Behaviour of Offshore Structures,
Elsevier Science Publishers B.V., Amsterdam, 1985 — Printed in The Netherlands

A JACKET LAUNCH COMPUTER PROGRAM COMPARED WITH TWO FULL-SCALE LAUNCHES

Christian Aage[1], Poul Erik Christiansen[2] and Jakob Møller[3]

[1]The Technical University of Denmark, Dept. of Ocean Engineering, DK-2800 Lyngby, Denmark

[2]Earl & Wright Ltd., Victoria Station House, 191 Victoria St., London SW1E, U.K.

[3]Mærsk Olie og Gas A/S, Esplanaden 50, DK-1263 Copenhagen, Denmark

SUMMARY

A 3-dimensional mathematical model and a computer program able of simulating the launch of a jacket from a barge are described. The launch is divided into four dynamically distinct phases, each characterized by the degrees of freedom. It has been attempted to take all important parameters into account, such as the variation of drag coefficients with respect to Reynolds' number and slamming on jacket members.

The computer results are compared with measurements of two different full-scale launches, the GORM C in 39 m water depth and the BERYL B in 119 m water depth, both in the North Sea. The full-scale launch photographic recording and analyzing methods are described and tentative conclusions are drawn as to the proper choice of hydrodynamic coefficients for launch calculations.

1. INTRODUCTION

During the development of the Danish oil and gas fields in the North Sea a need arose for launch simulation programs which could predict with great accuracy the minimum bottom clearance of jackets launched from barges. The water depth in the Danish fields is about 40 m and the bottom clearance for the largest jackets during the launch is only 3 - 5 m.

To obtain the desired degree of accuracy fully three-dimensional mathematical models and computer programs had to be developed, especially because unsymmetrical and damaged conditions (e.g. a flooded buoyancy tube) had to be considered. The computer programs should preferably be verified against full-scale launch measurements.

To promote this development Mærsk Olie og Gas A/S decided to carry out full-scale measurements of the GORM C jacket launch which took place on September 3rd, 1980. The total mass of the jacket was 4000 t and the water depth was 39 m. In 1981 - 83 a 3-D mathematical launch model and a computer program were developed at the Technical University of Denmark by two of the authors. By the kind support of Mobil North Sea Limited the University had the opportunity to carry out full-scale measurements on the BERYL B jacket launch in the British sector of the North Sea on May 8th, 1983. The total mass of this jacket was 14000 t and the water depth was 119 m. The two jackets represent nearly the lower and upper limits for launched jackets and so constitute an excellent material for comparison with the computer program.

Several launch simulation programs are commercially available, but very little has been published on the subject. Hambro (1982) describes a method of launch simulation by differentiation of constraints and compares the simulation with model test results. To the authors' knowledge, comparisons between computer simulations and full-scale jacket launches have not been published before.

2. LAUNCH DESCRIPTION

A jacket launch defines the event when a jacket starts sliding under its own weight down the sliding beams on a ballasted and pretrimmed launch barge. The sliding can be initialized by either removing the last sea fastening to the jacket if the barge trim angle is large enough, or by jacking the jacket to overcome the static friction. The launch is completed when the jacket has come to rest in a stable equilibrium position. Normally the jacket/barge system will go through four dynamically distinct phases during the launch.

Phase 1. The jacket slides down the deck of the barge towards the rocker beams. The jacket has only one degree of freedom relative to the barge.

Phase 2. The jacket slides on the rocker beams which rotate relative to the barge, hence the number of relative degrees of freedom for the jacket are two.

Phase 3. As Phase 2 but the jacket starts lifting off one of the rocker beams giving one translational and two rotational degrees of freedom for the jacket relative to the barge. For a jacket/barge system with lateral symmetry this phase will normally not be entered. Both of the recorded full-scale launches went directly from Phase 2 to 4.

Phase 4. The jacket has separated from the barge and the two bodies move completely independent of each other, each body having six degrees of freedom.

The launch characteristics have great impact on the jacket design. For shallow water jackets the auxiliary buoyancy configuration will be determined solely to provide satisfactory bottom clearance during launch. For medium and deep water jackets the launch loads become increasingly important and will be the governing design loads for a significant number of jacket members.

Equally important are the behaviour and the loads experienced by the barge. Calculation of barge bending moments and determination of the maximum barge keel immersion during launch are standard requirements for launch preparations.

For jacket designers the main information about the launch behaviour is obtained by performing model tests and simulations with 2- or 3-dimensional launch computer programs. Model testing involves a number of scale effects, where especially the overprediction of drag forces due to the low Reynolds number in model testing is significant. For that reason good correlation between model test results and computer simulations can not be expected.

3. 3-DIMENSIONAL MATHEMATICAL LAUNCH MODEL

The mathematical model used in this comparison with the two full-scale launch recordings is a 3-dimensional model developed and implemented on a main frame computer by the authors.

3.1 Jacket/barge model description

The mathematical representation of the jacket is set up by a normal 3-dimensional stick model, where jacket members are referenced to predefined nodes. The model operates with four different types of modelling elements: Cylinder, sphere, line, and point elements. Cylinder and sphere elements are used to model real jacket members of the same types. Line and point elements are used for modelling either mass, inertia, buoyancy, or hydrodynamic properties or any combination of these to suit arbitrary jacket members. The hydrodynamic properties can be specified individually in the three local member directions. The model accounts for jacket framing as brace members are stopped at the surface of chord members to ensure correct buoyancy of each node.

The barge model is defined by length, breadth and depth assuming the barge is box shaped. Additional information about sliding plane and rocker beam location is provided together with mass properties and hydrodynamic coefficients.

3.2 Equations of motion

Four reference co-ordinate systems have been adopted as shown in Figure 1. A space-fixed global system with the $x_0 - y_0$ plane coinciding with the sea surface. A jacket-fixed system with the origin at the jacket CoG (Center of Gravity) and a similar barge-fixed system also with the origin at the CoG. Finally a rocker-beam-fixed system with origin at the rocker pin.

