionally conservative) formulations used in design practice [29].

Note that in this step, it is important to use force prediction methods that result in unbiased predictions of the forces. Bias is defined as the ratio of the true or expected value of the parameter to its nominal or computed value. In this stage of the demand characterization, we want the ratio of true to predicted force to be near unity.

Also note that one could choose to focus the analyses on global load effects (such as total lateral base shear or total overturning moment at the seafloor) or local member load effects (such as the maximum forces in a brace, joint, or pile). In the remainder of the discussion that follows, the focus will be on global demands exerted on the platform. This is not meant to exclude the possibility of conducting similar analyses of elements or structural subsystems within the platform, for these may be of vital interest as well.

The final step in the demand characterization is the one of computing the maximum forces or force effects on the platform, based on the results of the first two steps [30]. The result (Fig. 9) is the characterization of the likelihood (expressed as the ARP) of various possible magnitudes of maximum demands (expressed as the total lateral force on the platform).

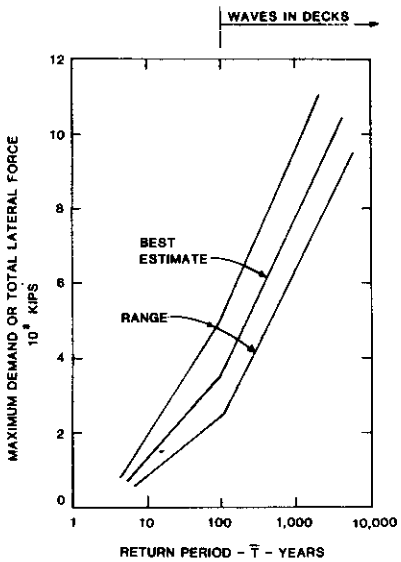


Fig. 9 Platform Demands

CAPACITIES

Platform capacities can be described in Serviceability Limit State and Ultimate Limit State behaviors where:

a. Serviceability Limit State (SLS) - demands or loading-deformation conditions under which the function of the structure may be impaired; damage results, but collapse is not imminent, nor is the platform rendered unserviceable.

b. Ultimate Limit State (ULS) - demands or loading-deformation conditions under which the structure is no longer serviceable, or is unable to fulfill its intended functions.

Capacities generally have been characterized in a resistance-deformation format for the entire structure system (Fig. 10). Generally the capacities are described by load or force resistances, although displacements or deformations may even be more descriptive. For example, if the structure is loaded so that a significant permanent tilt is developed in the structure, its load resistance may be relatively unaffected, but the structure is rendered unserviceable.

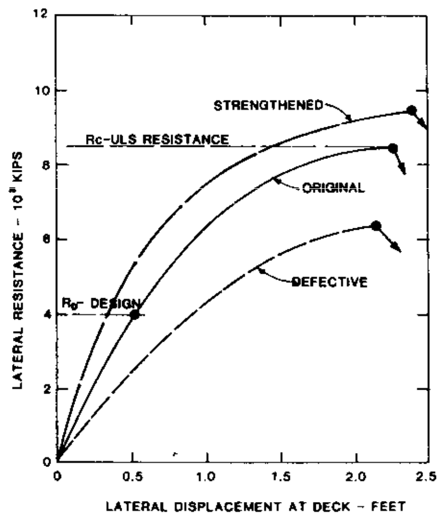


Fig. 10 Capacities of Original, Defective and Strengthened Platform

Capacity of the platform must be characterized in terms that are important to the serviceability properties of the system. In this paper, capacity of the system will be defined in terms of the static, lateral load resistance at which the system is unable to support its gravity or vertical loadings (R_C, Fig. 10). This state will be termed collapse or failure.

Due to the transient nature of most environmental loadings, the structure may or may not be in a true state of failure at this point. Limitations in practical analytical methods to define platform capacity make the definition only an index or imperfect reflector of the behavior of a structure at ULS.

