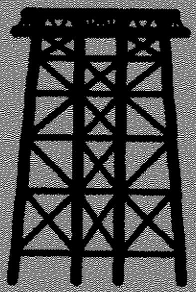
223D

Marine Technology
and Management
Group Project



SCREENING METHODOLOGIES FOR USE IN OFFSHORE PLATFORM ASSESSMENT AND REQUALIFICATION:
PHASE IV

Professor Robert G. Bea

Graduate Student Researcher James D. Stear

Graduate Student Researcher Zhaohui Jin

Graduate Student Researcher Rune Iversen

Department of Civil and Environmental Engineering

University of California at Berkeley

June 24-25, 1998

Marine Technology & Management Group - University of California at Berkeley

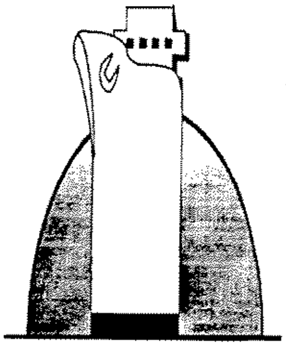
MEETING AGENDA

Wednesday:

1:00 PM	Introduction and project review - *Bob Bea*
1:30	TOPCAT Enhancements I - *Jim Stear*
2:30	Break
2:45	TOPCAT Enhancements II: - *Zhaohui Jin*
3:45	Break
4:00	Ductility-Level Earthquake Analysis Update - *Jim Stear*
5:00 PM	Conclude

Thursday:

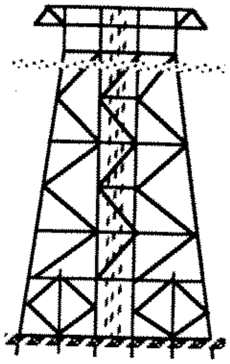
8:00 AM	Review issues from previous day - *Bob Bea*
8:30	Professional Development of TOPCAT- *Dave Garland, EDI*
9:30	SADWAS Proposal - *Bob Bea*
10:30	Phase IV Spring Work Plan - *Bob Bea, Jim Stear, Zhaohui Jin*
11:00	Discussion, sponsors' directions
12:00 PM	Adjourn



1998 - 1999

MARINE TECHNOLOGY & MANAGEMENT GROUP

INDUSTRY & GOVERNMENT AGENCIES SPONSORED RESEARCH PROJECTS SUMMARIES



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Goal: Develop engineering and management technology that will help improve the QUALITY (safety, serviceability, durability, compatibility - economy) of marine systems

RESEARCH AREAS

Human & Organization Factors

Ships & Floating Systems

Platforms & Pipelines

Human and Organization Factors	**Researcher**	**Goals and Objectives**
Human & organization factors in diving operations	Lt. Timothy Liberatore	Promote dive safety through identification, analysis, and management of human and organization factors in diving operations.
Human & organization factors in quality of offshore platforms	Lt. Richard Lawson	Develop and apply a computer program to facilitate analyses of human and organizational factors in the life-cycle quality performance of offshore platforms
Safety Managemen t Assessments in Ship Operations: Human and Organizational Factors	Lt. Paul Szwed Lt. Jason Tama	Develop, verify, and test a protocol and computer program to help perform ship operations Safety Management Assessments (ISM, International Safety Management, Code) with a focus on Human and Organizational Factors
Human and Organizational Factors in Emergency Medicine	Karlene Roberts	Develop and implement research in seven medical units, ranging from paramedic units in fire deaprtments to adut and child critical care units. This research tests a model of risk mitigation. Other investigators participating in this research include

Ships, Platforms, Pipelines	**Researcher**	**Goals and Objectives**
Design and construction of long-life marine composite structures: fatigue	Paul Miller	Develop and test panels of marine composites subjected to repeated loadings in submerged conditions. Develop and verify an analytical procedure to allow the evaluation of the long-term performance characteristics of marine composite panels.
Optimal strategies for the inspections of ships and offshore platforms for fatigue and corrosion damage	Dr. Tao Xu	Develop procedures and strategies to optimize the inspection and repair of ship and offshore platform structures. The inspection strategies will address predictable damage (e.g. fatigue of critical structural details) and unpredictable damage (e.g. due to accidents and errors).
Ultimate Limit State Limit Equilibrium Analyses of template-type offshore platforms - ULSLEA Phases 4 and 5	Jim Stear, Zhaohui-Jin, Pending Assignment	Continue development and verification of a simplified procedure to characterize the ultimate limit state loadings and capacities of offshore platforms and their reliabilities for extreme condition storms and earthquakes.
Performance of pile foundations subjected to earthquake excitations (Profs. Seed, Bray, Pestana)	Philip Meymand, Thomas Lok, Chris Hunt	Develop and verify analytical models to assess the performance characteristics of groups of piles supporting structures subjected to intense earthquake excitations. Perform shaking tests on model pile groups to provide test data to verify the analytical models.
Pipeline Integrity and Maintenance Information System - PIMPIS	Botond Farkis	Develop and verify an inspection and maintenance decision support system for submarine pipelines using a knowledge-based approach. PIMPIS will provide a means of embedding expert knowledge to help select options for pipeline inspections and maintenance.

Ships, Platforms, Pipelines	Researcher	Goals and Objectives
Platform, pipeline, and floating systems design and requalification criteria for the Bay of Campeche and offshore Tampico - Tuxpan	Dr. Tao Xu, Zhaohui-Jin	Develop and verify a general platform and pipeline design and reassessment - requalification system tailored to the unique environmental, operational, and economic characteristics of PEMEX operations in the Bay of Campeche and offshore Tampico and Tuxpan.
Pipeline design criteria for second trunkline North West Shelf Australia	Bob Bea	Develop risk based deformation - strain stability criteria for a 48-inch diameter gas pipeline offshore North West Shelf Australia
ISO earthquake guidelines for design and reassessment of offshore platforms	Bob Bea	Continue development of reliability based platform earthquake design and reassessment guidelines for the International Standards Organization.
Reliability based earthquake LRFD design guidelines for offshore Indonesia	Bob Bea	Develop oceanographic and earthquake platform load and resistance factor design guielines for offshore Indonesia
Decommissioning and re-use of offshore platforms	James Wiseman	Evaluate and document rigs-to-reef alternatives for decommissioning platforms offshore California
Wave loadings on decks of offshore platforms - laboratory data verifications	Rune Iversen	Verify Modified API wave in deck force guidelines with results from laboratory tests
Simplified Analyses of Deep Water Floating Systems (SADWFS)	Assignments Pending	Develop, program and verify simplified analytical procedures to determine the environmental forces and force effects, element and system capacities, and reliabilities of TLPs, FPSO's, and Spars
Wave attenuation due to deformable seafloor conditions	Assignment Pending	Develop guidelines to characterize how interactions between surface waves and deformable sea floors result in changes in the wave amplitude and energy characteristics of the surface waves

Current Publications

1997 - 1998

Fatigue of Ship Critical Structural Details, Journal of Offshore Mechanics and Arctic Engineering, Transactions of the American Society of Mechanical Engineers, Vol. 119, May, 96-107 (Dr. T. Xu, R. G. Bea).

Fatigue of Cracked Ship Critical Structural Details: Cracked S-N Curves and Load Shedding, International Journal of Offshore and Polar Engineering, Vol. 8, No. 2, June (Dr. T. Xu, R. G. Bea).

Towards Optimal Inspection Strategies for Fatigue and Corrosion Damage, 1997 Transactions of the Society of Naval Architects and Marine Engineers, Jersey City, New Jersey (Dr. K. T. Ma, Dr. I. R. Orisamolu, R. T. Huang, and R. G. Bea).

Siting and Evacuation Strategies for Mobile Drilling Units in Hurricanes, Journal of Marine Structures, Elsevier Science Ltdl., Kidlington, Oxford, UK (Dr. J. Ying, R. G. Bea).

Oceanographic and Reliability Characteristics of a Platform in the Mississippi River Delta, Journal of Geotechnical and Geoenvironmental Engineering, American Society of Civil Engineers, Herndon, Virginia (R. G. Bea)

A Reliability Based Screening Procedure for Platform Assessments and Requalifications, Journal of Offshore Mechanics and Arctic Engineering, Transactions of the American Society of Mechanical Engineers, Vol. 120, No. 3, (R. G. Bea, Dr. M. Mortazavi).

Hurricane Wave Conditions for Design and Requalification of Platforms in the Bay of Campeche, Mexico, Proceedings 1998 International OTRD Symposium Ocean Wave Kinematics, Dynamics and Loads on Structures, J. Zhang (Ed), American Society of Civil Engineers, Reston, Virginia (R. G. Bea, Dr. J. Suhayda, Z. Jin, and R. Ramos).

Hurricane Wave Forces on the Decks of Offshore Platforms, Proceedings 1998 International OTRD Symposium Ocean Wave Kinematics, Dynamics and Loads on Structures, J. Zhang (Ed), American Society of Civil Engineers, Reston, Virginia (R. G. Bea, J. Stear, T. Xu, and R. Ramos).

Simplified Strength-Level Earthquake Assessment of Jacket-Type Platforms, Proceedings 8th (1988) International Offshore and Polar Engineering Conference, Montreal, Canada, International Society of Offshore and Polar Engineering, Golden, Colorado (J. Stear, R. G. Bea).

Effects of Damage and Repairs on the Lateral Load Capacity of A Typical Template-Type Offshore Platform, Proceedings 8th (1988) International Offshore and Polar Engineering Conference, Montreal, Canada, International Society of Offshore and Polar Engineering, Golden, Colorado (T. Aviguetero, R. G. Bea).

Risk Based Hurricane and Earthquake Criteria for Design and Requalification of Platforms in the Bay of Campeche, Mexico, Proceedings Offshore Mechanics and Arctic Engineering Conference OMAE '98, Safety and Reliability Symposium, Lisbon, Portugal, American Society of Mechanical Engineers, New York, New York (R. G. Bea, R. Ramos, O. Valle, and V. Valdes).

Risk Assessment & Management Based Guidelines for Design & Reassessment of Pipelines in the Bay of Campeche, Mexico, Proceedings Offshore Mechanics and Arctic Engineering Conference OMAE '98, Safety and Reliability Symposium, Lisbon, Portugal, American Society of Mechanical Engineers, New York, New York (R. G. Bea, R. Ramos, T. Hernandez, and O. Valle).

Evaluation of the Reliability of Platform Pile Foundations in the Bay of Campeche, Mexico, Proceedings Offshore Mechanics and Arctic Engineering Conference OMAE '98, Safety and Reliability Symposium, Lisbon, Portugal, American Society of Mechanical Engineers, New York, New York (R. G. Bea, Z. Jin, C. Valle, and R. Ramos).

Risk Based Requalification of the Monopod Platform, Cook Inlet, Alaska, Proceedings Offshore Mechanics and Arctic Engineering Conference OMAE '98, Safety and Reliability Symposium, Lisbon, Portugal, American Society of Mechanical Engineers, New York, New York (R. G. Bea, Dr. J. Ying, D. Hopper, and M. Craig).

Safety Management Assessment System (SMAS) Part I: A Process for Identifying and Evaluating Human and Organization Factors in Operations of Offshore Platforms, Proceedings Offshore Mechanics and Arctic Engineering Conference OMAE '98, Safety and Reliability Symposium, Lisbon, Portugal, American Society of Mechanical Engineers, New York, New York (Dr. D. Hee, R. G. Bea, Dr. K. Roberts, and Dr. B. Williamson).

Safety Management Assessment System (SMAS) Part I: Field Test and Results, Proceedings Offshore Mechanics and Arctic Engineering Conference OMAE '98, Safety and Reliability Symposium, Lisbon, Portugal, American Society of Mechanical Engineers, New York, New York (Dr. D. Hee, R. G. Bea, Lt. Cmdr. Brant Pickrell, Dr. K. Roberts, and Dr. B. Williamson).

Non-Linear Dynamics of Caisson Well-Protectors During Hurricane Andrew, Report to U. S. Minearals Management Service, Herndon, Virginia, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, August (J. Wiseman, R. G. Bea).

Near Surface Wave Theory, Wave-in-Deck Forces, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown and Root International, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, August (Dr. T. Xu, R. G. Bea).

Reassessment of Tubular Joint Capacity, Uncertainty and Reliability, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown and Root International, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, August (Dr. T. Xu, R. G. Bea).

Analysis of Wave Attenuation in the Bay of Campeche, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown and Root International, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, August (Z. Jin, R. G. Bea).

Dynamic Response of a Single Pile to Lateral Loading, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown and Root International, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, August (Z. Jin, R. G. Bea).

Risk Based Hurricane and Earthquake Criteria for Design and Requalification of Platforms in the Bay of Campeche (Part I), Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown and Root International, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, September (R. G. Bea).

Risk Based Criteria for Design and Requalification of Pipelines and Risers in the Bay of Campeche (Part I), Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown and Root International, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, September (R. G. Bea).

Report #1 - Reliability Characteristics of the Pol A Compression Platform, Platform Structure & Foundation Performance Analyses, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown and Root International, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, October (R. G. Bea).

Report #2 - Reliability Characteristics of the Pol A Compression Platform, Platform Reassessment and Requalification Evaluations, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown and Root International, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, September (R. G. Bea).

Safety Management Assessment Systemn (SMAS), Marine Technology & Management Group, Dept. of Civil and Environmental Engineering, University of California, Berkeley, November (with Dr. D. Hee)

Risk Based Hurricane Criteria for Design of Floating and Subsea Systems in the Bay of Campeche, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown & Root International Inc., Marine Technology & Management Group, University of California, Berkeley, December (R. G. Bea).

Analysis of Hurricane Wave Decay Characteristics, Risk Based Criteria for Design & Requalification of Offshroe Platforms in the North Region, Report to Petroleos Mexicanos, and Instituto Mexicano del Petroleo, Marine Technology & Management Group, University of California, Berkeley, December (Z. Jin, R. G. Bea).

Risk Based Life Cycle Fatigue Criteria, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown & Root International Inc., Marine Technology & Management Group, University of California, Berkeley, December (Dr. T. Xu, R. G. Bea).

Dynamic Lateral and Axial Loading Capacities of Piles in the Bay of Campeche, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown & Root International Inc., Marine Technology & Management Group, University of California, Berkeley, December (Z. Jin, R. G. Bea)

Risk Based Hurricane Criteria for Design of Floating and Subsea Systems in the Bay of Campeche, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown & Root International Inc., Marine Technology & Management Group, University of California, Berkeley, December (R. G. Bea).

Report #1A, Reliability Characteristics of the Pol A Compression Platform, Platform Ultimate Limit State Limit Equilibrium (ULSLEA) and Reliability Analyses, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown & Root International, Inc., Marine Technology and Management Group, Dept. of Civil & Environmental Engineering, University of California at Berkeley, December (Dr. T.Xu, R. G. Bea)

Workshops on 1997 Projects - risk Based Hurricane and Earthquake Criteria for Design and Requalifiation of Platforms, Pipelines, Risers, and Floating Systems in the Bay of Campeche, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown & Root International, Inc., Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, December (Dr. T. Xum Z. Jin, R. G. Bea).

Risk Based Hurricane and Earthquake Criteria for Design and Requalification of Platforms in the North Region (Tampico and Tuxpan), Final Report to Petroleos Mexicanos and Instituto Mexicano del Petroleo, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, December (R. G. Bea).

Risk Based Stability Criteria for Dsign of the Second Trunkline on the North West Shelf of Western Australia, Report to BRK Joint Venture and Woodside Offshore Petroleum Pty. Ltd., Perth, Western Australia, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, December (R. G. Bea).

Risk Based Oceanographic & Earthquake Load and Resistance Factor Criteria for Design and Requalification of Platforms Offshore Indonesia, Report to Indonesian Petroleum Association, Directorate General of Oil & Gas of Indonesia, and Bandung Institute of Technology, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, December (R. G. Bea).

Comparative Evaluation of Minimum Structures and Jackets, Stage II: Analysis of Human and Organizational Factors, Report to Joint Industry - Government Sponsored Project, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, December (R. G. Bea, Lt. R. Lawson).

SYRAS, System Risk Assessment Software, Version 1.0, , Report to Joint Industry - Government Sponsored Project, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, December (Lt. R. Lawson, R. G. Bea).

Reassessment of Tubular Joint Capacity, Screening Methodolgies Project Phase IV, 38) Comparative Evaluation of Minimum Structures and Jackets, Stage II: Analysis of Human and Organizational Factors, Report to Joint Industry - Government Sponsored Project, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, January (Dr. T. Xu, R. G. Bea).

Loading and Capacity Characteristics of Pile Foundations: Correlation of Calculation Results with ULSLEA, Screening Methodlogies Project Phase IV, Report to Joint Industry - Government Sponsored Project, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, January (Z. Jin, R. G. Bea).

Continued Development of Earthquake Load and Resistance Factor Design Guidelines, Report 1, Concrete Gravity Based Structures LRFD Guidelines, Report to Health and Safety Executive, Offshore Safety Division, Bootle, Merseyside, UK, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, March (R. G. Bea).

Report #1B, Reliability Characteristics of the Pol A Compression Platform, Updated Platform Ultimate Limit State Limit Equilibrium (ULSLEA) and Reliability Analyses, Report to Petroleos Mexicanos, Instituto Mexicano del Petroleo, and Brown & Root International Inc., Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, April (Dr. T. Xu, R. G. Bea).

Continued Development of Earthquake Load and Resistance Factor Design Guidelines, Report 2, Seismic Hazard Characterizations, Report to STATOIL and UNOCAL, Stavanger, Norway, Houston, Texas, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, May.

Development of a Safety Management Assessment System for the International Safety Management Code, Report to the U. S. Coast Guard, Washington, DC, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, May (Lt. P. Szwed, R. G. Bea).

Rigs-to-Reefs Siting and Design Study for Offshore California: Addressing the Issues Developed During Workshop "Recent Experiences and Future Deepwater Challenges," Report to California Sea Grant College Program and the U. S. Minerals Management Service, La Jolla, California, Herndon, Virginia, Marine Technology & Management Group, Dept. of Civil & Environmental Engineering, University of California, Berkeley, May (J. Wiseman, R. G. Bea).

Risk Based Oceanographic Criteria for Platforms in the Bay of Campeche, Proceedings of the Symposium on Risk Based Criteria, Petroleos Mexicano (PEMEX0 and Instituto Mexicano del Petroleo (IMP), Mexico City, September (R. G. Bea).

Risk Based Criteria for the Design, Construction, and Operation of Deep Water Structures, Proceedings of the 3rd International Symposium on Offshore Hydrocarbon Exploration Technologies, Instituto Mexicano del Petroleo, Mexico, City, October (R. G. Bea).

Analysis of Siting and Evacuation Strategies for Mobile Drilling Units in Hurrianes, Proceedings of the Offshore Technology Conference, OTC 8707, Society of Petroleum Engineers, Richardson, Texas (Dr. J. Ying, R. G. Bea).

Risk Assessment & Management Based Hurricane Wave Criteria for Design and Requalification of Platforms in the Bay of Campeche, Proceedings of the Offshore Technology Conference, OTC 8692, Society of Petroleum Engineers, Richardson, Texas (R. G. Bea, R. Ramos, O. Valle, V. Valdes, andR. Maya).

Risk Assessment & Management Based Hurricane Wave Criteria for Design and Requalification of Pippelines and Risers in the Bay of Campeche, Proceedings of the Offshore Technology Conference, OTC 8695, Society of Petroleum Engineers, Richardson, Texas (R. G. Bea, R. Ramos, O. Valle, V. Valdes, andR. Maya).

Development and Application of Risk Evaluation Methods for a Bay of Campeche Offshore Platform, Proceedings of the Offshore Technology Conference, OTC 8696, Society of Petroleum Engineers, Richardson, Texas (M. Chavez, D. Hopper, R. Roberts, V. Valdes, O. Valle, R. G. Bea).