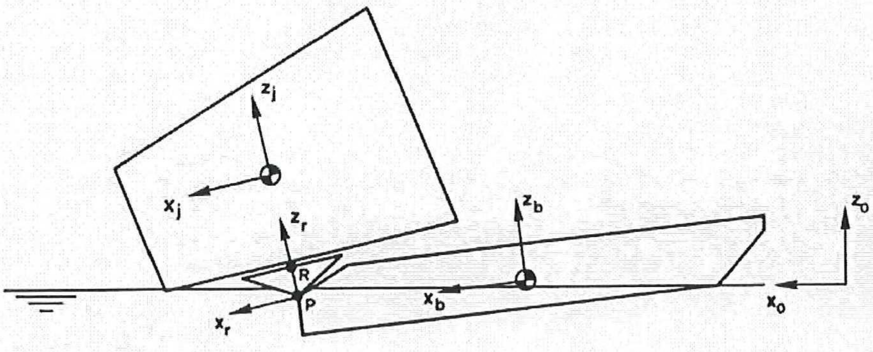

Figure 1. Launch model co-ordinate systems.

Initially the axes of the jacket-, the barge-, and the rocker-fixed systems will be parallel with the z-axis normal to the skid surface on the barge, and the x-axis in the skid direction of the jacket, which is also the orientation of the global x-axis. The space-fixed system has been chosen as reference system for the equations of motion.

Both bodies are assumed to be rigid, hence Newton's second law of motion can be applied for each body at the CoG.

$$\frac{d}{dt}\left(m[E]\{\dot{x}\}\right) = \{F\} \tag{1}$$

$$\frac{d}{dt}\left([I]\{\dot{\theta}\}\right) = \{M\} \tag{2}$$

where m is the mass of the body, E is the 3×3 unity matrix and [I] is the inertia matrix. Neglecting wind and assuming calm water the forces {F} are composed of

$$\{F\} = \{W\} + \{B\} + \{H\} + \{P\} + \{K\} \tag{3}$$

where

{W} = Gravity force
{B} = Buoyancy force
{H} = Hydrodynamic force
{P} = Interaction force between the two bodies
{K} = External forces, i.e. mooring lines, tugger lines etc.

{M} represents the moments of the same forces about the CoG.

For small displacements the buoyancy force can be linearized by including the hydrostatic stiffness matrix [S], where ~ designates linearized values:

$$\begin{Bmatrix}\{\tilde{B}\}\\ \{\tilde{M}_B\}\end{Bmatrix} = -[S]\begin{Bmatrix}\{\Delta x\}\\ \{\Delta\theta\}\end{Bmatrix} \quad \begin{Bmatrix}\{B\}\\ \{M_B\}\end{Bmatrix} \tag{4}$$

Closed form expressions for five fundamental different locations of tubes with respect to the water surface have been established for buoyancy, center of buoyancy, waterplane area and center of floatation, from which the buoyancy force vector and stiffness matrix can be calculated.

Morison's equation is applied to describe the hydrodynamic forces on the jacket. Linearized they can be expressed as:

$$\begin{Bmatrix}\{\tilde{H}\}\\ \{\tilde{M}_H\}\end{Bmatrix} = -[C_m]\begin{Bmatrix}\{\ddot{x}\}\\ \{\ddot{\theta}\}\end{Bmatrix} - [C_D]_1\begin{Bmatrix}\{\dot{x}\}\\ \{\dot{\theta}\}\end{Bmatrix} - [C_D]_2\begin{Bmatrix}\{\Delta\dot{x}\}\\ \{\Delta\dot{\theta}\}\end{Bmatrix} - [\Delta C_m]\begin{Bmatrix}\{\dot{x}\}\\ \{\dot{\theta}\}\end{Bmatrix} \tag{5}$$

The added mass matrix $[C_m]$ is established by the technique described by Hooft (1972), which effectively is an expansion of Morison's equation to the general 3-dimensional case using the projected acceleration perpendicular to the member method. The two damping matrices $[C_D]_1$ and $[C_D]_2$ are constructed in a similar manner using the projected velocity method, however due to the velocity square term in the Morison damping term the velocity has been Taylor expanded which produces the additional $[C_D]_2$ matrix. When calculating the damping matrices a linearly varying current velocity can be included. The slamming forces are included by the $[\Delta C_m]$ matrix, defined as:

$$[\Delta C_M] = \frac{[C_m]_t - [C_m]_{t_0}}{t - t_0} \tag{6}$$

The 3-component interaction force {P} can be expressed from the interaction force in jacket-fixed y- and z-directions.

$$\{P\} = [R^j]\begin{bmatrix}-\mu_y & -\mu_z\\ 1 & 0\\ 0 & 1\end{bmatrix}\begin{Bmatrix}P_{yj}\\ P_{zj}\end{Bmatrix} = [R][U]\begin{Bmatrix}P_{yj}\\ P_{zj}\end{Bmatrix} \tag{7}$$

where μ_y is the friction coefficient for a force in the y-direction and μ_z is the friction coefficient for a force in the z-direction. $[R^j]$ is the rotation matrix that rotates a vector from the jacket-fixed co-ordinate system to the space-fixed system.

Differentiating (1) and (2) with respect to time and inserting the force expressions (3) - (7) yields the following equation for the jacket:

$$\left(\begin{bmatrix} m[E] & [0] \\ [0] & [R^j][I^j][R^j]^T \end{bmatrix} + [C_m]\right)\begin{Bmatrix}\{\ddot{x}^j\} \\ \{\ddot{\theta}^j\}\end{Bmatrix}$$

$$+ \left(\begin{bmatrix} [0] & [0] \\ [0] & \left[[\dot{R}^j][I^j][R^j]^T + [R^j][I^j][\dot{R}^j]^T\right] \end{bmatrix}\right.$$

$$\left. + [C_D]_1 + [\Delta C_m]\right)\begin{Bmatrix}\{\dot{x}^j\} \\ \{\dot{\theta}^j\}\end{Bmatrix} + [C_D]_2\begin{Bmatrix}\{\Delta\dot{x}^j\} \\ \{\Delta\dot{\theta}^j\}\end{Bmatrix}$$

$$+ [S]\begin{Bmatrix}\{\Delta x^j\} \\ \{\Delta\theta^j\}\end{Bmatrix} - \begin{bmatrix} [E] & [0] \\ [L^j][E] \end{bmatrix}\begin{Bmatrix}[R^j][U]\begin{Bmatrix}P_{yj} \\ P_{zj}\end{Bmatrix} \\ \{M_P^j\}\end{Bmatrix}$$

$$= \begin{Bmatrix}\{W^j\} \\ \{0\}\end{Bmatrix} + \begin{Bmatrix}\{B^j\} \\ \{M_B^j\}\end{Bmatrix} + \begin{Bmatrix}\{K^j\} \\ \{M_K^j\}\end{Bmatrix} \qquad (8)$$

A similar equation exists for the barge. Note that the matrix $[L^j]$ contains the lever arms from the jacket CoG to the point where the contact forces P_{yj} and P_{zj} are assumed to act.

