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**기술보고**

# Onshore Deck Mating for Deepwater Nautilus by Super Lift

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**KEY WORDS:** Onshore Deck Mating 지상 데크조립, Super Lift 초대형 인양기, Deepwater Nautilus Drilling Rig 심해용 시추구조물 노틸러스

**요 약:** *대형 시추구조물의 건조는 보통 드라이도크에서 하거나, 해양에서 선체와 데크를 접합하는 방법을 사용한다. 그러나 적당한 해양 접합장소가 없거나 드라이도크의 공간부족으로 현대중공업에서는 드라이도크나 해양에서의 접합건조 대신 부유식 시추구조물을 지상에서 조립하는 방법을 채택하게 되었다. 현대중공업에서는 세 가지 단계를 통해 지상 데크조립을 수행하였다. 첫 번째는 네 개의 철골구조 리프팅타워 상에서 유압리프팅시스템을 이용하여 데크를 지상으로부터 38m 들어올린다. 두 번째는 마찰을 줄이기 위해 윤활제가 칠해진 합성 플라스틱으로 싸인 미끄럼틀(Skidway)을 이용하여 두 개의 6000톤 짜리 하부구조를 데크 아래로 끌어 들인다. 마지막 단계로 데크와 하부구조를 단단히 결합시킨다. 이 과정에 2주일이 소요되었으며 일련의 작업을 거쳐 중량 25,500톤급의 Deepwater Nautilus (RBS-8M) 시추선을 무사히 바다 위로 인도하였다. RBS-8M의 데크결합에 Super Lift를 적용하여 성공시킨 사례를 통해 현대중공업의 초대형 시추구조물 건조방식이 이상적이고, 작업 공기나 원가 측면에서 우위가 있음을 시사하고 있으며 이렇게 건조작업의 대부분을 지상에서 수행한 과정을 통해 작업관리, 품질관리, 일정관리에도 좋은 결과를 가져올 수 있었다.*

## 1. Introduction

It is a normal practice to build large semi-submersible vessels such as the RBS-8M in a dry dock or by mating the deck with the hull when afloat at sea. However, due to scheduling constraints and lack or access to either a suitable floating mating site or a dry dock, Hyundai Heavy Industries (HHI) had to find an alternative method for constructing this vessel. It was therefore decided to find a method for constructing the RBS-8M that allowed pre-assembly of components at ground level and did not require the use of a dry dock or a floating mating site. HHI carried out the onshore deck mating process in three main stages. Two portside and starboard lower hulls were simultaneously fabricated on ground along with the deck structure. Firstly, the upper deck was lifted to allow the two lower hulls to be side-skidded under the deck. The deck part of the rig, weighing 11,000 tons, was raised 38 meters off the ground using a hydraulic lifting system on four steel-framed temporary lifting towers located near the forward and aft ends of the rig, and two cylindrical temporary jacking legs at the center. The second stage is similar to skiing. The rigs of two 6,000 ton lower hull structures were side skidded under the deck for final deck mating on four skidways covered with lubricated synthetic plastic to reduce friction. Lastly, the upper deck and lower hull structures of the semi-submersible were securely joined together, with welding connections of the deck and the hull structures that met 5 mm fit-up tolerances. HHI completed the onshore deck mating within two weeks. After subsequent operations including loadout, floatoff, commissioning, and floaton, HHI sailed out the 25,500 ton drilling rig Deepwater Nautilus on 14th February, 2000.

Fig. 1, 2 are photographs showing sideskidding and loadout respectively.

## 2. Design of Lifting Systems

The basic criteria for the lifting system is as follows :

1) Reinforcement and change of the permanent deck structure should be kept to a minimum for both cost and weight.
2) The weight of reinforcement that could not be removed post lift should be as small as possible to maximise the vessel payload.
3) The lifting towers should re-use as much existing temporary works as possible to reduce temporary works costs. HHI had a substantial amount of lattice towers, box girder catheads and large diameter tubulars from two recent bridge construction jobs.

