# MEASUREMENT OF WIND LOAD RESISTANCE ON DRILLING STRUCTURES

## Phase One

Prepared for

JOINT INDUSTRY PROJECT
SPONSORS

DECEMBER 2001

CONFIDENTIAL

# MEASUREMENT OF WIND LOAD RESISTANCE
# ON
# DRILLING STRUCTURES
## Phase One

PN1996103

**Prepared for**
**Joint Industry Project Sponsors**

**Co-Prepared by:** Michael J. Effenberger
**Michael J. Effenberger, P. E.**
**Senior Associate**

**Co-Prepared by:** David R. Lewis
**David R. Lewis, P. E.**
**Lewis Engineering Group**

**Stress Engineering Services, Inc.**
**13800 Westfair East Drive**
**Houston, Texas 77041-1101**

**December 2001**

# CONFIDENTIALITY OF REPORT

The release and sharing of this report is restricted in accordance with the confidentiality restrictions of the Participation Agreement signed by all sponsors and Confidentiality Agreement signed by all contractors.

**Excerpts from Participation Agreement dealing with Confidentiality of Information**

**ARTICLE 7 - CONFIDENTIALITY AND USE OF TECHNICAL INFORMATION**

7.1 SES will hold title to all Program Results in accordance with the terms of this Agreement. Except as provided in this Article 7, SES and Sponsors will keep confidential in the same manner as they protect their own confidential information, all Program Results for a period of three (3) years following completion or termination of the Program. By unanimous written consent of SES and Tier I Sponsors, the confidentiality period for all or any portion of the Program Results may be reduced, changed or terminated. This confidentiality obligation, however, shall not apply to information, which SES or a Sponsor can show by reasonable proof:

a. was in the public domain prior to the time the information was developed or acquired thereunder or subsequently becomes part of the public domain through no fault of Sponsor;

b. was in the possession of SES or a Sponsor or its Affiliates prior to the time it was developed or acquired thereunder;

c. subsequent to the time it was developed or acquired thereunder, is obtained by SES or a Sponsor or its Affiliates without a confidential obligation; or

d. is developed by SES or a Sponsor or its Affiliates as a result of activities carried out independently of the Program.

For the purpose of this Agreement, specific items of Program Results will not be considered to fall within any of the exceptions recited above merely because such items are embraced in more general information, which falls within one or more of the exceptions.

7.2 Subject to the provisions of Article 7.1, SES and each Sponsor or its Affiliates shall have the right to freely use any of the Program Results developed or acquired by SES thereunder. Sponsor is responsible for its own interpretation and subsequent application of Program Results, and in no way shall SES be liable for use of data by Sponsor or its Affiliates. Each Sponsor shall also have the right to disclose such Program Results and to extend the right to use such information to each of its Affiliates who accepts the confidentiality obligation set forth in Article 7.1, above. Each Sponsor to this Agreement, and each Affiliate to whom a Sponsor has made Program Results available pursuant to this Paragraph, shall also have the right to disclose Program Results and extend the right to use such Program Results (a) to third party consultants and contractors who agree to the confidentiality obligation set forth in Article 7.1, above and agree to use the Program Results solely for the Sponsor or its Affiliates; and (b) to third party operators having working interest in Sponsors or its Affiliates gas or oil field, provided that each third party operator agrees to observe the confidentiality obligation set forth in Article 7.1 and agrees to use the Program Results only in connection with such oil or gas field. Each Sponsor and each Affiliate to whom the Sponsor has made Program Results available pursuant to this Article will also have the right to make appropriate disclosures of Program Results to governmental authorities in permitting procedures, provided such Sponsor or affiliate first makes a reasonable effort to obtain from such governmental authority in writing an acceptance of a confidentiality obligation similar to Article 7.1, above.

7.3 Following expiration of the confidentiality period specified in Article 7.1 hereof, SES and each Sponsor in the Program may freely use, sell, or license the Program Results without accounting to any other party.

7.4 Notwithstanding any other term or condition of this Agreement, the HSE reserves the right to publish any Program Results which it has a statutory duty to publish or make available to the public or a section of the public. Provided, however, that before taking the preceding action, HSE shall notify all Sponsors of the Program Results it intends to publish or make available and provide the statutory reason therefore. The Sponsors shall have one month from the date of HSE’s notification to provide HSE with any objections. Thereafter, HSE shall reply to any objections, but may then publish, hold or post a cautionary statement regarding the relevant Program Results.

# ACKNOWLEDGEMENTS

The authors wish to thank the sponsors for funding this project, furnishing information for the database, and drilling structures. Appreciation also goes to the steering committee for help in addressing questions during the JIP. Thanks, also goes to the 'best practice' committee for help in developing the best practice supplement. The database committee help was instrumental in identifying the database parameters. Appreciation also goes to the manufacturers for providing drawings and computer models for the wind load evaluations performed.

The authors wish to thank Mr. Mark Trevithick of T&T Engineering for the help with the best practice document, database parameters, and providing the first structure.

| **Sponsors** | **Sponsor Representative** | |
|---|---|---|
| American Bureau of Shipping | Dr. Yong | Bai |
| Atwood Oceanics, Inc. | Mark | Childers |
| BP Amoco Corporation | Shu-Yin | Yu |
| Cooper Manufacturing Corp. | Samir | Ghalayini |
| Ensco International Inc. | Tom C. | Baucke |
| ExxonMobil | J. Ward | Turner |
| GlobalSantaFe | Jim | Pittman |
| Grey Wolf Drilling Company L.P. | Robert | Urbanowski |
| Health & Safety Executive | Roland | Martland |
| Helmerich & Payne, Inc. | Scott | Armbrust |
| Lewis Engineering Group | David | Lewis |
| MH-Pyramid Inc. | Louis | Wells |
| Minerals Management Service | Robert | Smith |
| Nabors Drilling International Ltd | David | Mochizuki |
| National Oilwell | Abdul | Megahed |
| Noble Drilling Services Inc. | Jitendra | Prasad |
| Pride International | Pierre J. | Ferran |
| Rowan Companies, Inc. | Bob | Shetti |
| GlobalSantaFe | N Pharr | Smith |
| Transocean Sedco Forex | Darrel | Pelley |
| Woolslayer Companies, Inc. | Dewayne G. | Vogt |
| Zentech, Inc. | Ramesh | Maini |

## Project Management Team

| | | |
|---|---|---|
| Lewis Engineering Group | David | Lewis |
| Stress Engineering Services, Inc. | Terry | Lechinger |
| Stress Engineering Services, Inc. | Michael | Effenberger |

| **Best Practice Team** | **Database Team** |
|---|---|
| Michael Effenberger (Chairman) | Dave Lewis (Chairman) |
| Dave Lewis | Mike Effenberger |
| National Oilwell | Terry Lechinger |
| Woolslayer Companies | National Oilwell |
| MH-Pyramid | Woolslayer Companies |
| ABS Americas | MH-Pyramid |
| Mark Trevithick (T&T Engr.) | Pride Offshore |
| | Nabors Drilling |
| | Mark Trevithick (T&T Engr.) |

## STEERING COMMITTEE

*Government: Robert Smith (MMS)*

*Manufacturers: Louis Wells (Pyramid)*

*Oil Companies: Ward Turner (ExxonMobil)*

*Drilling Contractors*

| Group (1) | Group (2) | Group (3) |
|---|---|---|
| Land and Platform Rigs | Jack-up MODU's | Floating Systems |
| Scott Armbrust, H&P | Pharr Smith, GlobalSantaFe | Jitendra Prasad, Noble |
| 1. Helmerich & Payne, Inc. | 1. GlobalSantaFe | 1. Noble Drilling Services Inc. |
| 2. Nabors | 2. Ensco | 2. GlobalSantaFe |
| 3. Greywolf | 3. ABS (P.L. Tan) | 3. Transocean Sedco Forex |
| 4. Pride Offshore | 4. Rowan Companies, Inc. | |

The Drilling Contractors are grouped according to areas of interest. One drilling contractor was selected to represent the interests of the others in their group. ABS elected to be part of the Jack-up group.

# EXECUTIVE SUMMARY

An API workgroup developed a new methodology for determining wind loads on drilling structures, masts and derricks. In an effort to evaluate the proposed methodology, a Joint Industry Project (JIP) titled “Wind Loads on Drilling Structures” was developed to evaluate and compare the current and proposed methodologies for determining the wind force on drilling structures. The JIP is a cooperative project of interested industries and regulators. The JIP is a multi-phased project, with Phase I addressing desktop analyses of six structures and the effects of the proposed methodology on drilling structures. This report documents the work and conclusions of Phase I, which provides an understanding of the impact the proposed methodology, will have on present drilling structures.

Initially in Phase I, mast and derrick designers, drilling contractors and other industry representatives aided in developing a “best practice” supplement for the existing API-4F specification, addressing issues not covered by the current and proposed documents. A worked example for wind loading on a drilling structure for both methods is provided using this “best practice” supplement. The worked example is performed using a procedure developed for determining wind loads on drilling structures. The procedure uses reactions from StruCAD*3D preprocessor and performs wind calculations in EXCEL workbooks for wind acting in three directions for the frame and equipment.

In conjunction with the development of the best practice, a database was developed to provide information on the range of derricks and masts submitted by the sponsors. The size and diversity of the submitted fleet was captured in the database. The creation of the database aided in the selection of drilling structures that represented the range of the sponsor’s range. This permitted the selection of representative structures that satisfied the project requirement of six (6) drilling structures for the desktop analysis with a limitation that no more than two structures from any manufacturer would be selected. Pie charts created from the database demonstrate that the masts and derricks were representative of the majority of structures currently in use.

Desktop wind calculations of the six-selected derricks/masts were performed for both the current API-4F and proposed methodology. One drilling structure was evaluated to a range of code practices permitting a comparison of the API-4F and proposed method to other practices. From the evaluations, trends were documented which highlighted areas inadequately addressed.

As originally conceived, “an effects study” was to investigate the cost and affect of the new methodology on jack-up, land, platform etc. operations. After completion of the desktop analysis it was found that the effect would be small. At that time, the task scope was changed to a comparison of terms in the current API-4F and proposed methods.

The effects task reviewed the formulas used in the current and proposed methods. Comments and recommendations were provided based on these comparisons. This task also looked at results from the proposed ISO wind practice, providing a reference from other work. Finally the results of the six-derrick/mast analyses compared the global effects of the proposed method to current practice. The results demonstrate the two methods predict similar results; therefore, a detail comparison of effect was not required.

The Phase I work demonstrated that the present API 4F wind methodology is incomplete requiring the designers to supplement the specification with assumptions. These assumptions are different among users, depending on the range of assumptions used. The calculated wind force would vary by a factor of almost two. The present wind load methodology needs to be modified or replaced.

The desktop analyses determined, when using consistent conditions, the current and proposed wind load methodologies provided similar results. The text in the proposed method document, however, needs editing to reduce misinterpretation and address gusting effects for both individual member and global effects.

Also, the current methodology does not address gusting and this should be addressed.

Equipment wind loads were found to be significant with both methods. Wind forces on equipment may be as much as 36% of the total wind force and should be included in an analysis of drilling structures.

A 3-second gust velocity comparison of the proposed onshore and the offshore equations showed the onshore formula resulted in higher pressure, as expected, due to higher surface friction from the ground. The proposed offshore formula resulted in good agreement with the current API-4F method.

When the proposed method's shielding factor was used, the 1-hour wind for the proposed offshore wind pressure is found to compare well with the current methodology. The wind tunnel tests will aid in the validation of the shielding factor in the proposed methodology. This shielding factor's verification is an objective of the wind tunnel testing.

The proposed simplified approach is given in the Best Practice Example. The frame's wind load, as documented, is from StruCAD*3D wind load evaluation, but a good alternative for wind load on the derrick frame is given in ASCE7-98.

# TABLE OF CONTENTS

**Page No.**

# APPENDICES

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

An API workgroup developed and documented a new methodology for determining wind loads on drilling structures, such as, masts and derricks. In an effort to evaluate the proposed methodology, a Joint Industry Project (JIP) was developed to evaluate and compare the current and proposed methodologies for determining the wind force on drilling structures. The JIP is a cooperative project of interested industries (oil companies, drilling contractors, designers/manufacturers, and consultants) and regulators.

The Wind Loads on Drilling Structures' JIP is a multi-phased project. Phase I addresses the desktop analyses and the effects of the proposed methodology on drilling structures. This report documents the work and conclusions of Phase I. Completion of the desktop analysis provides an understanding of the impact the proposed methodology has on present drilling structures. With this understanding, an informed decision may be made with regard to further work and use of the new methodology.

At the start of Phase I, mast and derrick designers developed a "best practice" for the existing API-4F specification. This "best practice" is a supplement to the existing specification addressing issues not covered by the existing and proposed documents. A worked example using the "best practice" is provided covering wind loading on a drilling structure.

A procedure was developed for determining wind loads on drilling structures for the current and proposed methods. The procedure uses reactions from StruCAD*3D solutions and performs wind calculations in EXCEL spreadsheets. Wind calculations are performed for the structural frame, windwall, equipment and setback. Wind loads are evaluated for three wind attack angles; on two adjacent faces of the structure and 45 degrees off a face. In addition, the structures are evaluated with the traveling equipment in two positions: high in the structure and at the drill floor.

In conjunction with the development of the best practice, a database, covering wind parameters on drilling structure, was developed to aid in the selection of drilling structures for the wind load analyses and a study of the effect the proposed methodology has on the existing drilling fleet. The database aids in obtaining a reasonable cross-section of the full range of typical masts and derricks in use by the sponsors.

A desktop analysis of six derrick/mast structures are subjected to an analysis according to the current API-4F and proposed methodology. The example problem was one of the six selected structures. One of the selected drilling structures will be subjected to a range of code practices, such as, ABS, ASCE7, AS1170, and BS8100. These analyses permit a comparison of the API-4F and proposed method to other practices allowing for an interpretation of methodology results. From the evaluations, trends were documented, and highlighted areas inadequately addressed.

As originally conceived, “the effects study” evaluated the effects on load rating, stability, operations, systems, elevated storm criteria, and also addressed the cost impact of the new methodology on the industry. The report will show the proposed methodology will have minimum impact on existing fleet assuming that mid-range assumptions in the current Spec 4F specification were used. “The effects study” was modified to evaluate and compare the current API-4F methodology to the proposed method.

Phase I of “Measurement of Wind Load Resistance of Drilling Structures” included several objects. The project objectives were completed with the development of:

“Best Practice” Addendum to Current API-4F Methodology
“Derrick/Masts Database”
Documentation of an example problem to “Best Practice”
Benchmark Current and Proposed Methodologies for six structures
Interpretation of Results by benchmarking with other Wind Practices
Evaluate & Quantify Effect on Industry
Develop Simplified Conservative Method
Desktop Analysis Method Provided (Example Problem)
Derrick Structures Only: ASCE7 or ABS Method with Equipment

# CHAPTER 2

# BEST PRACTICE SUPPLEMENT

In developing wind loads on drilling structures using API's Specification 4F, "Specification for Drilling and Well Servicing Structures", the designer needs to obtain additional shape coefficients and apply considerable engineering judgment. This is due to incomplete wind load methodology in the specification. Since judgment is involved, the designer has broad latitude in the development of these loads. Therefore this joint industry project undertook a task of developing a best practice of the current API 4F methodology as applied by practitioners.

In developing the "best practice" guide, the designers were asked for procedures used in calculating the wind load where the specification does not provide guidance. Originally, as described in the JIP proposal, the "best practice" guide was to be a single set of guidelines for calculating the wind loads. But based on the practitioners contrasting responses, the guide below was setup as a high and a low set of guidelines to cover the range of practices used by the designers.

The wind loads reported for the best practice example structure were developed using the current published API-4F specification with the additional guidance listed in "best practice" document. These reported wind loads do not necessarily reflect the wind loads calculated by a manufacturer's design practice. A manufacturer may use any combination of the high/low guideline that is described in the following pages. Table 2.1 is attached describing the two sets of guidelines.

Although the proposed method (see Appendix 2.1) is not in use, the designers were asked to review the document and supplement areas not covered or needing further development. The only comment received from the practitioners was the need to check overturning against a factor of safety consistent with the current API-4F. As a result, no second best practice supplement was needed to cover the proposed methodology.

Some of the specific items addressed in the “best practice” document are: how the diagonal wind loading should be addressed for derricks and masts, what shape coefficients should be used for various items, and how setback and equipment should be included. One un-conservative method used by manufactures in the past for determining diagonal wind is illustrated in Figure 2.1. This method should not be used.

A comprehensive analysis of the derricks was performed from these inputs to assess the affects of using the current methodology and to assess the effects of the proposed methodology on current mast and derrick designs. The worked example of the “best practice” includes both orthogonal and the diagonal wind conditions.

