



The Stability of Well Service Unit Masts

Well Servicing Committee
Energy Workforce & Technology Council

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1) Introduction

Self-propelled (mobile) well service rigs are the backbone of the upstream oil and gas industry for providing efficient, economical and safe completion and servicing of oil and gas wells after they have been drilled. These mobile rigs, which have been designed and operating in a configuration that has essentially been unchanged since the 1960s, move from well site to well site, in some cases moving as often as two times per day for routine repair and maintenance of producing wells with mechanical issues. The primary changes in well service rigs over the past decades have been in increased mast height and hoisting capacity.¹

The self-propelled rigs use a specially designed carrier to transport, elevate and operate the hoist, and raise pipe and rods from the well and lower them back into the well.² The mast is attached to the carrier and is secured to that carrier through hinges and through internal load guy wires to provide stability to the mast and support the rig's hoisting capacity.³

In addition to the support from the carrier and the internal load guy wires, the foundation (ground or prepared well pad) below the rig is critical to support the load that is pulled and lowered by the rig.⁴ This foundation varies with local soil conditions, material used for the well pad, and weather conditions.⁵

Guy lines (also known as wind guys) provide additional stability to support the mast from external forces, such as wind.⁶ Guy lines extend from the mast and tubing board to anchors set outside of the rig carrier.⁷ Guy lines are secured to either external ground anchors, or to integral anchors manufactured into base beams, both of which provide both a foundation for the mast and the stabilizing anchors.⁸

The stability of a well service rig is impacted by multiple factors, which are interrelated. All of these factors must be addressed to maintain the hoisting capacity of the rig and its designed resistance to external forces including wind and unexpected loading or unloading of the mast that can occur as a result of mechanical failure of the well piping during normal and high load operations.

2) Factors Impacting Well Service Rig Stability

¹ See W. Lee Guice, *Workover Rig Stability*, at 1 (2019) (on file with EWTC) (hereinafter "Guice 2019").

² Kate Van Dyke, *A PRIMER OF OILWELL SERVICE, WORKOVER, AND COMPLETION*, FIRST EDITION at 59 (University of Texas Petroleum Extension Service 1997) (hereinafter "Van Dyke").

³ Van Dyke, at 62-63.

⁴ American Petroleum Institute, *Recommended Practice 4G, Operation, Inspection, Maintenance, and Repair of Drilling and Well Servicing Structures* (5th edition 2019 edition, with Addendum 2, Sept. 2020), § 15.1, at 24. (hereinafter "API RP 4G").

⁵ API RP 4G, § 15.1, at 24.

⁶ Van Dyke, at 63.

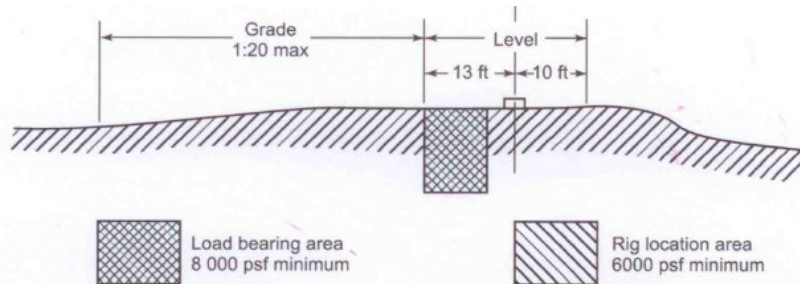
⁷ Van Dyke, at 63.

⁸ Van Dyke, at 63-64; Guice 2019, at 1.

Well service rigs are designed and manufactured to standards and requirements that are defined in American Petroleum Institute (API) Specification 4F, *Specification for Drilling and Well Servicing Structures* (the edition that is in force at the time the unit is manufactured). In addition, API Recommended Practice 4G, 5th Edition, *Inspection, Maintenance and Repair of Drilling and Well Servicing Structures* addresses the requirements for suitable foundations and acceptable guying of well servicing rigs. It is a reference for API Specification 4F.