There is a variety of engineering analytical methods to define the platform capacities. Conventional linear elastic analytical methods, such as those used in most design practice, have deficiencies in their abilities to characterize platform ULS capacities. This is due to nonlinear, behavior of platform elements at high loading levels.

Nonlinear, inelastic analytical methods, such as those used in design practice for severe earthquake prone regions, are the best presently available approach for characterizing behavior of the platform at the ULS. However, this approach suffers from complexity and from the general unfamiliarity of most engineers with the technology of nonlinear, inelastic analyses. Even in their simplest form, nonlinear static pushover analyses represent a significant engineering effort although the analytical tools are available [31-35].

To perform time-domain, nonlinear, inelastic structural analyses that properly track the ULS behavior of the structure requires an even more significant effort. Such analyses have been performed for relatively few structures [36-38].

In between these two extremes of analytical approaches lie equivalent linear methods that attempt to mimic the essential elements of nonlinear behavior, yet retain the basic computational tools of linear elastic analyses [16,39-41]. Such approaches require extensive studies of nonlinear behavior in typical platform systems or sub-systems. The results are used to guide the equivalent linear approximations to the true or best estimate nonlinear behavior. The guidance becomes dependent on the particular platform systems or sub-systems studied, and thus lacks generality. However, given sufficient development, this approach represents a practical alternative to either conventional linear elastic methods or nonlinear inelastic methods.

Generally, major AIM concerns with evaluating platform capacity will address the platform in its original (designed), as-is defective (damaged), and possibly strengthened (rehabilitated) conditions (Fig. 10). These capacities become the basis for judging the integrity of the structure and evaluating alternatives for its rehabilitation.

Repair Effects

The effectiveness of alternative repair or rehabilitation measures on the platform capacity should be carefully considered from several standpoints. Experience has shown that repairs to tubular joints and members and foundation elements are major engineering challenges [4,44-47]. These repairs are limited by the practicalities of what can reasonably be accomplished offshore (and often underwater). They call for innovative and effective engineering strategies for repairs that balance strength, stiffness, and ductililty of the single component and the structure system.

Experience has also shown that there is a potential liability that occurs from a poorly designed or poorly executed repair. In more than one case, attempts to repair a component have done more damage than leaving it alone. In some cases, damage has been done to other parts of the platform in the course of attempting the repairs. The potential effects of plausible downside outcomes of platform repairs should be investigated and considered before a repair scheme is selected.

Careful engineering analyses of alternative repair schemes can define effective and practical solutions to difficult repair problems. Evaluations of the results of repairs should include an evaluation of the expected, up-side and down-side effects of the repairs on the platform capacity (Fig. 11).

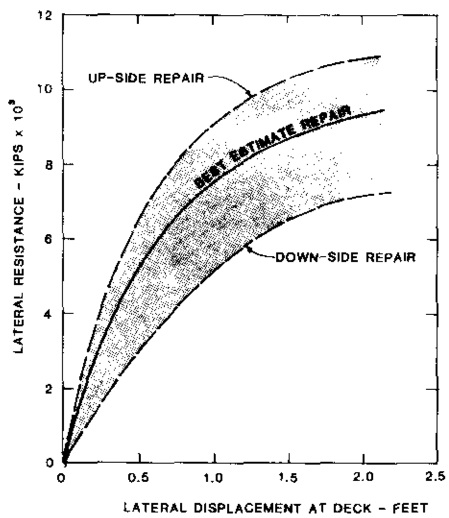


Fig. 11 Effect of Repairs on Platform Capacity

Provision of a rational basis for selecting a remedial alternative (mitigation measure) in the case of a damaged or defective platform is critically important. When condition surveys indicate that some platform element is damaged, the first tendency is to conclude that it must be repaired. In some cases, this is a valid conclusion. However, in many instances repair is unnecessary for the following reasons:

a. Platforms are generally designed to be highly redundant. This redundancy is an investment in producing a highly damage tolerant structure. Even though it is damaged, the structure's capacity may not be seriously affected. Alternative load paths may provide the necessary backup.