(Note: When evaluating the shielding effect of components behind a wind wall, different opinions were expressed by the “Best Practice” committee. These opinions included several assumptions from full to zero shielding. The committee discussed the use of a slope method (e.g. 1 to 10) to identify structures shielded. After this discussion, the two bounds cases in the table were selected. The question of shielding provided by the wind wall is open for consideration and should be addressed by the API 4F wind committee).

## TABLE 2.1: Best Practice Guidelines

| ITEM | BEST PRACTICE | |
|---|---|---|
| | LOW | HIGH |
| METHOD | | |
| ABS | Not Used | Not Used |
| PROJECTED AREA | YES | YES |
| PROJECTED PRESSURE | Not Used | Not Used |
| | | |
| DIAGONAL WIND | | |
| PROJECTED AREA | - | YES |
| SCALE FACTOR, Using Wind Loads on Adjacent Structure Faces | YES, SF=0.7071 | - |
| | | |
| DRAG COEFFICIENTS | | |
| SETBACK | 1.00 | 1.00 |
| MAST | 1.25 | 1.25 |
| DERRICK | 1.25 | 1.25 |
| CROWN | 1.0, BLOCK | 1.25, PRECISE |
| TRAVELING BLOCK | 1.0, BLOCK | 1.25, PRECISE |
| TOP DRIVE | 1.0, BLOCK | 1.25, PRECISE |
| GUIDE RAILS | 1.5, RAILS ALONE | 1.25, RAIL & BRACING |
| Pipes, Hoses, Round Tubing | 0.6 | 0.6 |
| WIND WALLS | 1.5, FRONT ONLY | 1.0, FRT & BCK |
| WIND WALLS Shielding of Setback | None | None |
| | | |
| SHIELDING | | |
| BEHIND SETBACK | 0 | 0 |
| BEHIND WINDWALLS | Note 1, 5 | Note 2, 5 |
| AT DRILL FLOOR | Note 3, 5 | Note 4, 5 |
| CROWN AREA | 100 | |
| SUBSTRUCTURE | 0 | 100%, WINTERIZED |
| | | |
| CRITICAL WIND DIR | 45 | 45 |
| | | |
| OVERTURNING | YES | YES |
| OVERTURNING F. S. | 1.25 | 1.25 |
| | | |
| ACCESSORIES<br>Ladders, Standpipe, Cable tray, etc. | None | 1.25 |

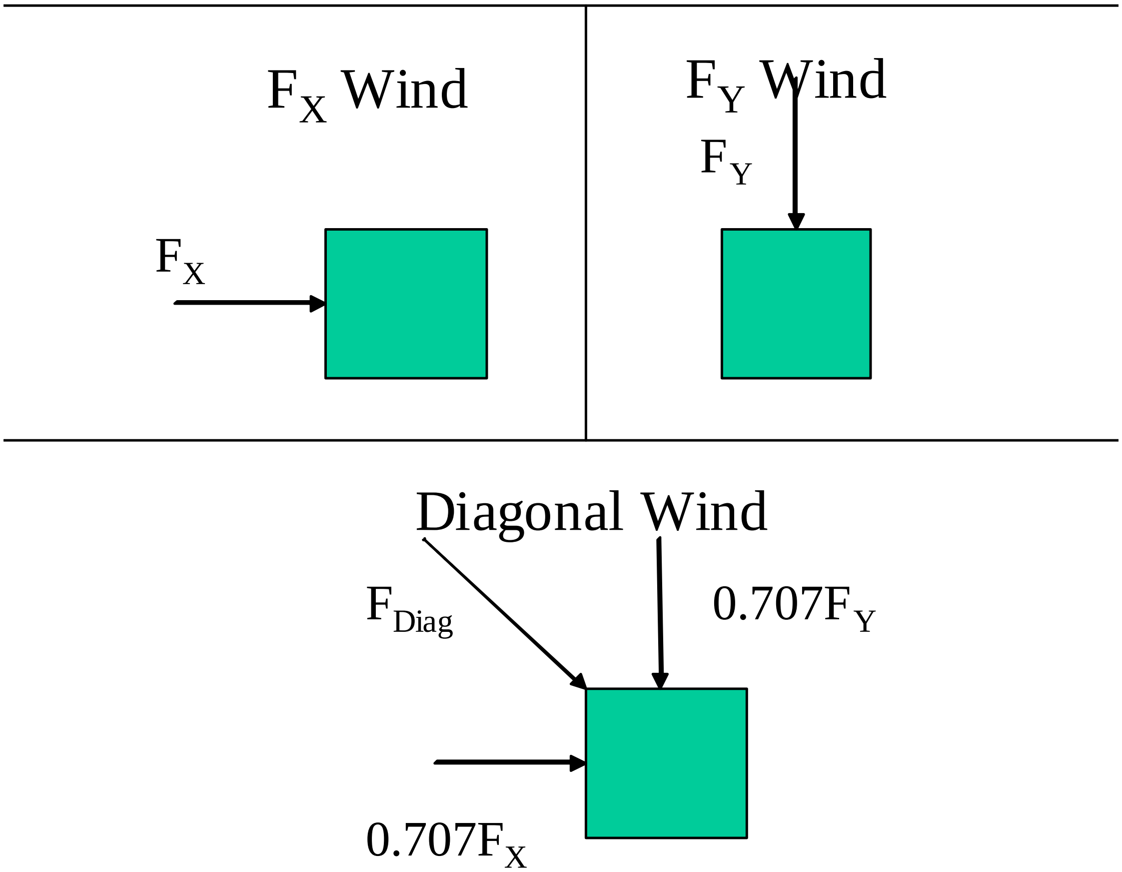
## TABLE 2.1

## (continued)

**Notes :**

| |
|---|
| **Block Area –** Taking a prismatic shape and breaking into rectangles. The rectangle dimensions are the maximum width and height of the region being evaluated. The block area is the sum of rectangles. |
| **Precise Area –** Taking a prismatic shape and calculated as close a possible the total projected area. |
| (1 On non-drill floor windwalls, framing directly behind windwall, that supports the windwall is 100% shielded. Shielded windwall (behind front windwall) is 100% shielded. |
| (2) On non-drill floor windwalls, framing directly behind windwall, that support the windwall is 100% shielded. Shielded windwall (behind front windwall) is calculated with no shielding (catching full wind). |
| (3) On drill floor windwalls, framing directly behind windwall, that supports the windwall is 100% shielded. Shielded windwall (behind front windwall) is 100% shielded. |
| (4) On drill floor windwalls, framing directly behind windwall, that support the windwall is 100% shielded. Shielded windwall (behind front windwall) is calculated with no shielding (catching full wind). |
| (5) Setback behind windwalls is NOT shielded. |

# 0.707 Diagonal Wind Approach



$$F_{Diag} = SQRT((0.707F_X)^2+(0.707F_Y)^2)$$

For a Square Symmetrical Frame,
Where $F_X = F_Y$ ; $F_{Diag} = F_X = F_Y$

**Figure 2.1: 0.707 Diagonal Wind Approach**

DO NOT USE THIS METHOD!

(Unless verification is provided)

# CHAPTER 3

# WIND ANALYSIS DESCRIPTION GENERAL

Wind load evaluations of the drilling structures, mast and derricks, were performed to the guidelines of the present API 4F specifications and proposed methodology. In addition, the calculations were performed to the current practices of manufacturers where the specification does not provide guidance. These manufacturer's practices are described in the best practice guideline. The best practice guidelines are detailed in Chapter 3 of this report.

For the JIP wind analysis, the primary information to be determined is the base shear and the centroidal elevation of the wind load. There are eighteen sets of wind calculation performed for each drilling structure. The wind loads were investigated for three wind directions. Wind on two adjacent faces of the structure and across the diagonal of the structure 0°, 45° and 90°. For each direction the wind loads were calculated for a Best Practice high and a low condition. In addition for these load cases the structure was evaluated with the traveling equipment in two positions:

Position 1 - the traveling equipment is at the highest position in the structure and
Position 2 the traveling equipment is at the lowest position.

Since these studies are investigating the amount of wind load on a drilling structure, no structural evaluations were performed.

The wind load evaluation was performed using the following computer programs, StruCAD*3D by Zentech, Inc. and Microsoft's EXCEL, a spreadsheet program. StruCAD*3D is a finite element program that performs wind calculations on beam type elements using both the projected area and projected velocity approaches. These two techniques for applying wind on members are required for the present and proposed methodologies.

## DESCRIPTION OF THE ANALYSIS FOR THE PRESENT (API-4F) WIND LOAD METHODOLOGY

The derrick finite element model was used to obtain the structure's base reactions and overturning moments from a specified list of load conditions (28 load conditions, Table 3.1). The model as provided by the designers required modifications. Gin pole frames were added to structures' 1 and 2. Group card names were changed for members to account for shielding of the members behind racking board and drill floor wind walls. In addition, several of the models group card names were changed isolating the top drive with bracing and gin pole structure members. With these modifications these components could be independently shielded in specified load cases.

Members defined by certain group cards are shielded in StruCAD*3D with the use of Group OVERRIDE cards and setting the wind coefficient to zero. The Group override cards are placed within the specified 28 required load cases. The specified list of load cases is given in Table. 3.1. The order of the load case is important as well as the structural component overridden within certain load cases. The reason it is important that these load cases are maintained is that certain components are overridden within certain load cases and the reactions for this load case are input directly into a reactions spreadsheet. The reactions that are input into a reaction spreadsheet is given in the last table of the StruCAD*3D OT3 output file. In this reaction spreadsheet the wind areas for the frame structure, the guide tracks with bracing, and gin pole are obtained with their centroidal elevation of the wind loads.

The StruCAD*3D solutions were performed with a 100 knot wind and no height coefficient. The spreadsheets are setup for these conditions. Therefore, if these variables are changed, the spreadsheet must also be changed for consistency.

In the same EXCEL workbook, but on separate worksheets, the structures wind areas are internally transferred into specified locations on the two "area" worksheets (representing different positions of traveling equipment). There are two "area" worksheets in every workbook and each of these worksheets has all the wind areas, including structure and equipment. Areas for items not included in the derrick's finite element model are also input on these two area worksheets. These other items are equipment areas, stairways, ladders, walkways, traveling equipment, etc. The only difference between the two worksheets is the location of the traveling equipment. The first "area" worksheet has the traveling equipment at the highest position in the structure and the second area worksheet has the traveling equipment at the lowest position in the structure. The "area" worksheets are also set-up to input areas for both the high and low conditions as described in the best practice document. Diagonal wind areas are also accounted for on these worksheets.

From these "area" worksheets data is transferred into six-wind "calculation" worksheets located in the same workbook. The wind calculations are performed using the wind force equation given in API-4F. These calculations are performed for each structured component or piece of equipment. The wind loads are combined using the principal of superposition. The six "calculation" worksheets are:

**TABLE 3.2: Six EXCEL Calculation Worksheets for Present Methodology**

| Worksheet Number | Worksheet Title | Description |
|---|---|---|
| 1 | X Low | Calculates wind along the X Axis according to Best Practice "Low Load Guidelines" |
| 2 | Y Low | Calculates wind along the Y Axis according to Best Practice "Low Load Guidelines" |
| 3 | 45 Low | Calculates wind along the 45 Degrees Off the X Axis according to Best Practice "Low Load Guidelines" |
| 4 | X High | Calculates wind along the X Axis according to Best Practice "High Load Guidelines" |
| 5 | Y High | Calculates wind along the Y Axis according to Best Practice "High Load Guidelines" |
| 6 | 45 High | Calculates wind along the 45 Degrees Off the X Axis according to Best Practice "High Load Guidelines" |

From these worksheets the results are tabularized in a worksheet titled Summary. There is an additional worksheet; this worksheet contains a table of the height coefficients versus elevation as given in API 4F (**Do not change this worksheet**). The wind calculation worksheets obtain the appropriate height coefficient from this table.

With the use of this EXCEL workbook, the structure can be evaluated for different wind velocities and the base of the structure can be adjusted to different elevations. Theses variables can be changed on the first worksheets tabbed General Info. Although the present API 4F does not address wind gusts, for comparison purposes, the wind load is assumed to be a 3-second gust so a direct comparison can be made with the proposed method.

An important point not covered in the discussion above is that all structural members have the same drag coefficient. For the present API 4F methodology structural shapes have only one drag coefficient, 1.25, which also includes shielding (see Chapter 6). Because of this, it allowed the structure to be evaluated with one StruCAD*3D solution. If the structural shapes were to have several different drag coefficients, multiple StruCAD*3D solutions would be required depending on the number of structural shapes having different drag coefficients.

### DESCRIPTION OF THE ANALYSIS FOR THE PROPOSED WIND LOAD METHODOLOGY

Many of the steps used in determining the wind loading on the drilling structure are the same for the proposed methodology. Both start with StruCAD*3D solutions that are fed into an EXCEL workbook. The basic format of the EXCEL workbook is similar. Both have reaction worksheet used to determine the drilling frame wind area, both have two area worksheets, both have work sheets to determine the wind loads by direction and both have summary pages.

There are differences as well. First the proposed method requires making multiple StruCAD*3D solutions. Where the present method has one drag coefficient for all structural shapes, the proposed method has different shape coefficients based on the member type (wide flange, channel, structural tube, etc.). For example, angles, channel and wide flanges have a drag coefficient of 1.8, square and rectangular tube sections have a 1.5 drag coefficient and circular cross sections have a 0.8 drag coefficient. Due to the three drag coefficients, three solutions are needed. Each solution is based on one of the drag coefficient with the other drag coefficients zeroed out. This results in wind areas based on each drag coefficients. The proposed method also only determines wind load for three basic directions; 0, 45 and 90 degrees. The high and low cases, resulting from the best practice differences, are not needed for the proposed method.

Another big difference in the two methodologies is the wind's velocity gust duration. In the proposed method a one-hour wind velocity is adjusted to a 3-second wind in the local wind velocity condition (see paragraph 6.2.1.3 of the proposed methodology) to design individual members.

The present methodology does not address gust duration needed in the design of a derrick or mast.

**NOTE**: MANY OF THE CELLS IN WORKBOOKS (DISCUSSED IN CHAPTERS 4 AND 5) CONTAIN EQUATIONS USING INFORMATION FROM OTHER WORKSHEETS. BECAUSE OF THIS MANY OF THE WORKSHEETS CELLS ARE PROTECTED AND CANNOT BE CHANGED. CELLS WITH VALUES HAVING A YELLOW BACKGROUND CAN BE CHANGED. THE MAIN INPUTS TO THE SPREADSHEETS ARE ON THE REACTIONS WORKSHEETS, GENERAL INFO WORKSHEET, AND THE POSITION 1 AREA WORKSHEET. THE SUMMARY WORKSHEET HAS NO INPUTS AND ALL VALUES ARE EQUATIONS OR DATA FROM CALCULATION WORKSHEETS.

## DESCRIPTION OF STRUCAD*3D LOAD CASES

### TABLE 3.1: Load Cases Used for Present and Proposed Methodology

| Load Case | WIND DIR. Measured From X-AXIS Deg. | WINDWALL | OVERRIDE CARDS |
|---|---|---|---|
| 1 | 0 | R | F&R |
| 2 | 45 | R | F&R |
| 3 | 90 | R | F&R |
| 4 | 135 | R | F&R |
| 5 | 0 | - | F&R |
| 6 | 45 | - | F&R |
| 7 | 90 | - | F&R |
| 8 | 135 | - | F&R |
| 9 | 0 | - | R |
| 10 | 45 | - | R |
| 11 | 90 | - | R |
| 12 | 135 | - | R |
| 13 | 0 | - | F |
| 14 | 45 | - | F |
| 15 | 90 | - | F |
| 16 | 135 | - | F |
| 17 | 0 | - | T |
| 18 | 45 | - | T |
| 19 | 90 | - | T |
| 20 | 135 | - | T |
| 21 | 0 | - | - |
| 22 | 45 | - | - |
| 23 | 90 | - | - |
| 24 | 135 | - | - |
| 25 | 0 | - | G |
| 26 | 45 | - | G |
| 27 | 90 | - | G |
| 28 | 135 | - | G |

Notes:

R – Area Cards are used to represent the racking board
F – Override Cards are used to set $C_d = 0$ for members behind the Drill Floor Wind Walls
R – Override Cards are used to set $C_d = 0$ for members behind the Racking Board Wind Walls
T – Override Cards are used to set $C_d = 0$ for Guide Track and Track Bracing members
G – Override Cards are used to set $C_d = 0$ for Gin Pole members

# CHAPTER 4

# EXAMPLE PROBLEM

An example problem was documented to demonstrate how wind loads on a drilling structure are developed. The example was performed on a generic derrick structure. The example derrick was furnished by T&T Engineering and is not a finalized structure ready for construction. The structure was selected because the information is not proprietary and the member sizes and dimensions could be included in this discussion. StruCAD*3D input of the model is given in Appendix 4.1a (Present) and 4.1b (Proposed).