Foundation Stability

The stability of the foundation that the rig is set upon is as essential as the foundation for a building. The loads that are transferred to the foundation by working well service rigs can reach 400,000 lbs. in routine working conditions and as much as 750,000 lbs. in conditions where all stated adverse factors exist.⁹ The native soil and all-weather topping applied to well pads are variable, and the load bearing capacity per square foot can change based on temperature and weather conditions. API RP 4G recommends that the soil load bearing capacity for service rig location be 6,000 psf at minimum and 8,000 psf for the load bearing area below the mast. Where the soil compressive strength does not meet these minimums, additional supplemental footing is required to support the loads.



NOTE 1 Load bearing area: compacted sand or gravel requiring picking for removal or better base. Safe bearing capacity desired—min., 8000 psf, level and drained.

NOTE 2 Rig location area: may grade away from well along centerline II at max. drop of 1:20. Should be level across grades parallel to centerline I. Safe bearing capacity desired—min., 6000 psf. Allow maneuvering entry for drive in or back in. Drainage of entire area required.

Figure 5—Portable Mast Location Preparation

Source: API RP 4G (5th edition 2019)

Mast Angle

The angle of the mast is a second critical factor in the stability of the rig. The operating angle of the mast is defined by the rig-mast manufacturer. This angle is typically between 2.5 and 3.5 degrees from vertical.¹⁰ Setting up (spotting) the rig further than the specified distance from the well center can result in increasing the mast tilt beyond the design angle. This increased tilt will change the force on the carrier during high-load lifts and can result in the lifting of the carrier with subsequent instability and possible overturn or mast collapse.

⁹ Based on rig manufacturer estimates provided to EWTC.

¹⁰ See Guice 2019, at 6.

Weight Distribution

The weight distribution on the rig carrier is a third critical factor impacting the stability of the rig. Many service rigs are designed with a double drum draw works (hoist). The hoist closest to the mast is the main hoist and provides the lifting power for the travelling block.¹¹ The second drum contains a smaller diameter wire rope for well swabbing.¹² Removing the typical 10,000 feet of 9/16 swab line removes 5,000 lbs. of load from the rig carrier and can result in the lifting of the carrier during high-load lifts, with subsequent instability and possible overturn.

Solid Foundation for Racked, Standing Tubulars

A solid foundation for racked, standing tubulars is the fourth critical factor impacting the stability of the rig. Service rigs are designed with mast-mounted racking boards that allow increased efficiency in “tripping pipe” out of the well and back in by pulling tubulars from the well in doubles and standing them vertically.¹³ This pipe is standing within a range from true vertical to approximately 2 degrees of tilt.¹⁴ At vertical, it places no load on the mast and at 2 degrees the load transferred to mast is negligible.¹⁵ A full load of standing pipe or hanging rods does increase the surface area and does have an impact on wind loading as well as the weight on the foundation. A full setback of tubing and rods can be 114,660 lbs. of tubing and 25,800 lbs. of rods.¹⁶ The rated wind capacity is defined in the design process with an empty mast and with a separate lower value for a full pipe and rod setback (load). Inadequate foundation below standing pipe and failure of this foundation can result in shifting of the tubulars and subsequent side loading of the mast that can result in mast failure or collapse or overturn.

Wind Guy Lines

The use of wind guy lines is the fifth critical factor impacting the stability of the rig. Wind guys attach from the crown of the mast and from the outside corners of the tubing racking board to anchors off of the carrier.¹⁷ These guy lines are set in limited tension (typically 1,000 lbs. of pretension) to allow for flexing of the mast under load.¹⁸ The wind guys allow for some operational movement of the mast but prevent significant movement to reduce the development of significant momentum and to provide stability against external loads, again, principally wind loading.¹⁹ API RP 4G, 5th Edition (published Feb 2019 last addendum Sept 2020) states that manufacturer’s guying patterns were preferred but other guying patterns could be utilized based upon the recommendations of a qualified person.²⁰ Anchors are required that either meet the

¹¹ University of Texas at Austin, Petroleum Extension Service (PETEX), A DICTIONARY FOR THE OIL AND GAS INDUSTRY, SECOND EDITION, at 76 (PETEX 2011) (hereinafter “PETEX”).

