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SCREENING METHODOLOGIES FOR USE IN PLATFORM ASSESSMENTS AND REQUALIFICATIONS

PROJECT PROGRESS REPORT 4

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March 1995

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1. Introduction

Work on further development and verification of simplified nonlinear analyses for offshore platforms has been continued in the past four months. The deterministic and probabilistic analyses procedures and their verification have been documented in a series of conference and journal papers and proposed for presentation and publication during 1995.

A literature review concerning ultimate and residual strength of damaged and grout repaired tubular members has been completed. Development of simplified procedures to predict the mean capacity of such members is being currently finalized. These developments are presented and briefly discussed. Work on verification cases 4 and 5 is being finalized. A summary of the progress of this work is also included.

Finally, an overview of our research plan and proposed activities for the next three months is presented.

2. Damaged and Repaired Members

2.1. Introduction

A major problem associated with reassessment of an older platform is locating and evaluating the effects of defects and member damage on platform response to extreme loadings. Damage such as dents, global bending, corrosion, and fatigue cracked tubular members can significantly affect the ultimate strength of an offshore platform.

Given the physical properties of damage, an estimate of the ultimate and residual strength of the damaged members is necessary to perform a strength assessment of an offshore platform system. Recently, numerous investigators have devoted their attention to this subject and several theoretical approaches have been developed addressing different types of damage. Small and large scale experiments have been performed to verify the analytical capacity formulations and to gain better understanding of the ultimate and post ultimate behavior of damaged and repaired tubular members.

The objective of this research was first to perform a literature review and identify simplified methods to estimate the ultimate and residual capacity of damaged and repaired tubular members. The simplified residual capacity estimation method is then used to predict the effects of member damage and repair on lateral capacity of platform system. In an effort to establish statistical properties for a bias factor (mean and standard deviation) for the residual strength, the results of the simplified method will be compared with existing theoretical and experimental test results given in literature.

In the following, our literature review on the ultimate strength behavior of damaged and repaired tubular braces with dents, global out-of-straightness, and corrosion is summarized and discussed.

2.2 Dents and Global Bending Damage

2.2.1 Background

Dent-damaged tubular bracing members have been analytically studied since late 70's. The analytical methods of strength prediction developed so far can be classified into three categories (Ricles, 1993):

a) Beam-column analysis (Ellinas, 1984; Chen, 1987; Ricles et al, 1992; Loh, 1993)
b) Numerical integration methods (Kim, 1992; Duan, 1993)
c) Nonlinear finite element methods

Beam-column analysis is based on formulation of equilibrium of the damaged member in its deformed shape. The P-delta effects and the effects of out-of-straightness are considered in the equilibrium equations. The effect of dent depth is taken into account by modifying the cross-sectional properties.

Numerical integration methods use empirical moment-axial load-curvature relationships to iteratively solve the differential equation of axially loaded damaged member. The empirical M-P-Φ relationship is usually based on experimental test results or finite element studies of dented tubular segments.

Nonlinear FE analyses represent the most general and rigorous method of analysis. However, their accuracy and efficiency require evaluation and they are expensive and time consuming to perform.

2.2.2 Loh's Interaction Equation

Developed at Exxon, BCDENT is a general computer program that uses M-p-Φ approach to evaluate the full behavior of dented member. The behavior of the dent section is treated phenomenologically using a set of M-P-Φ expressions. Compared with the experimental results, BCDENT gives mean strength predictions for both dented and undented members.

Based on BCDENT- results, Loh (1993) presented a set of new unity check equations for evaluating the residual strength of dented tubular members. The unity check equations have been calibrated to the lower bound of all existing test data. The equations cover axial compression and tension loading, in combination with multidirectional bending with respect to dent orientation. When the dent depth approaches zero, the recommended equation is identical to API RP 2A equation for undamaged members.