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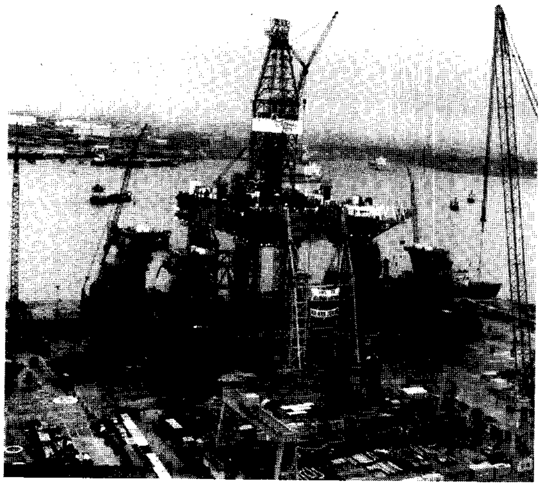

**Fig. 1** Deepwater Nautilus : Sideskidding after Super Lift

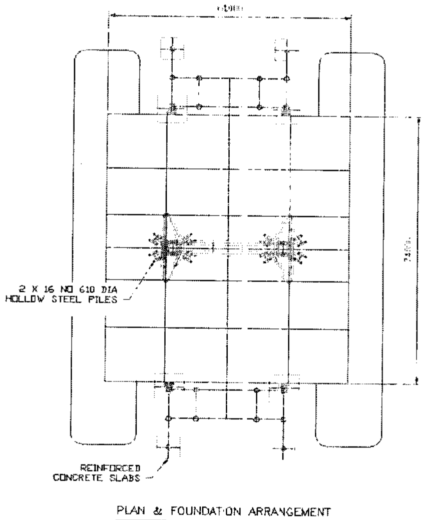

**Fig. 3** Plan view and foundation arrangements

**Fig. 2** Deepwater Nautilus : Loadout

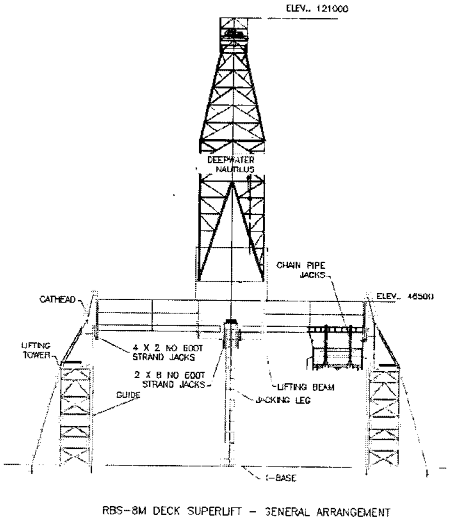

**Fig. 4** Elevation view of the deck lifted 38 m off ground

4) The lifting system design should comply with relevant design codes, typically the AISC code for the design of steel structures.
5) Lifting by means of hydraulic strand jacks.

## 2.1 Deck Structure

The permanent deck structure is a rectangular box of 61 *m* wide by 74 *m* long and 8.5 *m* deep. It interfaces with the hull at the four corners with footprints of 15.25 *m* by 15 *m*. The box is constructed from thin stiffened plate panels, the plate thickness varying from 9 to 16 mm. A large rectangular opening at the center, the moon-pool, provides drilling access. For structural analysis using models, very detailed finite element analyses were carried out to obtain a detailed picture of the stresses in the permanent plated structures and the temporary reinforcement provided for lift. The final extent of temporary steel that could not be easily removed amounted to approximately 26 tons.

## 2.2 Foundations

The lifting towers are founded on reinforced concrete slabs set level with the yard surface. The jacking legs, that carried 70% of the deck weight, are founded on a total of thirty-two tubular steel piles located in two main groups. The pile cap structure is designed to distribute the vertical loads equally to the sixteen piles in each group. Fig. 3 shows the layout of the foundations.

Jacking Leg Foundation Details

The estimated ultimate capacity is 840 tons and the

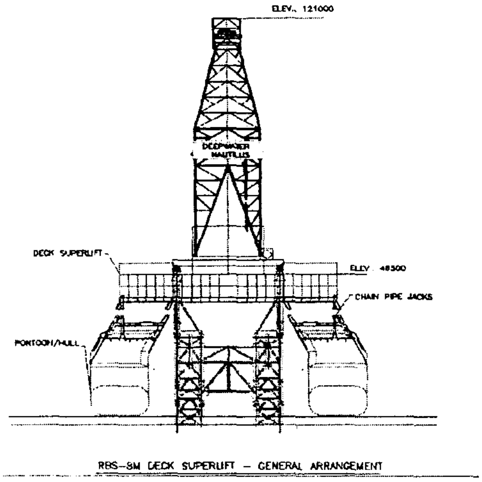

**Fig. 5** Side view of the deck 38m lifted off the ground

recommended factor of safety is 2.5. The maximum design load is 275 tons.

