(AN OFFSHORE MAGAZINE ARTICLE)
BUOYANT LEG STRUCTURES

AN ECONOMIC SOLUTION FOR MARGINAL DEEPWATER GULF OF MEXICO OIL FIELDS

There are large number of offshore oil and gas field discoveries with the recoverable reserves ranging from about 25 to 100 million barrels of oil equivalent. Many of these fields are in the deep waters of the Gulf of Mexico and are considered to be marginally economical as stand- alone developments. Thus, these fields which may have 4 to 6 billion barrels of oil may not be produced unless oil prices rise significantly or more cost effective field development solutions are developed.

This is the second of two articles submitted to the Offshore Magazine covering the Buoyant Leg Structure (BLS). The first article was published in May 2002 issue and primarily addressed the advantages of the BLS well systems. Since the BLS is heave restrained and provides lateral support to the wells from the seafloor to the deck, it extends the less expensive fixed platform operational methods to deep water areas of the world. This second article provides a comparative assessment of BLS, TLP and Spar, discusses characteristics of the BLS, and presents its cost advantages through an economic analysis for a BLS-based development of a marginal Gulf of Mexico oil field. It is believed that better than 50% Internal Rate of Return (IRR) can be achieved for a field with recoverable reserves (RR) of 55 million barrels during a 10-year field life based on a $18/bbl revenue. Even if a very pessimistic approach is taken to assume that the RR for the field will be limited to 26 million barrels during an 8-year field live, the IRR reduces to 21%. The CAPEX, OPEX and the economic data are presented as tables and plots.

The BLS is a positively buoyant structure inherently stable in both free-floating and tethered mode. It consists of a circular water-piercing column/hull that supports the deck structure and a restraining leg that tethers the column/hull to the seafloor. Several seafloor connection options are possible including the use of a suction pile, a template with drilled and grouted piles or a hybrid gravity base structure. The foundation type will depend both on management philosophy and the intended function of the BLS unit. A wide range of BLS configurations were developed to accommodate a small support facility with a 1,000 ton deck payload to a large drilling and production platform with a 16,000 ton deck payload. The proposed multi-cell BLS with a 4,000 ton deck payload is shown on the cover and identified as Figure 1.

A BLS resembles a Spar but behaves more like a Tension Leg Platform (TLP). Both the BLS and the TLP are heave restrained. While the TLP is completely pitch and roll restrained, a BLS is only partially restrained. However, the bending stiffness of the restraining leg and the BLS hull configuration provides the BLS with adequate rotational stiffness so that the pitch and roll motions are negligible in an operating environment while the maximum single amplitude pitch and roll in a hurricane environment is under 4 degrees, only about one-third the pitch and roll of a Spar. The BLS has smaller silhouette and displacement near the water surface than a comparable TLP and therefore it is subjected to wave and current forces that are substantially smaller than those on a TLP.

A Spar has 6-degrees of freedom and its keel has to be far below the water surface to minimize the dynamic heave motions in order to achieve acceptable operating motions. Consequently, a large hull displacement is required yielding a high displacement-to-deck payload ratio.
A TLP has 3-degrees of freedom and the restriction of pitch and roll results in large tendon tension variations. Thus, high initial tendon pretensions are required to prevent the tendons from buckling under compression. Consequently, a substantial percentage (20-25% for the largest to

40-45% for the smallest) of the TLP hull displacement is dedicated to pretension, thereby increasing the hull displacement-to-deck payload ratio. A BLS does not need to have a deep keel to reduce the heave motions since this motion is restricted by its restraining leg. It does not require large restraining leg pretensions as it is partially compliant in pitch and roll.
The magnitude of BLS pretension is determined by the desirable limit on quasi-static offset where the horizontal component of pretension equals static offset forces. Typically, less than 15 percent of the BLS displacement is dedicated to pretension. Thus, it can be said that a BLS retains the best characteristics of the both the Spar and the TLP and avoids their less desirable characteristics.

