



1. The CGS floating in the dock preparatory to being towed out.

# Malampaya: the first CGS built in Asia

## Background

The Malampaya Deep Water Gas to Power Project, a major development in the Philippines, presented an opportunity to demonstrate the benefits of a concrete gravity substructure (CGS) in South East Asia. The gas field is in 850m of water, to the north of Palawan Island. Arup Energy had been studying CGS applications in the region for 10 years, during which time the Wandoo CGS was successfully installed on the north west shelf of Australia in October 1996<sup>1</sup>, but Malampaya offered the chance to prove a CGS could be delivered in a developing country.

The overall development concept was to process the gas offshore and export it dry to an onshore plant for final processing, whence it will be used as fuel to generate electricity from three combined cycle gas turbine power stations of 2700MW overall capacity. Associated with the gas was condensate, a light oil, which was present in sufficient quantity that it could not be carried in the gas stream. The condensate was therefore to be separated and stored offshore before being exported via shuttle tankers.

The original development scenario led to two main concepts:

- a tension-leg platform installed at the deepwater offshore field location
- subsea facilities tied back to production facilities in shallower water, 30km from the field.

The options for the support of the shallow water production facilities included a jack-up, a steel jacket, and a CGS.

## Feasibility and bid

In 1996 Arup Energy was commissioned by Shell International Exploration & Production BV (SIEP) to confirm the technical feasibility, the cost, and the schedule for constructing a CGS in the Philippines.

David Collier

*The inauguration of the Malampaya Deep Water Gas to Power Project marked the birth of the Philippines' natural gas industry.*

The study was in two phases. The technical feasibility was assessed using the Arup Energy CGS sizing expert system, modified to take account of the implications of significant earthquake loading. Local investigation then took place to obtain accurate information on the capability and cost of construction in the Philippines. Contractors were interviewed and suitable CGS construction locations identified.

The indications were that it was technically feasible to construct a dock and build a CGS in the Philippines, with the preferred execution strategy being to select a contractor who had established a joint venture arrangement with a local contractor. Two construction locations were identified, Subic Bay and Batangas Bay, both on the east side of the main island, Luzon. Subic Bay is three hours' drive north of Manila and Batangas Bay two hours' drive south.

Compared with other shallow water development options, the CGS offered the two significant advantages of integral oil storage and the potential for local construction. All the other solutions considered required a separate structure, such as a tanker, to provide the condensate storage capacity, and it was generally accepted that none of the steel solutions could be fabricated in the Philippines. Although there was a perceived political risk associated with building in the country, the technical and economic advantages of the CGS resulted in it becoming the base case development option. Arup Energy and one other designer were each awarded a Front End Engineering Design (FEED) study in early 1998.

From the outset, the fundamental design aim was to develop the most economic and practical CGS design, consistent with the following objectives:

- to maximise safety
- to optimise the overall field development cost, not just the substructure cost
- to minimise the structure required solely for transportation and installation
- to maximise the proportion of the enclosed volume used for oil storage
- to minimise environmental impact

2.  
Location  
plan.



- to provide a flexible design and thereby minimise the impact of late revisions of the design brief
- to design a structure which would be simple and straightforward to build, with repetitive elements without excessive amounts of reinforcement and prestressing.

Following the FEED study, the Malampaya CGS Alliance was assembled by Arup Energy to bid for delivery of the CGS. The team comprised Arup Energy plus John Holland, a leading Australian civil contractor, and Van Oord ACZ, an internationally known marine contractor. Arup Energy had originated the shallow water CGS design, and Arup had had a permanent office in the Philippines since 1990. John Holland had been operating in the Philippines for over 10 years and had good local knowledge and experience, whilst Van Oord ACZ was selected on the basis of their specialist skills in dredging, rock dumping and installation.

On 25 September 1998, following an international tender, the Malampaya CGS Alliance was awarded the contract to design, construct, and install the CGS. The only key date in the substructure contract was that it had to be fully installed on the seabed before 1 September 2000.

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## Objectives

At the outset, the Alliance organised workshops to facilitate positive alliancing behaviour and build good personal relationships between the team members in the three companies. This proved very beneficial, as none of the parties had worked together before.