b. Platforms are generally designed and constructed with many explicit and implicit sources of conservatisms. Site- and platform-specific conditions may be such that even if there has been some reduction in the capacity of the structure as the result of damage or defects, the structure is still acceptable and highly serviceable.

c. There may be more effective mitigation measures to assure safe operation of the structure. Load (or demand) controls and operation controls can frequently be more effective and less costly in providing a structure that has acceptable serviceability characteristics.

d. There are many elements in a platform that are not important to in-place capacity or performance. Generally these elements are associated with construction (fabrication, transportation, installation) of the structure. Damage to these "secondary" elements does not necessarily imply that there has been an important decrease in the in-place capacity of the platform. Note that these secondary elements or systems can provide important back-up sources of strength to the primary in-place load-carrying members.

Fatigue Considerations

One important AIM concern is potential fatigue damage to platform elements. Fatigue damage, or the reduction in capacity and stiffness as the result of repeated loadings, is present to some extent in all of the platform superstructure and foundation elements. Current fatigue design approaches for those elements are intended to minimize the potential for fatigue damage during the life of the structure [48-50].

A primary concern is with elements that have been damaged, or poorly fabricated, or perhaps underdesigned for fatigue. These problems are usually identified by inspections that show the presence of cracks in the joints and members of the structure, or perhaps by indications that the foundation elements are "softening" (e.g. scour pits around the piles).

For tubular joints and members, a conventional S-N (stress-number of cycles to failure) - Miners Rule (damage accumulation rule for combining different stress-cycle history effects) can do little to assist in characterizing the remaining capacity of a damaged tubular member or joint [51-53]. Conventional foundation analyses are also rarely appropriate [54].

Alternative fatigue analysis approaches have been and are being developed, such as linear elastic and nonlinear fracture mechanics approaches for cracked tubular joints and members [52,55], and load cycle-by-cycle analyses for piles [56]. The approaches are complex. They are still under intensive development. It is not likely at this time (1987) that they can or should be incorporated into a general AIM approach at their present level of development. However, they can provide useful information in some special cases.

A viable approach for recognizing the effects of fatigue damage is that of determining how the capacity of the joint or brace might be reduced by fatigue cracking and other damage [52,57-61]. Analyses and experimental evidence can be used to assist such evaluations.

Inspections seem to provide the only reliable method of detecting fatigue damage [47,52,53], identifying the defects as cracks associated with this damage, and determining if the cracks are growing and leading to additional decreases in the element's capacity.

Projected decreases in the platform system capacity as a function of time (Fig. 12) can be used to guide definition of inspection intervals and consideration of alternative rehabilitation measures (and the timing of repairs). Uncertainties in fatigue effects can be recognized by injecting plausible changes in element capacities and stiffnesses as a function of time, and determining the resultant influences of these changes on platform capacity.

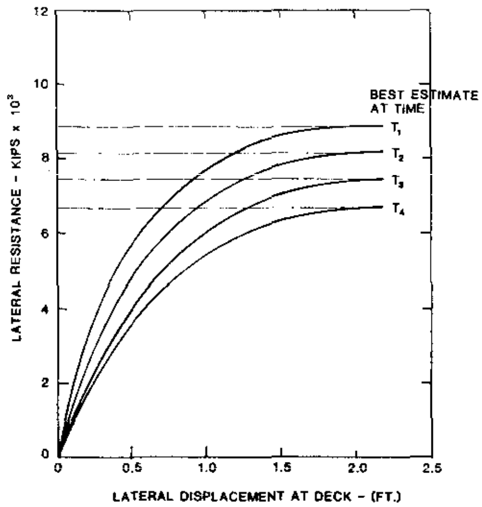


Fig. 12 Platform Capacity Decreases As A Function of Time Due to Fatigue Damage

RISK QUANTIFICATIONS

The approach used in this paper to quantify risk consists of three basic steps:

1. Based on a return period (RP) evaluation for the hazard of primary concern (e.g. hurricanes generating maximum wave heights, H_m) and a best estimate evaluation of the demand (e.g. total lateral force, S_m) associated with the range of the hazard, determine the return periods (likelihoods) associated with the potential demands (Fig. 9).