The BLS hull (i.e., buoyant leg), whether a single ring-and stringer-stiffened cylindrical shell or a column consisting of multiple cylindrical shells, does not have complex nodes or joint details and can be constructed quickly and cheaply with relative ease in any offshore fabrication site. The restraining leg consists of a transition cone and small diameter cylinders stiffened with rings only. Construction simplicity and the ability to construct the components in parallel reduces the unit cost and the construction duration. The buoyant hull and the restraining leg(s) can be joined at the quayside, wet towed to the installation site and upended by flooding the selected compartments. If the BLS is transported dry from an overseas yard to the GOM installation site, the transition cone and the components of the restraining leg will be assembled and lowered to the seafloor separately. The buoyant leg (i.e., hull) is upended by free-flooding the lowest three compartments. Since the BLS is stable in free-floating mode, the deck structure can be either floated-over or lift-installed. Then, the restraining leg is secured to the foundation system and several compartments deballasted to achieve the desirable pretension.

The restraining leg in-service stresses are small for the operating environment and moderate for the extreme environment. Thus, design fatigue lives are readily achieved and member utilization ratios for the extreme environment remain reasonable. However, an added restraining leg redundancy can be achieved by using two concentric cylindrical shells, multiple tubulars or a combination of a tubulars and a wire rope, the choice depending on the size of the BLS and the management philosophy.

A BLS unit is yet to be constructed and installed. However, numerous engineering studies and several preliminary designs have been completed resulting in further improvements to design including introduction of multi-cell hull to facilitate construction and to localize vortex induced vibrations. The BLS system is made up of standard well-proven components. A two-phase Joint Industry Project on BLS was completed successfully in March 2001. Several preliminary designs were developed and the analyses results of two designs were validated through model tests at Offshore Model Basin in Escondido, California. Construction specifications were prepared and together with design drawings transmitted to several construction yards. Cost quotations received confirmed the accuracy of estimated constructed costs.

The following paragraphs provide the development assumptions for a BLS intended for a 4,000-ft water depth site in the Gulf of Mexico to support a deck payload of 4,000 tons. The economic results are also presented.

The BLS developed for this marginal oil field has a processing capacity of 35,000 barrels of oil per day. The field has four production wells, which are predrilled with a semisubmersible drilling rig. A subsea template foundation option was chosen over a suction pile option since predrilling allows easy installation of foundation template and the piles, while the cost of these two options remain similar. The buoyant leg consists of a central 25-ft diameter cylinder surrounded by 17.5-ft diameter auxiliary cylinders. Variable spacing between these cylinders is intended to minimize Vortex Induced Vibrations (VIV) and keep them localized. The restraining leg consists of a 80-ft long by 10-ft diameter section attached to a 3,500-ft long by 5.5-ft diameter section. The total deck, buoyant leg and restraining leg steel weigh 7,400 short tons. With 600 ton appurtenances, 7,200 ton ballast and a pretension of 2,300 tons, the total displacement is 21,500 tons. This BLS design is illustrated on Figure 1 and a summary of component weights is presented on Table 1.

The total installed cost of the basic BLS unit is estimated to be 45 million dollars. Adding the installed and commissioned cost of topsides equipment of 41.5 million and the pipeline cost of 18.8 million, the total cost equals 105.3 million dollars. When the cost of the development wells is added, the total Capital Expenditures (CAPEX) reaches 151 million dollars (See Table 2).

For the purposes of this economic study three separate reservoir conditions were assumed. The Base Case (Case A) was assumed to have all four wells initially producing 8,000 BOPD with a well decay factor of 0.155 which yields recoverable reserves (RR) of 55 million barrels in 10 years. The other two cases are based on more pessimistic well production. Both Case B and Case C are based on the wells initially producing 6,000 and 5,000 BOPD, respectively and the fields having economic lives of 8 years each. The wells in Case B are assumed to have a decay factor of 0.18 and yielding RR of 34 million barrels. The wells in Case C are assumed to have a decay factor of 0.20 and yielding RR of 26 million barrels. The applicable royalty, cost recovery limit, depreciation rate, profit oil split, effective income tax and the operator effective after-tax split as well as the CAPEX and OPEX are shown on Table 3.