These workshops also included representatives from both the Alliance's client, HMI (a local subsidiary of Brown and Root) and its client, the field operator Shell Exploration Philippines (SPEX). It was recognised that, although HMI and SPEX were not Alliance members, their contribution was critical to the project's successful outcome. During the initial workshop, all parties committed themselves to achieving five key objectives:

- to build a CGS without injury or incident
- to minimise the project's environmental impact
- to meet all quality requirements
- to deliver the CGS for 1 September 2000
- to achieve the financial objectives of all parties.

Individual team members of the Alliance developed and implemented strategies to meet this challenge. In addition, several stretched targets were identified to focus the team on identifying improvements in how the project could be executed to the benefit of all the Alliance personnel, the Alliance companies, the local community, and the client.

## Site selection

In 1996, as part of the feasibility study, Arup Energy had identified Subic Bay, an ex-US naval base, as a good potential construction location. It has a natural deep-water harbour, reasonable road access, and plenty of local labour living just outside the former base. However, the local authority was very keen to offer SPEX a different location - an area of land on the other side of the Bay previously used by the US military as a firing range. It was found to be adequate in terms of area and access to deep water, but it had no road access. Nonetheless, its selection as the site was confirmed following a limited site investigation that showed that soil conditions were suitable, if not ideal, for building a dry dock.

In terms of project execution, the remoteness of the site was a challenge. All plant, materials, equipment and labour had to be imported by sea. Landing craft were a logical choice for supplying the site in the Philippines. However, it was considered undesirable to transport 1000 workers to and from site every day, so one of the first activities was to build a construction camp with site offices whilst the casting basin was being excavated.



3.  
The CGS en route  
to the field 80km  
north west of  
Palawan Island.

Although the area had no road access, there was an adjacent fishing village. The relationship between the village and the project remained very good throughout construction - indeed, many villagers were employed on the site.

Once the area had been cleared and checked for unexploded ordnance, construction of the dry dock could commence. A slurry wall was installed in the sea bund to cut off the sea from the excavation. Deep wells were used to draw down the water table generally and rings of well points placed to dewater the soil locally. The soils mostly comprised silty marine deposits, which are very easily eroded by surface run-off and difficult to dewater fully. The latter fact was most important in demonstrating acceptable seismic performance of the bund separating the dock from the sea.

### Design solutions

Outwardly the CGS appears similar to previous Arup designs. Many of the details Arup Energy had developed over the previous 12 years could be directly employed on the new project. The main functional requirements of the CGS were to store 385 000 barrels of stabilised condensate and to support a 16 500 tonne topsides, to be installed by the floatover technique, in 43m of water.

The major departures from previous practice were that: the seabed at the proposed site was uneven and could not directly support the CGS without the introduction of a levelling layer; there was a significant level of seismic activity at both the construction site and the offshore location and the environmental conditions were the most severe yet encountered on a shallow water gravity platform.

At tender, the design solution consisted of a base caisson 112m long by 70m wide by 16m high, with four 11m diameter shafts located eccentrically on the base caisson to minimise mechanical outfitting. It had been based on a water displacement condensate storage system that permitted direct discharge of ballast water to the sea. Arup Energy had reservations about this system because, of the possible storage systems that could have been selected, it posed the greatest risk to the environment.

One shaft on the end supported four external risers - two infield flowlines bringing gas from subsea wells to the platform, one export gas pipeline to shore, and one condensate export line to a CALM buoy. It also housed the condensate storage equipment internally. The other end shaft contained 11 J-tubes through which passed umbilicals that controlled the subsea equipment in the field. The two shafts towards the centre of the substructure were under the safe end of the platform topsides and only supported utilities caissons.

Design of the concrete structure followed what have become tried-and-tested techniques. Once the installation sequence was confirmed, and the structure found to be stable in tow and installation, the detailing and verification of the concrete elements could be progressed.

The key early design decision was how to overcome the unevenness of the seabed and resist the earthquake loading. One benefit of the alliance approach is that it enables discussion to be free-flowing, and the design and marine teams were able to identify the best answer unencumbered by company contractual considerations.

Several solutions were assessed, including placing a levelling layer on the seabed or gravel bed, or casting variously shaped downstand beams onto the underside of the base slab, or combinations of both approaches.