Key Issues Associated with Development of Reassessment & Requalifiation Criteria for Platforms int he Bay of Campeche, Mexico, Proceedings of the International Workshop on Platform Requalification, 17th International Conference on Offshore Mechanics and Arctic Engineering OMAE '98, Lisbon, Portugal, American Society of Mechanical Engineers, New Yortk, New York (R. G. Bea, O. Valle).

Quality Assurance for Marine Structures, Proceedings of the 13th International Ship and Offshore Structures Congress, Trondheim, Norway (R. G. Bea, Dr. S-C Leee, Prof. A. Ulvarson, Prof. O. Westby, Dr. W. H. Moore, Captain D. L. Stanley, Dr. B. L. Thompson, and Dr. T. Xu)

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Human and Organization Errors in Reliability of Offshore Structures, Transactions of the American Society of Mechanical Engineers, Vol. 119, Feb. 1997 (R. G. Bea).

Evaluation of Storm Loadings on and Capacities of Offshore Platforms, Journal of waterway. Port, Coastal, and Ocean Engineering, American Society of Civil Engineers, Vol. 123, No. 2, March/April 1997 (R. G. Bea, M. M. Mortazavi, and K. J. Lock).

Capacities of Template-Type Platforms in the Gulf of Mexico During Hurricane Andrew, Journal of Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers, Vol. 119, Feb. 1997 (R. G. Bea, K. J. Lock and P. L. Young).

ULSLEA: A Limit Equilibrium Procedure to Determine the Ultimate Limit State Loading Capacities of Template Type Platforms, Journal of Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers, Vol. 118, Nov. 1996 (R. G. Bea, M. M. Mortazavi).

Load Shedding of Fatigue Fracture in Ship Structures, Journal of Marine Structures, Vol 10, Elsevier, 1997 (R. G. Bea, T. Xu).

Assessing the Risks and Conutermeasures for Human and Organizational Error, Transactions, American Society of Naval Architects and Marine Engineers, 1996 (R. G. Bea, Lt. D. Boniface).

Human and Organization Factors: Engineering Operating Safety Into Offshore Structures, Reliability Engineering and System Safety, Vol 52, Elsevier Science Limited, 1997.

Fatigue of Ship Critical Structural Details, Journal of Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers, May 1997 (R. G. Bea, T. Xu).

In-Service Inspection Programs for Marine Structures, Proceedings 16th International Conference on Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers, Yokohama, Japan, 1997 (R. G. Bea, T. Xu).

Managing Rapidly Developing Crises: Real-Time Prevention of Marine System Accidents, Proceedings 16th International Conference on Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers, Yokohama, Japan, 1997 (R. G. Bea, K. Roberts).

Reliability Based Load and Resistance Factor Design Guidelines for Offshore Platforms to Resist Earthquakes, Proceedings 16th International Conference on Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers, Yokohama, Japan, 1997 (R. G. Bea, M. J. K. Craig).

Comparative Analysis of the Capacities of Gulf of Mexico Steel Template-Type Platforms Subjected to Hurricane Forces, Proceedings 16th International Conference on Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers, Yokohama, Japan, 1997 (R. G. Bea, J. Stear).

Background for the Proposed International Standards Organization Reliability Based Seismic Design Guidelines for Offshore Platforms, Earthquake Criteria Workshop Proceedings, 16th International Conference on Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers, Yokohama, Japan, 1997.

Reassessment and Requalification of Two Gulf of Mexico Platforms, Proceedings 7th International Conference on Offshore and Polar Engineering, Honolulu, Hawaii, May 1997 (R. G. Bea, A. Sturm and T. Miller).

Reliability Based Design & Requalification Criteria for Longitudinally Corroded Pipelines, Proceedings 7th International Conference on Offshore and Polar Engineering, Honolulu, Hawaii, May 1997 (Y. Bai, T. Xu, and R. G. Bea).

Offshore Single Point Mooring Systems for Import of Hazardous Liquid Cargoes Offshore Southern California, Proceedings 7th International Conference on Offshore and Polar Engineering, Honolulu, Hawaii, May 1997 (R. G. Bea, A. Salancy)

Experimental Validation of the Ultimate Limit State Limit Equilibrium Analysis (ULSLEA) with Results from Frame Tests, Proceedings 7th International Conference on Offshore and Polar Engineering, Honolulu, Hawaii, May 1997 (R. G. Bea, M. Mortazavi).

Experience with Fast Rack Risk Assessment Used to Compare Alternative Platforms, Proceedings of the International Conference on Safety and Reliability, European Safety and Reliability Association, Lisbon, Portugal, June 1997 (R. G. Bea, A. Brandtzaeg).

Human and Organizational Factor Considerations in the Structure Design Process for Offshore Platforms, Proceedings of the International Workshop on Human Factors in Offshore Operations, U. S. Minerals Management Service, New Orleans, Louisiana, Dec. 1996 (R. G. Bea).

Accident and Near-Miss Assessments and Reporting, Human and Organizational Factor Considerations in the Structure Design Process for Offshore Platforms, Proceedings of the International Workshop on Human Factors in Offshore Operations, U. S. Minerals Management Service, New Orleans, Louisiana, Dec. 1996 (R. G. Bea).

Real-Time Prevention of Platform Drilling Blowouts: Managing Rapidly Developing Crises, Human and Organizational Factor Considerations in the Structure Design Process for Offshore Platforms, Proceedings of the International Workshop on Human Factors in Offshore Operations, U. S. Minerals Management Service, New Orleans, Louisiana, Dec. 1996 (R. G. Bea).

A Safety Management Assessment System (SMAS) for Offshore Platforms, Human and Organizational Factor Considerations in the Structure Design Process for Offshore Platforms, Proceedings of the International Workshop on Human Factors in Offshore Operations, U. S. Minerals Management Service, New Orleans, Louisiana, Dec. 1996 (R. G. Bea).

Human and Organization Factors in Safety of Offshore Platforms, Proceedings of the International Workshop on Human Factors in Offshore Operations, U. S. Minerals Management Service, New Orleans, Louisiana, Dec. 1996 (R. G. Bea).

A Decision Analysis Framework for Assessing Human and Organizational Error in the Marine Industries, Proceedings of the Symposium on Human and Organizational Error in Marine Structures, Ship Structure Committee - Society of Naval Architects and Marine Engineers, Arlington, Virginia, November 1996 (R. G. Bea, Lt. D. Boniface).

Consideration of Human and Organization Factors in Development of Design, Construction, and Maintenance Guidelines for Ship Structures, Proceedings of the Symposium on Human and Organizational Error in Marine

Structures, Ship Structure Committee - Society of Naval Architects and Marine Engineers, Arlington, Virginia, November 1996 (R. G. Bea).

High Reliability Tanker Loading & Discharge Operations: Chevron Long Wharf, Richmond, California, Proceedings of the Symposium on Human and Organizational Error in Marine Structures, Ship Structure Committee - Society of Naval Architects and Marine Engineers, Arlington, Virginia, November 1996.

Ship Structural Integrity Information System Phase II, Ship Structure Committee SSC 388, Washington, DC, 1996, NTIS #PB96-167564 (R. G. Bea, M. Dry, R. Schulte-Strathaus).

Risk Based Oceanographic Criteria for Design and Requalification of Platforms in the Bay of Campeche, Report to Petroleos Mexicanos and Instituto Mexicano del Petroleo, March 1997 (R. G. Bea).

Structural Reliability of the Monopod Platform, Report to Unocal Corporation, December 1997 (R. G. Bea, J. Ying).

ULSLEA: Parametric Studies of the Effects of Local Damage and Repairs on Global Lateral Load Capacity of a Typical Offshore Platform, Report to U. S. Minerals Management Service and Joint Industry Project Sponsors, Dec. 1996 (R. G. Bea, T. Aviguerto).

Marine Infrastructure Rejuvenation Engineering: Fatigue and Fracture of Critical Structural Details (CSD), Marine Technology and Management Group Report, University of California at Berkeley, Jan. 1997 (R. G. Bea, T. Xu).

Ship Maintenance Project: Program Summary and Rational Basis for Corrosion Limits on Tankers, Ship Structure Committee SSC 395, Washington, DC, NTIS #PB97-142822.

Ship Maintenance Project: Study of Fatigue of Proposed Critical Structural Details in Double Hull Tankers, Ship Structure Committee SSC 395, Washington, DC, NTIS #PB97-142830.

Ship Maintenance Project: Repair Management System for Critical Structural Details in Ships, Ship Structure Committee SSC 395, Washington, DC, NTIS #PB97-142848.

Ship Maintenance Project: Fatigue Classification of Critical Structural Details in Tankers, Ship Structure Committee SSC 395, Washington, DC, NTIS #PB97-142855.

Ship Maintenance Project, Fitness for Purpose Evaluation of Critical Structural Details in Tankers, Ship Structure Committee SSC 395, Washington, DC, NTIS #PB97-142863.

Assessment of Human and Organizational Factors in Operations of Marine Terminals and Offshore Platforms, Marine Technology Management Group Report, University of California at Berkeley, May 1997 (R. G. Bea, Lt. B. Pickrell).

Ship Structural Integrity Information System: Phase III - SSIIS IIIl, Marine Technology and Managment Group Report, University of California at Berkeely, May 1997 (R. G. Bea, H. P. Reeve).

Life Cycle Reliability & Risk Characteristics of Minimum Structures, Proceedings of the Offshore Technology Conference, Houston, Texas, OTC 8361, May 1997 (R. G. Bea, M. Craig and T. Miller).

Ultimate Limit State Capacity Analyses of Two Gulf of Mexico Platforms, Proceedings of the Offshore Technology Conference, Houston, Texas, OTC 8418, May 1997 (R. G. Bea, J. Stear).

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SCREENING METHODOLOGIES FOR USE IN OFFSHORE PLATFORM ASSESSMENT AND REQUALIFICATION

Project Objective:

Further develop and verify simplified quantitative screening methodologies for Level 2 platform assessments so these methodologies may be used in practice

Phase I:	**June 1993 to May 1995**
Phase II:	**June 1995 to May 1996**
Phase III:	**June 1996 to May 1997**
Phase IV:	**June 1997 to December 1998**
Phase V:	

PHASE IV PROJECT SPONSORS

ARCO Exploration and Production Technology

Chevron Petroleum Technology Company

Exxon Production Research Company

Mobil Technology Company

Shell Deepwater Development Company

PEMEX / IMP / Brown & Root

US Minerals Management Service

PHASE IV DELIVERABLES

#1:

Documentation of ULSLEA/TOPCAT program enhancements, comparisons, developments, evaluations, and verifications

#2:

Updated ULSLEA/TOPCAT user manual; updated ULSLEA/TOPCAT software

#3:

Two meetings

ULSLEA PHASE I

- Aero and hydrodynamic loads ✓
- Unbraced deck legs capacity ✓
- Jacket capacity (legs, braces, joints) ✓
- Foundation capacity ✓
- Deterministic ULS analysis ✓
- Probabilistic ULS analysis ✓
- Damaged and grout-repaired members ✓
- Verification case studies (5) ✓
- ULSLEA software ✓
- Reports (2) ✓
- Meetings (2) ✓

ULSLEA PHASE II

- Modeling enhancements ✓
- Code updating and enhancement ✓
- Preliminary design of braces ✓
- Jacket horizontal framing effects ✓
- Additional verifications (2) ✓
- Linear analysis comparisons ✓
- ULSLEA software and user manual ✓
- Reports (3) ✓
- Meetings (2) ✓

ULSLEA PHASE III

- Fatigue analysis algorithms ✓
- Earthquake analysis algorithms ✓
- Verifications of earthquake analysis (3) ✓
- Earthquake deck accelerations ✓
- Additional configurations ✓
- Platform strength and robustness studies ✓
- Code updating ✓
- ULSLEA Software ✓
- Reports (3) ✓
- Meetings (2) ✓

ULSLEA/TOPCAT PHASE IV

- Platform Damage Studies (1) ✓
- Additional Configurations (2) ✓
- Tubular Joint Uncertainties ✓
- Platform Foundations ✓
- Improved Input / Output ✓
- Reliability Sensitivity Factors ✓
- Spatial Considerations for Wave Loads ✓
- Shallow Water Kinematics ✓
- Deck Elements → ✓
- Platform Damage Studies (2)
- Ductility-Level Earthquake Analysis → ✓
- Diagonal Loads on Platforms → ✓
- TOPCAT software and new user manual ✓
- Reports (3) ✓
- Meetings (2) ✓

TOPCAT ENHANCEMENTS I

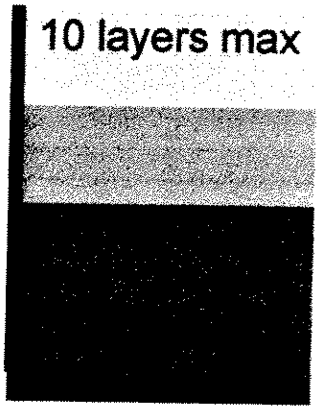
TOPCAT

Template Offshore Platform
Capacity Assessment Tools

- Foundation Features
- Coding Changes
- New Structures
- Input/Output
- User Manual

by James D. Stear

Soil Profile Definition

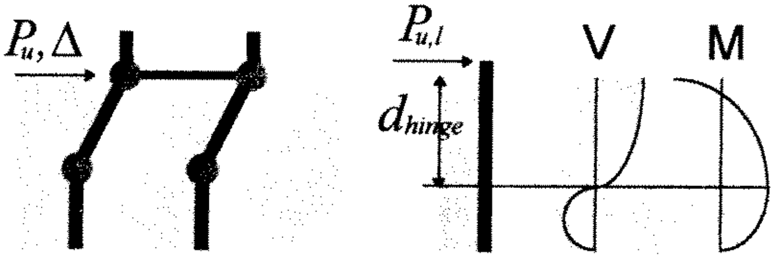


Sand: need ϕ

Clay: need p_s at top and bottom of layer

All: bottom of layer and submerged unit weight

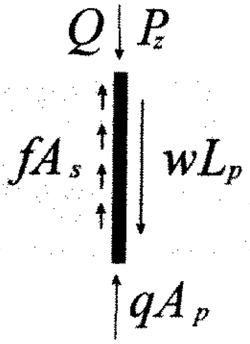
Piles Capacities: Lateral



$$P_{u,l} = \left[2M_u + \int_0^{d_{hinge}} z \cdot p_s(z)dz\right] \cdot \left(\frac{1}{d_{hinge}}\right)$$

$$P_{u,l} = \int_0^{d_{hinge}} p_s(z)dz$$

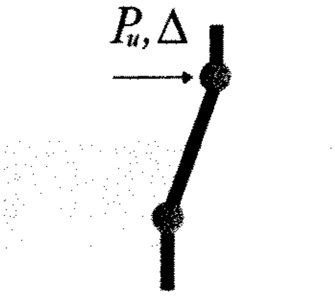
Pile Capacities: Axial



$$P_z = qA_p - wL_p - Q + \int_0^{L_p} f(z)A_s dz$$

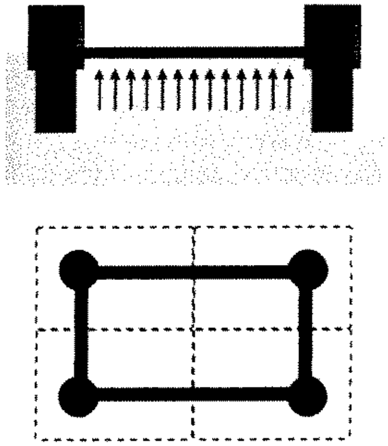
Conductors

- Model as piles
- Can bias for group effects
- No vertical strength or stiffness
- Return attachment load to user
- User defines M_p, l, w



Mats and Braces

- Sliding and vertical resistance
- Capacity based on soil yielding
- Mat, brace areas are lumped at pile locations
- Foundation level is rigid diaphragm
- Return surface loads on elements to user



Mats and Braces

Use API for bearing and sliding strength:

Clay, bearing: $Q = 5.14cA$

Clay, sliding: $H = cA$

Sand, bearing: $Q = 0.3\gamma' BN_\gamma A$

Sand, sliding: $H = c' A + Q \tan \phi'$

Mats and Braces

Use Barkan (1962) for stiffnesses:

Soil Group	Bearing Strength (ksf)	Vertical Stiffness (ksf/ft)
weak	3 or less	190
medium	3 to 7	190 to 310
strong	7 to 10	310 to 620
rock	10+	620

sliding stiffness is 50% vertical stiffness

Coding Changes

Internal Changes:

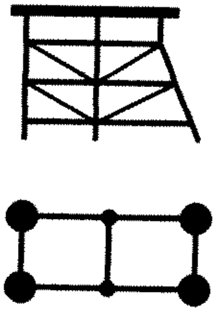
- Development done in Excel 7.0 for Win95
- Now a single workbook, INP.xls eliminated
- All Excel 4.0 macros replaced
- Stokes fifth-order kinematics no longer done on sheet

TOPCAT

Template Offshore Platform Capacity Assessment Tools

New Structures

- Can model jackets with equal batter on three sides, with different center and corner legs
- Can model tripods with a single vertical leg
- Caisson input interface completely revised



New Input

- New menu structure
- Local yield strength specification for braces, piles and joints
- Local k specification for braces
- Local SCF specification for joints
- Can store earthquake, fatigue parameters

TOPCAT

Template Offshore Platform Capacity Assessment Tools

Improved Output

Tabular Output:

- Revised printing features, no more blank pages
- Pile capacities, stiffnesses, loads
- Mode shapes and periods
- Fatigue damage
- Shears at framing levels and bay capacities
- Brace capacities with and without local forces

TOPCAT

Template Offshore Platform Capacity Assessment Tools

Improved Output

Graphical Output:

- Mode shapes
- Fatigue criticality for main diagonals
- Correct titles for plots

TOPCAT

Template Offshore Platform
Capacity Assessment Tools

New User Manual

- Incorporates information on all modifications to date
- Technical report sections are included as appendices
- Tutorial example for modeling and analysis of a jacket
- Modeling examples for jackets, tripods and caissons

TOPCAT

Template Offshore Platform
Capacity Assessment Tools

TOPCAT UPDATING AND ENHANCEMENTS, SPRING,'98

TOPCAT

Template Offshore Platform
Capacity Assessment Tools

Report to Joint Industry
Project ponsors

by
Zhaohui Jin
and Professor R.G. Bea
Departmentt of Civil and
Environmental Engineering
University of California at Berkeley

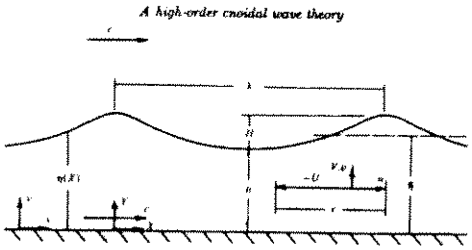
1. Shallow Water Wave Kinematics - Cnodial Wave Theory

- Reason for application of Cnoidal Theory
  -- Stokes V blows out in shallow water
- How well does Cnoidal approximation work?
  -- Second order approximation good enough for engineering practice

---

Wave Characteristics definition in Cnoidal Wave Theory

- Basic input:
  H -- wave height
  d -- water depth
  T -- wave period
- Principal output:
  h -- trough depth
  c -- celerity
  κ -- Jacobian elliptic function modulus



Basic Theoretical Stuffs

Complete elliptic integral of the first kind:

$$K(\kappa) = \int_0^{\pi/2} \frac{1}{\sqrt{1-\kappa^2 \sin^2 x}} dx$$

Complete elliptic integral of the second kind:

$$E(\kappa) = \int_0^{\pi/2} \sqrt{1-\kappa^2 \sin^2 x} dx$$

Key equations in the shallow water kinematics module in TOPCAT:

relationship between d and T:

$$\frac{d}{gT^2} = \frac{3\varepsilon}{16k^2K^2}\left\{\left(\frac{1+\varepsilon c_1+\varepsilon^2 c_2}{1-\varepsilon l_1}\right)^2 + [\varepsilon^3]\right\}$$