2.2.3 Comparison Between Experimental and Predicted Capacities

Based on a comparison between the experimental ultimate capacities and the corresponding predicted capacities of dented tubulars using different methods of analysis, Ricles (1993) concludes that Ellinas' formulation, which is based on first yield in the dent saddle, is overly conservative. In general, it has been found that Ellinas' approach can be either conservative or unconservative depending on the dent depth, member slenderness, and out-of-straightness.

Ricles further concludes that DENTA (a computer program developed by Taby (1988)), Loh's interaction equation, numerical integration based on M-P-Φ relationships, and the nonlinear FEM are able to predict the residual capacity of the test members reasonably well.

Also, a joint industry project on testing and evaluation of damaged jacket braces was performed by PMB Engineering and Texas A&M University (1990). Twenty salvaged braces were tested and their strength behavior compared with results gained from analyses using finite element beam column models of damaged braces. It was found that in average the analyses would overpredict the capacities by 21%. The agreement in this case is not as good as that presented by other investigators. Use of new and artificially damaged braces in other investigations may explain this inconsistency. Generally corrosion is found to add large uncertainties to the properties of the entire member.

2.2.4 Some Observations and Conclusions

Based on experimental test results and parametric studies using different analytical methods, the following observations, which are relevant to our study, have been made and presented in the literature:

- The residual strength decreases significantly as the dent depth increases.
- For a given dent depth, the analyses show a decrease in residual strength for members with higher D/t ratio.
- The axial compression capacity decreases as the out-of-straightness increases, but the impact on ultimate moment is negligible.
- There is negligible conservatism in assuming a mid-length dent location for any practical dent within the middle-half section of members effective length.
- Accounting for strain hardening has only a small effect on the maximum predicted capacity.
- Lateral loadings, such as those caused by wave forces, can significantly affect dented brace capacity.
- The behavior of members with multiple forms of damage are generally dominated by one damage site.
- The most severe corrosion can occur on the inside surface of the member. A hole in the member would be the primary indication of this condition.
- Corrosion is found to add large uncertainties to the properties of the entire member.
- Ricles (1993): DENTA (developed by Taby 1988), Loh's interaction equation, numerical integration based on M-P-F relationships, and the non-linear FEM are able to predict the residual capacity of the test members reasonably well.

2.3 Corrosion Damage

Marine environment is extremely corrosive. Although cathodic protection systems and protective coatings have been applied to prevent corrosion of steel members, in numerous cases corrosion damage of offshore platforms has been observed. Corrosion results in a reduced wall thickness of the steel member which can lead to premature local buckling at the corroded areas.

Ostapenko et. al. (1993) conducted experimental test on corroded tubulars from salvaged Gulf of Mexico platforms. Local buckling was reported at the most severely corroded area and an up to 50% reduction in capacity was observed. It was found that the patch with the most severe corrosion controls the local buckling of the member.

Ricles and Hebor (1994) performed and presented an analytical and experimental study on patch-corroded steel tubular members. They used the results of an experimental program to verify a non-linear finite element model. The calibrated FE model was then used to perform parametric studies and develop relationships between damaged member residual strength and corrosion patch geometry. Based on a multi-variable non-linear regression analysis, closed-form solution for patch-corroded tubular member strength were derived as a function of D/t ratio and corrosion patch geometry. Excellent agreement is reported between the predicted and experimental capacities.

2.4 Residual strength of grout-repaired damaged tubular members

2.4.1 Background

Given the loss of strength of a member due to damage has a significant impact on strength and reliability of the platform system, it is desirable to apply some measure of strengthening the damaged member. Internal full grouting or using grouted steel clamps are two economically attractive alternatives.

Experimental results have shown that grouting significantly increases the capacity of damaged tubular members and therefore is a viable mean of strengthening such members. In the past, practicing engineers have been applying existing analytical expressions for composite members to estimate the capacity of grout-filled damaged tubular members.