Let us resume the problem of determining the motions in 3-dimensions for the two bodies interacting with each other. This involves finding 2×6 kinematic and 5 static unknowns:

$\{\ddot{x}^j\}, \{\ddot{\theta}^j\}$ 6 kinematic DOF's for jacket

$\{\ddot{x}^j\}, \{\ddot{\theta}^j\}$ 6 kinematic DOF's for barge

$\begin{Bmatrix}P_{yj} \\ P_{zj}\end{Bmatrix} = -\begin{Bmatrix}P_{yb} \\ P_{zb}\end{Bmatrix}$ 2 interaction forces

$\{M_P^j\} = -\{M_P^b\}$ 3 interaction moments

The equations of motion for the jacket (8) and the similar ones for the barge provide a total of 12 simultaneous equations. Hence 5 additional equation of constraints will be necessary to solve the problem.

3.3 Equations of constraints

The equations of constraints are unique for each phase of the launch as described previously.

3.3.1 Phase 1. The jacket has only one degree of freedom relative to the barge, hence the jacket motions can be expressed by the barge motions and the relative motion:

$$\{x^j\} = \{x^b\} + [R^b]\{x_b^j\} \qquad (9)$$

$$\{\dot{x}^j\} = \{\dot{x}^b\} + [\dot{R}^b]\{x_b^j\} + [R^b]_1\dot{x}_b^j \qquad (10)$$

$$\{\ddot{x}^j\} = \{\ddot{x}^b\} + [\ddot{R}^b]\{x_b^j\} + 2[\dot{R}^b]_1\dot{x}_b^j + [R^b]_1\ddot{x}_b^j \qquad (11)$$

where $\{x_b^j\}$ denotes the vector from the barge CoG to the jacket CoG. Note that $\{x_b^j\}$ differentiated with respect to time, only has a component in the direction of motion, i.e. the barge x-direction, hence only the first column of $[R^b]$ should be used, indicated by $[\ ]_1$.

Furthermore Phase 1 implies identical rotations of the jacket and barge:

$$\{\Delta\theta^j\} = \{\Delta\theta^b\} \qquad (12)$$

$$\{\dot{\theta}^j\} = \{\dot{\theta}^b\} \qquad (13)$$

$$\{\ddot{\theta}^j\} = \{\ddot{\theta}^b\} \qquad (14)$$

By substituting (9) - (14) into (8) the jacket DOF's can be eliminated and the motion problem is reduced to solving 9 simultaneous equations with 9 unknowns, which are:

$\{\ddot{x}^b\}, \{\ddot{\theta}^b\}$ 6 kinematic DOF's for the barge

$\{\ddot{x}_b^j\}$ 1 relative jacket DOF

P_{yj}, P_{zj} 2 interaction forces

The equations of constraints change when the contact moment about the rocker pin becomes positive and the jacket enters phase 2.

3.3.2 Phase 2. The relative number of the jacket DOF's increases by one, as the jacket starts rotating relative to the barge. The jacket motions can again be expressed from the barge and the relative motions:

$$\{x^j\} = \{x^b\} + [R^b]\{x_b^P\} - [R^j]\{x_j^P\} \qquad (15)$$

$$\{\dot{x}^j\} = \{\dot{x}^b\} + [\dot{R}^b]\{x_b^P\} - [\dot{R}^j]\{x_j^P\} - [R^j]\dot{x}_j^P \qquad (16)$$

$$\{\ddot{x}^j\} = \{\ddot{x}^b\} + [\ddot{R}^b]\{x_b^P\} - [\ddot{R}^j]\{x_j^P\} - 2[\dot{R}^j]\dot{x}_j^P - [R^j]\ddot{x}_j^P \qquad (17)$$

where $\{x_b^P\}$ is chosen to be the vector from the barge CoG to the rocker pin in barge system co-ordinates, and $\{x_j^P\}$ the vector from the jacket CoG to the rocker pin in jacket system co-ordinates.

The jacket rotations can be expressed by the barge rotations and the relative jacket rotation about the rocker pin:

$$\{\Delta\theta^j\} = \{\Delta\theta^b\} + [R^b]_2\Delta\theta_b^j \qquad (18)$$

$$\{\dot{\theta}^j\} = \{\dot{\theta}^b\} + [\dot{R}^b]_2\Delta\theta_b^j + [R^b]_2\Delta\dot{\theta}_b^j \qquad (19)$$

$$\{\ddot{\theta}^j\} = \{\ddot{\theta}^b\} + [\ddot{R}^b]_2\Delta\theta_b^j + 2[\dot{R}^b]_2\dot{\theta}_b^j + [R^b]_2\ddot{\theta}_b^j \qquad (20)$$

The static condition which states that the interaction moment around the rocker pin (local barge y-direction) is zero, is utilized to obtain the last equation of constraint necessary to balance out the number of unknowns:

$$[R^b]_2^T\{M_P^j\} = [R^b]_2^T\{M_P^b\} = 0 \tag{21}$$

As in Phase 1 equations (15) - (21) can be substituted into (19) eliminating the jacket DOF's, giving 10 simultaneous equations with 10 unknowns:

$\{\ddot{x}^b\}$, $\{\ddot{\theta}^b\}$ 6 kinematic DOF's of barge

$\ddot{x}_j^P$, $\ddot{\theta}_b^j$ 2 relative jacket DOF's

P_{yj} , P_{zj} 2 interaction forces

The jacket leaves Phase 2 and goes to Phase 4, separation, when either the contact force between jacket and barge vanishes, or the end of the jacket launch rail passes over the rocker pin, allowing the rocker beam to rotate to its maximum angle. Phase 3 can be entered if the contact force on one of the rocker beams vanishes.