Horizontal velocity u:

$$\frac{u}{\sqrt{gd}} = \varepsilon(\mathrm{cn}^2 q - h_1) + \varepsilon^2\left\{(f_1 + f_2\,\mathrm{cn}^2 q - \mathrm{cn}^4 q) - \frac{3}{4k^2}\left(\frac{s}{d}\right)^2\left[k'^2 + 2(2k^2-1)\mathrm{cn}^2 q - 3k^2\,\mathrm{cn}^4 q\right]\right\} + O[\varepsilon^3]$$

Cnoidal Wave's Periodic Properties

The periodic properties cnoidal waves:

Jacobian elliptic function argument q:

$$q = K(kx - \omega t)/\pi$$

The period of cnq is 2K

Jacobian elliptic function cnq:

$$\mathrm{cn}^2 q = \sum_{n=0}^{\infty} A_n \cos(n\theta)$$

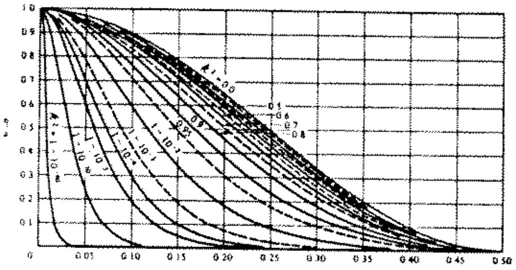
where:

$$A_n = \begin{cases} \dfrac{2\pi^2}{\kappa^2 K^2}\left(\dfrac{nr^n}{1-r^{2n}}\right) \ldots\ldots\ldots\ldots\ldots\ldots n \geq 1 \\ \dfrac{\gamma - \kappa'^2}{\kappa^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots n = 0 \end{cases}$$

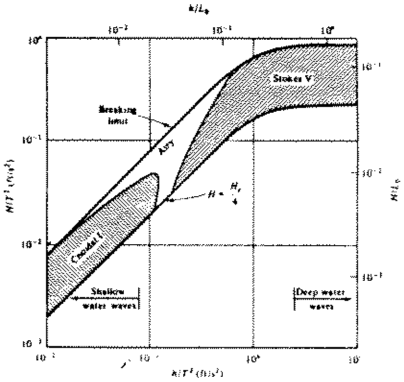
$$r = \exp[-\pi K(\kappa')/K(\kappa)]$$

Cnoidal Wave Profiles and Theory Validity

Free surface profile of cnoidal waves:



Comparison of validity of different wave theory:



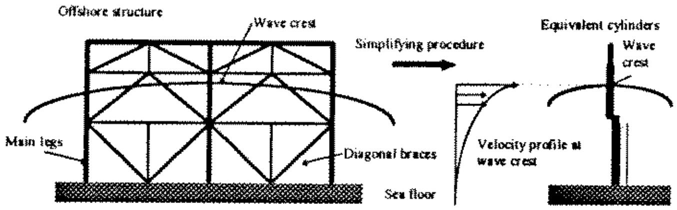
Comments on the Cnoidal Module in TOPCAT

- works well for water depth less than 30 ft.
- convergence cases:
  - converge to Airy theory for κ near 0.
  - converge to solitary theory for κ very close to 1
- duplicating the results from references
- calculating efficiency is being improved
- theory verification will be done this summer

Effects of Spatially Distributed Wave Loading

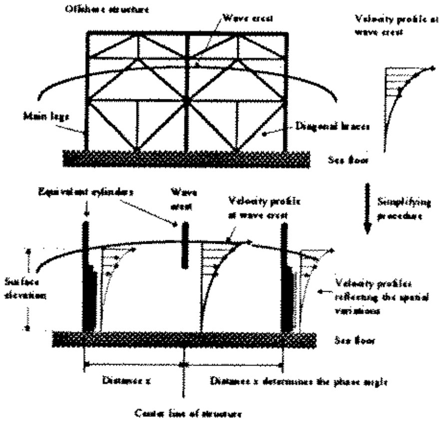
Problem definition:

- Wave loading spatially distributed along wave length
  - phase angles
  - wave free surface elevation
  - horizontal velocity changes
- Previous TOPCAT puts all members at wave crest
  -- one equivalent cylinder at wave crest, conservative!
- New spatial effects module in TOPCAT



Basic Approach of Analyzing the Spatial Effects of Loading

- Making analysis model more detailed by changing the equivalent projected areas of the structures --several equivalent cylinders
- Two major contributions to the spatial loading effect:
  - Surface elevation
  - water particle velocity



Formulation applied in TOPCAT

$$F_{total} = \sum_{n=1}^{N} \frac{1}{2} C_d \rho A'_n u'_n |u'_n| \qquad F_{spatial-distributed} = F_{crest} \bullet C_\theta \bullet C_\eta$$

For Stokes V: $\theta = kx - \omega t$

Surface elevation: $k\eta = \sum_{n=1}^{5} \eta'_n \cos(n\theta)$

Horizontal velocity: $\frac{u}{c} = \sum_{n=1}^{5} n\phi'_n \cosh(nks)\sin(n\theta)$

For Cnoidal : $q = \frac{K\theta}{\pi} = \frac{K}{\pi}(kx - \omega t)$

Surface elevation: $\frac{\eta}{d} = \varepsilon(cn^2 q - h_1) - \varepsilon^2 \left[\frac{3}{4} cn^2 q(1 - cn^2 q) + h_2\right]$

Horizontal velocity:

$$\frac{u}{\sqrt{gd}} = \varepsilon(cn^2 q - h_1) + \varepsilon^2 \left\{ (f_1 + f_2 cn^2 q - cn^4 q) - \frac{3}{4k^2}\left(\frac{s}{d}\right)^2 \left[k'^2 + 2(2k^2 - 1)cn^2 q - 3k^2 cn^4 q\right] \right\} + 0[\varepsilon^3]$$

Case Study of Loading Spatial Effect: Platform SP62

SP62: d=340ft, H=80ft, T=13.5s; 8-leg

EO: bcw=122ft, tcw=51ft

BS: bcw=202ft, tcw=131ft, msw=45ft

Mean loading on platform decreased by 10-20% considering spatial loading effect:

Loading spatial effect: comparison with results without considering spatial effect

Jacket Bay	Broad Side Loading(kips)			End On Loading(kips)		
Bay #	Without Effect	With Effect	Ratio	Without Effect	With Effect	Ratio
1	3344	2772	1.2061	3247	2757	1.1778
2	4529	3870	1.1702	4493	3904	1.1509
3	5421	4685	1.1571	5606	4839	1.1379
4	6021	5250	1.147	6203	5488	1.1303
5	6473	5671	1.1415	6752	6003	1.1248
6	6922	6093	1.1361	7271	6492	1.1201

Comments on Spatial Loading Effect Module

- Indicating relatively large decrease in drag force even for regular jacket platforms
- Change in velocity is the most important contribution to the change in drag force.
- Inertial component in wave force is still neglected for regular jacket platforms (drag dominated).
- For multi jacket platforms, inertial component may not be neglected; still being checked.

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3. Reliability Sensitivity Analysis

- Purpose:
  - Identifying the potential failure modes and weak-links
  - Estimating effects of changes of random variables' distribution parameters on the safety index β
- Major concerns for us: (in TOPCAT)
  - partial derivatives w.r.t. parameters (sensitivity vectors)
  - variation in biases (loading and capacities)
  - variation in COV's (loading and capacities)

Approaches in TOPCAT: Theoretical Basis

First order approximation :

$$\frac{\partial}{\partial p_i}\beta_R(\mathbf{p}_0) \sim \frac{\partial}{\partial p_i}\beta(\mathbf{p}_0) \qquad \beta(\mathbf{p}_0) \to \infty$$

first-order safety index:

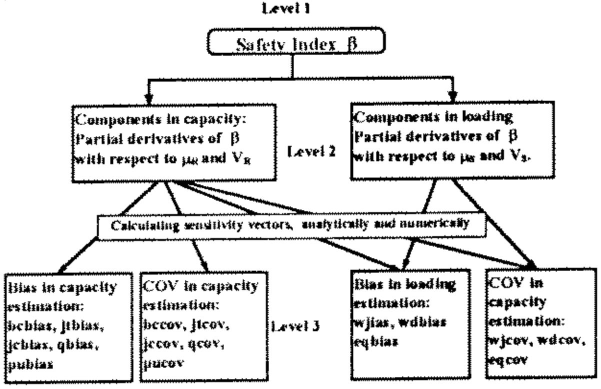
$$\beta(\mathbf{p}_0) = |\mathbf{u}^*| = (\mathbf{u}^{*T}\mathbf{u}^*)^{1/2}$$

Sensitivity vector:

$$\frac{\partial}{\partial p_i}\beta(\mathbf{p}_0) = \frac{1}{\beta}\mathbf{u}^{*T}\frac{\partial}{\partial p_i}\mathbf{u}^* = \frac{1}{\beta}\mathbf{u}^{*T}\frac{\partial}{\partial p_i}\mathbf{T}(\mathbf{z}^*,\mathbf{p}_0)$$

$$\mathbf{z} = \mathbf{T}^{-1}(\mathbf{u}^*,\mathbf{p}_0) \qquad \mathbf{u}^* = -\beta(\mathbf{p}_0)\frac{\nabla g(\mathbf{u}^*,\mathbf{p}_0)}{|\nabla g(\mathbf{u}^*,\mathbf{p}_0)|} = \lambda\nabla g(\mathbf{u}^*,\mathbf{p}_0)$$

Approach in TOPCAT: Practical Application:



Level 1

Safety Index β

Components in capacity: Partial derivatives of β with respect to μ_R and V_R

Level 2

Components in loading Partial derivatives of β with respect to μ_S and V_S.

Calculating sensitivity vectors, analytically and numerically

Bias in capacity estimation: bcbias, jtbias, jcbias, qbias, pubias

COV in capacity estimation: bccov, jtcov, jccov, qcov, pucov

Level 3

Bias in loading estimation: wjias, wdbias eqbias

COV in capacity estimation: wjcov, wdcov, eqcov

$$\frac{\partial\beta}{\partial p_i} = \sum_{j=1}^{n}\frac{\partial\beta}{\partial F_j}\frac{\partial F_j}{\partial p_i}$$

Formulation of Sensitivity Analysis

Jacket bay formulation as a demonstration:

First Level:

$$\overset{\varpi}{V}_s = \begin{bmatrix} \frac{\partial\beta}{\partial\mu_R} \\ \frac{\partial\beta}{\partial\mu_S} \\ \frac{\partial\beta}{\partial V_R} \\ \frac{\partial\beta}{\partial V_S} \end{bmatrix} = \begin{bmatrix} \frac{1}{\sigma_M\mu_R} \\ -\frac{1}{\sigma_M\mu_S} \\ \frac{V_R}{1+V_R^2}\cdot\frac{-\mu_M-\sigma_M^2}{\sigma_M^3} \\ \frac{V_S}{1+V_S^2}\cdot\frac{\sigma_M^2-\mu_M}{\sigma_M^3} \end{bmatrix}$$

Second Level (loading):

$$\overset{\varpi}{V}_{V_s} = \begin{bmatrix} \frac{\partial V_s}{\partial V_{k_w}} \\ \frac{\partial V_s}{\partial V_{k_s}} \\ \frac{\partial V_s}{\partial V_H} \end{bmatrix} = \begin{bmatrix} \frac{V_{k_w}}{V_s} \\ \frac{V_{k_s}}{V_s} \\ \frac{4V_H}{V_s} \end{bmatrix}$$

$$\overset{\varpi}{V}_{\mu_s} = \begin{bmatrix} \frac{\partial\mu_s}{\partial\mu_{k_w}} \\ \frac{\partial\mu_s}{\partial\mu_{k_s}} \\ \frac{\partial\mu_s}{\partial\mu_H} \\ \frac{\partial\mu_s}{\partial b_s} \end{bmatrix} = \begin{bmatrix} \mu_{k_s}\mu_H^2 \\ \mu_{k_s}\mu_H^2 \\ \mu_{k_s}\mu_{k_s}\mu \\ \mu_s \end{bmatrix}$$

Formulation of Sensitivity Analysis (cntd)

Second Level (capacity):

$$\overset{\varpi}{V}_{\mu_{R_k}} = \begin{bmatrix} \frac{\partial\mu_{R_k}}{\partial\mu_{\bar{B}_k}} \\ \frac{\partial\mu_{R_k}}{\partial\mu_{R}} \end{bmatrix} = \begin{bmatrix} \sum_i \mu_{k_i} \\ 1 \end{bmatrix}$$

$$\overset{\varpi}{V}_{V_{R_k}} = \begin{bmatrix} \frac{\partial V_{R_k}}{\partial\sigma_{\bar{B}_k}} \\ \frac{\partial V_{R_k}}{\partial\sigma_{F_k}} \\ \frac{\partial V_{R_k}}{\partial\beta_{F_k}} \end{bmatrix} = \begin{bmatrix} \frac{(\sum_i \mu_{k_i})^2\cdot\sigma_{\bar{B}_k}}{\sigma_{R_k}\cdot\mu_{R_k}} \\ \frac{B_{F_k}^2\cdot\sigma_{F_k}}{\sigma_{R_k}\cdot\mu_{R_k}} \\ \frac{B_{F_k}\cdot\sigma_{F_k}^2}{\sigma_{R_k}\cdot\mu_{R_k}} \end{bmatrix}$$

Third Level (capacity):

$$\begin{bmatrix} \frac{\partial\mu_{\bar{\alpha}_k}}{\partial \text{bcbias}} \\ \frac{\partial\mu_{\bar{\alpha}_k}}{\partial \text{Wjbias}} \end{bmatrix} = \begin{bmatrix} \frac{P_{u,MLTF}}{\text{bcbias}\cdot K_{MLTF}} \\ \frac{1}{K_{MLTF}}\cdot\left(-\frac{\mu_w\cdot l^2}{8\Delta_0\cdot \text{Wjbias}}\right)_{MLTF} \end{bmatrix}$$

$$\overset{\varpi}{V}_{\sigma_{F_k}} = \begin{bmatrix} \frac{\partial\sigma_{F_k}}{\partial \text{Wjcov}} \\ \frac{\partial\sigma_{F_k}}{\partial \text{Wd cov}} \\ \frac{\partial\sigma_{F_k}}{\partial \text{wjbias}} \\ \frac{\partial\sigma_{F_k}}{\partial \text{wdbias}} \end{bmatrix} = \begin{bmatrix} \mu_{F_k}\cdot\begin{bmatrix}1\\0\end{bmatrix} \text{or} \mu_{F_k}\cdot\begin{bmatrix}\frac{\text{Wjcov}}{V_t}\\ \frac{\text{Wd cov}}{V_t}\end{bmatrix} \\ \text{cov load}\cdot\frac{\partial\mu_{F_k}}{\partial \text{wjbias}} \\ \text{cov load}\cdot\frac{\partial\mu_{F_k}}{\partial \text{wdbias}} \end{bmatrix}$$

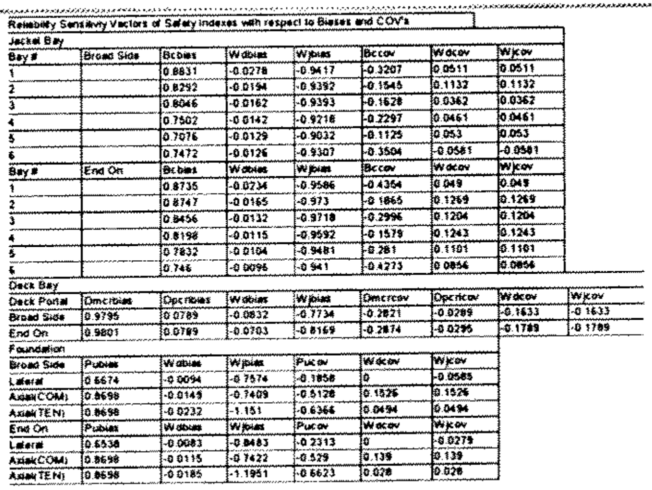
Formulation of Sensitivity Analysis (cntd)

Third Level (capacity):

$$\vec{V}_{\sigma_{\beta_{m}}} = \begin{bmatrix} \dfrac{\partial\sigma_{\beta_{m}}}{\partial bc\,cov} \\ \dfrac{\partial\sigma_{\beta_{m}}}{\partial wj\,cov} \\ \dfrac{\partial\sigma_{\beta_{m}}}{\partial wjbias} \\ \dfrac{\partial\sigma_{\beta_{m}}}{\partial bcbias} \end{bmatrix} = \begin{bmatrix} \dfrac{P_{u,MLTF}{}^{2}\cdot bc\,cov}{\sigma_{P_{u,MLTF}}\cdot K_{MLTF}} \\ \dfrac{(\frac{l^{2}}{8\Delta_{s}})^{2}\cdot\mu_{w}{}^{2}\cdot wjcov}{K_{MLTF}\cdot\sigma_{P_{u,MLTF}}} \\ \dfrac{(\frac{l^{2}}{8\Delta_{s}})^{2}\cdot(wjcov)^{2}\cdot\mu_{w}\cdot wjbias}{\sigma_{P_{u,MLTF}}\cdot K_{MLTF}} \\ \dfrac{bc\,cov\cdot P_{u,MLTF}}{K_{MLTF}\cdot bcbias} \end{bmatrix}$$

Other structure components such as foundation, deck are handled by the similar way, but in different formulation.