The performed economic study is based on a $18.0/bbl with both the OPEX and revenue subjected to 3% annual escalation. In addition to the Internal Rate of Return (IRR) on investment it was considered desirable to determine the Net Present Value (NPV). The IRR for Case A is 54 percent while the NPV is 420 million dollars without a discount rate. Even with a pessimistic Case B, the IRR is 33 percent and the NPV 192 million dollars. For a very pessimistic Case C, the IRR is 21 percent while the NPV is 105 million dollars. The revenue, CAPEX, OPEX and the Cumulative Net plots for Case A are presented on Table 3 and illustrated on Figure 2.

In addition to BLS superior in-service performance characteristics this economic study clearly shows that a BLS can be utilized to develop truly marginal fields and achieve a very good return on investment.

The BLS also offers many operational advantages. The main well system advantages include drilling and surface completion of wells, protecting the wells from the environment and laterally supporting them by running them through the restraining leg and easy and inexpensive entry for workover. Simple cylindrical components of the BLS facilitate its construction as well as its inspection and maintenance, thereby contributing to a reduction in both CAPEX and OPEX. Unlike most TLPs, stability characteristics of the BLS permit the unit to be in a free-floating mode. Since the BLS is inherently stable in a free-floating mode, it can be disconnected and relocated from one marginal field to another in an upright position. This characteristic makes it feasible for a BLS-based drilling unit to drill several wells in one location and several at another.

Table 1: Summary Particulars of BLS Configuration

DESCRIPTION	BASE CASE	COMMENTS
GENERAL:		
No. of Wells	4	
Max. Production (BOPD)	35,000	
Drilling System	Full or Workover	Workover selected
DECK:		
A1. Deck Payload (t)	4,000	
A2. Deck Steel (t)	1,100	
A3. Riser Wt+Pt (t)	(1)	(1) Included in Payload
BLS PARTICULARS:		
B1. Water Depth (ft)	4,000	
B2. BLS Hull Length (ft)	370	
B3. BLS Hull Dia (ft)	1-25 + 5-17.5	
B4. Transition Cone L (ft)	60	
B5. Restraining Leg Dia (ft)	10 + 5.5	
B6. Restraining Leg L (ft)	80 + 3,490	
WEIGHTS AND PRETENSION		
C1. BLS Hull Wt (t)	4,100	Steel weight in air
C2. Restraining Leg Wt (t)	2,200	
C3. Appurtenances Wt (t)	600	
C4. Ballast Wt (t)	7,200	in BLS hull. Restr. Leg will be
C5. Restr. Leg Pretension (t)	2,300	flooded
SUB-TOTALS		
Row A1+A2+A3	5,100	
Row C1+C2+C3+C4+C5	16,400	
TOTAL OF ROWS A AND C DISPLACEMENT (t)	21,500	i.e., ~670,000 cu ft displacement