The derrick is 160 feet clear height and a 30-foot square base. Figure 4.1 is a plot of the model. The structure is fully framed on all four sides and has 11 bays from bottom to top that are braced with Vee bracing. The derrick is primarily constructed with wide flange shapes used for legs and girts. Angles are primarily used for bracing. The structure has a gin pole frame above the crown that extends to an elevation of 192 feet above the base of the structure. A Varco TDS4 top drive with rails is installed on the off-drillers side. The racking area has two 6 by 6.5 foot rectangular shape areas. The two racking areas are on the off-drawworks side of the structure and are 5 foot apart. Drawings of attached equipment were not provided but an attempt was made to select accessory equipment typically used on derricks of this size.

There are two wind walls shielding the derrick. The drill floor wind wall shields the bottom 15 feet of the derrick and the racking board walls shield from elevation 80 feet to 95 feet of the derrick. The floor wind wall is on the substructure and the racking board wind wall is attached to the derrick.

The equipment areas are based on typical pieces of equipment used on this type of structure. Calculations were performed and are in Appendix 4.2 of this report. As stated above, these values are inline with similar equipment used for structures of this size.

Most equipment items are prismatic shapes and for both methodologies, the area is calculated based on projected area in the direction of the wind. A sample of one of these calculations is attached (see Appendix 4.2). For one item, the top drive, the manufacturer furnished a cad file of the projected shapes of the equipment. The precise area for this item and the traveling block were determined using the AutoCAD program. An alternative method of calculating the area is the block area method. For this method, the component is broken into a series of rectangles and the block area is the sum of these rectangles describing the equipment. One item needing special attention are wind wall areas using the proposed methodology. The walls are not based on projected areas but on actual width and height, even for diagonal winds. The pressure and suction coefficients are used with these areas. The calculations for the wind wall areas are attached (see Appendix 4.2).

Using the procedure described in the previous chapter, the "best practice" derrick is evaluated for the current API-4F and proposed methods. Summary tables for both methods are provided in Tables 4.1 and 4.2. In Appendices 4.3 and 4.4 are the Excel workbooks printouts for the both methods.

# TEST CASE

Since StruCAD*3D was used in calculating the basic frame structure wind areas using the projected area and projected velocity, a simple frame was developed to check the wind loads calculated by the program. This simple frame is a one bay structure with inverted Vee bracing on two opposite faces. The columns are rectangular tubing, the beams are wide flange shapes and the bracing has angle members. A plot (Figure 4.2) of the frame is attached. Appendix 4.5 is a StruCAD*3D listing of test case.

The wind loads were check for both methodologies for wind hitting both faces of the frame and across the frame's diagonal. Wind load calculations were performed for the six load cases using an EXCEL workbook. The calculated values are checked against the StruCAD*3D values. A description of the equations used in the calculations of the loads for both methodologies is described in the commentary of the proposed methodology. The calculations were performed using a rational observation of the winds attack angle on the member, i.e., the equations are not matrix algebra. Table 4.3 summarizes the comparison of the StruCAD*3D test case results. In Appendix 4.6 are six tables checking the StruCAD*3D results for the test case.

From the calculations, it was interesting to learn that for projected area method, StruCAD*3D treats an angle as a square or rectangular section where in the proposed methodology (projected velocity) the angle is correctly evaluated with only two plates, not a box section. In other words, if a wind is going across a diagonal of an angle's minor axis the projected velocity method only sees one leg of the angle (the other leg of the angle is shielded by the front leg). In the StruCAD*3D simulation projected area approach wind would be hitting both legs, one leg of the angle and a nonexistent leg because the angle is not a box section as StruCAD*3D assumes. However, the example case found good match for all six cases. The wind calculations are difficult for diagonal members not angling in the direction of the wind. Although these checks are approximate, the calculated values are well within 1% of the StruCAD*3D values.

## TABLE 4.1: JIP Structure 1 - Best Practice - Derrick Summary of Results/Present

### (30' Base X 160' Tall)

Analysis Using API 4F Present Wind Methodology
API 4F Present Methodology

| | Wind Direction | Low | | | | High | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft | Kips | Ft | Kips | Ft |
| Complete Structure with | | | | | | | | | |
| All Accessories | X | 197.0 | 184.2 | 197.0 | 179.4 | 254.5 | 185.6 | 258.0 | 182.5 |
| | Y | 213.8 | 181.1 | 213.8 | 177.1 | 256.8 | 182.2 | 260.3 | 179.1 |
| | 45 | 206.3 | 182.6 | 206.3 | 178.2 | 362.8 | 182.9 | 369.2 | 179.8 |
| Bare Str. w/o Ginpole & Windwalls | | | | | | | | | |
| | X | 106.5 | 185.4 | 106.5 | 185.4 | 106.5 | 185.4 | 106.5 | 185.4 |
| | Y | 108.5 | 185.2 | 108.5 | 185.2 | 108.5 | 178.8 | 108.5 | 185.2 |
| | 45 | 107.5 | 185.4 | 107.5 | 185.4 | 150.8 | 185.4 | 150.8 | 185.4 |
| Setback | | | | | | | | | |
| | X | 29.4 | 146.5 | 29.4 | 146.5 | 29.4 | 146.5 | 29.4 | 146.5 |
| | Y | 45.3 | 146.5 | 45.3 | 146.5 | 45.3 | 146.5 | 45.3 | 146.5 |
| | 45 | 38.2 | 146.5 | 38.2 | 146.5 | 62.7 | 146.5 | 62.7 | 146.5 |
| Wind Walls | | | | | | | | | |
| Only at Racking Board | X | 23.0 | 187.5 | 23.0 | 187.5 | 30.6 | 187.5 | 30.6 | 187.5 |
| | Y | 23.0 | 187.5 | 23.0 | 187.5 | 30.6 | 187.5 | 30.6 | 187.5 |
| | 45 | 23.0 | 187.5 | 23.0 | 187.5 | 43.3 | 187.5 | 43.3 | 187.5 |
| Equipment | | | | | | | | | |
| | X | 38.0 | 208.2 | 38.0 | 183.3 | 87.9 | 198.4 | 91.4 | 189.1 |
| | Y | 37.1 | 207.7 | 37.1 | 184.4 | 72.5 | 207.4 | 75.9 | 186.5 |
| | 45 | 37.7 | 208.3 | 37.7 | 184.1 | 106.0 | 199.0 | 112.4 | 187.9 |

## TABLE 4.2: JIP Structure 1 - Best Practice - Derrick Summary of Results/Proposed

## (30' Base X 160' Tall)

### Analysis Using API 4F Proposed Methodology

| | Wind Direction | API 4F Proposed Method | | | |
|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft |
| Complete Structure with all Accessories | | | | | |
| | X | 228.5 | 185.6 | 232.4 | 183.2 |
| | Y | 236.0 | 182.1 | 239.9 | 179.8 |
| | 45 | 312.2 | 180.3 | 315.6 | 177.6 |
| Bare Str. w/o Ginpole & Windwalls | | | | | |
| | X | 106.0 | 186.1 | 106.0 | 186.1 |
| | Y | 109.4 | 185.3 | 109.4 | 185.3 |
| | 45 | 129.6 | 181.9 | 129.6 | 181.9 |
| Setback | | | | | |
| | X | 28.2 | 146.5 | 28.2 | 146.5 |
| | Y | 43.3 | 146.5 | 43.3 | 146.5 |
| | 45 | 63.5 | 146.5 | 63.5 | 146.5 |
| Wind Walls (Racking Board Only) | | | | | |
| | X | 12.8 | 187.5 | 12.8 | 187.5 |
| | Y | 12.8 | 187.5 | 12.8 | 187.5 |
| | 45 | 17.4 | 187.5 | 17.4 | 187.5 |
| Equipment | | | | | |
| | X | 81.5 | 198.2 | 85.5 | 190.9 |
| | Y | 70.5 | 198.2 | 74.4 | 189.7 |
| | 45 | 101.6 | 198.0 | 105.1 | 189.3 |

## TABLE 4.3: Summary Table of StruCAD*3D Wind Load Preprocessor

| Load Case | Evaluation Method | Wind Attack Direction | StruCAD*3D (Kips) | Evaluation Check (Kips) | Evaluation Check |
|---|---|---|---|---|---|
| 1 | Velocity | X | 8.358 | 8.358 | Exact |
| 2 | Velocity | 45 | 7.082 | 7.082 | Exact |
| 3 | Velocity | Y | 6.064 | 6.064 | Exact |
| 4 | Area | X | 8.358 | 8.358 | Exact |
| 5 | Area | 45 | 10.772 | 10.771 | Good |
| 6 | Area | Y | 6.875 | 6.875 | Exact |

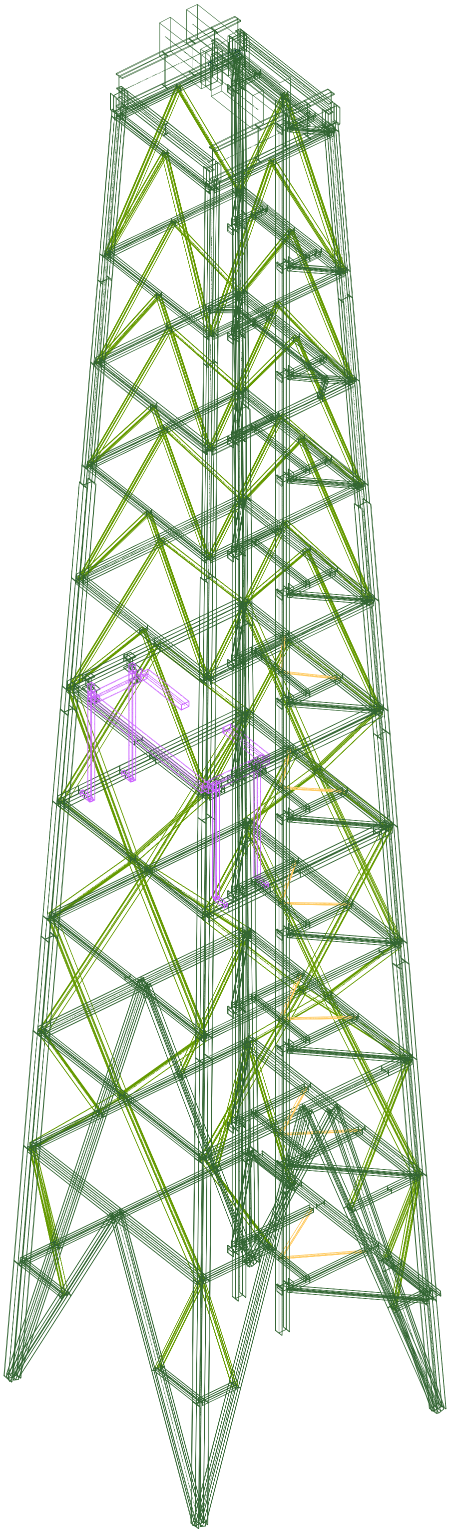


**Figure 4.1: Best Practice Example Model Structure Number 1**

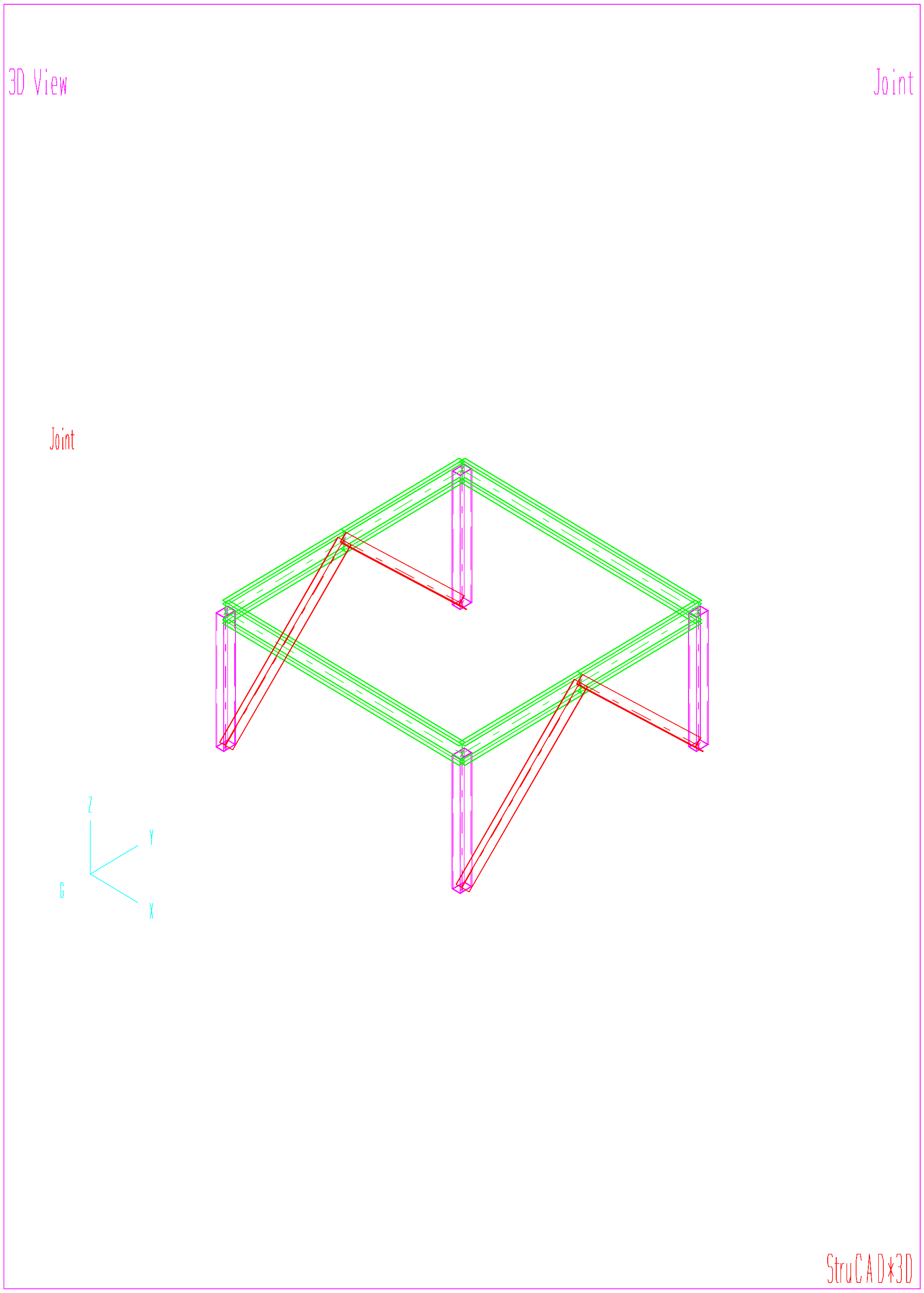


**Figure 4.2: Test Case Model**

LEG: Rectangular Tubes; DIAGONALS: Angles; BEAMS: WF Shapes

# CHAPTER 5

# DATABASE

The database goal, in the Wind Measurement JIP, was to identify the wind characteristics of the derricks and masts in the fleet of the fourteen (11) drilling contractor sponsors. These wind directed characteristics are documented in a database that represents the selected derrick/mast parameters that can be used to evaluate the derrick/mast fleet for the wind study. The completed database will aid in the selection of the structures for the six desktop analyses that are required of the program.

The derrick/mast includes parameters for identifying specific structure characteristics, which affect the wind force. Once these parameters were defined, Microsoft's Excel program was used to create a database template for documenting the parameters for individual structures. This template was distributed to all the drilling contractor sponsors who completed and returned the templates creating individual contractor databases. These individual databases were then combined into a master database for evaluation. Data reduction, including a statistical study, was performed.

The master database and reduced data was used to aid in the selection of the structures for the desktop analysis. A condition for selecting the structures required that the derrick/mast selected cover a wide range of drilling applications and these structures were valid for the ultimate intended use by the owner. The project limitation of six (6) structures for desktop analyses is limiting, in that, the selections made must represent small to large drill structures. Other limitations were that no more than two (2) structures may be submitted from any one-sponsor manufacturer and the selected structure must have a finite element model available. As the derrick/mast structures are used in many different applications, which gave the ability to compare similar parameters in the database permits and allowed the evaluation of the limited number of selected structures to be applied across the range of applications.

In the selection of the structures a common structure, an angle leg derrick, was deferred from the program. This was necessary due to the project limitations.

The database has provided the basis for selection of five desktop structural analyses. By evaluating selected characteristics, the selected five structures may be applied for different applications.

## DATABASE

The database represents derricks and mast drilling structures. The following definitions are used to defined these structures:

> DERRICKS – A derrick is a four-sided frame structure. Racked pipe is contained within the four sides of the structure. A derrick is considered a more permanent structure that is not as easily disassembled for moving as a mast. A derrick is commonly used on fixed platforms, jack-ups, drill ships, and semi-submersibles.
>
> MAST – An open-framed structure having a C shaped cross-section. The mast is open on the V-door side of the structure for racking pipe. The structure is typically a self-elevating structure that does not require an additional crane for assembly. Masts are commonly used for land operations or minimum space platforms.