Case Study of Sensitivity Analysis: platform SP62



Reliability Sensitivity Vectors of Safety indexes with respect to Biases and COV's								
Jacket Bay								
Bay #	Broad Side	Bcbias	Wdbias	Wjbias	Bccov	Wdcov	Wjcov	
1		0.8831	-0.0278	-0.9417	-0.3207	0.0511	0.0511	
2		0.8292	-0.0194	-0.9392	-0.1545	0.1132	0.1132	
3		0.8046	-0.0162	-0.9393	-0.1628	0.0362	0.0362	
4		0.7502	-0.0142	-0.9218	-0.2297	0.0461	0.0461	
5		0.7076	-0.0129	-0.9032	-0.1125	0.053	0.053	
6		0.7472	-0.0126	-0.9307	-0.3504	-0.0581	-0.0581	
Bay #	End On	Bcbias	Wdbias	Wjbias	Bccov	Wdcov	Wjcov	
1		0.8735	-0.0234	-0.9586	-0.4364	0.049	0.049	
2		0.8747	-0.0165	-0.973	-0.1865	0.1269	0.1269	
3		0.8456	-0.0132	-0.9718	-0.2996	0.1204	0.1204	
4		0.8198	-0.0115	-0.9592	-0.1579	0.1243	0.1243	
5		0.7832	-0.0104	-0.9481	-0.281	0.1101	0.1101	
6		0.746	-0.0096	-0.941	-0.4273	0.0856	0.0856	
Deck Bay								
Deck Portal	Dmcrbias	Dpcrbias	Wdbias	Wjbias	Dmcrcov	Dpcrcov	Wdcov	Wjcov
Broad Side	0.9795	0.0789	-0.0832	-0.7734	-0.2821	-0.0289	-0.1633	-0.1633
End On	0.9801	0.0789	-0.0703	-0.8169	-0.2874	-0.0295	-0.1789	-0.1789
Foundation								
Broad Side	Pubias	Wdbias	Wjbias	Pucov	Wdcov	Wjcov		
Lateral	0.6674	-0.0094	-0.7574	-0.1858	0	-0.0585		
Axial(COM)	0.8698	-0.0149	-0.7409	-0.5128	0.1526	0.1526		
Axial(TEN)	0.8698	-0.0232	-1.151	-0.6366	0.0494	0.0494		
End On	Pubias	Wdbias	Wjbias	Pucov	Wdcov	Wjcov		
Lateral	0.6538	-0.0083	-0.8483	-0.2313	0	-0.0279		
Axial(COM)	0.8698	-0.0115	-0.7422	-0.529	0.139	0.139		
Axial(TEN)	0.8698	-0.0185	-1.1951	-0.6623	0.028	0.028		

Comments on the Reliability Sensitivity Analysis Module

- Sensitivity Analysis assumed all structure members at wave crest (no spatial effect)
- Implications in application of TOPCAT:
  - Help to identify which input is the most important -- strength biases and drag force biases
  - Help to understand the effects on safety index while increasing structure member strength or increasing environmental loading

4. Basic Approaches for Diagonal loading Analysis

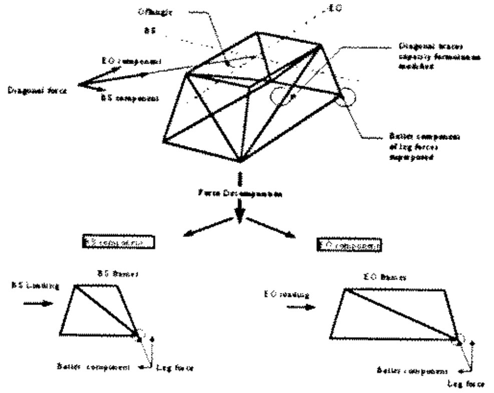
Assumption:

- **Diagonal load acting at the shape center(no torque)**
- **Spatial Effect not considered**

Two main steps:

- **Decomposition and superposition at global level**
- **Detailed analysis at local level, no decomposition and superposition allowed**

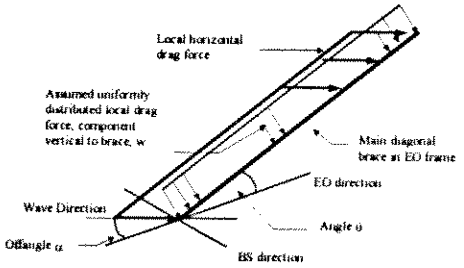
Global Superposition and Decomposition



- Diagonal force decomposed into BS and EO components, which are resisted by BS and EO frames respectively.
- Superposition of leg force:
  - Change of batter components leads to change of jacket bay capacity
  - Change of load patterns for pile foundation

Detailed analysis at local level

Diagonal wave force and brace capacity at local level:



Effects of Offangle at local level:

- **change of equivalent cylinder diameter:**

α=0 degree, EO loading: $D_{eq} = D \cdot \mathrm{Sin}^2\theta$

α=90 degree, BS loading: $D_{eq} = D/\mathrm{Sin}^2\theta$

any α, diagonal loading:

$$D_{eq} = D(\sin^3\alpha + \mathrm{Cos}^2\alpha \cdot \mathrm{Sin}^3\theta)/\mathrm{Sin}\theta$$

- **change of uniformly distributed vertical loading on brace, w:**

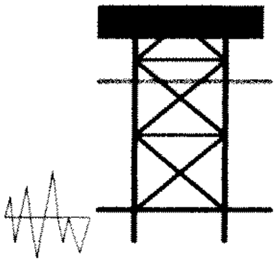
$$P_u = \frac{M_u}{8\Delta_0\left(\frac{1}{1+2\frac{\sin 0.5\varepsilon}{\sin\varepsilon}}\right)\frac{1}{\varepsilon^2}\left(\frac{1}{\cos\frac{\varepsilon}{2}}-1\right)} - \frac{wl^2}{8\Delta_0}$$

5. Future Development

- Deck Element Analysis Module

  Box girder deck and truss deck resisting gravity loading
- Long-term Reliability Analysis
- Based on the present study of spatial loading effect and diagonal loading, extending the 2-D analysis model to 3-D model in TOPCAT -- TORSION module

Earthquake Analysis Update



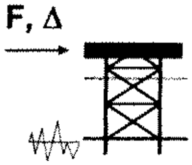
- Displacement Ductility Response Factors
- Element Cyclic Strain Capacities
- Verification Status

by James Stear

Ductility Response Factors

Factors relate:

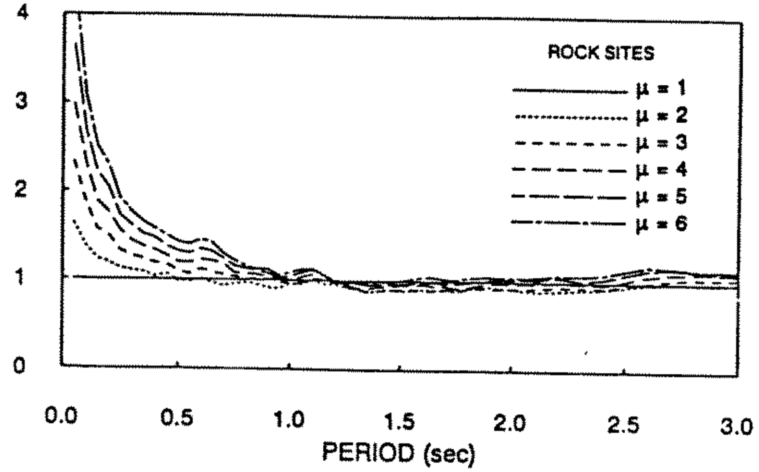
1. peak $\Delta_{inelastic}$ to peak $\Delta_{elastic}$
2. overload ($F_{elastic}/F_{yield}$) to peak μ_{demand}



Strong dependence on:

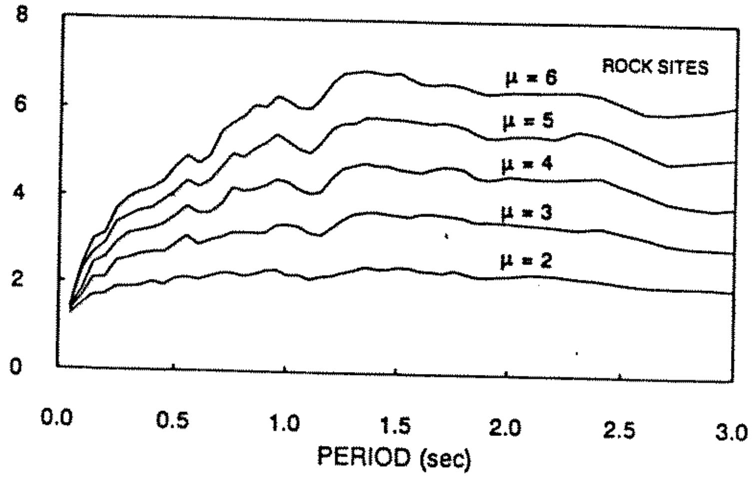
- period
- local soil conditions
- hysteresis involving strength loss

Ductility Response Factors



Rock sites:

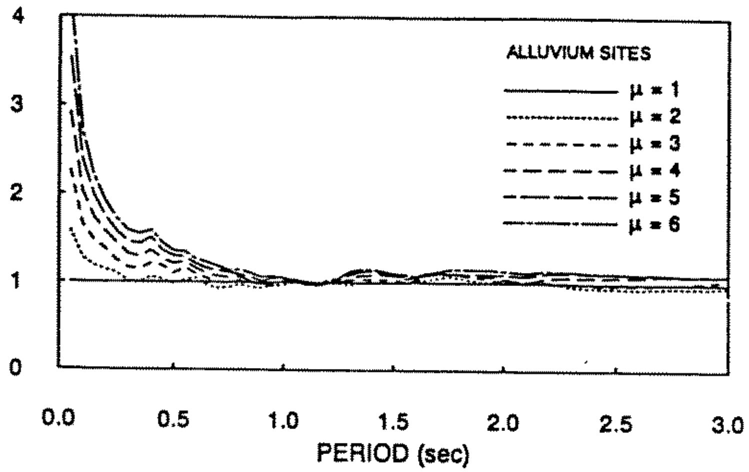
$\Delta_{inelastic}/\Delta_{elastic}$



$(F_{elastic}/F_{yield})$ to μ_{demand}

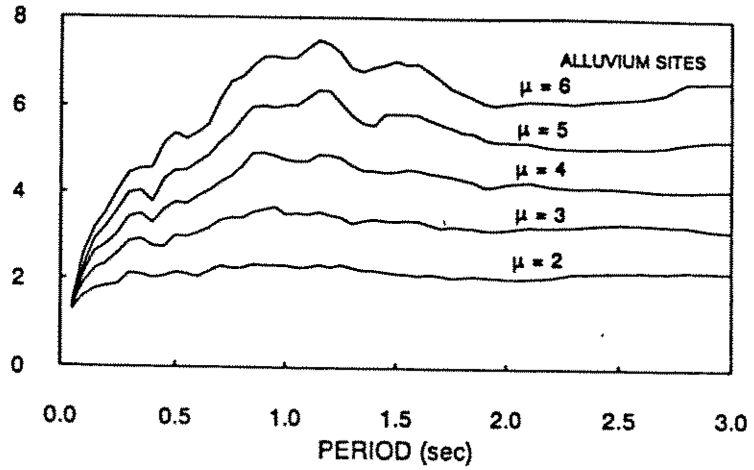
(Miranda, 1991)

Ductility Response Factors



Alluvium sites:

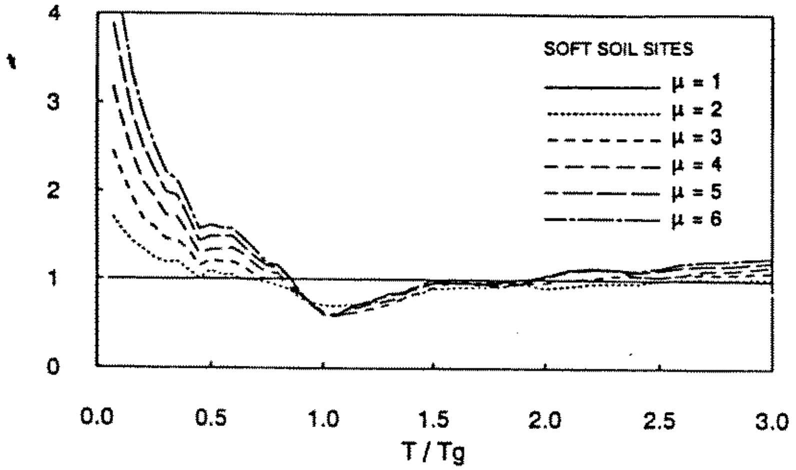
$\Delta_{inelastic}/\Delta_{elastic}$

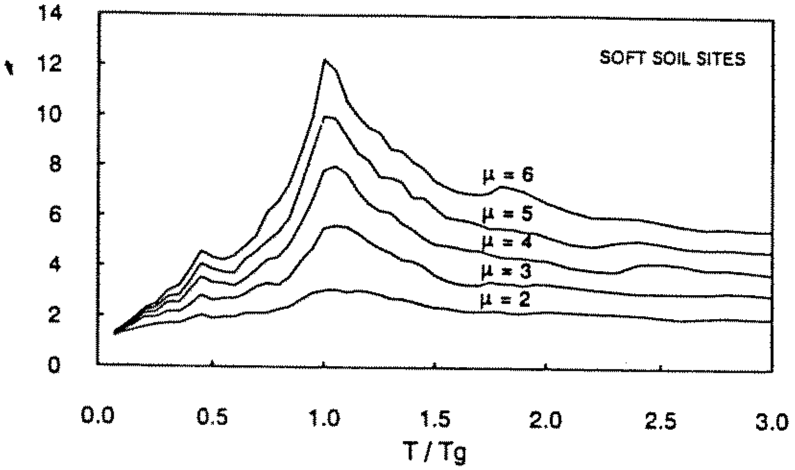


$(F_{elastic}/F_{yield})$ to μ_{demand}

(Miranda, 1991)

Ductility Response Factors





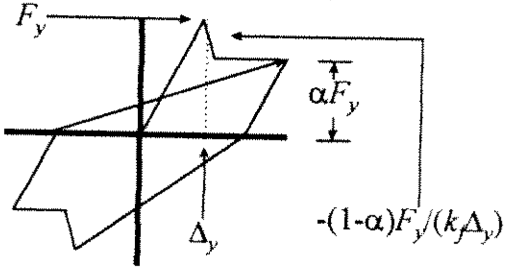
Soft soil sites:

$\Delta_{inelastic}/\Delta_{elastic}$

$(F_{elastic}/F_{yield})$ to μ_{demand}

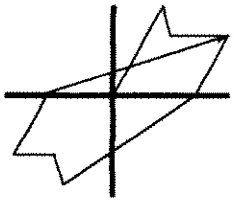
(Miranda, 1991)

Ductility Response Factors



- **Stiffness degrading**
- **80% and 60% residual (α)**
- **Five negative stiffness factors (k_f): 0.01, 1, 2, 3, 4**

Ductility Response Factors



- Using PC-NSPEC for study
- Study is covering same range of variables and use same ground motions as Miranda (1991)
- Also recording data on cycles, energy absorption

Cyclic Capacities: Legs

Use cyclic ductility limits from Astaneh (1996) for local buckling avoidance in leg plastic hinge rotations: $\mu_{rot}=\phi/\phi_y$

$$\mu_{rot} = 6 \text{ for } D/t \le \lambda_p$$

$$\mu_{rot} \ge 3 \text{ for } \lambda_r \ge D/t > \lambda_p$$

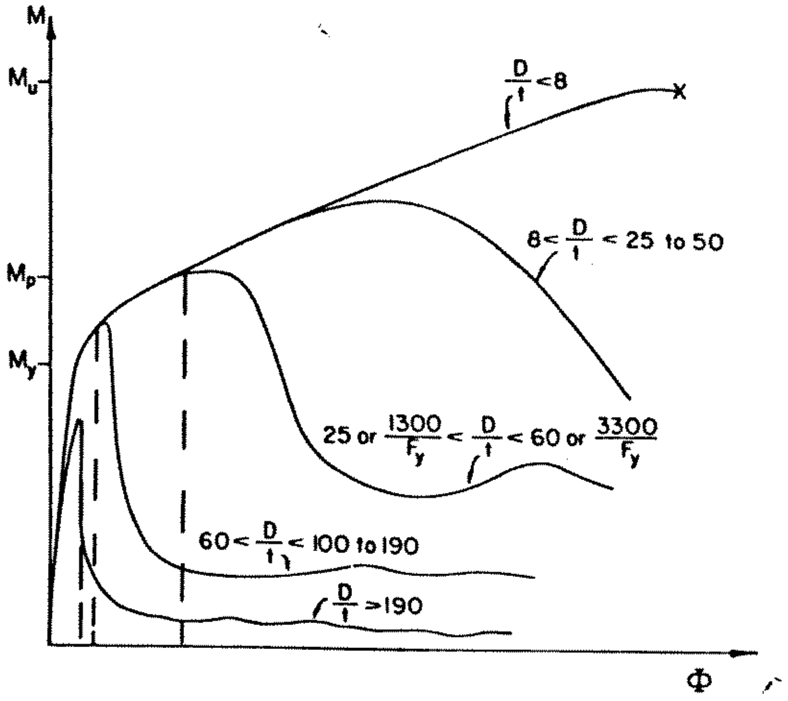
$$\mu_{rot} = 1 \text{ for } D/t > \lambda_r$$

$$\lambda_p = \frac{1{,}300}{F_y}$$

$$\lambda_r = \frac{3{,}300}{F_y}$$

$$\mu_{rot} = 6 - 5\left(\frac{q}{P_y}\right)$$

Cyclic Capacities: Legs



Astaneh Limits with Tests from Sherman (1980)

Cyclic Capacities: Braces

Use cyclic ductility limits from Astaneh (1996) for local buckling avoidance in brace buckling (hinge strains):

$$\mu = 4 \text{ for } \lambda_c \leq 1$$

$$\mu = 4 - 6(\lambda_c - 1) \text{ for } 1.5 \geq \lambda_c > 1$$

$$\mu = 1 \text{ for } \lambda_c > 1.5$$

$$\lambda_c = \frac{kl}{\pi r}\sqrt{\frac{F_y}{E}}$$

Cyclic Capacities: Braces

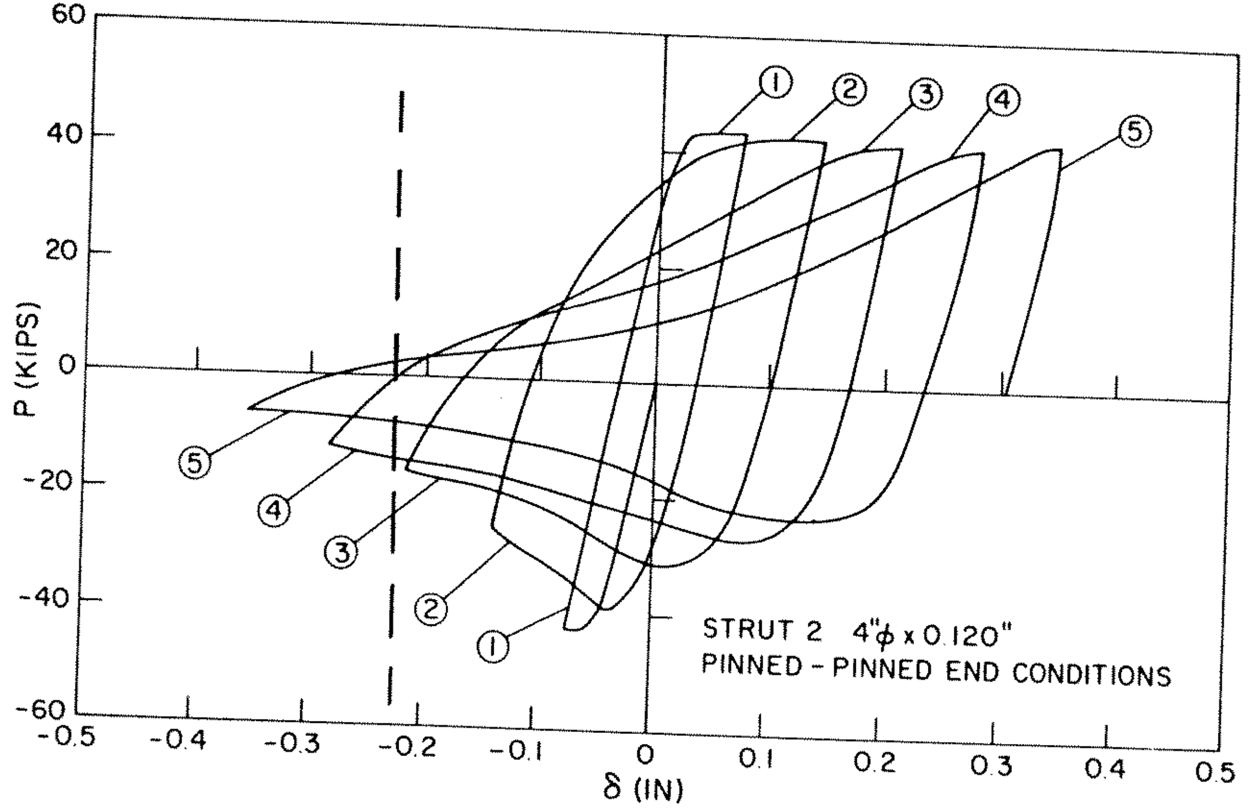
Use cyclic ductility limits from Astaneh (1996) for local buckling avoidance in brace buckling (axial strain):

$$\mu = 4 \text{ for } D/t \leq \lambda_p$$

$$\mu = 4 - 3\left(\frac{D/t - \lambda_p}{\lambda_r - \lambda_p}\right) \text{ for } \lambda_r \geq D/t > \lambda_p$$