2. Based on the structure in its as-is condition, in the various conditions represented by practical AIM and rehabilitation measures, and in the various time periods of concern (reflecting potential fatigue effects), determine the best estimate and range of ULS resistances of the platform (R_c) (Figs. 10-12).

3. Determine the annual (A) and exposure period (L) risks (Pf_A and Pf_L, respectively) from

$$Pf_A = P\ (R_c \leqq S_m) \qquad (5)$$

$$Pf_A = (RP_c)^{-1} \qquad (6)$$

$$Pf_L = L \cdot (Pf_A) \qquad (7)$$

where RP_c is the Return Period (years) of the demands that exceed platform capacities.

The range of risks for the range of as-is conditions of the structure (Fig. 13), for various alternative strengthening or AIM measures (Fig. 14), and for various periods of time (Fig. 15) can be used to quantitatively evaluate alternative AIM programs.

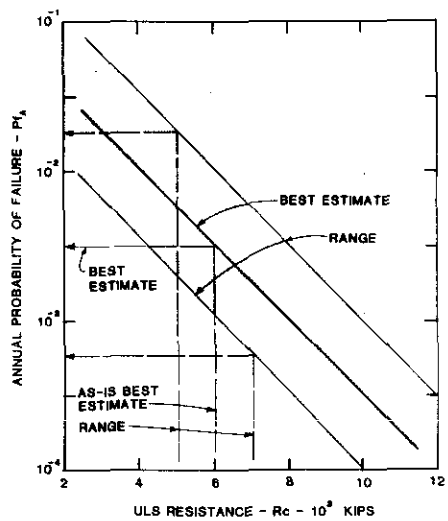


Fig. 13 As-As Condition Platform Risk

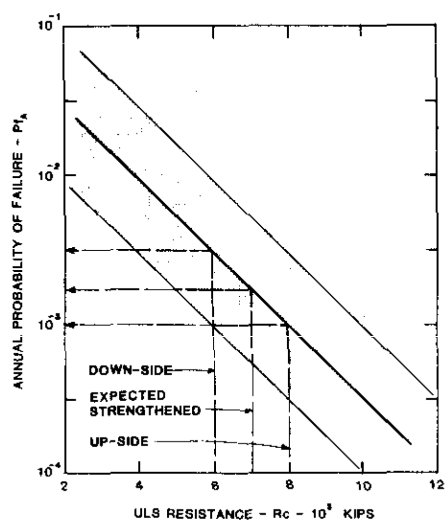


Fig. 14 Effect of Strengthening on Platform Risk

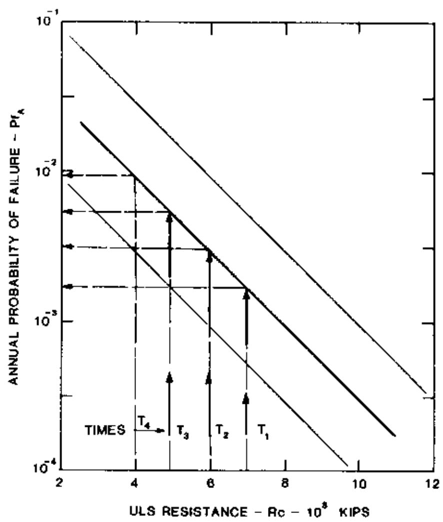


Fig. 15 Effect of Time (Fatigue Damage) on Platform Risk

EVALUATION OF AIM ALTERNATIVES

Evaluation of AIM program alternatives to determine the "best" program is basically a problem of determining the acceptable or tolerable level of risk associated with the platform operations, and the definition of a practical and affordable AIM program that will result in that level of risk. The level of acceptable risk is equivalent to an acceptable ULS resistance of the platform.