The aim was to limit the local contact force on the underside of the base and prevent overall bending of the caisson, and the final solution that appeared to satisfy most of the criteria was to install a series of equally spaced gravel humps on the seabed, to an out-of-level tolerance of  $\pm 100\text{mm}$ .

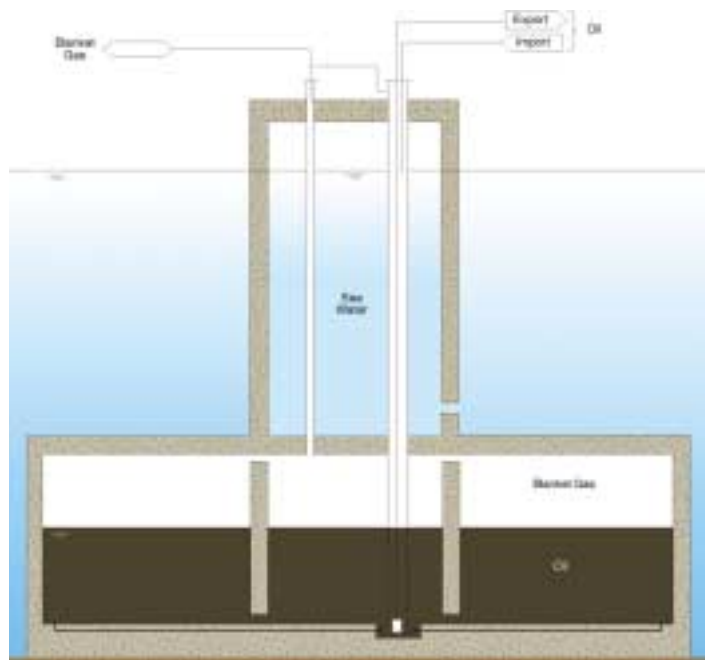
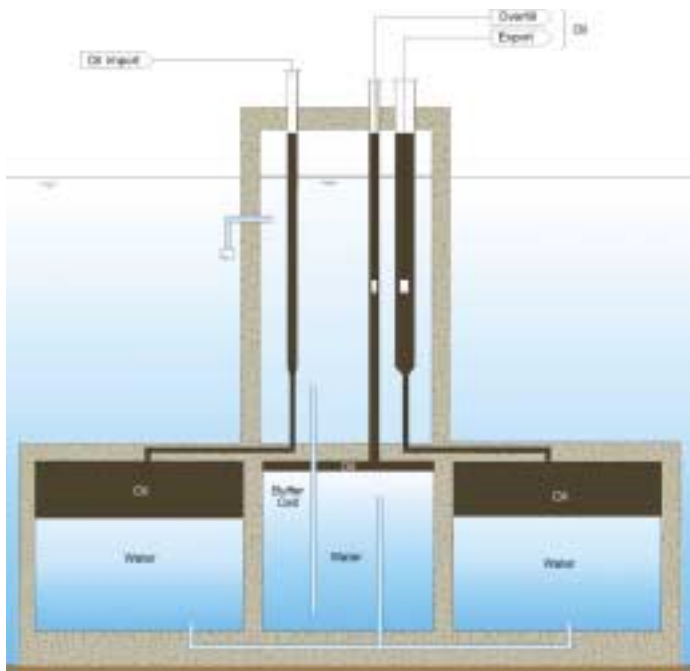
The benefit of humps to the design team was that their crush characteristics were tractable to analysis and variations in the heights of individual humps were statistically independent. The experience of the marine team in predicting the 'as-installed' shape of the humps was critical, as it was not possible to carry out any trials before base slab construction commenced.



4.  
Utility shaft  
under  
construction,  
October 1999



5.  
The CGS in the  
casting basin, with  
slipforming of the  
base caisson in  
progress.



Levelling the seabed, however, was only half the solution. The humps also had to give good resistance against wave and seismic loading. It was successfully argued that the performance criteria for the ductility level earthquake (DLE) and strength level earthquake (SLE) should be horizontal movement limits for CGS sliding. To maximise the performance of the sliding interface between the CGS and the humps, a series of tests was undertaken to assess the best method of roughening the concrete. The chosen solution was to cast the base slab on a dimpled plastic sheet, which had the effect of increasing the interface friction angle by 3° compared to plain concrete.