2.4.2 Parsanejad Method

Responding to the need for some sort of analytical expressions, Parsanejad (1987) presented a simple analytical expression for estimating the ultimate capacity of grout-filled damaged tubular members. The analysis is based on the following simplifying assumptions: a) full interaction exists between grout and the damaged tube and b) grout provides sufficient support to the tube wall in the damaged region to prevent premature local buckling.

The first yield collapse criterion is adopted by Parsanejad: it is assumed that the ultimate capacity of damaged tubular member is reached when the compressive stress in the steel tube at the dent equals the yield stress. The damaged member is treated as a beam column with uniform cross-sectional properties represented by the dented region. The total eccentricity is taken as the sum of eccentricities due to initial out-of-straightness, external load, and the distance between the original center of the tube and the centroid of the transformed cross section at the dent.

Comparing the analytical results with the limited experimental results existent at the time, Parsanejad reports good agreement: the analytical results present a close lower bound estimates of test results.

2.4.3 Comparison between experimental and predicted capacities

Ricles et al (1993) performed experiments on thirteen large scale damaged and repaired tubular members with the following objectives:

a) Assessing the residual strength of dent damaged steel tubular bracing members under combined flexural and axial load and
b) determining the effectiveness of using internal complete grouting and grouted steel clamps to repair dent damaged members.

The residual strength of damaged unrepaired and grout repaired specimens were compared to the undamaged design strength according to WSD and LRFD formats respectively. Test results were also compared to results gained from modified Ellinas equation, computer program DENTA, and Parsanejad formulation. The following conclusions regarding grout-filled damaged tubular members are drawn by Ricles et al (1993):

- Internal grout and grouted steel clamp repairs of a 0.1D dent damaged brace are successful in reinstating the original undamaged member's strength by arresting dent growth inwards.

- The predicted strength of internally grout repaired members based on Parsanejad's method provided a close lower bound to experimental data.

3. Verification Cases 4&5

The analysis results for Amoco's ST 161A and the PMB Benchmark platform were presented during the project meeting in October of 1994. These platform analyses have been verified and documented. Their results were used to further calibrate ULSLEA.

The next two platforms to be used for ULSLEA calibration are eight leg platforms located in approximately 137 feet of water. The platforms have very similar configurations and member sizes. They are located near each other and have similar orientations. One of these platforms failed during Hurricane Andrew, while the other survived with almost no observed damage. Thus, these two platforms should provide ULSLEA with a true engineering challenge. The platforms have both been modeled and visually verified using USFOS's postprocessing program. The analysis for both broadside and endon loading of the platform that failed during Andrew is being finalized. A fixed-base broadside analysis is also being performed. The results of these analyses will be verified and compared with ULSLEA results. The second platform will be analyzed in similar fashion as the first. It is expected that these analyses will be completed by the end of March.

4. Plans for next 3 months

In the next three months, we are planning to finalize the development of damaged and repaired element algorithms, improve and finalize the foundation capacity formulation in ULSLEA, and complete the verification case studies with finalizing the analysis and verification of case studies 4&5.

The immediate focus will be to complete the analyses for and document the results of the next two platforms. As indicated above, the analyses are expected to be completed within two weeks. After completion, the results will be verified and compared with ULSLEA.

The analyses for the four aforementioned platforms will also become part of Ken Loch's Master's thesis. In addition to the analysis results, the thesis will document the results of three parameter studies. The studies concern the effects of member initial imperfection magnitude and direction, soil spring modeling assumptions and vertical wave-in-deck forces. Appendix A of the thesis will document the errors and limitation that we encountered during this research. Both human errors and software errors, which in reality are human errors, are discussed. This portion of the thesis should be very useful to the project sponsors, and can be used as a pre- and post-analysis checklist of Level 4 analysis potential pitfalls. A complete copy of the thesis will be available to all project sponsors.

Finally the Personal Computer program ULSLEA will be updated and finalized to incorporate the latest research developments and verification results. A comprehensive Final Project Report and a first version of ULSLEA will be delivered to project sponsors by June 1995.

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