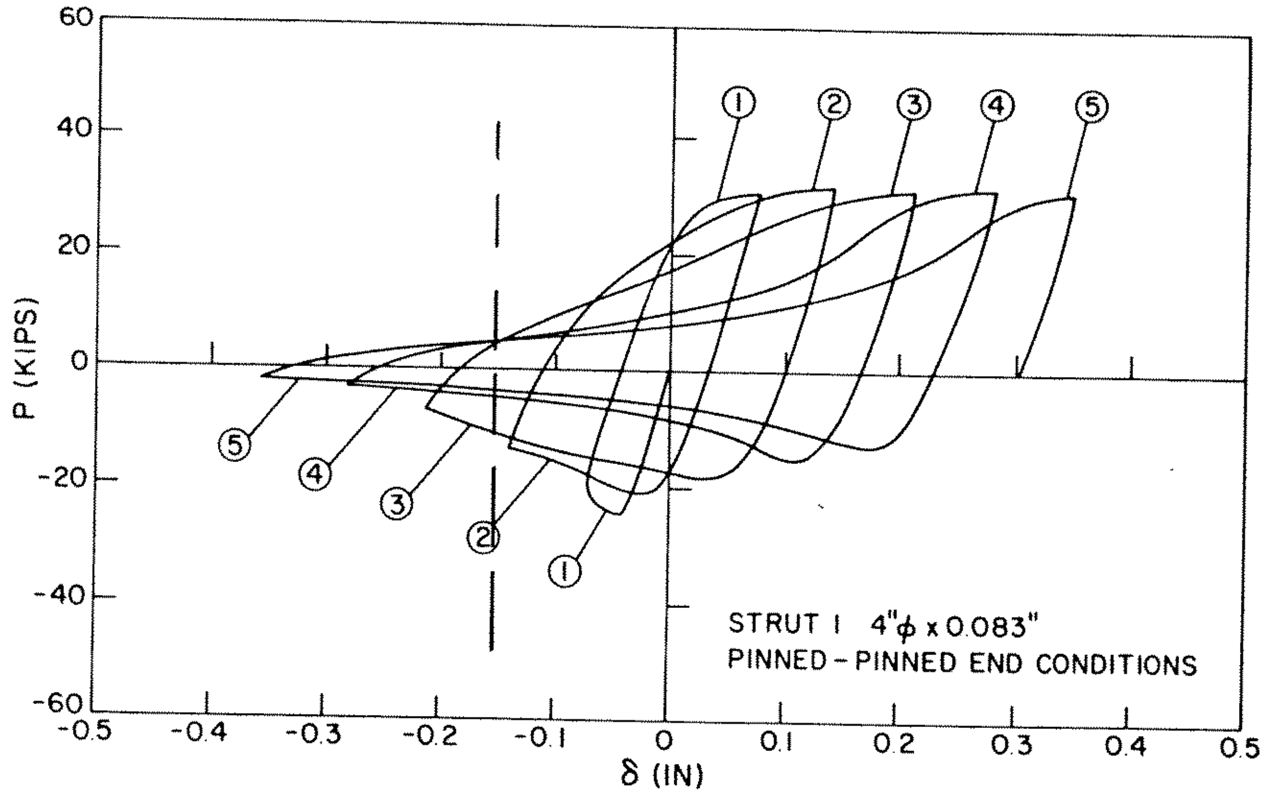
$$\mu = 1 \text{ for } D/t > \lambda_r$$

Cyclic Capacities: Braces



Astaneh Limits with Tests from Zayas (1980)

Cyclic Capacities: Braces



Astaneh Limits with Tests from Zayas (1980)

Case Studies

Cases Selected:

- Southern California Example Platform (have model)
- Ellen / Platform G (have model)
- Elly / Platform H (have model)

Will include two additional cases if time permits

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SIMPLIFIED STRENGTH-LEVEL EARTHQUAKE ASSESSMENT OF JACKET-TYPE PLATFORMS

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ABSTRACT

This paper summarizes a simplified method with which strength-level earthquake analyses of jacket-type platforms can be performed. By examining the primary bending, shear, and foundation rotation responses, estimates of platform vibration characteristics can be obtained from which earthquake forces can be estimated by the response spectrum method. This process is referred to as SRSA (Simplified Response Spectrum Analysis). These forces can then be taken together with capacities derived from ULSLEA (Ultimate Limit State Limit Equilibrium Analysis) to develop an evaluation of the demand-capacity behavior of the platform. The ULSLEA-SRSA method is applied to the assessment of two platforms. Results from 3-D frame analyses of the two platforms are used for validation of the simple approach. Agreement between the ULSLEA-SRSA and detailed 3-D analyses is excellent.

Several studies related to the simplified assessment of platforms subject to earthquakes are documented in this paper. In the first, a design code approach to earthquake forces based on that contained with the Uniform Building Code is demonstrated and compared to more detailed earthquake force estimates. Next, common simple approximations to pile-head stiffnesses are reviewed, and the impact of foundation flexibility on platform response examined. Last, the impact of local inertia forces on brace axial capacity is studied.

KEY WORDS: Earthquakes, platforms, loading capacities, ultimate limit state, foundations, structures, dynamic analysis, design, requalification

INTRODUCTION

During the past five years there has been growing interest in the development of simplified structural analysis methods which are inexpensive to apply yet provide sufficiently accurate results to help make timely and economic engineering assessments. A major reason for this development is the re-assessment of aging infrastructure. As many structures (buildings, bridges, offshore platforms, etc.) approach the end of their original service lives, many owner/operators desire to keep these structures in service. As many of the structures in existence today were designed for much less stringent load criteria than current code recommendations, some form of analysis must be performed.

While there are many structural analysis tools available today to perform detailed assessments, these tools usually require a high degree of expertise to operate, and to apply to a large number of structures would be prohibitive in terms of time and money. What is needed is a staged process of assessment, by which the bulk of the structure population can be assessed quickly using cheap, conservative methods, leaving the more problematic cases for further rigorous analysis.

Previous work has been performed by the Marine Technology and Management Group at U. C. Berkeley concerning the development and verification of simplified analysis methods for offshore platforms. This earlier effort addressed the evaluation of jacket-type platforms subject to wind and wave forces, and resulted in the procedure known as ULSLEA (Ultimate Limit State Limit Equilibrium Analysis). Based on a simple demand-capacity format, and considering only the primary failure mechanisms in a platform (hinging of unbraced deck legs, diagonal brace buckling in the jacket bays, exceeding of pile group lateral or overturning capacity), procedures were developed to estimate loads and platform component capacities (Bea, Mortazavi, 1995). This demand-capacity procedure has been the subject of much testing and verification; readers are referred to Bea, et al. 1995; Mortazavi and Bea, 1997; and Stear and Bea, 1997.

This paper documents a simplified procedure for estimating earthquake forces which is intended to compliment ULSLEA-based capacity procedures. Using simplified estimates of the primary bending, shear and foundation responses of the platform, vibration properties for the platform are approximated. Then, through application of response spectrum analysis, earthquake demands on the platform are estimated. This process is referred to as SRSA: Simplified Response Spectrum Analysis. It is intended to allow for the estimation of earthquake forces without resorting to detailed finite-element models.

The ULSLEA-SRSA approach is used to assess two platforms: a 4-leg and an 8-leg. To verify the accuracy of the ULSLEA-SRSA approach, 3-D frame analyses of these platforms has been performed, and the results from these more detailed analyses compared to those from ULSLEA-SRSA. The results are found to be in excellent agreement; application of ULSLEA-SRSA yields earthquake failure intensities (the zero-period acceleration for the API RP 2A response spectrum [API, 1993] associated with the load at first member failure) within 15 % of those found from the 3-D frame analyses.

In addition to describing the ULSLEA-SRSA method and demonstrating its application, three other studies related to simple assessment of jacket-type platforms subject to earthquakes are also documented in this paper. The first study demonstrates an alternative method to estimating earthquake forces based on a modified Uniform Building Code approach (UBC, 1994). The second reviews several common approximations to pile-head stiffnesses, and demonstrates the sensitivity of platforms to foundation flexibility. Finally, the significance of local forces on tubular braces is investigated.

ESTIMATING SEISMIC DEMANDS: SRSA

The procedure by which seismic demands are estimated for the platform components (deck bay, jacket bays, and foundation) is based on response spectrum analysis; it is referred to as SRSA: Simplified Response Spectrum Analysis. By considering the primary bending, shear and foundation displacement mechanisms in the platform, simple estimates of platform vibration properties are made. These properties are then used together with response spectrum analysis to develop appropriate earthquake loads on the platform.

Response Components

The horizontal response of a platform can be thought of as consisting of three components (Fig. 1):

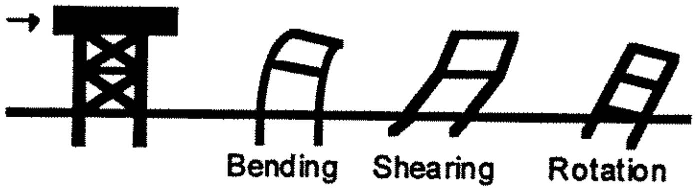

Fig. 1: Horizontal response components

There is a bending component, from the cantilever deflection of the platform due to the axial loads on the piles from overturning; a shear component, from the shear deformations of each braced jacket bay and the foundation, and a rotation component due to tension and compression of the piles.

Using very simple structural relationships, it is possible to establish the load-deflection properties of each individual response component without much effort. Deflections due to bending can be found from:

$$\Delta = \frac{PL^3}{3EI} \qquad (1)$$

where I refers to the moment of inertia of the platform tower structure based on the platform pile cross sections. Shear deflections can be found by considering the deformation of the individual shear mechanisms at each level in the platform. For a braced jacket bay, the shear stiffness is:

$$k_{bay} = \Sigma k_i \cos^2 \vartheta_i \qquad (2)$$

where:

k_i = axial stiffness of each individual brace, i.e. EA/L
θ_i = angle between each brace and the horizontal

For bays which do not have braces (the deck bay on many platforms do not) the shear deformation will be controlled by the bending of the platform legs. In this case, the shear stiffness is:

$$k_{bay} = \Sigma k_i \qquad (3)$$

where:

k_i = effective horizontal stiffness of each individual leg assuming fixed-fixed conditions, i.e. $12EI/L^3$

The shear stiffness at the foundation level will be the sum of the pile-head lateral stiffnesses.

Deflections from foundation rotation can be calculated by considering the platform to be a rigid structure mounted on a rotational spring. This spring is the sum of the products of the axial stiffnesses of the piles and the square of their distance from the platform axis of rotation (either end-on or broadside).

Considering the platform to be a system of lumped masses (one at each horizontal framing level, the decks, and the mudline), the flexibility matrix for this simple system can easily be constructed by summing the component responses to unit loads at each level. The vibration properties of the system can then be found through solution of the standard eigenvalue problem of the form:

$$\mathbf{f}\mathbf{m}\phi_n = \frac{1}{\omega_n^2}\phi_n \qquad (4)$$

where:

$\mathbf{f}$ = matrix of flexibility coefficients
$\mathbf{m}$ = matrix of lumped masses
ϕ = mode shape
ω = natural frequency

This form has the advantage of converging to the largest values of $1/\omega^2$ with each iteration, which correspond to the largest periods. In this fashion, the first mode will be found first, then the second, and so on.

If modal analysis is not possible, this approach conveniently provides displacements which can then be used together with Rayleigh's method to obtain approximate vibration periods:

$$T_1 = 2\pi\sqrt{\frac{\sum_{j=1}^{N} m_j u_j^2}{g\sum_{j=1}^{N} m_j u_j}} \qquad (5)$$

$$\phi_1 = \mathbf{u} / u_{\max} \qquad (6)$$

where $\mathbf{u}$ is the vector of nodal displacements associated with nodal forces gm_j. This approach is very amenable to hand calculation.

Masses are concentrated at each horizontal framing level and at the deck. These masses include the mass of any hydrodynamic added

$$m_{added} = K\rho_w \pi r^2 \sin\theta \tag{7}$$

where:

K = flexibility factor for members; ranges from 0.6 for pinned-end members to 1.0 for fixed-end members
ρ_w = density of the surrounding fluid
r = radius of the member
θ = the angle between the cylindrical length axis and the direction of translation

To account for proximity to the free surface, the added mass is further scaled according to (Goyal, Chopra, 1989):

$$m_{added}(z) = m_{added} \text{ when } z > 0.1\, H_o \tag{8}$$

$$m_{added}(z) = m_{added}(z / 0.1\, H_o) \text{ when } z \leq 0.1\, H_o \tag{9}$$

where:

z = depth below the surface
H_o = water depth

Soil mass consisting of the soil contained within the piles to a depth of five pile diameters is included in the mass lumped at the mudline.

Platform vertical response can be determined in a similar fashion. In this case, only the axial stiffnesses of the jacket legs and piles are used to construct the flexibility matrix; the solution procedure to find vertical modes will be the same as for horizontal modes.

For platforms possessing significant mass and/or stiffness eccentricities, torsion response can also be developed in a simple fashion. Rotational stiffnesses between framing levels can be developed based on the layout of the diagonal braces (or piles, for the foundation level), while mass moments of inertia can be derived from the spatial distribution of the mass as each level.

Modal Analysis and Demands

Together with an appropriate response spectrum, modal demands can be estimated as shown below for shear and overturning moment:

$$V_{in} = \sum_{j=1}^{N} \Gamma_n m_j \phi_{jn} \left(\frac{4\pi}{T_n^2} \right) D_n \text{, shear for } i^{th} \text{ level} \tag{10}$$

$$M_{bn} = \Gamma_n L_n^{\theta} \left(\frac{4\pi}{T_n^2} \right) D_n \text{, overturning moment} \tag{11}$$

where:

D_n = modal displacement from response spectrum
n = mode index
j = DOF index

The individual modal responses can then be combined to find the total response on a given component. The square-root sum-of-the-squares (SRSS) rule is commonly used within civil engineering practice; however, as noted in API RP-2A, this rule can on occasion provide results which are unconservative when compared to a time-history analysis.

PLATFORM COMPONENT CAPACITIES: ULSLEA

The strength limits for platform components are determined through application of ULSLEA (Mortazavi, 1995). The strength formulations for these components are listed in the following sections.

Unbraced Leg Sections

The ultimate shear force which can be resisted by an unbraced section in the platform structure is based on bending capacities of the tubular legs in the section. Assuming the formation of a story mechanism based on the simultaneous hinging of the legs at the top and bottom of the structural bay, and accounting for P-Δ effects, the shear capacity of the bay can be estimated from:

$$P_u = \frac{2nM_u}{H_d} - V_{P\Delta} \tag{12}$$

where:

$$V_{P\Delta} = \frac{QD}{H_d} \text{, P-}\Delta \text{ effects due to drift or displacement } D \tag{13}$$

$$M_u = M_{cr} \cos\left(\frac{\pi Q / n}{2P_{cr}} \right) \text{, ultimate leg moment} \tag{14}$$

and:

H_d = height of bay
M_{cr} = critical moment, governed by local buckling
Q = vertical force on bay
P_{cr} = critical axial load, governed by local buckling
n = number of legs

Braced Bays

The shear force which can be resisted by a braced bay is dependent on the axial tension and compression capacities of the bracing members and their connections to the legs. A mechanism is assumed to form when the first member in the load path fails; i.e. the bay is assumed to possess no strength beyond first yield.

Based on a three-hinge failure mode, the exact solution for the bending moment in a beam-column at collapse is:

$$M_u = \left(\frac{1}{1 + 2\frac{\sin 0.5\varepsilon}{\sin\varepsilon}} \right) \frac{1}{\varepsilon^2} \left(\frac{1}{\cos 0.5\varepsilon} - 1 \right) \left(wl^2 + 8P_u\Delta_0 \right) \tag{15}$$

where:

$$\varepsilon = l\sqrt{\frac{P_u}{EI}} \tag{16}$$

and:

P_u = ultimate axial capacity
w = distributed local load

l = length of brace
Δ_0 = initial out-of-straightness
E = elastic modulus
I = cross-section moment of inertia of brace

Using P-M interaction in the brace as a second equation relating M_u and P_u:

$$\frac{M_u}{M_p} - \cos\left(\frac{\pi P_u}{2 P_p}\right) = 0 \qquad (17)$$

where:

M_p = plastic moment capacity of brace cross section
P_p = tension capacity of brace cross section

Solving for Δ_0 assuming $P_u = P_{cr}$ from API RP 2A (1993), it is possible to solve for P_u using iteration.

The distributed local load w on the brace is assumed to result from local response of the brace to earthquake excitation. To estimate the local acceleration on the brace, it is possible to treat the brace as mounted equipment, and then apply a procedure such as that described by Bowen and Bea (1995) to determine the filtered response.

Tubular joint tension and compression capacities can be established through application of empirical formulas documented in API (1993). It should be noted that these equations are somewhat conservative.

Overall bay capacity will be given by:

$$P_{u_{bay}} = \sum_{i=1}^{N} D_{1st} K_i + F_{1L} \qquad (18)$$

where:

D_{1st} = failure displacement of most likely member to fail, found from the smallest ratio of P_u/K
K = effective horizontal stiffness of individual braces
P_u = minimum of brace strength or connections to which brace is attached
F_{1L} = batter forces from legs

No reduction is taken for local P-Δ effects, as these are generally quite small for braced sections due to the smaller displacements needed to mobilize horizontal capacity.

It should be noticed that if there is an unbraced portal above a braced section, there could be noticeable reduction in the capacity of the braced section due to the need to balance the large bending moments in the legs of the unbraced section (Mortazavi, 1995). This can be accounted for by further reducing the shear capacity of the braced section by the effective shear needed to balance the leg moments.

Pile Horizontal Capacity

The horizontal capacity of the foundation is determined in a manner similar to that for an unbraced leg section, with the exception that the horizontal support provided by the surrounding soils and the batter shear component of the piles are included.

For a pile deeply imbedded in cohesive soils, the ultimate horizontal force that can be resisted at the pile top is given by (Tang, Gilbert, 1990):

$$P_u = 0.5\left\{-\left(27D^2S_u + 18S_uXD\right) + \sqrt{\left(27D^2S_u + 18S_uXD\right)^2 + 144S_uDM_p}\right\} \qquad (19)$$

where:

M_p = plastic moment capacity of a pile
D = pile diameter
S_u = effective undrained shear strength of the soil
X = scour depth

For cohesionless soils, the pile capacity is given by (Tang, Gilbert, 1990):

$$P_u = 2M_p\left(X + 0.544P / \left(\gamma D \tan\left(45 + \phi/2\right)\right)\right) \qquad (20)$$

where:

ϕ = effective angle of internal friction of the soil
γ = submerged unit weight of the soil

Pile Axial Capacity

The axial yield capacity of a pile is based on the combined effects of a shear yield force acting on the surface of the pile and a normal yield force acting over the pile end. Capacity is thus given by:

$$Q = qA_p + f_{av}A_s \qquad (21)$$

where:

q = normal end yield force per unit of pile-end area
f_{av} = average shear yield force per unit of embedded shaft surface area
A_p = area of pile tip
A_s = embedded shaft surface area

Approximations for q and f_{av} for cohesive and cohensionless soils can be found in Mortazavi (1995).

APPLICATION OF ULSLEA-SRSA

To assess the accuracy of the ULSLEA-SRSA approach relative to more rigorous analysis, the simple method was used to determine the demand-capacity behavior of two platforms: a 4-leg and an 8-leg. From the demand-capacity profiles established for each platform, the earthquake intensity (expressed as the response spectrum zero-period acceleration or ZPA) necessary to generate loads resulting in the formation of a collapse mechanism were calculated. These collapse intensities were then compared to collapse intensities calculated from 3-D response spectrum analyses of each platform using a 3-D frame model. The following sections describe each platform, and the results obtained from analyzing them using both the simple approach and the 3-D analysis.