3.3.3 Phase 3. Similarly to Phases 1 and 2 the jacket motions are determined from the barge and the relative motions:

$$\{x^j\} = \{x^b\} + [R^b]\left(\{x_b^P\} + [R_b^r]\{x_r^R\}\right) - [R^j]\{x_j^R\} \tag{22}$$

$$\{\dot{x}^j\} = \{\dot{x}^b\} + [\dot{R}^b]\left(\{x_b^P\} + [R_b^r]\{x_r^R\}\right) + [R^b][\dot{R}_b^r]\{x_r^R\} - [\dot{R}^j]\{x_j^R\} - [R^j]_1\dot{x}_j^R \tag{23}$$

$$\{\ddot{x}^j\} = \{\ddot{x}^b\} + [\ddot{R}^b]\left(\{x_b^P\} + [R_b^r]\{x_r^R\}\right) + 2[\dot{R}^b][\dot{R}_b^r]\{x_r^R\} + [R^b][\ddot{R}_b^r]\{x_r^R\} - [\ddot{R}^j]\{x_j^R\} - 2[\dot{R}^j]_1\dot{x}_j^R - [R^j]\ddot{x}_j^R \tag{24}$$

$\{x_r^R\}$ denotes the vector in rocker-beam-fixed co-ordinates from the rocker pin, to the point on the skid rail which the jacket rotates about. $\{x_j^R\}$ is the vector from the jacket CoG to the same point in jacket-fixed co-ordinates. $[R_b^r]$ is the rotation matrix that rotates a vector from the rocker-beam-fixed system to the barge-fixed system.

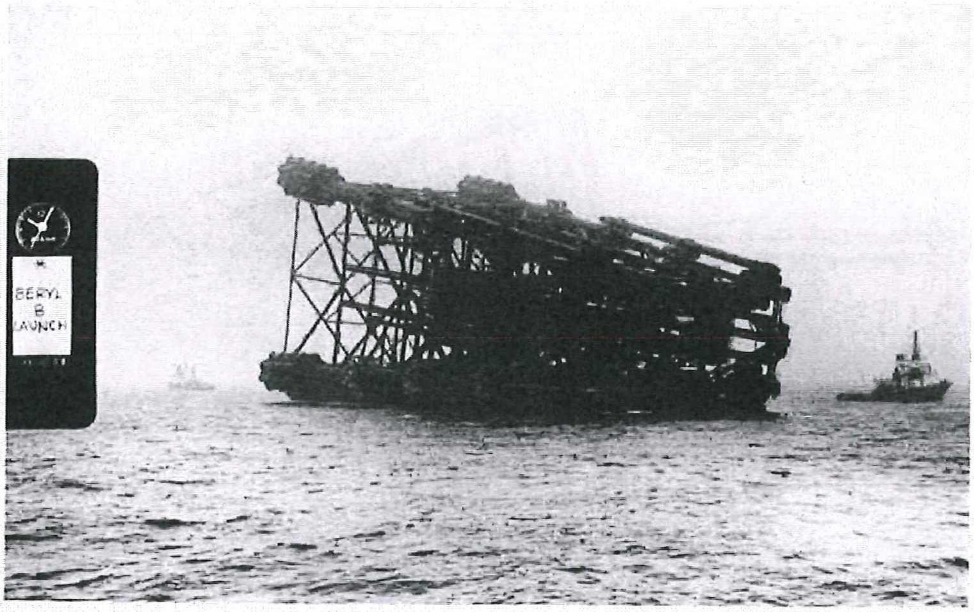

Figure 2. The BERYL B jacket before the launch.

The jacket rotations can be obtained from the barge rotations, the rocker beam rotation $\Delta\theta_b^r$ and the jacket rotations relative to the rocker beam $\Delta\theta_r^j$.

$$\{\Delta\theta^j\} = \{\Delta\theta^j\} + [R^b]_2\Delta\theta_b^r + [R^j]_1\Delta\theta_r^j \qquad (25)$$

$$\begin{aligned}\{\dot{\theta}^j\} &= \{\dot{\theta}^b\} + [\dot{R}^b]_2\Delta\theta_b^r + [R^b]_2\dot{\theta}_b^r \\ &\quad + [\dot{R}^j]_1\Delta\theta_r^j + [R^j]_1\Delta\dot{\theta}_r^j \end{aligned} \qquad (26)$$

$$\begin{aligned}\{\ddot{\theta}^j\} &= \{\ddot{\theta}^b\} + [\ddot{R}^b]_2\Delta\theta_b^r + 2[\dot{R}^b]_2\dot{\theta}_b^r \\ &\quad + [R^b]_2\ddot{\theta}_b^r + [\ddot{R}^j]_1\Delta\theta_r^j + 2[\dot{R}^j]_1\dot{\theta}_r^j \\ &\quad + [R^j]_1\ddot{\theta}_r^j \end{aligned} \qquad (27)$$

The last two equations of constraint are made up of the static moment conditions, saying that the moment about the axis of rotation for the rocker beam, and the moment about the point R on the launch rail which the jacket pivots about are zero. Assuming the interaction forces act at the point R the equations of moment can be expressed as:

$$[R^b]_2\{M_p^j\} + [L_R]\begin{Bmatrix} P_{yj} \\ P_{zj} \end{Bmatrix} = 0 \qquad (28)$$

$$[R^j]_1\{M_p^j\} = 0 \qquad (29)$$

where $[L_R]$ is a 3×2 matrix containing the lever arms from the launch rail point R down to the rocker pin.

The actual number of unknowns in Phase 3, when equations (22) - (29) are incorporated in (8), can be summerized as:

$\{\ddot{x}^b\}$, $\{\ddot{\theta}^b\}$	6 kinematic DOF's for barge
$\ddot{x}^j$, $\ddot{\theta}^r$, $\ddot{\theta}^j$	3 kinematic relative jacket DOF's
P_{yj}, P_{zj}	2 interaction forces

3.3.4 <u>Phase 4.</u> As the jacket separates from the barge, the equations of motion for the jacket and the barge decouple, and the motions for the jacket are governed solely by equation (8), the barge motions by a similar equation.