One unusual feature was that although the site was in 43m of water, it was surrounded by much deeper water. This proved to be challenging for calculating the extreme wave loading on the CGS, as the deep water wave was likely to be near breaking as it passed over the caisson. After taking advice from external experts, additional non-linear surface forces, rarely encountered on CGS designs (Faltinsen, Newman, Vinje forces), were accommodated. These act over a depth of around 5m below the instantaneous water surface and increase overall wave loading by about 10%.

The innovative aspects of the Malampaya CGS design described above are presented in greater detail in reference<sup>4</sup>.

As on Wandoo, a change to the performance criteria of the substructure was made after construction had commenced. This, once again, tested the flexibility of the dry-build CGS concept. By the end of February 1999 the first base slab reinforcement drawings, detailed by a team established in Subic Bay, had been issued to site.

Then the carefully planned production of site information was radically disrupted. In March 1999, due to concerns about the quality of ballast water discharged from the storage system, the Alliance was asked to quantify the impact of changing from the open system to a dry storage system where seawater is not used to displace condensate. The only constraint was that the original schedule had to be maintained.

Within three weeks a revised scheme was developed and costed, and measures to accelerate the programme to meet the original schedule identified. Within a very short time the decision to change the storage system was made, and the pressure was on the design team to re-do the analysis, design, and provide a new set of drawings.

Changing from a wet to a dry system had two major effects on the design. In a dry system, when the storage compartments are empty, there is a significant buoyancy effect, tending to lift the substructure off the seabed. This can only be overcome by adding more solid ballast to hold the substructure down. To accommodate this extra ballast, the open cells were increased in volume by 50% and the structure had to be strengthened to resist the extra weight. The second effect is the fact that the base caisson can experience the full external hydrostatic pressure under normal operation, which requires additional strengthening to the external caisson walls and slabs. The combination of these two effects resulted in the concrete volume increasing from 27 000m<sup>3</sup> to 34 000m<sup>3</sup> and the reinforcement weight from 7500 to 12 000 tonnes.

The interface with Brown & Root, the topsides designers, ran very smoothly, founded on mutual understanding of each other's requirements and the desire to find the best overall solution for the project. This was most evident in the approach taken to satisfying acceleration limits in the topsides, a contractual requirement placed on the CGS designer. Acceleration of the topsides under seismic events had to be limited to 0.4g for the SLE and 0.65 for the DLE respectively, and this was achieved by adopting an integrated approach.

The two main structural models of the substructure and topside were connected and subjected to a non-linear time domain analysis to determine the earthquake response. It was found that accelerations in the topsides could be tuned by varying the stiffness of the connection between the topsides and CGS, the final solution consisting of a steel tubular connection with a flange supported by but not bolted to the top of the concrete shaft. Under extreme seismic events, the flange will tend to lift off one side, introducing flexibility into the connection. This effect was found to limit the acceleration in the topsides to an acceptable level.

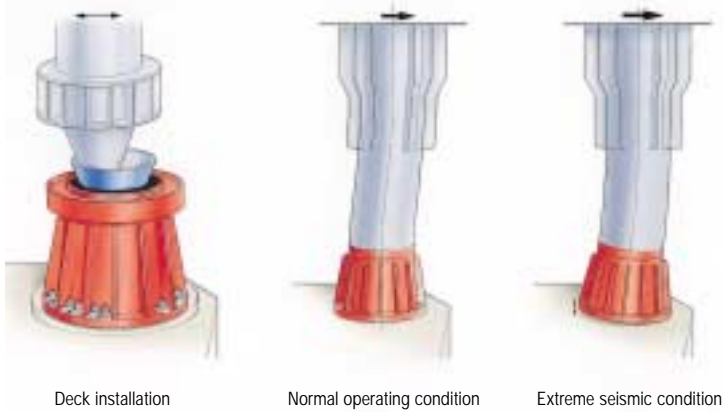
### Construction

Within six weeks of the decision to change from wet to dry storage, reinforcement drawings were issued allowing concrete works to proceed. In the same period, the dry dock and sea bund were extended to accommodate the extra width of the base caisson. The first base slab pour was completed on 10 June 1999, some two months later than the original schedule.