A technical committee selected variables to represent parameters that will impact the wind area in the evaluation of wind loads. These variables were grouped into four categories:

1. Identification
2. Design
3. Leg Member
4. Appurtenances affected by wind

The variables representing the four categories are incorporated into an Excel workbook. Spreadsheet templates were developed to aid in recording the structure information. These templates were aided with a general description of the parameters and sketches showing the information requested. The sketches were cross-referenced with the database variables to further describe the requested information. This package was then submitted to the drilling contractor sponsors of the Wind Measurement JIP. (A copy of the package is attached as Appendix 5.2).

For ease of use, the database was subdivided into five worksheets of common information.

1. Identification
2. Modifications
3. API Name Plate
4. Dimensional Information
5. Miscellaneous Information (Leg Construction, Application, and Wind Walls)

These five worksheets templates fed a master spreadsheet that, once completed by the drilling contractor, represented a drilling contractor's master database.

Drilling Contractor, Rig Name, substructure and derrick/mast manufacturers comprised the identification work sheet. The substructure and derrick/mast manufacturers are important to identify the different original manufacturers (44 total) and allows sorting by sponsor manufacturers (Cooper Industries, National Oilwell, Pyramid, and Woolslayer). The manufacturer information allows the project to contact the manufacturer for information on the drilling structure. The substructure information originally was requested because this structure supports the drill floor wind walls. Therefore these details would be on the substructure manufacturer's drawings rather than the derrick/mast manufacturer's drawing. This request proved difficult to obtain and as a result the variable was eventually eliminated from the request.

Several drilling contractors have modified their derrick/mast to accommodate top drives and pipe handling systems. The modifications worksheet permits the project to identify the number of derrick/masts that have undergone this modification. A modification for a top drive and/or pipe handling system will increase the wind force from the added system(s). The supporting structure, particularly where the derrick/mast structure is modified to accommodate new equipment, will change the total wind force for all components.

API Manufacturers building derrick/masts supply an API nameplate to the purchaser of the equipment. Drilling contractors have a different use for the information contained on the nameplate than the project. However, this plate is an excellent resource for information related to the calculation of wind effects. API worksheet requested information contained on the nameplate and some non-API nameplate information.

The API nameplate identifies the API standard used in the original design, which contains the methodology used in predicting wind forces for the derrick/mast. The racking capacity provides an approximation of the setback wind area. The project requested the setbacks configuration, and drill pipe stands in setback (doubles or triples). Through manipulation of this setback information, the project is able to get an estimate of the exposed area due to racked drill pipe. Hook capacity generally controls the leg member’s selection that may, depending on design approach, have an affect on wind area of this member. Finally, the mast is identified as freestanding (cantilevered) or guyed. A change in wind force will affect the anchor design of the guyed mast.

The dimensional information worksheet requested lengths, widths, and heights at various locations on the derrick/mast. The dimensional information requested only applies to the drilling structure and does not include wind walls. These are addressed on another worksheet.

The miscellaneous worksheet identified the leg type (wide flange, channel, angle etc.) used in the construction of the derrick/mast. The importance of this variable can be seen in the table below that lists shape coefficient for different sections.

| Member Description | Shape Coefficient |
|---|---|
| Wide flange | 1.8 |
| Tee | 1.8 |
| Angle | 1.8 |
| Channel | 1.8 |
| Tube (square) | 1.5 |
| Tube (Round) | 0.8 |

The structural use of each derrick/mast will identify the effect analyses of interest to the project sponsors. The windwalls at the racking board, drill floor, and substructure were requested to evaluate the effect of these structures on the wind calculation. After issuance of the database, the project recognizing the wind measurement program is limited to the derrick/mast effects, the wind walls on the substructure (area below drill floor) were considered outside of the project scope and the request for this variable was eliminated.

During the course of collecting data a reduced set of parameters representing minimum variables was issued to aid any drilling contractor wishing to provide input but unable to provide all the requested data.

The drilling contractor completed the database for their units and returned these to the project. The individual master databases were collected and incorporated into a final master database that included the first three selected JIP derrick/mast structures. The database has a total population of 575 derrick/mast structures and calculations on the setback area, racking board windwall, and drill floor windwall. These calculations were included to provide additional information for the evaluation of the database. This aided in the selection of the final structures for the desktop analyses.

The data was sorted against the different variables and results plotted on forty-one (41) pie and bar charts (Appendix 5.1). In addition to presenting the results in this visual format, statistics for mean (average), median (mid point of population), and mode (maximum recurring in population) were calculated for the variables requested. These statistics allow the project to evaluate how well the analyzed selected derrick/mast represented the population.

### SELECTION OF DERRICK/MAST

In selecting the derricks/masts for the desktop analysis, the selected structure must represent the largest possible range of the population. The selected derrick/mast also should represent the different applications (platform rig, land, jack-up etc) in which the sponsors use these structures, and finally, the structures selected will be used in the effects analysis. The project would prefer selecting a structure in an application that would be directly affected by the wind method to evaluate the effect of a change in methodology. However, limitations described below prevented, in some cases, these structures being selected.

The selection is limited by non-technical considerations relating to finite element models availability and a manufacturer limitation. The StruCAD*3D program by Zentech, Inc (the program developer) has been modified in recent years to perform wind calculations on beam elements for the projected area method (present API 4F) and the projected velocity method (proposal method). In the development of the Wind Measurement Joint Industry Project, the use of this StruCAD*3D was assumed to keep the man-hour and schedule to a minimum. Therefore, the availability of a StruCAD*3D (or SACS) model is extremely important. To avoid inconveniencing one or two manufacturer sponsors who must supply drawings and technical support, a maximum of two structures are selected from any one manufacturer. As a result a structure other than one best suited for the effects analysis may be selected.

The database and best practice tasks were started at the same time. A typical or general mast and derrick were needed to begin the best practice analysis. A preliminary database of available variables was used to define parameters for the selection of these structures. Using these parameters, two of the manufacturer sponsors provided the information on a typical mast and derrick to begin the desktop analyses. Once selected, the project completed a database (SES Database) for these two structures and an 'example derrick'. This latter structure was included because the best practice deliverable required providing sample calculations. These calculations could not be performed on the typical derrick or mast because they would have violated the proprietary agreement with the manufacturer.

Having already selected the typical derrick and mast, these selected structures were evaluated against the norm. The statistics for eighteen variables were found and summarized in attached tables. The typical "general" derrick and mast are described in Table 5.1 Derricks and Table 5.2: Masts. In the attached statistical table, the requested database parameters are given for all six selected structures. This table includes the statistical values for mean, median and mode. Where applicable, the minimum and maximum values are included in the table to provide a perspective on where the selected structures fall relative to these values.

Comparison of the typical derrick/mast shows the structures selected are representative of the typical structure with many variables falling within or just outside the statistical range. D1 and M1 are plotted on the pie charts (see Appendix 5.1) and a review shows many locations fall near the statistical norm.

An area where the typical mast and derrick fall near the maximum is the racking board wind wall. The mast and derrick used in the analyses are recent designs reflecting the deeper depths drilled. In the case of the derrick, the leg batter (taper) starts above the racking area (~95') to provide for the pipe handling systems preferred by many contractors. Using the final master, derricks/masts were sorted to identify three additional structures that represented additional applications to the typical derrick/mast (semi-submersibles, self-erecting platform rigs, and guyed masts). In the evaluation, the project also looked for alternative member sizes. Potential candidate rigs were selected for consideration for the last three structures. Once the candidate rigs were identified, the limitation that no more than two structures could be requested from any manufacturer eliminated some potential candidates and in one incidence only one manufacturer was identified for a particular type of structure. The manufacturers were contacted concerning available structures that have both drawing packages and computer model. The last three drilling structures included in the desktop analysis task are the results of the selection process.

The three additional structures include a dynamic derrick representing a structure used on drill ships and semi-submersibles. A self-erecting (boot strap) mast was one of two selected mast structures to evaluate the impact on limited area platforms. Finally, a guided mast was selected to evaluate the effect on anchor design. The inclusion of the best practice derrick, general derrick, general mast, dynamic derrick, self-erecting mast, and guided mast completed the six structures to be analyzed in the desktop analysis. The characteristics of these structures are presented in the database template included in Chapter 6.

In reviewing the statistics for these three structures (see Tables 5.1 and 52) the project finds, the dynamic derrick has characteristics that fall towards the upper bound of the database. This is expected as these structures are found in harsh environments. These structures are on semi-submersibles drill ships where they are also subjected to vessel motions while drilling. The self-erecting mast (Mast 2) has characteristics that match the norms with a few exceptions. These exceptions include setback plan area and racking board wind walls. The reasons for the exceptions are similar to the general mast exceptions that resulted from using a more recent design. Therefore, this mast and the derrick likely represent future construction. The guided mast represents the lower statistical end of the masts in the database.

A dual-purpose derrick was given serious consideration for inclusion in the desktop analysis, as these structures are believed to become more common in the future. The inclusion of this structure would have increased the number of desktop analyses. The limiting factors described above, time, budget, and scheduling considerations prevented the inclusion of this structure at this stage of the project.  Also, no sponsor provided data for a dual-purpose derrick in the final master database for any of the sponsors.

It was also necessary for the project to defer an analysis of an angle derrick.  The angle and "Tee" derrick are commonly occurring structures in the population.  However, the addition of a non-proprietary structure for the sample calculations resulted in man-hour and schedule constraints in the best practice and desktop analysis task.  FEA models for an angle derrick were not readily available as the manufacturers have moved to other member types in recent construction and the angle derrick design preceded the common use of computer models (StruCAD*3D and SACS) in design.  The project believed changes in wind methodology could be approximated on the angle derricks by applying ratios that represent changes in wind force prediction for the typical derrick selected.  For these reasons, the absence of an angle derrick is not considered detrimental to the project scope.

## Table 5.1: Derricks Matrix

| Description | Mean | Median | Mode | Minimum | Maximum | General Derrick | Dynamic Derrick | Best Practice Derrick |
|---|---|---|---|---|---|---|---|---|
| Manufacturers | ▨ | ▨ | ▨ | ▨ | ▨ | Dreco | WCI | T&T Eng'r |
| Top Drive Installations | ▨ | ▨ | ▨ | ▨ | ▨ | Yes | Yes | No |
| Pipe Handlers | ▨ | ▨ | ▨ | ▨ | ▨ | No | Yes | No |
| Design Standard | API 4E | API 4E | API 4E | ▨ | ▨ | API 4F | API 4F | API 4F |
| Setback Capacity | 19,000-21,000 | 19,000-21,000 | 19,000-21,000 | 13,000 | 42,000 | 25,366 | 33,820 | 25,500 |
| Set Back Plan Area | 100-149 | 100-149 | 50-99 | 20 | 510 | 163 | 240 | 163 |
| Set Back Projected Wind Area | 2000-2299 | 2000-2299 | 1500-1999 | 1,230 | 5,760 | 3,285 | 3,960 | 3,285 |
| Setback Configuration | 3 | 3 | 3 | ▨ | ▨ | 2 | 2 | 2 |
| Hook Load | 1000-1299 | 1300-1600 | 1300-1600 | 500 | 2,500 | 1,000 | 2,500 | 1,000 est. |
| Clear Height | 150-170 | 150-170 | 150-170 | 139 | 220 | 170 | 170 | 160 |
| Leg Construction | T | T | L | ▨ | ▨ | W | W | W |
| Application | Jack-up | Jack-up | Jack-up | ▨ | ▨ | Jack-up | Jack-up | No Answer |
| Racking Board Height | 11-14 | 15-19 | 20-25 | 10 | 114 | 15 | 25 | 15 |
| Racking Board Plan Area | 100-399 | 400-699 | No Wall | 140 | 1,849 | 1,292 | 1,849 | 1,225 |
| Racking Board Projected Wind Area | 100-499 | 500-999 | 500-999 | 320 | 2,150 | 1,080 | 2,150 | 1,050 |
| Rig Floor Wind Wall Height | 15-19 | 15-19 | 20-25 | 10 | 114 | 15 | 15 | 15 |
| Rig Floor Plan Area | 2000-2499 | 2000-2499 | 2000-2499 | 1,600 | 3,988 | Assumed | Assumed | Assumed |
| Rig Floor Projected Wind Area | 850-1499 | 850-1499 | 1500-2499 | 850 | 12,996 | Assumed | Assumed | Assumed |

## Table 5.2: Mast Matrix

| Description | Mean | Median | Mode | Minimum | Maximum | General Mast | Self Erecting | Guyed Mast |
|---|---|---|---|---|---|---|---|---|
| Manufacturers | ▨ | ▨ | ▨ | ▨ | ▨ | Pyramid | WCI | Skytop B |
| Top Drive Installations | ▨ | ▨ | ▨ | ▨ | ▨ | No | Yes | No |
| Pipe Handlers | ▨ | ▨ | ▨ | ▨ | ▨ | No | Yes | No |
| Design Standard | API 4E | API 4E | API 4E | ▨ | ▨ | API 4E | API 4F | API 4F |
| Setback Capacity | 19,000-21,000 | 19,000-21,000 | 19,000-21,000 | 3,000 | 32,000 | 26,691 | 20,460 | 13020 |
| Set Back Plan Area | 50-99 | 50-99 | 50-99 | 12 | 360 | 98 | 288 | 66 |
| Set Back Projected Wind Area | 2000-2299 | 2000-2299 | 2300-2499 | 510 | 5,184 | 2,520 | 2171 | 1416 |
| Setback Configuration | M | M | M | ▨ | ▨ | M | 4 | M |
| Hook Load | 500-999 | 500-999 | 25-500 | 25 | 2,500 | 1,275 | 1,000 | 410 |
| Clear Height | 120-139 | 120-139 | 120-139 | 48 | 170 | 152 | 150 | 119 |
| Leg Construction | T | W | W | ▨ | ▨ | W | W | Tube |
| Application | Land/Cant'l | Land/Cant'l | Land/Cant'l | ▨ | ▨ | Jack-up | Platform | Guided |
| Racking Board Height | 15-19 | 15-19 | No Wall | 8 | 60 | 15 | 15 | No Wall |
| Racking Board Plan Area | 100-299 | 100-299 | 100-299 | 144 | 513 | 405 | 520 | No Wall |
| Racking Board Projected Wind Area | 100-299 | 100-299 | 100-299 | 208 | 763 | 605 | 690 | No Wall |
| Rig Floor Wind Wall Height | 15-19 | 15-19 | No Wall | 8 | 60 | 25 | 15 | No Wall |
| Rig Floor Plan Area | 295-499 | 500-999 | No Wall | 296 | 2,860 | Assumed | Assumed | No Wall |
| Rig Floor Projected Area | 350-499 | 500-999 | No Wall | 352 | 2,870 | Assumed | Assumed | No Wall |

# CHAPTER 6

# DESKTOP ANALYSIS & INTERPRETATION OF ANALYSIS RESULTS

In the enhanced Joint Industry Project, “Measurement of Wind Load Resistance on Drilling Structures”, a task performing desktop analysis of typical derricks and masts was enlarged to six drilling structures. This task evaluated the structures using the current API 4F specification and the proposed wind load method. The example problem (Best Practice Analysis), covered previously, was one of these six structures. The other five structures were selected with the aid of the previously described database and the database workgroup. These five structures were subjected to the same analysis as used in the best practice analysis example problem.

After the six-structure wind analyses were performed using the two methodologies, one structure was selected for evaluation by other wind load methodologies. A natural selection for the structure used for these load calculations was the structure selected for the wind tunnel testing. The voting Tier I sponsors selected between structures #2 and #3, the general mast and general derrick. The voting sponsors selected the general derrick (structure #2) for testing in the wind tunnel. The other methodologies include non-API wind methodologies, such as, national wind codes and regulatory organizations.

## 6.1 DESKTOP WIND ANALYSIS

### *Present API 4F & Proposed Wind Load Methodology*

Six structures were evaluated using the present and proposed API 4F methodologies. These six structures were evaluated using the same format as described in the example problem. Refer to Chapters 3 and 4 for an understanding of the procedure presented and the organizational format.

Table 6.1 list the six structures and identifies the manufacturers of these structures on which wind loads were performed. Table 6.2 gives a description of the six selected structures. The descriptive information covers the rig parameters requested for the database. In Appendix 6.1 are plots of the five remaining structures. Plots of the example structure were covered earlier.

In Appendix 6.2 are the wind load calculations for the remaining structures. Both calculation methods are included for five structures (ten calculation packages). Tables 6.3 through 6.12 are wind load summary tables for the five structures. As in the example problem, the wind loads are for 100-knot winds with the drill-floor evaluated at a 100-foot elevation. For the proposed method the structures were evaluated for a 3-second gust wind. The present methodology does not address the effects of wind gust.