Platform A

Platform A is a hypothetical design for a symmetric 4-leg production platform (see Fig. 2). The structure is designed for 100 ft water depth. The deck is at +50 ft MWL and supports a load of 5,000 kips. The main diagonals in the first jacket bay are 24 in.-diameter (w.t. 0.5 in.), while those in the second bay are 30 in.-diameter (w.t. 0.625 in.); the diagonals in the deck bay are 36 in.-diameter (w.t. 0.75 in.). The legs are 78 in.-diameter (w.t. 0.875 to 1.125 in.); they are grouted, and possess heavy joint cans. The piles are 72 in.-diameter (w.t. 1 to 1.5 in.), and are designed for 150 ft penetration in medium to stiff clay. The shear strength of the clay is 2.5 kips/ft^2 at the surface, and increases by 0.01 kip/ft^2 per ft of depth. The pile ends are founded on a very stiff soil layer (rock) which has a shear strength of 184 kips/ft^2. All steel is A36.

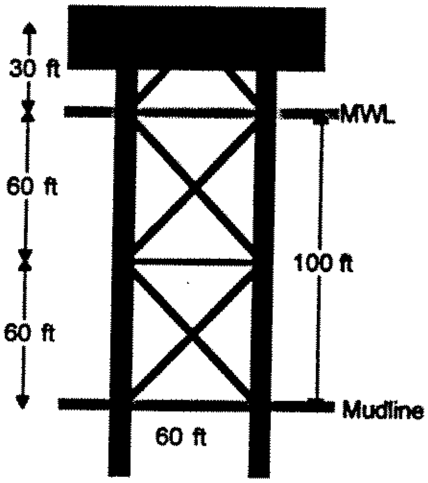

Fig. 2: Platform A

The platform was analyzed using both ULSLEA-SRSA as well as 3-D response spectrum analysis. For the 3-D response spectrum analysis, joints were assumed to be rigid, and the deck was assumed to act as a rigid diaphragm. Tubular steel member axial strengths were taken from buckling strength curves (API, 1993). Imbedded pile performance was established by modeling a single pile as a segmented beam supported by springs (following the guidelines of API RP 2A, API, 1993), and then performing a series of analyses to determine pile-head force-displacement relationships suitable for use with a 3-D elastic model. The pile-head stiffnesses derived from these analyses were used in both the simple and 3-D analyses. For both the simple analysis and the 3-D analysis, the brace buckling length factor was taken to be 0.65, and a local acceleration of 1.0 g was applied to all members in the jacket to represent the local response contribution. Selected member properties are shown below in Tables 1, 2 and 3. It can be seen that the brace buckling strengths determined from limit equilibrium (ULSLEA) are slightly overestimated (by at most 8%) relative to those determined from empirical data, while the pile capacities are underestimated (in the range of 8 to 18%).

Each approach utilized the API Soil B response spectrum (API, 1993) to derive earthquake loads once vibration properties were established. Loads were assumed to act on all three platform principal axes; the square-root sum-of-the-squares (SRSS) rule was used to combine the individual modal and directional responses. The load case used in both analyses consisted of the load on one horizontal axis found using the API spectrum for a given ZPA combined with load on the other axis found using 67% of this ZPA and load on the vertical axis found using 50% of this ZPA. No torsional response was considered.

The major vibration characteristics of the structure estimated using the two approaches are shown below in Fig. 3 and Fig. 4. The simple method provides excellent estimates of the first two horizontal mode periods as compared with the 3-D frame analysis, but subsequent period estimates begin to deviate. The vertical mode period found from the simple method is also in good agreement with the period estimated in the 3-D frame analysis.

Table 1: Tubular Brace Capacities

Brace Diameter and Thickness	Axial Capacity (kips) - API	Axial Capacity (kips) - ULSLEA
24" ϕ 0.5"	1100	1190
30" ϕ 0.625"	1880	1920
36" ϕ 0.75"	2820	2890

Table 2: Pile Strengths

Pile Strength	Capacity (kips) - API	Capacity (kips) - ULSLEA
Tension	6000	4892
Compression	11200	10400
Lateral	1960	1750

Table 3: Pile Stiffnesses

Pilehead Springs	Stiffness
Vertical	3150 kips / in
Horizontal	470 kips / in
Rotational	40×10^6 kip-ft / rad

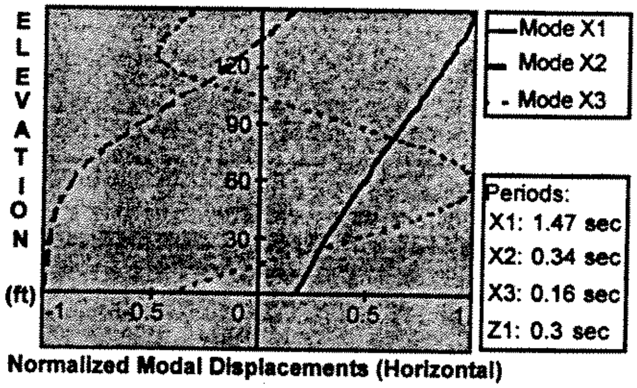

Fig. 3: Platform Vibration Properties (3-D)

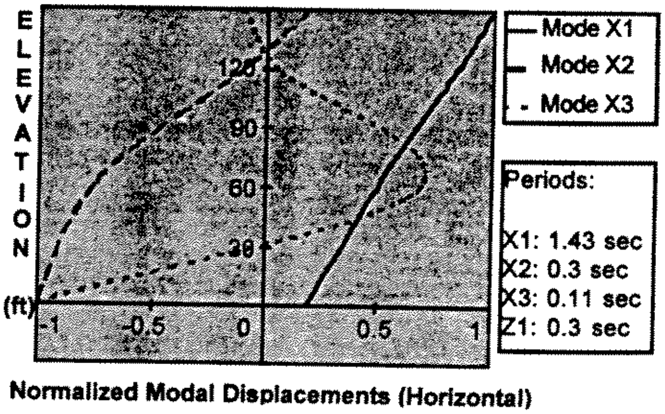

Fig. 4: Platform Vibration Properties (SRSA)

Loads calculated from the two methods are, not surprisingly, in excellent agreement, given the agreement between the estimated platform vibration properties and the fact that most of the platform response is in the first few modes. Horizontal shears acting at each level along with peak pile loads are shown in Fig. 5 and Table 4 for a spectrum ZPA of 0.25 g. The peak loads differ by at most 5%.

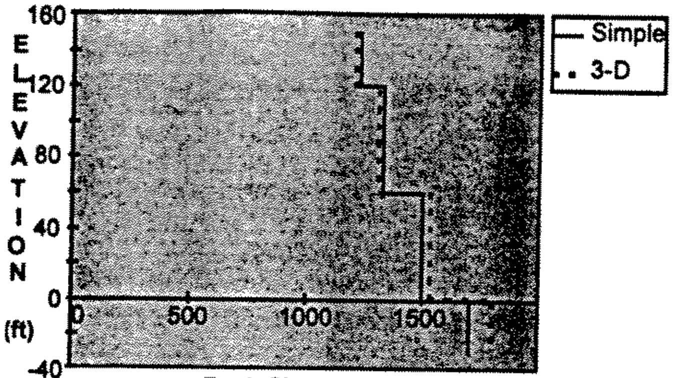

Fig. 5: Platform Loads, ZPA = 0.25 g

Table 4: Pile Loads, ZPA = 0.25g

Pile Load	3-D (kips)	SRSA (kips)
Tension	359	362
Compression	3859	3862
Lateral	541	511

Using the simple method, the earthquake intensity resulting in the formation of a collapse mechanism is 0.625 g. Loads for this case and the associated platform capacity profile are shown in Fig. 6. Failure is initiated by the buckling of the diagonal braces in the first jacket bay. The 3-D analysis indicates the earthquake intensity resulting in the formation of a collapse mechanism is 0.645 g (4% higher); this analysis also indicates the first elements to fail will be the diagonal braces in the first jacket bay. For this example application, ULSLEA-SRSA provides an excellent estimate of the earthquake intensity needed to cause the formation of a collapse mechanism, as compared to the results of the 3-D frame analysis.

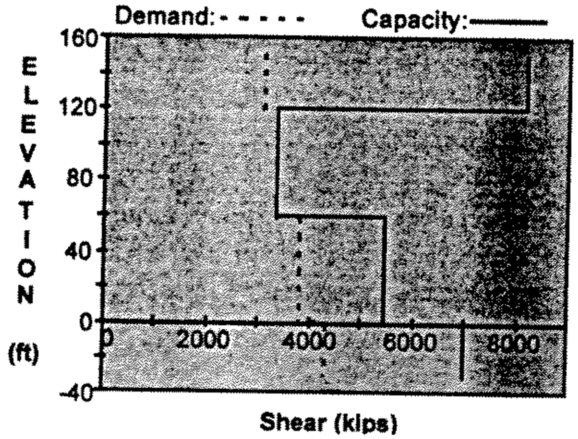

Fig. 6: Demand - Capacity Shear Profile from ULSLEA-SRSA

Platform B: 8-Leg Structure

Platform B is an 8-leg drilling platform sited in 265 ft of water in San Pedro Bay off Southern California (see Fig. 7). It was designed to support 80 24 in.-diameter conductors. The platform has two decks located at +45 ft MWL and +64 ft MWL respectively; the deck bay is braced. The jacket is battered 1:7 in the broadside direction, and 1:12 in the end-on direction. The main diagonals range from 20 in.-diameter (w.t. 0.75 in.) to 36 in.-diameter (w.t. 1.125 in.). The corner legs of the jacket are 71 in.-diameter (w.t. 1 in. to 2 in.), while the interior legs are 54 in.-diameter (w.t. 0.675 to 2 in.); the legs have heavy joint cans but are not grouted. The corner piles of the platform are 66 in.-diameter, and penetrate to 264 ft. The center piles are 48 in.-diameter, and penetrate to 232 ft. The soil at the site is predominantly clay (medium-stiff to stiff). The majority of the structural members are 36 ksi steel, while the piles are 50 ksi steel.

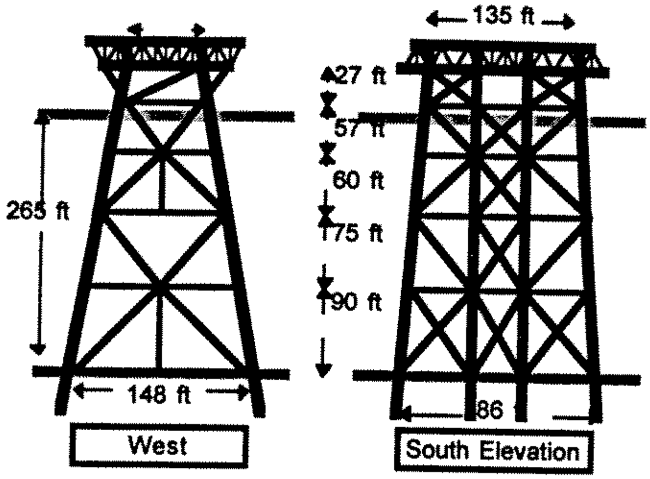

Fig. 7: Platform B Elevations

This platform was also analyzed using both ULSLEA-SRSA as well as 3-D response spectrum analysis with a 3-D frame model. The same approaches taken for determining member strength and pile characteristics for Platform A were used in these studies. Joints were assumed to be rigid, and the deck was modeled as a rigid diaphragm. For both the simple and 3-D analyses, the brace buckling length factor was taken to be 0.65, and a local acceleration of 1.0 g was applied to all members in the jacket.

Each analysis utilized the API Soil B response spectrum (API, 1993) to derive earthquake loads once vibration properties were established. Loads were assumed to act on all three platform principal axes; the SRSS rule was used to combine the individual modal responses and directional responses. The platform was analyzed for two load cases: end-on and broadside. For each load case, the load on the major horizontal considered was combined with 67% of the load on the other horizontal axis, along with 50% of the load on the vertical axis. As the platform possessed no mass or stiffness eccentricities, no torsional response was considered.

The major vibration characteristics of the platform estimated using the two approaches are shown in Fig. 8 to Fig. 11. It should be noted that the simple method provides fundamental horizontal period estimates smaller than those from the 3-D frame analysis, especially for the end-on direction; this is due to the fact that the jacket is substantially more flexible in shear due to the absence of grouting. This additional shear or warping flexibility is not captured by the simple approach. When both the 3-D frame model and the simple model were changed to reflect grouting, the fundamental horizontal periods for the end-on case became 2.24 sec (3-D) and 2.3 (SRSA), while the fundamental period estimates for the broadside case became 2.1 (3-D) and 2.2 (SRSA).

Loads calculated using the two methods for the original (un-grouted) case are still in very good agreement, with the simple loads being with 12 % of those from the 3-D frame. Horizontal shears acting at each level along with peak pile loads are shown in Tables 5 and 6 and Fig. 13 and Fig. 14 for a spectrum ZPA of 0.25 g. The platform's 80 conductors carry a substantial amount of the lateral load at the foundation level; this drives down the lateral load carried by the main piles.

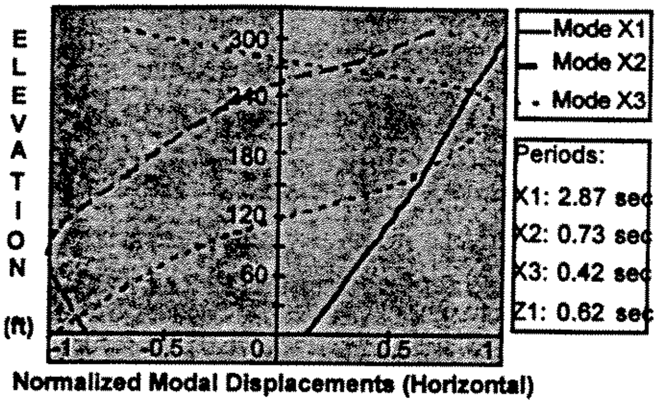

Fig. 8: Platform Vibration Properties, End-On (3-D)

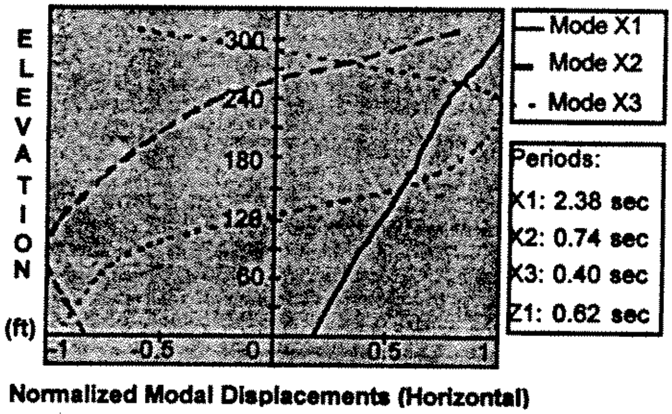

Fig. 9: Platform Vibration Properties, End-On (SRSA)

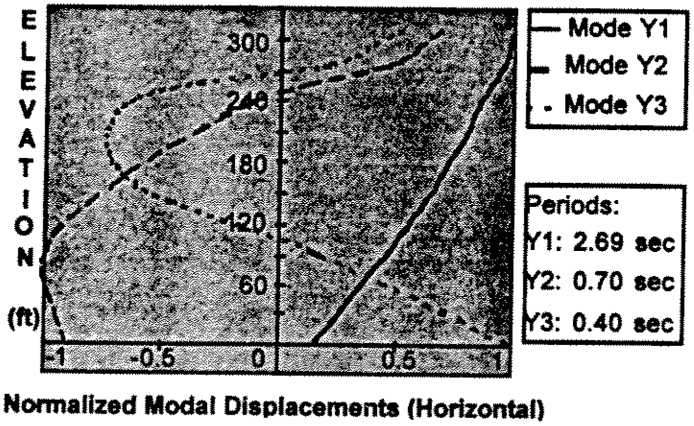

Fig. 10: Platform Vibration Properties, Broadside (3-D)

Table 5: Pile Loads on 66 in. ϕ

Pile Load	3D (kips)	Simple (kips)
Tension	4337	5034
Compression	6837	7534
Lateral	449	479

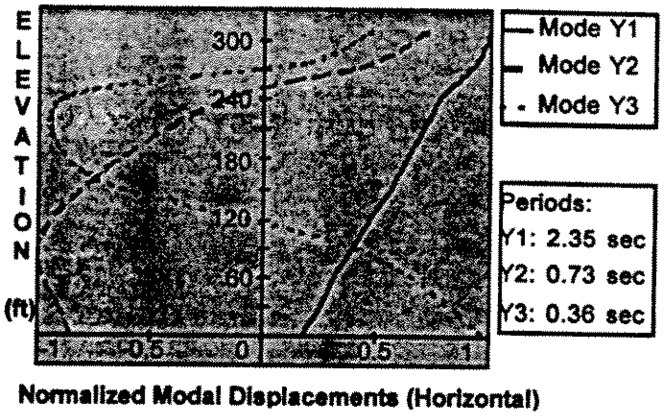

Fig. 11: Platform Vibration Properties, Broadside (SRSA)

Table 6: Pile Loads on 48 in. ϕ

Pile Load	3D (kips)	Simple (kips)
Tension	1952	2522
Compression	4452	5022
Lateral	233	248

Application of the simple method indicates an earthquake intensity of 0.36 g at full strength end-on will result in yielding of the corner piles in compression. Increasing the load further results in full collapse with the failure of braces in the first jacket bay; this is achieved for an earthquake intensity of 0.42 g. For the case of full strength broadside load, the simple method indicates piles will yield at an intensity of 0.4 g, while collapse in the jacket starts in the first jacket bay for an intensity of 0.52 g. Demand - capacity diagrams for these two cases are shown below in Fig.s 13 and 14 (note that the foundation lateral capacities do not have the conductor strength contributions included). Using the 3-D frame model, an end-on full-strength intensity of 0.38 g was found to initiate yielding in the corner piles, while an intensity of 0.48 g resulted in the buckling of braces in the first jacket bay. For the case of full-strength broadside loading, an intensity of 0.4 g initiated pile yielding, while buckling of first bay braces occurred at an intensity of 0.55 g.

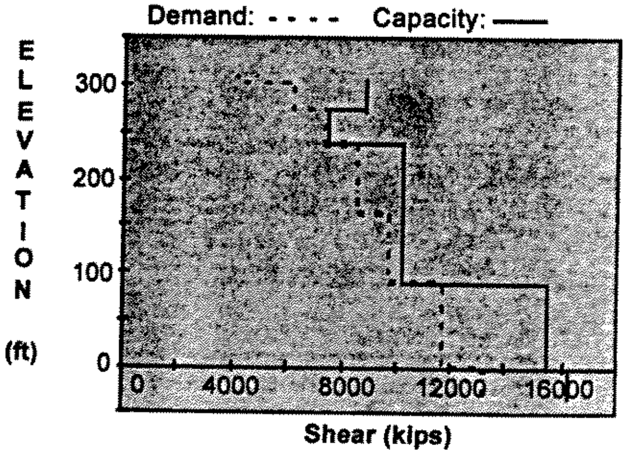

Fig. 13: Demand - Capacity Profile, ULSLEA-SRSA (End-On)

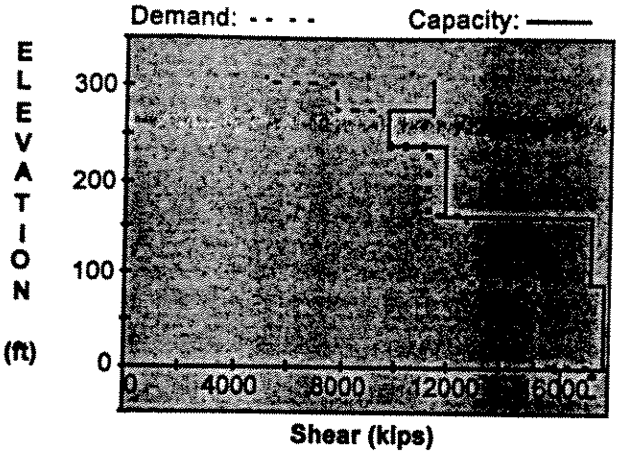

Fig. 14: Demand - Capacity Profile, ULSLEA-SRSA (Broadside)

The ULSLEA-SRSA results are in good agreement with those obtained from the 3-D analysis, providing failure intensities within 15% of those obtained from the 3-D analysis.