3.4 The time integration procedure

The launch problem is determined by the equations of motion together with the equations of constraint for each phase. The unknowns comprise the kinematic DOF's for the barge and relative jacket DOF's, plus the dependent unknowns of interaction forces. Together they form a system of integro-differential equations. The equations are highly non-linear, hence a numerical solution to the problem can only be obtained by a time step integration procedure.

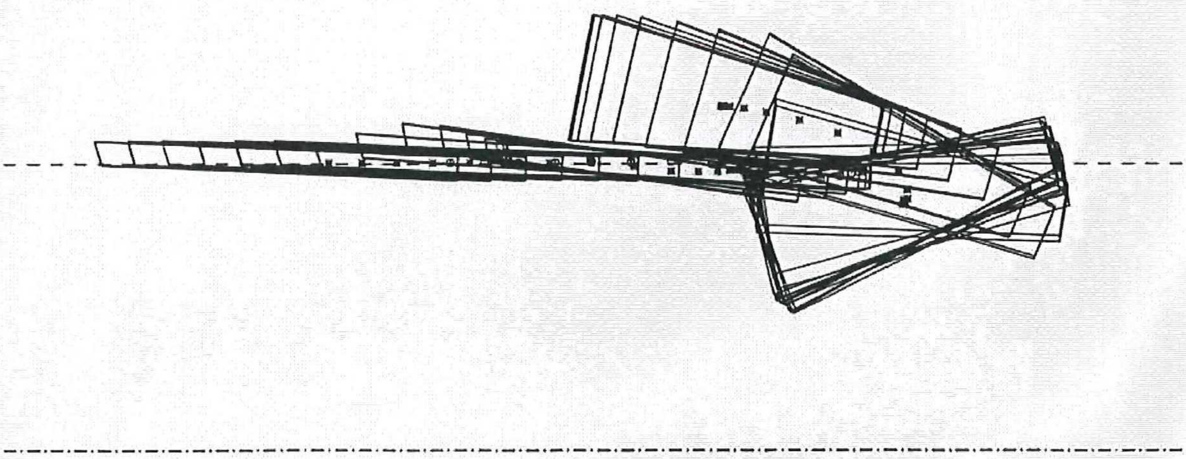

Figure 3. BERYL B launch computer simulation - time steps 4,0 s.

The Newmark β method, Newmark (1959), has been applied with $\beta = 1/6$, corresponding to accelerations varying linearly over a time step. The connections between positions, velocities, and accelerations are as follows:

$$\{\ddot{x}_t\} = \{\ddot{x}_{t_0}\} + \{\Delta\ddot{x}_t\} \tag{30}$$

$$\{\dot{x}_t\} = \{\dot{x}_{t_0}\} + \Delta t\{\ddot{x}_{t_0}\} + \tfrac{1}{2}\Delta t\{\Delta\ddot{x}_t\} \tag{31}$$

$$\{x_t\} = \{x_{t_0}\} + \Delta t\{\dot{x}_{t_0}\} + \tfrac{1}{2}\Delta t^2\{\ddot{x}_t\} + \beta\Delta t^2\{\Delta\ddot{x}_t\} \tag{32}$$

where $\Delta t = t - t_0$.

Note the vector symbol $\{\ \}$ denotes an r-dimensional vector, r being the local number of independent DOF's in each phase.

Assuming the positions, velocities and accelerations are known at time t_0, the integration procedure of finding the same quantities at time t can be summarized in these five steps:

1. Guess the acceleration at time t, for instance assume them to be identical with time t_0, i.e. $\{\Delta\ddot{x}_t\} = \{0\}$.
2. Update positions and velocities using (31) - (32)
3. Calculate all the motion dependent vectors and matrices on the basis of these velocities and positions (i.e. $\{B\}$, $\{K\}$, $[R]$, $[\dot{R}]$, $[L]$, $[C_m]$, $[\Delta C_m]$, $[C_D]_1$, $[C_D]_2$, $[S]$).
4. Solve the equations of motion (8) together with the respective equations of constraint. The result is a correction to the acceleration guess $\{\Delta\ddot{x}_t\}$.
5. Compare the correction with the required accuracy. Are the corrections converging, update positions and velocities by (31) - (32) and go to the next time step. Otherwise use (30) with the improved guess and repeat from 2.

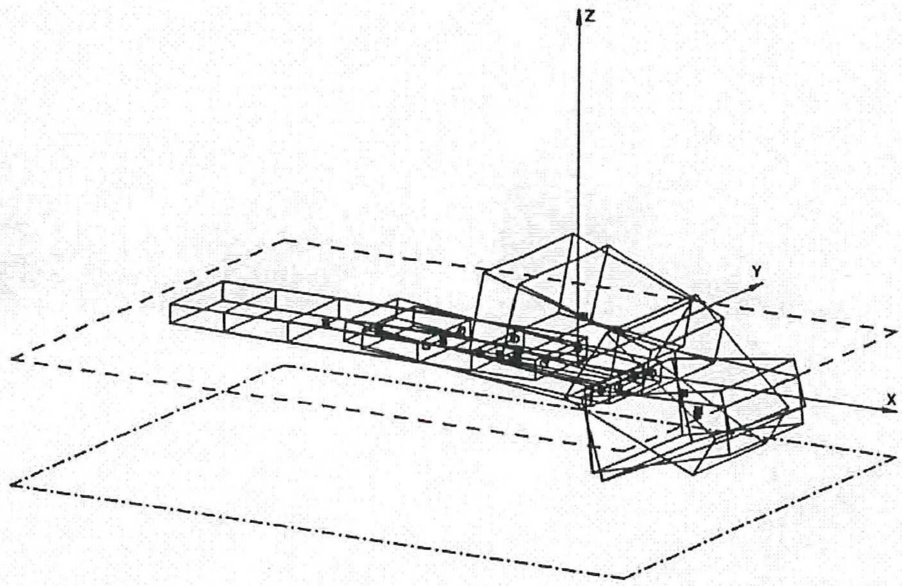

Figure 4. GORM C launch computer simulation - time steps 7,0s.