¹² PETEX, at 76.

¹³ See Van Dyke, at 71-72.

¹⁴ Based on petroleum engineer calculations provided to EWTC.

¹⁵ Based on petroleum engineer calculations provided to EWTC.

¹⁶ Based on rig manufacturer information provided to EWTC.

¹⁷ Van Dyke, at 63; American Petroleum Institute, Recommended Practice 54, *Occupational Safety and Health for Oil and Gas Well Drilling and Servicing Operations*, § 3.1.36 (Feb. 2019 edition) (hereinafter “API RP 54”).

¹⁸ See, e.g., API RP 4G, § 13.5 Table 4, at 20.

¹⁹ See API RP 4G, § 13.5, at 20.

²⁰ API RP 4G, § 14.3 states:

manufacturer's recommendations or that are designed to support the determined guy wire loads. API RP 4G, 5th Edition (published Feb 2019 last addendum Sept 2020) also allows for alternative anchoring practices including properly designed substructures and base beams that are designed and approved by the manufacturer.²¹

Acceleration Loading

Acceleration loading can affect rig stability. Acceleration loading does occur in both normal and non-routine operations. Acceleration loading is dynamic and the increased load is variable and difficult to anticipate or calculate with a high degree of accuracy.²² Instances where acceleration loading can occur can include:

- A tubing anchor or packer setting unexpectedly while pulling out of the well.
- Pulling into closed or partially opened BOP rams.
- Pulling into BOP rams with a tubing anchor or packer.
- Jarring on stuck pipe.

3) Guying to Base Beams

Since the 1990s, well pad configurations have continued to evolve, and multi-well pads have now become typical. The advent of multi-well pads and the "well factory" concept²³ created well sites where multiple well bores exist near each other. The flow lines and production facilities for adjacent wells create a landscape where rig carriers must align in a variety of directions from the well bores to avoid impinging on the adjacent well bores, production equipment and piping.²⁴ New technology, specifically the advent of rig-specific engineered base beams, allows rigs to work within these facilities without the limitations of extended guying patterns and accompanying ground anchors, which are difficult to install on an equilateral pattern due to the positioning of production lines.²⁵ In these cases, ground anchors are also difficult to access for pull testing.

Properly designed substructures and base beams have been designed and approved by the manufacturer and used as anchorage for mast guywires. In such cases, dead weight of equipment and fabricated components such as deadeyes determine anchor capacity. The capacity of such items can be determined through engineering calculations. Base beam anchor pull testing is not necessary, but calculations should be done by the manufacturer of the anchor or a Professional Engineer.

²¹ API RP 4G, § 14.3.

²² See William C. Lyons, Gary J. Plisga, STANDARD HANDBOOK OF PETROLEUM AND NATURAL GAS ENGINEERING, § 4.1, at 4-2 (2011).

²³ See, e.g., Chris Carpenter, *A Flexible "Well-Factory" Approach to Developing Unconventionals*, 68 J. PETROLEUM TECH. 75-77 (July 2016) (describing and summarizing the "well factory" approach).

²⁴ Karl Demong, Ken Boulton, Tyler Elgar, et al., *The Evolution of High Density Pad Design and Work Flow in Shale Hydrocarbon Developments*, SPE-165673 (August 2013).

²⁵ Guice 2019, at 4-5.



Example of a multi-well pad. Photo by Chris Boyer, Kestrel Aerial Services / NPCA via Creative Commons.