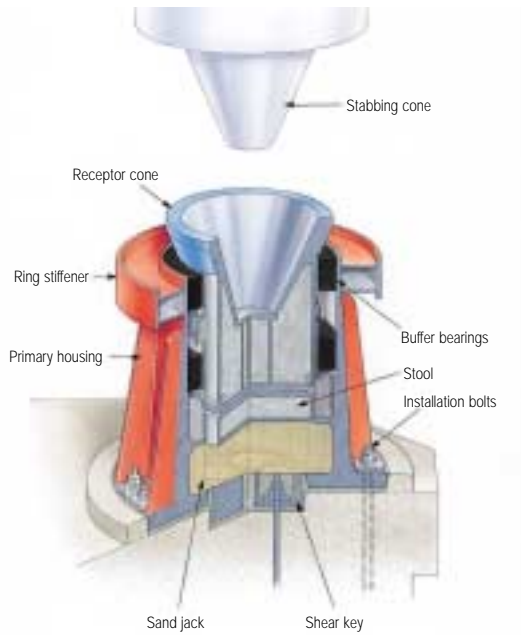
Construction was by civil engineering techniques that have become conventional through their use on previous dry-built CGS projects. The slabs and caisson walls were split into eight sections for pouring, and the caisson walls and shafts slipformed. Construction was managed by foreign staff, with the labour and most of the supervision from the Philippines.

6.  
 (a) Above left:  
 Open wet  
 storage system.  
 (b) Above right:  
 Dry storage  
 system.

*Malampaya,  
 the third  
 successful  
 CGS designed  
 by Arup Energy,  
 won the  
 International  
 Projects section  
 of the Concrete  
 Institute of  
 Australia's 2001  
 Awards.*



7.  
Deck connection behaviour.



8.  
Topside connection detail.

Considerable attention was given to training the local staff to achieve requisite levels of quality and safety on site, and the result exceeded most people's expectations. The standard of steel fixing and the finished quality of the concrete was acknowledged to match if not exceed that produced on similar projects anywhere in the developed world. The level of safety was also exceptional, with only two lost time incidents being recorded. The first occurred near the beginning of the project. Subsequently, over 4M manhours were worked without further mishap. Productivity also was higher than expected, the local labour proving highly motivated and very capable.

Once the first concrete slab had been poured, the benefit of all the preplanning and training became evident. There was a continuous improvement in the speed in forming walls and shafts. In fact the final slip was completed at twice the rate of the initial slip. All the reinforcement, apart from the first pour, was detailed on-site to suit the agreed method of construction. By December 1999, the original schedule had been regained and the construction was running approximately one and a half months ahead of programme.

A modular approach, successfully introduced on Wandoo, was again used for the mechanical outfitting inside the shafts. This greatly benefited the construction schedule and productivity as it minimised the amount of work inside the shafts. A modular steel tower was developed for the utility shaft, which provided support for the oil storage pipework and routing for the controls and instrumentation caisson.