There are a wide variety of bases for determining what constitutes a tolerable level of risk. One is historical, i.e., the level of risk that has been developed by the industry and accepted by the public. The difficulty in equating actuarial (historical) and computed risks is twofold: (a) the data from which actuarial risks are derived are very limited (few failures), and (b) the information and analytical methods used to calculate risks result in approximations of the true risk (notional risk). Because quantified risks involve many approximations, they are only an index of the true risk.

Another problem is that the past risks may not be a valid basis to define acceptable future risks. Changing bases of engineering, construction and operations by the industry, and changing values of the public can make past risk bases invalid.

A second approach to defining an acceptable risk level is requiring that the structure be returned to its original or as-designed condition. In the case of platforms that were designed with unconservative criteria, the validity of such an approach is questionable. Similarly, if the platform were conservatively designed originally, then defects or damage need not necessarily imply that the platform risks are below an acceptable level.

A third approach is based on selection of an AIM alternative that attempts to optimize the use of resources, results in the highest possible utility, or develops the greatest present valued benefits associated with operations of the structure [1-3]. This approach is one that attempts to define the AIM program that results in a minimum total expected cost, $E(T)_O$, associated with AIM operations. The total expected cost, E(T) is taken as the sum of expected initial AIM costs E(I), and expected future loss of service costs, E(L):

$$E(T) = E(I) + E(L) \tag{8}$$

The expected initial costs (Fig. 16) are all of those investments that are associated with implementing a particular AIM alternative. These costs could be those associated with strengthening, inspection, and operations changes intended to maintain or increase the platform capacity at some given level.

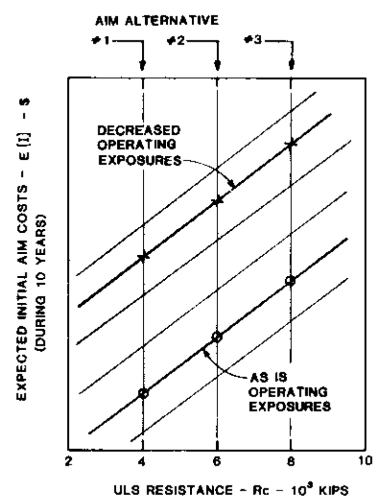


Fig. 16 Platform Initial A I M Alternatives Costs

In addition, initial costs could be associated with changing operations exposures (Fig. 16). For example, reducing onboard oil storage, requiring platform evacuations in advance of storms, and incrementing down-hole safety shut-in equipment can substantially reduce the costs associated with a loss of serviceability of the structure.

The expected costs associated with loss of serviceability (Fig. 17) can be computed as the product of the total costs given a loss of serviceability, C_f, the annual likelihood of the loss of serviceability, Pf_a, and the period of time being considered, L:

$$E(L) = (C_f) \cdot (Pf_a) \cdot L \quad (9)$$

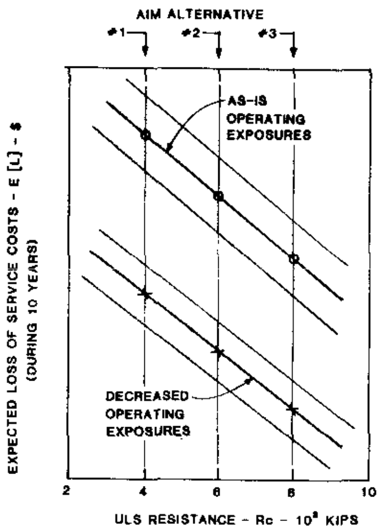


Fig. 17 Platform Expected Loss of Serviceability Costs

The loss of serviceability costs should include the expected value of all of those costs associated with the platform reaching its ULS at the point in time of concern. Such an estimate could be based on a replacement cost or on a salvage and abandonment cost (including the value of lost production or reserves).