Discussion

The simple approach to assessing platform earthquake resistance compares very well to the more rigorous 3-D frame analysis. For substantially less effort than that required for the creation and analysis of a 3-D model, excellent estimates of platform performance can still be obtained. However, it must be emphasized that the simple modal analysis procedure loses accuracy as the complexity of the structure increases, as seen by the differences in the period estimates for the 8-leg structure. While the simple results are sufficient to envelope behavior for preliminary design and initial structural integrity assessments, they would not be of great use when trying to analyze a platform for a specific earthquake (i.e. with a jagged point spectrum), due to the possible variation in structural period.

PARAMETER STUDIES

In this section, several additional issues related to the simplified analysis of offshore platforms are explored. As an alternative to using the SRSA approach to generate earthquake force estimates, an approach based on modified Uniform Building Code (UBC, 1994) earthquake forces is reviewed. Also, several common approximate procedures for determining pile stiffnesses are compared, and the general dependence of platform response on foundation flexibility is studied. Finally, the significance of including local member forces on tubular braces is examined.

A Design Code Approach to Seismic Demands

As an alternative to rigorously evaluating the vibration properties of a platform using modal analysis and then applying the response spectrum approach, there exist several semi-empirical earthquake-demand estimating approaches such as the one contained in Chapter 16 of the Uniform Building Code (UBC, 1994). These approaches are based upon the study of general trends of structural response to earthquakes, and are intended to allow for the development of forces with which a structural design can be started.

The UBC approach for horizontal forces assumes the structure in question has no great stiffness discontinuities, and that higher mode effects will decrease rapidly in significance. A total approximate base shear is estimated, and then distributed over the height of the structure in proportion with the mass at each level. In addition, a concentrated force is applied at the top to ensure that forces from higher modes will not be neglected in the upper portions of the structure.

To evaluate the utility of this approach in estimating earthquake demands for offshore structures, the basic force estimating procedure has been adapted for use with the API response spectrum. Base shear (immediately above the foundation) is estimated from:

$$V = SA_{T_1} W \qquad (22)$$

where:

SA_{T1} = pseudo-acceleration from response spectrum for fundamental period
W = total mass of the structure, not including foundation

The UBC recommends the following formula to estimate fundamental horizontal periods for braced frame structures:

$$T_1 = 0.02(h)^{0.75} \qquad (23)$$

where:

h = height of structure above ground line (ft)

This period assumes no foundation flexibility, and hence will be too rigid for most offshore platforms. However, if estimates of foundation stiffnesses can be made, the fundamental period can be modified according to a period-lengthening procedure suggested by Veletsos and Boaz (1979):

$$\tilde{T}_1 = T_1\sqrt{1+\frac{k_1^*}{K_x}\left[\frac{1}{1-(T_o/\tilde{T}_1)^2}+\frac{K_x h_1^{*2}}{K_\theta}\right]} \qquad (24)$$

where:

T_1 = fixed-base fundamental period
T_o = natural period of foundation mass
k_1 = effective horizontal stiffness of fixed-base fundamental
K_x = horizontal stiffness of foundation
K_θ = rotational stiffness of foundation
h_1^* = effective mass center above base, not including foundation mass

The effective horizontal stiffness can be approximated by:

$$k_1^* = \frac{4\pi^2(0.9M_1)}{T_1^2} \qquad (25)$$

where:

M_1 = inertial mass of platform

The natural period of the foundation mass can be estimated from:

$$T_o = 2\pi\sqrt{\frac{W_o}{gK_x}} \qquad (26)$$

where:

W_o = weight of foundation mass included in model
g = acceleration due to gravity

The forces distributed at the various levels in the structure are then determined in accordance with:

$$F_x = \frac{(V - F_t)w_x h_x}{\sum_{i=1}^{n} w_i h_i} \qquad (27)$$

where:

F_t = $0.07VT_1$
w = mass at level
h = height of level

F_t is applied at the top of the structure, in addition to F_x at the top level. To obtain an estimate of the shear imposed on the foundation, the maximum base shear V found above is combined with an approximate value of the inertia force of the foundation mass (Veletsos, Boaz, 1979):

$$V_o = \left(\left(\frac{W_o A_o}{g}\right)^2 + V^2\right)^{0.5} \qquad (28)$$

where:

A_o = pseudo-acceleration of the foundation mass calculated from the response spectrum

To evaluate the utility of this modified UBC approach, it has been applied to the analysis of both Platform A and Platform B from the previous section. Earthquake shears determined from 3-D response spectrum analysis (the SRSS rule was used to combine modes) are shown together with shears estimated by the modified UBC approach in Fig.s 15 and 16. The same pile and conductor stiffnesses used in the previous section were used to develop foundation translation and rotation stiffnesses.

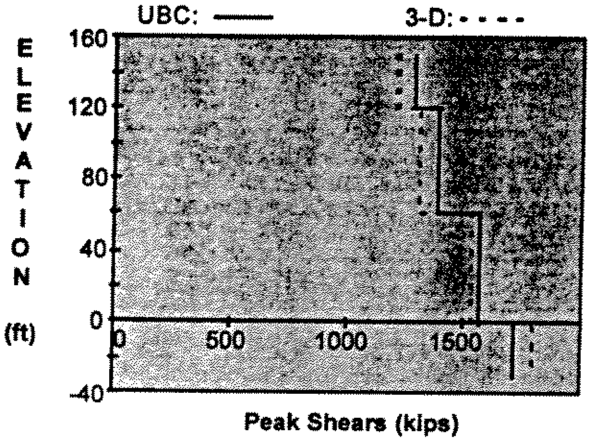

Fig. 15: Comparison of UBC Forces and 3-D Modal Analysis Forces, Platform A

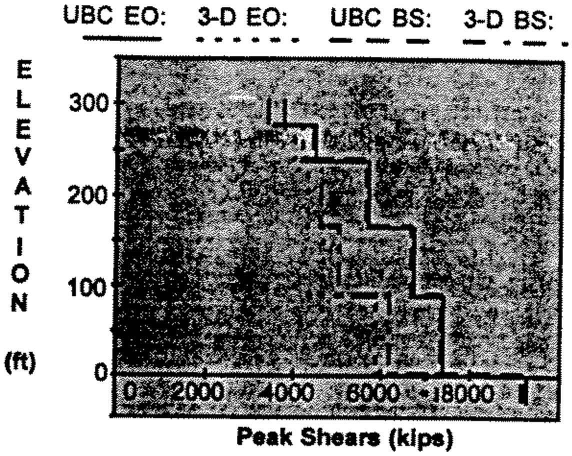

Fig. 16: Comparison of UBC Forces and 3-D Modal Analysis Forces, Platform B

For Platform A, the shears found using the UBC approach agree quite well with those found through application of 3-D RSA, being within 6% of the RSA values. The fundamental period estimate is quite good, 1.44 sec compared to 1.47 sec from 3-D modal analysis. For Platform B, the results are less in agreement. The periods estimated using the UBC approach are low for both primary directions of load (2.23 sec vs. 2.89 for end-on, and 2.28 sec vs. 2.69 sec for broadside). Consequently, the estimated shears are higher, in some instances by as much as 25%.

The modified UBC approach provides another simple method of obtaining demands on a platform for preliminary design or initial structural assessment purposes. However, it must be recognized that the approach will tend to under-predict the periods of large structures, leading to associated changes in predicted load dependent upon the response spectrum.

Foundation Stiffness

As the foundation is a significant source of platform flexibility, it is important that the associated stiffness properties of the foundation be well represented. Typically, the stiffness contributions of mud mats and mudline braces are ignored, while stiffnesses for piles and conductors are developed by modeling the pile as a segmented beam supported by springs, and then developing pile-head load-deflection behavior from these models. Developing pile-head behavior using this approach can be quite time-consuming.

In lieu of using the above procedure, a number of approximate approaches are available to estimate pile-head stiffnesses. Perhaps the most common approach to estimating lateral pile-head stiffnesses is to consider the pile to be a beam fixed at the mudline and fixed at some depth L (between five and ten pile diameters) below the mudline:

$$k_x = \frac{12EI}{L^3} \qquad (29)$$

An alternative for pile-head horizontal stiffness is that used by Penzien (1975) in a series of studies of offshore platforms subjected to earthquakes:

$$k_x = 18.2Gr\frac{(1-\upsilon^2)}{(2-\upsilon)^2} \qquad (30)$$

where:

G = shear modulus of the foundation soil
υ = Poisson's ratio for the foundation soil
r = pile radius

This horizontal stiffness k_x is derived using elastic half-space theory and assuming the pile is deeply imbedded. Unless the foundation is extremely soft, the horizontal loads will be transferred quite rapidly to the surrounding soil with depth. Hence, the horizontal stiffness of each pile can be derived by considering the pile-head to be a rigid circular footing supported on an elastic medium. It is assumed to connection between the pile and jacket is rigid and allows for no pile-head rotation.

Pile-head vertical stiffnesses are often estimated by considering the basic stiffness *EA/L* of the pile column and then modifying this stiffness for the mechanism by which vertical loads are transferred to the surrounding soil. Various transfer mechanisms are shown in Fig. 17.

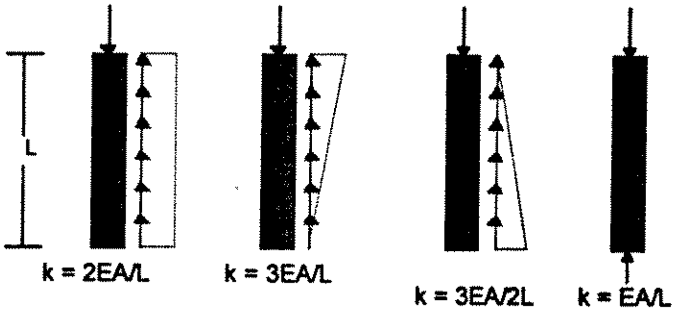

Fig. 17: Vertical Load Transfer Mechanisms for Imbedded Piles

Another approach to estimating pile head stiffnesses is that suggested by Dobrey (1980). These approximations are based on previous work by Novak (1974) and Blaney, et al. (1976). Assuming foundation strength to rely upon soil elastic modulus and assuming as a basis a beam on an uniform elastic foundation, pile-head stiffnesses take the form:

$$k_z = 0.8\frac{E_p A}{r}\left(\frac{E_s}{E_p}\right)^{0.5} \qquad (31)$$

$$k_x = 2\frac{E_p I}{r^3}\left(\frac{E_s}{E_p}\right)^{0.75} \qquad (32)$$

$$k_\theta = 1.6\frac{E_p I}{r}\left(\frac{E_s}{E_p}\right)^{0.25} \qquad (33)$$

$$k_{\theta x} = -1.2\frac{E_p I}{r^2}\left(\frac{E_s}{E_p}\right)^{0.5} \qquad (34)$$

where:

E_p = Elastic modulus of pile material
E_s = Elastic modulus of soil material
I = Moment of inertia of pile steel cross-section

Assuming there is no applied moment at the pile head, the effective horizontal stiffness can be represented by:

$$k_{x\,\mathrm{effective}} = k_x - \frac{k_{\theta x}^2}{k_\theta + k_{\theta\,\mathrm{structure}}} \qquad (35)$$

This effective stiffness will vary depending on the amount of rotational stiffness supplied by the structure attached to the pile head, $k_{\theta\,structure}$. These formulas are intended for intermediate values of E_s/E_p, and r/L ratios in the range of 10 to 50.

A comparison has been made between the various approximate pile-head stiffness and those derived during the course of the two example platform analyses described in the previous section. Pile-head stiffnesses from the different approximations along with those used in the examples are shown below in Tables 7 and 8:

Table 7: Horizontal Pile-Head Stiffnesses (kips/in)

Diameter (in.)	$12EI/L^3$ L=5D	$12EI/L^3$ L=10D	Penzien kx	Dobry kx	3-D kx
72	1093	136	870	515	469
66	1640	205	598	623	260
48	1640	205	435	623	135

Table 8: Vertical Pile-Head Stiffnesses (kips/in)

Diameter (in.)	3EA/L	EA/L	Dobry kz	3-D kz
72	10933	3644	2915	3150
66	8541	2847	3787	4496
48	7069	2356	3787	2825

There is much variation between the approximate methods and the springs derived for the 3-D analyses. However, it must be remembered that these estimates can be obtained with much less effort than constructing and analyzing a segmented pile model. Furthermore, given the fact that soil properties can possess significant biases due to sampling and testing methods, there will be an element of variation to the springs derived from detailed analyses; this must be recognized by the analyst. The best of action when making use of these approximations is to select sets which will provide upper and lower bounds on the stiffnesses.

To study the effect of foundation flexibility on the horizontal response of a platform, the axial and horizontal pile-head stiffnesses used with Platform A and Platform B were varied with respect to the values calculated from the detailed analysis (see Tables 6 and 7). The variation in fundamental horizontal period for both Platforms are shown below in Fig. 18 and 19. Varying the stiffnesses for Platform A can change the period by as much as 33%. This could have a significant effect on calculated loads, depending upon the response spectrum being used. For Platform B, the maximum variation is 14%. This is less significant, and is due to the larger flexibility of the un-grouted 8-leg jacket. Nevertheless, it is important to recognize that there can be significant variation in the pile stiffnesses due to factors beyond the control of the analyst.

Effects of Local Acceleration on Brace Capacity

The tubular braces which make up the framing system of an offshore platform can develop significant local inertia forces when the platform structure is subjected to earthquake excitation. These forces can in some instances substantially reduce the axial capacity of the bracing member by increasing bending stresses in the member. API RP 2A (API, 1993) specifically mentions the need to include these local forces, primarily due to the typically use of very long, heavy members in jacket-type structures.

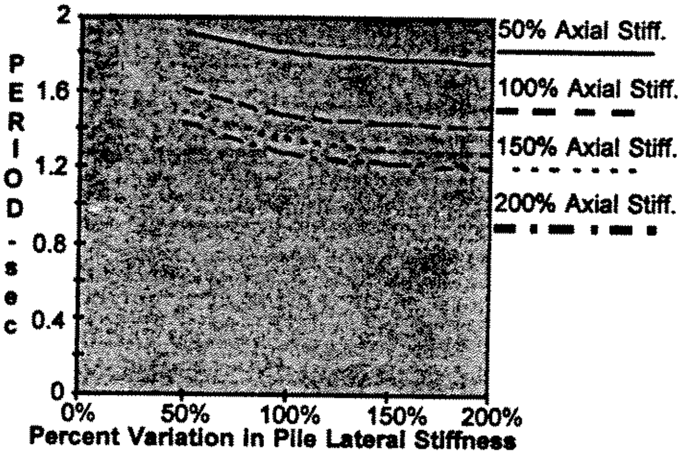

Fig. 18: Platform A, Variation in Fundamental Period

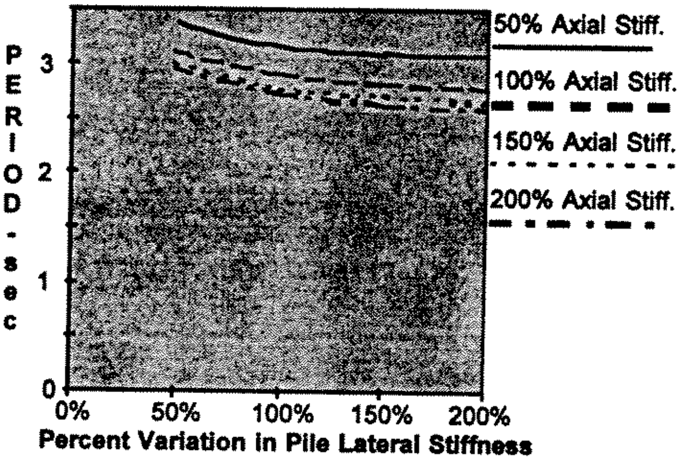

Fig. 19: Platform B, Variation in End-On Fundamental Period

To study the general impact of these forces, both Platform A and Platform B were analyzed using the simple approach with the local inertia forces set to zero. Demand - capacity profiles for both platforms are shown in Fig. 20, Fig. 21 and Fig. 22, with capacities derived both with and without local forces. For Platform A, the effect of the local inertia forces is small. However, many members in Platform B are strongly affected by the presence of these forces. This difference is due to the fact that many members in the lower bays of Platform B are very long, even though they possess similar cross section properties to those members in Platform A. Fig.s 21 and 22 make clear the necessity of including these local forces in design considerations; several members in Platform B have their axial capacities reduced on the order of 38 %.

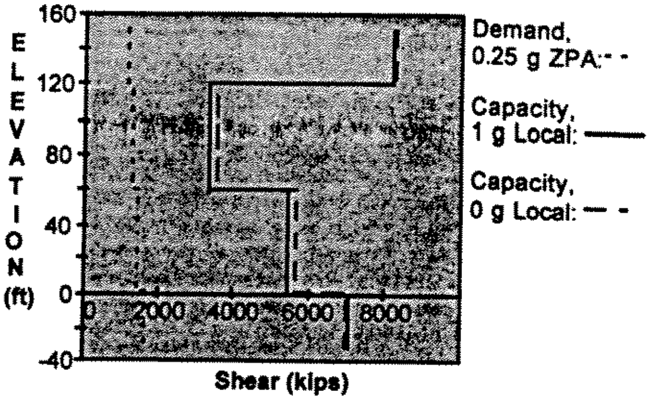

Fig. 20: Platform A

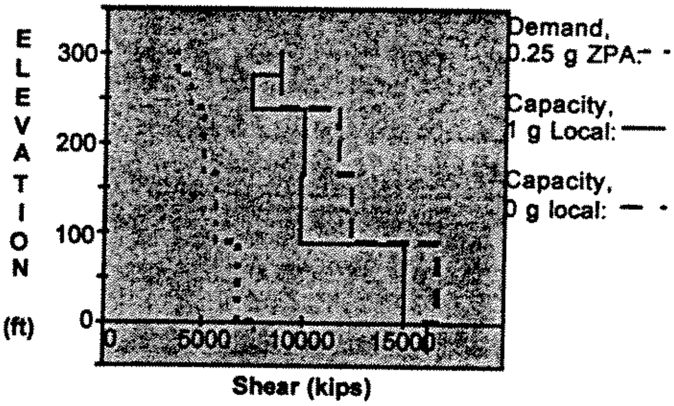

Fig. 21: Platform B, End-On

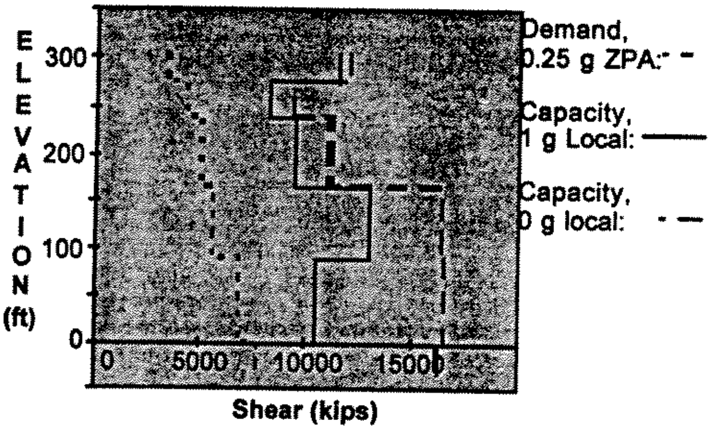

Fig. 22: Platform B, Broadside

OBSERVATIONS AND CONCLUSIONS

The ULSLEA-SRSA earthquake assessment approach described within the first section provides results which are in very good agreement with those obtained from more rigorous analysis effort. The approach does, however, have limitations when applied to complicated structures, especially those which have no grout between the jacket legs and piles. For the cases studied, ULSLEA-SRSA was able to provide earthquake failure intensities (spectrum ZPA for the API response spectrum when load pattern indicates first member failure) for strength-level evaluations within 15 % of those estimated using 3-D frame analysis. It must be noted, however, that vibration periods estimated by the simple approach tend towards being low compared to periods estimated using a more-complete model; while the observed variation did not effect loads much this should be taken into account when using spectra where the higher period range sees the greatest excitation. Given that the simple approach requires much less effort than that involved in performing a 3-D frame analysis, it is ideally suited to performing preliminary design studies and preliminary assessments of existing structures

The modified UBC approach was demonstrated to be another satisfactory method by which estimates of horizontal forces can be obtained for a platform in lieu of performing a 3-D frame analysis. This approach provides an excellent starting point to the estimation of earthquake forces for a strength-level design.

