Design of the topsides structures

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Synopsis

The topsides structures for an offshore platform, although serving essentially the same purpose as in an onshore process facility, have to be modularized to facilitate onshore fabrication and subsequent movement of the relatively large packages for installation offshore in their final location. The movement of the substructures, the size and weight of each package and the availability of transportation vessels and equipment place demands and constraints on the design that make it different from conventional onshore process plant design.

Introduction

The ‘topsides’ is that part of an offshore platform that is above the highest design wave crest and splash zone. Everything required to extract the gas and condensate from the subterranean reservoir and to process it to a state in which it can be economically routed to the onshore refinery is housed here. Along with the mechanical, electrical and process plant, there is accommodation for 270 staff, including sleeping quarters, entertainment facilities and all the required services. In short, it is a combination of a drilling rig, a process plant, a power station, an airport and a hotel.

Description of FA topsides

The FA platform topsides consists of eight separate modules, or substructures, of between 1 000 t and 2 200 t each and measuring 36 m by 15 m to 19 m. The modules are supported by a 70 m by 45 m module support frame that is on top of the 126 m high jacket structure. The topsides has a floor area of approximately 12 000 m² and competition by the various disciplines for floor space on the platform is fierce.

As normal practice for offshore platforms, the topsides is divided into a hazardous and a non-hazardous area. The hazardous area houses all the process equipment that comes into direct contact with the flammable product. Contained in this area are the wellheads, also known as ‘Christmas trees’, where the gas is received from the wells, the process plant used for preliminary refining of the product, the flare boom where waste products are burned off, and the storage tanks for flammable products.

The non-hazardous area houses all the utilities and life support equipment. This includes the power generation equipment and switchgear, the firefighting equipment, the stores, the workshops and offices, the living quarters and the helideck. The hazardous and non-hazardous areas are separated by fire-proof barriers and at some levels by blast-proof walls.

For the first several years of the platform’s life the drilling equipment is located directly above the wellheads, as most of the wells are drilled after platform completion and during production from the first wells. During drilling operations mud is required to prevent the wells from collapsing, and there is a 400 m³ mud storage tank on the platform as well as pumping and mixing equipment.

The movement of stores to and from the platform takes place via cantilevered laydown platforms on the perimeter of the topsides that are serviced by the platform’s two 30 t cranes. Access for personnel is via the helideck on the accommodation module.

The platform has perimeter and transverse escape routes at every level with interconnecting staircases, and lifeboats with adjacent muster areas are placed at strategic locations.

Modularization

To construct the topsides offshore in its final position would have been an expensive and time-consuming process. Furthermore, the total weight of the topsides for the Mossgas FA platform is 20 000 t, and there is at present no viable method for constructing the entire topsides onshore and transporting it offshore for installation. The compromise solution was therefore to modularize the platform into units or modules that could be transported offshore, installed onto the jacket and coupled in the minimum of time. This coupling process is called hook-up.

For the initial design of the FA platform it was assumed that the maximum capacity crane vessel or SSCV that could be contracted with certainty was 2 200 t. The FA topsides was therefore separated into eight modules stacked onto a module support frame, or MSF, in two layers of four varying in weight between 1 000 t and 2 200 t. The MSF, which weighs 4 080 t at lift, was initially designed to be installed in two parts, each weighing around 2 000 t.

To minimize the hook-up time each module is dedicated, as far as possible, to a specific function, thereby reducing the number of interfaces between the different modules.

MSF: Module support frame

The module support frame (MSF) is a 10 m deep space truss with approximate plan dimensions of 70 m by 45 m. The main trusses are at 28 m centres and are supported laterally by four transverse trusses spanning between them. A 'cellar' deck is located at the level of the bottom chords of the trusses.

The purpose of the MSF is to transfer the topsides load from the two tiers of four modules to the jacket below. In addition the cellar deck houses approximately 2 000 t of services and facilities equipment, eg pumps, refrigeration packages, pressure vessels, piping and storage
tanks to hold 360 m³ of fresh water, 530 m³ diesel oil and 150 m³ of base oil. Design of the tanks was complicated by the requirements for lifting the completely fabricated tanks into place, the support configuration offered by the cellar deck, which was limited by the need to conserve space, and consideration of racking effects transmitted during the fitting of the MSF.

Module M01: Process module

The process module contains most of the required process equipment, which includes heat exchangers, filters, pressure vessels, chillers, scrubbers and metering units along with the associated piping, pumps, cable and fire-fighting equipment. M01 also serves as the supporting structure for the 75 m long fire boom and the mud storage tank. The lift weight of M01 was 1 300 t.