COMPONENTS	FOUNDATION Template+Piles	BLS DECK	BLS HULL	RESTR. LEG	PIPELINE TO GRID	TOPSIDE	WELLS ($12MM/well)	TOTAL
STEEL WEIG HT (Tons)	400	1100	4100	2200				
MATERIAL	$350,000	$800,000	$3,200,000	$1,600,000	$3,000,000			$8,950,000
CONSTRUCT ION Rate $/ton	2125	3775	2100	1050				
Basic Unit	$850,000	$4,150,000	$8,610,000	$2,310,000	$4,000,000			$19,920,000
Others Helideck		$350,000						$350,000
Quarters		$1,100,000						$1,100,000
Connectors/Outfitting			$1,500,000	$2,500,000				
MAJOR PURCHASED EQUIPMENT								
Drilling System-Workover						$3,500,000		$3,500,000
Process System						$12,000,000		$12,000,000
Water Inj. System						$3,600,000		$3,600,000
Utility/Control system						$11,500,000		$11,500,000
Mooring System								$0
Dynamic Assist								$0
Hybrid Prod. Line						$2,000,000		$2,000,000
								$0
OUTFITTING/		$640,378	$1,331,210			$3,260,000		$5,231,588
TRANSPORTATION	$165,000	$300,000	$1,000,000	$200,000				$1,665,000
PIPEL NE INSTALLATION					$9,800,000			
INSTALLATIC N OF FOUNDATION	$1,600,000							$1,600,000
SITE II STALL ATION DECK/BLS		$1,800,000	$800,000	$1,200,000		$1,200,000		$5,000,000
HOOK UP/COMMISSIONING		$1,600,000						
DRILL NG -- PREDRILLING							$43,200,000	$43,200,000
WELL COMPLETIONS							$2,800,000	
Sub-Total CAPEX	$2,967,125	$10,744,153	$16,443,310	$7,811,050	$16,800,000	$37,060,000	$46,000,000	$137,825,638
ENGINEERIN (@4%)	$118,685	$429,766	$657,732	$312,442	$672,000	$1,482,400		$3,673,026
PROJECT MC T (@8%)	$237,370	$859,532	$1,315,465	$624,884	$1,344,000	$2,964,800		$7,346,051
OTHER								
Consultants	$750,000	$250,000						$1,000,000
Insurance (Fab, Trans,Instl)	$71,211	$257,860	$460,413	$156,221				$945,704
Inspection/Certification	$50,000	$150,000	$200,000	$150,000				$550,000
TOTAL	$4,194,391	$12,691,310	$19,076,920	$9,054,597	$18,816,000	$41,507,200	$46,000,000	$151,340,418
YEAR 1	$2,097,196	$3,172,828	$4,769,230				$23,000,000	$33,039,253
YEAR 2	$2,097,196	$9,518,483	$14,307,690	$9,054,597	$18,816,000	$41,507,200	$20,199,980	$115,501,145
YEAR 3							$2,800,020	$2,800,020

Table 2: Capital Expenditures (CAPEX) by Component and Function (US$ x 1,000)

151340418.3

	CALENDAR	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7
EXPENDITURES								
OPEX in 2003 $		$0	$995,800	$15,169,465	$14,476,330	$13,961,309	$13,434,596	$11,513,510
OPEX @ Inflation Rate=	3%	$0	$1,025,674	$16,093,285	$15,818,677	$15,713,576	$15,574,378	$13,747,733
CAPE: in 2003 $		$33,039,253	$115,501,145	$2,800,020				
CAPEX @ Inflation Rate=	3%	$33,039,253	$118,966,180	$2,970,541				
OIL PRODUCTION				10002929.27	18569589.72	25906207.75	32189398.78	37570418.94
Base Price of Oil ($/bbl)=	$18							
Oil Price with Inflation=	3%	$18.00	$18.54	$19.10	$19.67	$20.26	$20.87	$21.49
Production Rate (bbl/day)		0	0	27,405	23,470	20,100	17,214	14,743
Production Rate (bbl/year)		0	0	10,002,929	8,566,660	7,336,618	6,283,191	5,381,020
REVENUE								
Gross Revenue		$0	$0	$191,017,938	$168,498,381	$148,633,708	$131,110,928	$115,653,951
Royalty @	12.5%	$0	$0	$23,877,242	$21,062,298	$18,579,214	$16,388,866	$14,456,744
Pre-Tax Revenue		$0	$0	$167,140,696	$147,436,083	$130,054,495	$114,722,062	$101,197,207
Cum Pre-Tax Revenue		$0	$0	$167,140,696	$314,576,779	$444,631,274	$559,353,336	$660,550,543
Cum Avail CAPEX to Recover	100%	$33,039,253	$152,005,433	$154,975,974	$154,975,974	$154,975,974	$154,975,974	$154,975,974
Cum Avail CAPEX-Cum Revenue		$33,039,253	$152,005,433	($12,164,722)	($159,600,805)	($289,655,300)	($404,377,362)	($505,574,569)
Tax Credit		$0	$0	$154,975,974	$0	$0	$0	$0
Cum Tax Credit		$0	$0	$154,975,974	$154,975,974	$154,975,974	$154,975,974	$154,975,974
Tax	34%	$0	$0	$4,136,005	$50,128,268	$44,218,528	$39,005,501	$34,407,050
Net Operator's Revenue		$0	$0	$163,004,690	$97,307,815	$85,835,966	$75,716,561	$66,790,157
Cum Operator's Revenue		$0	$0	$163,004,690	$260,312,505	$346,148,472	$421,865,033	$488,655,189