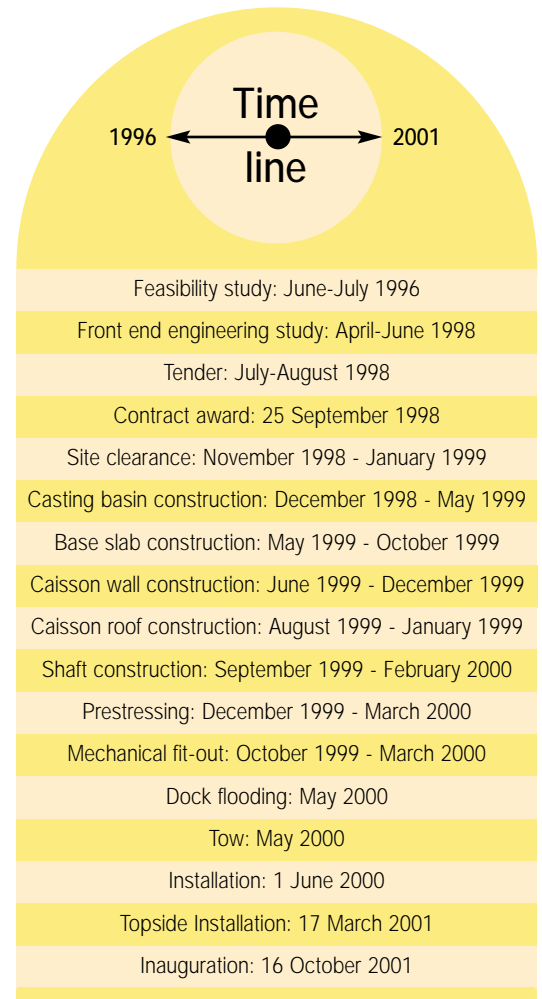
This was fabricated offsite in sections and outfitted horizontally at low level, before being lifted into the shaft and bolted together. Being self-supporting for vertical loading, it only required a small number of connections to the shaft wall. Overall, Malampaya is the fastest dry built CGS yet to have been constructed<sup>5</sup>.

### Marine operations

The concrete structure was complete by March 2000. Meanwhile, the marine operations were well under way. The fall pipe vessel 'Rocky Giant' was busily installing 361 humps to level the seabed - and their shape and size turned out exactly as predicted. However, positioning the fall pipe proved to be time-consuming. The main problem was that the global positioning system was not very stable, even though there was theoretically sufficient satellite coverage in the area.

Each hump was typically placed with more than one dump of rock, to ensure that its height was not overshoot. Dumping rock on an existing hump was found to be relatively fast as the existing hump provided a visual reference. The overall accuracy of the hump placement was very good, with only a few outside the specified tolerance. The stiffness of each hump was determined from its 'as built' shape and height. This information was used to calculate the peak reactions to compare with the design forces. A small number of humps were modified using an airlift to ensure that their reaction satisfied design criteria.

By the end of April testing of the structure and the outfitting was complete. The dock was flooded on 16 May, and dredging the sea bund then commenced. The moment of truth for the weight control engineer occurred early in the morning of 28 May when his prediction of the final weight of the structure could be checked with the draft at float-up. The final weight was back-calculated to be within 250 tonnes (ie 0.3%) of the predicted weight - a testament both to the quality of the dimensional survey and the method of establishing concrete densities through correlation of the cube testing with coring of selected elements.



9.

## Installation

Float out from the dock took place in the early afternoon of 28 May 2000, using two harbour tugs and one main tow tug. Once outside the dry dock, the marine fleet was reconfigured and the tow to field commenced. It was uneventful. The weather was fine for the whole route, and the fleet arrived at the field early on the morning of 1 June.

Four tugs moored in star formation were used for installation, each moored to pre-laid anchors to control the position of the CGS during the inclined installation. Ballasting commenced at 13.00 hrs, with the leading edge of the base slab touching down on the prepared bed five hours later. Thereafter the CGS was rotated to the horizontal position before touching down completely just after midnight. The crushed rock scour protection blanket was placed around the structure, followed by placing of iron ore in the open cells.

Installation of the deck was completed on 17 March 2001. It was transported on a specially modified barge which was moored to the shafts during the floatover operations. The total weight of the deck at mating was 11 500 tonnes.

10.  
The CGS during installation.



11.  
The CGS fully submerged in position awaiting topsides.



12.  
The topsides approaching the CGS for installation.

## Operation

On 16 October 2001, Her Excellency President Gloria Macapagal-Arroyo inaugurated the Malampaya Deep Water Gas to Power Project at the onshore gas plant inside the Shell Tabangao Refinery in Batangas City.

The inauguration, three and a half years after the Project's declaration of commerciality in May 1998, marked the birth of the Philippines' natural gas industry.

The success of the Malampaya CGS project in the Philippines has demonstrated that concrete gravity substructures can be constructed to internationally recognised levels of quality and safety in developing regions of the world.

The fact that the CGS was installed three months early, in spite of delays caused by the change from a wet to a dry storage system, can be attributed to the alliance method of working and the dedication and commitment of the team.

The CGS concept has once again shown itself to be economical, flexible, adaptable and, above all, robust.

## References

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