## 6.2 INTERPRETATION OF ANALYSIS RESULTS

*Non- API Methods*

After completion of the two API 4F wind load methodologies, a task of evaluating one drilling structure using other methodologies was performed. These methodologies were performed on General Derrick (D2), which was also selected as the structure for the wind tunnel test structure.

The derrick's wind loads were evaluated using the methodologies in the following documents:

> ABS, "Rules for Building and Classing Mobile Offshore Drilling Units (MODU)", American Bureau of Shipping, 1991
>
> ASCE 7-99, ASCE Standard, "Minimum Design Loads for Buildings and Other Structures", American Society of Civil Engineers.
>
> AS 1170, Australian Standard, "Minimum Design Loads on Structures" (Known as the SAA Loading Code) Part 2, Wind Loads.
>
> BS 8100, British Standard, "Lattice Towers and Masts, Part 2, Guide to the background and use of Part 1" "Code of practice for loading".

As was used in the API 4F desktop analyses, the derrick was evaluated for a 100-knot, 3-second gust (if applicable) wind and structure elevated 100 feet above the water.

Table 6.13 is a summary of results for the four different wind load methodologies. All "non-API" methodologies used in the evaluation were for square trussed towers. These procedures appear to have the same basic method for determining the wind load but with several different starting assumptions and also differ whether to add wind loads for attachments or appurtenances, however, results are unreasonably low compared to other methodologies because of the appurtenance issue. These documents usually call the appurtenances or attachments, ancillaries, a term from the electrical tower industry. Most of the tower work was directed toward the electrical industry.

ASCE 7-99 document is the simplest of the methods, which covers most of the aspects of wind force prediction. It covers all aspect concerning the tower with regard to wind: varying solidity ratios, appurtenances and diagonal winds. The AS1170 is very similar to the ASCE document but does not address appurtenances. This Australian standard also has another method to address member aspect ratio and inclination in a more complete manner than the other standards (this method is the basis for the proposed method). The ABS method is very simple but only addresses a tower with a 30% solidity ratio and does not address appurtenances or a diagonal wind. In Appendix 6.3 is a brief investigation/explanation of the 1.25 drag coefficient. The BS8100 is the most complex of the "non API methods" but very complete. This method addresses gust effects not addressed by the API methods.

**TABLE 6.1: JIP Structures Manufacturers Description**

| Structure | Company |
|---|---|
| Best Practice Derrick | T & T Engineering |
| General Derrick | National Oilwell |
| General Mast | MH Pyramid |
| Dynamic Derrick | Woolslayer Companies Inc. |
| Self Erecting Mast | Woolslayer Companies Inc. |
| Guyed Mast National | Oilwell |

# TABLE 6.2: Characteristics of JIP Structures Evaluated

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MAST/DERRICK INFORMATION | Substructure | | Company Name: | JIP | JIP | JIP | JIP | JIP | JIP |
| | | | Rig Name/Number: | 1 - Best Practice | 2 - General Derrick | 3 - General Mast | 4 - Dynamic Derrick | 5 - Vert. Erect. Mast | 6 - Guided Mast |
| | | | Manufacturer | NA | NA | NA | NA | NA | NA |
| | | | Substructure S/N | NA | NA | NA | NA | NA | NA |
| | | | Date of Manufacture | NA | NA | NA | NA | NA | NA |
| | Mast/ Derrick | | Mast (M) or Derrick(D) | D | D | M | D | M | M |
| | | | Manufacturer | T&T Engr | Dreco | Pyramid | WCI | WCI | Skytop Brewster |
| | | | Mast/Derrick S/N | NA | H-D6670-D44 | DA-M733-91-1 | W-15263-GVI | TV -07 | 115-XF-410 |
| | | | Date of Manufacture | NA | April 1, 1998 | December 1, 1991 | April 5, 1999 | August 1, 1995 | April 20, 1994 |
| | Mast/Derrick Modifications by Contractor | | Top Drive Manufacturer | Varco TDS 4 | Varco TDS 4H | Varco TDS 4 | National | Varco | N A |
| | | | Modifications by | N A | N A | N A | N A | N A | N A |
| | | | Date | N A | N A | N A | N A | N A | N A |
| | | | Pipe Handler Manufacturer | N A | N A | N A | Varco | Varco Star Racking | N A |
| | | | Modifications by | N A | N A | N A | N A | N A | N A |
| | | | Date | N A | N A | N A | N A | N A | N A |
| | API Ratings (Name Plate if Available) | | Design Standard | API-4F | API-4F | API-4E | API-4F | API-4F | API-4F |
| | | | Racking Capacity (Lin. Feet) | 25,500 | 25,366 | 26,691 | 33,820 | 20,460 | 13,020 |
| | | Setback | No. | 2 | 2 | 2 | 2 | 1 | 2 |
| | | | Length x Width List Each (feet) | 11 x 8<br>7.5 x 10 | 11 x 8<br>7.5 x 10 | 7.5 x 6.5<br>7.5 x 6.5 | 12 x 10<br>12 x 10 | 22.33 x 12.9 | 7.3 x 4.5<br>7.3 x 4.5 |
| | | | Capacity (Lin. Feet) | 25,500 | 25,366 | 26,691 | 14345 19475 | 20,460 | 13,020 |
| | | | Rack (Doubles **D** / Triples **T**) | T | T | T | T | T | D |
| | | | Setback Config. Option (See Sketches) | 4 | 2 | M | 2 | 4 | M |
| | | | Hook Capacity (lbs.) | | 1,000,000 | 1,275,000 | 2,500,000 | 1,000,000 | 410,000 |
| | | | Guyed (G) or Freestanding (F) | F | F | F | F | F | G |
| | | | Wind Velocity w/ Set Back (knots) | | 100 | 87 (100 mph) | 120 | 2 | 70 mph |
| | | | Wind Velocity w/o Set Back (knots) | | 107 | 100 (115 mph) | 120 | 107 | 100 mph |
| | Mast/Derrick Package Dimensions | Sub-structure | Clear Height "D" (feet) | NA | NA | NA | NA | NA | NA |
| | | | Overall height "E" (feet) | NA | NA | NA | NA | NA | NA |
| | | Mast/Derrick Dimensions | Clear Height "A" (feet) | 160 | 170 | 152 | 170 | 150 | 115 |
| | | | Overall Height "B" (feet) | 189.25 | 192.5 | 160 | 195 | 156 | 118.5 |
| | | | Length (Side) "S" (feet) | 30 | 30 | 23 | 40 | NA | 130 |
| | | | Width "T" (feet) | 30 | 30 | 30 | 40 | NA | 150 |
| | Leg Member | | Wide Flange **(W)**<br>Channel **(C)**<br>Angle **(L)**<br>Tube **(T)** | W | W | W | W | W | Pipe |
| | Type Application | | Land (**L**)<br>Jack-up (**J**)<br>Semi-Submersible (**S**)<br>Drillship (**D**)<br>Platform Rig (**P**)<br>Cantilever Mast (C)<br>Guided Mast (**G**) | ?? | J | BARGE | J | P | G |
| EOUS | eights | Racking Board | Height "F" (feet) | 15 | 15 | 10 | 25 | 15 | NA |
| | | | Length "G" (feet) | 35 | 38 | 22.25 | 43 | 26 | NA |
| | | | Width "H" (feet) | 35 | 34 | 19 | 43 | 20 | NA |

## TABLE 6.3: JIP Structure 2 - General Derrick Summary of Results/Present

## (30' Base X 169.625' Tall)

Analysis Using API 4F Present Wind Methodology

API 4F Present Methodology

| | Wind Direction | Low | | | | High | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft | Kips | Ft | Kips | Ft |
| Complete Structure | | | | | | | | | |
| with All Accessories | X | 250.4 | 184.6 | 250.4 | 181.2 | 296.1 | 185.5 | 299.7 | 182.7 |
| | Y | 230.6 | 186.7 | 230.6 | 182.6 | 269.9 | 187.5 | 273.6 | 184.9 |
| | 45 | 242.4 | 185.8 | 242.4 | 182.0 | 443.7 | 181.4 | 450.4 | 178.9 |
| Bare Str. w/o Ginpole & Windwalls | | | | | | | | | |
| | X | 113.8 | 190.4 | 113.8 | 190.4 | 113.8 | 190.4 | 113.8 | 190.4 |
| | Y | 108.4 | 189.0 | 108.4 | 189.0 | 108.4 | 182.2 | 108.4 | 189.0 |
| | 45 | 111.1 | 190.4 | 111.1 | 190.4 | 154.9 | 189.2 | 154.9 | 189.2 |
| Setback | | | | | | | | | |
| | X | 56.6 | 146.5 | 56.6 | 146.5 | 56.6 | 146.5 | 56.6 | 146.5 |
| | Y | 33.9 | 146.5 | 33.9 | 146.5 | 33.9 | 146.5 | 33.9 | 146.5 |
| | 45 | 46.7 | 146.5 | 46.7 | 146.5 | 115.1 | 146.5 | 115.1 | 146.5 |
| Wind Walls | | | | | | | | | |
| Only at Racking Board | X | 36.1 | 187.5 | 36.1 | 187.5 | 48.1 | 187.5 | 48.1 | 187.5 |
| | Y | 39.5 | 187.5 | 39.5 | 187.5 | 52.7 | 187.5 | 52.7 | 187.5 |
| | 45 | 37.9 | 187.5 | 37.9 | 187.5 | 71.3 | 187.5 | 71.3 | 187.5 |
| Equipment | | | | | | | | | |
| | X | 43.9 | 216.5 | 43.9 | 196.9 | 77.6 | 205.5 | 81.2 | 194.4 |
| | Y | 48.6 | 208.9 | 48.6 | 189.5 | 74.8 | 213.7 | 78.5 | 194.1 |
| | 45 | 46.8 | 212.6 | 46.8 | 193.1 | 102.4 | 204.6 | 109.1 | 192.7 |

## TABLE 6.4: JIP Structure 2 - General Derrick Summary of Results/Proposed

## (30' Base X 169.625' Tall)

### Analysis Using API 4F Proposed Methodology

| | Wind Direction | API 4F Proposed Method | | | |
|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft |
| Complete Structure with all Accessories | | | | | |
| | X | 261.7 | 184.8 | 265.6 | 182.6 |
| | Y | 235.1 | 186.3 | 239.0 | 184.2 |
| | 45 | 371.9 | 176.9 | 375.2 | 174.6 |
| Bare Str. w/o Ginpole & Windwalls | | | | | |
| | X | 112.3 | 190.5 | 112.3 | 190.5 |
| | Y | 107.9 | 188.4 | 107.9 | 188.4 |
| | 45 | 129.3 | 184.8 | 129.3 | 184.8 |
| Setback | | | | | |
| | X | 54.2 | 146.5 | 54.2 | 146.5 |
| | Y | 32.5 | 146.5 | 32.5 | 146.5 |
| | 45 | 116.6 | 146.5 | 116.6 | 146.5 |
| Wind Walls (Racking Board Only) | | | | | |
| | X | 20.1 | 187.5 | 20.1 | 187.5 |
| | Y | 22.0 | 187.5 | 22.0 | 187.5 |
| | 45 | 27.3 | 187.5 | 27.3 | 187.5 |
| Equipment | | | | | |
| | X | 75.2 | 203.0 | 79.1 | 194.8 |
| | Y | 72.6 | 200.7 | 76.6 | 193.4 |
| | 45 | 98.8 | 199.5 | 102.0 | 190.4 |

## TABLE 6.5: JIP Structure 3 - General Mast Summary of Results/Present

### (30' Wide X 25' Deep X 152' Tall)

Analysis Using API 4F Present Wind Methodology
API 4F Present Methodology

| | Wind Direction | Low | | | | High | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft | Kips | Ft | Kips | Ft |
| Complete Structure with | | | | | | | | | |
| All Accessories | X | 145.5 | 179.7 | 145.5 | 173.2 | 170.3 | 179.0 | 174.6 | 174.6 |
| | Y | 169.0 | 175.5 | 169.0 | 170.4 | 196.0 | 175.6 | 200.2 | 171.7 |
| | 45 | 159.3 | 177.0 | 159.3 | 171.3 | 283.2 | 175.6 | 290.6 | 171.8 |
| Bare Str. w/o Ginpole & Windwalls | | | | | | | | | |
| | X | 60.1 | 188.8 | 60.1 | 188.8 | 60.1 | 188.8 | 60.1 | 188.8 |
| | Y | 71.0 | 189.3 | 71.0 | 189.3 | 71.0 | 181.0 | 71.0 | 189.3 |
| | 45 | 65.8 | 188.8 | 65.8 | 188.8 | 91.0 | 189.2 | 91.0 | 189.2 |
| Setback | | | | | | | | | |
| | X | 33.9 | 146.5 | 33.9 | 146.5 | 33.9 | 146.5 | 33.9 | 146.5 |
| | Y | 56.6 | 146.5 | 56.6 | 146.5 | 56.6 | 146.5 | 56.6 | 146.5 |
| | 45 | 46.7 | 146.5 | 46.7 | 146.5 | 90.5 | 146.5 | 90.5 | 146.5 |
| Wind Walls | | | | | | | | | |
| Only at Racking Board | X | 14.7 | 190.0 | 14.7 | 190.0 | 19.6 | 190.0 | 19.6 | 190.0 |
| | Y | 12.5 | 190.0 | 12.5 | 190.0 | 16.7 | 190.0 | 16.7 | 190.0 |
| | 45 | 13.6 | 190.0 | 13.6 | 190.0 | 25.6 | 190.0 | 25.6 | 190.0 |
| Equipment | | | | | | | | | |
| | X | 36.8 | 191.2 | 36.8 | 165.5 | 56.7 | 184.4 | 61.0 | 171.2 |
| | Y | 28.9 | 191.9 | 28.9 | 162.0 | 51.7 | 195.3 | 55.9 | 169.2 |
| | 45 | 33.3 | 191.3 | 33.3 | 163.9 | 76.0 | 189.1 | 83.4 | 174.8 |

# TABLE 6.6: JIP Structure 3 - General Mast Summary of Results/Proposed

## (30' Wide X 25' Deep X 152' Tall)

Analysis Using API 4F Proposed Methodology

| | Wind Direction | API 4F Proposed Method | | | |
|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft |
| Complete Structure with all Accessories | | | | | |
| | X | 160.5 | 177.5 | 164.4 | 174.2 |
| | Y | 179.0 | 174.9 | 182.9 | 172.0 |
| | 45 | 242.0 | 179.4 | 245.7 | 176.0 |
| Bare Str. w/o Ginpole & Windwalls | | | | | |
| | X | 63.3 | 188.9 | 63.3 | 188.9 |
| | Y | 67.6 | 190.2 | 67.6 | 190.2 |
| | 45 | 90.5 | 187.9 | 90.5 | 187.9 |
| Setback | | | | | |
| | X | 33.9 | 146.5 | 33.9 | 146.5 |
| | Y | 54.2 | 146.5 | 54.2 | 146.5 |
| | 45 | 63.5 | 146.5 | 63.5 | 146.5 |
| Wind Walls (Racking Board Only) | | | | | |
| | X | 8.2 | 190.0 | 8.2 | 190.0 |
| | Y | 7.0 | 190.0 | 7.0 | 190.0 |
| | 45 | 10.3 | 190.0 | 10.3 | 190.0 |
| Equipment | | | | | |
| | X | 55.2 | 181.7 | 59.1 | 172.3 |
| | Y | 50.3 | 183.0 | 54.2 | 172.4 |
| | 45 | 77.7 | 195.0 | 81.3 | 184.1 |

# TABLE 6.7: JIP Structure 4 - Dynamic Derrick Summary of Results/Present

Analysis Using API 4F Present Wind Methodology
API 4F Present Methodology

| | Wind Direction | Low | | | | High | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft | Kips | Ft | Kips | Ft |
| Complete Structure with | | | | | | | | | |
| All Accessories | X | 374.5 | 184.1 | 374.5 | 179.0 | 448.6 | 184.4 | 455.7 | 181.0 |
| | Y | 356.6 | 193.2 | 356.6 | 189.4 | 439.9 | 191.5 | 447.0 | 188.9 |
| | 45 | 364.0 | 185.6 | 364.0 | 181.0 | 631.8 | 186.5 | 641.8 | 183.5 |
| Bare Str. w/o Ginpole & Windwalls | | | | | | | | | |
| | X | 162.3 | 190.3 | 162.3 | 190.3 | 162.3 | 190.3 | 162.3 | 190.3 |
| | Y | 176.5 | 200.5 | 176.5 | 200.5 | 176.5 | 181.5 | 176.5 | 200.5 |
| | 45 | 164.9 | 190.3 | 164.9 | 190.3 | 228.6 | 195.1 | 228.6 | 195.1 |
| Setback | | | | | | | | | |
| | X | 84.6 | 146.5 | 84.6 | 146.5 | 84.6 | 146.5 | 84.6 | 146.5 |
| | Y | 49.8 | 146.5 | 49.8 | 146.5 | 49.8 | 146.5 | 49.8 | 146.5 |
| | 45 | 69.4 | 146.5 | 69.4 | 146.5 | 110.1 | 146.5 | 110.1 | 146.5 |
| Wind Walls | | | | | | | | | |
| Only at Racking Board | X | 72.5 | 186.3 | 72.5 | 186.3 | 96.7 | 186.3 | 96.7 | 186.3 |
| | Y | 72.5 | 186.3 | 72.5 | 186.3 | 96.7 | 186.3 | 96.7 | 186.3 |
| | 45 | 72.5 | 186.3 | 72.5 | 186.3 | 136.7 | 186.3 | 136.7 | 186.3 |
| Equipment | | | | | | | | | |
| | X | 55.1 | 220.7 | 55.1 | 185.7 | 105.0 | 203.9 | 112.1 | 188.9 |
| | Y | 57.9 | 219.7 | 57.9 | 196.3 | 117.0 | 230.0 | 124.1 | 191.5 |
| | 45 | 57.2 | 218.3 | 57.2 | 189.2 | 156.4 | 202.2 | 166.4 | 189.9 |