	YEAR 8	YEAR 9	YEAR 10	YEAR 11	YEAR 12
OPEX in 2003 $	$11,127,194	$10,796,346	$10,513,004	$10,270,345	$10,062,528
OPEX @ Inflation Rate=	$13,685,045	$13,676,489	$13,717,085	$13,802,485	$13,928,892
OIL PRODUCTION	42178806.28				
Oil Price with Inflation=	$22.14	$22.80	$23.49	$24.19	$24.92
Production Rate (bbl/day)	12,626	10,813	9,260	7,931	6,792
Production Rate (bbl/year)	4,608,387	3,946,693	3,380,008	2,894,690	2,479,056
Gross Revenue	$102,019,233	$89,991,944	$79,382,581	$70,023,980	$61,768,687
Royalty @	$12,752,404	$11,248,993	$9,922,823	$8,752,998	$7,721,086
Pre-Tax Revenue	$89,266,829	$78,742,951	$69,459,758	$61,270,983	$54,047,601
Cum Pre-Tax Revenue	$749,817,372	$828,560,322	$898,020,080	$959,291,063	$1,013,338,665
Cum Avail CAPEX to Recover	$154,975,974	$154,975,974	$154,975,974	$154,975,974	$154,975,974
Cum Avail CAPEX-Cum Revenue	($594,841,398)	($673,584,348)	($743,044,106)	($804,315,089)	($858,362,691)
Tax Credit	$0	$0	$0	$0	$0
Cum Tax Credit	$154,975,974	$154,975,974	$154,975,974	$154,975,974	$154,975,974
Tax	$30,350,722	$26,772,603	$23,616,318	$20,832,134	$18,376,185
Net Operator's Revenue	$58,916,107	$51,970,348	$45,843,440	$40,438,849	$35,671,417
Cum Operator's Revenue	$547,571,296	$599,541,644	$645,385,084	$685,823,933	$721,495,350

Year	1	2	3	4	5	6	7
REVENUE	$0	$0	$163,004,690	$97,307,815	$85,835,966	$75,716,561	$66,790,157
CAPEX	($33,039,253)	($118,966,180)	($2,970,541)	$0	$0	$0	$0
OPEX	$0	($1,025,674)	($16,093,285)	($15,818,677)	($15,713,576)	($15,574,378)	($13,747,733)
TOTAL	($33,039,253)	($119,991,854)	$143,940,864	$81,489,138	$70,122,390	$60,142,183	$53,042,423

Year	8	9	10	11	12
REVENUE	$58,916,107	$51,970,348	$45,843,440	$40,438,849	$35,671,417
CAPEX	$0	$0	$0	$0	$0
OPEX	($13,685,045)	($13,676,489)	($13,717,085)	($13,802,485)	($13,928,892)
TOTAL	$45,231,062	$38,293,859	$32,126,355	$26,636,364	$21,742,525