Since short periods of time are of usual concern, it may not be necessary to consider present-valuing potential future costs associated with loss of serviceability.

Each AIM program can be associated with maintaining the platform at some ULS resistance for some period of time. The objective is to find the AIM program that develops a minimum total expected cost (Fig. 18).

It should be noted that the total expected cost associated with the AIM programs over the life of the facility must be such that the operations can be maintained at an economic level.

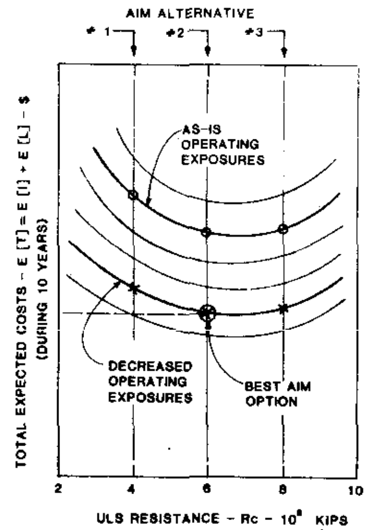


Fig. 18 Total Expected A I M Alternatives Costs

SUMMARY

The objective of this paper has been to outline an integrated, general, and non-prescriptive engineering approach to the requalification of existing platforms. Practicality, in the context of present engineering capabilities, was a key aspect in development of this approach. Keeping platforms in service and establishing their integrity at the least possible cost were key precepts.

Inspection, definition of defects and damage, and repairs and improvements must be given high priority in platform operations if structures are to retain high degrees of serviceability. Poorly maintained structures cost. It costs scarce resources to maintain structures. However, AIM investments can return significant dividends by increasing platform capabilities, lowering the incidence of serious down-time events, and lowering future repair costs. The benefits of AIM engineering and operations should be justified by the benefits that are achieved, and the resources that an operator can invest to keep a vital resource flowing to the market place.

The AIM approach is one of progressive reduction of risks to tolerable levels. The AIM approach proceeds in a step-wise manner through platform identification, a structure condition survey, screening of potential defects and the need for mitigation of these defects to determine the nature of and justification for alternative AIM programs. Once a particular AIM program has been chosen, it is engineered, implemented, and its results recorded as a basis for continuing the next AIM cycle.

Realistic analytical engineering models are a particularly critical element in any platform requalification. Realistic models are needed for characterizing the platform's future demands (loadings) and capacities (loading resistances). It is here that the best available current technology needs to be implemented. It is also here that site- and platform-specific factors may be injected into the analytical models. Of particular importance are the "experience factors." The experience factors pertain to knowledge of how a particular platform, or similar platforms, have performed in the past, especially in high loading (demand) situations. This up-dating information can serve as proof-loading or proof-capacity (resistance) data to assure reality of the analytical models results. It is important that conventional design-oriented analytical procedures and methods be re-examined, site/ platform-specific conditions recognized, and sources of implicit conservatism removed from the characterizations of future demands and capacities.

Uncertainties and the attendant risks are an important aspect of AIM processes and programs. A basic approach has been suggested to characterize platform demands, capacities, and performance. Broad scope AIM programs to manage uncertainties, risks and potential consequences are evaluated in the context of their costs and their benefits. These programs are implemented in a repetitive, continuing process of improving understanding and practices to lower risks associated with existing platforms.

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Metric Conversion Table

1 m = 3.28 ft
1 mm = 0.04 in.
1 m^2 = 10.76 ft^2
1 m^3 = 35.31 ft^2
1 kg m^3 = 0.062 lb/ft^3
1 kg = 2.20 lb.