## TABLE 6.8: JIP Structure 4 - Dynamic Derrick Summary of Results/Proposed

### Analysis Using API 4F Proposed Methodology

| | Wind Direction | API 4F Proposed Method | | | |
|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft |
| Complete Structure with all Accessories | | | | | |
| | X | 392.0 | 184.2 | 397.8 | 181.7 |
| | Y | 374.3 | 193.1 | 380.3 | 191.1 |
| | 45 | 578.8 | 187.0 | 584.0 | 184.6 |
| Bare Str. w/o Ginpole & Windwalls | | | | | |
| | X | 172.9 | 189.9 | 172.9 | 189.9 |
| | Y | 179.5 | 200.2 | 179.5 | 200.2 |
| | 45 | 258.8 | 194.8 | 258.8 | 194.8 |
| Setback | | | | | |
| | X | 81.0 | 146.5 | 81.0 | 146.5 |
| | Y | 49.6 | 146.5 | 49.6 | 146.5 |
| | 45 | 111.6 | 146.5 | 111.6 | 146.5 |
| Wind Walls (Racking Board Only) | | | | | |
| | X | 40.3 | 186.3 | 40.3 | 186.3 |
| | Y | 40.3 | 186.3 | 40.3 | 186.3 |
| | 45 | 54.8 | 186.3 | 54.8 | 186.3 |
| Equipment | | | | | |
| | X | 97.9 | 204.7 | 103.6 | 193.9 |
| | Y | 104.9 | 205.7 | 110.9 | 198.1 |
| | 45 | 153.6 | 203.5 | 158.8 | 194.1 |

## TABLE 6.9: JIP Structure 5 - Vertical Erecting Mast Summary of Results/Present

Analysis Using API 4F Present Wind Methodology
API 4F Present Methodology

| | Wind Direction | Low | | | | High | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft | Kips | Ft | Kips | Ft |
| Complete Structure | | | | | | | | | |
| with All Accessories | X | 216.2 | 168.5 | 216.2 | 166.2 | 237.1 | 170.0 | 240.3 | 167.8 |
| | Y | 188.7 | 172.6 | 188.7 | 170.6 | 215.3 | 174.1 | 218.6 | 172.2 |
| | 45 | 204.2 | 170.2 | 204.2 | 168.0 | 290.3 | 174.4 | 295.8 | 172.0 |
| Bare Str. w/o Ginpole & Windwalls | | | | | | | | | |
| | X | 81.7 | 176.9 | 81.7 | 176.9 | 81.7 | 176.9 | 81.7 | 176.9 |
| | Y | 72.8 | 178.4 | 72.8 | 178.4 | 72.8 | 184.8 | 72.8 | 178.4 |
| | 45 | 77.4 | 176.9 | 77.4 | 176.9 | 106.8 | 178.0 | 106.8 | 178.0 |
| Setback | | | | | | | | | |
| | X | 84.2 | 146.5 | 84.2 | 146.5 | 84.2 | 146.5 | 84.2 | 146.5 |
| | Y | 58.4 | 146.5 | 58.4 | 146.5 | 58.4 | 146.5 | 58.4 | 146.5 |
| | 45 | 72.5 | 146.5 | 72.5 | 146.5 | 75.2 | 146.5 | 75.2 | 146.5 |
| Wind Walls | | | | | | | | | |
| Only at Racking Board | X | 27.7 | 192.0 | 27.7 | 192.0 | 36.9 | 192.0 | 36.9 | 192.0 |
| | Y | 29.7 | 192.0 | 29.7 | 192.0 | 39.5 | 192.0 | 39.5 | 192.0 |
| | 45 | 28.7 | 192.0 | 28.7 | 192.0 | 54.1 | 192.0 | 54.1 | 192.0 |
| Equipment | | | | | | | | | |
| | X | 22.6 | 192.0 | 22.6 | 169.2 | 34.3 | 187.5 | 37.4 | 172.2 |
| | Y | 27.8 | 191.4 | 27.8 | 177.9 | 44.5 | 176.8 | 47.9 | 177.9 |
| | 45 | 25.6 | 193.0 | 25.6 | 175.4 | 54.2 | 188.4 | 59.7 | 175.4 |

## TABLE 6.10: JIP Structure 5 - Vertical Erecting Mast Summary of Results/Proposed

Analysis Using API 4F Proposed Methodology

| | Wind Direction | API 4F Proposed Method | | | |
|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft |
| Complete Structure with all Accessories | | | | | |
| | X | 205.0 | 167.0 | 208.4 | 165.3 |
| | Y | 189.3 | 171.7 | 192.8 | 170.3 |
| | 45 | 264.1 | 171.7 | 267.1 | 169.7 |
| Bare Str. w/o Ginpole & Windwalls | | | | | |
| | X | 85.0 | 177.1 | 85.0 | 177.1 |
| | Y | 75.7 | 178.6 | 75.7 | 178.6 |
| | 45 | 117.7 | 178.3 | 117.7 | 178.3 |
| Setback | | | | | |
| | X | 80.6 | 146.5 | 80.6 | 146.5 |
| | Y | 55.9 | 146.5 | 55.9 | 146.5 |
| | 45 | 76.2 | 146.5 | 76.2 | 146.5 |
| Wind Walls (Racking Board Only) | | | | | |
| | X | 8.5 | 192.0 | 8.5 | 192.0 |
| | Y | 16.5 | 192.0 | 16.5 | 192.0 |
| | 45 | 17.9 | 192.0 | 17.9 | 192.0 |
| Equipment | | | | | |
| | X | 30.9 | 185.7 | 34.3 | 173.5 |
| | Y | 41.1 | 185.1 | 44.6 | 177.9 |
| | 45 | 52.2 | 186.5 | 55.2 | 176.3 |

## TABLE 6.11: JIP Structure 6 - Guyed Mast Summary of Results/Present

Analysis Using API 4F Present Wind Methodology

API 4F Present Methodology

| | Wind Direction | Low | | | | High | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft | Kips | Ft | Kips | Ft |
| Complete Structure | | | | | | | | | |
| with All Accessories | X | 55.5 | 156.2 | 55.5 | 155.3 | 56.7 | 157.2 | 58.6 | 156.0 |
| | Y | 56.1 | 155.6 | 56.1 | 154.2 | 57.4 | 156.6 | 59.2 | 155.0 |
| | 45 | 55.8 | 156.2 | 55.8 | 155.0 | 73.8 | 156.7 | 76.8 | 154.9 |
| Bare Str. w/o Ginpole & Windwalls | | | | | | | | | |
| | X | 30.5 | 158.5 | 30.5 | 158.5 | 30.5 | 158.5 | 30.5 | 158.5 |
| | Y | 30.3 | 157.5 | 30.3 | 157.5 | 30.3 | 100.0 | 30.3 | 157.5 |
| | 45 | 30.4 | 158.5 | 30.4 | 158.5 | 34.2 | 158.3 | 34.2 | 158.3 |
| Setback | | | | | | | | | |
| | X | 23.7 | 151.0 | 23.7 | 151.0 | 23.7 | 151.0 | 23.7 | 151.0 |
| | Y | 24.5 | 151.0 | 24.5 | 151.0 | 24.5 | 151.0 | 24.5 | 151.0 |
| | 45 | 24.1 | 151.0 | 24.1 | 151.0 | 36.1 | 151.0 | 36.1 | 151.0 |
| Wind Walls | | | | | | | | | |
| Only at Racking Board | X | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 |
| | Y | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 |
| | 45 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 | 0.0 | 100.0 |
| Equipment | | | | | | | | | |
| | X | 1.2 | 201.4 | 1.2 | 157.6 | 2.4 | 202.7 | 4.4 | 165.8 |
| | Y | 1.4 | 196.0 | 1.4 | 137.4 | 2.6 | 863.6 | 4.4 | 160.1 |
| | 45 | 1.3 | 198.5 | 1.3 | 146.9 | 3.5 | 200.8 | 6.5 | 159.2 |

# TABLE 6.12: JIP Structure 6 - Guyed Mast Summary of Results/Proposed

## Analysis Using API 4F Proposed Methodology

| | Wind Direction | API 4F Proposed Method | | | |
|---|---|---|---|---|---|
| | | Position 1 | | Position 2 | |
| | | Shear | CG | Shear | CG |
| | | Kips | Ft | Kips | Ft |
| Complete Structure with all Accessories | | | | | |
| | X | 45.7 | 156.5 | 47.7 | 155.2 |
| | Y | 46.4 | 157.9 | 48.3 | 156.1 |
| | 45 | 65.1 | 157.4 | 66.9 | 155.7 |
| Bare Str. w/o Ginpole & Windwalls | | | | | |
| | X | 21.9 | 158.0 | 21.9 | 158.0 |
| | Y | 22.6 | 160.8 | 22.6 | 160.8 |
| | 45 | 28.4 | 160.6 | 28.4 | 160.6 |
| Setback | | | | | |
| | X | 21.9 | 151.0 | 21.9 | 151.0 |
| | Y | 21.7 | 151.0 | 21.7 | 151.0 |
| | 45 | 33.9 | 151.0 | 33.9 | 151.0 |
| Wind Walls (Racking Board Only) | | | | | |
| | X | 0.0 | 100.0 | 0.0 | 100.0 |
| | Y | 0.0 | 100.0 | 0.0 | 100.0 |
| | 45 | 0.0 | 0.0 | 0.0 | 0.0 |
| Equipment | | | | | |
| | X | 1.9 | 202.5 | 3.9 | 163.4 |
| | Y | 2.0 | 199.3 | 4.0 | 157.5 |
| | 45 | 2.9 | 200.8 | 4.7 | 159.5 |

# TABLE 6.13: Interpretation of Results Summary

Evaluation by Non – API Methods
General Derrick
Structure Number 2

| **Evaluation Method** | **BARE FRAME w/WW** | | **COMPLETE FRAME w/WW, SETBACK, & EQUIP.** | |
|---|---|---|---|---|
| | **Base Shear** | | **Base Shear** | |
| | **X-Dir** | **45 Deg** | **X-Dir** | **45 Deg** |
| | (Kips) | (Kips) | (Kips) | (Kips) |
| | | | | |
| **Current API 4F Method** (Low) | 149.9 | 149.0 | 250.4 | 242.0 |
| | | | | |
| **Current API 4F Method** (High) | 161.9 | 226.2 | 296.1 | 443.7 |
| | | | | |
| **Propose API 4F Method** | 132.4 | 156.6 | 261.7 | 371.9 |
| | | | | |
| **ABS** | 134.0 | N.C. | 134.0 | N.C. |
| | | | | |
| **ASCE 7-98** | 157.0 | 181.7 | 286.4 | 397.1 |
| | | | | |
| **AS1170** | 141.8 | 166.2 | 141.8 | 166.2 |
| | | | | |
| **BS8100** | 160.6 | 194.1 | 317.4 | 467.0 |

WW - Wind Walls
High - Best Practice Upper Bound
Low - Best Practice Lower Bound
N. C. – Not Covered

# CHAPTER 7

# WIND LOAD EFFECTS

Derricks and masts are used in various applications in the exploration of oil and gas. These applications include mobile offshore drilling units (MODU), offshore platforms, floating units and land operations. Depending on the application, a change in wind force may affect the operation of the derrick/mast differently. The purpose of the “effects analysis” task is to evaluate any affect on operation of the derrick/mast structures due to a change in wind loading calculation methodology.

Comprehensive analyses of six derrick/mast combinations were performed to predict the wind forces using current API-4F and proposed method on derrick/mast structures. These desktop analyses are based on the current API-4F and proposed practice as defined in these documents.

For the “effects analysis” to fully evaluate the proposed equation, the current and proposed method will be presented and discussed. Recommendations for both methods will be provided as a way forward.

The effects study will evaluate the results from implementing the practice using the 3-second gust wind velocity currently required by the proposed practice. Since the current and proposed methods use different approaches for calculation of wind force, this comparison will involve the determination of height coefficients, wind velocity, and pressure in determining the wind force. (Note: For the purpose of the effects study the pressure is a report specific definition).

The effect study will then compare the present and proposal wind load methods using the same velocity and pressure for an assumed 1-hour wind. Included in this comparison will be the proposed 1-hour wind prediction for ISO 19901-1. This latter practice is being developed for the design of fixed offshore structures.

The methods compared will consider the effect of shielding with the pressure calculation. Finally evaluating the desktop results for complete structures using a steady wind force assumption such as 1-hour wind will complete the effects analysis.

## CURRENT AND PROPOSED METHODS

The current and proposed methods are based on Bernoulli's Equation for flow. This equation is modified with correction factors that are intended to match test results. Both methods use member drag correction factors, with the proposed method adding additional factors to address additional characteristics affecting the wind.

Height coefficients are included as a step-function in the current method and directly in the proposed equation. The proposed method adjusts the wind velocity from a one-hour wind to a three-second gust. This section presents the two equations used in the desktop analysis.

### 1. Current API Spec 4F Equations

The basic equation from API-Specification 4F is shown below. Included in the equation are shape and height coefficients. Dividing both sides of the equation by the area (A), the quantity has units of pressure. For the purpose of this report, $P_z$ will be defined for convenience as pressure.

$$F = 0.00338 \times V_z^2 \times C_s \times C_h \times A \qquad (1)$$

$V_z = V_{ref}$ = Wind Velocity (Knots)

$C_S$ = 1.25 (Constant Shape Coefficient) (See Note)

$C_h$ = Height Coefficient from Table (See Table in Specification)

$A$ = Total Projected Area Perpendicular to the Direction of the Wind

$$P_z = F/A \qquad (2)$$

*Combine Eqs. 1 and 2*

$$P_z = 0.00338 * C_h * V_{ref}^2$$

Note: The 1.25 is typically described as a shape factor. However, the derivation of this value assumes a shielding factor of 0.85.

The API-4F specification requires that "wind forces for various design wind speeds shall be calculated" for two conditions (with setback and without setback). Typically the user will specify wind velocity for dynamic derricks/masts but typically these specifications are based on providing a steady wind velocity. As a result many manufacturer/designers use the referenced wind velocities for the derrick/mast analysis for all design considerations unless the owner modifies this assumption. Therefore, the same wind velocities are used for design of individual members, global analysis of the derrick/mast (e.g. overturning, combined operating and wind), and combined analysis for a derrick/mast system (platform, jack-up, semi-submersible etc…).

Many design practices, including API-RP2A, recommend lower gust time periods (e.g. 3 second) for design of individual members to ensure that these elements will not be overstressed due to local peaks in velocity. As the component or structure increases in size, this practice permit increase in return (15-second, 1-minute, and 1-hour) period to allow for reasonable design of connections and assessment of global effects. A similar approach should be adopted for the continued use of the current equation.

## 2. Proposed API-4F Equation

The proposed method expands the Bernoulli Equation to incorporated correction factors for shielding ($K_{sh}$), $K_{ar}$ (member aspect ratio), and $K_i$ (member inclination). This result in the following equation:

$$F = 0.00338 \; x \; K_{sh} \; x \; K_{ar} \; x \; K_i \; x \; V_z^2 \; x \; C_s \; x \; A \qquad (3)$$

Terms defined in Specification 4F final draft (Appendix 2.1) page 3.

The proposed method provides both an onshore and offshore equation for determining the design velocity (discussed later). These equations convert the reference 1-hour wind velocity into a 3-second gust to be used in individual member design. The proposed method does not provide guidance on other gust factors to be used in other design or assessment conditions. This restricts the user, without outside information, in evaluating these structures for other purposes.

The height coefficient modifies the velocity term and as velocity is squared in the Bernoulli Equation, this factor should also be squared to compare to equivalent factors in the current method.