While initially focused on the multi-well pads and in areas where the topography is not suitable for the installation of ground anchors, the use of engineered beams grew in areas where ground anchors were difficult or impossible to install and achieve the required load capacity. This included geographic areas where well sites are cut from rock mountainsides, deep ground freeze penetration, deep layers of sandy or loamy soil, or swampy – water saturated soils. The ongoing implementation of engineered base beams to support the rig as supplemental foundation and to provide anchors of known and reliable capacity provide improved anchoring and guying capability and thereby improve rig stability for these areas.²⁶

The industry works with the original equipment manufacturers and engineering firms with specialized knowledge for well service rigs and masts to analyze the loads, wind and operating factors that impact the well service rigs. Early work focused on providing engineered base beams for existing well servicing rigs. At present, the majority of the well service rigs performing work in the industry are rigged up on and guyed to base beams that are engineered for the specific make and model of rig and mast that they are supporting.²⁷ Engineering analysis of the load capacity and stability are in place for the paired rigs and their base beams.²⁸

During the last decade, original equipment manufacturers of well service rigs engineered and designed their units for guying to OEM base beams from the inception of the designs.

4) Industry Guidance for Guying Mobile Well Service Rigs to Base Beams

In order to provide safe, efficient and economical service and support to the upstream oil and gas market well service rigs must be operated safely within their designed limits. They must be stable and capable of performing the work within the designed load capacity, the rated wind loads and the reasonably anticipated operational variables.

²⁶ Lee Guice, *Base Beam Design and Use Guide*, WELL SERVICING MAGAZINE, Jan./Feb. 2016, at 12 (hereinafter “Guice WSM Article”).

²⁷ Guice WSM Article, at 12.

²⁸ Guice WSM Article, at 12.

As described above, the stability of well servicing rigs is achieved by at least six preplanned, interrelated, engineering and design factors.

- Stability of the foundation that the rig is set upon
- Angle of the mast
- Weight distribution on the rig carrier
- A solid foundation for racked, standing tubulars
- The use of wind guy lines
- Acceleration loads
- When guyed to a base beam, rigged up on and guyed to a base beam that is engineered for the specific make and model of rig and mast that they are supporting. Engineering analysis of the load capacity and stability are in place for the paired rig and the base beam.

Well service rig crews are trained and capable of rigging their equipment to perform safely. They rig up on acceptable foundation for both the rig and for the pipe that they will be working with. They position the rig so that the mast tilt is within the design range. They do not modify the rig or its equipment so that the weight distribution on the carrier is changed significantly from the designed configuration. They guy the rig according to the manufacturer's or qualified person's instructions to either engineered and tested external ground anchors or to an engineered base beam that has been analyzed for the rig that it is paired with.

Original equipment manufacturers, including National Oilwell Varco²⁹ and Rig Works,³⁰ design and engineer their rigs and masts for safe, efficient and economical operation when guyed to base beams per O.E.M. recommendations. Engineering firms, including Guice Engineering³¹ and Herman J. Schellstede and Associates,³² design base beams and perform rigorous analysis to confirm the capacity and stability of service rigs when guyed to base beams.

5) Conclusion

The use of engineered base beams for stability and wind guying affords the well servicing industry a safe, efficient means of addressing a multitude of variables on diverse well sites and pad configurations to efficiently meet E&P demands.

Reference

API Recommended Practice 4G, Operation, Inspection, Maintenance and Repair of Drilling and Well Servicing Structures, 5th Edition (February 2019).

API Specification 4F, Specification for Drilling and Well Servicing Structures, 5th Edition.

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²⁹ See NOV base beam and rig design, construction and operating instructions (on file with EWTC).

³⁰ See Rig Works base beam and rig design, construction and operating instructions (on file with EWTC).

³¹ See <http://www.guiceoilfield.com/base-beam/>.

³² See <https://www.schellstede.com/>.