NPV (0) = $419,736,056

IRR= 54%

$291,301,055

Table 3: Case A Data – IRR, NPV, Revenue, CAPEX and OPEX

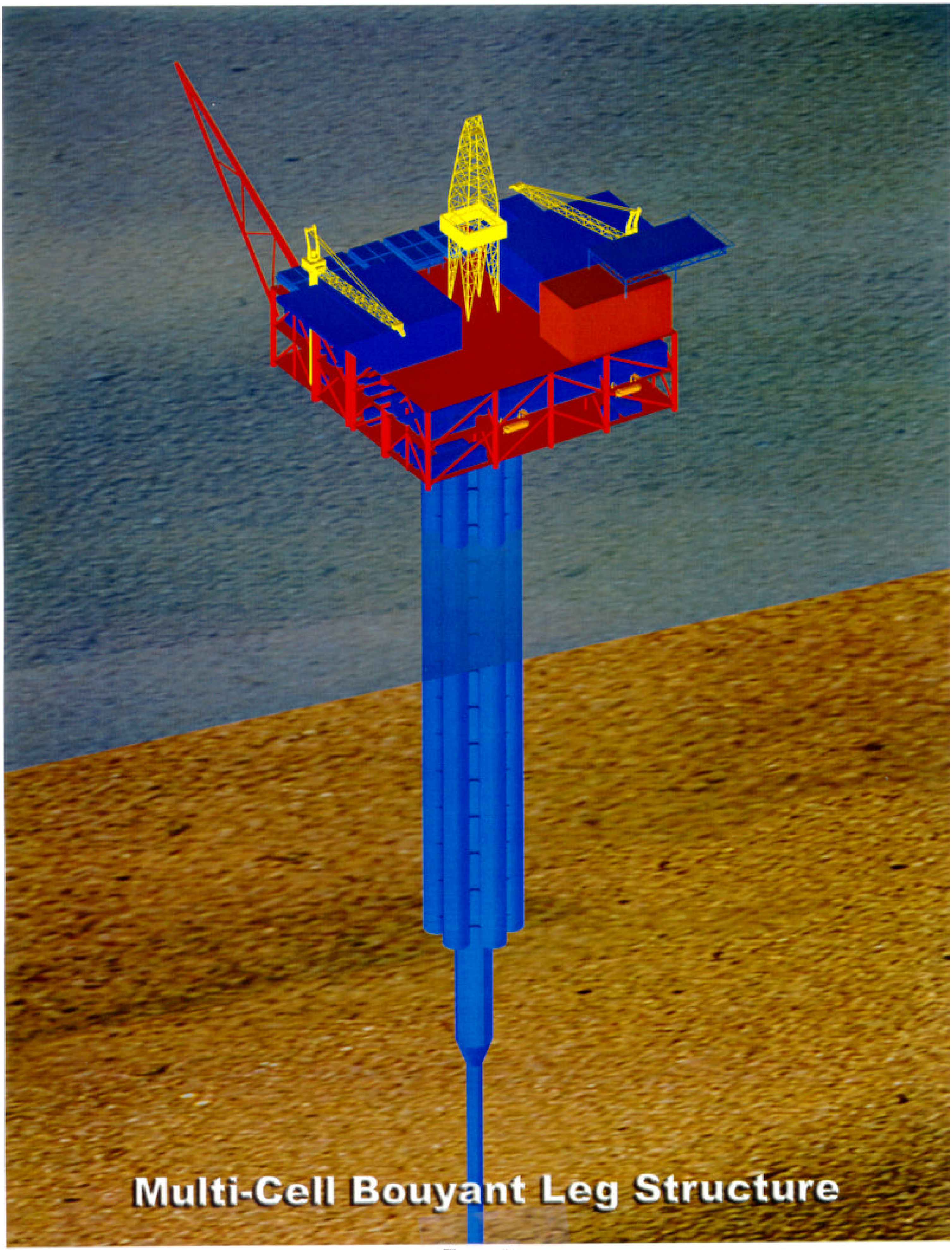