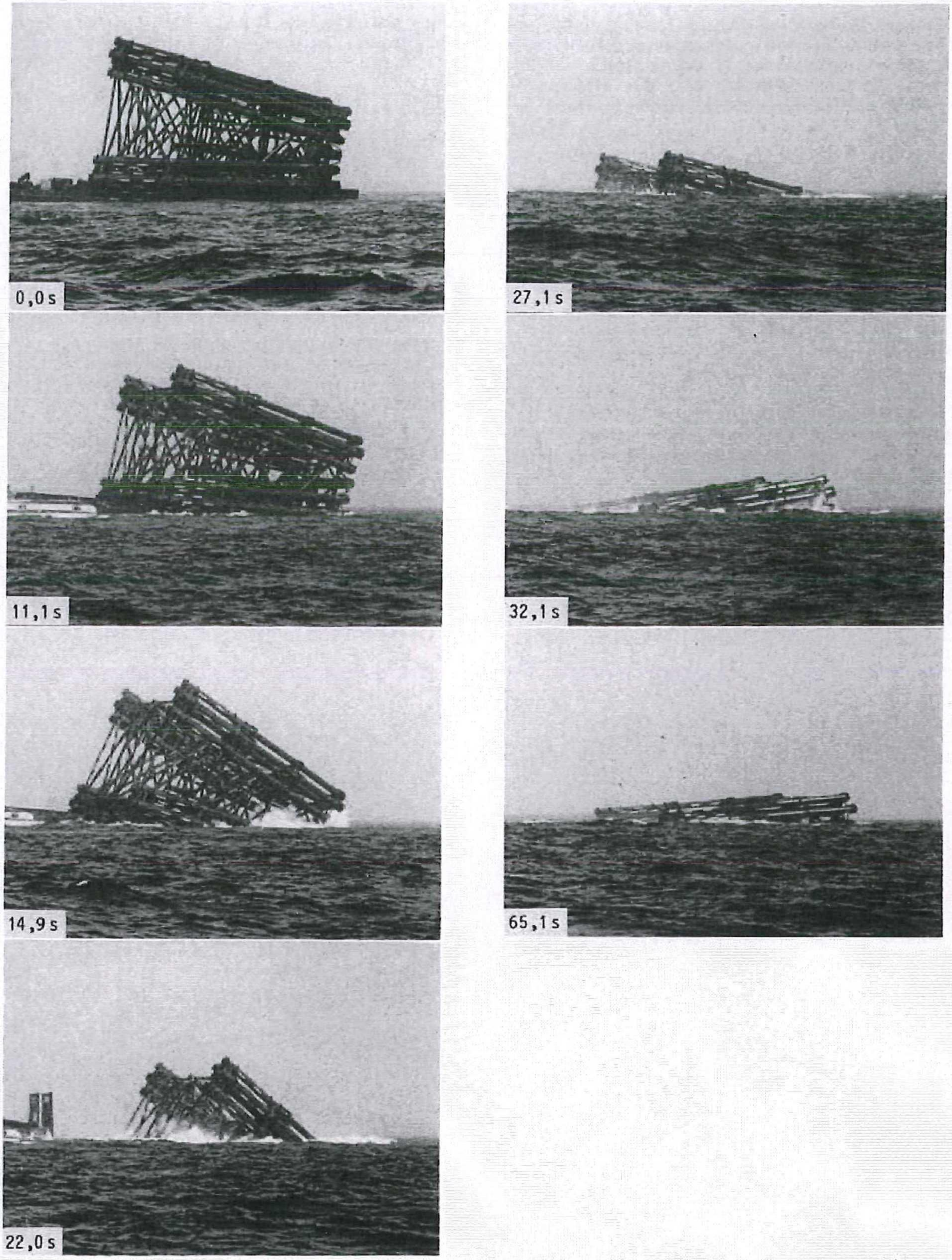

Figure 5. GORM C launch photographic recording (7 out of 27 pictures).