Module M02: Wellhead module

Module M02 is positioned directly above the wells and contains the wellheads, or Christmas trees, and associated piping. It also forms the support basis for the drill derrick to operate on. For this purpose the upper longitudinal 1 500 mm deep plate girders have skidrails on the top flange with slots for drop-lugs used to jack the 1 572 t drill derrick and sub-base assembly along the rail. Lift weight was 1 432 t.

Module M03: Utility module

The utility module houses the stores, the workshops and offices, the emergency control room and the potable water maker. At 1 059 t this module is the lightest on the FA platform.

Module M04: Power generation module

Power for the platform is provided by three turbine generators of 3,2 MVA each and backed up by an emergency diesel generator. The turbine generators are mounted on skids supported on gimbals to prevent the racking distortions that occur during load-out, lift and transport from interfering with the precise alignment of the turbines and alternators. This module also houses the switchgear and control rooms along with the associated cabling. The module weighed 1 664 t and had the greatest eccentricity during lift.

Module M05: Future compression module

It is normal for the pressure in a natural reservoir to fall as the hydrocarbons are extracted. During the latter stages of the reservoir's productive life, a compression module can be added to boost the pressure in the wells by pumping in either air or steam. Although the compression module is a future requirement (2000 onwards), it has not been designed in detail at this stage. The conceptual design was, however, progressed sufficiently for the necessary allowance to be made in the design of the supporting steelwork. It is envisaged that the mud storage tank will eventually be removed from the top of M01 and M05, weighing approximately 1 786 t., will be installed in its place.

Module M06: Drill derrick and substructure

The drill derrick and its supporting structure were designed by specialist designers Bay Drilling. The 1 572 t drill derrick is moved around on skid rails on the roof of module M02 and the resulting loads were catered for in the design of M02. Additional loads on M02 result from the force exerted by the drilling equipment in dislodging the drill string should it become stuck and the forces generated during the driving of conductor tubes into the seabed.

Module M07: Mud module

The mud module, which was also designed by Bay Drilling, is used for mixing, storing and pumping mud during the drilling operations and weighed 1 561 t at lift. During operation, with the storage tanks full, this module weighs 3 230 t.

Module M08: Accommodation module

The platform provides housing for 270 people in double cabins, the principle being that the occupants of one cabin work alternate 12-hour shifts. The accommodation module also provides dining, washing and recreational facilities such as a gym and cinema. To prevent vibrations caused by the mechanical equipment on the platform from reaching the living quarters, the accommodation module is supported on elastomeric anti-vibration mountings.

Module M04, the power generation module, being moved by two rows of self-propelled trailers during load-out (Photo: N Fourie)

Primary structure

Each of the modules consists of three or more rectangular decks with plan dimensions of 36 m by 15 m to 19 m. Vertical framing is provided by plane trusses on each of the four faces of the module. Racking resistance is provided by 8 mm thick deck plate or, in the modules that have gratings, by horizontal bracing in the decks.

The trusses are fabricated from grade 50E steel with plate girders as chords and rolled tubulars for bracing. Typical plate girders for the modules have webs between 600 mm and 2 000 mm deep and flanges up to 600 mm wide and 60 mm thick. The tubulars have diameters of up to 800 mm and wall thicknesses between D/60 and D/20.

The MSF, with a gross weight of 4 411 t, is fabricated of heavier plate girders and tubulars up to 1 400 mm in diameter and with wall thicknesses of 75 mm. The layout is also less regular than that of the modules, as the MSF transfers the topsides loads from the five-gridline topsides arrangement to the four-gridline jacket configuration.

The connection between MSF and jacket is a tubular to tubular load transfer, whereas the module to MSF interface is a bearing plate to tubular connection. Some of the plate used in the intermediate nodes is 140 mm thick and there are full penetration butt welds in plate up to 120 mm thick necessitated by the available plate sizes.

Secondary steelwork and clash checking

Along with the hundreds of kilometres of piping and cabling on the platform there is a maze of secondary steelwork in the form of equipment supports, cable rack and pipe supports, access platforms, overhead crane rails, partitions, stairways and walkways.

In order to minimize the number of clashes between the various services and structural members, the entire platform - structure, equipment and services, barring pipework smaller than 25,4 mm diameter, which is site run - was coded into a 3-D CAD model and clash checked by computer. Clashes were then printed out, plotted if required from any perspective, and resolved by interdisciplinary negotiation.