Reviewing some approximations to pile-head stiffnesses, it was seen that there was wide variation in the estimated stiffnesses as compared to the results of more detailed modeling. However, it must be recognized that there can be substantial variation in true pile performance due to uncertainties in the properties of the surrounding soil. Therefore, attempts should be made to obtain upper and lower bounds on pile stiffnesses, in order to obtain a range in expected behavior of the attached platform. It should be noted that most current modeling practice for these platforms do not account for mud mat and mudline brace contributions to foundation stiffness; past experience (Ruhl, 1976; Bannon, Penzien, 1992) has indicated that many platforms behave as though they are fixed at the bottom, due to contact between the jacket and sea floor. While it is possible that softening could taken place for the soils beneath these mudline elements, the possibility of actually possessing a significantly stiff foundation should be considered when performing an analysis.

Finally, the relative significance of local forces on long, unsupported tubular members was qualitatively examined. It was demonstrated that for some large bracing members, the effective axial capacity can be reduced by as much as 30 % by the presence of local inertia forces. It is imperative that these forces not be neglected when performing an analysis.

ACKNOWLEDGEMENTS

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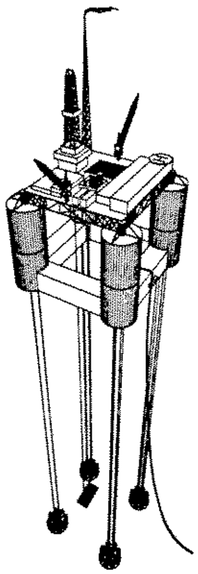
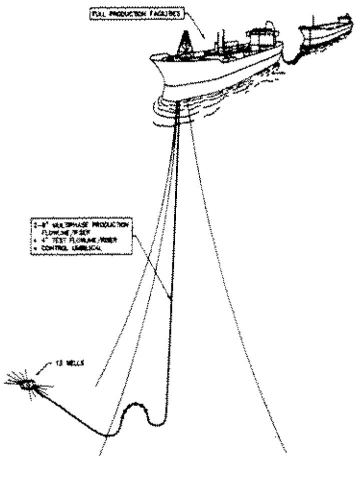
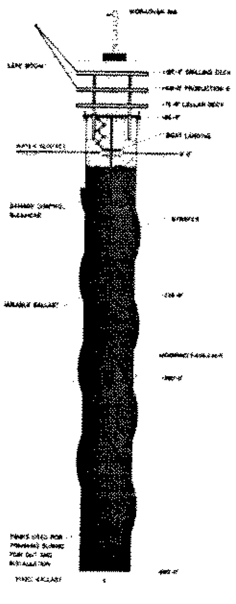
Simplified Analyses of Deep Water Floating Systems
SADWFS

Objective: develop, verify, and document a computer program that will facilitate **simplified** analyses of deep water floating systems including TLP's, FPSO's, and Spars.

Systems





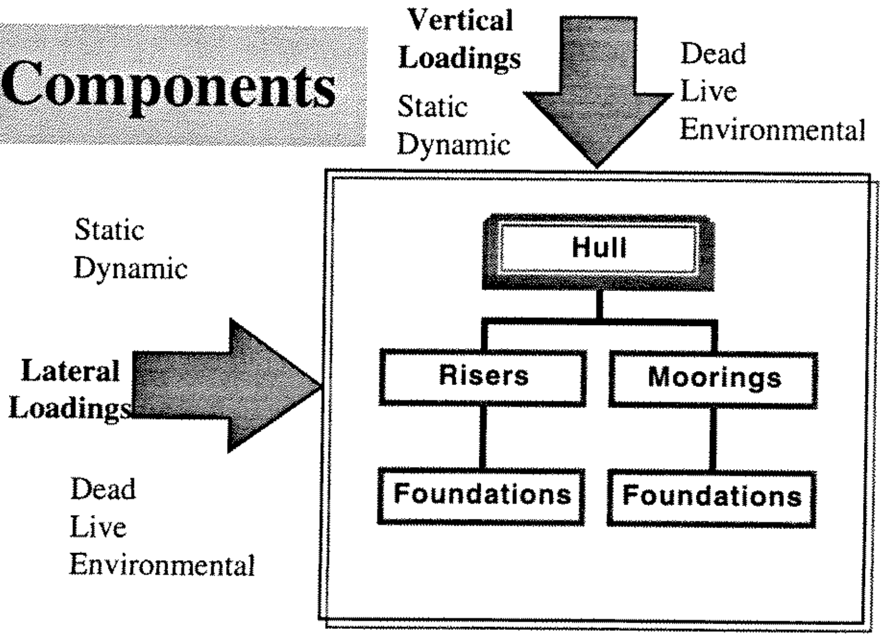


Why *Simplified* ?

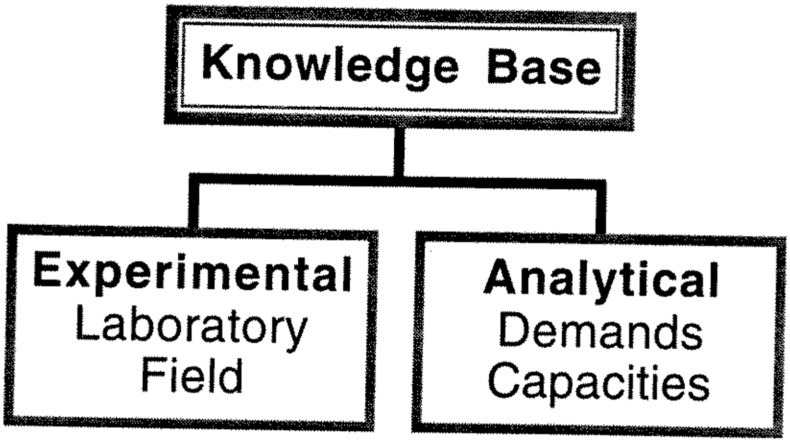
Justifications

- Verify Results from Complex Analyses
- Parametric Studies to Quantify Effects
- Rapid Assessments of Effects of Changes
- Deterministic & Probabilistic Insights
- Develop Understanding of Controlling Aspects Robustness - Damage Defect Tolerance
- Preliminary Evaluations Design, Reassessments, Modifications

Components



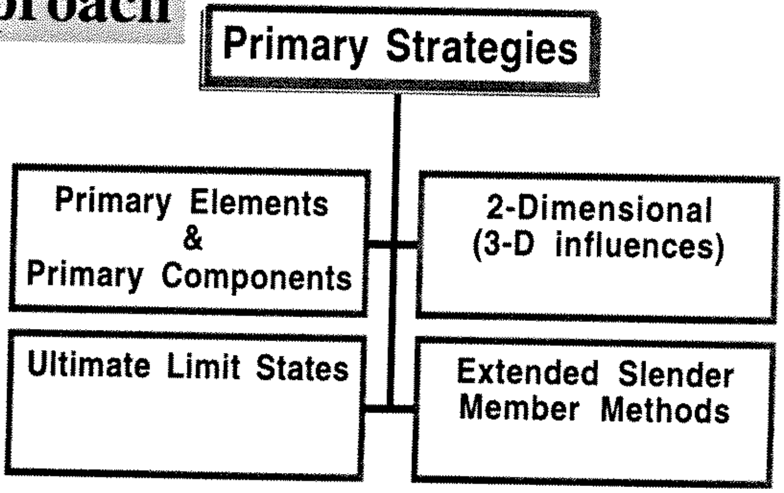
Approach


Knowledge Base

Experimental
Laboratory
Field

Analytical
Demands
Capacities

Simplfied Approach


Primary Strategies

Primary Elements
&
Primary Components

2-Dimensional
(3-D influences)

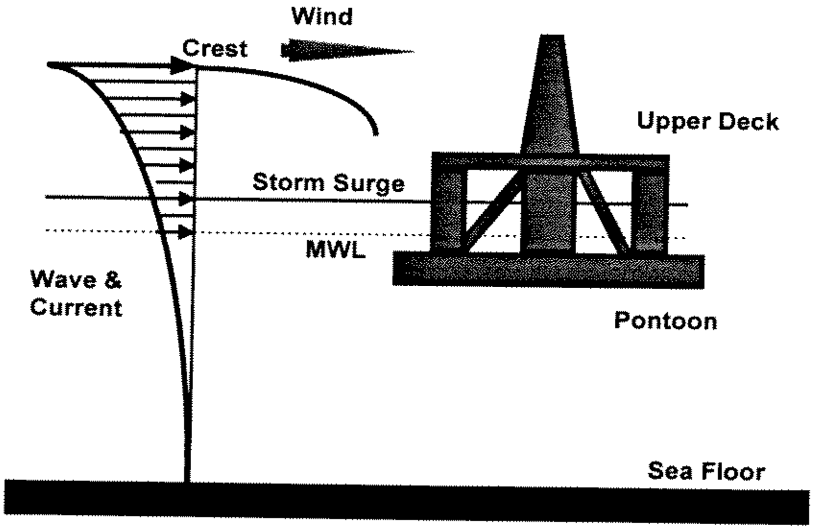
Ultimate Limit States

Extended Slender
Member Methods

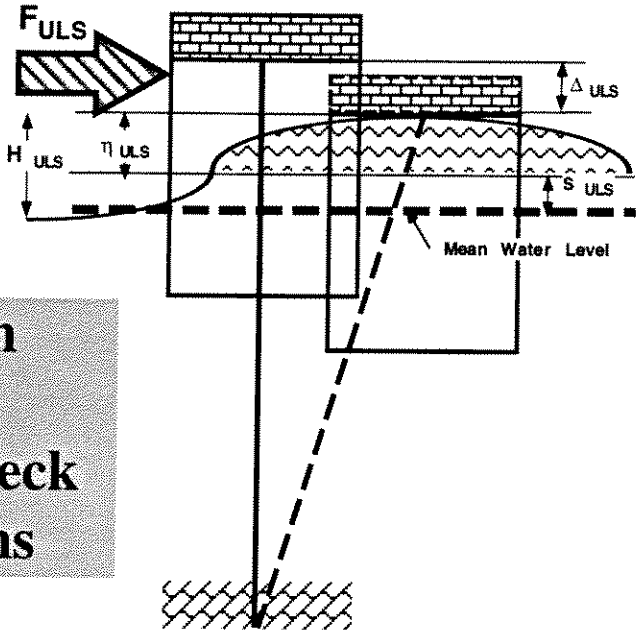
Development Tasks

- #1 - imposed forces algorithms
- #2 - dynamic nonlinear loading effects
- #3 - motions evaluations
- #4 - element, component, and system capacities
- #5 - capacity biases and uncertainties
- #6 - force and capacity reliability assessment
- #7 - input screens
- #8 - output screens
- #9 - program and document SADWFS
- #10 - verification analyses
- #11 - project meetings

Environmental Loadings

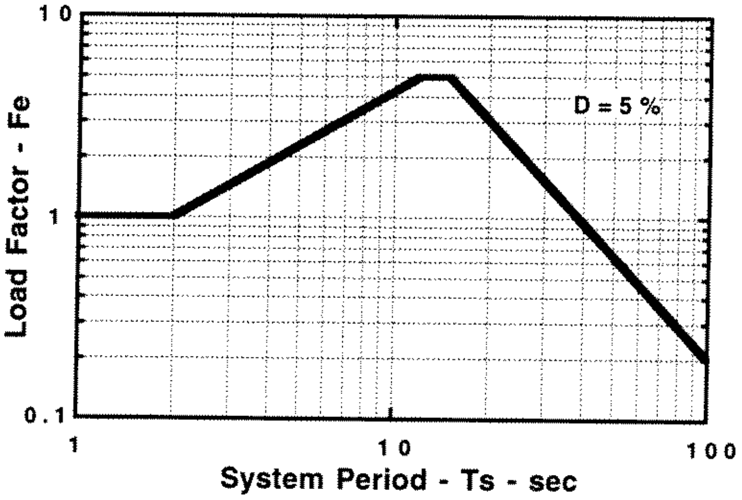


Set Down & Lower Deck Elevations

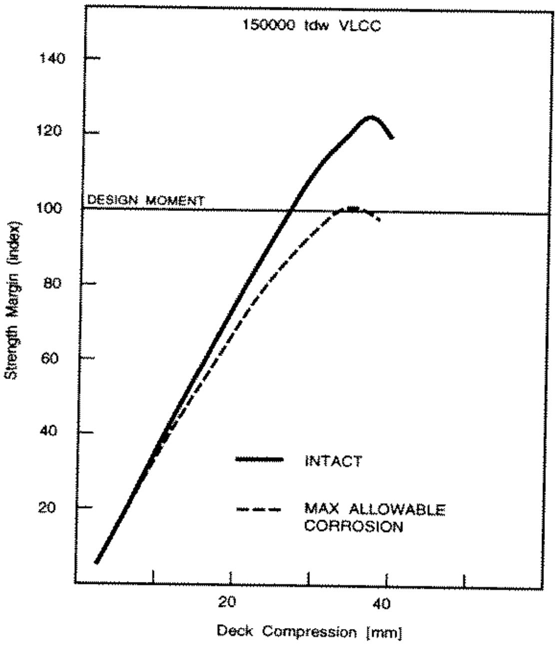


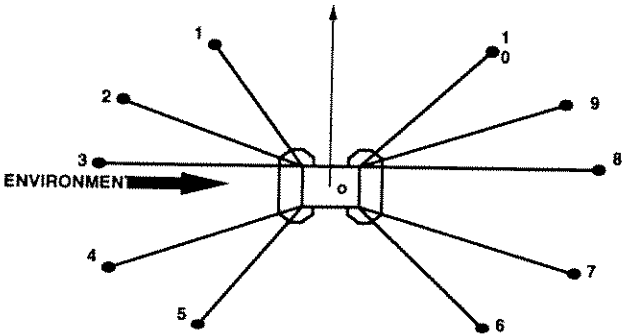
Dynamic Loading Effects

first order wave motions

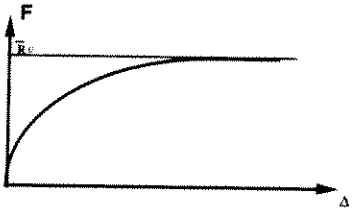


Hull Component Capacities





Mooring Component Capacities



Mooring Capacity

Element Capacities

Structure Element	Median Bias B_{50Ru}	Capacity Uncertainty COV %	Structure Element	Median Bias B_{50Ru}	Capacity Uncertainty COV %
Tubular					
Braces			**Plates**	1.05	7 - 8
tension	1.3	10 - 12			
compression	1.4	15 - 18	**Stiffened Panels**	1.1	10 - 12
bending	1.5	10 - 12			
hydrostatic	1.4	10 - 12			
Tubular Joints			**Cylinders**		
T, Y					
compression	1.2	20 - 22	**Ring-Stringer Stiffened**	1.0	15 - 18
tension	2.7	15 - 16			
X, DT					
compression	1.1	10 - 12			
tension	1.7	20 - 22	**Ring Stiffened**	1.0	10 - 12
K, YT					
compression	1.3	20 - 24	**Box Girders**	1.1	10 - 12
tension	1.7	20 - 24			
Piles			**Drag Anchors**		
Static axial			**clays**	1.5	40 - 50
clays	1.0	30 - 40	**sands**	1.2	50 - 60
sands	0.8	50 - 60			
Static lateral					
clays	1.0	20 - 30	**Cables**	1.5	10 - 15
sands	1.1	40 - 50			
Dyn. axial					
clays	2.5	35 - 45	**Tendons (machined connections)**	1.1	7 - 8
sands	0.9	50 - 60			
Dyn. lateral					
clays	1.0	25 - 35			
sands	1.1	40 - 50			

First Order Second Moment Reliability Analyses

- element capacities: Pfels
- component capacities, Pfc = Σ Pfels to Pfem
- system capacities: Pfsyls = Σ Pfcls to Pfcm
- loadings: Ps
- probabilities of failure Pf = Σ Pfcls • Ps
- biases & uncertainties
- correlations

Uncertainties & Biases

Case	Bias (true / computed value)	Lifetime (25 yea %
Tankers (hogging \ sagging)	1.13 \ 1.13	8
Container Ships (hogging / sagging	0.88 / 1.28	9
Still-water bending	1.0	15 - 35
Wave bending	1.1 - 1.3	8 - 12
Local pressure	1.0 - 1.5	20 - 30

Schedule

Task	First 6 months	Second 6 months	Third 6 months	Fourth 6 months	Fifth 6 months
1	--------------X				
2		--------------X			
3			--------------X		
4	--------------X				
5		--------------X			
6		--------------X			
7			--------------X		
8			--------------X		
9				--------------X	--------------X
10				--------------X	--------------X
11	X	X	X	X	X

Budget

Cost Category	Year 1 $	Year 2 $	Year 3 $	Total $
Personnel	65,000	66,000	13,000	144,000
Benefits	34,000	37,000	19,000	90,000
Expenses	14,000	14,000	6,000	34,000
Total direct costs	113,000	117,000	38,000	268,000
Indirect Costs	41,000	42,000	9,000	92,000
Total Costs	154,000	159,000	47,000	360.000

Deliverables

1) bi-annual project meetings and documentation
2) SADWFS program development, verification, and documentation reports, and
3) SADWFS computer program

Project Funding

- 6 sponsors
- 2.5 years
- $24,000 (1999), $24,000 (2000),
  $12,000 (2001)
- reduce participation cost if more than 6 sponsors

PENDING PROJECTS: SPONSOR COMMITMENT LEVEL

COMPANY	TOPCAT PRO	TOPCAT TORSION/ LESS GENERIC	SADWFS
ARCO	YES	YES	NO
CHEVRON	YES	?	?
EXXON	YES	YES	INTEREST
MOBIL	YES	YES	NO
SHELL	YES	NO	INTEREST
UNOCAL	YES	INTEREST	INTEREST
PEMEX/IMP	YES	INTEREST	?
B&R	YES	INTEREST	?
MMS/CSLC	YES	INTEREST	INTEREST

PHASE IV: PLAN FOR NEXT 6 MONTHS

Task /GSR	1998 7 12
Damage Studies	
New Student	-----------------x
Earthquakes	
Stear	-----------------x
Diagonal Loads	
Jin	-----x
Deck Elements	
Jin	-----------------x
Wave-in-Deck	
New Student	------------x
Verify Cnoidal	
Jin	-----------------x
Updated Software	
	x