The proposed specification Section 6.2.1.3 has two potentially confusing statements. The first states:

> *"The reference wind velocities listed in Tables 6.2.1.1 and 6.2.1.2 are to be scaled by the appropriate elevation factors to obtain the velocity to be used to estimate wind forces per Paragraph 6.2.2".*

The onshore and offshore design velocities are adjusted to a 3-second-wind velocity and height correction factor. This was confirmed by the "effects analysis" task. The API wind committee should review and revise this language to avoid confusion and the possibility of "double dipping" on height correction coefficient. This language may cause confusion with users of the proposed practice as a result of including an additional height adjustment. The second paragraph in Section 6.2.1.3 has caused confusion in the design velocity:

> *"The design wind velocity is a five-second wind gust. The equations below include a conversion from a one-hour duration wind to a wind with a three-second gust."*

The equations provided are intended for individual member design. However, in the method's brief existence this language has proven to be confusing. Also, the wording should be to a single design wind velocity, 3-second or a 5 second.

The $P_z$ term discussed in the current method will be again included to permit comparison of the methods.

*Onshore:*

$$V_z = V_{ref} \times 2.17 \times (Z/900)^{0.105}\text{, knots} \qquad (4)$$

$$P = F/A \qquad (5)$$

*Combine Eqs. 3, 4, & 5; Set $K_{sh}$, $K_{ar}$, $K_i$, $C_s = 1.0$*

$$P_z = 0.00338\ V_r{*}2.17 \times (Z/900)^{0.105}$$

*By setting terms to unity, these terms can be investigated independently.*

(Note: This equation is referenced from ASCE 7-95 and is developed for an exposure C category. Exposure C is for open terrain with scattered obstructions, generally less than 30 feet tall. The derivation of this equation is included in Appendix 7.1.)

A single correction constant for height and gust may be appropriate for derrick/mast structures but separate equations permitting the user to calculate the gust and height terms independently will add flexibility to the procedure.

*Offshore:*

$$V_z = V_{ref} \times [(Z/33)^{0.125}] \times [1 + 0.45 \times (Z/66)^{-0.275}], \text{ knots} \qquad (6)$$

$Z$ = *Elevation above sea level, feet*

*Height Coefficient* $C_h = [(Z/33)^{0.125}]$

*Gust Correction* $= [1 + 0.45 \times (Z/66)^{-0.275}]$

*Combine Eqs. 3,5, &6; Set* $K_{sh,} K_{ar,} K_i\, C_s = 1.0$

$$P_z = 0.00338 \times V_{ref} \times [(Z/33)^{0.125}] \times [1 + 0.45 \times (Z/66)^{-0.275}]$$

*By setting terms to unity, these terms can be investigated independently.*

(Note: For offshore structures, velocity is adjusted for height and gust using a procedure from the API-RP2A 20th edition)

## EFFECT EVALUATION

The method described in the current “API Specification 4F” (API-4F) is based on a projected area approach for calculating wind force of a derrick/mast. This approach has association to the “ABS method” because of the reference in the API specification to ABS height and shape factors used in the method. In the current method, the height coefficient is external to the calculation of velocity whereas the new method uses this term to modify the velocity. This means an apparent difference in the tables will appear due to the squaring of velocity in the proposed method.

A 100-knot 3-second gust wind velocity is assumed for the comparison of the current and proposed methods. To compare the methods the velocity is calculated for both approaches and includes the height coefficient. In the current API Spec 4F method the velocity is backed calculated from the pressure multiplied by the height coefficient. As stated in the above discussion, the proposed method starts with 1-hour wind velocity assumption that is adjusted in the velocity equation to a 3-second wind. To match the 100-knot assumption for the current wind velocity approach for member design, the proposed method required a 65-knot 1-hour wind be used in the proposed equations of Section 6.2.1.3 (reference). This results in the same 100-knot wind velocity at 10 meters reference elevation for both methods.

The results of the calculations are shown in Table 7.1 for the current, proposed onshore, and proposed offshore methods. The results show the velocity for the onshore method increases from the present API method. This is probably due to lower friction effects between winds moving over water verses land. The proposed offshore method provides similar velocities up to 65.6 feet (20 meters) at which point the proposed offshore method actually predicts a smaller wind velocity than the corresponding current API method.

The resulting equivalent wind pressure $P_z$ is calculated for all methods as this value is used in the force equation. The desktop analysis, discussed below, used the offshore approach to evaluate six drilling structures. Due to this fact the “effects study” was limited to only the offshore equation. When applicable, conclusions and recommendations are discussed for both onshore and offshore equations.

Both the onshore and offshore wind pressure is compared to the current method. In Table 7.1, the percentage change from the current API method is calculated and shows that the resulting pressure for the onshore equation increases above the 10-meter reference elevation. In contrast, the offshore equation results in an equal or smaller pressure for the proposed methodology 3-second gust. This is more clearly shown in Figure 7.1. In this figure the pressure for the proposed offshore, current API-4F, and proposed onshore methods are plotted. One may conclude, when only pressure is assumed, the results from an analysis using the proposed method in a 3-second gust condition will affect an onshore structure but the offshore will not be affected (or may be improved slightly). The increased onshore pressure appears to be the result of the higher surface friction (ground versus water) and the exclusion of the ASCE7-98’s rigid structure gust effect factor, 0.85, in the derivation.

For the current API-4F method, it has been assumed the height coefficient will not change from the 3-second gust and these values are used from the previous calculations. The current method does not differentiate between different wind gusts. Therefore, the velocity, and pressure are the same as previously calculated. In the proposed offshore method, the 3-second gust velocity and pressure are modified to a 1-hour wind to allow for evaluating the affect the proposed methodology would have on derrick/mast use when compared to current practice. Finally, the proposed international standard for calculating wind force (ISO 19901-1) is included for comparison to the proposed method. The results of these calculations are summarized in Table 7.2. Since the gust and height correction factor are not easily extracted from the onshore equation, a 1-hour wind velocity comparison was not considered.

As with the 3-second gust comparison, the wind velocity and pressure parameters are used to evaluate the affect of the proposed methodology on the wind force prediction. Implementing the proposed method increases the wind pressure as the desired elevation moves above the reference elevation. The increase in pressure is approximately 120% with a maximum of 124%. However, this ignores the other wind force modifiers including shielding discussed below.

The wind committee may consider changing the current or proposed methods to the ISO wind approach (height and gust) in a future revision. When the ISO and proposed method are compared, the values are found to be similar. The ISO method is more conservative by approximately 8%. Therefore, for a 1-hour wind condition the resulting wind force would be greater than the proposed method. This fact should be included in any consideration of adopting the ISO wind approach.

The current method includes shielding in the drag coefficient of 1.25. The proposed methodology includes a factor of 0.85 for structural shielding ($K_{sh}$). This is a constant applied to the wind force equation that is not affected by elevation or member characteristics. The shielding coefficient is applied to the calculated equivalent pressure for the onshore and offshore methods (3-second and 1-hour wind velocities). The pressures are then compared to the current API 4F specification and the results reported as percentage of the current method and presented in Table 7.3. Similar pressure were predicted for the current and proposed onshore method when shielding is included. For the offshore method, the 3-second gust is approximately 75-80% of the current method for the 3-second gust condition and the 1-hour wind slightly larger than the current method. This difference is due to the fact the present method does not address gusting effects.

Therefore, including the height, gust, and structural shielding in the proposed methodology, and excluding the member characteristics, the proposed method will provide an equivalent (onshore) or smaller (offshore) member design for a 3-second gust condition. An equivalent design will result for the 1-hour offshore conditions. Other wind gust assumptions will be between these two gust velocities.

The current method has the one remaining variable ($C_d = 1.25$) to evaluate. The proposed method has shape coefficients associated with member type. This method also includes coefficients for aspect ratio and angle. To evaluate these characteristics the global structure is evaluated.

As FEA program developers included automated load generating options in their products, as in StruCAD*3D, the industry moved away from the block approach to automated load generation. The use of the ABS shape factor of 1.25 was applied to individual elements in a derrick/mast structure analysis. The “current” procedure, referenced in this report, uses the desktop analysis (see Chapter 6) results. The FEA model used a shape factor of 1.25 for all elements.

As the API Method evolved among the designer/manufactures independent interpretations of the API-4F specifications were implemented. This resulted in a lack of consistent application between the designer/manufacturers. For example, some designer/manufacturers method of calculating a diagonal wind equals the wind load on a face of a structure (see best practice Figure 2.1). The API-4F committee proposed an alternate method for API 4F that expands the recommended shape coefficients and provided a constant shielding value. The JIP “Measurement of Wind Load Resistance on Drilling Structures” analyzed representative derrick/mast structures in the desktop analysis task to compare the wind force results from the current and proposed methodology.

The proposed method in the desktop analysis is based on a 3-second wind gust. For the current method a referenced wind velocity of 100-knot was assumed for calculating wind forces. Using the conversion, a steady 1-hour wind velocity of 66.67 would correspond to the assumed 100-knots 3-second gust, which is used in the proposed equation. The current method does not address the use of gust factors but the proposed method is for a 3 second gust of 100 knots. Therefore, the resulting 100 knots used in both cases represents an equivalent comparison of global effects. To the reference wind velocities the height corrections are applied.

The shape coefficient of 1.25 is used for the current analysis method. The proposed method has shape coefficients based on the member type or construction as shown in the following examples. Wind walls are addressed in the proposed method.

| | |
|---|---|
| Sharp Edge Members (WF, Angles, Tee, Channel) | 1.8 |
| Built-up Members | 2.0 |
| Square and Rectangular Tube | 1.5 |
| Round Pipe | 0.8 |

Included in the proposed method are additional member characteristics for aspect ratio and inclination. The results from the desktop analysis for current and proposed methods are extracted from the desktop analysis and incorporated into one table for each of the six structures (see Appendix 7.2: General Information Section). Results of the desktop analyses are manipulated and summarized in Table 7.4.

Included in the desktop analysis is equipment such as traveling block, top drive, and pipe handling systems. Equipment represents a significant percentage of the total wind force as seen in Table 7.4.

The lower bound values contain two columns to represent different assumptions for diagonal wind. As reported above, some designer/manufacturers assume the diagonal wind factor of 0.707 resulting in the same wind force as on the face of the structure. This effectively reduces the equivalent area. To evaluate this assumption, one table column (“Lower Bound w/o Scale Fac.”) represents a condition where the diagonal assumption is ignored. When using the lower bound assumptions without the 0.707 factor, results are found to be within 10-12% of the current prediction for the 45-degree assumption. This range would have minimal effect on the global structure. The second lower bound table column ("Lower Bound w/Scale Fac.") includes the lower bound assumption for diagonal wind. In this column we see a decrease in wind force as great as 28% when compared to the proposed methodology. This will have an affect on the design of a derrick or mast. Any designer/manufacturers using the diagonal scale factor approach should demonstrate the factor is appropriate to their structure.

The actual comparison of results for the current and proposed methods likely fall between the lower and upper bound "best practice" assumptions. Without performing an analysis of each current derrick/mast structure and including each designer/manufacturer assumptions in the analysis a definitive conclusion cannot be made. However, based on the results of this study, the two methods, when all factors are included, result in similar wind force predictions. Therefore, a study of individual affect on application (land, jack-up operation, platform, etc.) is not needed.

## TABLE 7.1: Comparison of Wind Velocity and Pressure/Height and Gust Effects/3 Second Gust

Comparison of Wind Velocity and Pressure
Evaluation Height and Gust Effects
(3 Second Gust Assumption)

| | | |
|---|---|---|
| Reference Wind Velocity (Uo), 1 hour | 65 | knots |
| Reference Wind Velocity (Uo), 3 sec. gust | 100 | knots |

| Elevation Z (feet) | API Spec 4F and ABS MODU Practice | | | Proposed Onshore API-4F (with 3 second Gust Correction) | | | |
|---|---|---|---|---|---|---|---|
| | ABS Coefficient | Velocity (knots) | Pressure (psf) | Height & Gust Correction | Velocity (knots) | Pressure (psf) | Percent Chg Current API |
| 0.0 | 1.00 | 100.0 | 33.80 | 1.53 | 100.01 | 33.80 | 100% |
| 32.8 | 1.00 | 100.0 | 33.80 | 1.53 | 100.01 | 33.80 | 100% |
| 65.6 | 1.03 | 101.5 | 34.84 | 1.65 | 107.56 | 39.10 | 112% |
| 98.4 | 1.10 | 104.7 | 37.07 | 1.72 | 112.23 | 42.58 | 115% |
| 147.6 | 1.19 | 109.2 | 40.34 | 1.79 | 117.12 | 46.36 | 115% |
| 196.9 | 1.29 | 113.7 | 43.71 | 1.85 | 120.71 | 49.25 | 113% |
| 246.1 | 1.37 | 116.8 | 46.15 | 1.89 | 123.57 | 51.61 | 112% |
| 295.3 | 1.42 | 119.3 | 48.14 | 1.93 | 125.96 | 53.62 | 111% |
| 344.5 | 1.48 | 121.4 | 49.85 | 1.96 | 128.01 | 55.39 | 111% |
| 393.7 | 1.51 | 123.1 | 51.20 | 1.99 | 129.82 | 56.96 | 111% |
| 442.9 | 1.55 | 124.7 | 52.55 | 2.01 | 131.43 | 58.39 | 111% |
| 492.2 | 1.59 | 126.2 | 53.86 | 2.04 | 132.90 | 59.70 | 111% |
| 541.4 | 1.63 | 127.5 | 54.92 | 2.06 | 134.23 | 60.90 | 111% |
| 590.6 | 1.66 | 128.9 | 56.18 | 2.08 | 135.47 | 62.03 | 110% |
| 639.8 | 1.69 | 130.2 | 57.26 | 2.09 | 136.61 | 63.08 | 110% |
| 656.2 | 1.70 | 130.5 | 57.55 | 2.10 | 136.97 | 63.41 | 110% |

| Elevation Z (feet) | API Spec 4F and ABS MODU Practice | | | Proposed Offshore API-4F (with 3 second Gust Correction) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ABS Coefficient | Velocity (knots) | Pressure (psf) | Height Coefficient | Gust Factor Correction | Combined Correction | Velocity (knots) | Pressure (psf) | Percent Chg Current API |
| 0.0 | 1.00 | 100.0 | 33.8 | 1.00 | 1.55 | 1.54 | 100.0 | 33.79 | 100% |
| 32.8 | 1.00 | 100.0 | 33.8 | 1.00 | 1.55 | 1.54 | 100.0 | 33.79 | 100% |
| 65.6 | 1.03 | 101.5 | 34.8 | 1.09 | 1.45 | 1.58 | 102.4 | 35.42 | 102% |
| 98.4 | 1.10 | 104.7 | 37.1 | 1.15 | 1.40 | 1.61 | 104.2 | 36.67 | 99% |
| 147.6 | 1.19 | 109.2 | 40.3 | 1.21 | 1.36 | 1.64 | 106.2 | 38.15 | 95% |
| 196.9 | 1.29 | 113.7 | 43.7 | 1.25 | 1.33 | 1.67 | 107.9 | 39.36 | 90% |
| 246.1 | 1.37 | 116.8 | 46.1 | 1.29 | 1.31 | 1.69 | 109.3 | 40.39 | 88% |
| 295.3 | 1.42 | 119.3 | 48.1 | 1.32 | 1.30 | 1.71 | 110.5 | 41.30 | 86% |
| 344.5 | 1.48 | 121.4 | 49.9 | 1.34 | 1.29 | 1.72 | 111.6 | 42.10 | 84% |
| 393.7 | 1.51 | 123.1 | 51.2 | 1.36 | 1.28 | 1.74 | 112.6 | 42.84 | 84% |
| 442.9 | 1.55 | 124.7 | 52.5 | 1.38 | 1.27 | 1.75 | 113.5 | 43.51 | 83% |
| 492.2 | 1.59 | 126.2 | 53.9 | 1.40 | 1.26 | 1.76 | 114.3 | 44.14 | 82% |
| 541.4 | 1.63 | 127.5 | 54.9 | 1.42 | 1.25 | 1.78 | 115.0 | 44.72 | 81% |
| 590.6 | 1.66 | 128.9 | 56.2 | 1.43 | 1.25 | 1.79 | 115.7 | 45.27 | 81% |
| 639.8 | 1.69 | 130.2 | 57.3 | 1.45 | 1.24 | 1.80 | 116.4 | 45.79 | 80% |
| 656.2 | 1.70 | 130.5 | 57.5 | 1.45 | 1.24 | 1.80 | 116.6 | 45.96 | 80% |

Note: 1) The Percent Change to Current API is based on a comparison of calculated proposed pressure compared to the current API method.
2) The shaded area represents typical range of elevations for drilling structures exposed to wind loading for onshore and offshore application..