Offshore-related design aspects

Design of structures for offshore platforms differs from onshore design primarily in that the structure must be moved from the onshore fabrication position to the offshore platform location. In the process of fabrication and installation a typical module undergoes the following stages:

1. Fabrication in yard
2. Movement to quayside
3. Loading onto transportation vessel
4. Transportation to final location
5. Lift off transportation vessel
6. Installation onto platform
7. Hook-up of interconnecting pieces
8. In-place or operational condition

The exact sequence and the methods used to achieve each stage of the procedure differ from module to module. Within the offshore industry the names of the various analyses have been standardized for jacket and topsides design, and the following analyses are done for topsides design:
Load-out

The term 'load-out' is used to describe the transfer of the module from the fabrication position to the cargo barge, which could be by lifting or on wheeled trailer or skids. When applied to topides analyses the term load-out is used only for the wheeled or skidded movement of the module, even if the final transfer to the cargo barge is by lifting. The lift portion of the load-out design is covered under lift design. For the FA platform the MSF and M08 were loaded out by trailer onto barges and the remaining modules were only moved by trailer from the fabrication position to the quayside, from where they were lifted directly onto the deck of the semi-submersible crane vessel or SCV.

Load-out of modules M01 to M07 was performed by placing two rows of Mamoot synchronized self-propelled and steerable trailers longitudinally below the bottom deck of each module. The trailers were then lifted hydraulically to raise them off the fabrication supports. The modules were linked hydraulically in three separate lifts to minimize racking. The MSF was supported by two rows of trailers alongside of each of the two main trusses. The following are some of the possible occurrences that must be accounted for in the load-out analyses:

1. Loss of support as a result of undulating ground or loss of hydraulic pressure. One bank of trailers can lose hydraulic pressure, which can cause racking of the structure. The MSF is especially sensitive to loss of support and use was made of trailers that lock automatically upon loss of pressure.
2. The hydraulic system tends to apply more force to soft points than a static distribution would. At the same time the spine beams of the trailers tend to distribute load to the hard points. Both these aspects must therefore be accounted for during a load-out analysis.
3. During lifting of the module off the trailer the module rotates as a result of the eccentricity of the module centre of gravity relative to the centre of lift. This results in a transfer of load towards the lower corner, which remains in contact with the trailer after the opposite corner has lifted off.
4. Inertia forces due to braking and acceleration must be taken into account.

Lift

Although the initial design phases assumed the use of a 2 000 t lift capacity floating crane or semi-submersible crane vessel (SCV), the actual installation was performed by probably the largest SCV in the world. The vessel has two cranes, each with a maximum lift capacity of 7 000 t, and therefore a theoretical maximum lift capability of 14 000 t provided that the reach is within certain limits. The boom length is 140 m and the deck of the vessel is approximately 37 m above water level at minimum draught.

The availability of such a vessel made it possible to design the 4 600 t MSF as a single lift, although all lift weights remained critical owing to constraints such as padeye capacity, available slings, shackles capacity and total tuples loads on the supporting structure and piles.

The modules were lifted by slings attached to padeyes near the four corners of the upper decks. The main padeyes for the heavier modules are 120 mm thick plates with 60 mm thick plates on either side for bearing and pull-out shear and as spacers for the jaws of the 1 000 t capacity shackles. To save time offshore during installation, the module padeyes were recessed into the upper decks to obviate the need to cut them off before installing the next tier of modules.

To reduce transverse lateral forces and resulting moments on the padeyes, the padeyes were orientated towards the centre of lift. Module M02 necessitated a modified solution, as the requirement for clear well-bay openings resulted in inadequate deck stiffness to withstand the racking caused by eccentricity of load and sling mismatch. To overcome the problem M02 was lifted using two parallel sets of slings attached to a spreader bar. By doing this any sling mismatch is relieved through horizontal displacement of the spreader bar rather than raking of the structure.

The module support frame (MSF) lifting padear (Photo: S Amod)

The MSF framing configuration necessitated the use of parallel padears and consequently a spreader bar. The padears are fabricated from 140 mm thick main shear plates with transverse shear plates slotted through. Shaped cast iron bobbins are slotted over the transverse shear plates on either side of the main plate to match the desired grommet radius.

Fourteen inch (356 ± mm) diameter slings were used for the MSF lift and a 260 t temporary sling laydown platform had to be provided to support the weight of the 310 t slings and the 210 t spreader bar during rigging and derigging. The roof of the MSF is generally open, exposing relatively light service support steelwork that would not support the weight of the rigging.

This additional platform was used to advantage by attaching it to the padears so that the padears and rigging platform could be removed after installation of the MSF and cutting of the padears without derigging, thereby saving valuable offshore installation time.