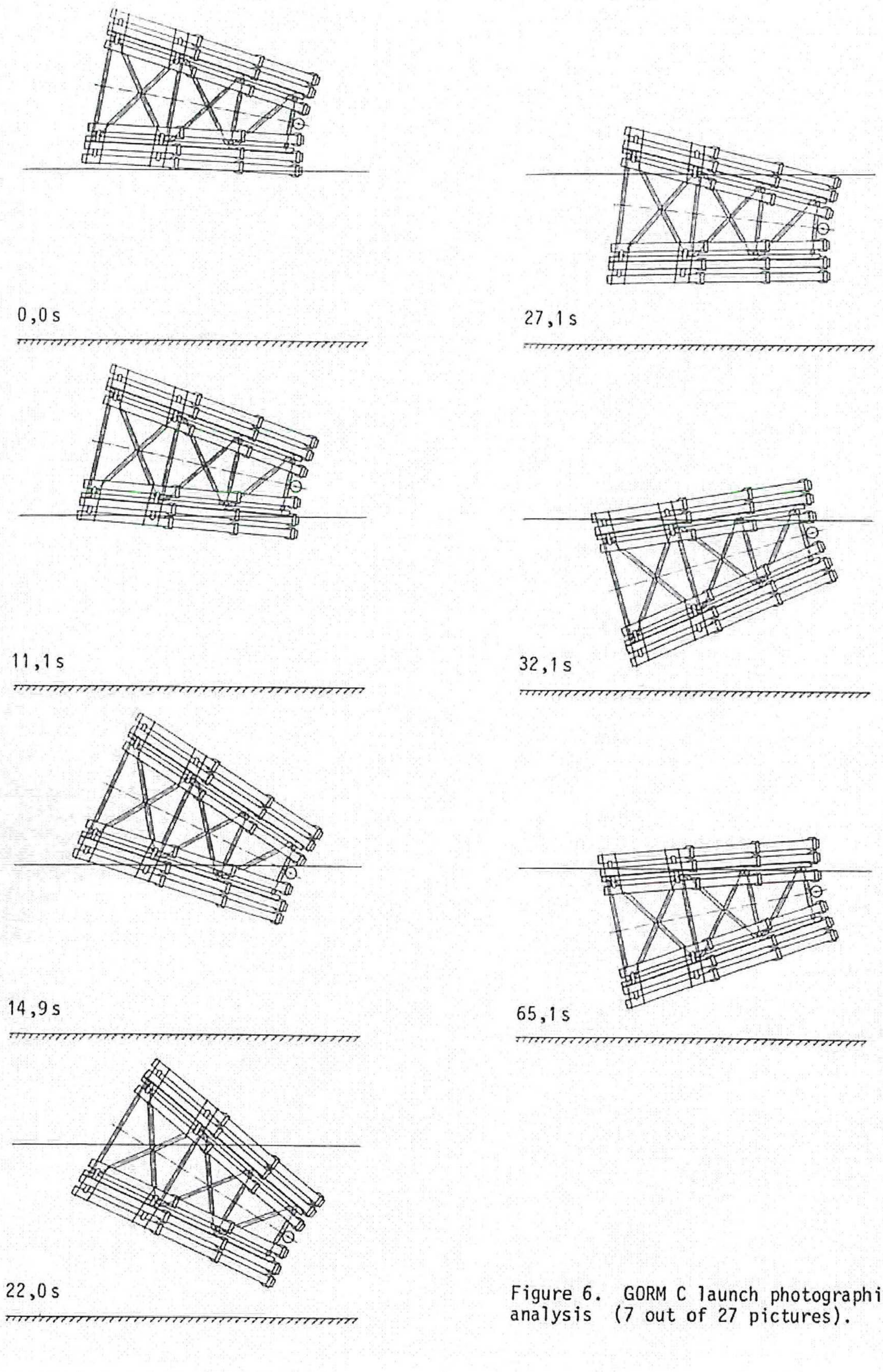

Figure 6. GORM C launch photographic analysis (7 out of 27 pictures).

4. HYDRODYNAMIC COEFFICIENTS

The drag coefficient is calculated for each jacket member at each time step as function of the momentary Reynolds' number. As basis for the calculation a simplified version of the curve in Miller (1977) Fig.8 has been used with roughness parameter $0{,}4\times10^{-3}$. For $Re > 2\times10^{6}$ the drag coefficient is assumed constant $C_D = 0{,}7$.

The added mass coefficient is assumed constant $C_m = 1{,}0$ for the circular cylinders. For other bodies such as flat plates standard values have been used.

As pointed out by Singh et al. (1982) the sacrificial anodes may cause both an increase and a decrease in the fluid loading depending on the flow direction relative to the anode position. In this program the anodes are taken into account simply as additions to the effective areas and volumes of the respective members.

During the immersion of the members there will even at low speed be large time derivatives of the momentum of the added mass and hence a force, here called the slamming force. The program takes this force into account by calculating the time derivative of the added mass matrix.

The damping and added mass coefficient for the barge have been taken from Vugts (1970) p.41. The coefficients have been doubled for the aft end sections of the barge that are totally submerged, to provide for the water on top of the deck.

Surface waves created by the jacket during the launch and thereby wave damping are not taken into consideration.

5. PHOTOGRAPHIC RECORDING AND ANALYSIS

A relatively simple photographic recording and analysis method has been developed by one of the authors who also carried out the two full-scale measurements. Two independent recording systems were used, still photos and film, both of which could yield the desired information: jacket position as function of time.

The photo system consisted of a motor-driven 35mm camera with zoom-lens, in one case (GORM C) coupled to another camera photographing a stop watch, in the other case (BERYL B) with a built-in clock as seen in Fig.2. About 30 - 40 photos with intervals of 1 - 2s are sufficient to describe the launch. In both cases the observation platform was a stand-by boat, situated 200 - 300m from the jacket. Colour diapositive film was used for optimum resolution.

The film system was a 16mm colour film camera with crystal-controlled film transportation clock-work set at 25 frames per second. So the film itself is a very accurate time reference for the launch.

The analysis has been based on the photo system alone because the photographs have a slightly better resolution than single frames of a 16mm film. The film, however, is a good supplement to the photo series because it represents the dynamics of the launch more effectively than a series of still photos. The analysis was made with the aid of an accurate side-view drawing of the jacket. The jacket positions were determined from the photos by identifying the characteristic nodes, beam ends, diagonal crossings etc. close to the waterline and then plotting the waterline position relatively to these points. By using 4 - 5 points, the waterline position could be determined quite precisely. Examples are shown in Figs. 5 - 6.

The vertical, horizontal and angular motions and the important bottom clearance were then plotted as functions of time. Velocities and accelerations can be found by simple difference methods but the uncertainties will increase.

6. RESULTS AND CONCLUSIONS

Two full-scale launch measurements, the GORM C of 4000t and the BERYL B of 14000t, have been compared with computer calculations as seen in Figs. 7 - 8. Generally the agreement is very good.

For the GORM C jacket the calculated deepest draught curve, which gives the important bottom clearance, comes very close to the measured values whereas the computer calculation is about 4m on the safe side for the BERYL B.

The calculations seem to have a somewhat contracted time scale, more pronounced for the small GORM C than for the larger BERYL B jacket. An explanation to this phenomenon has not yet been found. Increased added mass coefficients of 1,5 or 2,0 improve a bit on the time scale, but the vertical and angular motions become less accurate. The theoretical value of $C_m = 1{,}0$ gives the best overall results.

For both calculations the damping seems to be too small. It has been attempted to use a constant drag coefficient equal to 0,7 instead of the Re-dependent C_D. Surprisingly, this means only a very insignificant change in the results. The explanation must be that, the dominating part of the damping forces on the jacket are created at super-critical Reynolds' numbers.

The added mass and damping forces on the barge are calculated in a rather simple way. A better description of the hydrodynamic behaviour of a partly submerged launch barge would undoubtedly improve the calculations.