Figure 1

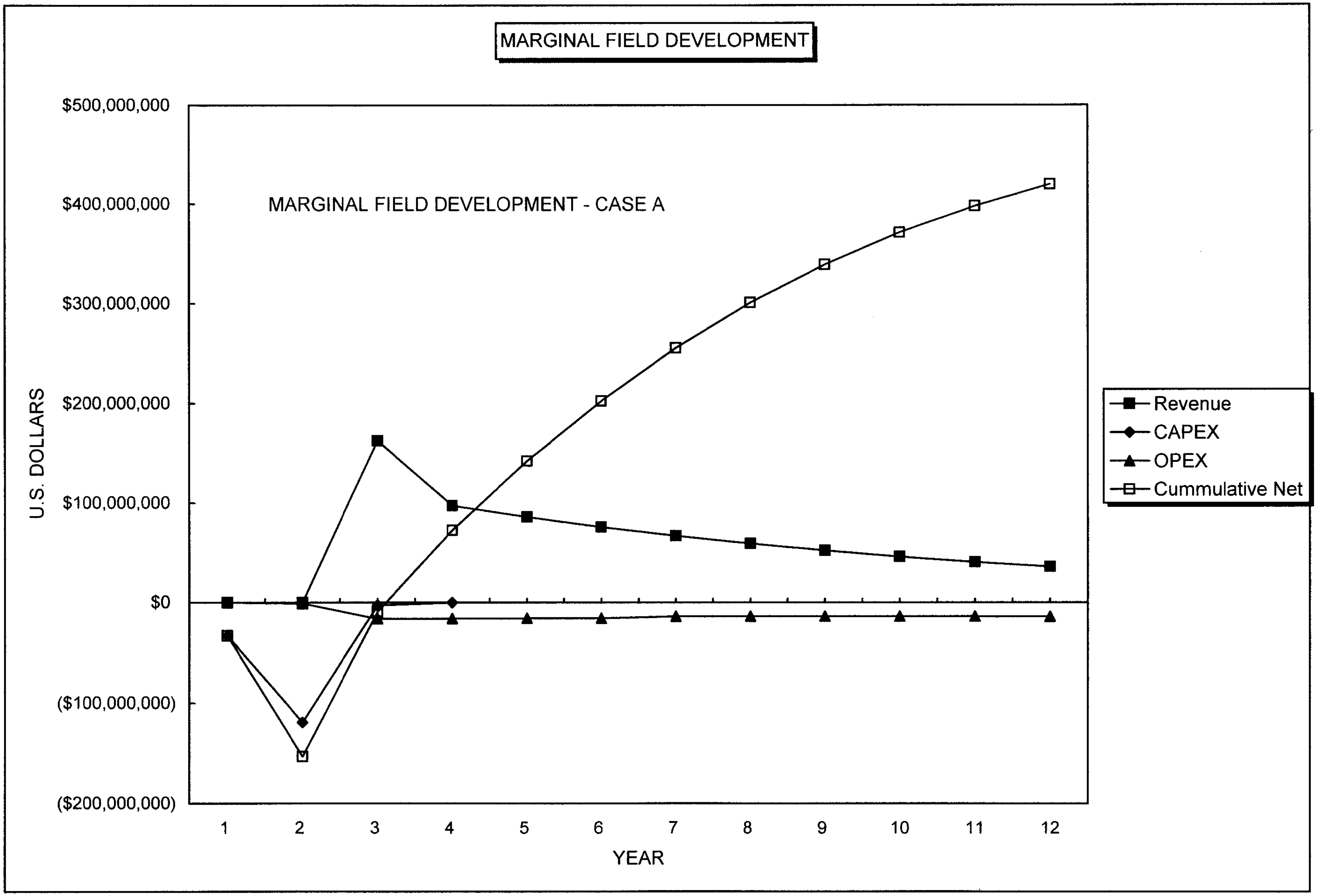

Figure 2: Case A Data Plot – Revenue, CAPEX, OPEX and Cumulative Net