Because weight and eccentricity have a marked effect on the lift design, weight and centre of gravity were constantly monitored throughout the design and fabrication phases of the project. A monthly weight report kept track of weight growth.

The primary design considerations during lift analysis are the following:

1. Racking of the structure owing to sling mismatch or uneven stretching. The use of matched pairs of slings or spreader bars reduces the problem. This is allowed for in the design by a racking factor that depends upon whether a spreader bar and matched or prestretched slings are used.
2. Dynamic amplification of gravity loads during lift. DAFs of between 1.05 and 2.0 are applied to various members, depending on the importance and redundancy of the member, whether the lift is in a sheltered location or exposed and whether the lift is off the quayside, off a cargo barge or off the deck of the SCV. To establish DAFs for lifting off the SCV directly, a dynamic analysis was performed that included considerations such as vessel accelerations.

THE CIVIL ENGINEER in South Africa – September 1991
and crane and cable elasticity.

3. Eccentricity between the centre of gravity and the centre of lift, which results in a rotation of the structure during lift. This in turn results in transverse loads on the lifting attachments and can result in the tilted and supporting structures transferring loads at points other than the intended supports during setting down. On MO4 a total of 100 t of removable steel counterweight was added to keep the lift angle within limits. This was calculated to be more cost-effective than fabricating link plates to shift the centre of lift.

4. Available rigging and lifting equipment. These are expensive reusable items and designing for reuse of heavier slings may be more cost-effective than optimizing sling sizes for each module.

Transportation analyses

The transportation analyses appraise the structure for motions and support conditions during the transportation by sea to the erected jacket. Two different concepts were used for the transportation of the FA platform topsides modules. For the PE fabricated modules, MO1 to MO4, and the Cape Town modules, MO6 and MO7, the modules were loaded out directly onto the SSCV deck and transported on the comparatively stable vessel. The MSF and module MO8 were constructed in Durban. Access and SSCV time considerations made it necessary for these structures to be loaded onto a cargo barge and then transferred to the SSCV deck closer to the Mossel Bay site.

Factors to be accounted for in transportation analyses include the following:

1. The motions of the transportation vessel, viz pitch, roll and heave, cause horizontal, vertical and rotational accelerations and consequent inertial loadings on the structure and the equipment on the structure. In some cases inertia design loads of up to 0.6 g were considered.

2. Structure supports on vessel decks must be positioned to suit the vessel grillages, which may not coincide with acceptable support locations on the structure. The support must then be checked for the perhaps unfavourable support locations and stiffened if required or the vessel must be strengthened at the module support locations. On the FA project, in addition to the supports being in unfavourable locations, the transportation reactions had large horizontal components that in some instances necessitated the addition of in-deck transverse bracing.

3. Sea fastenings to resist the horizontal inertial forces must be so designed that they can be cut quickly during installation with the minimum of equipment and without compromising the integrity of the permanent structure.

Installation

Installation, in the topsides context, implies placing a 1 000 t to 4 600 t structure that is suspended at an angle from a crane moving with the swell onto a support structure 30 m to 60 m above the sea, within a 50 mm tolerance at each of its four corners. The manner in which this is achieved is by adding bumpers to absorb the impact loads and primary and secondary guides to position the structure.

After piling of the jacket the legs were surveyed, cut to level within a 25 mm tolerance and propped for welding. The MSF was positioned by locating the stabbing cones on the MSF legs into the top of the jacket legs. The legs were then part-pen welded to make the MSF an integral part of the support structure.

Before installation, module support bearing surfaces were ground flat to within ±2 mm. The bearing surfaces were then surveyed offshore and shimmed to a height tolerance of ±10 mm between the four supports. The modules were first located by a system of bumpers and rubbing strips to within a tolerance of ±50 mm and then by setting wedges on the structure below to within ±25 mm.

Aspects of the installation procedure that had to be accounted for in the design include the following:

1. The impact loads applied to the structure via the bumpers and guides. Typical values for the type of vessel, seastates and rigging configurations used are of the order of 10 per cent of the module weight. The possibility of exceeding the installation loads was catered for by designing the bumpers and guides to yield before damage to the primary structure occurs.

2. The logistics of performing certain fabrication procedures offshore,

which place constraints on the types of solutions that can be used. The MSF padear plates, for instance, appear to provide ideal bearing surfaces for the modules above, but the time and expense of machining the 140 mm thick plates offshore dictated that a different load path be found.

3. The effect of the cumulative tolerances, which was included in the analysis. For instance the 25 mm module support level tolerance consisting of module fabrication tolerance, MSF shimming tolerance and jacket movement under wave loading was applied as a forced deflection in the module analysis. The resulting reaction shift was then accounted for in the design of the supporting structures.