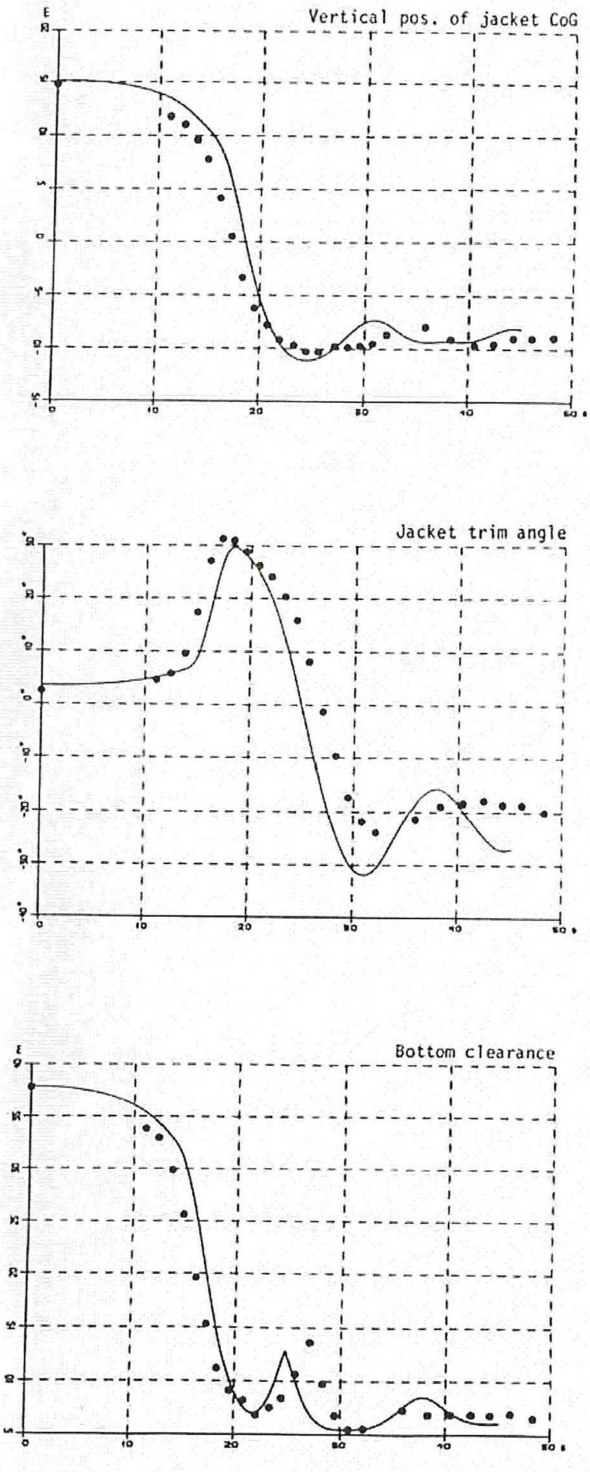

Figure 7. GORM C launch computer simulation and full-scale measurements.

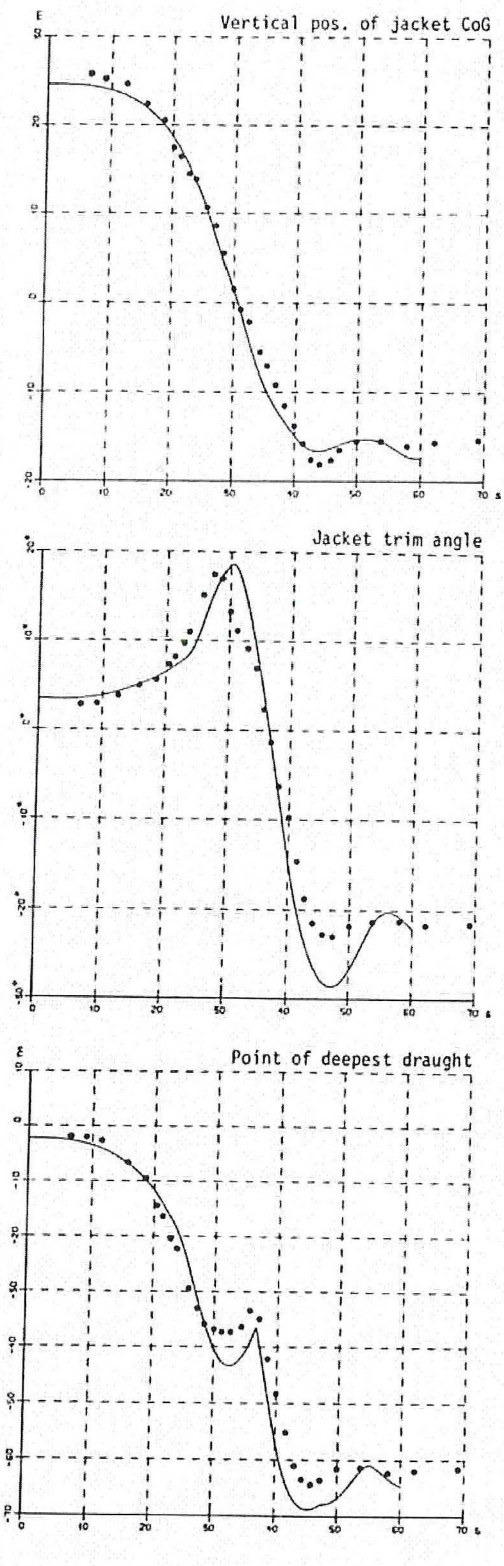

Figure 8. BERYL B launch computer simulation and full-scale measurements.

7. ACKNOWLEDGEMENTS

The authors are grateful to the managements of Mærsk Olie og Gas A/S and Mobil North Sea Limited for their help and support during the full-scale measurements, for the access to all necessary data, and for permission to publish this paper.

Special thanks are given to Mrs. Gitte Bruun and to Mr. Leif Stubkjær for excellent film and photographic work under difficult conditions.

The work has been supported financially by the Danish Council for Scientific and Industrial Research.

8. REFERENCES

Hambro, L. (1982), "Jacket launching simulation by differentiation of constraints", Applied Ocean Research, Vol.4, No.3, pp.151-159.

Hooft, J.P. (1972), "Hydrodynamic aspects of semi-submersible platforms", NSMB Publication No. 400, Wageningen, Netherlands, 132 p.

Miller, B.L. (1977), "The hydrodynamic drag of roughened circular cylinders", Transactions of RINA, England, Vol. 119, pp. 55-70.

Møller, J. and Christiansen, P.E. (1983), "Matematisk model for søsætning af jacket fra pram", (in Danish), Dept. of Ocean Engineering, The Technical University of Denmark, Lyngby, 218 p. + App.

Newmark, N.M. (1959), "A method of computation for structural dynamics", Journal of the Engineering Mechanics Division, ASCE, Vol.85 , No.EM 3, Proc. Paper 2094, U.S.A., pp.67-94.

Singh, S., Cash, R., Harris, D. and Boribond, L.A. (1982), "Wave forces on circular cylinders with large excrescences at low Keulegan and Carpenter numbers", NMI Report 133, England, 63 p.

Vugts, J.H. (1970), "The hydrodynamic forces and ship motions in waves", Delft, Netherlands, 113 p.