## TABLE 7.2: Comparison of Wind Velocity and Pressure/1-hour Steady Wind Velocity

***Comparison of Wind Velocity and Pressure***
***(1-hour Steady Wind Velocity Assumption)***

Referenced Wind Velocity 1-hour 100

| Elevation Z (feet) | API Spec 4F and ABS MODU Practice | | | ISO 19901-1 1 Hour Wind | | Proposed Offshore API-4F (for 1-hr Wind Velocity) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ABS Coefficient | Velocity (knots) | Pressure (psf) | Velocity (knots) | Pressure (psf) | Height Coefficient | Velocity (knots) | Pressure (psf) | Percent Chg Current API |
| 0.0 | 1.00 | 100.0 | 33.80 | 100.0 | 33.80 | 1.00 | 100.0 | 33.80 | 100% |
| 32.8 | 1.00 | 100.0 | 33.80 | 100.0 | 33.80 | 1.00 | 100.0 | 33.80 | 100% |
| 65.6 | 1.03 | 101.5 | 34.84 | 111.7 | 42.19 | 1.09 | 109.0 | 40.19 | 115% |
| 98.4 | 1.10 | 104.7 | 37.07 | 118.6 | 47.53 | 1.15 | 114.7 | 44.48 | 120% |
| 147.6 | 1.19 | 109.2 | 40.34 | 125.4 | 53.19 | 1.21 | 120.7 | 49.23 | 122% |
| 196.9 | 1.29 | 113.7 | 43.71 | 130.3 | 57.40 | 1.25 | 125.1 | 52.90 | 121% |
| 246.1 | 1.37 | 116.8 | 46.15 | 134.1 | 60.78 | 1.29 | 128.6 | 55.93 | 121% |
| 295.3 | 1.42 | 119.3 | 48.14 | 137.2 | 63.60 | 1.32 | 131.6 | 58.54 | 122% |
| 344.5 | 1.48 | 121.4 | 49.85 | 139.8 | 66.05 | 1.34 | 134.2 | 60.84 | 122% |
| 393.7 | 1.51 | 123.1 | 51.20 | 142.0 | 68.20 | 1.36 | 136.4 | 62.91 | 123% |
| 442.9 | 1.55 | 124.7 | 52.55 | 144.0 | 70.13 | 1.38 | 138.4 | 64.79 | 123% |
| 492.2 | 1.59 | 126.2 | 53.86 | 145.8 | 71.87 | 1.40 | 140.3 | 66.52 | 123% |
| 541.4 | 1.63 | 127.5 | 54.92 | 147.4 | 73.47 | 1.42 | 142.0 | 68.12 | 124% |
| 590.6 | 1.66 | 128.9 | 56.18 | 148.9 | 74.94 | 1.43 | 143.5 | 69.62 | 124% |
| 639.8 | 1.69 | 130.2 | 57.26 | 150.3 | 76.31 | 1.45 | 145.0 | 71.02 | 124% |
| 656.2 | 1.70 | 130.5 | 57.55 | 150.7 | 76.75 | 1.45 | 145.4 | 71.48 | 124% |

## TABLE 7.3: Comparison of Wind Pressure/Shielding Correction/1-hour Stead Wind Velocity

***Comparison of Wind Pressure with Shielding (Ksh) Correction***
***(1-hour Steady Wind Velocity Assumption)***
Shielding Correction Factor $K_{sh}$ = 0.85

| Elevation Z (feet) | Current API Spec 4F | Proposed Onshore API-4F (3 second Gust Correction) | | Proposed Offshore API-4F (with Correction) | | | |
|---|---|---|---|---|---|---|---|
| | | | | 3 second Gust | | 1 Hour Wind | |
| | Pressure (psf) | Pressure w/ $K_{sh}$ (psf) | Percent Chg Current API | Pressure w/ $K_{sh}$ (psf) | Percent Chg Current API | Pressure w/ $K_{sh}$ (psf) | Percent Chg Current API |
| 0.0 | 33.80 | 28.73 | 85% | 28.72 | 85% | 28.73 | 85% |
| 32.8 | 33.80 | 28.73 | 85% | 28.72 | 85% | 28.73 | 85% |
| 65.6 | 34.84 | 33.24 | 95% | 30.10 | 86% | 34.16 | 98% |
| 98.4 | 37.07 | 36.19 | 98% | 31.17 | 84% | 37.81 | 102% |
| 147.6 | 40.34 | 39.41 | 98% | 32.43 | 80% | 41.84 | 104% |
| 196.9 | 43.71 | 41.86 | 96% | 33.46 | 77% | 44.96 | 103% |
| 246.1 | 46.15 | 43.87 | 95% | 34.33 | 74% | 47.54 | 103% |
| 295.3 | 48.14 | 45.58 | 95% | 35.10 | 73% | 49.76 | 103% |
| 344.5 | 49.85 | 47.08 | 94% | 35.79 | 72% | 51.71 | 104% |
| 393.7 | 51.20 | 48.42 | 95% | 36.41 | 71% | 53.47 | 104% |
| 442.9 | 52.55 | 49.63 | 94% | 36.99 | 70% | 55.07 | 105% |
| 492.2 | 53.86 | 50.74 | 94% | 37.52 | 70% | 56.54 | 105% |
| 541.4 | 54.92 | 51.77 | 94% | 38.02 | 69% | 57.90 | 105% |
| 590.6 | 56.18 | 52.72 | 94% | 38.48 | 68% | 59.17 | 105% |
| 639.8 | 57.26 | 53.62 | 94% | 38.92 | 68% | 60.37 | 105% |
| 656.2 | 57.55 | 53.90 | 94% | 39.06 | 68% | 60.75 | 106% |

## TABLE 7.4: Effect on Wind Force Prediction

| ***Effect on Wind Force Prediction*** | | | | | |
|---|---|---|---|---|---|
| Description | Equipment Wind Force Increase | | Average Wind Force Increase (Propose/Current) | | |
| Derrick/Mast | Present (High) | Proposed | Lower Bound w/o Scale Fac | Lower Bound w/Scale Fac | Upper Bound |
| Best Practice Derrick | 35% | 37% | 115% | 128% | 89% |
| General Derrick | 27% | 30% | 105% | 122% | 86% |
| General Mast | 35% | 36% | 111% | 125% | 90% |
| Dynamic Derrick | 23.4% | 26% | 106% | 124% | 88% |
| Vertically Erecting Mast | 16% | 16% | 99% | 110% | 88% |
| Guided Mast | 7% | 8% | 86% | 97% | 83% |

Note: Two tables are provided for the Best Practice low comparison. The best practice low includes an assumption for a 0.707 scale factor for diagonal winds. Including this assumption increases the effect of the proposed methodology. However, using a typical approach of calculating wind force in "X" and "Y" direction and combining these for off diagonal wind results in a better comparison between the two methods.

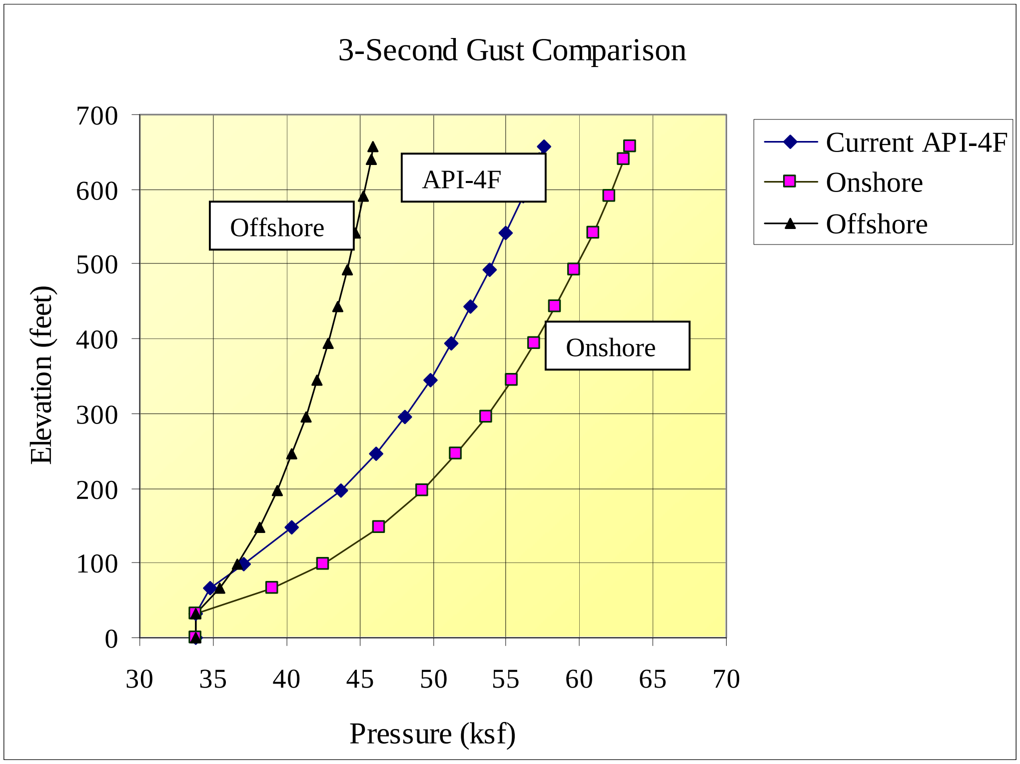


Figure 7.1: Proposed “Offshore” and “Onshore” Compared to Present “API-4F”

# CHAPTER 8

# CONCLUSION FROM “PHASE I” STUDY

Phase I, Desktop Analysis, of the JIP included specific objectives to be satisfied by the desktop analysis. These objectives were completed and have been discussed in the previous chapters. Conclusions from these studies are summarized below.

The present method is incomplete requiring the designer to use interpretation of API Specification 4F. Manufacturers make many assumptions in performing wind load analysis using current API-4F. Among manufacturers, these assumptions differ as seen by best practice high/low conditions. The list of items in the best practice document illustrates the need for a change. The present wind load methodology needs to be modified or replaced.

The desktop analysis uses the StruCAD*3D FEA package in the desktop analysis. An independent verification of the StruCAD*3D wind force prediction was performed. This check demonstrated the StruCAD*3D wind loads were correctly calculated according to the proposed methodology.

The desktop analyses included the current specification with best practice in the wind force prediction of derricks and masts. The current and proposed methods compare favorably.

The text in the proposed methodology has resulted in “test case” users misinterpreting the gust velocity for calculated global wind forces. This resulted in an over-prediction of the wind force when calculating the total global wind force for comparing the two methods.

A commonly perceived belief that a smaller wind force would result from stowing the traveling block at the drill floor was found to be invalid. The results of the desktop analysis show the total shear force is greater when the traveling block is at the drill floor and the moments are about equal for both positions. This is due to the wire rope between the crown and traveling block.

For operations, it is better to keep traveling equipment near the drill floor where is can be restrained.

The database proved to be a valuable tool in selecting structures for the desktop analysis. The pie charts will be useful to evaluate the applicability of future analysis results for the range of drill structures. The project sponsors may find additional use for the database not recognized by the project. The database, charts, and statistics created from drilling contractor submittals confirmed the general mast and derrick selected early in the project were representative of typical structures that would be subjected to wind calculations.

A parameter outside the statistical base is the racking board wind wall area. This outlier is due to the structures investigated are of recent construction and these designs have larger wind walls. This increase in wind wall force is reported as a separate item in the desktop analysis results. This permits the analyst to exclude these effects when comparing wind force predictions between methods.

Equipment wind load was found to contribute equally and significantly to both the current API-4F and proposed methods. The affect on the calculated wind force may be as much as 36% of the total wind force. The impact of this load is significant. Therefore, equipment should be included in an analysis of drilling structures.

The lower and upper bound current methodology compare favorably to the proposed method when the diagonal scale factor of 0.707 is ignored. The structures diagonal wind force, using the 0.707 scale factor method (see Figure 2.1), results in approximately 20% less wind force when compared to the proposed method and the projected area method.

A 3-second gust velocity comparison showed the proposed onshore equation would predict higher calculated wind pressure while the proposed offshore equation would result in equal or smaller pressure when compared to the current API-4F method. This is due to the higher ground surface frictional effects compared to a water surface effect and the exclusion of the ASCE7-98's rigid structure gust effect factor, 0.85, in the derivation.

The proposed method addresses local member design only but no guidance was given for overall structural wind loads. The current methodology does not address gusting effects.

For the 1-hour wind, the proposed offshore calculated wind pressure was 20% over the current methodology. However, incorporating the shielding factor reduced the wind pressure for the 1-hour wind to a general equivalent condition. The wind tunnel tests will aid in the validation of the shielding factor in the proposed methodology. This was one of the original objectives of the proposed wind testing.

Where similar assumptions for velocity and elevation of structure are made, the results of the two methods are reasonably close. As a result, the effect on the drilling contractor operations should be negligible.

The proposed simplified approach is given in the Best Practice Example. The frame's wind load, as documented, is from StruCAD*3D wind load evaluation. The manufacturer may provide this information. A good alternative for wind load on the derrick frame is the method given in ASCE7-98. The ABS method showed good agreement for the wind on a face of a derrick but did not give guidance for diagonal wind across the derrick. The ABS method is based on a frame structure with 30% solidity ratio, where ASCE permits variable solidity ratios.

# CHAPTER 9

# RECOMMENDATIONS “PHASE I” STUDIES

The wind loads reported for the best practice example structure were developed using the current published API-4F specification with additional guidance listed in “best practice” document. For the immediate future, the additional guidance required to perform a consistent wind calculation should be disseminated to the industry while the current API-4F method is modified or the new method adopted. The final API-4F document may be a combination of both methods.

Regardless of the method used, the drilling equipment is found to contribute significantly to the calculated wind force. Equipment exposed to wind should be included in calculations.

The use of the 0.707 diagonal scale factor should not be used. If a designer/manufacture incorporates a scale factor in a design then the factor used must be validated by wind tunnel testing or existing test data.

Other practices (including API RP2A) recommend different wind gust velocities for member and system design. The owners and designer/manufacturer should develop guidelines for the inclusion of gust factors and definitions for use in the design and assessment of drilling structures. These guidelines can be forwarded to the API-4F committee for inclusion in the specification.

The proposed “Onshore Method” and “Offshore Methods” should include gust and height correction factor as separate terms in the velocity equation. This will permit the design/assessment of drilling structures to evaluate different wind gust velocities in member and system design. Separate terms will allow the designer/manufacturer to adopt correction factors from other design practice.

The API-4F wind committee should make available the derivation of their proposed equations. The review of the onshore equation should include consideration of the ASCE7-98's rigid structure gust effect factor, 0.85, previously ignored.

In the proposed specification Section 6.2.1.3 is potentially confusing with respect to the application of height coefficients in the velocity equation. The height correction is built into the velocity equations. Since the height correction term is not identified in the velocity equation, the following statement may result in incorporating an additional height correction.

> Section 6.2.1.3 says, "The reference wind velocities listed in Tables 6.2.1.1 and 6.2.1.2 are to be scaled by the appropriate elevation factors to obtain the velocity to be used to estimate wind forces per Paragraph 6.2.2".

Both methods are based on imperial units. For ISO standards, equivalent SI units should be developed.

In checking StruCAD*3D's wind load processor it was learned, for the projected area method, StruCAD*3D treats an angle as a square or rectangular section. In their velocity component approach (proposed methodology) for determining wind loads, the angle is correctly evaluated. Users of this program should be made aware of this characteristic. The program developer (Zentech) should document the velocity component approach and make users aware of the projected area limitation.

In the definition of areas in the proposed method document, the areas definition should be fully described. The area term only covers beam members but does not cover wind walls or equipment areas. In addition, for wind walls, guidance for other angles of attached besides 0 and 45° should be developed and shielding of equipment behind windwalls should be considered. The committee may consider a slope method (see page 7).

# BIBLIOGRAPHY

ABS, “Rules for Building and Classing Mobile Offshore Drilling Units (MODU)”, American Bureau of Shipping, 1991

ASCE 7-95, ASCE Standard, “Minimum Design Loads for Buildings and Other Structures”, American Society of Civil Engineers, 1996.

ASCE 7-98, ASCE Standard, “Minimum Design Loads for Buildings and Other Structures”, American Society of Civil Engineers, 2000.

AS 1170.2, “Minimum Design Loads on Structures” (Known as the SAA Loading Code) Part 2, Wind Loads, Australian Standard, 1989.

BS 8100 : Part 2 : 1986, British Standard, “Lattice Towers and Masts, Part 2, Guide to the background and use of Part 1” “Code of practice for loading”, British Standards Institute, 1986.

Specification for Drilling and Well Servicing Structures, API Specification 4F, Second Edition, American Petroleum Institute, June 1, 1995,

Draft Specification for Drilling and Well Servicing Structures (Wind), API Specification 4F, API Specification 4F Committee.

API RP2A-WSD “Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design” 20th Edition, July 1, 1993

“Wind Effects on Structures”, 3rd Edition by Emil Simiu and Robert H.Scanlan, John Wiley & Son, Inc., 1996

“Applied Fluid Dynamics Handbook”, by Robert D. Blevins, Krieger Publishing Co., 1984