In-place condition: Functional requirements

The in-place loadings differ from onshore design only in that heavy equipment that would normally be supported on the ground, on surface beds or on separate structures is now supported on the steel decks or on the primary structure. This results in high live loadings of up to 50 kPa in certain areas, and point loads from equipment supports of up to 78 t.

Other large loads on the structures come from the two cranes cantilevered off MO7, which each have a capacity of 30 t at full reach. The drill derrick on MO2 applies loads similar to a gantry crane with the additional factor that the derrick weighs more than 1 500 t. On the roof of MO1 a 400 t mud storage tank is located on bearing pads on the transverse girders. In addition to the magnitude of the loads, many items had to be isolated from the remainder, necessitating the use of spring or elastomeric bearings, as well as PTFE sliding bearings.

Suppressive and protective steel cages were designed for equipment, such as emergency shutdown valves, that onshore could be protected against explosions by earth beams or concrete structures.

Lastly, all the stores for the platform are supported on the structure, eg the diesel for the emergency generator, the spares for the process equipment and the water and food for the workforce.

Environmental conditions

For each phase of the life of the platform, the applicable environmental conditions are different, as the duration of exposure differs. The
design wind under operating conditions was for instance 47.9 m/s, whereas for transportation the 10-year maximum of 34.5 m/s was used. The wind and seastates used for the topsides analyses are basically the same as those for the equivalent jacket analyses.

Vortex shedding checks were done on exposed tubular members and fatigue checks were performed where members are subject to cyclic loadings mainly from wind gusting, as for instance on the flare boom support brackets on M01.

Corrosion protection
Owing to the different degrees of exposure in the different areas of the platform, a variety of corrosion preventive measures were used throughout the topsides. The most common system used for most of the structural steelwork was an inorganic zinc ethyl silicate primer, a high-build epoxy intermediate coat and a recoatable polyurethane top coat. This system, along with some alternatives, was subjected to accelerated exposure tests to confirm its adequacy.

Handrails on the platform are hot-dipped galvanized and 3Cr12 was used in some non-structural applications. All the bolts used on the platform are either fluoro-carbon coated, stainless steel or hot-dipped spun-galvanized.

Construction materials
The primary structure is fabricated from grade 50E plate for plate girders and rolled tubulars and grade 50D hot-rolled sections and tubulars. The secondary steelwork and deckplate is grade 43C and limited use was made of RoqTuf (600 MPa yield) and 3Cr12. Most of the plate for the platform was rolled to order by Iscor, and only a small amount of plate and most of the hot-rolled grade 50D tubulars were ordered from overseas.

Design codes and standards
To gain full advantage from the experience obtained in offshore design in other countries, the FA platform was designed using the codes of practice that are generally accepted in the United Kingdom, Europe and America as being state of the art for offshore design. In addition, the insurers of the platform impose their own design rules and limitations.

The steel structure was designed using the American Institute for Steel Construction (AISC) Code for the Design of Buildings with Rolled Tubulars designed according to the American Petroleum Institute Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms API RP 2A.

Stress and load factors for the design come mainly from the DnV (Det Norske Veritas) rules and wind loadings are in accordance with the British Standards Institute Code of Practice CP3 read in conjunction with procedures conducted by the CSIR. Weldments and fabrication procedures were assessed with the American Welding Society Structural Welding Code (AWS D1.1) as a guideline. Fatigue was assessed mainly in accordance with BS 6235 Code of Practice for Fixed Offshore Structures and fracture mechanics to PD 6493.

Reference was also made to applicable SABS codes and specifications as well as to a supply of in-house design guidelines provided by the overseas partners in the joint venture companies as part of a technology transfer agreement. Also provided by the overseas partners were computer programs developed in-house specifically for offshore application with built-in code checks for the above design codes.

Conclusion
The topsides design of the Mossgas FA platform was the product of a multi-national, multi-company joint venture. The technology was new to South Africa, but there is now a core of proficient offshore designers and detailers available locally to service future local projects and perhaps foreign projects as well.

Fatigue design of structural jacket (continued from page 327)

Conclusion
The Mossgas FA jacket structure has been designed to satisfy fatigue requirements of the highest standard, using the most up-to-date technology and computer software currently available.

The design processes used and the results obtained have provided the client with a safe and fatigue-efficient structure capable of withstanding the aggressive fatigue wave loading climate for the expected 30-year life of the platform.

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Reference

THE CIVIL ENGINEER in South Africa - September 1991