Lifting Tower Foundation Details

The inner slabs are 9.5 m x 9.5 m x 1.8 m and the outer slabs are 6.0 m x 6.0 m x 1.8 m. The inner slabs are designed to carry 1720 tons vertically and 375 tons horizontally. The outer slabs are designed to carry a 105 ton uplift. The maximum differential settlement between slabs is limited to 20 to 25 millimeter.

Settlement Contingency Plan

Considering the varying soil conditions, large applied loads and the extremely stringent settlement criteria, a contingency plan was adopted. Any differential settlement causes the lifting points at the tops of the towers to be misaligned with the lifting strand connection points on the deck. A 150 mm lateral displacement at the top of the tower is anticipated. Therefore the towers are pre-set back from the deck so that they will become theoretically true when the lifting load is applied.

## 2.3 Lifting Towers and Catheads

The four lifting towers are each designed to lift 1000 tons using existing steel works. The top one third comprises box girder catheads that were used on the same bridge except that the catheads are rotated through 90 degrees and extended to the height required. Each cathead supports two 600 ton strand jacks. Each cathead is braced to form a tripod. The steel in the lattice tower has yield strength of 2.5 ton/cm$^2$ and while the steel in the catheads has a yield of 3.5 ton/cm$^2$.

To reduce the overturning effect on the tower assembly, the loaded foot of the lattice tower is extended horizontally towards the deck. This increases the stresses in the tower at the bottom but significantly reduces the amount of uplift restraint and counterweight required at the base that is used to prop the tower. Fabricated steel guide rails are mounted on the loaded leg. The guide rail structure helps to carry the offset vertical forces at the base of the loaded leg. The guide rails also carry side loads applied by the deck. A lateral load of 7.5% of the deck weight is assumed to act during the lift. This is distributed only to the four lifting towers and carried via sliding bearings to the rails mounted on the towers. For side wind, the four towers are assumed to share the lateral load. For longitudinal wind, only two towers carry the load.

## 2.4 Jacking Legs and X-base

The jacking leg is a 2.4 m diameter pipe with a wall thickness varying from 75 to 90 mm. A jacking leg is mounted on an X-base that is supported on sixteen 610-millimeter tubular steel piles. The piles are shear and moment connected to the X-base adopting structural details that permitted the piles to be installed before the X-base. The structural configuration ensures that the vertical design load of 4000 ton is distributed equally to the sixteen piles. For design, the jacking leg is assumed to have an initial vertical misalignment of 150 mm at the top.

**Table 1** Properties of piles

| | |
|---|---|
| Total number of piles | 32 |
| Number of piles in each leg | 16 |
| Pile diameter | 610 mm |
| Pile wall thickness | 16 mm |
| Pile shoe length | 1000 mm |
| Pile shoe thickness | 28 mm |
| Pile length | 20~28 m |
| Yield strength | 2.45 ton/㎠ |

The jacking leg is surmounted by a crosshead that supports eight 600 ton strand jacks. Each jack has thirty-seven 18 mm Dyform strands. The strand jacks are anchored to the lifting beam that is free to slide on the jacking leg. The lifting beam effectively controls the location of the strand anchors so that they are concentric to the jacking leg at the start of the lift. Therefore, the effective length of the jacking leg is assumed to be 1.0 and not 2.0 as would be the case if the jacking leg supported a 4,000 ton vertical load at the top.

Fig. 6 shows that if the top of the jacking leg is deflected

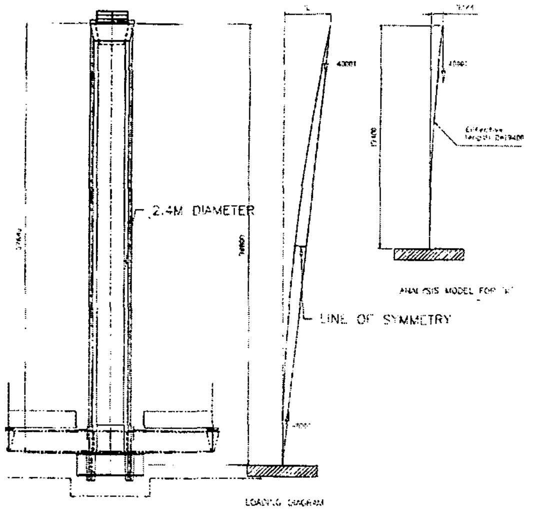

Fig. 6 Assumed deflected shape and load paths of jacking leg

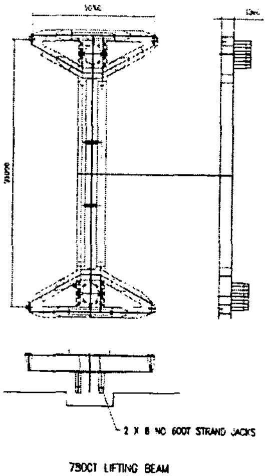

Fig. 7 Details of lifting beam

the lifting strands become inclined so that their centre of effort passes through the centre of the leg at the base. This effect reduces the moment on the leg due to the eccentricity compared to the case if the lifting strands remained vertical, as would be the case if the vertical load were applied at the top as a load, for example. A point of symmetry can be considered at the half height of the jacking leg. The model can then be reduced to the simple flag pole model except that the height of the leg is half the actual height. Applying an effective length factor of 2.0 to this flag pole gives an effective length equivalent to the actual height. Hence, an effective length factor of 1.0 is used in design of jacking leg. In addition, the effects of unbalanced jacking loads are considered in the design. The four jacks on one side are considered to be loaded 50 ton more than the design value and the four jacks on the opposite side are considered to be loaded 50 ton less than the design value.

## 2.5 Lifting Beam

The lifting beam is shown in Fig. 7. It is mounted on the two jacking legs and it is designed to lift 8000 ton at four points. The beam is constructed from I-section girders and therefore has low torsional strength permitting the beam to follow the shape of the deck to ensure uniform transfer of load. The lifting beam is only 2 m deep due to the need to keep the deck as close to the ground as possible for the assembly stage. Therefore, the girders are stocky with total flange plate thickness up to 140 mm.

The deformations of the lifting beam when under load produce quite large structural rotations at the 4 interface points with the deck. Self-aligning rubber pot bearing pads are used at the load points to ensure uniform distribution of the loads onto the underside of the deck. The lifting beam weight is 400 tons, which is about 5% of its rated lifting capacity. This demonstrates the good structural efficiency and high stress utilisation achieved. It should be noted that the self-weight of the lifting beam represents loss of lifting capacity, hence the need to make it as light as possible. The deck is reinforced at the lift points by means of varying thickness corner plates that convert the original plated cruciform detail to a square box within the deck structure. This steel remains permanently in the deck. The weight of this additional steel is approximately 13 tons.

## 2.6 Strand Jack System

Twenty-four 600 ton strand jacks are used to lift the deck. The average utilisation is about 76%. All strand jacks are mounted in the inverted position, two on each cathead and eight on each jacking leg. The inverted position of the strand jacks avoids the necessity of handling moving strand as it emerges from each strand jack. Six hydraulic power packs are mounted on the deck to power the strand jacks.

## 2.7 Final mating between Deck and Hull

Horizontal welded splices located 1500 mm below the underside of the deck formed the connection between hull and deck at the four corners. Each footprint is approximately 15 m square and the plate thickness is 14 mm. The precision necessary to make these splices successfully was very great. It was considered necessary to have precise control of the deck location with respect to the hull.

## 3. Super Lift Operation

All temporary structures and jacking systems were checked before commencing the lift. A water level was set up on the top surface of the deck and calibrated to the start position. Surveying targets were set on the tops and the bases of both jacking legs and the four lifting towers so that the deflections of the structures and their foundations could be monitored continuously from survey stations surrounding the Super Lift. Stations were manned continuously and survey data reported to a central control point.

First, the lifting systems were test loaded against the mass of the deck. All four lifting towers were progressively loaded up to 110% of their rated capacity. The loads were held for several hours while all temporary structures and the more highly stressed parts of the permanent structure were inspected visually.

Secondly, the two jacking legs were test loaded to 110 percent of their rated capacity resulting in a total load of 8800 ton, or 80 percent of the deck weight.. All systems were re-checked and the lift began. The lift rate was slow and it took nearly two days to reach the final soffit elevation of 38 meter. It was anticipated that it would become more difficult to maintain the individual strand jack loads within the required tolerance because of the relatively high stiffness of the deck structure and the fact that the stand length under load became shorter as the lift progressed, further increasing the stiffness of the system.

## 4. Future Use of Lifting System

The success of the Super Lift for the Deepwater Nautilus has confirmed the construction philosophy of HHI for these large drilling rigs. Carrying out the majority of the construction for such projects on the ground results in better control of the work, better quality control and assurance and completion on time.

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